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Sensors
Device Data

Freescale Semiconductor
Reference Manual

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Section One

Introduction

This version of the Sensor Products Device Data Handbook is organized to provide easy reference to sensor device information. We have organized the book based upon your recommendations with our goal to make designing in pressure, acceleration, safety and alarm ICs, and electric field sensing easy. If you do have a question, you will have access to the technical support you need.

The handbook is organized by product line, acceleration, pressure, safety and alarm ICs and electric field sensing. Once in a section, you will find a glossary of terms, a list of frequently asked questions, or other relevant data. If you have recommendations for improvement, please email us at support@freescale.com, as there will not be a comment card, especially electronically, and the hot line number is no longer valid.

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Quality and Reliability

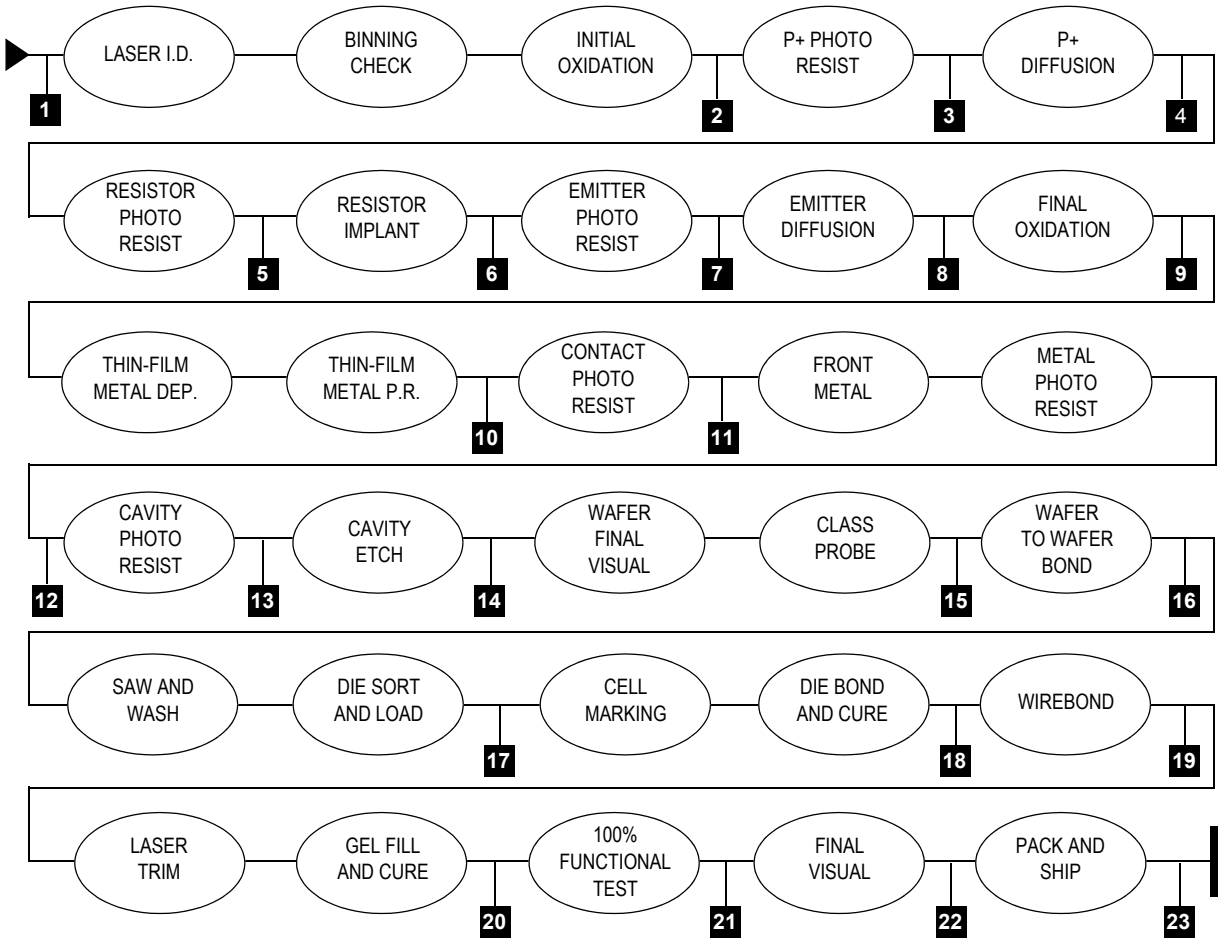
OVERVIEW

A Major Objective of the Production Cycle

From rigid incoming inspection of piece parts and materials, to stringent outgoing quality verification, Freescale's assembly and process flow is encompassed by an elaborate system of test and inspection stations; stations to ensure a step-by-step adherence to prescribed procedure. This produces the high level of quality for which Freescale is known from start to finish.

As illustrated in the process flow overview, every major manufacturing step is followed by an appropriate in-process quality inspection to insure product conformance to specification. In addition, Statistical Process Control (S.P.C.) techniques are utilized on all critical processes to insure processing equipment is capable of producing the product to the target specification while minimizing the variability. Quality control in wafer processing, assembly, and final test impart Freescale sensor products with a level of reliability that easily exceeds almost all industrial, consumer, and military requirements.

Compensated Sensor Flow Chart



RELIABILITY ISSUES FOR SILICON PRESSURE SENSORS

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Revised June 9, 1997

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ABSTRACT

Reliability testing for silicon pressure sensors is of greater importance than ever before with the dramatic increase in sensor usage. This growth is seen in applications replacing mechanical systems, as well as new designs. Across all market segments, the expectation for the highest reliability exists. While sensor demand has grown across all of these segments, the substantial increase of sensing applications in the automotive arena is driving the need for improved reliability and test capability. The purpose of this paper is to take a closer look at these reliability issues for silicon pressure sensors.

INTRODUCTION

Discussing reliability as it pertains to semiconductor electronics is certainly not a new subject. However, when developing new technologies like sensors how reliability testing will be performed is not always obvious. Pressure sensors are an intriguing dilemma. Since they are electromechanical devices, different types of stresses should be considered to insure the different elements are exercised as they would be in an actual application. In addition, the very different package outlines relative to other standard semiconductor packages require special fixtures and test set-ups. However, as the sensor marketplace continues to grow, reliability testing becomes more important than ever to insure that products being used across all market segments will meet reliability lifetime expectations.

RELIABILITY DEFINITION

Reliability is [1] the probability of a product performing its intended function over its intended lifetime and under the operating conditions encountered. The four key elements of the definition are probability, performance, lifetime, and operating conditions. Probability implies that the reliability lifetime estimates will be made based on statistical techniques where samples are tested to predict the lifetime of the manufactured products. Performance is a key in that the sample predicts the performance of the product at a given point in time but the variability in manufacturing must be controlled so that all devices perform to the same functional level. Lifetime is the period of time over which the product is intended to perform. This lifetime could be as small as one week in the case of a disposable blood pressure transducer or as long as 15 years for automotive applications. Environment is the area that also plays a key role since the operating conditions of the product can greatly influence the reliability of the product.

Environmental factors that can be seen during the lifetime of any semiconductor product include temperature, humidity, electric field, magnetic field, current density, pressure differential, vibration, and/or a chemical interaction. Reliability testing is generally formulated to take into account all of these potential factors either individually or in multiple combinations. Once the testing has been completed predictions can be made for the intended product customer base.

If a failure would be detected during reliability testing, the cause of the failure can be categorized into one of the following: design, manufacturing, materials, or user. The possible impact on the improvements that may need to be made for a product is influenced by the stage of product development. If a product undergoes reliability testing early in its development phase, the corrective action process can generally occur in an expedient manner and at minimum cost. This would be true whether the cause of failure was attributed to the design, manufacturing, or materials. If a reliability failure is detected once the product is in full production, changes can be very difficult to make and generally are very costly. This scenario would sometimes result in a total redesign.

The potential cause for a reliability failure can also be user induced. This is generally the area that the least information is known, especially for a commodity type manufacturer that achieves sales through a global distribution network. It is the task of the reliability engineer to best anticipate the multitudes of environments that a particular product might see, and determine the robustness of the product by measuring the reliability lifetime parameters. The areas of design, manufacturing, and materials are generally well understood by the reliability engineer, but without the correct environmental usage, customer satisfaction can suffer from lack of optimization.

RELIABILITY STATISTICS

Without standardization of the semiconductor sensor standards, the end customer is placed in a situation of possible jeopardy. If non-standard reliability data is generated and published by manufacturers, the information can be perplexing to disseminate and compare. Reliability lifetime statistics can be confusing for the novice user of the information, “let the buyer beware.”

The reporting of reliability statistics is generally in terms of failure rate, measured in FITs, or failure rate for one billion device hours. In most cases, the underlying assumption used in reporting either the failure rate or the MTBF is that the failures occurring during the reliability test follow an exponential life distribution. The inverse of the failure rate is the MTBF, or mean time between failure. The details on the various life distributions will not be explored here but the key concern about the exponential distribution is that the failure rate over time is constant. Other life distributions, such as the lognormal or Weibull can take on different failure rates over time, in particular, both distributions can represent a wear out or increasing failure rate that might be seen on a product reaching the limitations on its lifetime or for certain types of failure mechanisms.

The time duration use for the prediction of most reliability statistics is of relatively short duration with respect to the product's lifetime ability and failures are usually not observed. When a test is terminated after a set number of hours is achieved, or time censored, and no failures are observed, the

failure rate can be estimated by use of the chi-square distribution which relates observed and expected frequencies of an event to established confidence intervals. The relationship between failure rate and the chi-square distribution is as follows:

$$\lambda_{L1} = \frac{\chi^2\,(\alpha,\ \text{d.f.})}{2t}$$

Where:

λ = failure rate
L1 = lower one side confidence limit
χ^2 = chi-square function
α = risk, (1-confidence level)
d.f. = degrees of freedom = 2 (r + 1)
r = number of failures
t = device hours

Chi-square values for 60% and 90% confidence intervals for up to 12 failures is shown in Table 1.

As indicated by the table, when no failures occur, an estimate for the chi-square distribution interval is obtainable. This interval estimate can then be used to solve for the failure rate, as shown in the equation above. If no failures occur, the failure rate estimate is solely a function of the accumulated device hours. This estimate can vary dramatically as additional device hours are accumulated.

As a means of showing the influence of device hours with no failures on the failure rate value, a graphical representation of cumulative device hours versus the failure rate measured in FITs is shown in Figure 1.

A descriptive example between two potential vendors best serves to demonstrate the point. If vendor A is introducing a new product and they have put a total of 1,000 parts on a high temperature storage test for 500 hours each, their corresponding cumulative device hours would be 500,000 device hours. Vendor B has been in the business for several years on the same product and has tested a total of 500,000 parts for 10 hours each to the same conditions as part of an in-line burn-in test for a total of 5,000,000 device hours. The corresponding failure rate for a 60% confidence level for vendor A would be 1,833 FITs, vendor B would have a FIT rate of 183 FITs.

Table 1. Chi-Square Table

Chi-Square Distribution Function			
60% Confidence Level		90% Confidence Level	
No. Fails	χ^2 Quantity	No. Fails	χ^2 Quantity
0	1.833	0	4.605
1	4.045	1	7.779
2	6.211	2	10.645
3	8.351	3	13.362
4	10.473	4	15.987
5	12.584	5	18.549
6	14.685	6	21.064
7	16.780	7	23.542
8	18.868	8	25.989
9	20.951	9	28.412
10	23.031	10	30.813
11	25.106	11	33.196
12	27.179	12	35.563

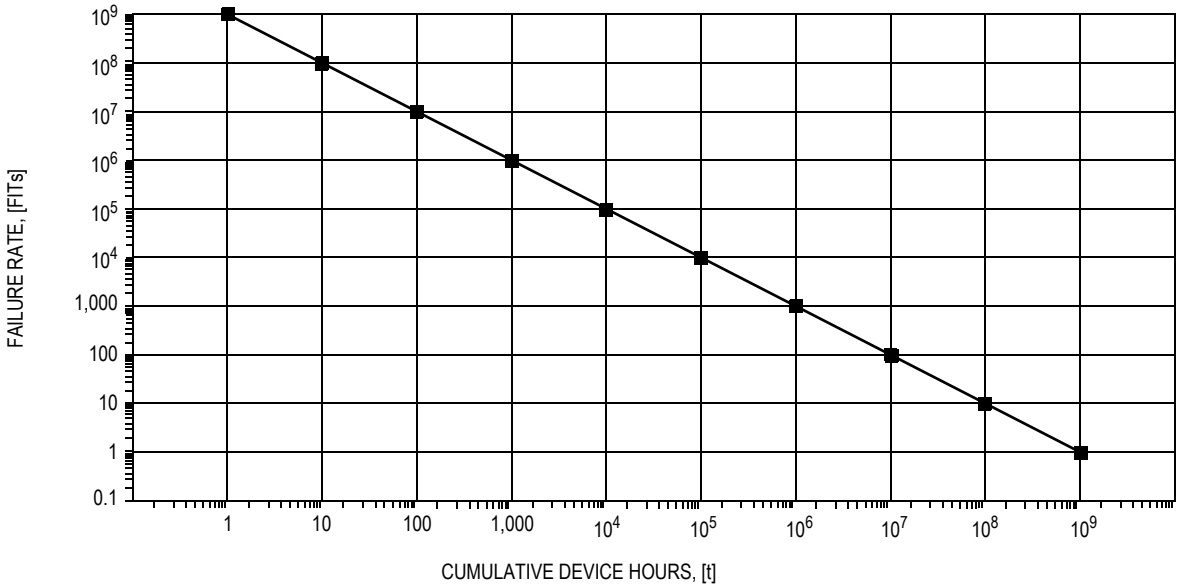

Figure 1. Depiction of the influence on the cumulative device hours with no failures and the Failure Rate as measured in FITs.

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One could thus imply that the reliability performance indicates that vendor B has an order of magnitude improvement in performance over vendor A with neither one seeing an occurrence of failure during their performance.

The incorrect assumption of a constant failure rate over time can potentially result in a less reliable device being designed into an application. The reliability testing assumptions and test methodology between the various vendors needs to be critiqued to insure a full understanding of the product performance over the intended lifetime, especially in the case of a new product. Testing to failure and determination of the lifetime statistics is beyond the scope of this paper and presented elsewhere [2].

INDUSTRY RELIABILITY STANDARDS

Reliability standards for large market segments are often developed by “cross-corporation” committees that evaluate the requirements for the particular application of interest. It is the role of these committees to generate documents intended as guides for technical personnel of the end users and suppliers, to assist with the following functions: specifying, developing, demonstrating, calibrating, and testing the performance characteristics for the specific application.

One such committee which has developed a standard for a particular application is the Blood Pressure Monitoring Committee of the Association for the Advancement of Medical Instrumentation (AAMI) [3]. Their document, the “American National Standard for Interchangeability and Performance of Resistive Bridge Type Blood Pressure Transducers”, has an objective to provide performance requirements, test methodology, and terminology that will help insure that safe, accurate blood pressure transducers are supplied to the marketplace.

In the automotive arena, the Society of Automotive Engineers (SAE) develops standards for various pressure sensor applications such as SAE document J1346, “Guide to Manifold Absolute Pressure Transducer Representative Test Method” [4].

While these two very distinct groups have successfully developed the requirements for their solid-state silicon pressure sensor needs, no real standard has been set for the general industrial marketplace to insure products being offered have been tested to insure reliability under industrial conditions. Freescale has utilized MIL-STD-750 as a reference document in establishing reliability testing practices for the silicon pressure sensor, but the differences in the technology between a discrete semiconductor and a silicon pressure sensor varies dramatically. The additional tests that are utilized in semiconductor sensor reliability testing are based on the worst case operational conditions that the device might encounter in actual usage.

ESTABLISHED SENSOR TESTING

Freescale has established semiconductor sensor reliability testing based on exercising to detect failures by the presence of the environmental stress. Potential failure modes and causes are developed by allowing tests to run beyond the normal test times, thus stressing to destruction. The typical reliability test matrix used to insure conformance to customers end usage is as follows [5]:

Pulsed Pressure Temperature Cycling with Bias (PPTCB)

This test is an environmental stress test combined with cyclic pressure loading in which the devices are alternately subjected to a low and high temperature while operating under bias under a cyclical pressure load. This test simulates the extremes in the operational life of a pressure sensor. PPTCB evaluates the sensor's overall performance as well as evaluating the die, die bond, wire bond and package integrity.

Typical Test Conditions: Temperature per specified operating limits (i.e., Ta = -40 to 125°C for an automotive application). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, bias = 100% rated voltage. Pressure = 0 to full scale, pressure frequency = 0.05 Hz, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Die defects, wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

High Humidity, High Temperature with Bias (H^3TB)

A combined environmental/electrical stress test in which devices are subjected to an elevated ambient temperature and humidity while under bias. The test is useful for evaluating package integrity as well as detecting surface contamination and processing flaws.

Typical Test Conditions: Temperature between 60 and 85°C, relative humidity between 85 and 90%, rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Shift from ionic affect, parametric instability, moisture ingress resulting in excessive package stress, corrosion.

High Temperature with Bias (HTB)

This operational test exposes the pressure sensor to a high temperature ambient environment in which the device is biased to the rated voltage. The test is useful for evaluating the integrity of the interfaces on the die and thin film stability.

Typical Test Conditions: Temperature per specified operational maximum, bias = 100% rated voltage, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, film stability and ionic contamination.

High and Low Temperature Storage Life (HTSL, LTSL)

High and low temperature storage life testing is performed to simulate the potential shipping and storage conditions that the pressure sensor might encounter in actual usage. The test

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also evaluates the devices thermal integrity at worst case temperatures.

Typical Test Conditions: Temperature per specified storage maximum and minimum, no bias, test time = up to 1000 hours.

Potential Failure Modes: Parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Bulk die or diffusion defects, mechanical creep in packaging components due to thermal mismatch.

Temperature Cycling (TC)

This is an environmental test in which the pressure sensor is alternatively subjected to hot and cold temperature extremes with a short stabilization time at each temperature in an air medium. The test will stress the devices by generating thermal mismatches between materials.

Typical Test Conditions: Temperature per specified storage maximum and minimum (i.e., -40 to +125°C for automotive applications). Dwell time ≥ 15 minutes, transfer time ≤ 5 minutes, no bias. Test time up to 1000 cycles.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Wire bond fatigue, die bond fatigue, port adhesive failure, volumetric gel changes resulting in excessive package stress. Mechanical creep of packaging material.

Mechanical Shock

This is an environmental test where the sensor device is evaluated to determine its ability to withstand a sudden change in mechanical stress due to an abrupt change in motion. This test simulates motion that may be seen in handling, shipping or actual use. MIL STD 750, Method 2016 Reference.

Typical Test Conditions: Acceleration = 1500 g's, orientation = X, Y, Z planes, time = 0.5 milliseconds, 5 blows.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

Variable Frequency Vibration

A test to examine the ability of the pressure sensor device to withstand deterioration due to mechanical resonance. MIL STD 750, Method 2056 Reference.

Typical Test Conditions: Frequency - 10 Hz to 2 kHz, 6.0 G's max, orientation = X, Y, Z planes, 8 cycles each axis, 2 hrs. per cycle.

Potential Failure Modes: Open, parametric shift in offset and/or sensitivity.

Potential Failure Mechanisms: Diaphragm fracture, mechanical failure of wire bonds or package.

Solderability

In this reliability test, the lead/terminals are evaluated for their ability to solder after an extended time period of storage (shelf life). MIL STD 750, Method 2026 Reference.

Typical Test Conditions: Steam aging = 8 hours, Flux= R, Solder = Sn63, Pb37.

Potential Failure Modes: Pin holes, non-wetting, dewetting.

Potential Failure Mechanisms: Poor plating, contamination.

Over Pressure

This test is performed to measure the ability of the pressure sensor to withstand excessive pressures that may be encountered in the application. The test is performed from either the front or back side depending on the application.

Typical Test Conditions: Pressure increase to failure, record value.

Potential Failure Modes: Open.

Potential Failure Mechanisms: Diaphragm fracture, adhesive or cohesive failure of die attach.

A pressure sensor may be placed in an application where it will be exposed to various media that may chemically attack the active circuitry, silicon, interconnections and/or packaging material. The focus of media compatibility is to understand the chemical impact with the other environmental factors such as temperature and bias and determine the impact on the device lifetime. The primary driving mechanism to consider is permeation which quantifies the time for a chemical to permeate across a membrane or encapsulant corrosion can result.

Media related product testing is generally very specific to the application since the factors that relate to the product lifetime are very numerous and varied. An example is solution pH where the further from neutral will drive the chemical reaction, generally to a power rule relationship. The pH alone does not always drive the reaction either, the non-desired products in the media such as strong acids in fuels as a result of acid rain can directly influence the lifetime. It is recommended the customer and/or vendor perform application specific testing that best represents the environment. This testing should be performed utilizing *in situ* monitoring of the critical device parameter to insure the device survives while exposed to the chemical. The Sensor Products Division within Freescale has a wide range of media specific test capabilities and under certain circumstances will perform application specific media testing.

A sufficient sample size manufactured over a pre-defined time interval to maximize process and time variability is tested based on the guidelines of the matrix shown above. This test methodology is employed on all new product introductions and process changes on current products.

A silicon pressure sensor has a typical usage environment of pressure, temperature, and voltage. Unlike the typical bipolar transistor life tests which incorporate current density and temperature to accelerate failures, a silicon pressure sensor's acceleration of its lifetime performance is primarily based on the pressure and temperature interaction with a presence of bias. This rationale was incorporated into the development of the Pulsed Pressure Temperature Cycling

with Bias (PPTCB) test where the major acceleration factor is the pressure and temperature component. It is also why PPTCB is considered the standard sensor operational life test.

To insure that silicon pressure sensors are designed and manufactured for reliability, an in-depth insight into what mechanisms cause particular failures is required. It is safe to say that unless a manufacturer has a clear understanding of everything that can go wrong with the device, it cannot design a device for the highest reliability. Figure 2 provides a look into the sensor operating concerns for a variety of potential usage applications. This information is utilized when developing the Failure Mode and Effects Analysis (FMEA). The FMEA then serves as the documentation that demonstrates all design and process concerns have been addressed to offer the most reliable approach. By understanding how to design products, control processes, and eliminate the concerns raised, a reliable product is achieved.

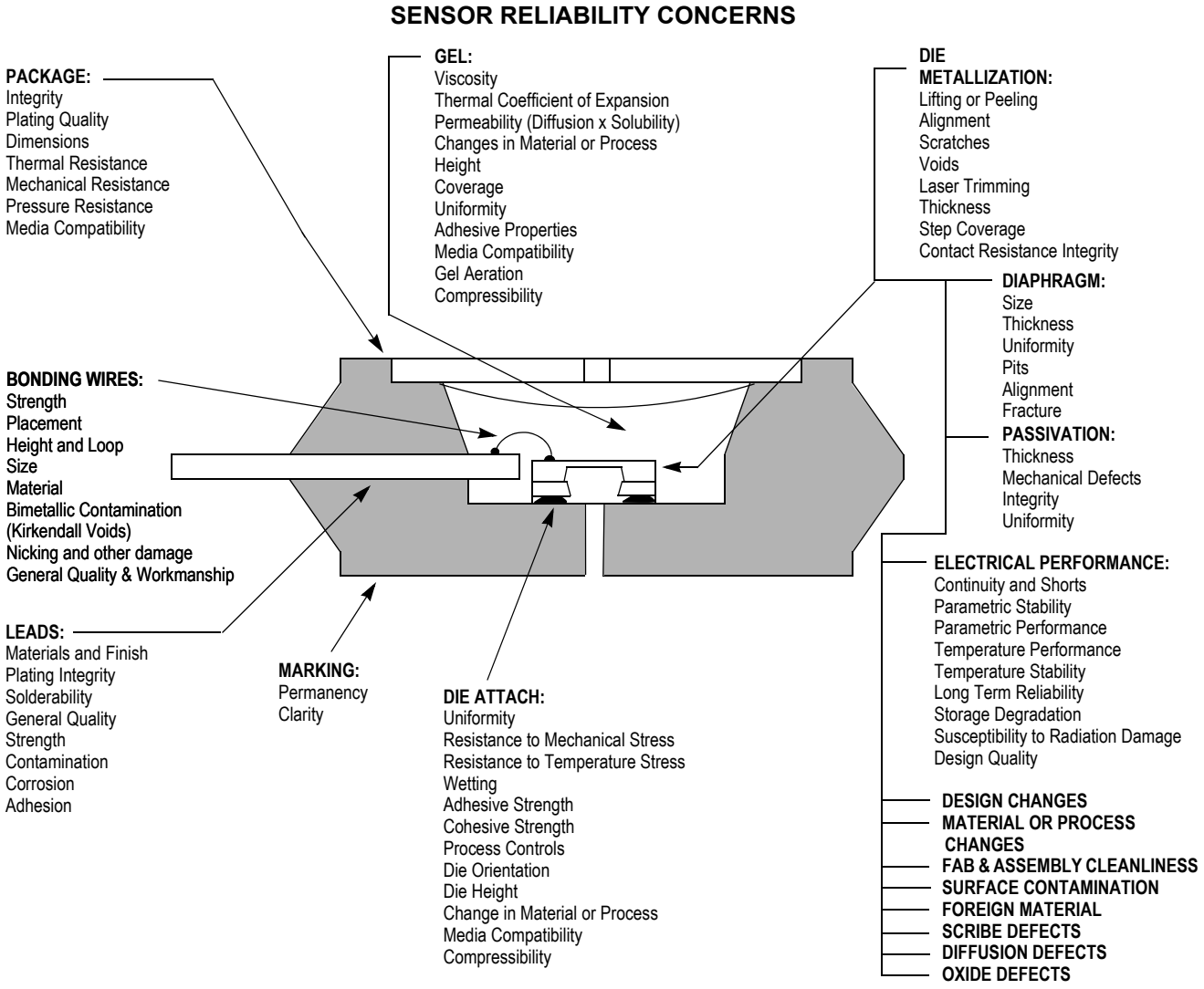

Figure 2. Process and Product Variability Concerns During Reliability Testing

ACCELERATED LIFE TESTING

It is very difficult to assess the reliability statistics for a product when very few or no failures occur. With cost as a predominant factor in any industrial setting and time of the utmost importance, the reliability test must be optimized. Optimization of reliability testing will allow the maximum amount of information on the product being tested to be gained in a minimum amount of time, this is accomplished by using accelerated life testing techniques.

A key underlying assumption in the usage of accelerated life testing to estimate the life of a product at a lower or nominal stress is that the failure mechanism encountered at the high stress is the same as that encountered at the nominal stress. The most frequently applied accelerated environmental stress for semiconductors is temperature, it will be briefly explained here for its utilization in determining the lifetime reliability statistics for silicon pressure sensors.

The temperature acceleration factor for a particular failure mechanism can be related by taking the ratio for the reaction

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rate of the two different stress levels as expressed by the Arrhenius type of equation. The mathematical derivation of the first order chemical reaction rate computes to:

$$AF = \frac{(R_T)_{HS}}{(R_T)_{LS}} = \frac{t_{HS}}{t_{LS}}$$

$$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

AF = Acceleration Factor
R_T = Reaction Rate
t = time
T = temperature [°K]
Ea = activation energy of expressed in electron-volts [eV]
k = Boltzman's constant, 8.6171 x 10^{-5} eV/°K
LS = Low stress or nominal temperature
HS = High stress or test temperature

The activation energy is dependent on the failure mechanism and typically varies from 0.3 to 1.8 electron-volts. The activation energy is directly proportional to the degree of influence that temperature has on the chemical reaction rate. A listing of typical activation energies is included in reference [6] and [7].

An example using the Arrenhius equation will be demonstrated. A 32 device HTB test for 500 hours total and no failure was performed. The 125°C, 100% rated voltage test resulted in no failures. If a customer's actual usage conditions was 55°C at full rated voltage, an estimate of the lower one side confidence limit can be calculated. An assumption is made that the failure rate is constant thus implying the exponential distribution. The first step is to calculate the equivalent device hours for the customer's use conditions by solving for the acceleration factor.

From the acceleration factor above, if eA is assumed equal to 1,

$$AF = \exp\left[\frac{Ea}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

eA = 0.7 eV/°K (assumed)
T_{LS} = 55°C + 273.16 = 328.16°K
T_{HS} = 125°C + 273.16 = 398.16°K

then;

AF = 77.64

Therefore, the equivalent cumulative device hours at the customer's use condition is:

T_{LS} = AF x T_{HS} = (32 · 500) · 77.64

or

T_{LS} = 1,242,172 device hours

Computing the lower one sided failure rate with a 90% confidence level and no failures:

$$\lambda = \frac{\chi^2\,(\alpha,\ \text{d.f.})}{2t}$$

or

λ = 1.853E-06 failures per hour

or

λ = 1,853 FITs

The inverse of the failure, λ, or the Mean Time To Failure (MTTF) is:

$$MTTF = \frac{1}{\lambda}$$

or

MTTF = 540,000 device hours

CONCLUSION

Reliability testing durations and acceptance numbers are used as a baseline for achieving adequate performance in the actual use condition that the silicon pressure sensor might encounter. The baseline for reliability testing can be related to the current record high jump bar height. Just as athletes in time achieve a higher level of performance by improvements in their level of physical and mental fitness, silicon pressure sensors must also incorporate improvements in the design, materials, and manufacturability to achieve the reliability growth demands the future market place will require. This philosophy of never ending improvement will promote consistent conformance to the customer's expectation and production of a best in class product.

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[6] Wayne Nelson, “Accelerated Testing: Statistical Models,” *Test Plans, and Data Analyses,* John Wiley & Sons, Inc., New York, N.Y., 1990.
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SOLDERING PRECAUTIONS

The melting temperature of solder is higher than the rated temperature of the device. When the entire device is heated to a high temperature, failure to complete soldering within a short time could result in device failure. Therefore, the following items should always be observed in order to minimize the thermal stress to which the devices are subjected.

- Always preheat the device.
- The delta temperature between the preheat and soldering should be 100°C or less.*
- For pressure sensor devices, a no-clean solder is recommended unless the silicone die coat is sealed and unexposed. Also, prolonged exposure to fumes can damage the silicone die coat of the device during the solder reflow process.
- When preheating and soldering, the temperature of the leads and the case must not exceed the maximum temperature ratings as shown on the data sheet. When using infrared heating with the reflow soldering method, the difference should be a maximum of 10°C.
- The soldering temperature and time should not exceed 260°C for more than 10 seconds.
- When shifting from preheating to soldering, the maximum temperature gradient shall be 5°C or less.
- After soldering has been completed, the device should be allowed to cool naturally for at least three minutes. Gradual cooling should be used since the use of forced cooling will increase the temperature gradient and will result in latent failure due to mechanical stress.
- Mechanical stress or shock should not be applied during cooling.

*Soldering a device without preheating can cause excessive thermal shock and stress which can result in damage to the device.

Typical Solder Heating Profile

For any given circuit board, there will be a group of control settings that will give the desired heat pattern. The operator must set temperatures for several heating zones and a figure for belt speed. Taken together, these control settings make up a heating “profile” for that particular circuit board. On machines controlled by a computer, the computer remembers these profiles from one operating session to the next. Figure 3 shows a typical heating profile for use when soldering a surface mount device to a printed circuit board. This profile will vary among soldering systems, but it is a good starting point. Factors that can affect the profile include the type of soldering system in use, density and types of components on the board, type of solder used, and the type of board or substrate material being used. This profile shows temperature versus time. The line on the graph shows the actual temperature that might be experienced on the surface of a test board at or near a central solder joint. The two profiles are based on a high density and a low density board. The Vitronics SMD310 convection/infrared reflow soldering system was used to generate this profile. The type of solder used was 62/36/2 Tin Lead Silver with a melting point between 177-189°C. When this type of furnace is used for solder reflow work, the circuit boards and solder joints tend to heat first. The components on the board are then heated by conduction. The circuit board, because it has a large surface area, absorbs the thermal energy more efficiently, then distributes this energy to the components. Because of this effect, the main body of a component may be up to 30 degrees cooler than the adjacent solder joints.

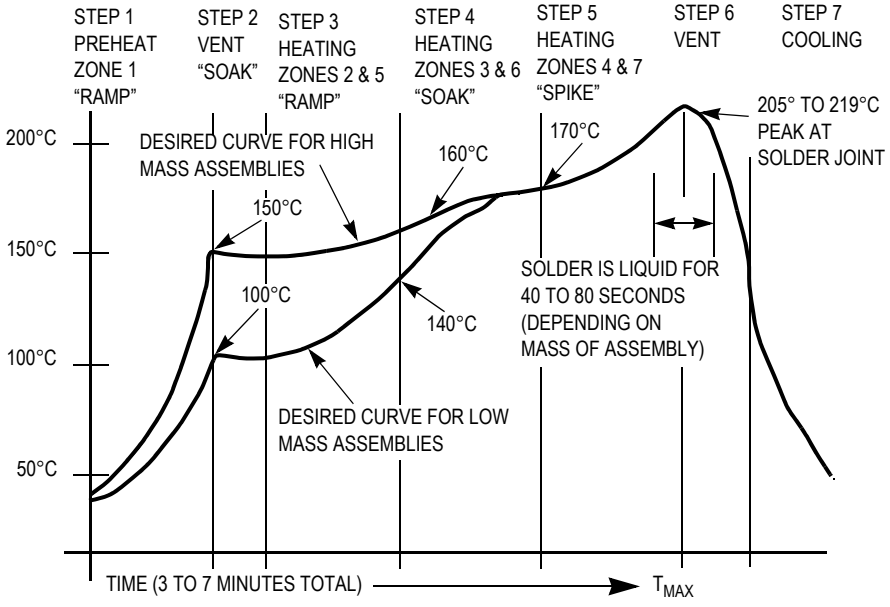

Figure 3. Typical Solder Heating Profile

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ELECTROSTATIC DISCHARGE DATA

Electrostatic damage (ESD) to semiconductor devices has plagued the industry for years. Special packaging and handling techniques have been developed to protect these sensitive devices. While many of Freescale's semiconductors devices are not susceptible to ESD, all products are revered as sensitive and handled accordingly.

The data in this section was developed using the human-body model specified in MIL-STD-750C, Method 1020. The threshold values (Eth, kV) of ten devices was recorded, then the average value calculated. This data plus the device type, device source, package type, classification, polarity and general device description are supplied. Devices listed are mainly JEDEC registered 1N and 2N numbers. Military QPL devices and some customer specials are also in this database. The data in this report will be updated regularly, and the range will be added as new data becomes available.

The sensitivity classifications listed are as follows:

Class 1 . . . 1 to 1999 volts

Class 2 . . . 2000 to 3999 volts

Class 3 . . . 4000 to > 15500 volts

The code “N/S” signifies a non-sensitive device. “SEN” are considered sensitive and should be handled according to ESD procedures. Of the various products manufactured by the Communications, Power and Signal Technologies Group, the following examples list general device families by not sensitive to extremely sensitive.

Not sensitive . . . . . FET current regulators

Least sensitive . . . . . Zener diodes (on a square mil/mil-lijoule basis)

Less sensitive . . . . . Bipolar transistors

More sensitive . . . . . Bipolar darlington transistors

Very sensitive . . . . . Power TMOS® devices

Extremely sensitive . . . Hot carrier diodes and MOSFET transistors without gate protection

The data supplied herein, is listed in numerical or alphabetical order.

Device	Line	Case	Class	Product Description
MPX10D	XL0010V1	344-15	3-SEN	Uncompensated
MPX10DP	XL0010V1	344C-01	3-SEN	Uncompensated
MPX10GP	XL0010V1	344B-01	3-SEN	Uncompensated
MPX12D	XL0012V1	344-15	3-SEN	Uncompensated
MPX12DP	XL0012V1	344C-01	3-SEN	Uncompensated
MPX12GP	XL0012V1	344B-01	3-SEN	Uncompensated
MPX2010D	XL2010V5	344-15	1-SEN	Temperature Compensated/Calibrated
MPX2010DP	XL2010V5	344C-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GP	XL2010V5	344B-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GS	XL2010V5	344E-01	1-SEN	Temperature Compensated/Calibrated
MPX2010GSX	XL2010V5	344F-01	1-SEN	Temperature Compensated/Calibrated
MPX2300DT1	XL2300C1,01C1	423-05	1-SEN	Temperature Compensated/Calibrated
MPX4100A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4100AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX4100AS	XL4101S2	867E-03	1-SEN	Signal-Conditioned
MPX4101A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4115A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4115AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX4115AS	XL4101S2	867E-03	1-SEN	Signal-Conditioned
MPX4250A	XL4101S2	867-08	1-SEN	Signal-Conditioned
MPX4250AP	XL4101S2	867B-04	1-SEN	Signal-Conditioned
MPX5010D	XL4010S5	867-08	1-SEN	Signal-Conditioned
MPX5010DP	XL4010S5	867C-05	1-SEN	Signal-Conditioned
MPX5010GP	XL4010S5	867B-04	1-SEN	Signal-Conditioned
MPX5010GS	XL4010S5	867E-03	1-SEN	Signal-Conditioned
MPX5010GSX	XL4010S5	867F-03	1-SEN	Signal-Conditioned
MPX5050D	XL4051S1	867-08	1-SEN	Signal-Conditioned

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Device	Line	Case	Class	Product Description
MPX5050DP	XL4051S1	867C-05	1-SEN	Signal-Conditioned
MPX5050GP	XL4051S1	867B-04	1-SEN	Signal-Conditioned
MPX5100D	XL4101S1	867-08	1-SEN	Signal-Conditioned
MPX5100DP	XL4101S1	867C-05	1-SEN	Signal-Conditioned
MPX5100GP	XL4101S1	867B-04	1-SEN	Signal-Conditioned
MPX5700D	XL4701S1	867-08	1-SEN	Signal-Conditioned
MPX5700DP	XL4701S1	867C-05	1-SEN	Signal-Conditioned
MPX5700GP	XL4701S1	867B-04	1-SEN	Signal-Conditioned
MPX5999D	XL4999S1	867-08	1-SEN	Signal-Conditioned

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Statistical Process Control

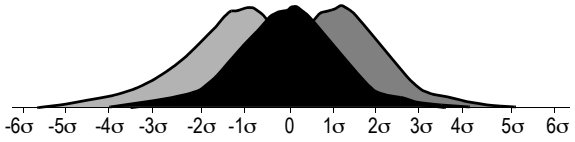
Freescale Semiconductor is continually pursuing new ways to improve product quality. Initial design improvement is one method that can be used to produce a superior product. Equally important to outgoing product quality is the ability to produce product that consistently conforms to specification. Process variability is the basic enemy of semiconductor manufacturing since it leads to product variability. Used in all phases of Freescale's product manufacturing, STATISTICAL PROCESS CONTROL (SPC) replaces variability with predictability. The traditional philosophy in the semiconductor industry has been adherence to the data sheet specification. Using SPC methods assures the product will meet specific process requirements throughout the manufacturing cycle. The emphasis is on defect prevention, not detection. Predictability through SPC methods requires the manufacturing culture to focus on constant and permanent improvements. Usually these improvements cannot be bought with state-of-the-art equipment or automated factories. With quality in design, process and material selection, coupled with manufacturing predictability, Freescale produces world class products.

The immediate effect of SPC manufacturing is predictability through process controls. Product centered and distributed well within the product specification benefits Freescale with fewer rejects, improved yields and lower cost. The direct benefit to Freescale's customers includes better incoming quality levels, less inspection time and ship-to-stock capability. Circuit performance is often dependent on the cumulative effect of component variability. Tightly controlled component distributions give the customer greater circuit predictability. Many customers are also converting to just-in-time (JIT) delivery programs. These programs require improvements in cycle time and yield predictability achievable only through SPC techniques. The benefit derived from SPC helps the manufacturer meet the customer's expectations of higher quality and lower cost product.

Ultimately, Freescale will have Six Sigma capability on all products. This means parametric distributions will be centered within the specification limits with a product distribution of plus or minus Six Sigma about mean. Six Sigma capability, shown graphically in Figure 1, details the benefit in terms of yield and outgoing quality levels. This compares a centered distribution versus a 1.5 sigma worst case distribution shift.

New product development at Freescale requires more robust design features that make them less sensitive to minor variations in processing. These features make the implementation of SPC much easier.

A complete commitment to SPC is present throughout Freescale. All managers, engineers, production operators, supervisors and maintenance personnel have received multiple training courses on SPC techniques. Manufacturing has identified 22 wafer processing and 8 assembly steps considered critical to the processing of semiconductor products. Processes, controlled by SPC methods, that have shown significant improvement are in the diffusion, photolithography and metallization areas.



Standard Deviations From Mean

Distribution Centered	Distribution Shifted ± 1.5
At ± 3σ 2700 ppm defective 99.73% yield	66810 ppm defective 93.32% yield
At ± 4σ 63 ppm defective 99.9937% yield	6210 ppm defective 99.379% yield
At ± 5σ 0.57 ppm defective 99.999943% yield	233 ppm defective 99.9767% yield
At ± 6σ 0.002 ppm defective 99.9999998% yield	3.4 ppm defective 99.99966% yield

Figure 1. AOQL and Yield from a Normal Distribution of Product With 6σ Capability

To better understand SPC principles, brief explanations have been provided. These cover process capability, implementation and use.

PROCESS CAPABILITY

One goal of SPC is to ensure a process is capable. Process capability is the measurement of a process to produce products consistently to specification requirements. The purpose of a process capability study is to separate the inherent random variability from assignable causes. Once completed, steps are taken to identify and eliminate the most significant assignable causes. Random variability is generally present in the system and does not fluctuate. Sometimes, these are considered basic limitations associated with the machinery, materials, personnel skills or manufacturing methods. Assignable cause inconsistencies relate to time variations in yield, performance or reliability.

Traditionally, assignable causes appear to be random due to the lack of close examination or analysis. Figure 2 shows the impact on predictability that assignable cause can have. Figure 3 shows the difference between process control and process capability.

A process capability study involves taking periodic samples from the process under controlled conditions. The performance characteristics of these samples are charted against time. In time, assignable causes can be identified and engineered out. Careful documentation of the process is key to accurate diagnosis and successful removal of the assignable causes. Sometimes, the assignable causes will remain unclear requiring prolonged experimentation.

Elements which measure process variation control and capability are Cp and Cpk respectively. Cp is the specification width divided by the process width or Cp = (specification width) / 6σ. Cpk is the absolute value of the closest specification value to the mean, minus the mean, divided by half the process width or Cpk = | closest specification $-\overline{X}/3\sigma$.

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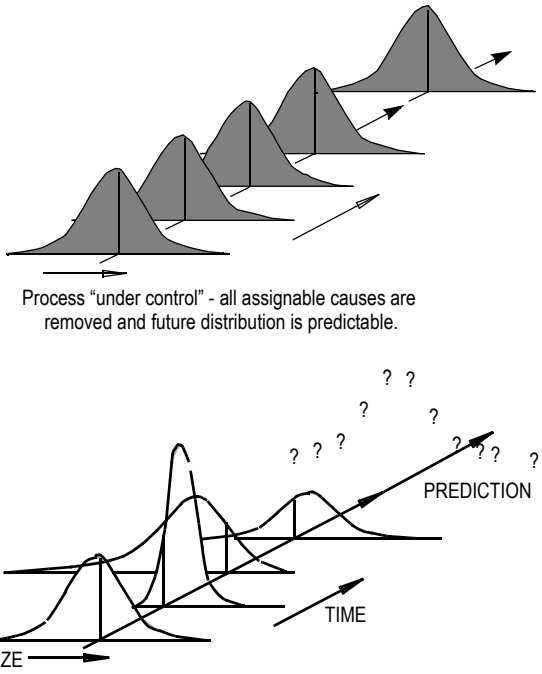

Figure 2. Impact of Assignable Causes on Process Predictable

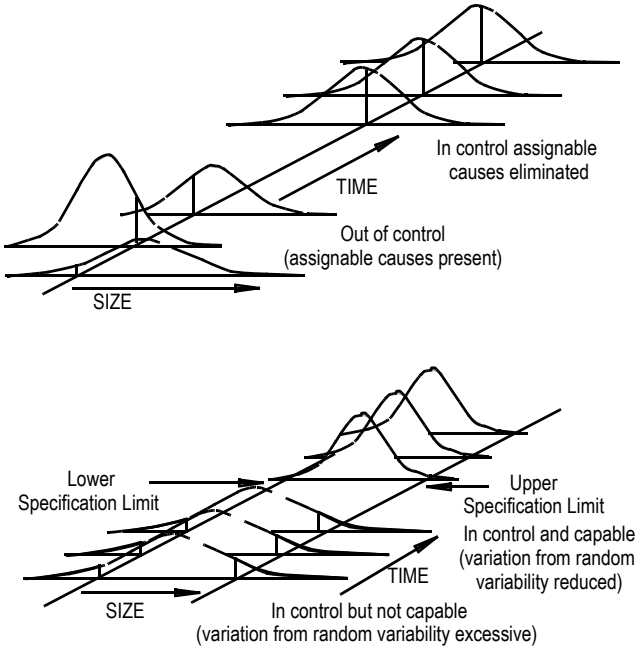

Figure 3. Difference Between Process Control and Process Capability

At Freescale, for critical parameters, the process capability is acceptable with a Cpk = 1.33. The desired process capability is a Cpk = 2 and the ideal is a Cpk = 5. Cpk, by definition, shows where the current production process fits with relationship to the specification limits. Off center distributions or excessive process variability will result in less than optimum conditions

SPC IMPLEMENTATION AND USE

DMTG uses many parameters that show conformance to specification. Some parameters are sensitive to process variations while others remain constant for a given product line. Often, specific parameters are influenced when changes to other parameters occur. It is both impractical and unnecessary to monitor all parameters using SPC methods. Only critical parameters that are sensitive to process variability are chosen for SPC monitoring. The process steps affecting these critical parameters must be identified also. It is equally important to find a measurement in these process steps that correlates with product performance. This is called a critical process parameter.

Once the critical process parameters are selected, a sample plan must be determined. The samples used for measurement are organized into RATIONAL SUBGROUPS of approximately 2 to 5 pieces. The subgroup size should be such that variation among the samples within the subgroup remain small. All samples must come from the same source e.g., the same mold press operator, etc. Subgroup data should be collected at appropriate time intervals to detect variations in the process. As the process begins to show improved stability, the interval may be increased. The data collected must be carefully documented and maintained for later correlation. Examples of common documentation entries would include operator, machine, time, settings, product type, etc.

Once the plan is established, data collection may begin. The data collected will generate $\overline{X}$ and R values that are plotted with respect to time. $\overline{X}$ refers to the mean of the values within a given subgroup, while R is the range or greatest value minus least value. When approximately 20 or more $\overline{X}$ and R values have been generated, the average of these values is computed as follows:

$$\overline{\overline{X}} = (\overline{X} + \overline{X}2 + \overline{X}3 + \ldots)/K$$

$$\overline{R} = (R1 + R2 + R3 + \ldots)/K$$

where K = the number of subgroups measured.

The values of $\overline{\overline{X}}$ and $\overline{R}$ are used to create the process control chart. Control charts are the primary SPC tool used to signal a problem. Shown in Figure 4, process control charts show $\overline{X}$ and R values with respect to time and concerning reference to upper and lower control limit values. Control limits are computed as follows:

$$\text{R upper control limit} = UCL_R = D4\ \overline{R}$$

$$\text{R lower control limit} = LCL_R = D3\ \overline{R}$$

$$\overline{X}\text{ upper control limit} = UCL_{\overline{X}} = \overline{\overline{X}} + A2\ \overline{R}$$

$$\overline{X}\text{ lower control limit} = LCL_{\overline{X}} = \overline{\overline{X}} - A2\ \overline{R}$$

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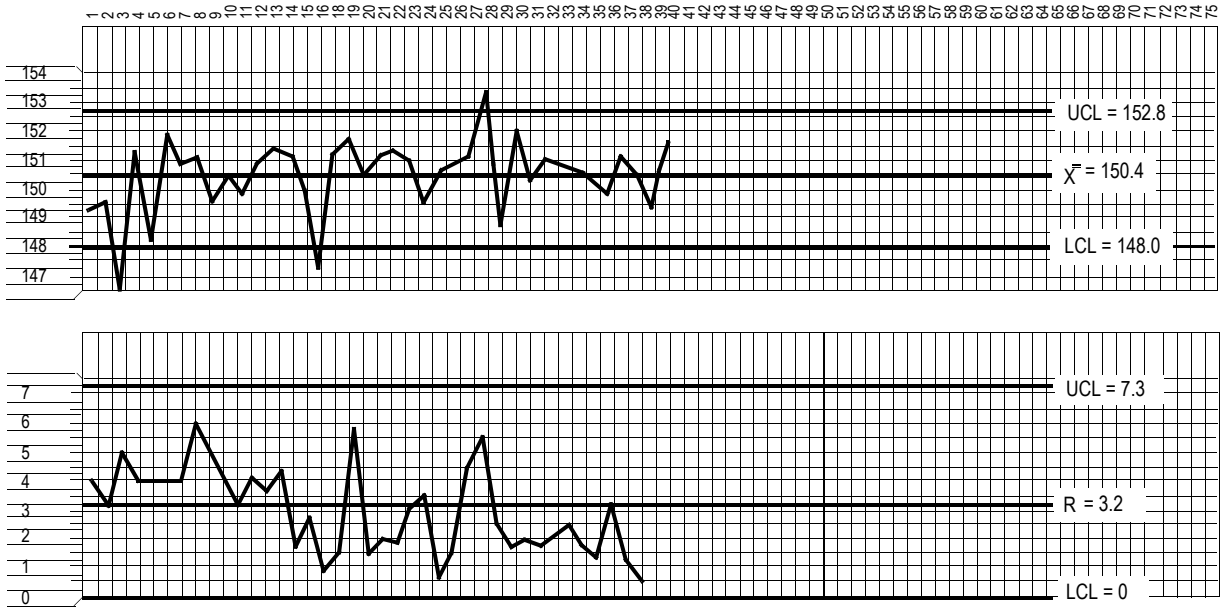

Figure 4. Example of Process Control Chart Showing Oven Temperature Data

Where D4, D3 and A2 are constants varying by sample size, with values for sample sizes from 2 to 10 shown in the following partial table:

n	2	3	4	5	6	7	8	9	10
D_4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78
D_3	*	*	*	*	*	0.08	0.14	0.18	0.22
A_2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31

* For sample sizes below 7, the LCL_R would technically be a negative number; in those cases there is no lower control limit; this means that for a subgroup size 6, six “identical” measurements would not be unreasonable.

Control charts are used to monitor the variability of critical process parameters. The R chart shows basic problems with piece to piece variability related to the process. The X chart can often identify changes in people, machines, methods, etc. The source of the variability can be difficult to find and may require experimental design techniques to identify assignable causes.

Some general rules have been established to help determine when a process is OUT-OF-CONTROL. Figure 5 shows a control chart subdivided into zones A, B, and C corresponding to 3 sigma, 2 sigma, and 1 sigma limits respectively. In Figure 6 through Figure 9, four of the tests that can be used to identify excessive variability and the presence of assignable causes are shown. As familiarity with a given process increases, more subtle tests may be employed successfully.

Once the variability is identified, the cause of the variability must be determined. Normally, only a few factors have a significant impact on the total variability of the process. The importance of correctly identifying these factors is stressed in the following example. Suppose a process variability depends on the variance of five factors A, B, C, D and E. Each has a variance of 5, 3, 2, 1 and 0.4 respectively.

Since:

$$\sigma \text{ tot} = \sqrt{\sigma A^2 + \sigma B^2 + \sigma C^2 + \sigma D^2 + \sigma E^2}$$

$$\sigma \text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 6.3$$

Now if only D is identified and eliminated then;

$$\sigma \text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + (0.4)^2} = 6.2$$

This results in less than 2% total variability improvement. If B, C and D were eliminated, then;

$$\sigma \text{ tot} = \sqrt{5^2 + (0.4)^2} = 5.02$$

This gives a considerably better improvement of 23%. If only A is identified and reduced from 5 to 2, then;

$$\sigma \text{ tot} = \sqrt{2^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 4.3$$

Identifying and improving the variability from 5 to 2 gives us a total variability improvement of nearly 40%.

Most techniques may be employed to identify the primary assignable cause(s). Out-of-control conditions may be correlated to documented process changes. The product may be analyzed in detail using best versus worst part comparisons or Product Analysis Lab equipment. Multi-variance analysis can be used to determine the family of variation (positional, critical or temporal). Lastly, experiments may be run to test theoretical or factorial analysis. Whatever method is used, assignable causes must be identified and eliminated in the most expeditious manner possible.

After assignable causes have been eliminated, new control limits are calculated to provide a more challenging variability criteria for the process. As yields and variability improve, it may become more difficult to detect improvements because they become much smaller. When all assignable causes have been eliminated and the points remain within control limits for 25 groups, the process is said to be in a state of control.

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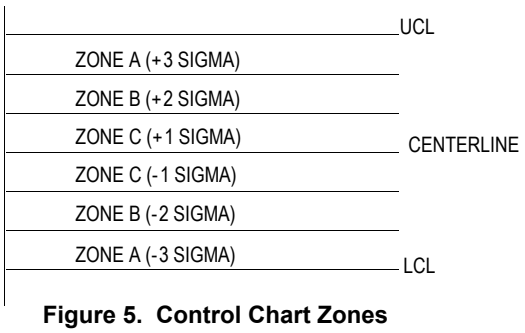

Figure 5. Control Chart Zones

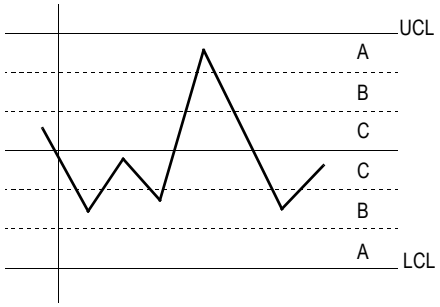

Figure 6. One Point Outside Control Limit Indicating Excessive Variability

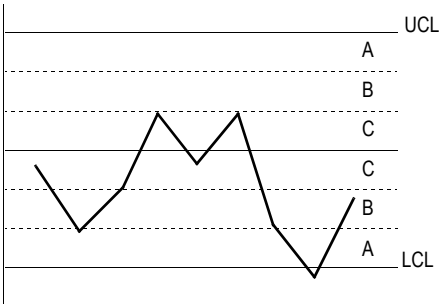

Figure 7. Two Out of Three Points in Zone A or Beyond Indicating Excessive Variability

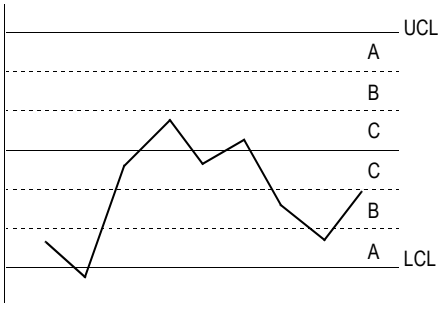

Figure 8. Four Out of Five Points in Zone B or Beyond Indicating Excessive Variability

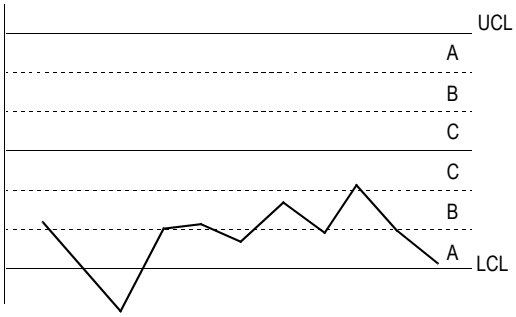

Figure 9. Seven Out of Eight Points in Zone C or Beyond Indicating Excessive Variability

SUMMARY

Freescale's commitment to statistical process controls has resulted in many significant improvements to processes. Continued dedication to the SPC culture will allow Freescale to reach beyond Six Sigma and zero defect capability goals. SPC will further enhance the commitment to Total Customer satisfaction.

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MICROMACHINED ACCELEROMETER RELIABILITY TESTING RESULTS

LIFE AND ENVIRONMENTAL TESTING RESULTS

STRESS TEST	CONDITIONS	RESULTS FAILED/PASS
High Temperature Bias	T_A = 90°C, V_{DD} = 5.0 V t = 1000 hours, 12 minutes on, 8 seconds off	0/32
High Temperature/High Humidity Bias	T_A = 85°C, R_H = 85%, V_{DD} = 5.0 V, t = 2016	0/38
High Temperature Storage (Bake)	T_A = 105°C, t = 1000 hours	0/35
Temperature Cycle	–40 to 105°C, Air to Air, 15 minutes at extremes, ≤ 5 minutes transfer, 1000 cycles	0/23
Mechanical Shock	5 blows X1, X2, Y1, Y2, Z1, Z2 2.0 G's, 0.5 mS, T_A = –40°C, 25°C, 90°C	0/12
Vibration Variable Frequency with Temperature Cycle	10 - 1 Khz @ 50 G's max, 24 hours each axis, X1, X2, Y1, Y2, Z1, Z2, T_A = –40 to 90°C, Dwell = 1 Hour, transfer = 65 minutes	0/12
Autoclave	T_A = 121°C, R_H = 100% 15 P_{SIG}, t = 240 hours	0/71
Drop Test	10 Drops from 1.0 meters onto concrete, any orientation	0/12

PARAMETERS MONITORED

		LIMITS			
		INITIAL		END POINTS	
PARAMETER	CONDITIONS	MIN	MAX	MIN	MAX
Offset	V_{DD} = 5.0 V, 25, –40 & 90°C	2.15 V	2.95 V	2.15 V	2.95 V
Self Test	V_{DD} = 5.0 V, 25, –40 & 90°C	20G	30 G	20 G	30 G
Sensitivity	V_{DD} = 5.0 V, 25, –40 & 90°C	45 mV/G	55 mV/G	45 mV/G	55 mV/G

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MEDIA COMPATIBILITY DISCLAIMER

Freescale Semiconductor has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Freescale Semiconductor. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

[1]

SENSOR MEDIA COMPATIBILITY: ISSUES AND ANSWERS

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ABSTRACT

As sensors and actuators are embedded deeper into electronic systems, the issue of media compatibility as well as sensor and actuator performance and survivability becomes increasingly critical. With a large number of definitions and even more explanations of what media compatibility is, there is a ground swell of confusion not only within the industry, but among end users as well. The sensor industry must respond to create a clear definition of what media compatibility is, then strive to provide a comprehensive understanding and industry wide agreement on what is involved in assessing media tolerance and compatibility. Finally, the industry must create a standard set of engineering parameters to design, evaluate, test, and ultimately qualify sensor and actuators functioning in various media conditions. This paper defines media compatibility, identifies pertinent compatibility issues, and recommends a path to industry standardization.

INTRODUCTION

Microelectromechanical System (MEMS) reliability in various media is a subject that has not yet received much attention in the literature yet [1-3], but does bring up many potential issues. The effects of long term media exposure to the silicon MEMS device and material still need answers [4]. Testing can result in predictable silicon or package related failures, but due to the complexity of the mechanisms, deleterious failures can be observed. The sensor may be exposed to diverse media in markets such as automotive, industrial, and medical. This media may include polar or nonpolar organic liquids, acids, bases, or aqueous solutions. Integrated circuits (ICs) have long been exposed to temperature extremes, humid environments, and mechanical tests to demonstrate or predict the reliability of the device for the application. Unlike a typical IC, a sensor often must exist in direct contact with a harsh environment. The lack of harsh media simulation test standardization for these direct contact situations necessitates development of methods and hardware to perform reliability tests.

The applicability of media compatibility affects all sensors to some degree, but perhaps none more dramatically than a piezoresistive pressure sensor. In order to provide an accurate, linear output with applied pressure, the media should come in direct contact with the silicon die. Any barrier provided between the die and the media, limits the device performance. A typical piezoresistive diaphragm pressure sensor manufactured using bulk micromachining techniques is shown in Figure 1. A definition for a media compatible pressure sensor will be proposed.

To ensure accurate media testing, the requirements and methods need to be understood, as well as what constitutes a failure. An understanding of the physics of failure can significantly reduce the development cycle time and produce a higher quality product [5,6]. The focus of the physics-of-failure approach includes the failure mechanism, accelerating environment, and failure mode. The requirement for a typical pressure sensor application involves long term exposure to a variety of media at an elevated temperature and may include additional acceleration components such as static or cyclic temperature and pressure.

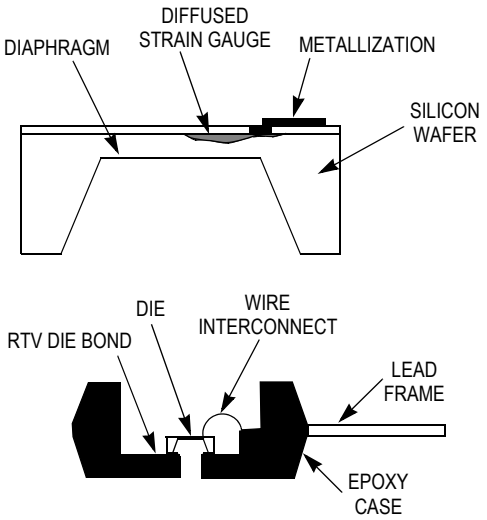

Figure 1. Typical Bulk Micromachined Silicon Piezoresistive Pressure Sensor Device and Package Configuration

1. This paper was presented at Sensors Expo, Anaheim, CA, and is reprinted with permission, Sensors Magazine (174 Concord St., Peterborough, NH 03458) and Expocon Management Associates, Inc. (P.O. Box 915, Fairfield, CT 06430).

The failure mechanisms that may affect a sensor or actuator will be discussed along with the contributors and acceleration means. Failure mechanisms of interest during media testing of semiconductor MEMS devices are shown in Table 1. MEMS applications may involve disposable applications such as a blood pressure monitor whose lifetime is several days. General attributes to consider during testing include: lifetime expectations, cost target, quality level, size, form, and functionality.

Table 1. Typical Failure Mechanisms for Sensors and Actuators [6-10]

Uniform Corrosion
Localized Corrosion
Galvanic Corrosion
Silicon Etching
Polymer Swelling or Dissolution
Interfacial Permeability
Adhesive Strength
Fatigue Crack Initiation
Fatigue Crack Propagation
Environment Assisted Cracking
Creep

Methods for performing media compatibility testing to determine the potential for the various failure mechanisms will be presented. Attributes of the testing need to be well understood so that proper assessment of failure and lifetime approximation can be made. The lifetime modeling is key for determination of the ability of a sensor device to perform its intended function. Reliability modeling and determination of activation energies for the models will provide the customer with an understanding of the device performance. The definition of an electrical failure can range from catastrophic, to exceeding a predetermined limit, to just a small shift. The traditional pre to post electrical characterization (before and after the test interval) can be enhanced by *in situ* monitoring. *In situ* monitoring may expose a problem with a MEMS device during testing that might have gone undetected once the media or another environmental factor is removed. This is a common occurrence for a failure mechanism, such as swelling, that may result in a shift in the output voltage of the sensor. Response variables during environmental testing can include: electrical, visual, analytical, or physical characteristics such as swelling or weight change.

DEFINITIONS AND UNDERLYING CAUSES

The definition of a media compatible pressure sensor is as follows: the ability of a pressure sensor to perform its specified electromechanical function over an intended lifetime in the chemical, electrical, mechanical, and thermal environments encountered in a customer's application.

The key elements of the definition are perform, function, lifetime, environment, and application. All of these elements are critical to meet the media compatibility needs. The underlying causes of poor media compatibility is the hostile environment and permeability of the environment. The environment may consist of media or moisture with ionics, organics, and/or aqueous solutions, extreme temperatures, voltage, and stress.

Permeability is the product of diffusivity and solubility. Contributors to permeability include materials (e.g. polymeric structures), geometry, processing, and whether or not the penetration is in the bulk or at an interface. The environment can also accelerate permeation if a concentration gradient, elevated temperature and/or pressure exist. An example of material dependence of permeation is shown in Figure 2. Organic materials such as silicone can permeate 50% of the relative moisture from the exterior within minutes where inorganic materials such as glass takes years for the same process to occur.

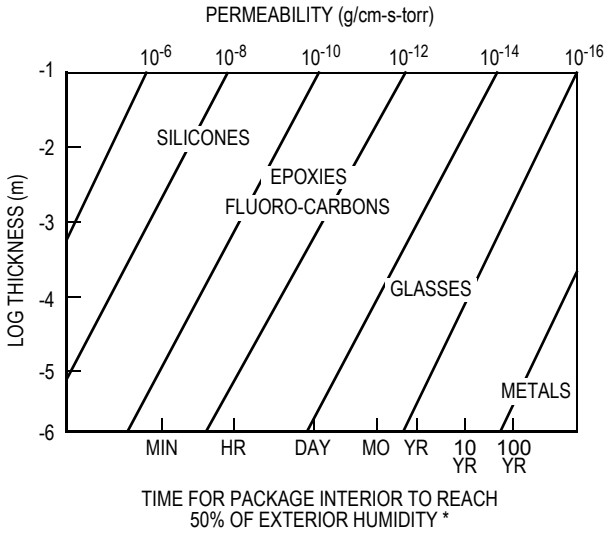

Figure 2. Permeation relationship for various materials.

** Richard K. Traeger, "Nonhermiticity of Polymeric Lid Sealants, IEEE Transactions on Parts, Hybrids, and Packaging, Vol. PHP-13, No. 2, June 1977.*

Gasoline and aqueous alkaline solutions represent two relatively diverse applications that are intended for use with a micromachined pressure sensor. The typical automotive temperature range is from -40° to 150°C. This not only makes material selection more difficult but also complicates the associated hardware to perform the media related testing [11]. A typical aqueous alkaline solution application would be found in the appliance industry. This industry typically has a narrower temperature extreme then the automotive market, but the solutions and the level of ions provide a particular challenge to MEMS device reliability.

Gasoline contains additives such as: antiknock, anti-preignition agents, dyes, antioxidants, metal deactivators, corrosion inhibitors, anti-icers, injector or carburetor detergents, and intake valve deposit control additives [12]. To develop a common test scheme for the liquid, a mixture table was developed for material testing in gasoline/methanol mixtures. The gasoline/methanol mixtures developed were intended for accelerated material testing with a gasoline surrogate of ASTM Fuel Reference "C" (50% toluene and 50% iso-octane) [13]. Material testing is performed with samples either immersed in the liquid or exposed to the vapor over the

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liquid. The highly aromatic Fuel “C” is intended to swell polymeric materials. Contaminants in actual gasoline can result in corrosion or material degradation, so chloride ions or formic acid with distilled water are added to create an aggressive fuel media. Gasoline can decompose by a process called auto-oxidation that will form aggressive substances that can dissolve polymers or corrode metal. Copper is added as a trace metal to accelerate the formation of free radicals from the hydroperoxides. Table 2 details the various gasoline/methanol mixtures with additives recommended by the task force from Chrysler, Ford, and General Motors.

Table 2. Fuel Testing Methods

	Elastomer	Polymer	Metal
Alcohol/Fuel Blends	CMO	CMO	
	CM15	CM15	CM15
	CM30	CM30	
	CM50	CM50	
	CM85	CM85	CM85
Aggressive Fuel, Add		Chloride ion	Distilled water
		Formic Acid	Chloride ion
		Sodium Chloride	Formic Acid
Auto Oxidized Fuels, Add		t-Butyl Hydroperoxide	t-Butyl Hydroperoxide
		Cu^{+}	

Recommended gasoline/methanol mixtures for material testing. The recommended testing for metals should include immersion in the liquid as well as exposure to the vapor. The coding for the alcohol/fuel blends, CMxx is: C for Fuel C; M for methanol; and xx indicating the percentage of methanol in the mixture.

The general question for the appliance industry compatibility issues is not whether the media will contain ions (as it most assuredly will) but at what concentration. Tap water with no alkali additives contains ions capable of contributing to a corrosive reaction [14]. A typical application of a pressure sensor in the appliance industry is sensing the water level in a washing machine. The primary ingredients of detergent used in a washing machine are: surfactants, builders, whitening agents and enzymes [15]. The surfactants dissolve dirt and emulsify oil, grease and dirt. They can be anionic or cationic. Cationic surfactants are present in detergent-softener combinations. Builders or alkaline water conditioning agents are added to the detergent to soften the water, thus increasing the efficiency of the surfactant. These builders maintain alkalinity that results in improved cleaning. Alkaline solutions at temperatures indicated by the appliance industry range can etch bare silicon similar to the bulk micromachining process. Thus bare silicon could be adversely affected by exposure to these liquids [16].

FAILURE MECHANISMS

The failure mechanisms that can affect sensors and actuators are similar to that for electronic devices. These failure mechanisms provide a means of categorizing the varlous effects caused by chemical, mechanical, electrical, and thermal environments encountered. An understanding of the potential failure mechanisms should be determined before media testing begins. The typical industry scenario has been to follow a set boiler plate of tests and then determine reliability. This may have been acceptable for typical electronic devices, but the applications for sensors are more demanding of a thorough understanding before testing begins. The sensitivity of the device to its physical environment is heightened for a pressure sensor. Any change in the material properties results in a change of the sensor performance. Failure mechanisms for pressure sensors in harsh media application are listed below. The pressure sensor allows a format for discussion, though the mechanisms discussed are applicable in some degree to all sensor and actuator devices.

Corrosion

Corrosion has been defined as any destructive result of a chemical reaction between a metal or metal alloy and its environment [17]. Several metal surfaces exist within a pressure sensor package: metallic lines on the die, trimmable resistors, bonding pads, wires, leadframes, etc. Much of the die-level metal is protected by an overlying inorganic passivation material (e.g., PECVD silicon nitride); however, unless some package-level encapsulant is used, bondpads, wires, and leadframes are exposed to the harsh media and are potential corrosion sites. Furthermore, an energized pressure sensor has a voltage difference between these exposed metallic surfaces, which compounds the corrosion problem. Generally, corrosion problems are organized into the following categories: uniform corrosion; galvanic corrosion, and localized corrosion (including, crevice corrosion, pitting corrosion, etc.) [17]. The factors that contribute to corrosion are: the substrate (metallic) material and its surface structure and composition; the influence of a barrier coating, its processing conditions and/or adhesion promotion; the cleanliness of the surface, adhesion between a coating and the surface, solution concentration, solution components (especially impurities and/or oxidizers); localized geometry and applied potential. In addition, galvanic corrosion is influenced by specific metal-to-metal connections.

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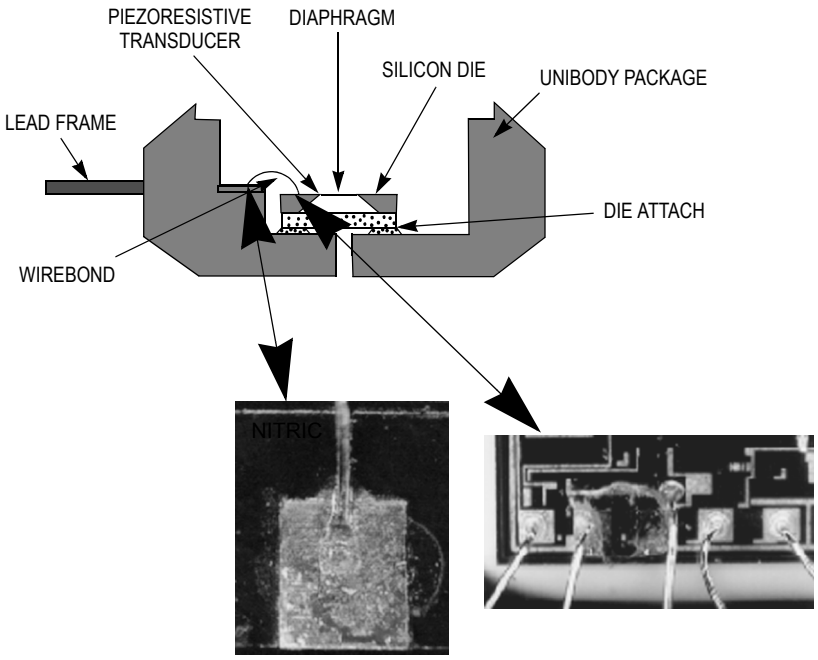

Figure 3. Examples of uniform corrosion of a gold leadframe in nitric acid at 5 Vdc and galvanic corrosion on an unbiased device at the gold wire/aluminum bondpad interface in commercial detergent

Part of Figure 3 shows an example of what we have described as electrolytic corrosion (i.e., corrosion of similar metallic surfaces in an electrolytic solution caused by a sufficient difference in potential between the two surfaces). This appears to be uniform corrosion of the gold leadframe surface. It should be noted that this type of failure is observed even on 'noble' metals like gold. Applied potential is the driving force for the reaction. All metals can corrode in this fashion depending on the solution concentration (pH) and the applied potential. Pourbaix diagrams describe these thermodynamic relationships [18].

Figure 3 shows an example of galvanic corrosion. The figure illustrates that corrosion can also occur because of dissimilar metals that are connected electrically and are immersed in an electrolytic solutions. A difference in the corrosion potential between the two metals is the driving force for the reaction. Localized corrosion examples are prevalent as well. Often they may be the precursor to what appears on a macro scale to be uniform or galvanic corrosion. *In situ* monitoring of devices in electrolytic media will allow better diagnosis of this failure mechanism. Typical *ex situ* or interval reliability testing may not allow diagnosis of the root cause to the failure, thus limiting the predictive power of any resulting reliability models.

Silicon Etching

Figure 4 shows the result of an accelerated test of a pressure sensor die to a high temperature detergent solution. The detergent used was a major consumer brand and resulted in dramatic etching of the silicon. Alkaline solutions that undergo a hydrolysis reaction may result in etching of the silicon similar to a bulk micromaching operation. This failure mechanism can cause a permanent change in the sensitivity of the device because the sensitivity is proportional to the inverse square of the silicon thickness. Moreover, it can lead to loss in bond integrity between wafers (Fig. 4). Silicon etching [19-20], like corrosion reactions, is a chemical reaction, so the contributing factors include the silicon material, its crystal orientation and its doping level, the solution type, concentration and pH, and the applied potential. Temperature, concentration (i.e., pH), and voltage all act to accelerate this process. Figure 5 shows an example of modeling results that illustrates two of these variables.

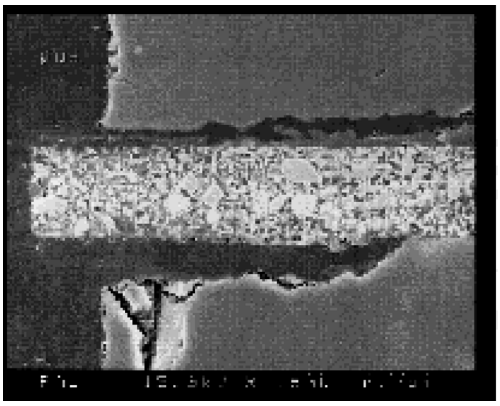

Figure 4. Photograph of silicon etching after exposure to an aqueous detergent solution at elevated temperature for an extended time. A frit layer, horizontally in the middle, adheres to silicon on either side. The amount of etching is evident by referencing the glass frit edge on the far left. These two silicon edges were aligned to the frit edge when the die was sawn.

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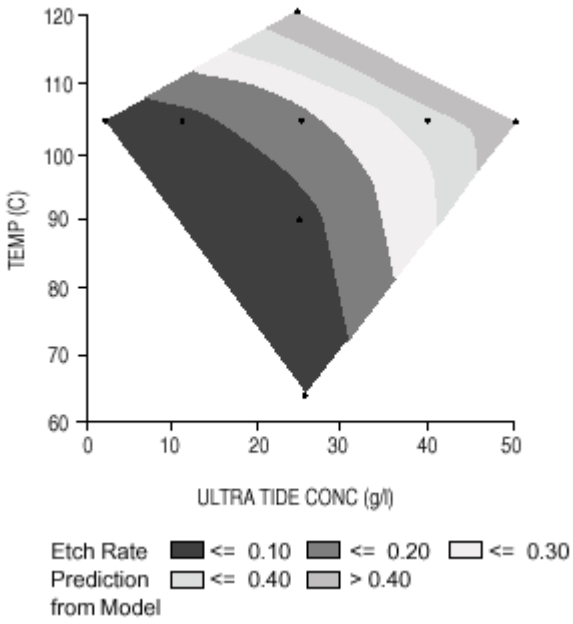

Figure 5. Experimental results for the etching of (100) silicon with approximately 5x10^{-5} cm^{-3} boron doping density in a commercially available detergent as a function of temperature and detergent concentration (which is proportional to pH).

Polymer Swelling or Dissolution

Swelling or dissolution affects those polymers typically employed to package the micromachined structure and depending on the nature of the media, may have a degrading effect on device performance. These two related phenomena are caused by solvent diffusing into the material and occupying free volume within the polymer. The solubility parameter gives a quantitative measure of the potential for swelling [21]: i.e., it provides a quantitative measure of "like dissolves like" (Figure 6). Both the polymer and the solution contribute to this failure mechanism, while the media (specifically, the solubility parameter), the temperature, and the pressure can be used as acceleration factors.

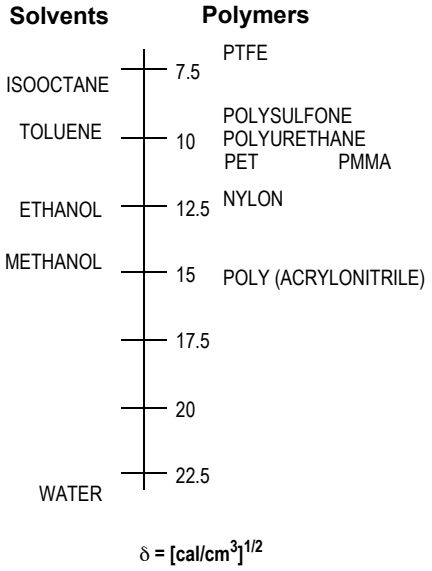

Figure 6. Typical values of solubility parameter (δ [cal/cm^3]$^{1/2}$) for solvents and polymers.

Figure 7 shows a photograph of a device after exposure to a harsh fuel containing corrosive water solution. This corrosion and evidence of swelling of the gel demonstrates the vital importance the package has on the reliability of the pressure sensor device. Also, it has been observed that corrosion occurs more readily following swelling of a polymeric encapsulant.

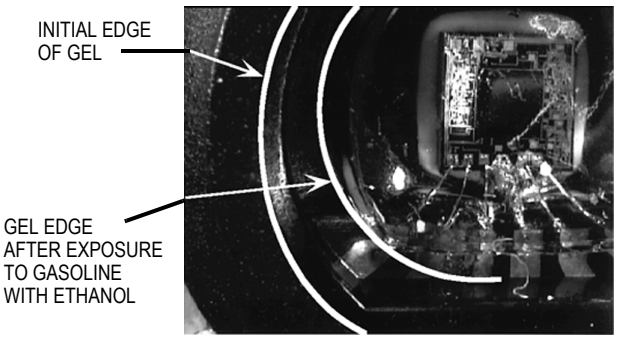

Figure 7. Photograph of a pressure sensor device after extended exposure to harsh fuel containing corrosive water, followed by exposure to a strong acid. Evidence of the gel swelling during the test, and corresponding shrinkage after removal from the test media can be seen by the gel retracting away from the sidewall of the package.

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Interfacial Permeability

Lead leakage is a specific example of interfacial permeability. It is pressure leakage through the polymer housing material/metallic leadframe material interface from the inside of the pressure sensor package to the outside of the pressure sensor package or vice versa [22]. In addition, other material interfaces can result in leakage. We describe another specific example of this in the next section. Lead leakage is like polymer swelling in that it may allow another failure mechanism, like corrosion, to occur more readily. It also causes a systematic pressure measurement error. Figure 8 shows the result of lead leakage measurements as a function of temperature cycling. The polymer housing material (and its CTE as a function of temperature), the leadframe material (and its CTE), surface preparation and contamination, the polymer matrix composition, and polymer processing all contribute to this effect. It is accelerated by media, temperature cycling, and applied pressure.

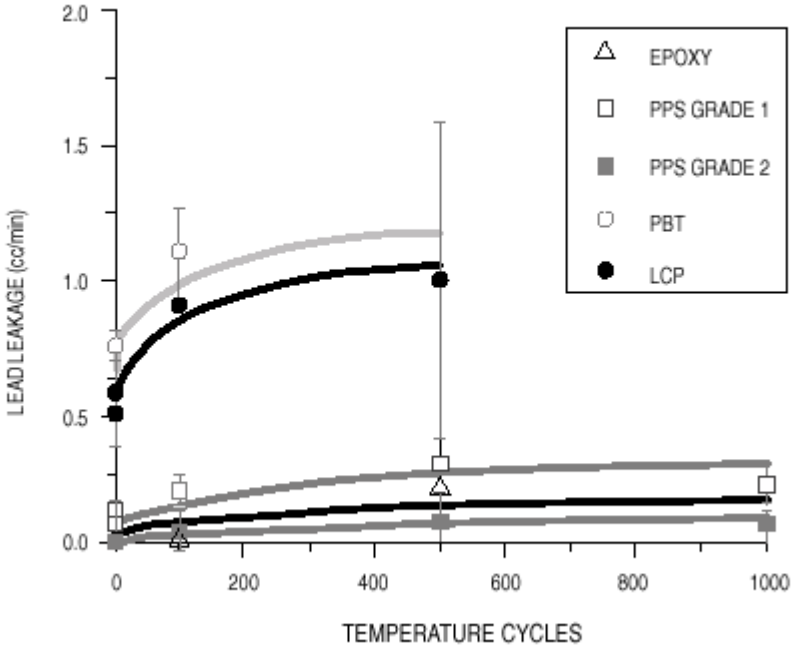

Figure 8. Pressure leakage measurements through the metallic leadframe/polymeric housing material interface on a pressure sensor as a function of temperature cycles between -40 and 125°C.

Adhesive Strength

Packaging of the sensor relies on adhesive material to maintain a seal but not impart stress on the piezoresistive element. Polymeric materials are the primary adhesive materials which can range from low modulus material such as silicone to epoxy with a high modulus. An example of a typical joint is shown in Figure 9. The joint has three possible failure locations with the preferred break being cohesive. Contributors to a break include whether the joint is in tension or compression, residual stresses, the adhesive material, surface preparation, and contamination. An adhesive failure is accelerated by media contact, cyclic or static temperature, and cyclic or static stress (e.g. pressure).

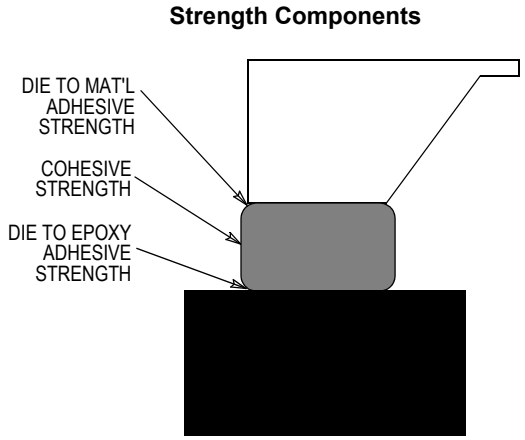

Figure 9. Failure locations for an adhesive bond of dissimilar materials.

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Mechanical Failures

The occurrence of mechanical failures include components of fatigue, environment assisted cracking, and creep. Packaging materials, process, and residual stresses are all contributors to mechanical failure. A summary of acceleration stresses is shown in Table 3. Contact with harsh media is an accelerating stress for all of the mechanical failure mechanisms.

Table 3. Mechanical Failure Mechanisms

Failure Mechanism	Acceleration Stresses
Fatigue crack initiation	Mechanical stress/strain range Cyclic temperature range Frequency Media
Fatigue crack propagation	Mechanical stress range Cyclic temperature range Frequency Media
Environment assisted cracking	Mechanical stress Temperature Media
Creep	Mechanical stress Temperature Media

PRESSURE SENSOR SOLUTIONS

The range of solutions for pressure sensors to media compatibility is very diverse. Mechanical pressure sensors still occupy a number of applications due to this media compatibility concern. These devices typically operate on a variable inductance method and are typically not as linear as a piezoresistive element. Figure 10 shows a comparison between a mechanical pressure sensor and a piezoresistive element for a washing machine level sensing application. The graph shows a nonlinear response for the mechanical sensor and a corresponding straight line for the piezoresistive element.

A common method of obtaining media compatibility is to place a barrier coating over the die and wire interconnection. This organic encapsulant provides a physical barrier between the harsh environment and the circuitry. The barrier coating can range from silicone to parylene or other dense films that are typically applied as a very thin layer. This technique offers limited protection to some environments due to swelling and/or dissolution of the encapsulant material when in contact with media with a similar solubility. When a polymeric material has a solubility parameter of the same value as the corresponding media, swelling or dissolution will occur.

Stainless steel diaphragms backfilled with silicone oil provide a rugged barrier to most media environments, but

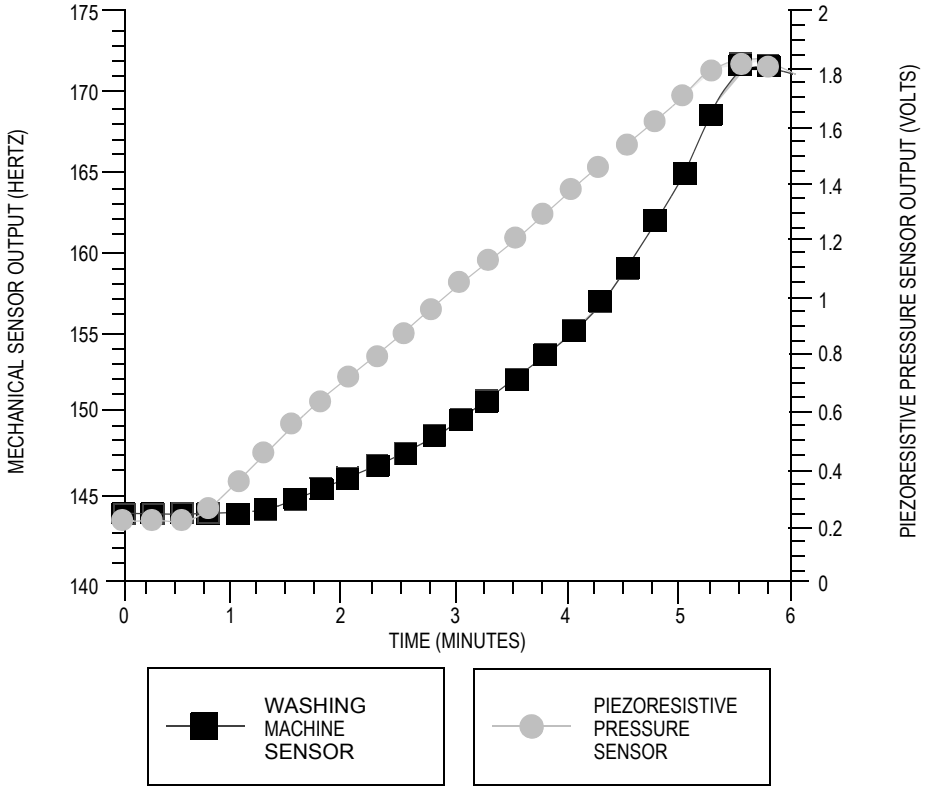

Figure 10. Graphical comparison of the output from a mechanical pressure sensor compared to a piezoresistive sensor during a washing machine fill cycle.

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MEDIA TEST METHODS

Figure 11 and Figure 12 show a test apparatus specifically intended for use with solvents and Figure 13 an apparatus for aqueous solutions. This test system has resulted in a realistic test environment that provides electrical bias, *in situ* measurements, consistent stoichiometry, and temperature control all within a safe environment. The safety aspects of the testing were obtained by creating an environment free of oxygen to eliminate the possibility of a fire. Results from the testing have included swelling of silicone materials, corrosion, and adhesive failures.

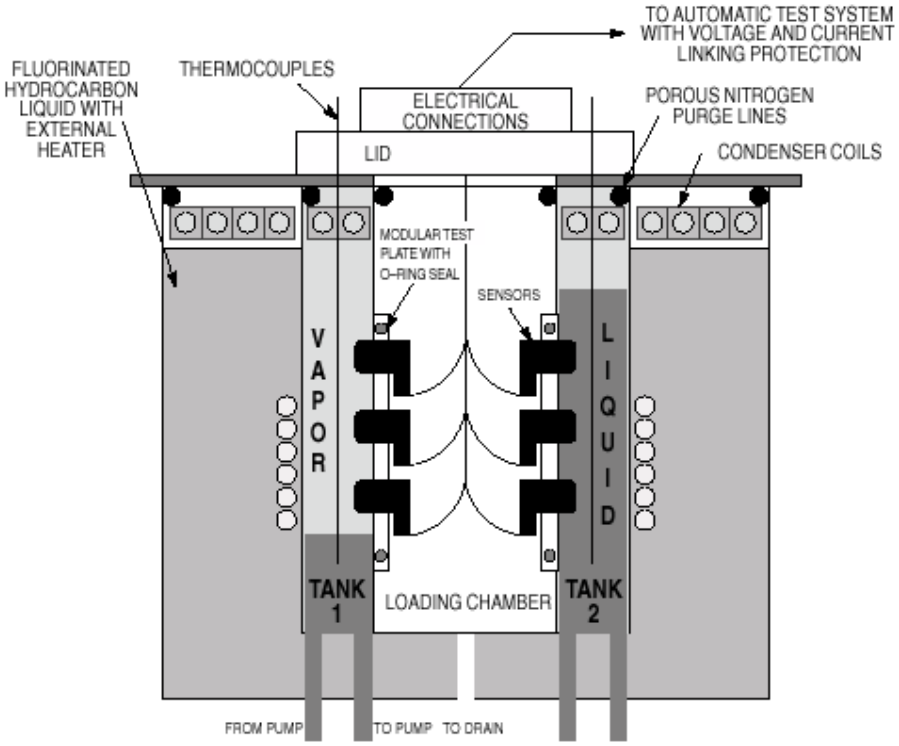

Figure 11. Graphical depiction of the sensor media tester used for liquid or vapor exposure of the device to the harsh media to accelerate the failure mechanisms or demonstrate compatibility.

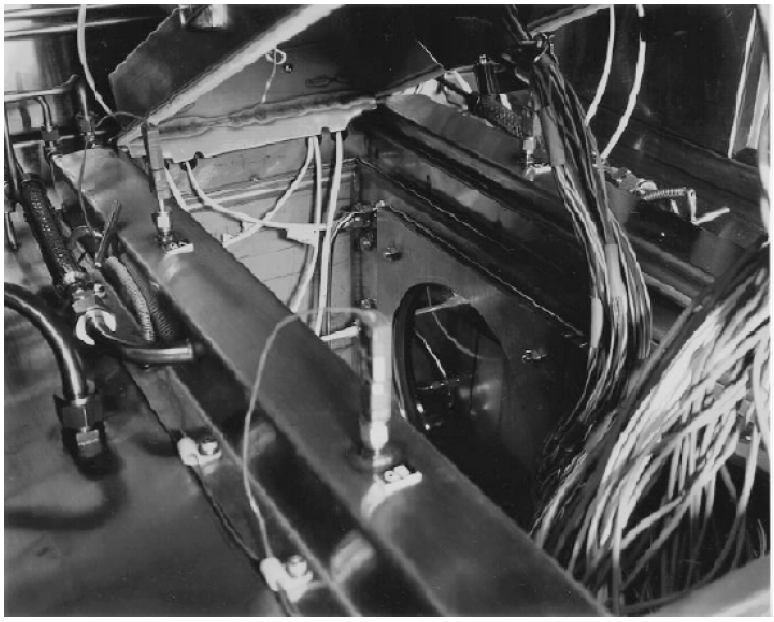

Figure 12. Photograph of the load chamber area of the Media Test System allowing for fuel or solvent testing at temperature with in situ monitoring of the devices under test (DUT's) output.

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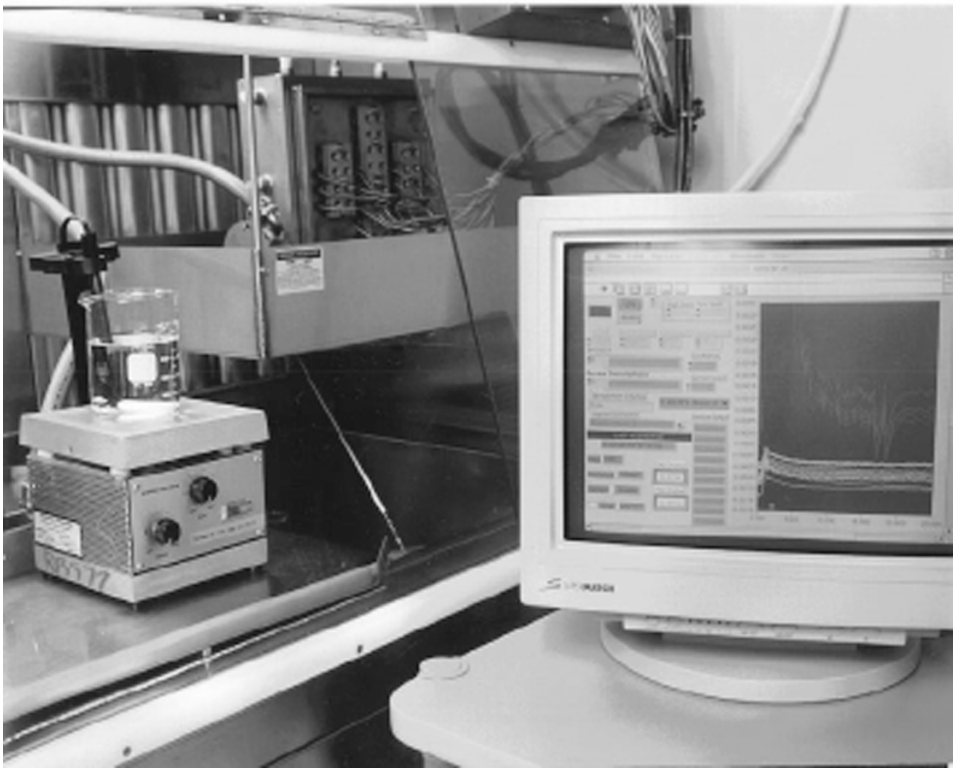

Figure 13. Photograph of the aqueous alkaline solution test system and the data acquisition system for *in situ* monitoring of the MEMS devices.

LIFETIME MODELING

Reliability techniques provide a means to analyze media test results and equate the performance to a lifetime [23-24]. The primary reliability techniques involve an understanding of the failure rate, life distributions, and acceleration modeling. The failure rate for a product's lifetime follows the bathtub curve. This curve, as shown in Figure 14, has an early life period with a decreasing failure rate. Manufacturing defects would be an example of failures during this portion of the curve. The second portion of the curve, often described as the useful life region has a constant failure rate. The last section has an increasing failure rate and is referred to as the wearout region. This wearout region would include failure mechanisms such as corrosion or fatigue.

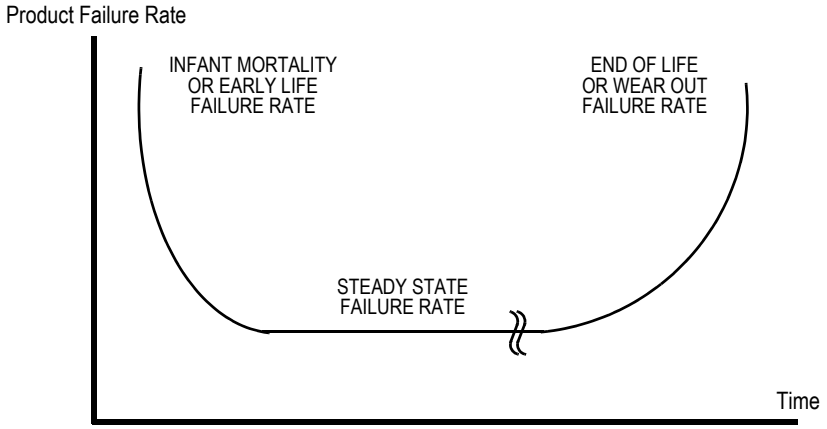

Figure 14. Bathtub curve showing various failure rate regions.

Lifetime distributions provide a theoretical model to describe device lifetimes. Common lifetime distributions include the exponential, Weibull, lognormal, and extreme value. The exponential distribution models a lifetime with a constant failure rate An example of the exponential distribution is a glass which has an equal probability of failing the moment after it is manufactured, or when its ten years old. The Weibull and lognormal distribution are all right, or positively skewed

distributions. A right skewed distribution will be a good model for data in a histogram with an extended right tail. The Weibull distribution is sometimes referred to as a distribution of minima. An example of a Weibull distribution is the strength to break a chain where the weakest link describes the strength of the chain. The extreme value distribution is a distribution of maxima. It is the least utilized of the four life distributions.

For means of example, the Weibull distribution will be used. The Weibull lifetime distribution as the form:

$$F(t, \theta, \beta) = 1 - e^{-\left(\frac{t}{\theta}\right)^{\beta}} \quad (1)$$

The two parameters for the Weibull distribution are q and b. Theta is the scale parameter, or characteristic life. It represents the 63.2 percentile of the life distribution. Beta is the shape parameter. In order to determine the parameters for the Weibull distribution, testing must be performed produce failure on the devices. The failure data can be used to calculate the maximum likelihood estimates or determined graphically. It has not always been customary to perform reliability demonstration testing until failures occur. In regards to media testing, this seems to be the only method to derive lifetime estimates that reflect a true understanding of the device capability.

$$AF = e^{\left[\frac{Ea}{k}\left(\frac{1}{T_{low}} - \frac{1}{T_{high}}\right)\right]} \bullet \left(\frac{RH_{high}}{RH_{low}}\right)^{n} \quad (2)$$

A media test typically needs to take results received in weeks or months to predict lifetime in years. Acceleration models are used to determine the relationship between the accelerated test and the normal lifetime. Literature has reported numerous models to equate testing to lifetime including the Peck model for temperature and humidity [25]. The acceleration equation based on Peck's model is where Ea is 0.9 eV and n is -3.0. The value K is Boltzmann's constant which is equal to 8.6171×10^{-5} eV/K. The relative humidity is entered as a whole number, i.e. 85 for 85%. Using this sample model, test results from humidity testing can be related to the lifetime. The methods to equate test time to lifetime first involves fitting the failure data to a lifetime distribution. For an example, humidity data at 60°C, 90% relative humidity and bias was tested to failure. The failure data fit a Weibull distribution with a characteristic life of 40,000 hours. By applying the acceleration factor equation shown above, quantification of the lifetime in the use conditions can be calculated. Figure 15 shows the cumulative failure distribution for the test and use conditions for a 15 year lifetime. This technique is key for media testing since the range of use conditions is very broad. The consumer can determine the attributes for the sensor to use for the application. The attributes might include cost, performance, and possibility for replacement.

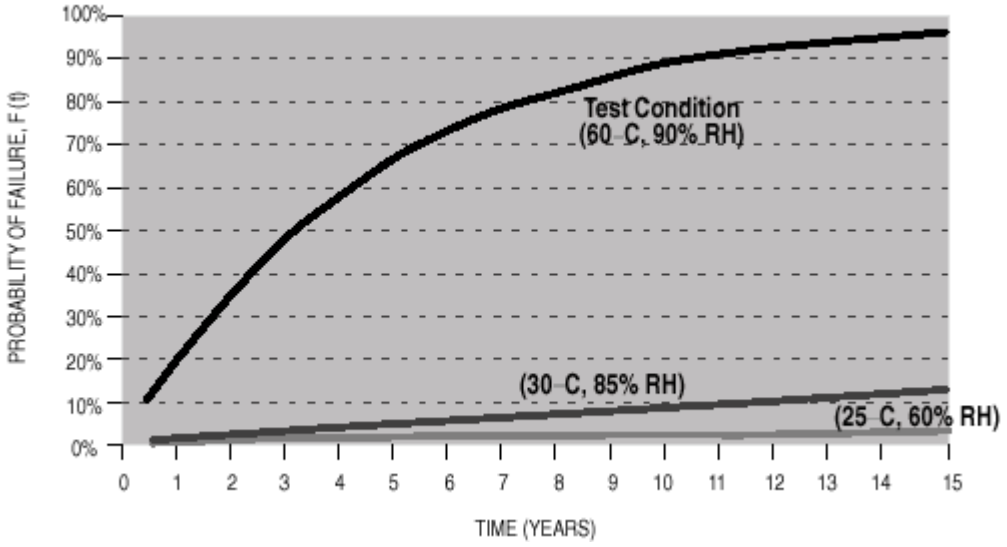

Figure 15. Probability of failure versus time for humidity testing with bias on an integrated sensor device.

The failure distribution example shown typically represents one failure mechanism. The failure mechanism that typifies humidity testing is mobile ions. An elevated test temperature, humidity and bias contributes to the mobility of the ions and the ability to create a surface charge. By lowering the temperature, humidity or switching the bias, an improvement in the lifetime can be obtained. If a device manufacturer would test to failure and report the lifetimes, the customer could select the appropriate product for their application. Following a template of reliability tests that have not been verified and do not coincide with the applicable failure mechanism may put the application at risk for surviving.

Humidity testing was used as an example above, but a similar case could be made of other attributes involved with media testing. Other attributes of the media test may include the bias level and duty cycle, the pH or conductivity of the

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solution, and any stress such as a pressure differential. By modeling these attributes against the various solutions, models for media compatibility can be developed.

INDUSTRY STANDARDIZATION

Why an industry standard? The increasing use of electronic sensors in everyday life has designers wrestling with the complexity of defining the compatibility of a sensor with the media they are measuring. A designer may decide to solve the question of media compatibility by choosing to isolate the sensor from the media via a stainless steel diaphragm. While this solution provides very good media isolation, it is not without some drawbacks such as cost, size of packaging, decreased sensitivity and long term drift. Without a recognized standard for defining media compatibility, the designer is left to a series of ad hoc test methods and conflicting specifications.

An industry media compatibility standard will provide the designer with a method of evaluating sensor performance. The designer could match an application's requirements, for media compatibility, with the available sensor products thus taking price and performance into account. This will enable the designer to minimize the total cost of an application. A standard will also enable suppliers to provide products warranted to defined criteria. Once a standard is adopted, the suppliers may rationalize their test efforts and pass the savings on to their customers.

A standard should provide a designer with a simple, coherent, complete definition of a media's effects on a sensor. The standard should included an accepted test methodology, test equipment guidelines, life time model, acceleration factors model, and a definition of failures. A proposed list of criteria to include in a model are shown in Table 4.

Table 4. Suggested Criteria for Media Compatibility

Media Contact - Front or Back	Supply Voltage	Solubility Parameter
Pressure Range	Supply Voltage Duty Cycle	Conductivity of Media
Temperature Range	Voltage Potential within Media	pH
Recipe of Media and Contaminants	Frequency Output is Measured	Lifetime Expectancy
Sensor to Media Interconnection	Relative Motion of Media (e.g., Flow)	

These criteria must be included not only for the media, but also for the contaminants in the media. An example is a washing machine level sensor which must be compatible with water vapor (the media) and detergent and chlorine (the contaminant). To create a standard, a series of tests which benchmark the criteria must be designed and performed. The results would form the basis of the life time and acceleration factor models.

There are several ways to create a standard, each of which have their own associated pros and cons. Three possible ways to create a standard are: an industry association committee, a panel of industry representatives, or a de facto standard set by one or more industry suppliers. To define a standard for media compatibility may require more than one of these methods. An industry leader may define a standard form to which they deliver product. This may stimulate the formation of a committee which defines a broader standard for the industry. As this standard becomes more accepted by the industry, the committee may work with an industry association to “legitimize” the de facto standard. No matter how the standard is formulated, receiving broad industry acceptance will require meeting the customers' needs.

CONCLUSION

Investigation of media compatibility for pressure sensors has been presented from a physics-of-failure approach. We have developed a set of internal standard test and reliability lifetime analysis procedures to simulate our customers' requirements. These activities have incorporated information from several fields beyond sensors and/or electronics, including: electrochemistry and corrosion, polymers, safety and environmental, automotive and appliance industry standards, and reliability. The next critical step to elevating the awareness of this problem, in our opinion, is to develop an industry-wide set of standards, driven by customer applications, that include media testing experimental procedures, reliability lifetime analysis, and media compatibility reporting to allow easier customer interpretation of results.

ACKNOWLEDGEMENTS

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Section Two

Accelerometer Overview

Freescale's series of acceleration sensors incorporate a surface micromachined structure. The force of acceleration moves the seismic mass, thereby changing the g-cell's capacitance. Coupled with the g-cell is a control chip to provide the accelerometer with signal amplification, signal conditioning, low pass filter, and temperature compensation. With Zero-g offset, sensitivity and filter roll-off that is factory set, the device requires only a few external passives. In fact, this acceleration sensor device offers a calibrated self-test feature that mechanically displaces the seismic mass with the application of a digital self-test signal. The g-cell is hermetically sealed at the die level, creating a particle-free environment with features such as built in damping and over-range stops to protect it from mechanical shock. These acceleration sensors are rugged, highly accurate and feature X, XY, XYZ, and Z axis of sensitivity.

Freescale's acceleration sensors are economical, accurate, and highly reproducible for the ideal sensing solution in automotive, industrial, commercial, and consumer applications.

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Mini Selector Guide

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Accelerometer Sensor

Device	Acceleration (g)	Sensing Axis	Sensitivity (mV/g)	Rolloff Frequency (Hz)	VDD Supply Voltage (Typ) (V)
MMA7260QT	1.5/2/4/6	XYZ	800/600/300/200	350/150	3.3
MMA6260Q	1.5	XY	800	50	3.3
MMA2260D	1.5	X	1200	50	5.0
MMA1260D	1.5	Z	1200	50	5.0
MMA1270D	2.5	Z	750	50	5.0
MMA1250D	5.0	Z	400	50	5.0
MMA1220D	8.0	Z	250	250	5.0
MMA6231Q	10	XY	120	300	3.3
MMA3201D	40/40	XY	50/50	400	5.0
MMA2201D	40	X	50	400	5.0
MMA2202D	50	X	40	400	5.0
MMA3202D	100/50	XY	50/100	400	5.0
MMA2204D	100	X	20	400	5.0
MMA1213D	50	Z	40	400	5.0
MMA1210D	100	Z	20	400	5.0
MMA1211D	150	Z	13	400	5.0
MMA2301D	200	X	10	400	5.0
MMA1212D	200	Z	10	400	5.0
MMA2300D	250	X	8.0	400	5.0
MMA1200D	250	Z	8.0	400	5.0
MMA3204D	100/30	XY	20/66.67	400	5.0
MMA6270QT	1.5/2/4/6	XY	800/600/300/200	350	3.3
MMA6271QT	2.5/3.3/6.7/10	XY	480/360/180/120	350	3.3
MMA6280QT	1.5/2/4/6	XZ	800/600/300/200	350/150	3.3
MMA6281QT	2.5/3.3/6.7/10	XZ	480/360/180/120	350/150	3.3
MMA7261QT	2.5/3.3/6.7/10	XYZ	480/360/180/120	350/150	3.3

Sensor Applications

AUTOMOTIVE APPLICATIONS

- Airbags
- Rollover detection
- Fuel shut-off valve
- Crash detection
- Suspension control
- Vehicle dynamic control
- Braking systems
- Occupant safety

HEALTHCARE / FITNESS APPLICATIONS

- Physical therapy
- Rehabilitation equipment
- Range of body motion measurement
- Pedometers
- Ergonomics tools
- Sports medicine equipment
- Sports diagnostic systems

INDUSTRIAL / CONSUMER APPLICATIONS

- Fall detection
- Fall log
- HDD protection
- MP3 players
- Portable electronics
- Warranty purpose recording
- E-compass
- Ergonomic tools
- Gaming
- Image stability
- Physical therapy
- Text scrolling
- 3-D motion dialing
- Pedometer
- Robotics
- Virtual reality input devices
- Anti-theft devices
- Car/personal navigation
- Dead reckoning for GPS
- Black boxes/event recorders
- Shipping/handling monitor
- Tap to mute
- Acoustics
- Appliance balance/monitoring
- Bearing wear monitoring
- Seismic monitoring
- Smart motor maintenance

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Acceleration Sensor FAQ's

We have discovered that many of our customers have similar questions about certain aspects of our accelerometer's technology and operation. Here are the most frequently asked questions and answers that have been explained in relatively non-technical terms.

Q. What is the g-cell?

A. The g-cell is the acceleration transducer within the accelerometer device. It is hermetically sealed at the wafer level to ensure a contaminant free environment, resulting in superior reliability performance.

Q. What does the output typically interface with?

A. The accelerometer device is designed to interface with an analog to digital converter available on most microcontrollers. The output has a 2.5 V DC offset, therefore positive and negative acceleration is measurable. For unique customer applications, the output voltage can be scaled and shifted to meet requirements using external circuitry.

Q. What is the resonant frequency of the g-cell?

A. The resonant frequency of the g-cell is much higher than the cut-off frequency of the internal filter. Therefore, the resonant frequency of the g-cell does not play a role in the accelerometer response.

Q. What is ratiometricity?

A. Ratiometricity simply means that the output offset voltage and sensitivity scales linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter. Ratiometricity allows for system level cancellation of supply induced errors in the analog to digital conversion process. Refer to the Special Features section under the Principle of Operation for more information.

Q. Is the accelerometer device sensitive to electro static discharge (ESD)?

A. Yes. The accelerometer should be handled like other CMOS technology devices.

Q. Can the g-cell part “latch"?

A. No, overrange stops have been designed into the g-cell to prevent latching. (Latching is when the middle plate of the g-cell sticks to the top or bottom plate.)

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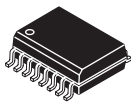
Surface Mount Micromachined Accelerometer

MMA1200

MMA1200D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±250g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

The MMA series of silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA1200D	– 40 to +125°C	475-01	SOIC-16
MMA1200DR2	– 40 to +125°C	475-01	SOIC-16, Tape & Reel
MMA1200EG	– 40 to +125°C	475-01	SOIC-16
MMA1200EGR2	– 40 to +125°C	475-01	SOIC-16, Tape & Reel

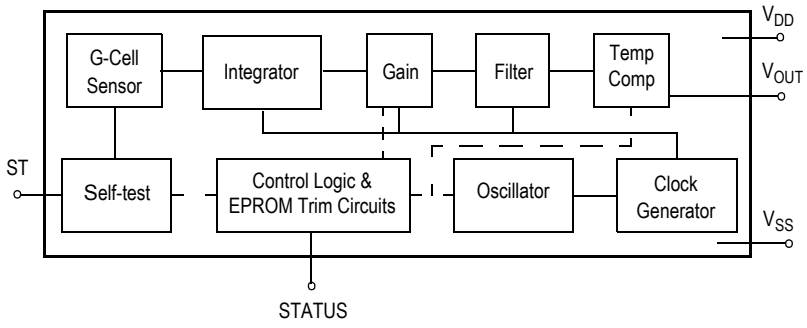


Figure 1. Simplified Accelerometer Functional Block Diagram

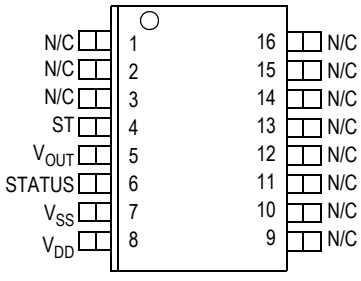


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	281	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.47 V_{DD}	0.50 V_{DD}	0.53 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	7.6	8.0	8.4	mV/g
Sensitivity	S_V	1.49	1.6	1.71	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9],[10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

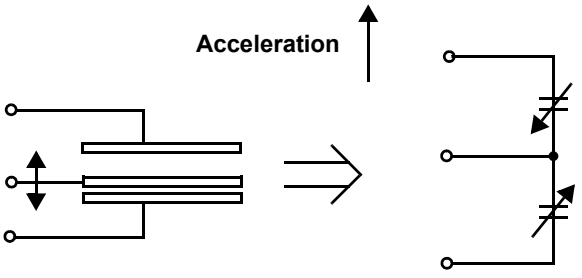

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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Pinout Description

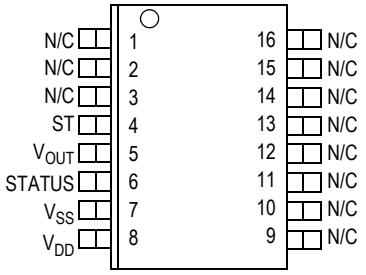

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

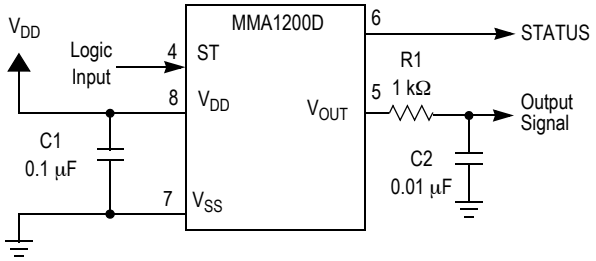

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

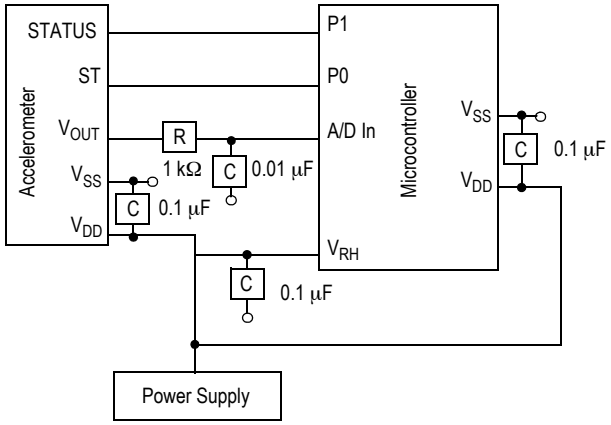

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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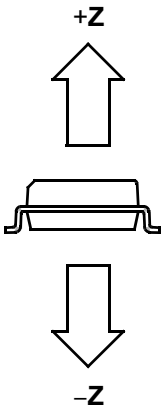
Dynamic Acceleration Sensing Direction



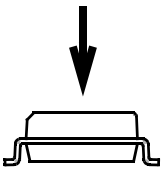
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field(1)



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

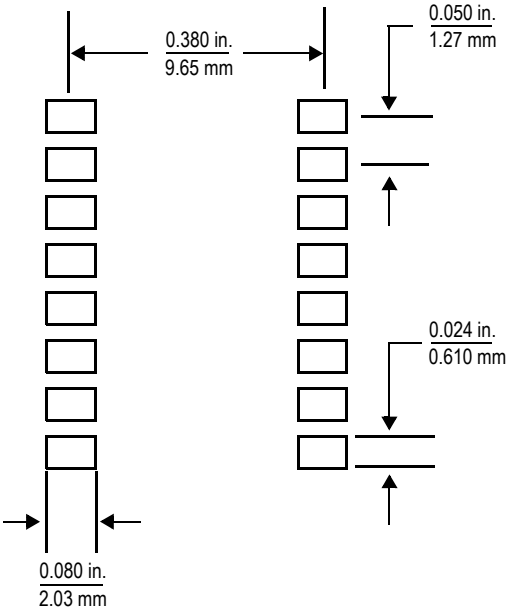

Figure 7. Footprint SOIC-16 (Case 475-01)

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Surface Mount Micromachined Accelerometer

MMA1210

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

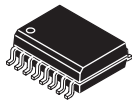
MMA1210D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1210D	–40° to 125°C	475-01	SOIC-16
MMA1210DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA1210EG	–40° to 125°C	475-01	SOIC-16
MMA1210EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

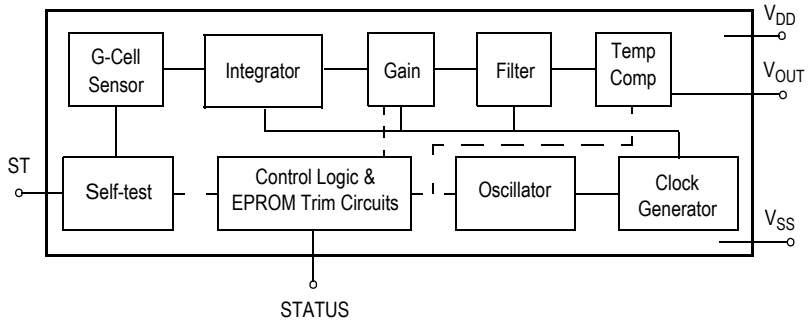


Figure 1. Simplified Accelerometer Functional Block Diagram

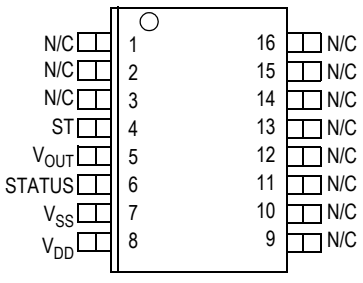


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	112.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20.0	21	mV/g
Sensitivity	S_V	3.72	4.0	4.28	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (0.1–1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
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4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
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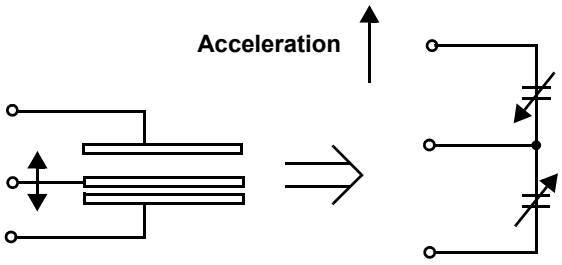

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

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Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

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Pinout Description

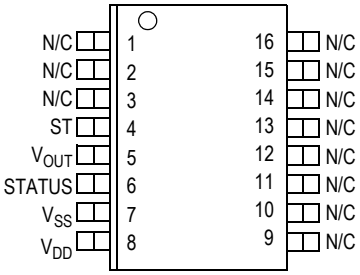

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

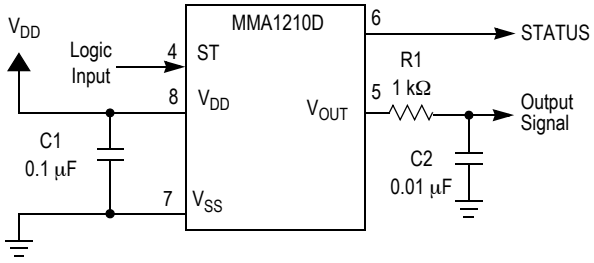

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

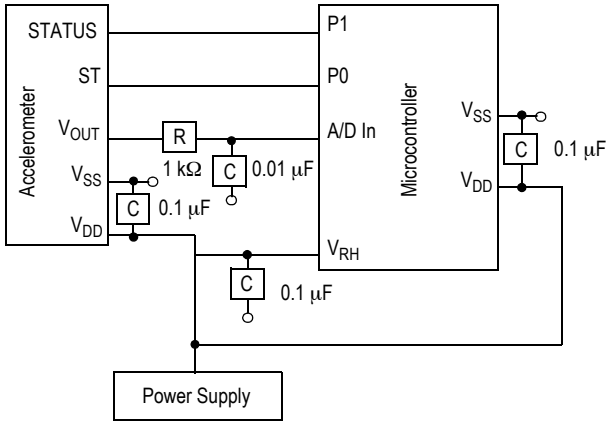

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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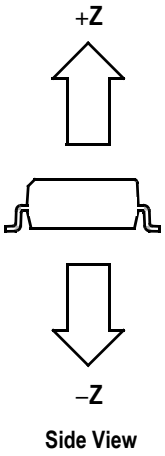
Dynamic Acceleration Sensing Direction



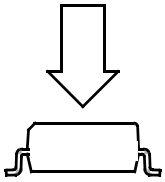
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field[1]



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

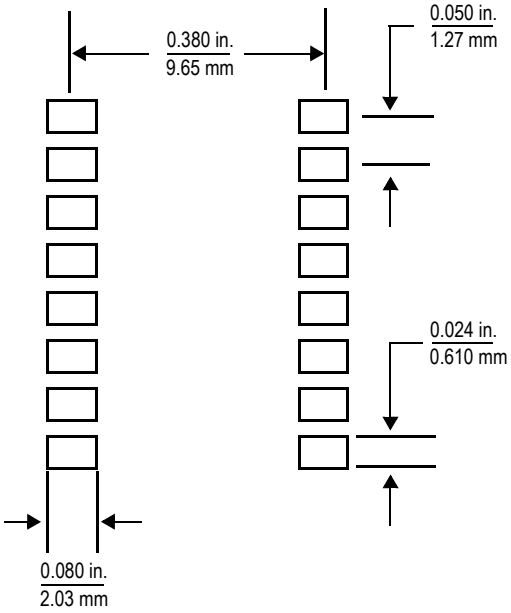

Figure 7. Footprint SOIC-16 (Case 475-01)

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Surface Mount Micromachined Accelerometer

MMA1211

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

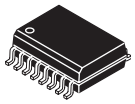
MMA1211D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±150g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1211D	–40° to 125°C	475-01	SOIC-16
MMA1211DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA1211EG	–40° to 125°C	475-01	SOIC-16
MMA1211EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

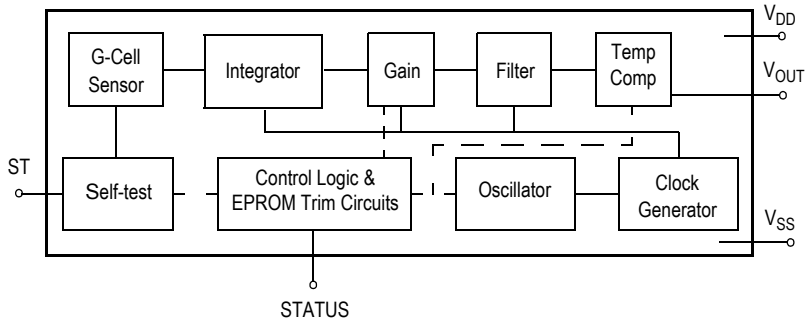


Figure 1. Simplified Accelerometer Functional Block Diagram

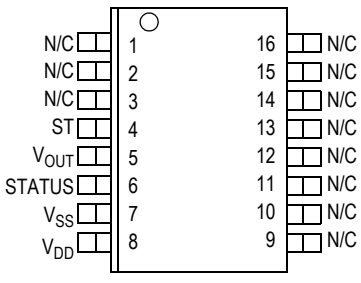


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test[1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	169	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	12.66	13.33	14.00	mV/g
Sensitivity	S_V	2.480	2.667	2.853	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	-30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

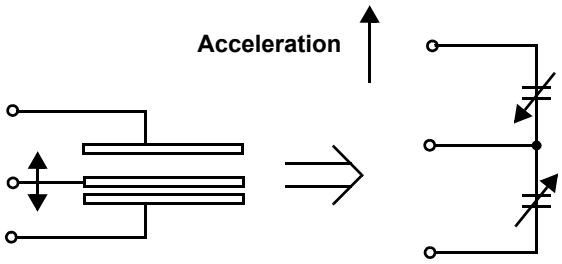

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive air bag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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Pinout Description

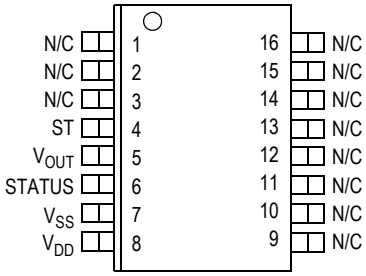

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected
4	ST	Logic input pin used to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	The power supply ground
8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

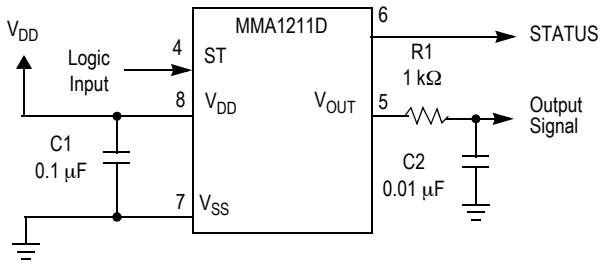

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

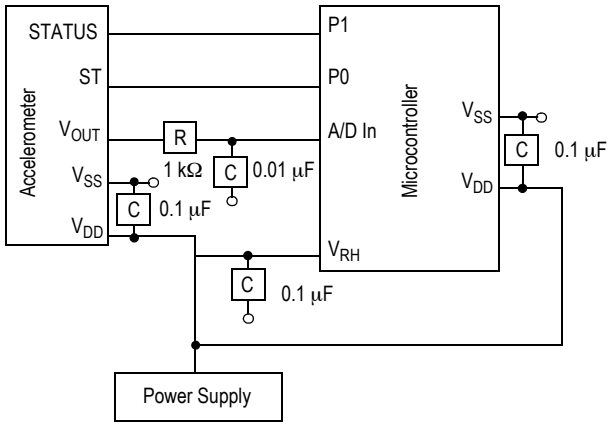

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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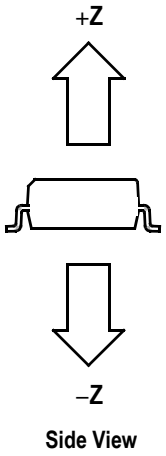
Dynamic Acceleration Sensing Direction



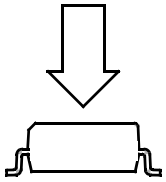
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field[1]



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

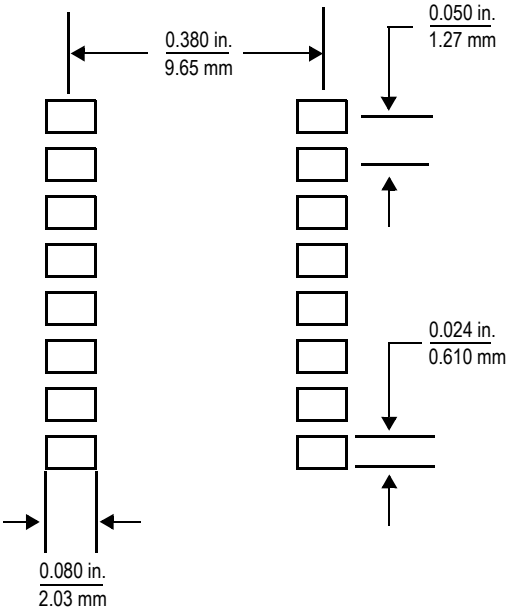

Figure 7. Footprint SOIC-16 (Case 475-01)

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Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

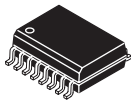
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Functional Description

- Vibration Monitoring and Recording
- Impact Monitoring

MMA1212

MMA1212D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±200g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1212D	–40° to 125°C	475-01	SOIC-16
MMA1212DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA1212EG	–40° to 125°C	475-01	SOIC-16
MMA1212EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

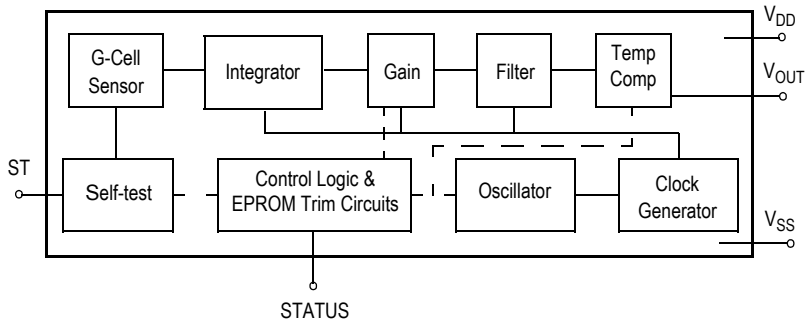


Figure 1. Simplified Accelerometer Functional Block Diagram

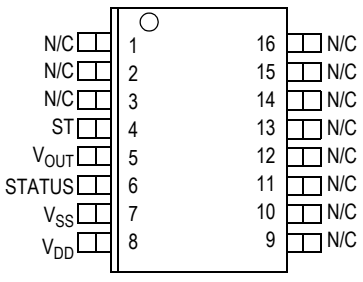


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	225	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.47V_{DD}	0.50 V_{DD}	0.53 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	9.5	10	10.5	mV/g
Sensitivity	S_V	1.86	2	2.14	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–2.0	—	2.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/($Hz^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	55	75	95	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{MIN}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (poly silicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

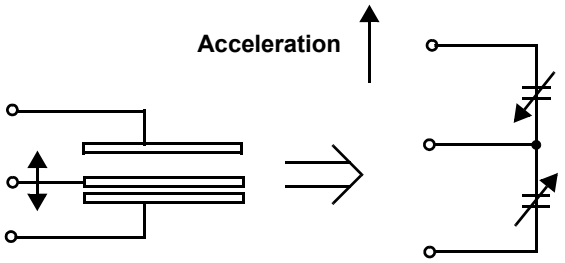

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive air bag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

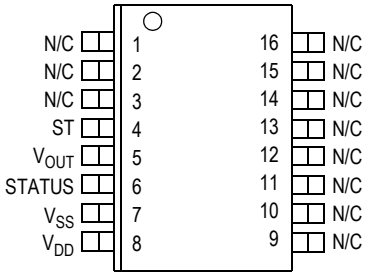

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected
4	ST	Logic input pin used to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	The power supply ground
8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

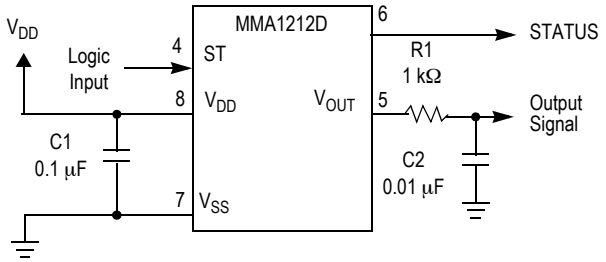

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

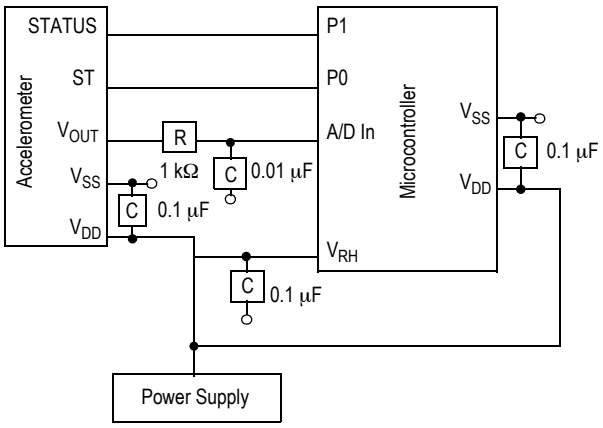

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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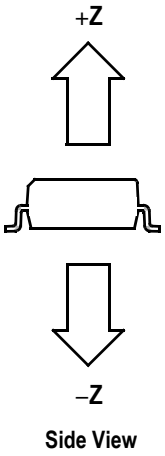
Dynamic Acceleration Sensing Direction



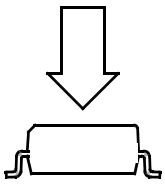
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field(1)



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

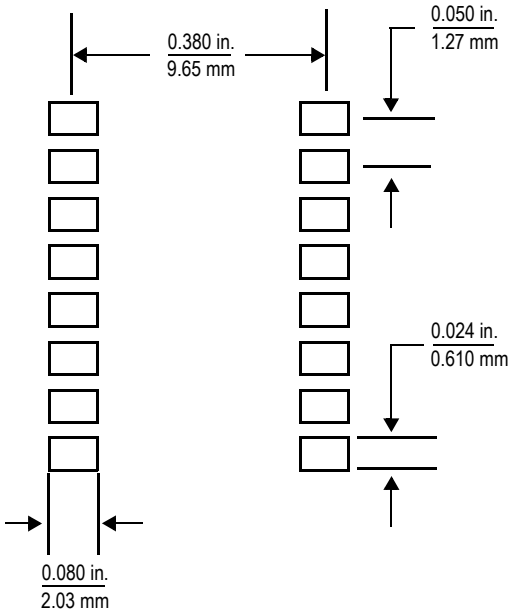


Figure 7. Footprint SOIC-16 (Case 475-01)

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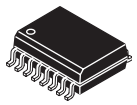
Surface Mount Micromachined Accelerometer

MMA1213

MMA1213D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±50g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1213D	–40° to 125°C	475-01	SOIC-16
MMA1213DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA1213EG	–40° to 125°C	475-01	SOIC-16
MMA1213EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

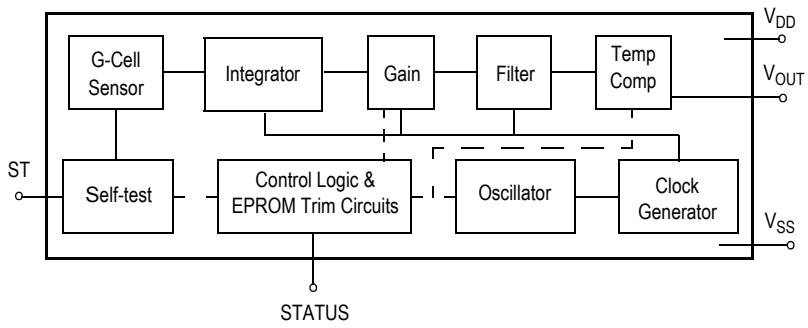


Figure 1. Simplified Accelerometer Functional Block Diagram

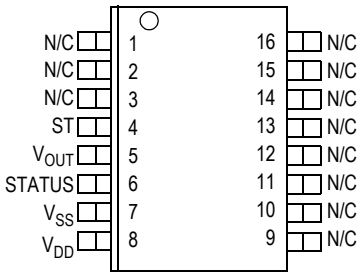


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	38	40	42	mV/g
Sensitivity	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (0.1-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{MIN}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	–0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at mid supply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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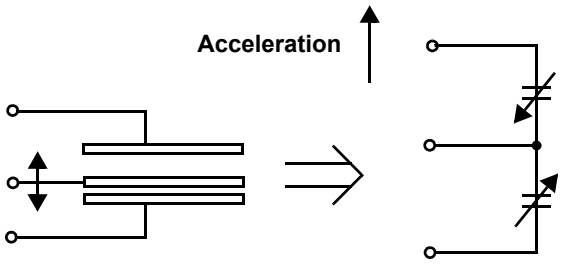

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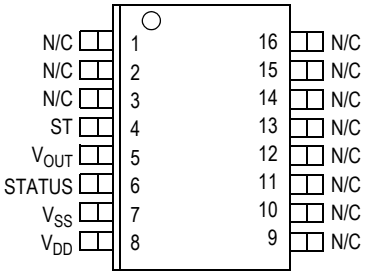
Pinout Description



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8	V_{DD}	The power supply input
9 thru 13	Trim pins	Used for factory trim. Leave unconnected
14 thru 16	—	No internal connection. Leave unconnected

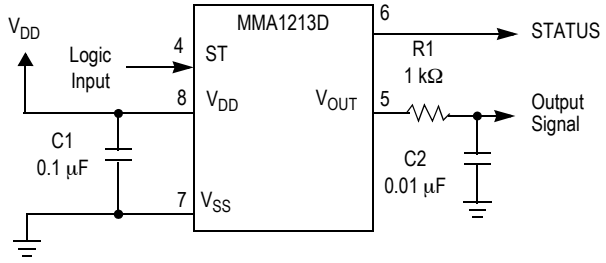

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

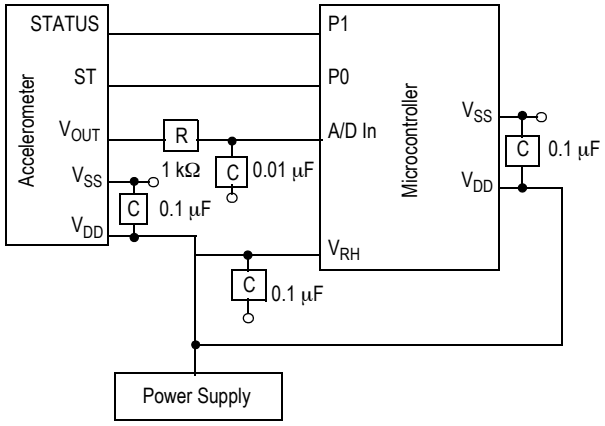

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
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5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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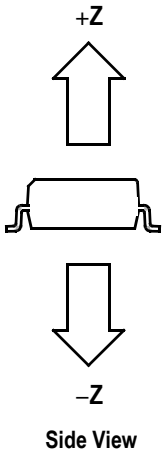
Dynamic Acceleration Sensing Direction



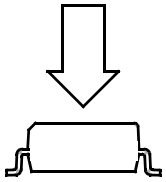
Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.

Side View

Static Acceleration Sensing Direction

Direction of Earth's gravity field(1)



Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

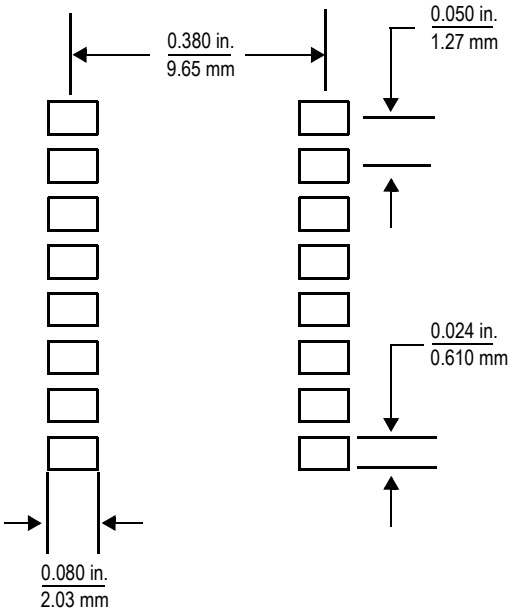


Figure 7. Footprint SOIC-16 (Case 475-01)

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Low G Micromachined Accelerometer

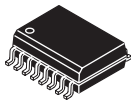
MMA1220

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1220D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±8g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA1220D	–40° to 125°C	475-01	SOIC-16
MMA1220DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA1220EG	–40° to 125°C	475-01	SOIC-16
MMA1220EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

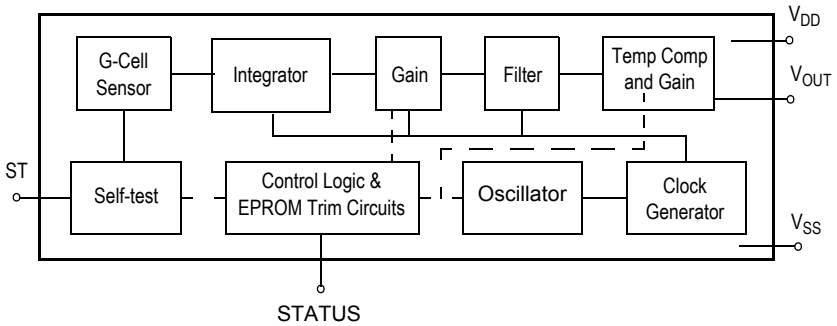


Figure 1. Simplified Accelerometer Functional Block Diagram

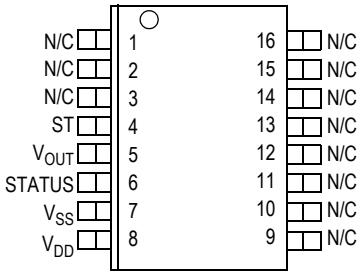


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	11.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g	$V_{OFF,V}$	0.45 V_{DD}	0.50 V_{DD}	0.55 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	237.5	250	262.5	mV/g
Sensitivity	S_V	46.5	50	53.5	mV/g/V
Bandwidth Response	f_{-3dB}	150	250	350	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+3.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	6.0	mVrms
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	ΔV_{ST}	0.2 V_{DD}	—	0.3 V_{DD}	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	VIH	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–100	–200	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

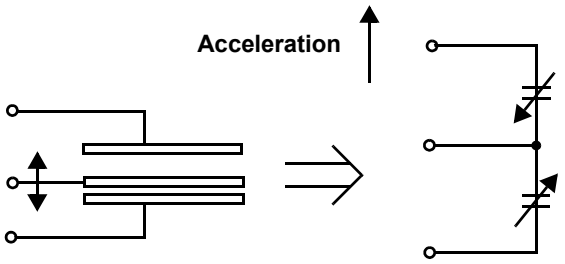

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

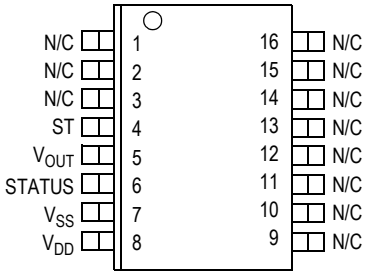

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Redundant V_{SS}. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

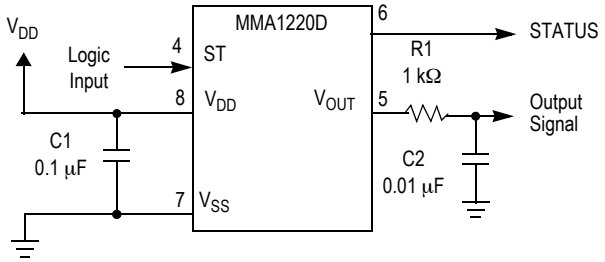

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

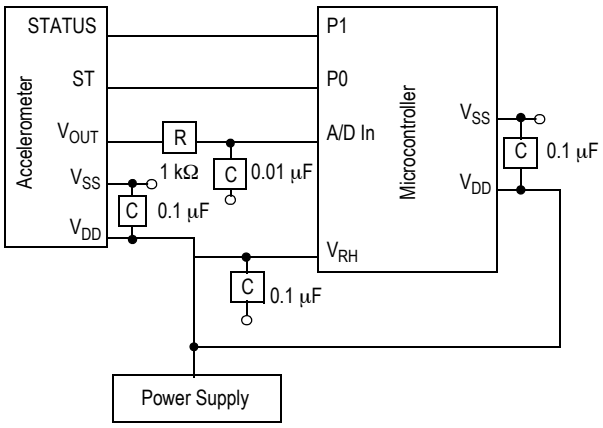

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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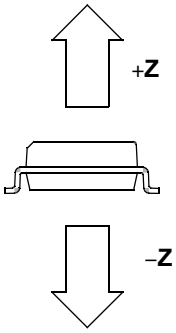
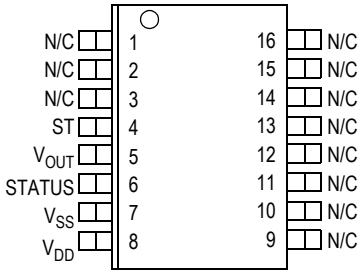
DYNAMIC ACCELERATION SENSING DIRECTION

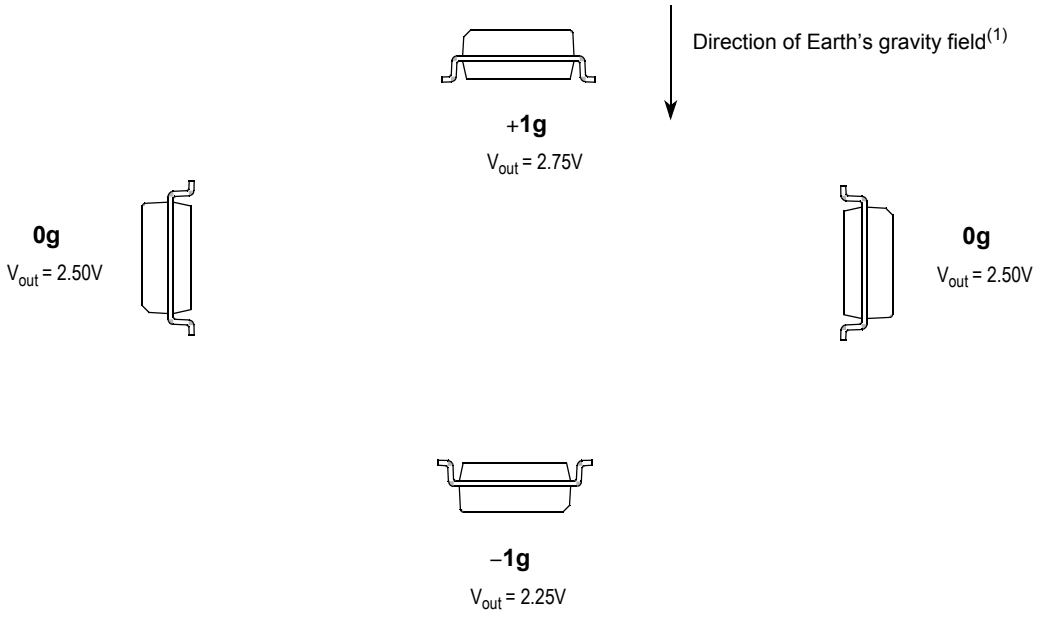


Acceleration of the package in the +Z direction (center plate moves in the –Z direction) will result in an increase in the output.

Activation of Self test moves the center plate in the –Z direction, resulting in an increase in the output.



STATIC ACCELERATION SENSING DIRECTION



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

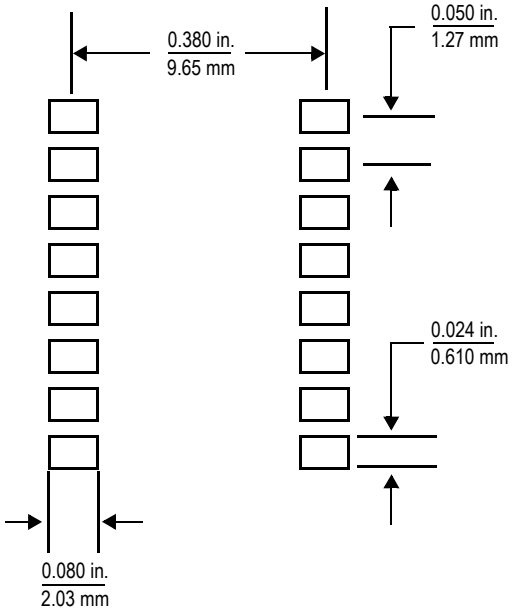

Figure 7. Footprint SOIC-16 (Case 475-01)

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Low G Micromachined Accelerometer

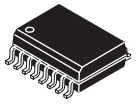
MMA1250

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1250D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±5g

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1250D	–40° to 125°C	475-01	SOIC-16
MMA1250EG	–40° to 125°C	475-01	SOIC-16
MMA1250EGR2	–40° to 125°C	475-01	SOIC-16

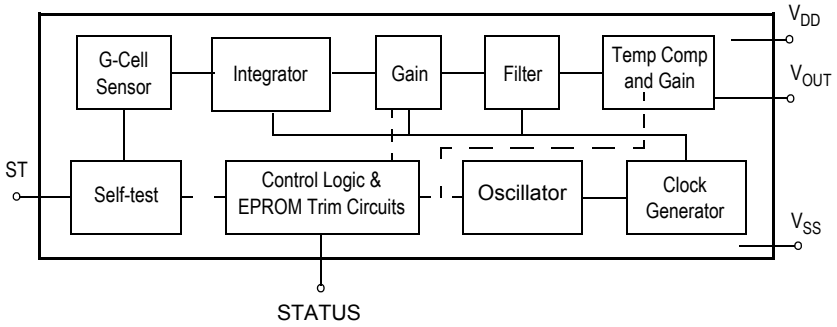


Figure 1. Simplified Accelerometer Functional Block Diagram

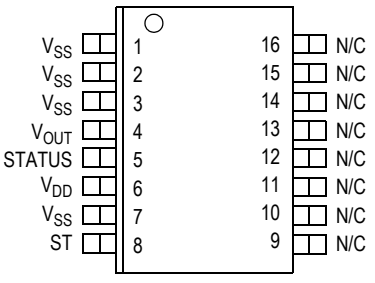


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test [1]	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	2.1	3.0	mA
Operating Temperature Range	T_A	–40	—	+105	°C
Acceleration Range	g_{FS}	—	5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.0	2.5	3.0	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	380	400	420	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	370	400	430.1	mV/g/V
Bandwidth Response	f_{-3dB}	42.5	50	57.5	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	2.0	4.0	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	700	—	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	1.0	1.25	1.5	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–125	–300	μA
Response Time[8]	t_{ST}	—	2.0	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
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5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
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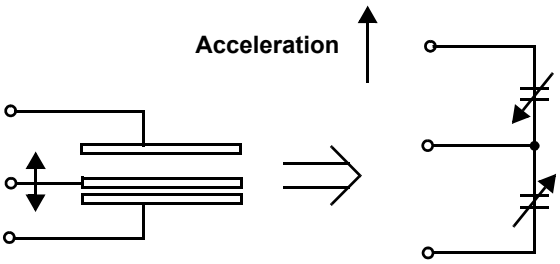

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

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Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

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Pinout Description

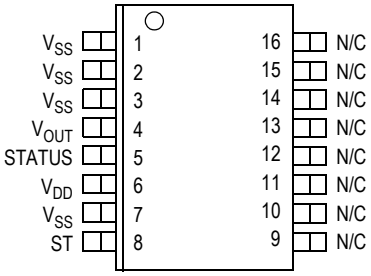

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

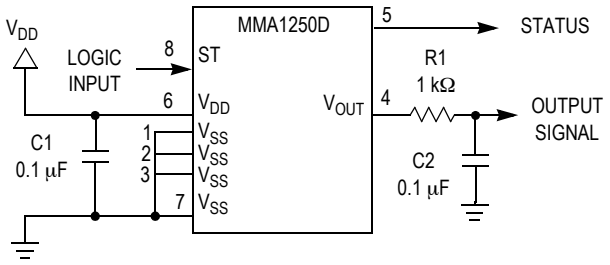

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

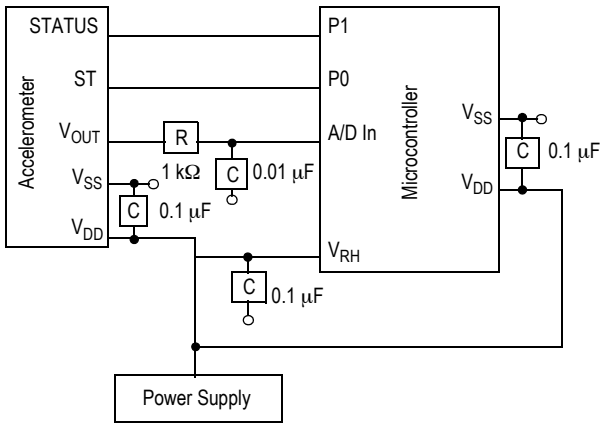

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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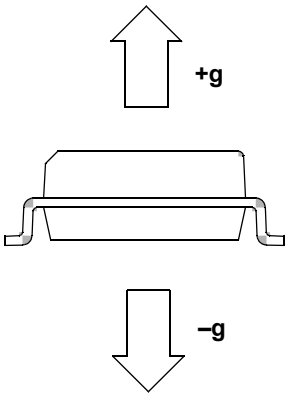
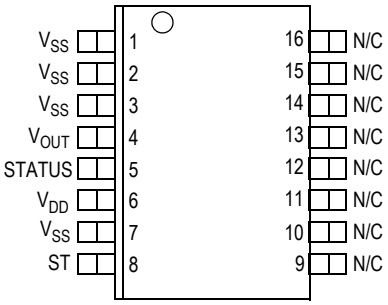
ACCELERATION SENSING DIRECTIONS

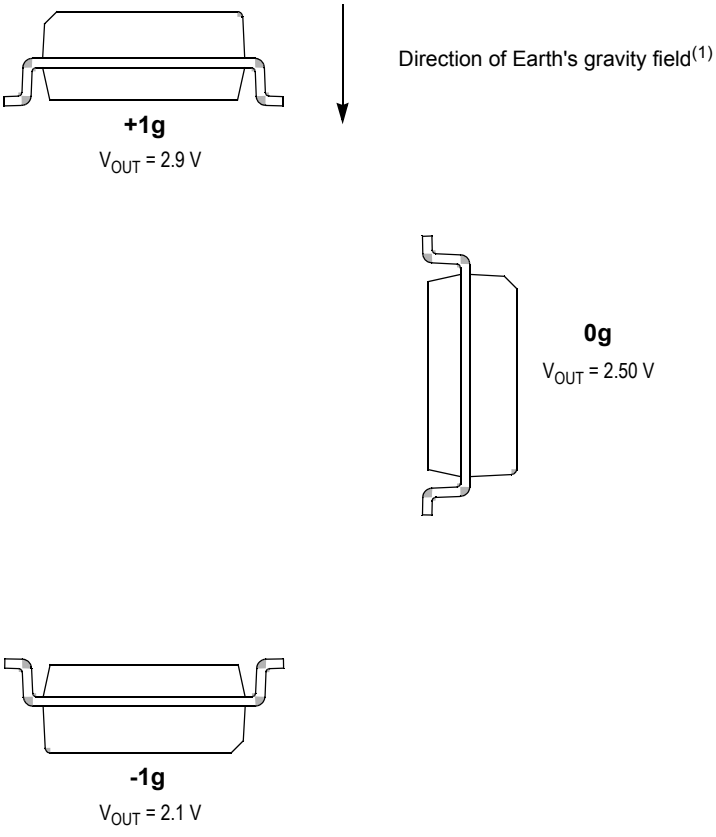
DYNAMIC ACCELERATION





16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

STATIC ACCELERATION



1. When positioned as shown, the Earth's gravity will result in a positive 1g output

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Low G Micromachined Accelerometer

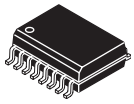
MMA1260

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA1260D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±1.5g

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA1260D	–40° to 105°C	475-01	SOIC-16
MMA1260EG	–40° to 105°C	475-01	SOIC-16
MMA1260EGR2	–40° to 105°C	475-01	SOIC-16

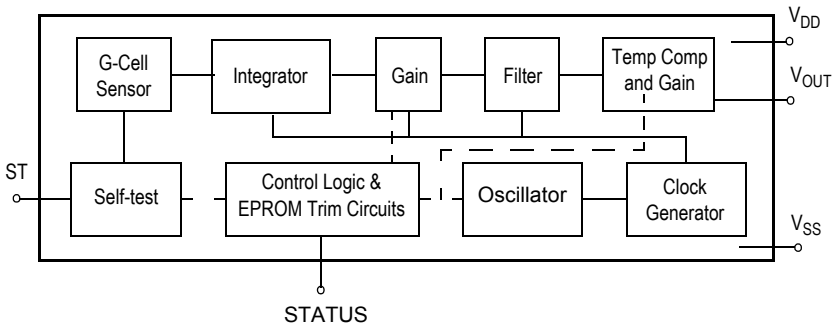


Figure 1. Simplified Accelerometer Functional Block Diagram

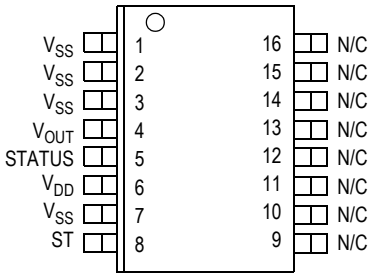


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.2	3.2	mA
Operating Temperature Range	T_A	–40	—	+105	°C
Acceleration Range	g_{FS}	—	1.55	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.2	2.5	2.8	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	1140	1200	1260	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	1110	1200	1290	mV/g/V
Bandwidth Response	f_{-3dB}	40	50	60	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	5.0	9.0	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	500	—	$\mu g/\sqrt{Hz}$
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.3	0.6	0.9	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–25	–300	μA
Response Time[8]	t_{ST}	—	10	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	V_{SS} + 0.25	—	V_{DD} – 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 5g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

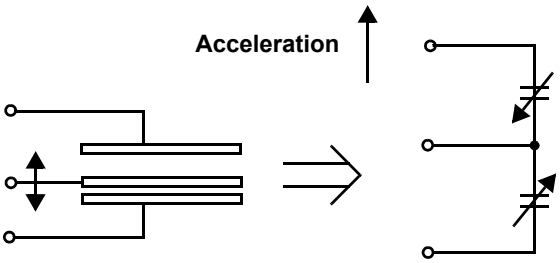

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

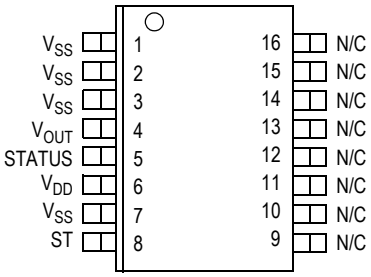

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

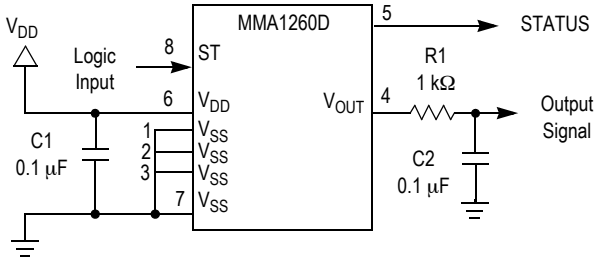

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

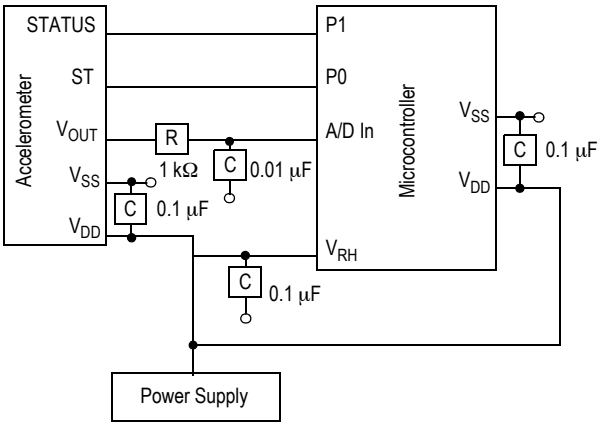

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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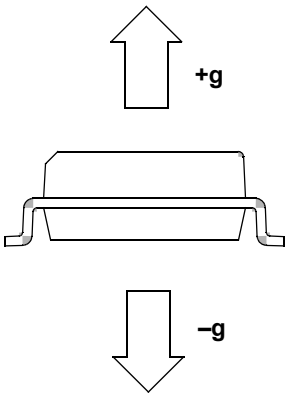
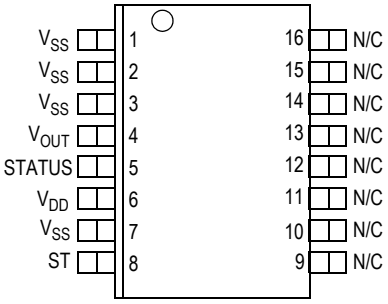
ACCELERATION SENSING DIRECTIONS

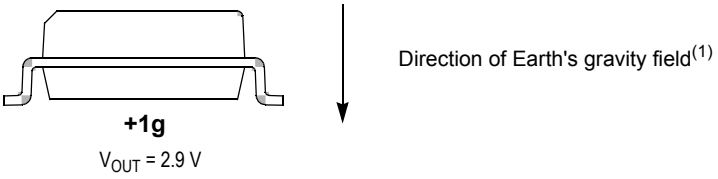
DYNAMIC ACCELERATION



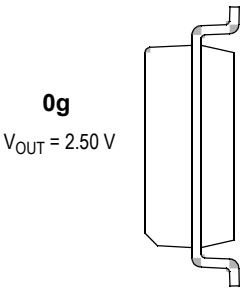


16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

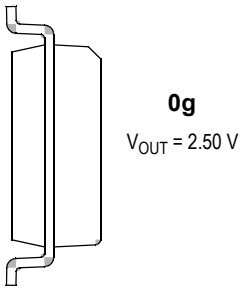
STATIC ACCELERATION



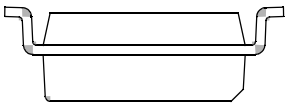
+1g
V_{OUT} = 2.9 V



0g
V_{OUT} = 2.50 V



0g
V_{OUT} = 2.50 V



-1g
V_{OUT} = 2.1 V

1. When positioned as shown, the Earth's gravity will result in a positive 1g output

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Low G Micromachined Accelerometer

MMA1270

MMA1270D: Z AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±2.5g

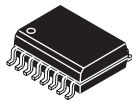
The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA1270D	–40° to 105°C	475-01	SOIC-16
MMA1270EG	–40° to 105°C	475-01	SOIC-16
MMA1270EGR2	–40° to 105°C	475-01	SOIC-16

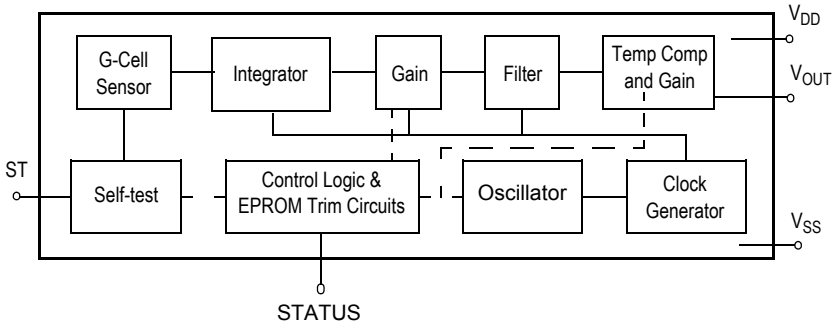


Figure 1. Simplified Accelerometer Functional Block Diagram

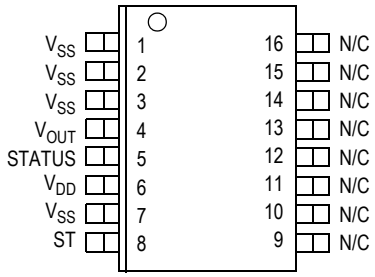


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	H_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.1	3.0	mA
Operating Temperature Range	T_A	–40	—	+105	°C
Acceleration Range	g_{FS}	—	2.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g (V_{DD} = 5.0 V)	V_{OFF}	2.2	2.5	2.8	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	712.5	750	787.5	mV/g
Sensitivity (V_{DD} = 5.0 V)	S	693.8	750	806.3	mV/g
Bandwidth Response	f_{-3dB}	40	50	60	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	—	3.5	6.5	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 KHz)[6]	n_{SD}	—	700	—	μg/√Hz
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.9	1.25	1.6	V
Input Low	V_{IL}	V_{SS}	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–125	–300	μA
Response Time[8]	t_{ST}	—	10	25	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	—	2.0	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. Sensitivity limits apply to 0 Hz acceleration.
6. At clock frequency ≅ 35 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high.
10. The Status pin output latches high if the EPROM parity changes to odd. The Status pin can be reset by rising edge on self-test, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as two stationary plates with a moveable plate in-between. The center plate can be deflected from its rest position by subjecting the system to an acceleration (Figure 3).

When the center plate deflects, the distance from it to one fixed plate will increase by the same amount that the distance to the other plate decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

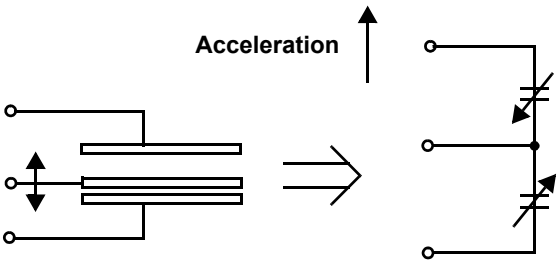

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 2-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.
- The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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Pinout Description

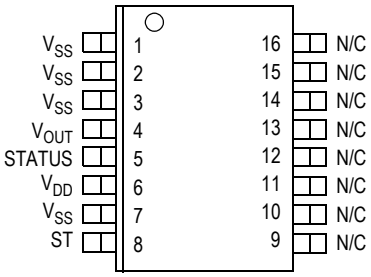

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin used to indicate fault.
6	V_{DD}	The power supply input.
7	V_{SS}	The power supply ground.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

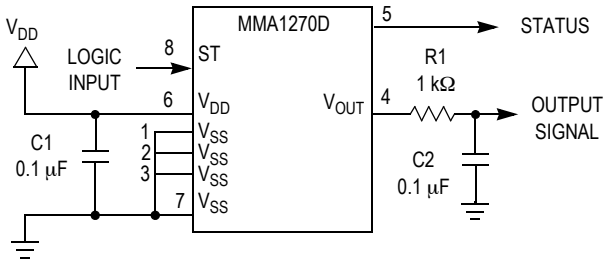

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

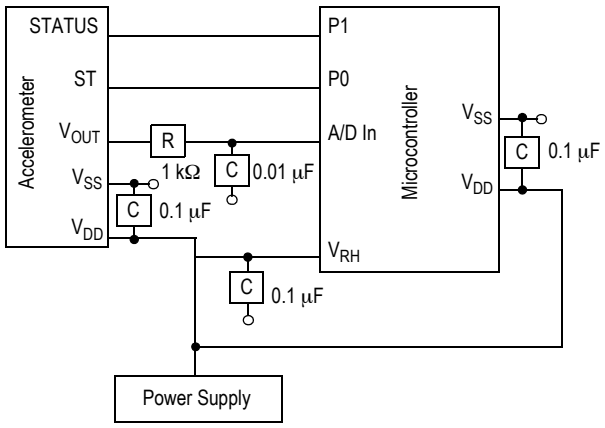

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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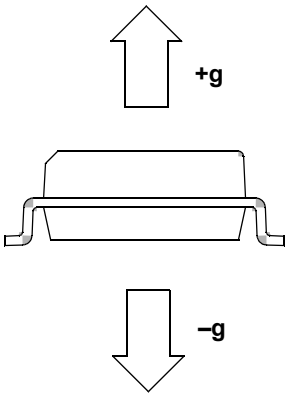
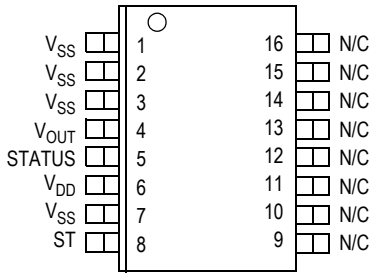
ACCELERATION SENSING DIRECTIONS

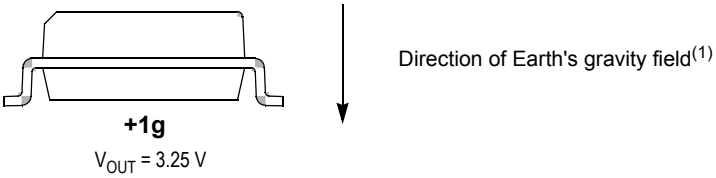
DYNAMIC ACCELERATION



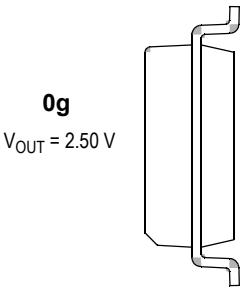


16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

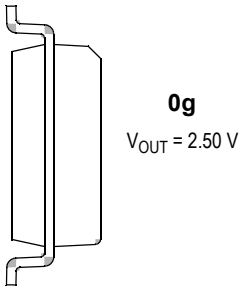
STATIC ACCELERATION



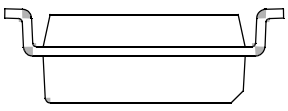
+1g
V_{OUT} = 3.25 V



0g
V_{OUT} = 2.50 V



0g
V_{OUT} = 2.50 V



–1g
V_{OUT} = 1.75 V

1. When positioned as shown, the Earth's gravity will result in a positive 1g output

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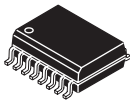
Low G Micromachined Accelerometer

MMA2201

MMA2201D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±40g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA2201D	–40° to 105°C	475-01	SOIC-16
MMA2201DR2	–40° to 105°C	475-01	SOIC16, Tape & Reel
MMA2201EG	–40° to 105°C	475-01	SOIC-16
MMA2201EGR2	–40° to 105°C	475-01	SOIC16, Tape & Reel

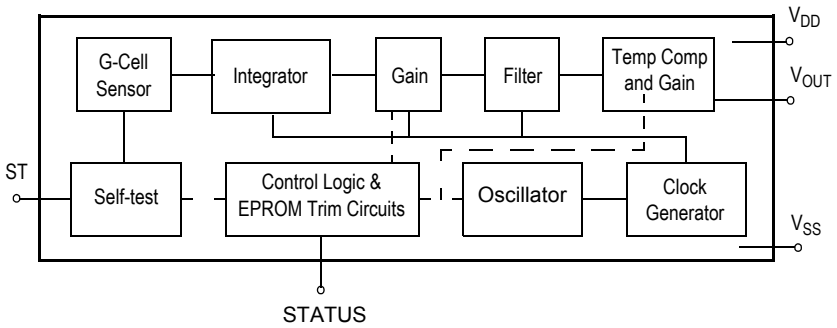


Figure 1. Simplified Accelerometer Functional Block Diagram

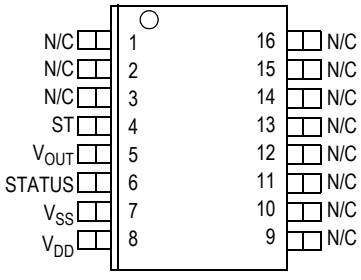


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	45	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	47.5	50	52.5	mV/g
Sensitivity	S_V	9.3	10	10.7	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap” wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

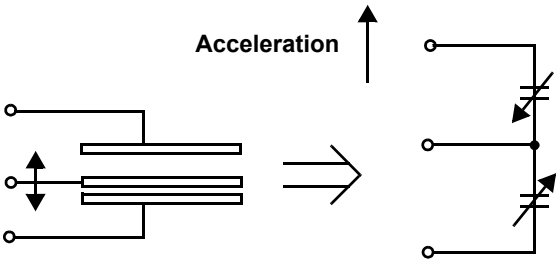

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate” is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer’s control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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Pinout Description

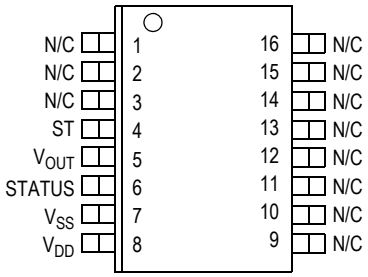

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

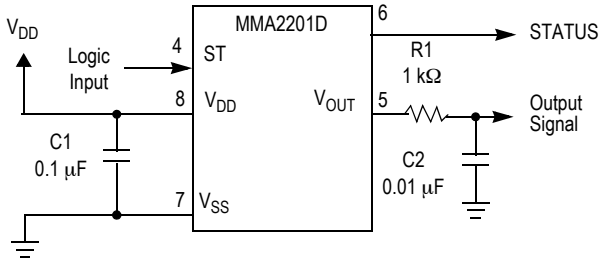

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

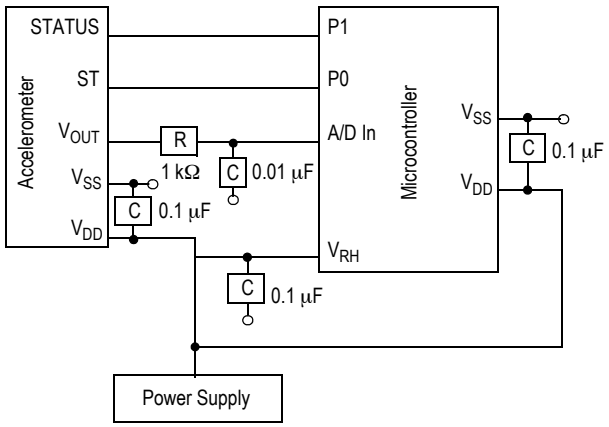

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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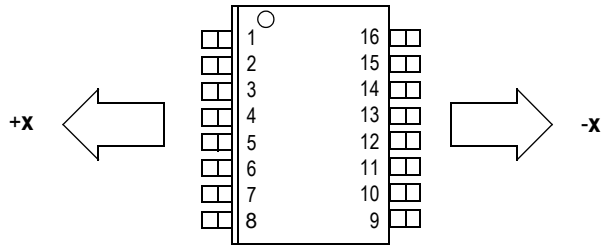
Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

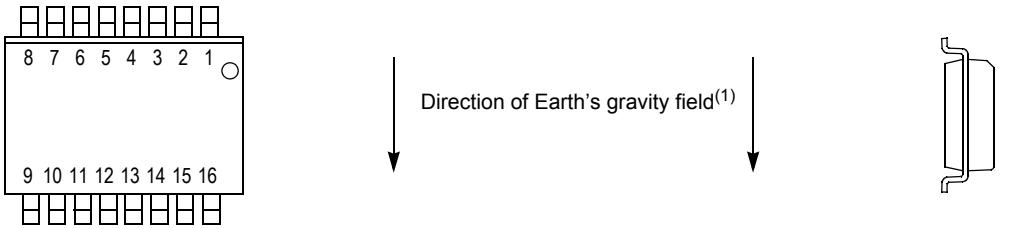


Activation of Self test moves the center plate in the –X direction, resulting in an increase in the output.

Top View

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Static Acceleration Sensing Direction



Front View

Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

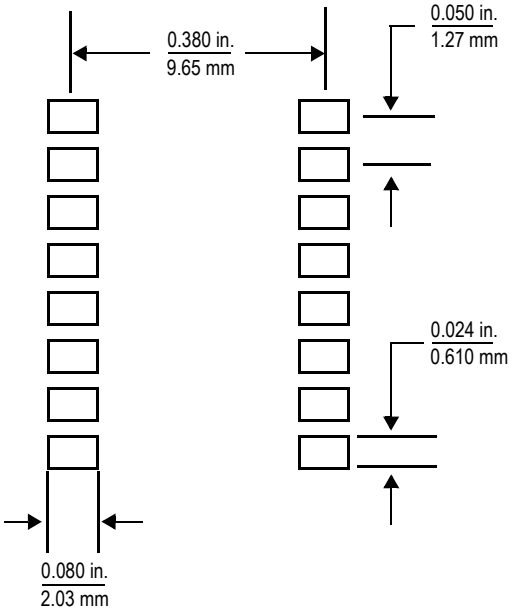


Figure 7. Footprint SOIC-16 (Case 475-01)

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Surface Mount Micromachined Accelerometer

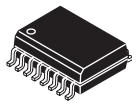
MMA2202

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA2202D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±50g

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA2202D	–40° to 125°C	475-01	SOIC-16
MMA2202DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA2202EG	–40° to 125°C	475-01	SOIC-16
MMA2202EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

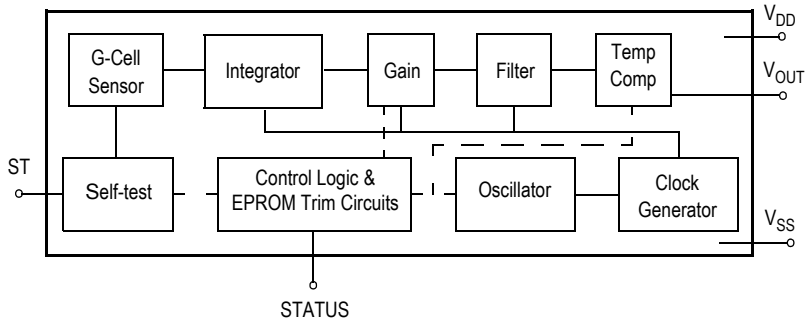


Figure 1. Simplified Accelerometer Functional Block Diagram

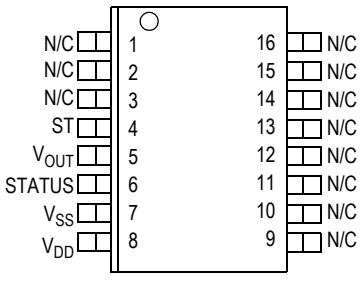


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	−40	—	+125	C
Acceleration Range	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46V_D	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	38	40	42	mV/g
Sensitivity	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/($Hz^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	VIH	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 V and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 20g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

When the beams attached to the center mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, and D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

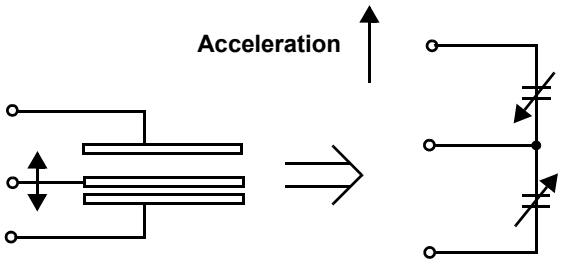

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

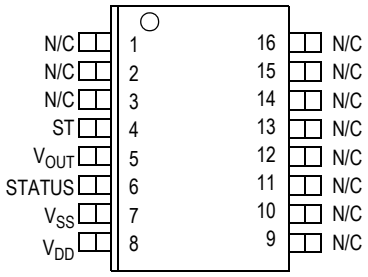

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	No internal connection. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

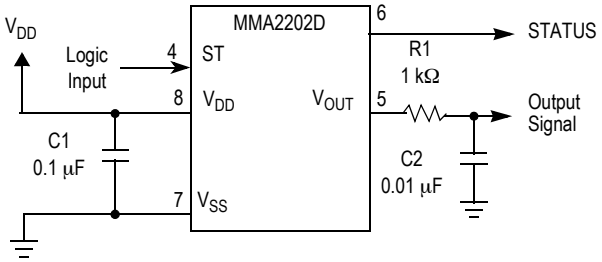

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

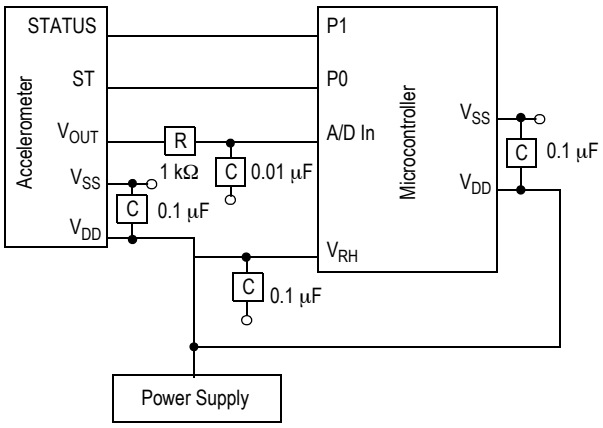

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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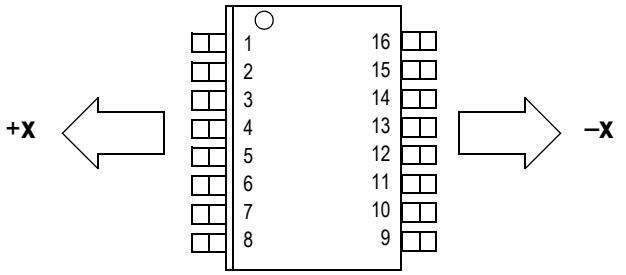
Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

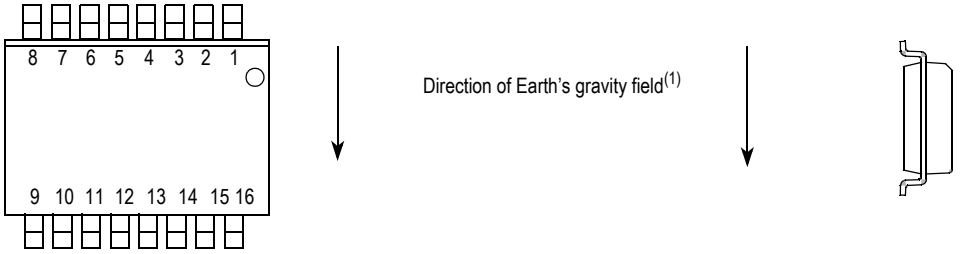


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View **Side View**

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

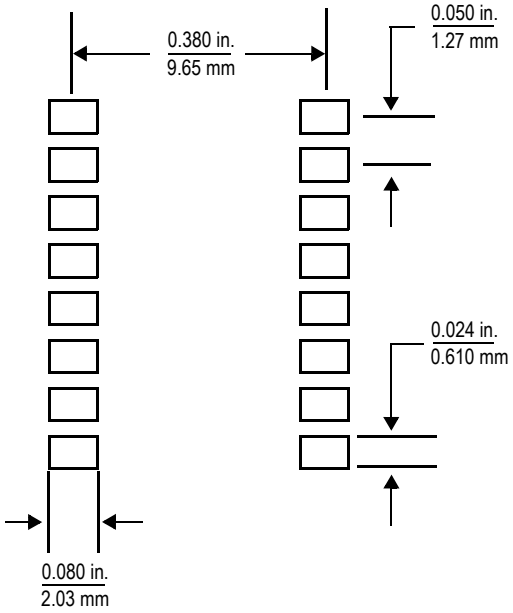


Figure 7. Footprint SOIC-16 (Case 475-01)

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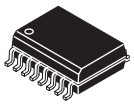
Surface Mount Micromachined Accelerometer

MMA2204

MMA2204D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

The MMA series of silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Appliance Control
- Mechanical Bearing Monitoring
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- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sport Diagnostic Devices and Systems

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA2204D	–40° to 125°C	475-01	SOIC-16
MMA2204DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA2204EG	–40° to 125°C	475-01	SOIC-16
MMA2204EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

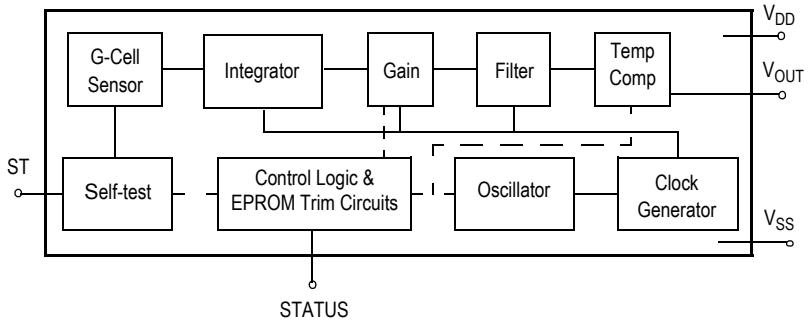

Figure 1. Simplified Accelerometer Functional Block Diagram

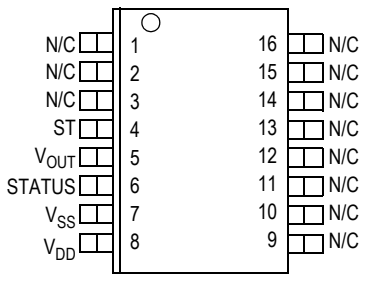

Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	4.0	5.0	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	112.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20	21	mV/g
Sensitivity	S_V	3.72	4	4.28	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	10	12	14	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–110	–300	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	150	—	400	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
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Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
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1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
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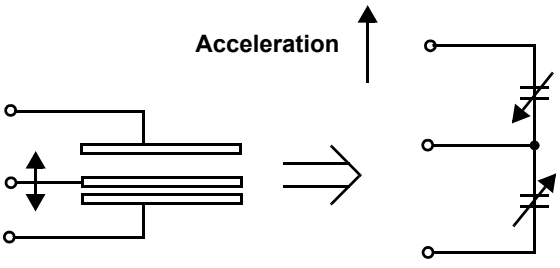

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

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The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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Pinout Description

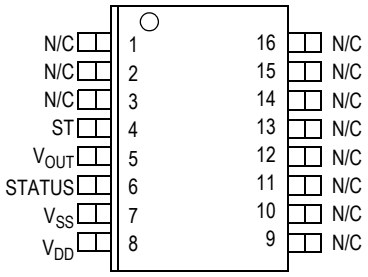

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	No internal connection. Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

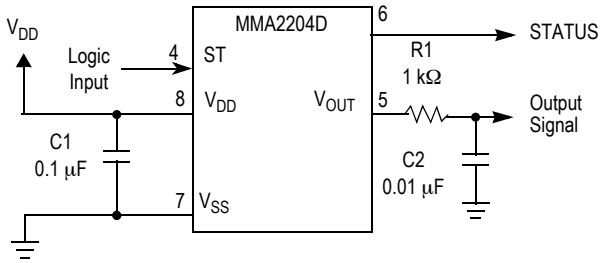

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

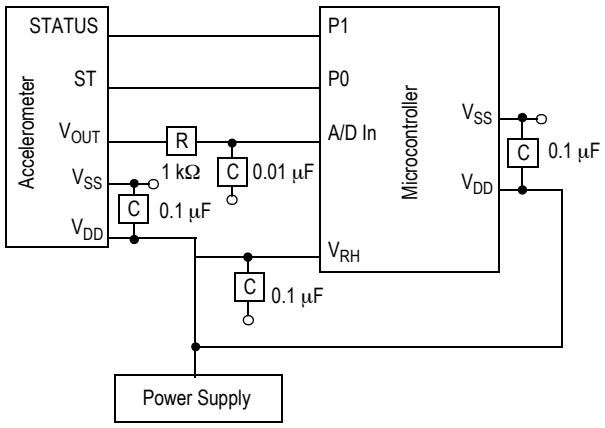

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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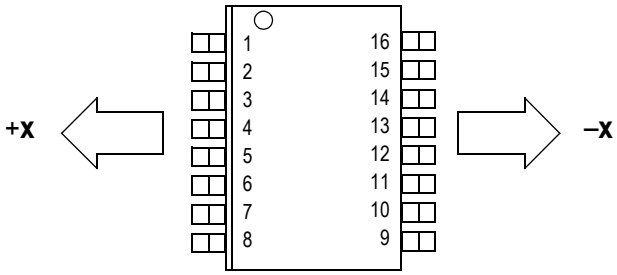
Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the –X direction) will result in an increase in the output.

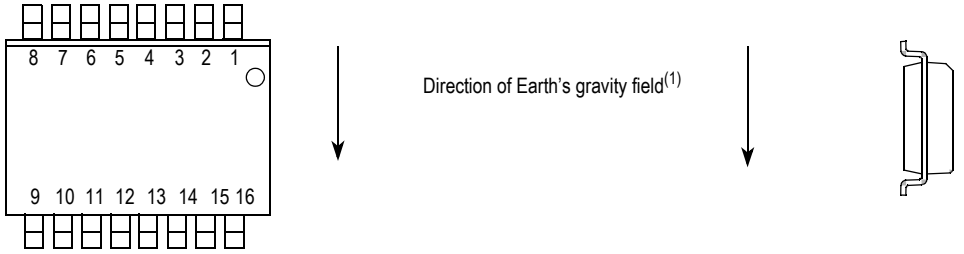


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

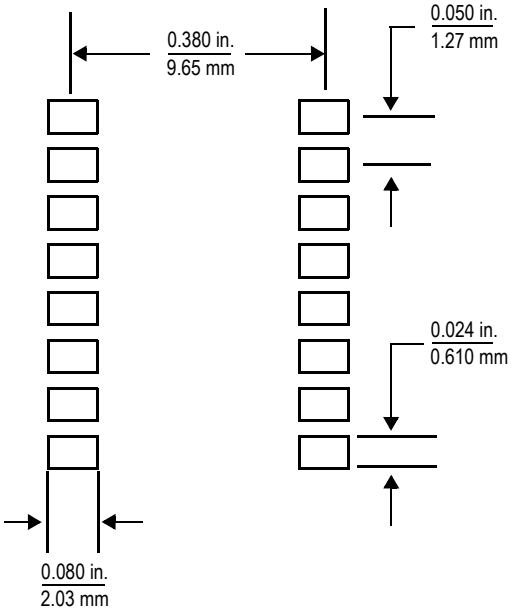


Figure 7. Footprint SOIC-16 (Case 475-01)

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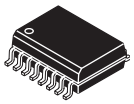
±1.5g X-Axis Micromachined Accelerometer

MMA2260

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 2-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA2260D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±1.5g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

Features

- Integral Signal Conditioning
- High Sensitivity
- Linear Output
- 2nd Order Bessel Filter
- Calibrated Self-test
- EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shock Survivability

Typical Applications

- Tilt Monitoring
- Inclinometers
- Appliance Control
- Mechanical Bearing Monitoring
- Vibration Monitoring and Recording
- Sports Diagnostic Devices and Systems
- Trailer Brake Controls
- Automotive Aftermarket

ORDERING INFORMATION			
Device	**Temperature Range**	**Case No.**	**Package**
MMA2260D	–40 to +105°C	475-01	SOIC-16
MMA2260DR2	–40 to +105°C	475-01	SOIC-16, Tape & Reel
MMA2260EG	–40 to +105°C	475-01	SOIC-16
MMA2260EGR2	–40 to +105°C	475-01	SOIC-16, Tape & Reel

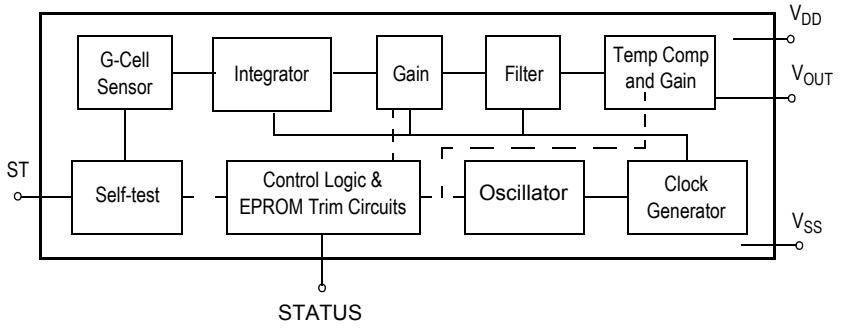


Figure 1. Simplified Accelerometer Functional Block Diagram

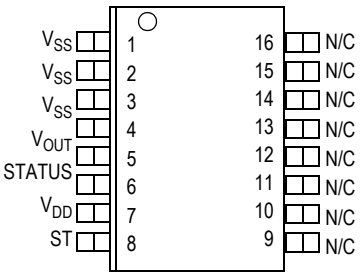


Figure 2. Pin Connections

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Table 1. Maximum Ratings[1]

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Unpowered Acceleration (all axes)	g_{upd}	2000	g
Supply Voltage	V_{DD}	-0.3 to +7.0	V
Drop Test[1]	H_{drop}	1.2	m
Storage Temperature Range	T_{stg}	-40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	1.1	2.2	3.2	mA
Operating Temperature Range	T_A	–40	–	+105	°C
Acceleration Range	g_{FS}	–	1.5	–	g
Output Signal					
Zero g (V_{DD} = 5.0 V)[4]	V_{OFF}	2.3	2.5	2.7	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	1140	1200	1260	mV/g
Sensitivity (V_{DD} = 5.0 V)[5]	S	1110	1200	1290	mV/g
Bandwidth Response	f_{-3dB}	40	50	60	Hz
Nonlinearity	NL_{OUT}	–1.0	–	+1.0	% FSO
Noise					
RMS (0.1 Hz – 1.0 kHz)	n_{RMS}	–	3.5	–	mVrms
Spectral Density (RMS, 0.1 Hz – 1.0 kHz)[6]	n_{SD}	–	350	–	μg/√Hz
Self-Test					
Output Response (V_{DD} = 5.0 V)	ΔV_{ST}	0.3	0.4	0.5	V
Input Low	V_{IL}	V_{SS}	–	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	–	V_{DD}	V
Input Loading[7]	I_{IN}	–50	–125	–300	μA
Response Time[8]	t_{ST}	–	20	25	ms
Status[9][10]					
Output Low (I_{load} = 100 μA)	V_{OL}	–	–	0.4	V
Output High (I_{load} = –100 μA)	V_{OH}	V_{DD} –0.8	–	–	V
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	–	–	2.0	ms
Full Scale Output Range (I_{OUT} = –200 μA)	V_{FSO}	V_{SS}+0.25	–	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	–	–	100	pF
Output Impedance	Z_O	–	50	–	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{YX,ZX}$	–	–	5.0	% FSO

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.1 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. Sensitivity limits apply to 0 Hz acceleration.
6. At clock frequency ≅ 34 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high.
10. The Status pin output latches high if the EPROM parity changes to odd. The Status pin can be reset by a rising edge on self-test, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, e is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

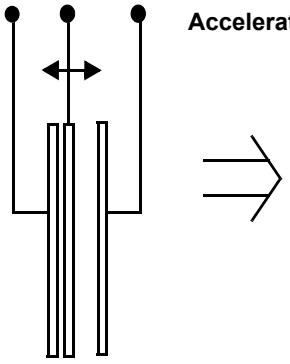

Figure 3. Transducer Physical Model

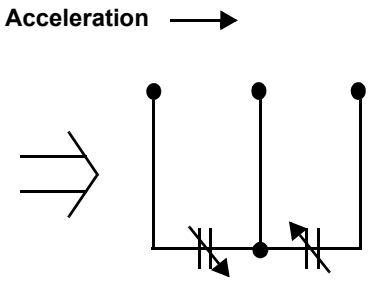

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

Freescale accelerometers contain an onboard 2-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever the following event occurs:

- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

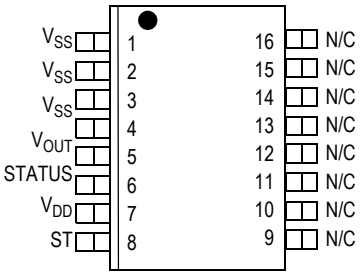

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Table 3. Pin Description

Pin No.	Pin Name	Description
1 thru 3	V_{SS}	Redundant connections to the internal V_{SS} and may be left unconnected.
4	V_{OUT}	Output voltage of the accelerometer.
5	STATUS	Logic output pin to indicate fault.
6	V_{DD}	The power supply ground.
7	V_{SS}	The power supply input.
8	ST	Logic input pin used to initiate self-test.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

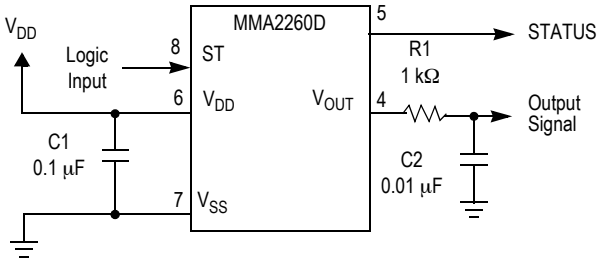

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

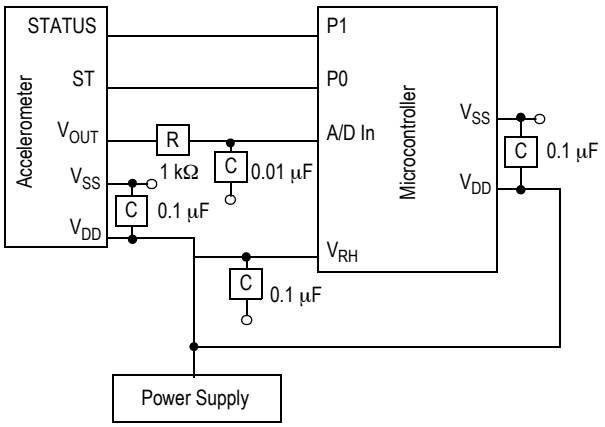

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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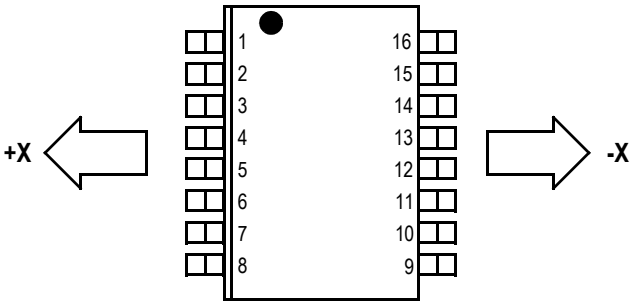
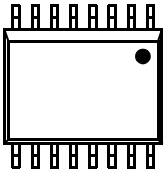
DYNAMIC ACCELERATION



16-Pin SOIC Package

Top View

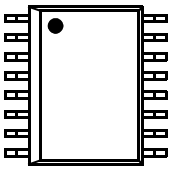
STATIC ACCELERATION



Direction of Earth's gravity field.(1)

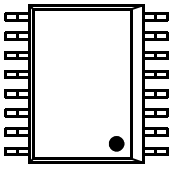
-1g

V_{OUT} = 3.7V



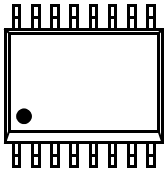
0g

V_{OUT} = 2.50V



0g

V_{OUT} = 2.50V



+1g

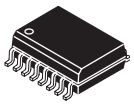
V_{OUT} = 1.3V

1. When positioned as shown, the Earth's gravity will result in a positive 1g output

Surface Mount Micromachined Accelerometer

MMA2300

MMA2300D: X AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±250g



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

ORDERING INFORMATION

Device Name	Temperature Range	Case No.	Package
MMA2300D	–40° to 125°C	475-01	SOIC-16
MMA2300DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA2300EG	–40° to 125°C	475-01	SOIC-16
MMA2300EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

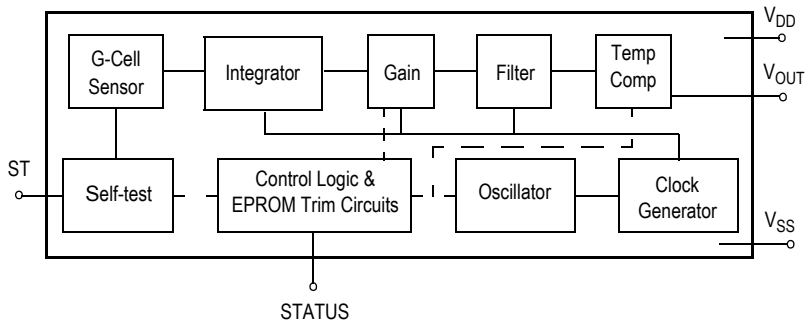


Figure 1. Simplified Accelerometer Functional Block Diagram

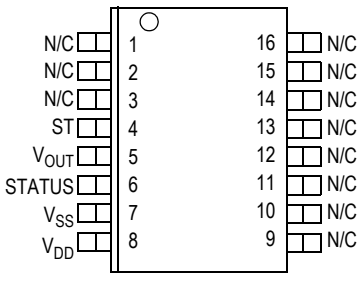


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	–40	—	+125	C
Acceleration Range	g_{FS}	—	281	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.4	2.5	2.6	V
Zero g	$V_{OFF,V}$	0.47 V_{DD}	0.50 V_{DD}	0.53 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	7.6	8.0	8.4	mV/g
Sensitivity	S_V	1.488	1.6	1.712	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	1.0	% FSO
Noise					
RMS (10 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/($Hz^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	VIH	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causes them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

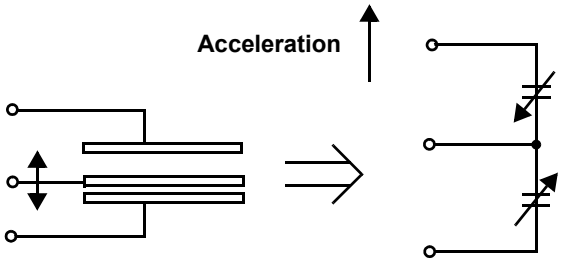

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a falling edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

Pinout Description

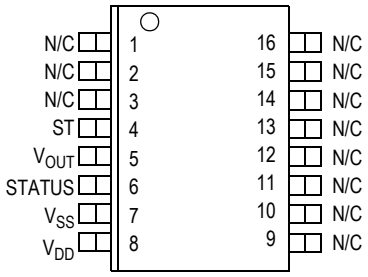

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

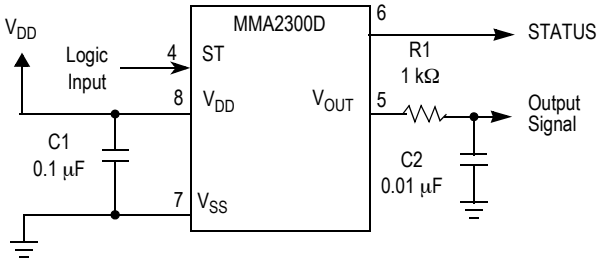

Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

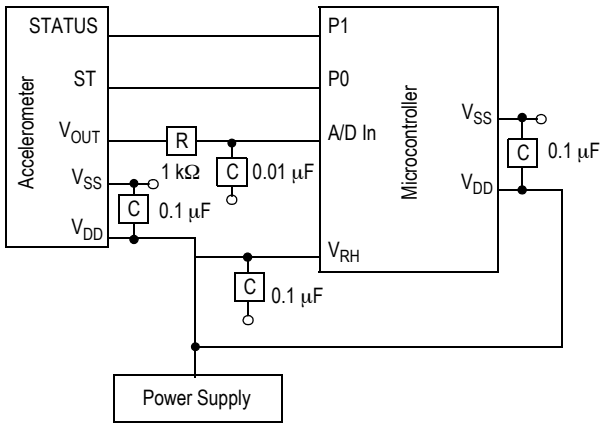

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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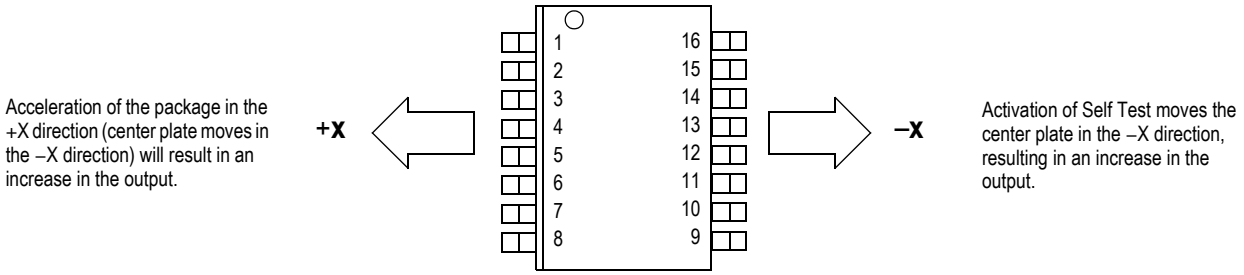
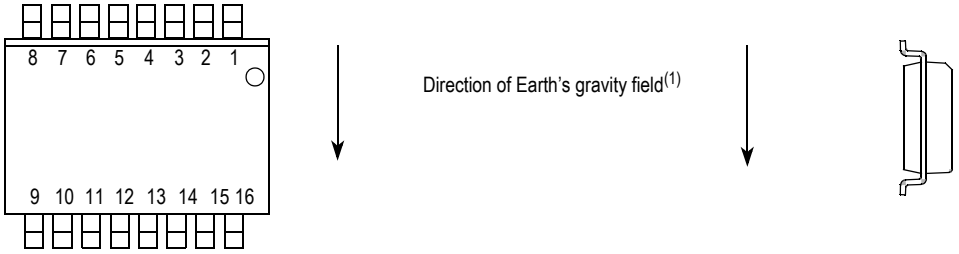
Dynamic Acceleration Sensing Direction



16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View **Side View**

1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

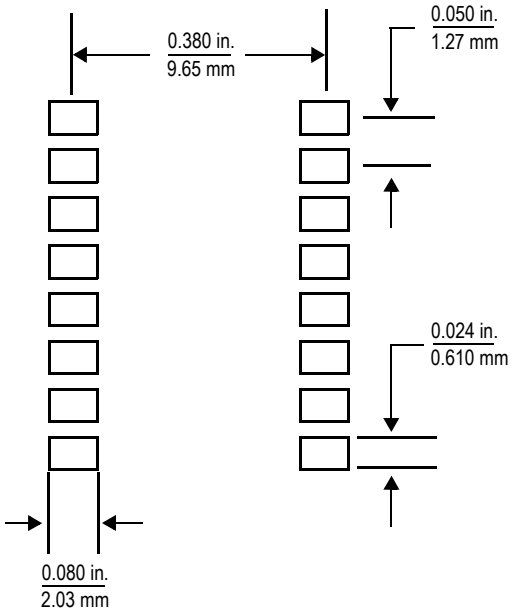


Figure 7. Footprint SOIC-16 (Case 475-01)

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Surface Mount Micromachined Accelerometer

The MMA series of silicon capacitive, micromachined accelerometers feature signal conditioning, a 4-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

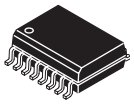
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring

MMA2301

MMA2301D: X-AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±200G



D SUFFIX
EG SUFFIX (Pb-FREE)
16-LEAD SOIC
CASE 475-01

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No.**	**Package**
MMA2301D	–40° to 125°C	475-01	SOIC-16
MMA2301DR2	–40° to 125°C	475-01	SOIC16, Tape & Reel
MMA2301EG	–40° to 125°C	475-01	SOIC-16
MMA2301EGR2	–40° to 125°C	475-01	SOIC16, Tape & Reel

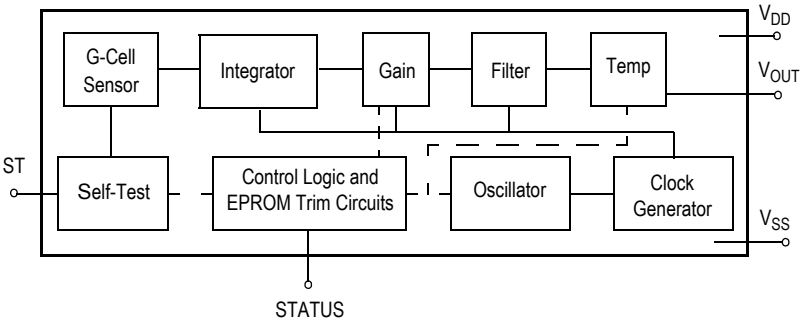


Figure 1. Simplified Accelerometer Functional Block Diagram

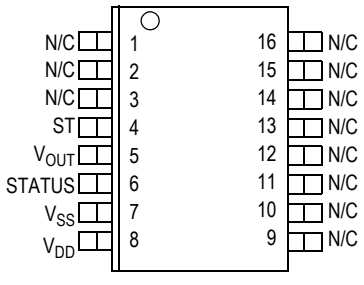


Figure 2. Pin Connections

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Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: -40°C ≤ T_A ≤ +105°C, 4.75 ≤ VDD ≤ 5.25, Acceleration = 0g, Loaded output)[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.0	5.25	V
Supply Current	I_{DD}	3.0	—	6.0	mA
Operating Temperature Range	T_A	-40	—	+125	°C
Acceleration Range	g_{FS}	—	225	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.4	2.5	2.6	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	9.5	10.0	10.5	mV/g
Sensitivity	S_V	1.86	2.0	2.14	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	-1.0	—	1.0	% FSO
Noise					
RMS (.01-1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/($Hz^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	24	30	36	g
Input Low	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input High	V_{IH}	0.7 x V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	-30	-100	-260	μA
Response Time[8]	t_{ST}	—	2.0	10	ms
Status[9] [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} -0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD} -0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and - acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 35g.
6. At clock frequency ≅ 70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
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11. Time for amplifiers to recover after an acceleration signal causing them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale Semiconductor, Inc. accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration(Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 3). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

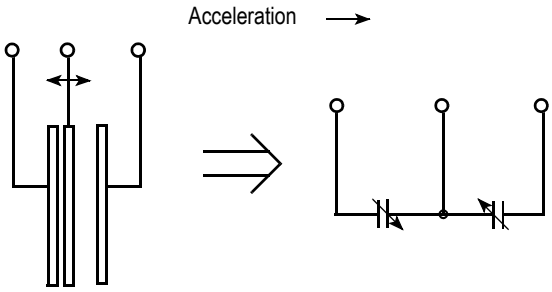

Figure 3. Simplified Transducer Physical Model versus Transducer Physical Model

SPECIAL FEATURES

Filtering

The accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth *plate* is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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PINOUT DESCRIPTION

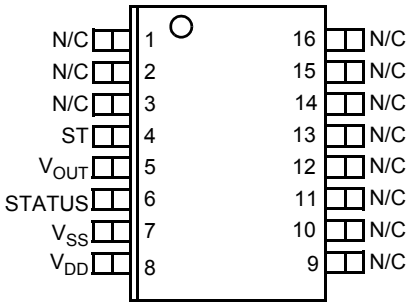

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	N/C	Leave unconnected.
4	ST	Logic input pin used to initiate self-test.
5	V_{OUT}	Output voltage of the accelerometer.
6	STATUS	Logic output pin to indicate fault.
7	V_{SS}	The power supply ground.
8	V_{DD}	The power supply input.
9 thru 13	Trim pins	Used for factory trim. Leave unconnected.
14 thru 16	—	No internal connection. Leave unconnected.

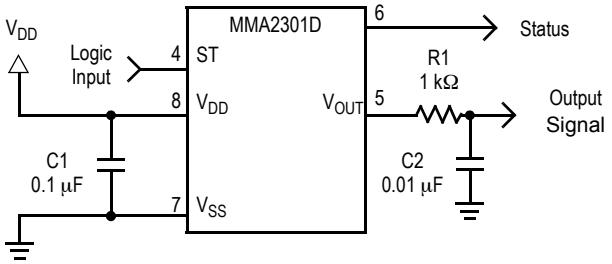

Figure 4. SOIC Accelerometer with Recommended Connection Diagram

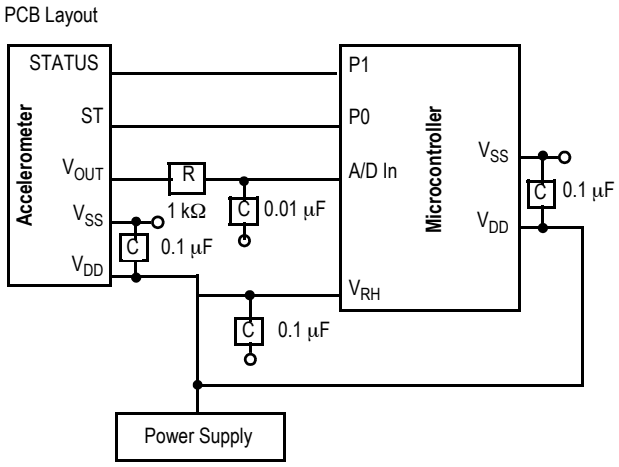

Figure 5. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

- Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
- Physical coupling distance of the accelerometer to the microcontroller should be minimal.
- Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 5
- Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
- PCB layout of power and ground should not couple power supply noise.
- Accelerometer and microcontroller should not be a high current path.

A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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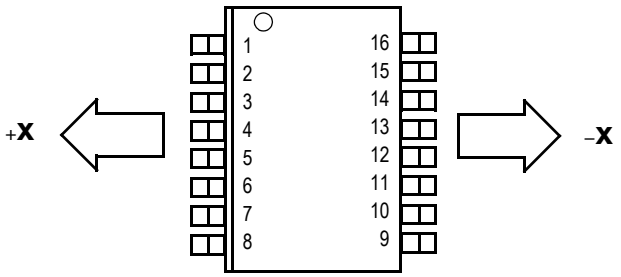
Dynamic Acceleration Sensing Direction

Acceleration of the package in the +X direction (center plate moves in the -X direction) will result in an increase in the output.

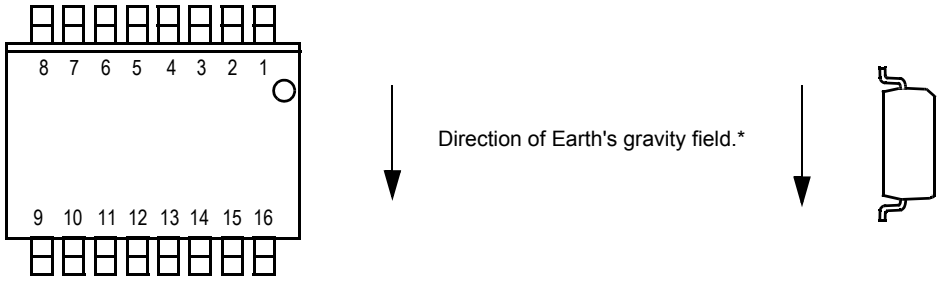


Activation of Self Test moves the center plate in the –X direction, resulting in an increase in the output.

16-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

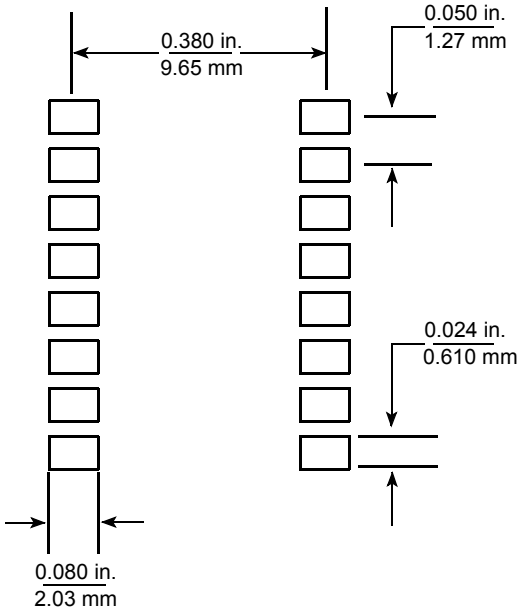

Figure 6. Footprint SOIC-16 (Case 475-01)

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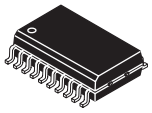
Surface Mount Micromachined Accelerometer

MMA3201

MMA3201D: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±40g



D SUFFIX
EG SUFFIX (Pb-FREE)
20-LEAD SOIC
CASE 475A-02

The MMA3200 series of dual axis (X and Y) silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation, and separate outputs for the two axes. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Sensitivity in two separate axes: 40g X-axis and 40g Y-axis
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Case No,**	**Package**
MMA3201D	–40 to +125°C	475A-02	SOIC-20
MMA3201DR2	–40 to +125°C	475A-02	SOIC-20, Tape & Reel
MMA3201EG	–40 to +125°C	475A-02	SOIC-20
MMA3201EGR2	–40 to +125°C	475A-02	SOIC-20, Tape & Reel

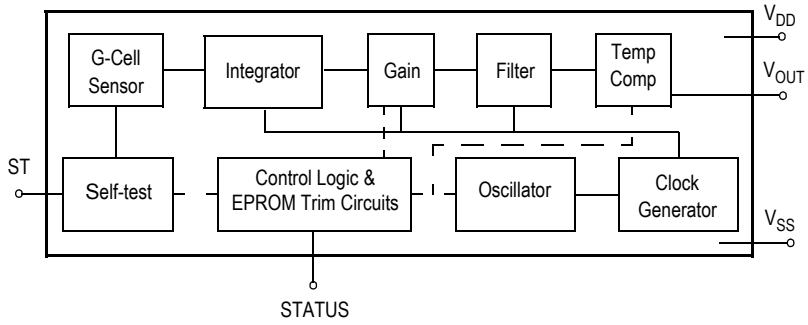


Figure 1. Simplified Accelerometer Functional Block Diagram

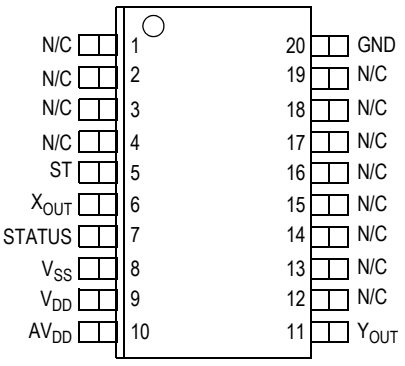


Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, X and Y Channels, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	6	8	10	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range	g_{FS}	—	45	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	45	50	55	mV/g
Sensitivity	S_V	9.3	10	10.7	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	9.6	12	14.4	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–110	–300	μA
Response Time[8]	t_{ST}	—	2.0	–	ms
Status[9], [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}–0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedance	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causing them to saturate.
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a CMOS signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined “cap" wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 4). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams. The X-Y device contains two structures at right angles to each other.

The CMOS ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

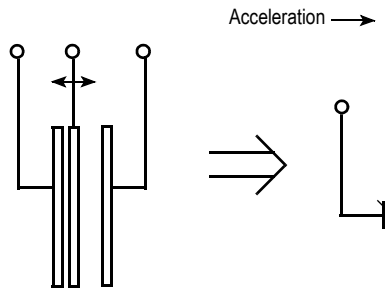

Figure 3. Transducer Physical Model

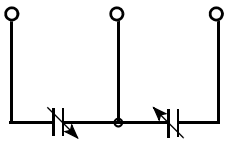

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

The Freescale accelerometers contain an on board 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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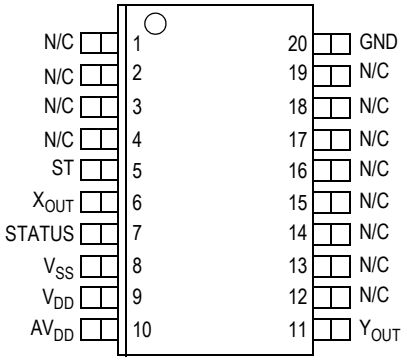
BASIC CONNECTIONS

Pinout Description



Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	—	No internal connection. Leave unconnected.
5	ST	Logic input pin used to initiate self-test.
6	X_{OUT}	Output voltage of the accelerometer. X Direction.
7	STATUS	Logic output pin to indicate fault.
8	V_{SS}	The power supply ground.
9	V_{DD}	The power supply input.
10	AV_{DD}	Power supply input (Analog).
11	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
12 thru 16	—	Used for factory trim. Leave unconnected.
17 thru 19	—	No internal connection. Leave unconnected.
20	GND	Ground.

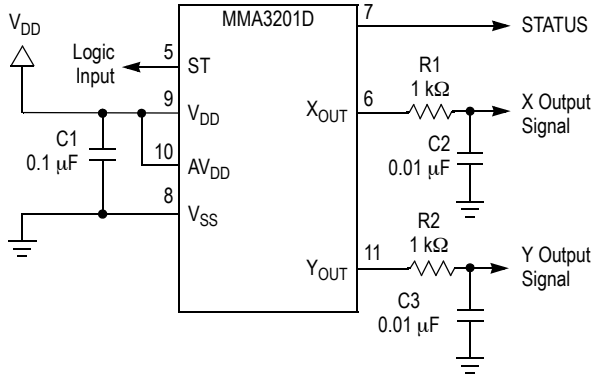


Figure 5. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

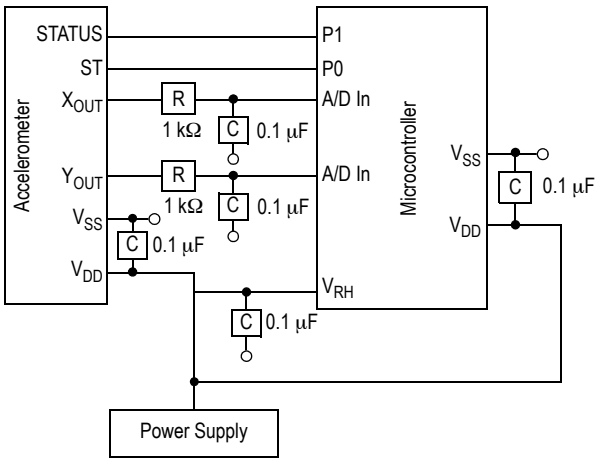


Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use a 0.1 μF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
4. Use an RC filter of 1 kΩ and 0.01 μF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
5. PCB layout of power and ground should not couple power supply noise.
6. Accelerometer and microcontroller should not be a high current path.
7. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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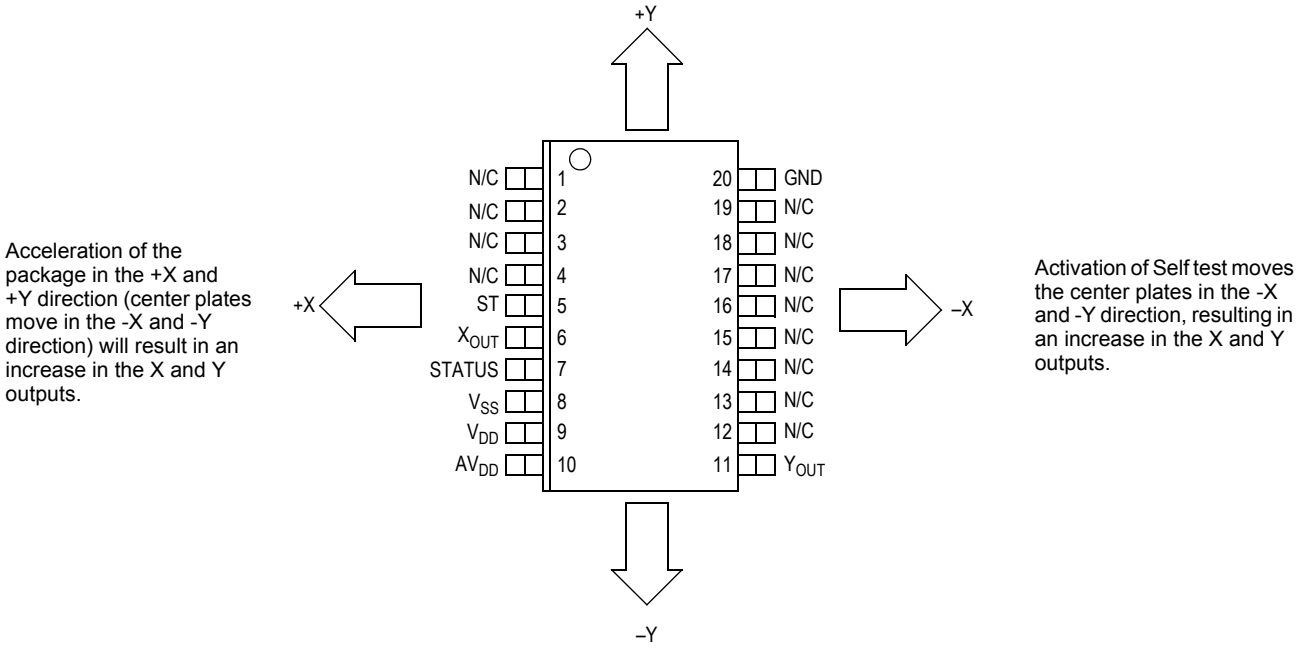
Dynamic Acceleration Sensing Direction



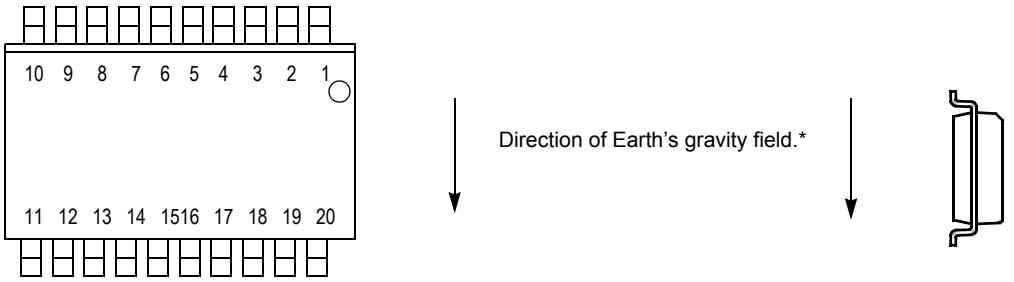
Acceleration of the package in the +X and +Y direction (center plates move in the -X and -Y direction) will result in an increase in the X and Y outputs.

Activation of Self test moves the center plates in the -X and -Y direction, resulting in an increase in the X and Y outputs.

20-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output in the X channel.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

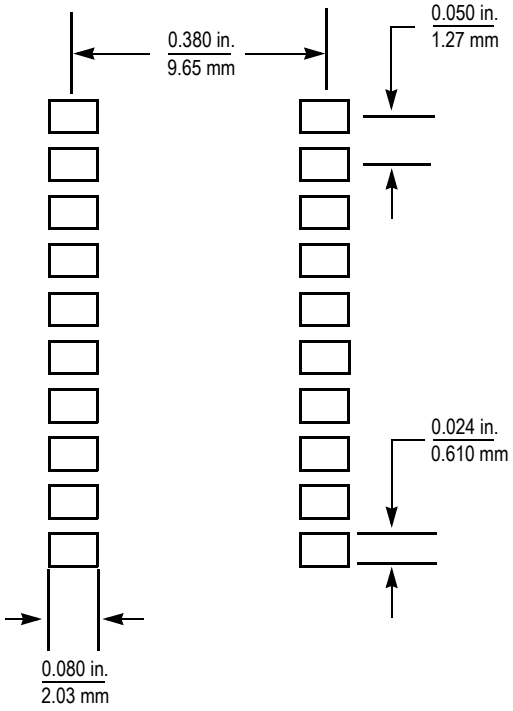

Figure 7. Footprint SOIC-20 (Case 475A-01)

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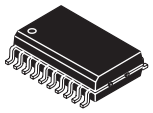
Surface Mount Micromachined Accelerometer

MMA3202

MMA3202D: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100/50g



D SUFFIX
EG SUFFIX (Pb-FREE)
20-LEAD SOIC
CASE 475A-02

The MMA3202 series of dual axis (X and Y) silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation and separate outputs for the two axes. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Sensitivity in two separate axes: 100g X-axis and 50g Y-axis
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
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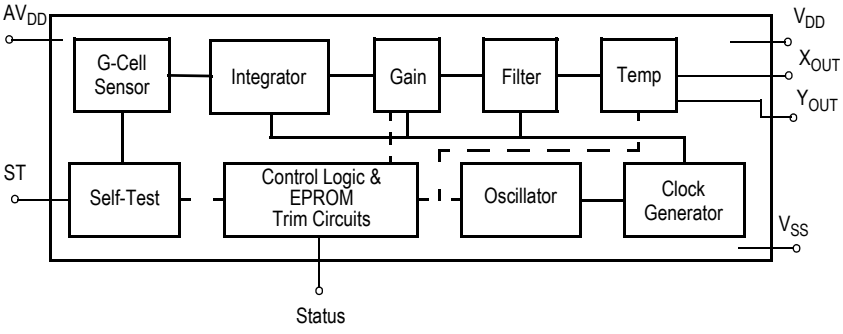
Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION

Device	Temperature Range	Case No.	Package
MMA3202D	– 40 to +125°C	475A-02	SOIC-20
MMA3202DR2	– 40 to +125°C	475A-02	SOIC-20, Tape & Reel
MMA3202EG	– 40 to +125°C	475A-02	SOIC-20
MMA3202EGR2	– 40 to +125°C	475A-02	SOIC-20, Tape & Reel



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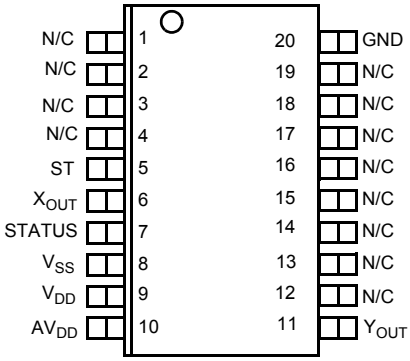

Figure 2. Pin Connections

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Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.)[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	6	8	10	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range X-axis	g_{FS}	—	112.5	—	g
Acceleration Range Y-axis	g_{FS}	—	56.3	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Sensitivity X-axis (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20	21	mV/g
Sensitivity Y-axis (T_A = 25°C, V_{DD} = 5.0 V)	S	38	40	42	mV/g
Sensitivity X-axis	S_V	3.72	4	4.28	mV/g/V
Sensitivity Y-axis	S_V	7.44	8	8.56	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	2.8	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	9.6	12	14.4	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	μA
Response Time[8]	t_{ST}	—	2.0	–	ms
Status[9] [10]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} – 0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[11]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}– 0.25	V
Capacitive Load Drive[12]	C_L	—	—	100	pF
Output Impedence	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[13]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

1. For a loaded output the measurements are observed after an RC filter consisting of a 1 kΩ resistor and a 0.01 μF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 4.75 and 5.25 volts, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2 and for negative acceleration the output will decrease below V_{DD}/2.
5. The device is calibrated at 20g.
6. At clock frequency ≅70 kHz.
7. The digital input pin has an internal pull-down current source to prevent inadvertent self test initiation due to external board level leakages.
8. Time for the output to reach 90% of its final value after a self-test is initiated.
9. The Status pin output is not valid following power-up until at least one rising edge has been applied to the self-test pin. The Status pin is high whenever the self-test input is high, as a means to check the connectivity of the self-test and Status pins in the application.
10. The Status pin output latches high if a Low Voltage Detection or Clock Frequency failure occurs, or the EPROM parity changes to odd. The Status pin can be reset low if the self-test pin is pulsed with a high input for at least 100 μs, unless a fault condition continues to exist.
11. Time for amplifiers to recover after an acceleration signal causing them to saturate
12. Preserves phase margin (60°) to guarantee output amplifier stability.
13. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

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As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the central mass moves with acceleration, the distance between the beams change and each capacitor's value will change, ($C = NA\varepsilon/D$). Where A is the area of the facing side of the beam, ε is the dielectric constant, D is the distance between the beams, and N is the number of beams. The X-Y device contains two structures at right angles to each other.

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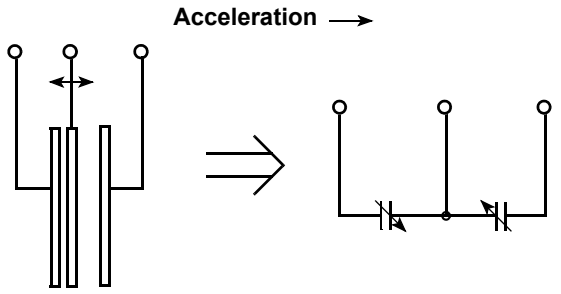

Figure 3. Simplified Transducer Physical Model

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Filtering

The Freescale Semiconductor, Inc. accelerometers contain an onboard 4-pole switched capacitor filter. A Bessel implementation is used because it provides a maximally flat delay response (linear phase) thus preserving pulse shape integrity. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature that allows the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. This feature is critical in applications such as automotive airbag systems where system integrity must be ensured over the life of the vehicle. A fourth “plate" is used in the g-cell as a self-test plate. When the user applies a logic high input to the self-test pin, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^{1}/_{2}\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's control ASIC and a proportional output voltage results. This procedure assures that both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Ratiometricity

Ratiometricity simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as you increase supply voltage the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

Status

Freescale accelerometers include fault detection circuitry and a fault latch. The Status pin is an output from the fault latch, OR'd with self-test, and is set high whenever one (or more) of the following events occur:

- Supply voltage falls below the Low Voltage Detect (LVD) voltage threshold
- Clock oscillator falls below the clock monitor minimum frequency
- Parity of the EPROM bits becomes odd in number.

The fault latch can be reset by a rising edge on the self-test input pin, unless one (or more) of the fault conditions continues to exist.

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BASIC CONNECTIONS

PINOUT DESCRIPTION

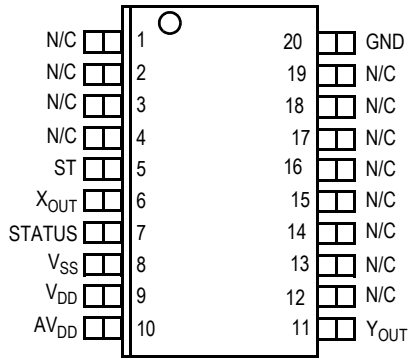

Table 3. Pin Descriptions

Pin No.	Pin Name	Description
1 thru 3	—	Leave unconnected.
4	—	No internal connection. Leave unconnected.
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6	X_{OUT}	Output voltage of the accelerometer. X Direction.
7	STATUS	Logic output pin to indicate fault.
8	V_{SS}	The power supply ground.
9	V_{DD}	The power supply input.
10	AV_{DD}	Power supply input (Analog).
11	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
12 thru 16	—	Used for factory trim. Leave unconnected.
17 thru 19	—	No internal connection. Leave unconnected.
20	GND	Ground.

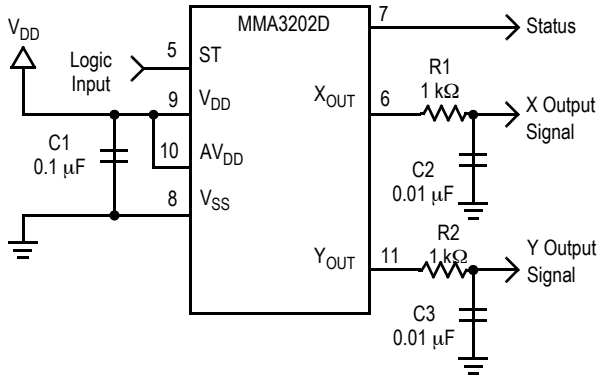

Figure 4. SOIC Accelerometer with Recommended Connection Diagram

PCB Layout

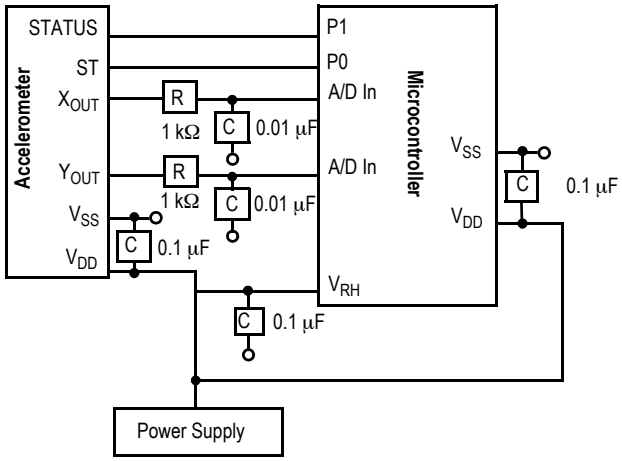

Figure 5. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTE:

- Use a 0.1 µF capacitor on V_{DD} to decouple the power source.
- Physical coupling distance of the accelerometer to the microcontroller should be minimal.
- Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 5.
- Use an RC filter of 1 kΩ and 0.01 µF on the output of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
- PCB layout of power and ground should not couple power supply noise.
- Accelerometer and microcontroller should not be a high current path.
- A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency. This will prevent aliasing errors.

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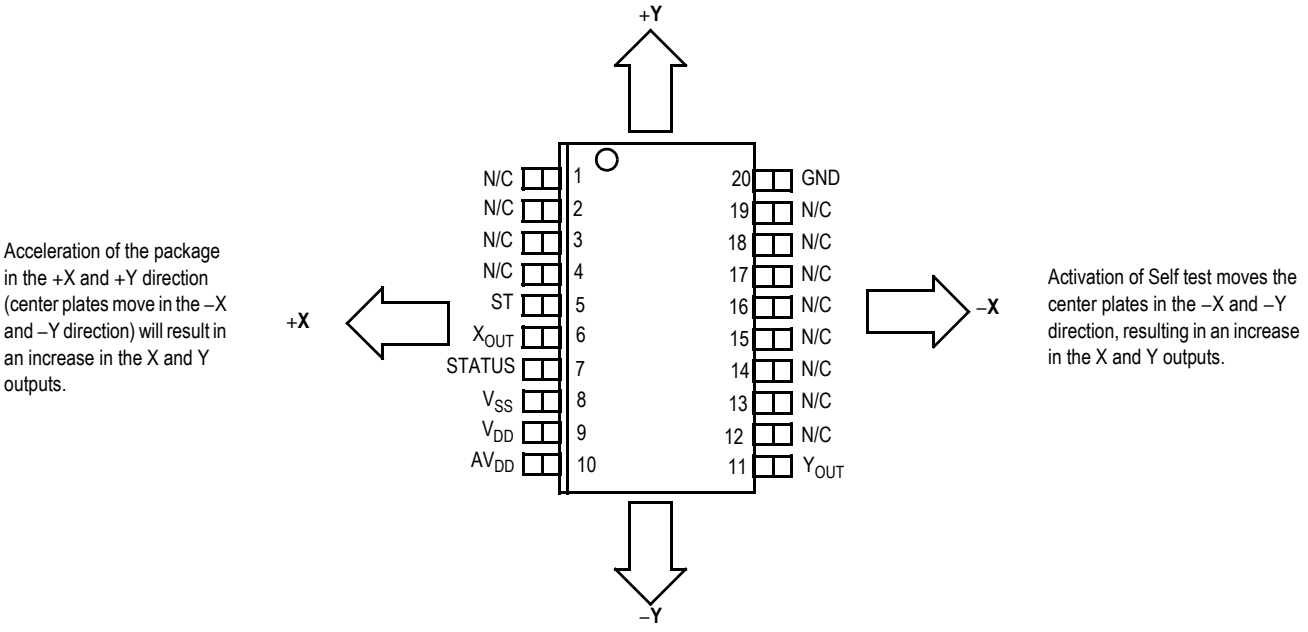
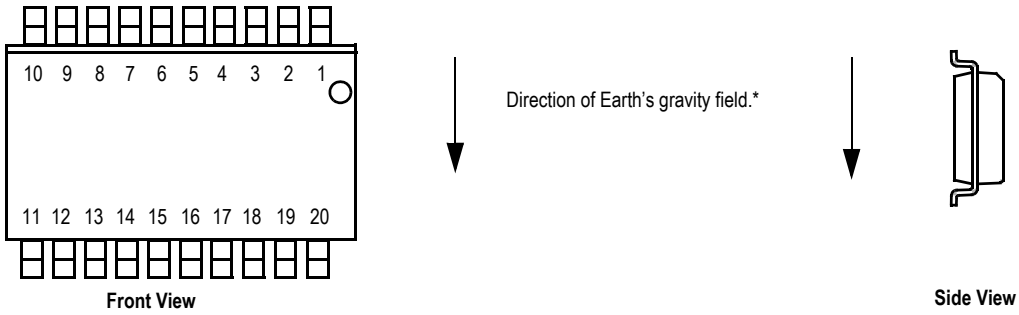
Dynamic Acceleration Sensing Direction



20-Pin SOIC Package
N/C pins are recommended to be left FLOATING

Top View

Static Acceleration Sensing Direction



Front View

Side View

* When positioned as shown, the Earth's gravity will result in a positive 1g output in the X channel.

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

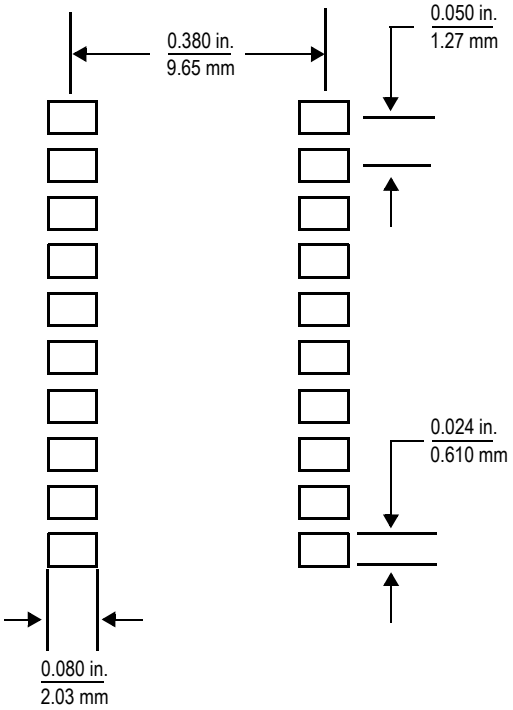

Figure 6. Footprint SOIC-20 (Case 475A-01)

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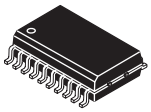
Surface Mount Micromachined Accelerometer

MMA3204

MMA3204D: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±100/30G



D SUFFIX
EG SUFFIX (Pb-FREE)
20-LEAD SOIC
CASE 475A-02

The MMA3200 series of dual axis (X and Y) silicon capacitive, micromachined accelerometers features signal conditioning, a 4-pole low pass filter and temperature compensation and separate outputs for the two axes. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- Sensitivity in two separate axes: 100g X-axis and 30g Y-axis
- Integral Signal Conditioning
- Linear Output
- Ratiometric Performance
- 4th Order Bessel Filter Preserves Pulse Shape Integrity
- Calibrated Self-test
- Low Voltage Detect, Clock Monitor, and EPROM Parity Check Status
- Transducer Hermetically Sealed at Wafer Level for Superior Reliability
- Robust Design, High Shocks Survivability

Typical Applications

- Vibration Monitoring and Recording
- Impact Monitoring
- Appliance Control
- Mechanical Bearing Monitoring
- Computer Hard Drive Protection
- Computer Mouse and Joysticks
- Virtual Reality Input Devices
- Sports Diagnostic Devices and Systems

ORDERING INFORMATION

Device	Temperature Range	Case No.	Package
MMA3204D	– 40 to +125°C	475A-02	SOIC-20
MMA3204DR2	– 40 to +125°C	475A-02	SOIC-20, Tape & Reel
MMA3204EG	– 40 to +125°C	475A-02	SOIC-20
MMA3204EGR2	– 40 to +125°C	475A-02	SOIC-20, Tape & Reel

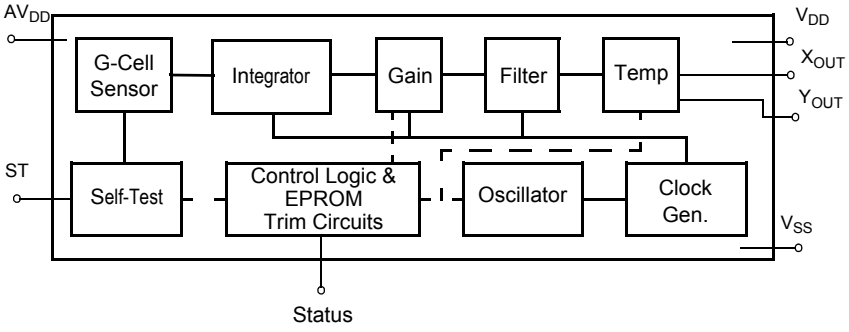


Figure 1. Simplified Accelerometer Functional Block Diagram

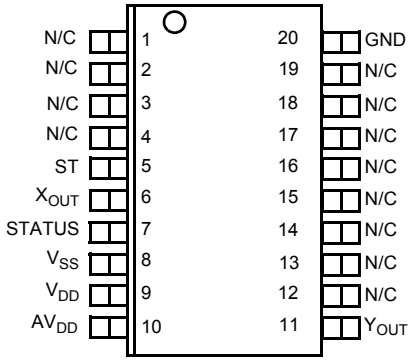


Figure 2. Pin Connections

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Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Powered Acceleration (all axes)	G_{pd}	1500	g
Unpowered Acceleration (all axes)	G_{upd}	2000	g
Supply Voltage	V_{DD}	–0.3 to +7.0	V
Drop Test (1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

NOTES:
1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the accelerometers contain internal 2kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

(Unless otherwise noted: –40°C ≤ T_A ≤ +105°C, 4.75 ≤ V_{DD} ≤ 5.25, Acceleration = 0g, Loaded output.[1])

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range [2]					
Supply Voltage [3]	V_{DD}	4.75	5.00	5.25	V
Supply Current	I_{DD}	6	8	10	mA
Operating Temperature Range	T_A	–40	—	+125	°C
Acceleration Range X-axis	g_{FS}	—	112.5	—	g
Acceleration Range Y-axis	g_{FS}	—	33.75	—	g
Output Signal					
Zero g X-axis (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.35	2.5	2.65	V
Zero g Y-axis (T_A = 25°C, V_{DD} = 5.0 V)[4]	V_{OFF}	2.25	2.5	2.75	V
Zero g X-axis	$V_{OFF,V}$	0.46 V_{DD}	0.50 V_{DD}	0.54 V_{DD}	V
Zero g Y-axis	$V_{OFF,V}$	0.44 V_{DD}	0.50 V_{DD}	0.56 V_{DD}	V
Sensitivity X-axis (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	19	20	21	mV/g
Sensitivity Y-axis (T_A = 25°C, V_{DD} = 5.0 V)[5]	S	63.33	66.67	70.0	mV/g
Sensitivity X-axis	S_V	3.72	4	4.28	mV/g/V
Sensitivity Y-axis	S_V	12.40	13.33	14.27	mV/g/V
Bandwidth Response	f_{-3dB}	360	400	440	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
RMS (.01 Hz – 1 kHz)	n_{RMS}	—	—	3.5	mVrms
Power Spectral Density	n_{PSD}	—	110	—	μV/(Hz$^{1/2}$)
Clock Noise (without RC load on output)[6]	n_{CLK}	—	2.0	—	mVpk
Self-Test					
Output Response	g_{ST}	9.6	12	14.4	g
Input Low	V_{IL}	V_{SS}	—	0.3 × V_{DD}	V
Input High	V_{IH}	0.7 × V_{DD}	—	V_{DD}	V
Input Loading[7]	I_{IN}	–30	–100	–300	μA
Response Time[8]	t_{ST}	—	2.0	–	ms
Status[12][13]					
Output Low (I_{load} = 100 μA)	V_{OL}	—	—	0.4	V
Output High (I_{load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Minimum Supply Voltage (LVD Trip)	V_{LVD}	2.7	3.25	4.0	V
Clock Monitor Fail Detection Frequency	f_{min}	50	—	260	kHz
Output Stage Performance					
Electrical Saturation Recovery Time[9]	t_{DELAY}	—	0.2	—	ms
Full Scale Output Range (I_{OUT} = 200 μA)	V_{FSO}	0.25	—	V_{DD}– 0.25	V
Capacitive Load Drive[10]	C_L	—	—	100	pF
Output Impedence	Z_O	—	300	—	Ω
Mechanical Characteristics					
Transverse Sensitivity[11]	$V_{XZ,YZ}$	—	—	5.0	% FSO
Package Resonance	f_{PKG}	—	10	—	kHz

NOTES:

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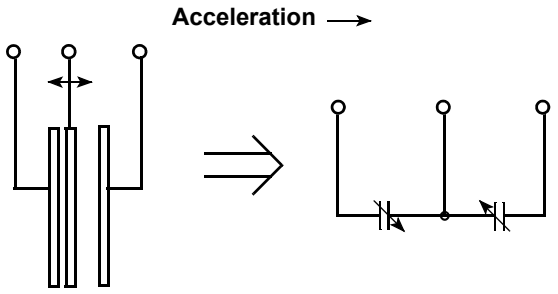

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BASIC CONNECTIONS

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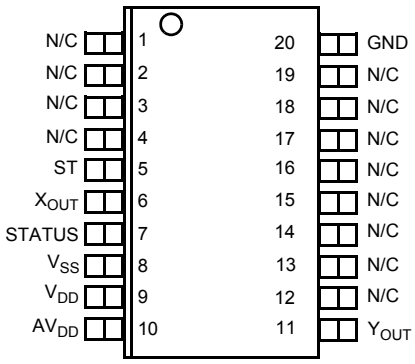

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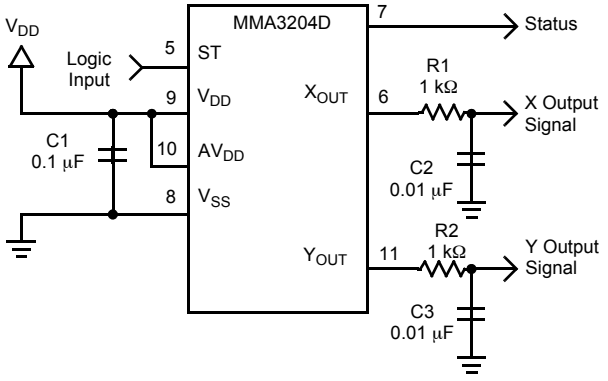

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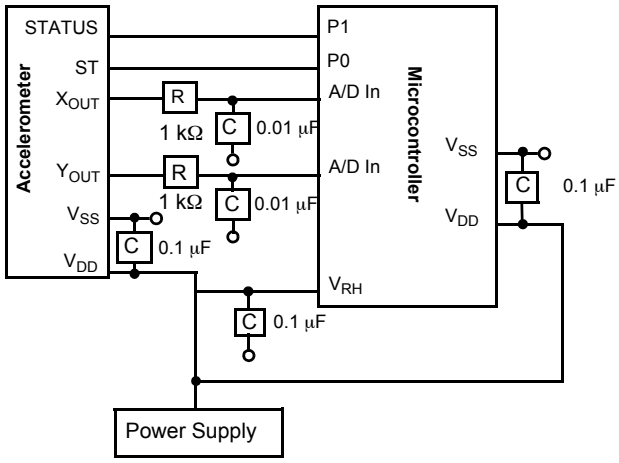

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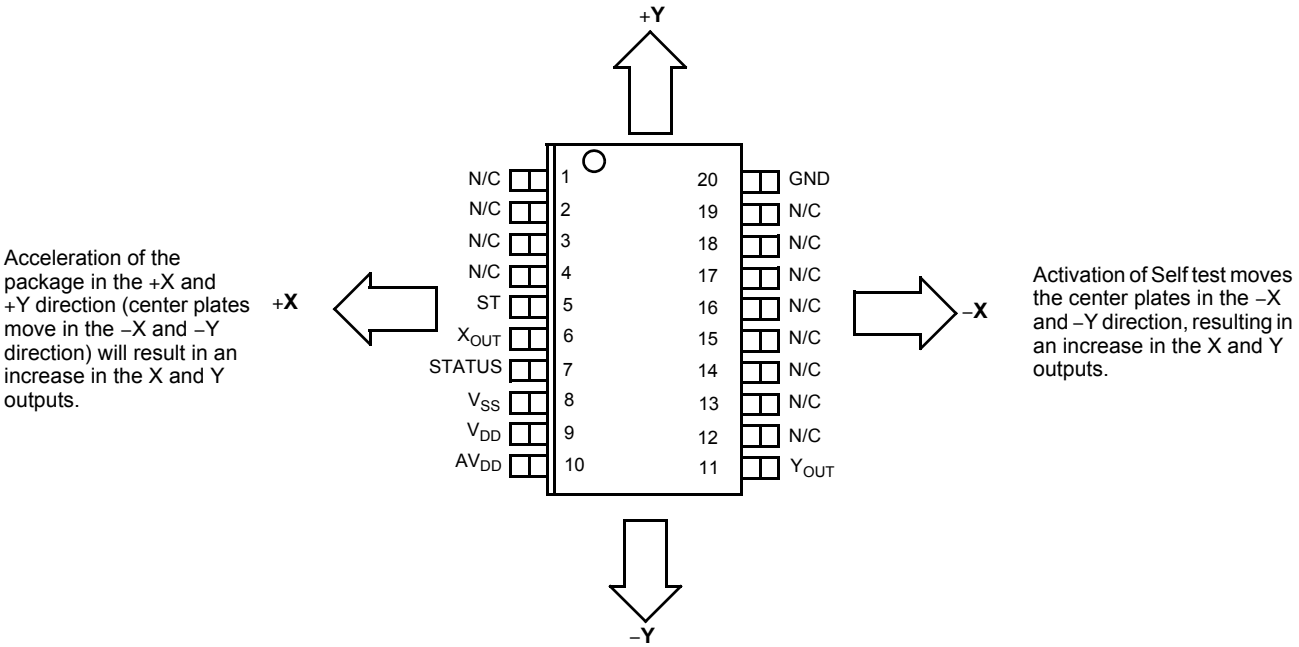

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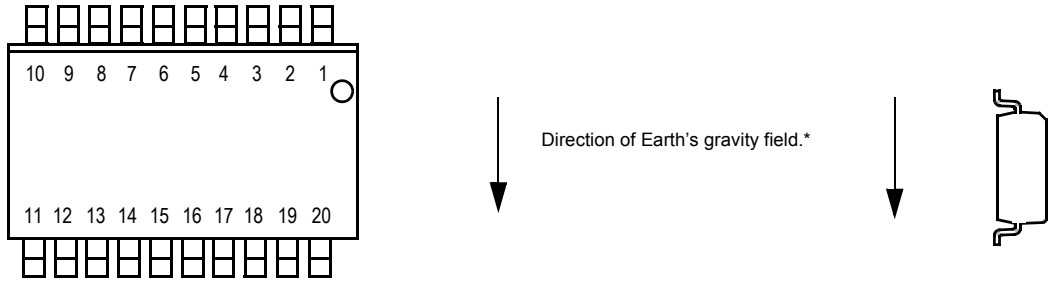

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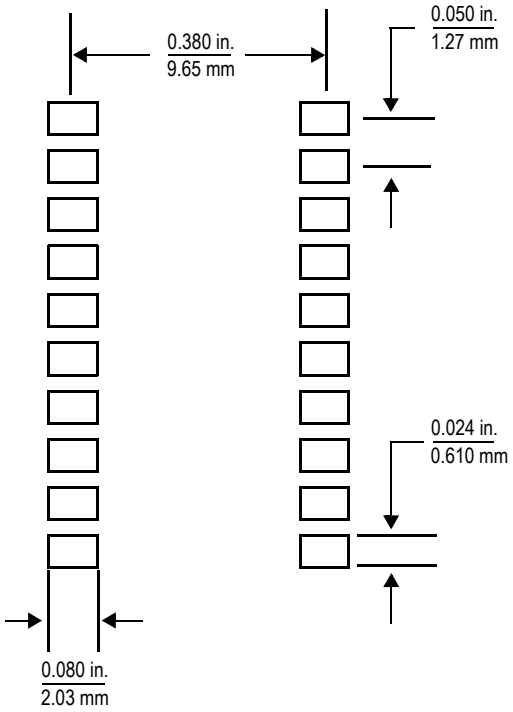

Figure 6. Footprint SOIC-20 (Case 475A-01)

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±10g Dual Axis Micromachined Accelerometer

MMA6231Q
MMA6233Q

The MMA6200 series of low cost capacitive micromachined accelerometers feature signal conditioning, a 1-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

MMA6230Q Series: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±10 g

Features

- Low Noise
- Low Cost
- Low Power
- 2.7 V to 3.6 V Operation
- 6mm x 6mm x 1.98 mm QFN
- Integral Signal Conditioning with Low Pass Filter
- Linear Output
- Ratiometric Performance
- Self-Test
- Robust Design, High Shocks Survivability

Typical Applications

- Pedometer
- Appliance Control
- Impact Monitoring
- Vibration Monitoring and Recording
- Position & Motion Sensing
- Freefall Detection
- Smart Portable Electronics

Bottom View

16-LEAD QFN CASE 1477-02

Top View

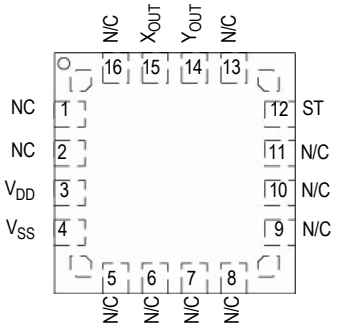

Figure 1. Pin Connections

ORDERING INFORMATION				
Device Name	**Bandwidth Response**	**I_{DD}**	**Case No.**	**Package**
MMA6231Q	300 Hz	1.2 mA	1477-02	QFN-16, Tube
MMA6231QR2	300 Hz	1.2 mA	1477-02	QFN-16,Tape & Reel
MMA6233Q	900 Hz	2.2 mA	1477-02	QFN-16, Tube
MMA6233QR2	900 Hz	2.2 mA	1477-02	QFN-16,Tape & Reel

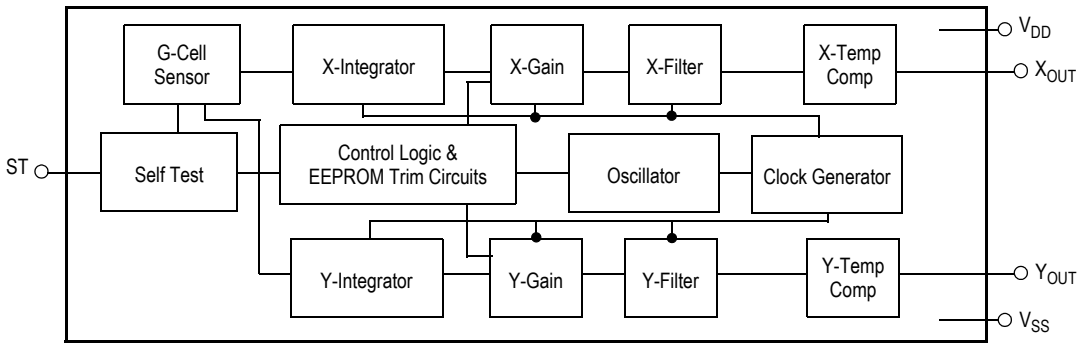

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: -20°C ≤ T_A ≤ 85°C, 3.0 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output (1)

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range(2)					
Supply Voltage(3)	V_{DD}	2.7	3.3	3.6	V
Supply Current					
MMA6231Q	I_{DD}	—	1.2	1.5	mA
MMA6233Q	I_{DD}	—	2.2	3.0	mA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range	g_{FS}	—	10	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)(4)	V_{OFF}	1.485	1.65	1.815	V
Zero g	V_{OFF}, T_A	—	2.0	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)	S	111	120	129	mV/g
Sensitivity	S, T_A	—	0.015	—	%/°C
Bandwidth Response					
MMA6231Q	f_{-3dB}	—	300	—	Hz
MMA6233Q	f_{-3dB}	—	900	—	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
MMA6231Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	0.7	—	mVrms
MMA6233Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	0.6	—	
Power Spectral Density RMS (0.1 Hz – 1 kHz)					
MMA6231Q	n_{PSD}	—	50	—	ug/$\sqrt{Hz}$
MMA6233Q	n_{PSD}	—	30	—	
Self-Test					
Output Response	g_{ST}	2.0	—	—	g
Input Low	V_{IL}	—	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Pull-Down Resistance(5)	R_{PO}	43	57	71	kΩ
Response Time(6)	t_{ST}	—	2.0	—	ms
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} –0.25	V
Capacitive Load Drive(7)	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	300	Ω
Power-Up Response Time					
MMA6231Q	$t_{RESPONSE}$	—	2.0	—	ms
MMA6233Q	$t_{RESPONSE}$	—	0.7	—	ms
Mechanical Characteristics					
Transverse Sensitivity(8)	$V_{ZX, YX, ZY}$	–5.0	—	+5.0	% FSO

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor to ground.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.7 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
5. The digital input pin has an internal pull-down resistance to prevent inadvertent self-test initiation due to external board level leakages.
6. Time for the output to reach 90% of its final value after a self-test is initiated.
7. Preserves phase margin (60°) to guarantee output amplifier stability.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of a surface micromachined capacitive sensing cell (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that moves between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell plates form two back-to-back capacitors (Figure 4). As the center plate moves with acceleration, the distance between the plates changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the plate, ε is the dielectric constant, and D is the distance between the plates.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

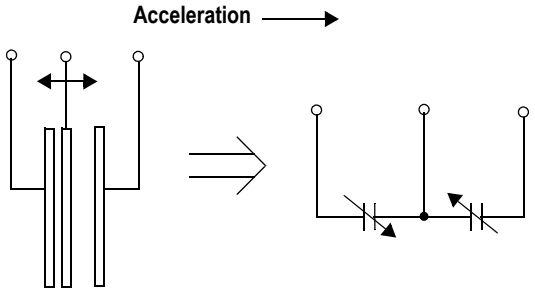

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

Filtering

These Freescale accelerometers contain an onboard single-pole switched capacitor filter. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Self-Test

The sensor provides a self-test feature allowing the verification of the mechanical and electrical integrity of the accelerometer at any time before or after installation. A fourth *plate* is used in the g-cell as a self-test plate. When a logic high input to the self-test pin is applied, a calibrated potential is applied across the self-test plate and the moveable plate. The resulting electrostatic force ($Fe = {}^1/_2\ AV^2/d^2$) causes the center plate to deflect. The resultant deflection is measured by the accelerometer's ASIC and a proportional output voltage results. This procedure assures both the mechanical (g-cell) and electronic sections of the accelerometer are functioning.

Freescale accelerometers include fault detection circuitry and a fault latch. Parity of the EEPROM bits becomes odd in number.

Self-test is disabled when EEPROM parity error occurs.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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BASIC CONNECTIONS

Pinout Description

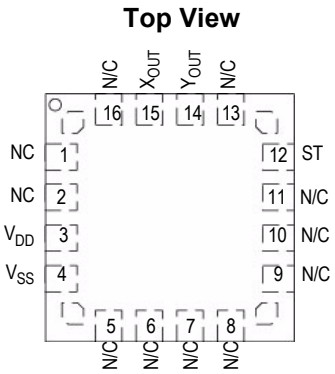

Figure 4. Pinout Description

Pin No.	Pin Name	Description
1, 5–7, 13, 16	N/C	No internal connection. Leave unconnected.
14	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
15	X_{OUT}	Output voltage of the accelerometer. X Direction.
3	V_{DD}	Power supply input.
4	V_{SS}	The power supply ground.
2, 8–11	N/C	Used for factory trim. Leave unconnected.
12	ST	Logic input pin used to initiate self-test.

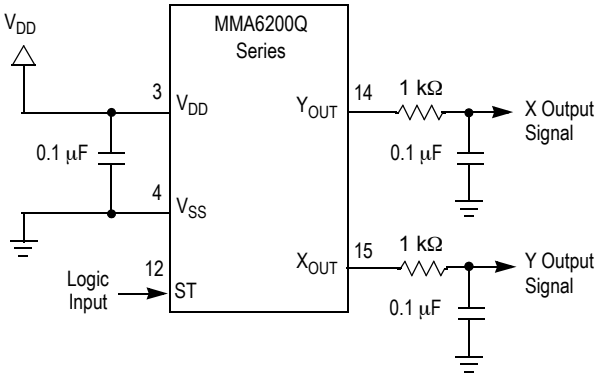

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

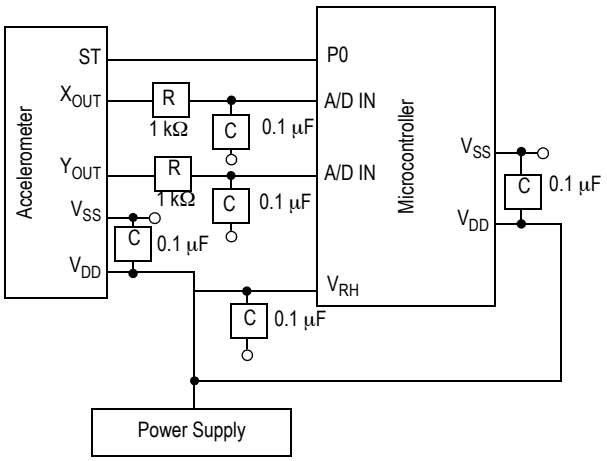

Figure 6. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Flag underneath package is connected to ground.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (16 kHz for Low I_{DD} and 52 kHz for Standard I_{DD} for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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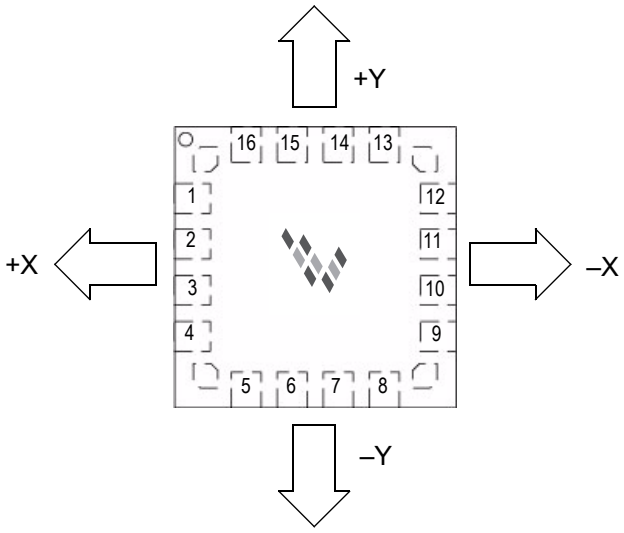
DYNAMIC ACCELERATION

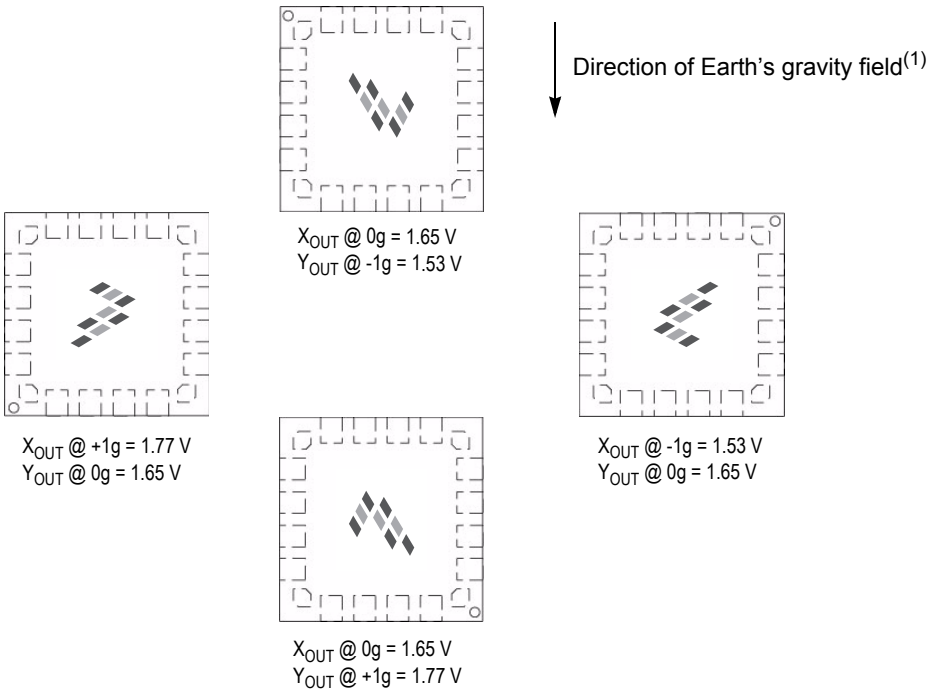
Top View



16-Pin QFN Package

STATIC ACCELERATION

Top View

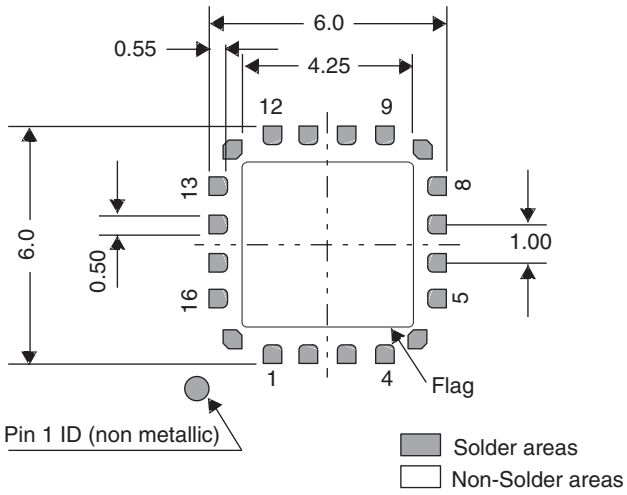


1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.



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±1.5g Dual Axis Micromachined Accelerometer

MMA6260Q
MMA6261Q
MMA6262Q
MMA6263Q

The MMA6200 series of low cost capacitive micromachined accelerometers feature signal conditioning, a 1-pole low pass filter and temperature compensation. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. A full system self-test capability verifies system functionality.

Features

- High Sensitivity
- Low Noise
- Low Power
- 2.7 V to 3.6 V Operation
- 6mm x 6mm x 1.98mm QFN
- Integral Signal Conditioning with Low Pass Filter
- Linear Output
- Ratiometric Performance
- Self-Test
- Robust Design, High Shocks Survivability

Typical Applications

- Tilt Monitoring
- Position & Motion Sensing
- Freefall Detection
- Impact Monitoring
- Appliance Control
- Vibration Monitoring and Recording
- Smart Portable Electronics

MMA6260Q Series: X-Y AXIS SENSITIVITY MICROMACHINED ACCELEROMETER ±1.5 g

Bottom View

16-LEAD QFN CASE 1477-02

ORDERING INFORMATION				
Device Name	**Bandwidth Response**	**I_{DD}**	**Case No.**	**Package**
MMA6260Q	50 Hz	1.2 mA	1477-02	QFN-16, Tube
MMA6260QR2	50 Hz	1.2 mA	1477-02	QFN-16,Tape & Reel
MMA6261Q	300 Hz	1.2 mA	1477-02	QFN-16, Tube
MMA6261QR2	300 Hz	1.2 mA	1477-02	QFN-16,Tape & Reel
MMA6262Q	150 Hz	2.2 mA	1477-02	QFN-16,Tube
MMA6262QR2	150 Hz	2.2 mA	1477-02	QFN-16,Tape & Reel
MMA6263Q	900 Hz	2.2 mA	1477-02	QFN-16, Tube
MMA6263QR2	900 Hz	2.2 mA	1477-02	QFN-16,Tape & Reel

Top View

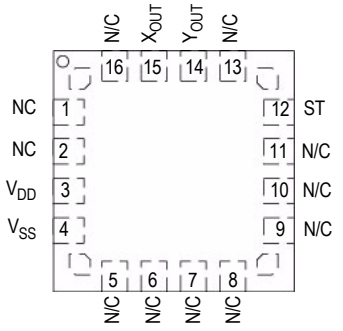

Figure 1. Pin Connections

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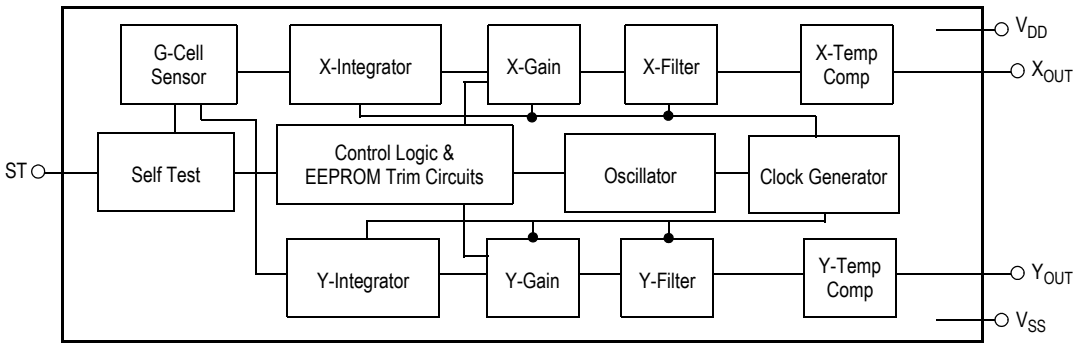

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.2	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometers contain internal 2 kV ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 3.0 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output [1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.7	3.3	3.6	V
Supply Current					
MMA6260Q, MMA6261Q	I_{DD}	—	1.2	1.5	mA
MMA6262Q, MMA6263Q	I_{DD}	—	2.2	3.0	mA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range	g_{FS}	—	1.5	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[4]	V_{OFF}	1.485	1.65	1.815	V
Zero g	V_{OFF}, T_A	—	2.0	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)	S	740	800	860	mV/g
Sensitivity	S, T_A	—	0.015	—	%/°C
Bandwidth Response					
MMA6260Q	f_{-3dB}	—	50	—	Hz
MMA6261Q	f_{-3dB}	—	300	—	Hz
MMA6262Q	f_{-3dB}	—	150	—	Hz
MMA6263Q	f_{-3dB}	—	900	—	Hz
Nonlinearity	NL_{OUT}	–1.0	—	+1.0	% FSO
Noise					
MMA6260Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	1.8	—	mVrms
MMA6261Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	3.5	—	
MMA6262Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	1.3	—	
MMA6263Q RMS (0.1 Hz – 1 kHz)	n_{RMS}	—	2.5	—	
Power Spectral Density RMS (0.1 Hz – 1 kHz)					
MMA6260Q, MMA6261Q	n_{PSD}	—	300	—	ug/√Hz
MMA6262Q, MMA6263Q	n_{PSD}	—	200	—	
Self-Test					
Output Response	V_{ST}	0.9 V_{DD}	—	V_{DD}	V
Input Low	V_{IL}	—	—	0.3 V_{DD}	V
Input High	V_{IH}	0.7 V_{DD}	—	V_{DD}	V
Pull-Down Resistance[5]	R_{PO}	43	57	71	kΩ
Response Time[6]	t_{ST}	—	2.0	—	ms
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 200 µA)	V_{FSO}	V_{SS} +0.25	—	V_{DD} –0.25	V
Capacitive Load Drive[7]	C_L	—	—	100	pF
Output Impedance	Z_O	—	50	300	Ω
Power-Up Response Time					
MMA6260Q	$t_{RESPONSE}$	—	14	—	ms
MMA6261Q	$t_{RESPONSE}$	—	2.0	—	ms
MMA6262Q	$t_{RESPONSE}$	—	4.0	—	ms
MMA6263Q	$t_{RESPONSE}$	—	0.7	—	ms
Mechanical Characteristics					
Transverse Sensitivity[8]	$V_{ZX, YX, ZY}$	–5.0	—	+5.0	% FSO

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor to ground.
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PRINCIPLE OF OPERATION

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The device consists of a surface micromachined capacitive sensing cell (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing element is sealed hermetically at the wafer level using a bulk micromachined *cap* wafer.

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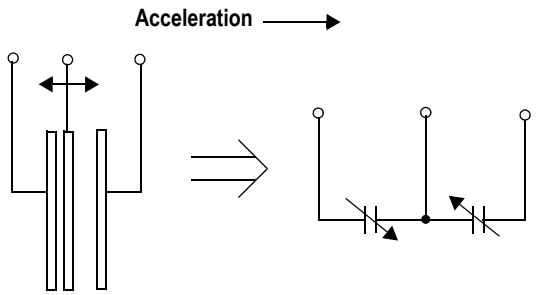

Figure 3. Transducer Physical Model

Figure 4. Equivalent Circuit Model

SPECIAL FEATURES

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BASIC CONNECTIONS

Pinout Description

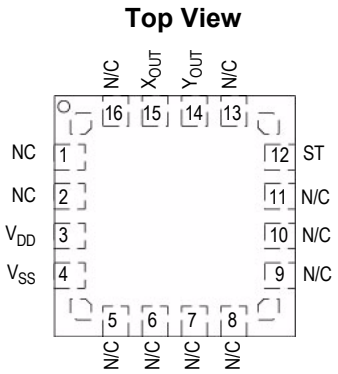

Figure 4. Pinout Description

Pin No.	Pin Name	Description
1, 5 – 7, 13, 16	N/C	No internal connection. Leave unconnected.
14	Y_{OUT}	Output voltage of the accelerometer. Y Direction.
15	X_{OUT}	Output voltage of the accelerometer. X Direction.
3	V_{DD}	Power supply input.
4	V_{SS}	The power supply ground.
2, 8 – 11	N/C	Used for factory trim. Leave unconnected.
12	ST	Logic input pin used to initiate self-test.

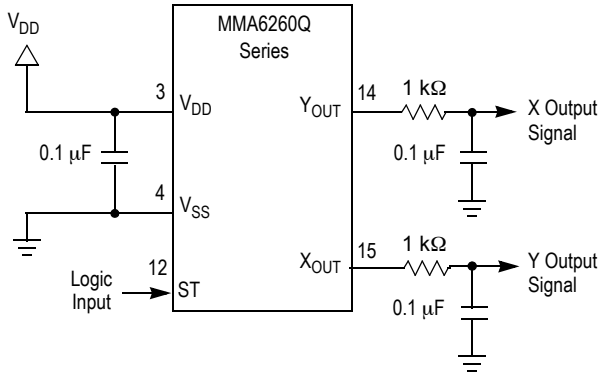

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

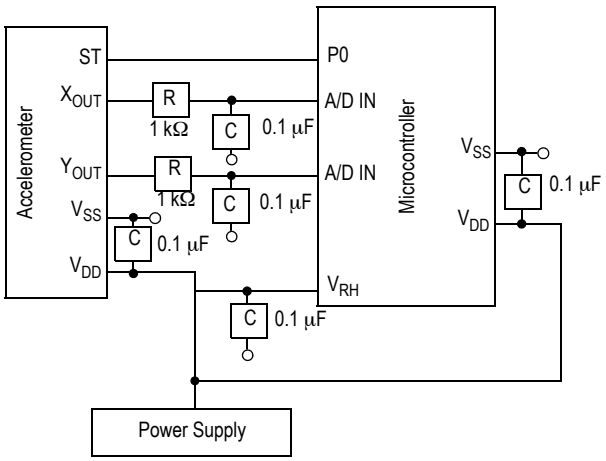

Figure 6. Recommend PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. Flag underneath package is connected to ground.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (16 kHz for Low I_{DD} and 52 kHz for Standard I_{DD} for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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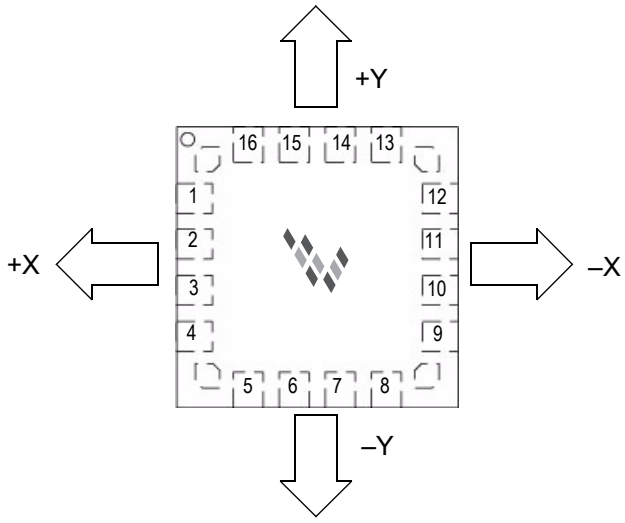
DYNAMIC ACCELERATION

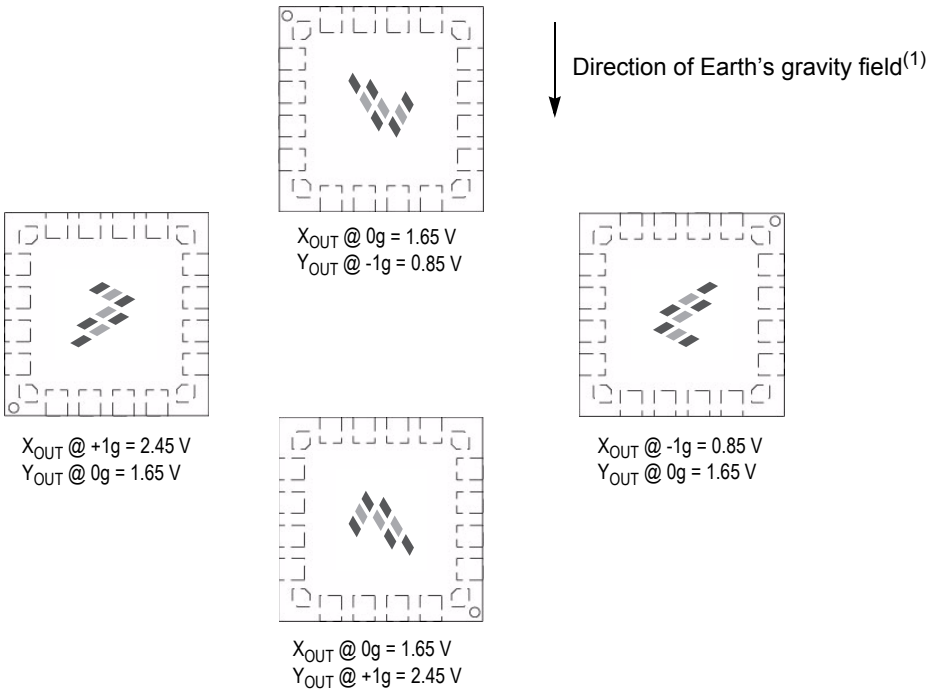
Top View



16-Pin QFN Package

STATIC ACCELERATION

Top View



1. When positioned as shown, the Earth's gravity will result in a positive 1g output.

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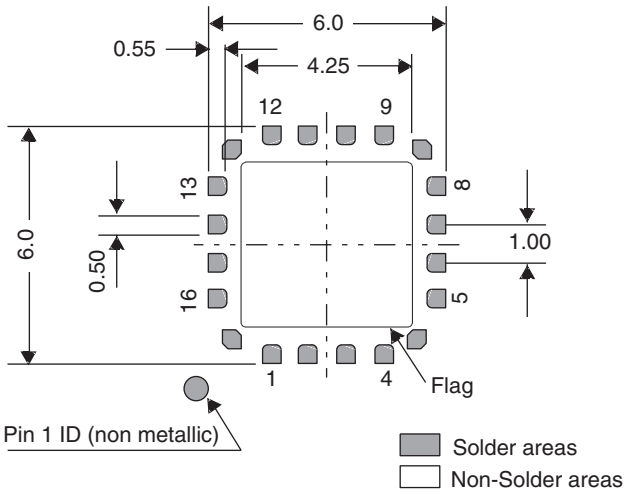
MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.



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RoHS

±1.5 g - 6 g Dual Axis Low-g Micromachined Accelerometer

The MMA6270QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among four sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

MMA6270QT

MMA6270QT: XY AXIS ACCELEROMETER ±1.5 g / 2 g / 4 g / 6 g

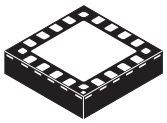
Features

- Selectable Sensitivity (1.5 g / 2 g / 4 g / 6 g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6 mm x 6 mm x 1.45 mm QFN
- High Sensitivity (800 mV/g @1.5 g)
- Fast Turn On Time
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Pb-Free Terminations
- Environmentally Preferred Package
- Low Cost

Typical Applications

- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing
- Appliances: Vibration Sensing

Bottom View



16-LEAD QFN CASE 1622-02

Top View

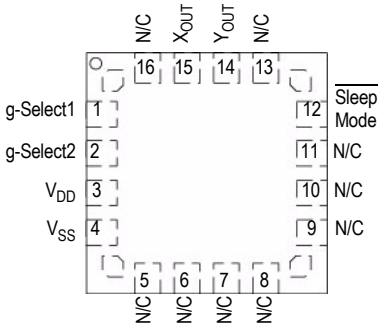


Figure 1. Pin Connections

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Package Drawing**	**Package**
MMA6270QT	– 20 to +85°C	1622-02	QFN-16, Tray
MMA6270QR2	– 20 to +85°C	1622-02	QFN-16,Tape & Reel

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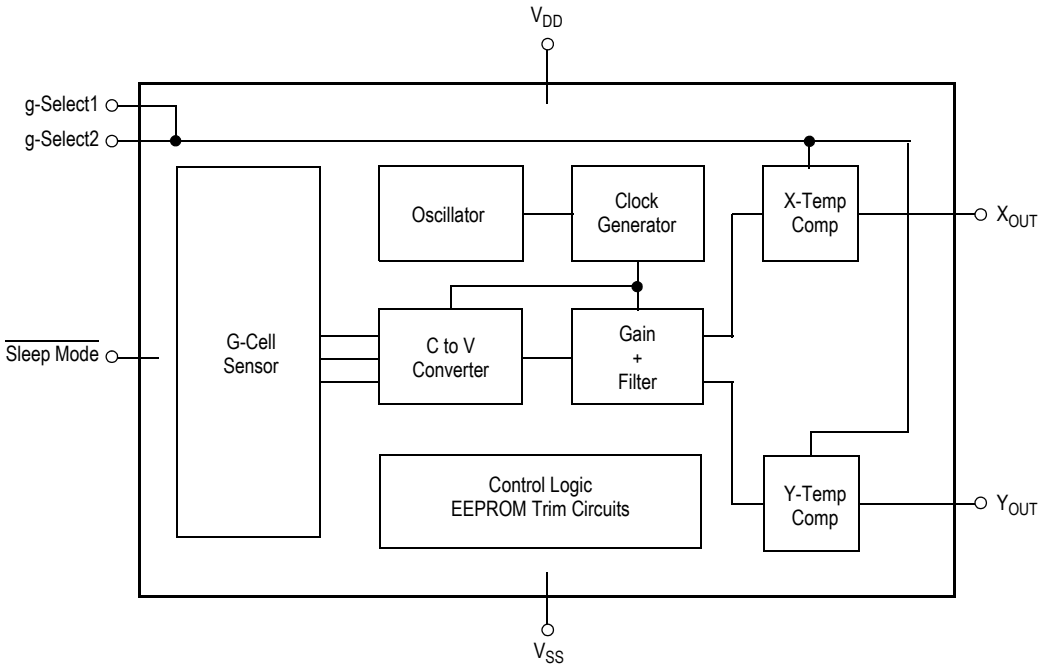

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0 g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	µA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	µA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Y-Axis,					
g-Select1 & 2: 00	g_{FS}	—	±1.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±2.0	—	g
g-Select1 & 2: 01	g_{FS}	—	±4.0	—	g
g-Select1 & 2: 11	g_{FS}	—	±6.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±2	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
1.5 g	$S_{1.5g}$	740	800	860	mV/g
2 g	S_{2g}	555	600	645	mV/g
4 g	S_{4g}	277.5	300	322.5	mV/g
6 g	S_{6g}	185	200	215	mV/g
Sensitivity[4]	S, T_A	—	±0.03	—	%/°C
Bandwidth Response					
XY	f_{-3dB}	—	350	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	4.7	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
XY	f_{GCELL}	—	6.0	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 µA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Y_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	$V_{XY, XZ, YZ}$	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 1.5 g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

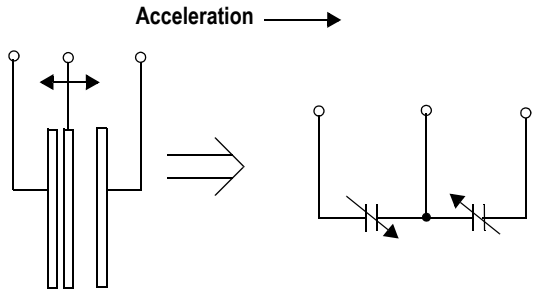

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 1.5 g, 2 g, 4 g, or 6 g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 1.5 g sensitivity as the device has an internal pull-down to keep it at that sensitivity (800 mV/g).

Table 3. g-Select Pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5 g	800 mV/g
0	1	2 g	600 mV/g
1	0	4 g	300 mV/g
1	1	6 g	200 mV/g

Sleep Mode

The dual axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3 uA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 1.5 g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The dual axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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BASIC CONNECTIONS

Pin Descriptions

Top View

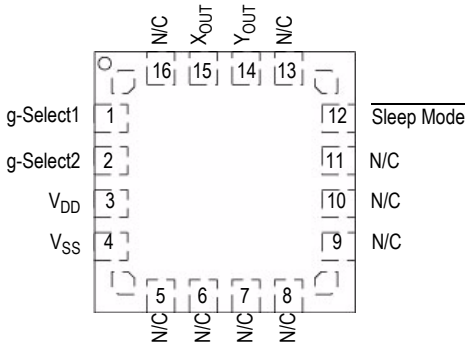

Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	Sleep Mode	Logic input pin to enable product or Sleep Mode.
13	N/C	No internal connection. Leave unconnected
14	Y_{OUT}	Y direction output voltage.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

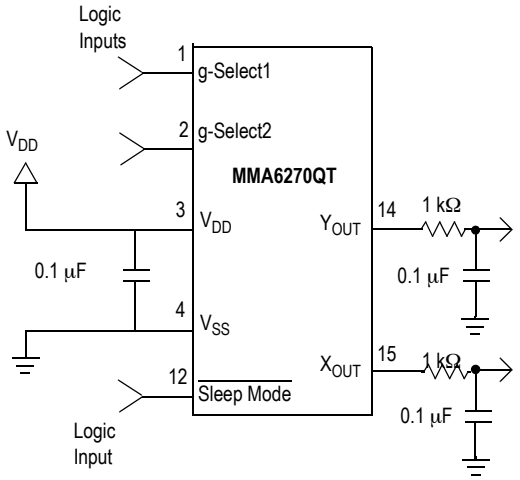

Figure 5. Accelerometer with Recommended

Connection Diagram

PCB Layout

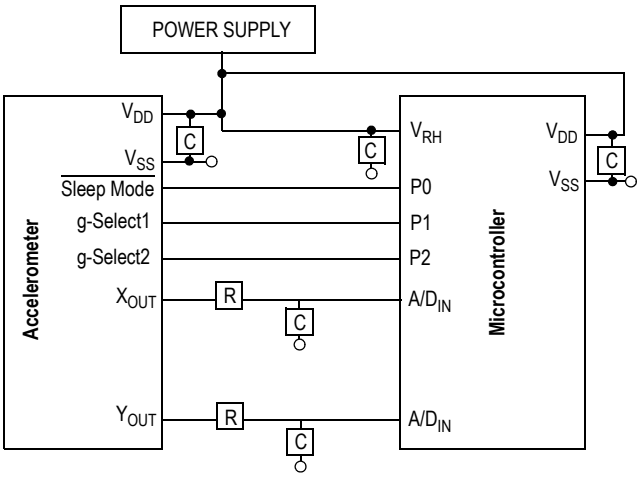

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kW and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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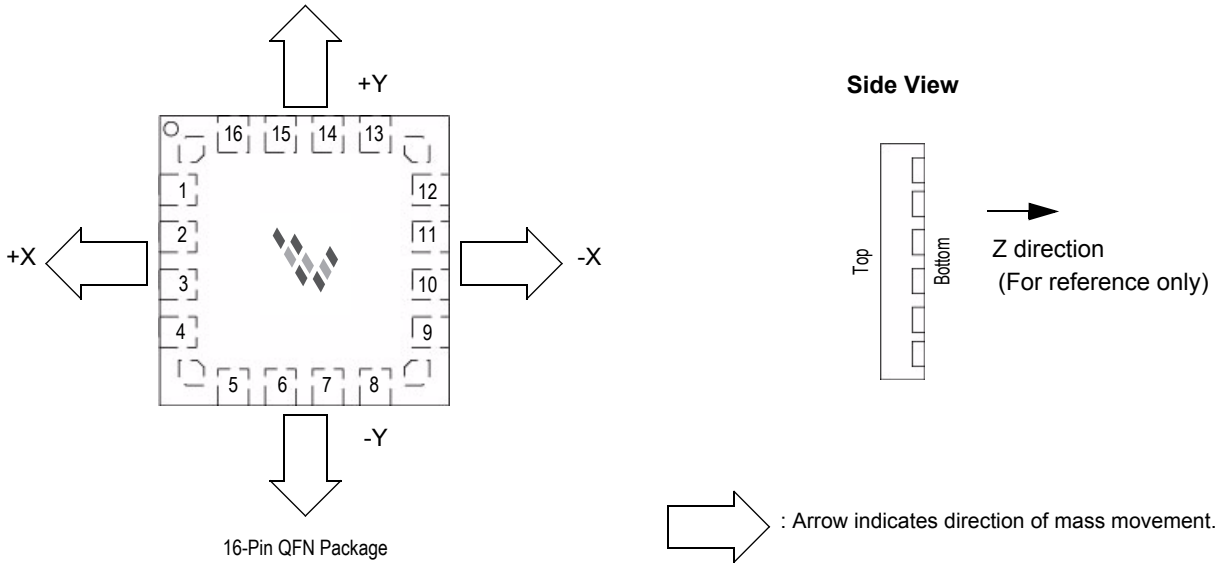
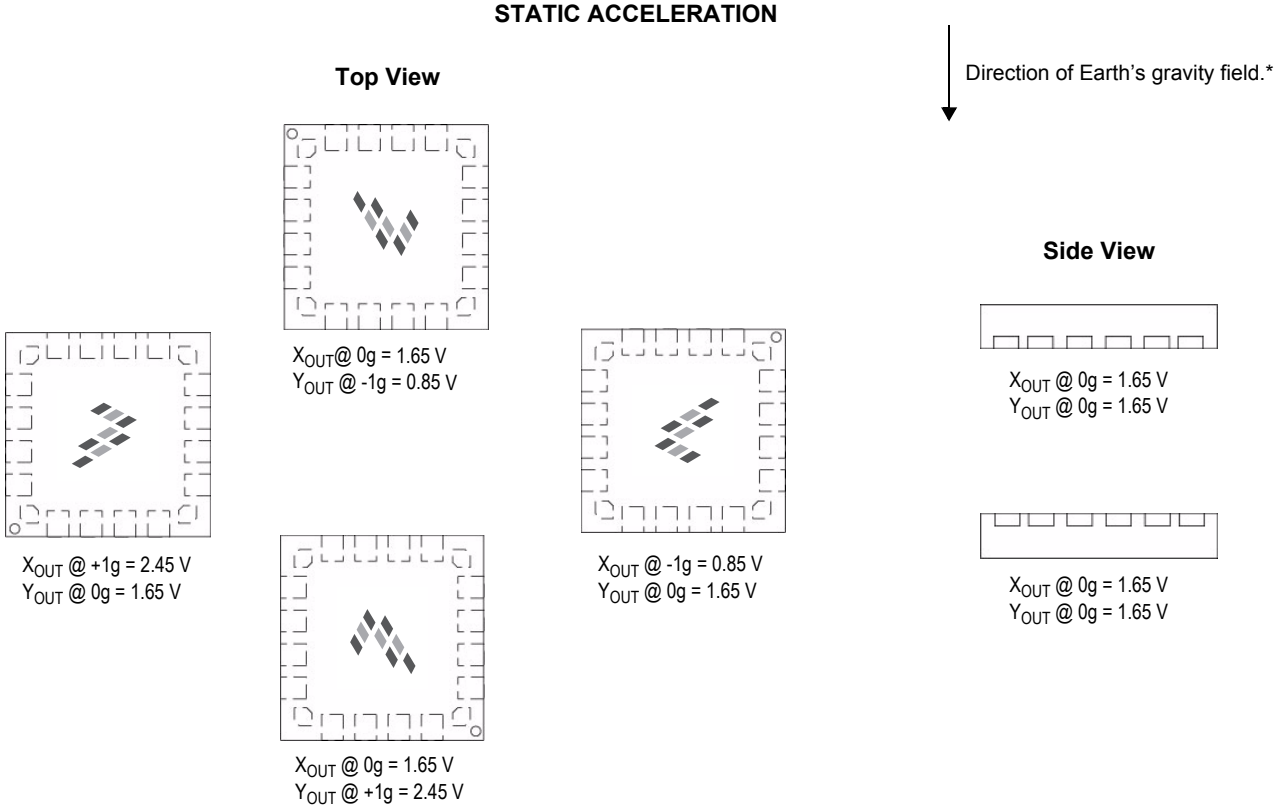
DYNAMIC ACCELERATION



STATIC ACCELERATION



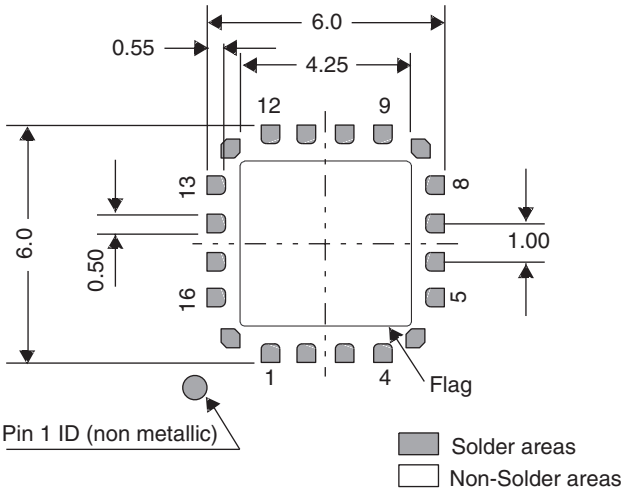
* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.



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RoHS

±2.5g - 10g Two Axis Low-g Micromachined Accelerometer

The MMA6271QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (2.5g/3.3g/6.7g/10g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- Fast Turn On Time
- High Sensitivity (2.5 g)
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Environmentally Preferred Package
- Low Cost

Typical Applications

- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Vibration: Shock Sensing

ORDERING INFORMATION			
Device	**Temp. Range**	**Case No.**	**Package**
MMA6271QT	– 20 to +85°C	1622-02	QFN-16, Tray
MMA6271QR2	– 20 to +85°C	1622-02	QFN-16,Tape & Reel

MMA6271QT

MMA6271QT: XY AXIS ACCELEROMETER ±2.5g/3.3g/6.7g/10g

Bottom View

16-LEAD QFN CASE 1622-02

Top View

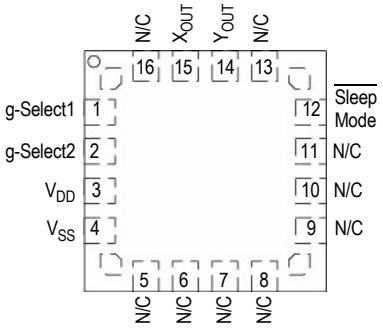

Figure 1. Pin Connections

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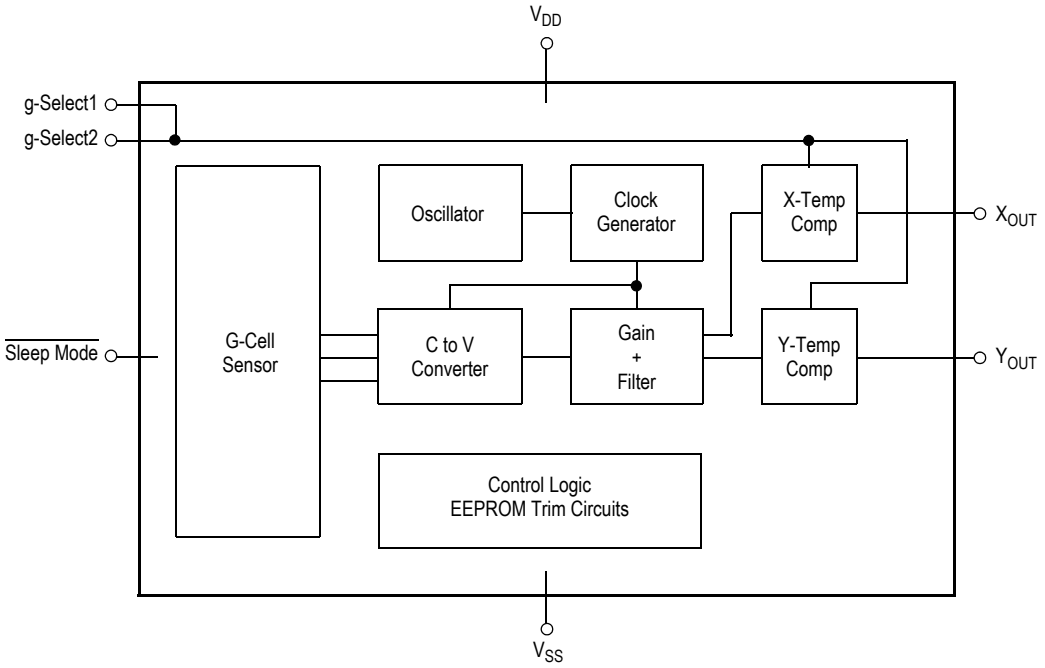

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	μA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	μA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Y-Axis					
g-Select1 & 2: 00	g_{FS}	—	±2.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±3.3	—	g
g-Select1 & 2: 01	g_{FS}	—	±6.7	—	g
g-Select1 & 2: 11	g_{FS}	—	±10.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±2	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
2.5g	$S_{2.5g}$	444	480	516	mV/g
3.3g	$S_{3.3g}$	333	360	387	mV/g
6.7g	$S_{6.7g}$	167	180	193	mV/g
10g	S_{10g}	111	120	129	mV/g
Sensitivity[4]	S,T_A	—	±0.03	—	%/°C
Bandwidth Response, XY	f_{-3dB}	—	350	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	3.0	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency, XY	f_{GCELL}	—	6.0	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 μA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Y_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	V_{XY}	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 μF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 2.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (postillion) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

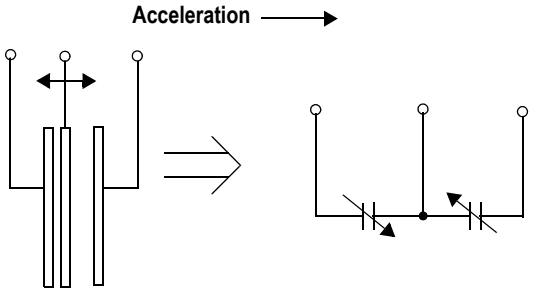

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 2.5g, 3.3g, 6.7g, or 10g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 2.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (480 mV/g).

Table 3. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	2.5g	480 mV/g
0	1	3.3g	360 mV/g
1	0	6.7g	180 mV/g
1	1	10g	120 mV/g

Sleep Mode

The 2 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3 μA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 2.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The 2 axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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Pin Descriptions

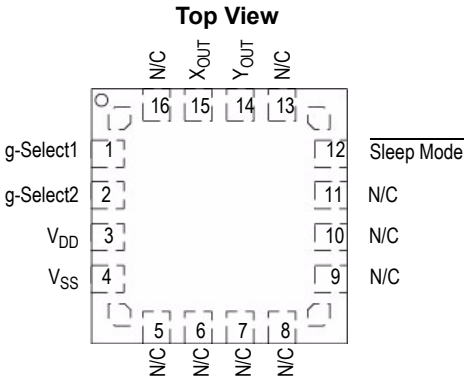

Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	$\overline{\text{Sleep Mode}}$	Logic input pin to enable product or Sleep Mode.
13	N/C	No internal connection. Leave unconnected.
14	Y_{OUT}	Y direction output voltage.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

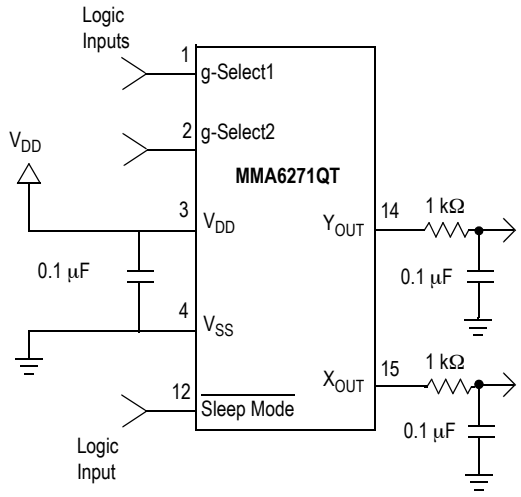

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

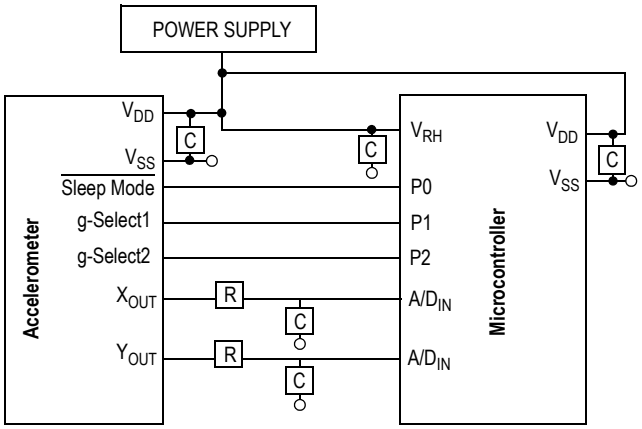

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF on V_{DD}-GND.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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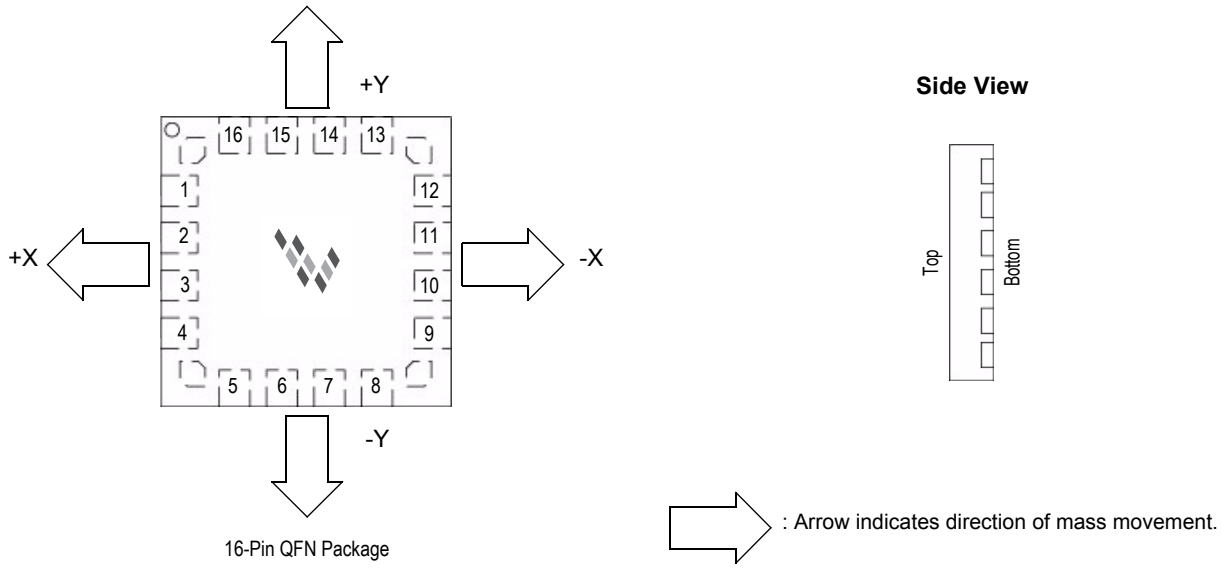
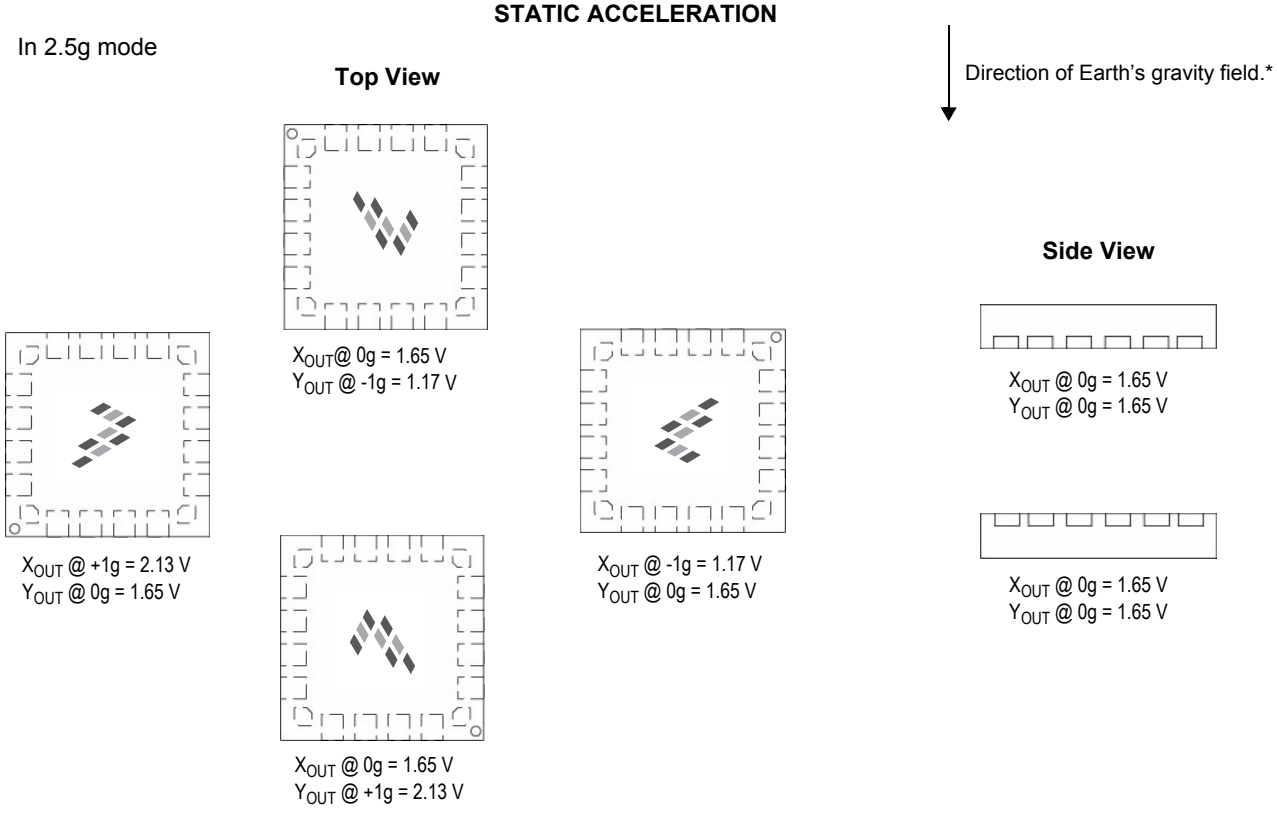
DYNAMIC ACCELERATION



STATIC ACCELERATION

In 2.5g mode



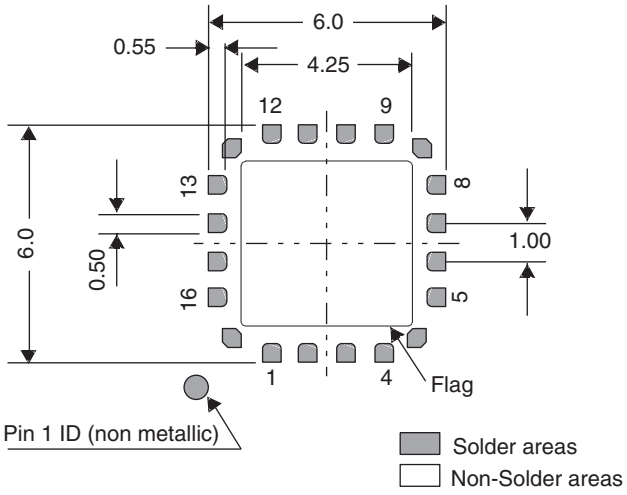
* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.



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RoHS

±1.5 g - 6 g Dual Axis Low-g Micromachined Accelerometer

The MMA6280QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (1.5 g / 2 g / 4 g / 6 g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6 mm x 6 mm x 1.45 mm QFN
- High Sensitivity (800 mV/g @1.5 g)
- Fast Turn On Time
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Pb-Free Terminations
- Environmentally Preferred Package
- Low Cost

Typical Applications

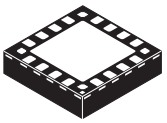
- Portable Applications: Tilt Monitoring, Anti-Theft
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing
- Impact Monitoring (shipping/handling, black box event recorder)
- Vibration Monitoring and Recording (appliance balance, seismic, smart motors, etc.).

ORDERING INFORMATION			
Device Name	**Temperture Range**	**Package Drawing**	**Package**
MMA6280QT	– 20 to +85°C	1622-02	QFN-16, Tray
MMA6280QR2	– 20 to +85°C	1622-02	QFN-16,Tape & Reel

MMA6280QT

MMA6280QT: XZ AXIS ACCELEROMETER ±1.5 g / 2 g / 4 g / 6 g

Bottom View



16-LEAD QFN CASE 1622-02

Top View

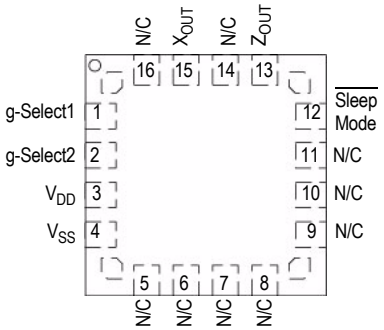


Figure 1. Pin Connections

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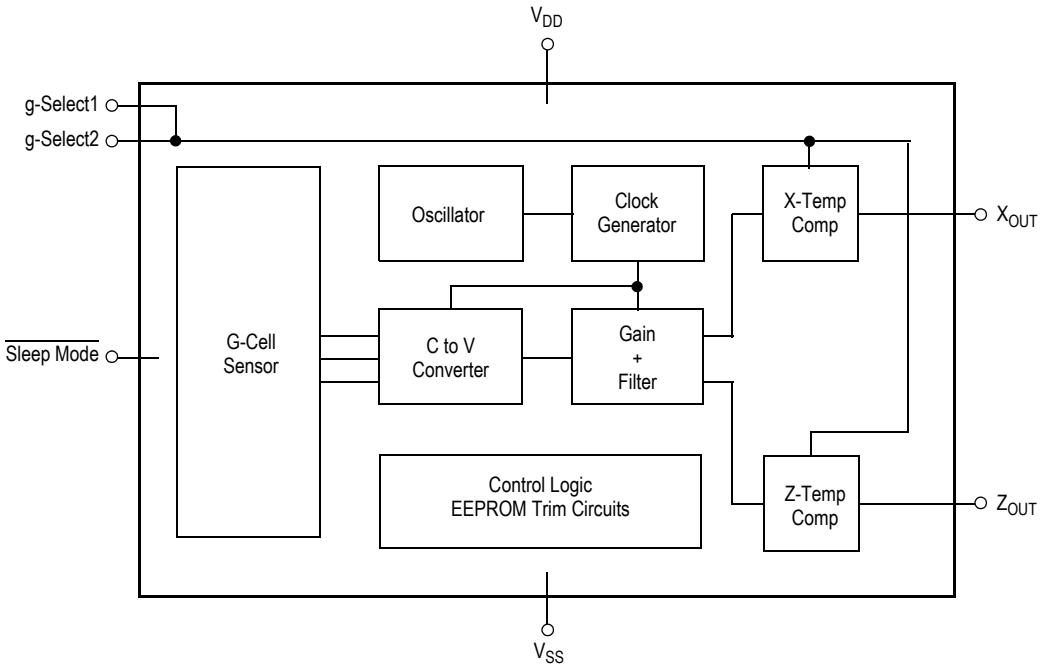

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0 g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	µA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	µA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Z-Axis					
g-Select1 & 2: 00	g_{FS}	—	±1.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±2.0	—	g
g-Select1 & 2: 01	g_{FS}	—	±4.0	—	g
g-Select1 & 2: 11	g_{FS}	—	±6.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±2	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
1.5 g	$S_{1.5g}$	740	800	860	mV/g
2 g	S_{2g}	555	600	645	mV/g
4 g	S_{4g}	277.5	300	322.5	mV/g
6 g	S_{6g}	185	200	215	mV/g
Sensitivity[4]	S,T_A	—	±0.03	—	%/°C
Bandwidth Response					
X	f_{-3dB}	—	350	—	Hz
Z	f_{-3dB}	—	150	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	4.7	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	µg/$\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
X	f_{GCELL}	—	6.0	—	kHz
Z	f_{GCELL}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 µA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Z_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	$V_{XY, XZ, YZ}$	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 µF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 1.5 g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

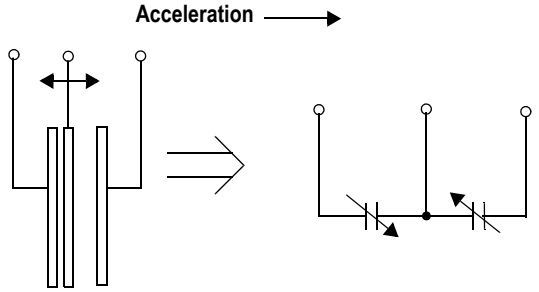

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 1.5 g, 2 g, 4 g, or 6 g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 1.5 g sensitivity as the device has an internal pulldown to keep it at that sensitivity (800 mV/g).

Table 3. g-Select Pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5 g	800 mV/g
0	1	2 g	600 mV/g
1	0	4 g	300 mV/g
1	1	6 g	200 mV/g

Sleep Mode

The dual axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3uA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 1.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The dual axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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Pin Descriptions

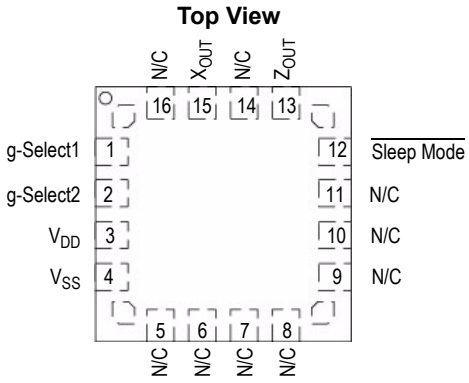

Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	Sleep Mode	Logic input pin to enable product or Sleep Mode.
13	Z_{OUT}	Z direction output voltage.
14	N/C	No internal connection. Leave unconnected.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

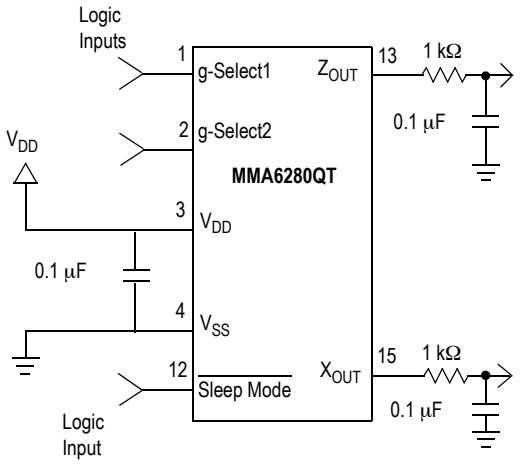

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

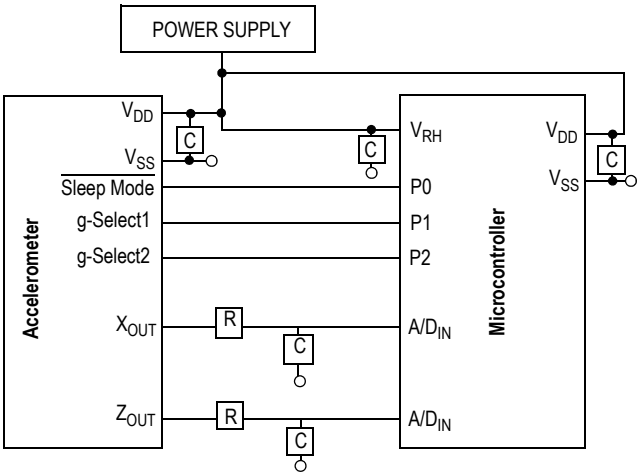

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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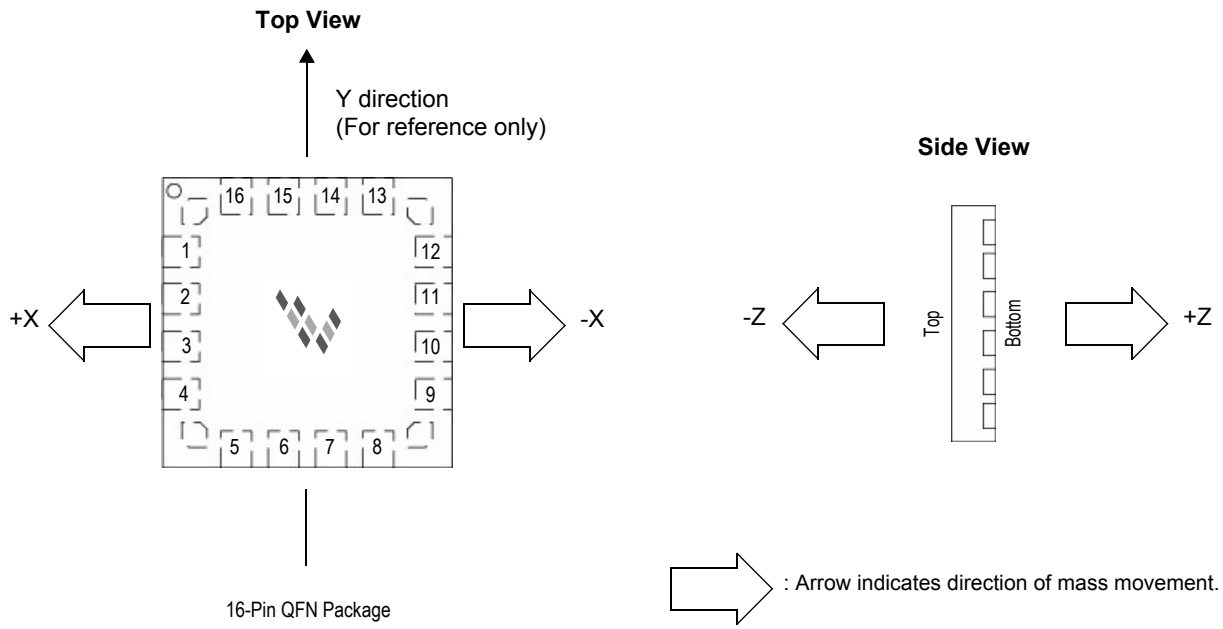
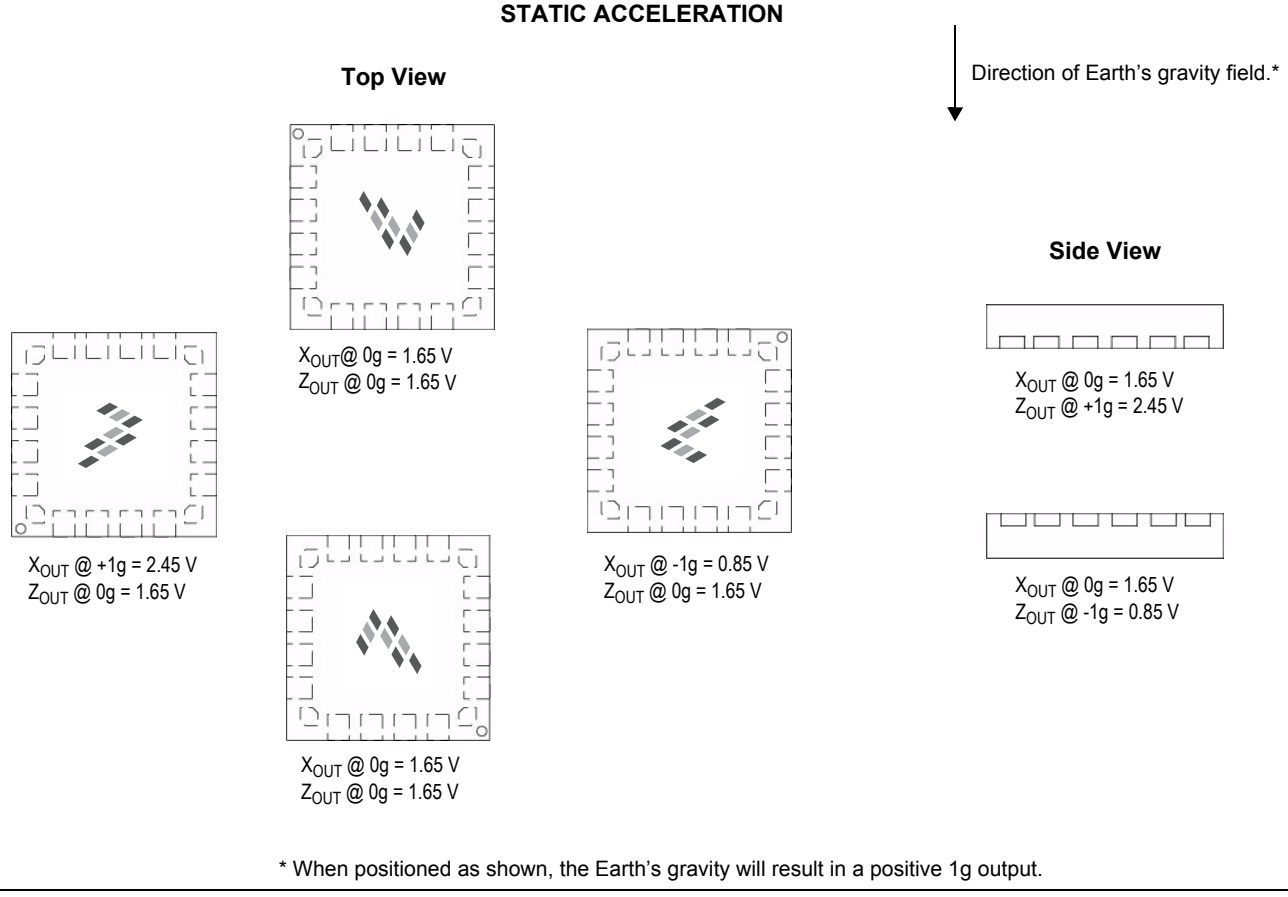
DYNAMIC ACCELERATION



STATIC ACCELERATION



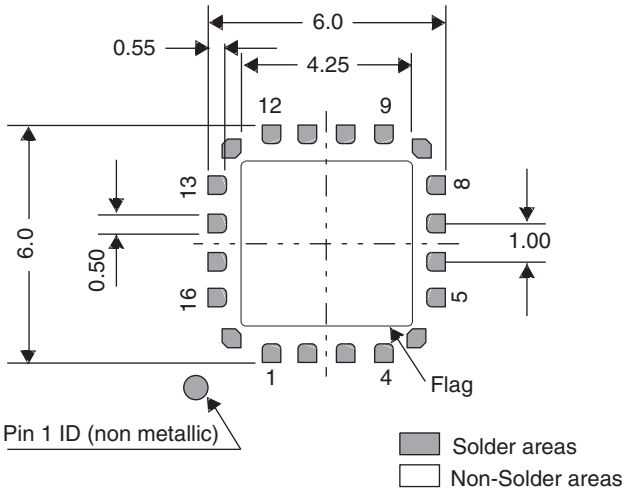
* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.



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RoHS

±2.5g - 10g Two Axis Low-g Micromachined Accelerometer

The MMA6281QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (2.5g/3.3g/6.7g/10g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- Fast Turn On Time
- High Sensitivity (2.5 g)
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Environmentally Preferred Package
- Low Cost

Typical Applications

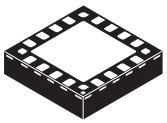
- Portable Applications: Tilt Monitoring Anti-Theft
- Vibration Monitoring and Recording: Appliance Balance, Seismic, Smart Motors)
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing
- Impact Monitoring (Shipping, Handling, Black Box Event Recorder)

ORDERING INFORMATION			
Device	**Temp. Range**	**Case No.**	**Package**
MMA6281QT	– 20 to +85°C	1622-02	QFN-16, Tray
MMA6281QR2	– 20 to +85°C	1622-02	QFN-16,Tape & Reel

MMA6281QT

MMA6281QT: XZ AXIS ACCELEROMETER ±2.5g/3.3g/6.7g/10g

Bottom View



16-LEAD QFN CASE 1622-02

Top View

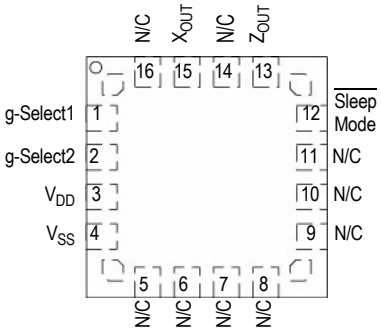


Figure 1. Pin Connections

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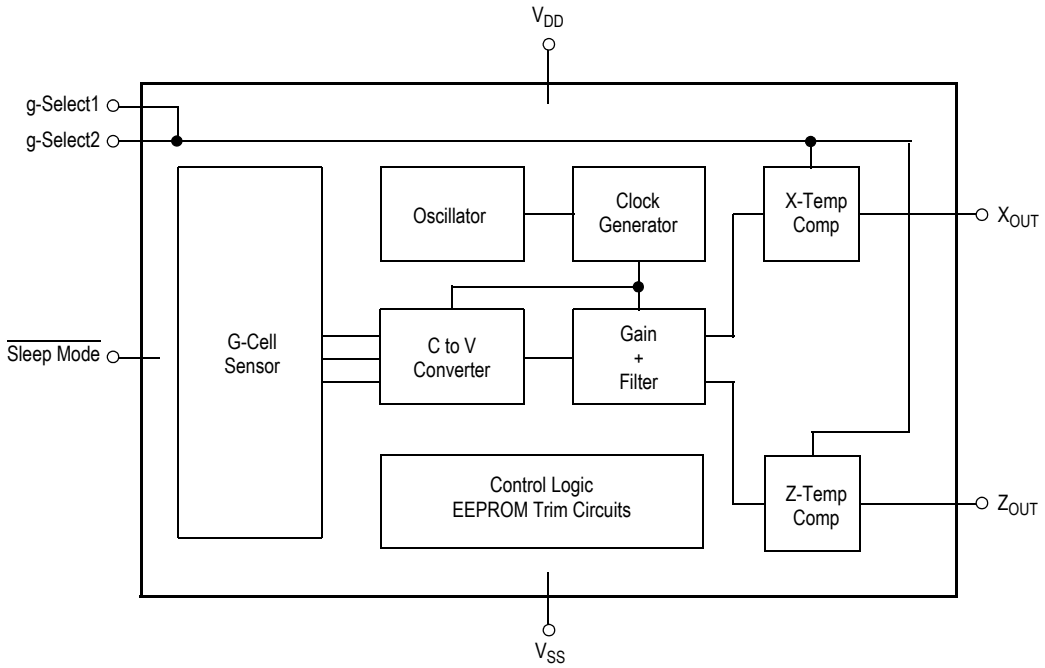

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings

(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	μA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	μA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Z-Axis					
g-Select1 & 2: 00	g_{FS}	—	±2.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±3.3	—	g
g-Select1 & 2: 01	g_{FS}	—	±6.7	—	g
g-Select1 & 2: 11	g_{FS}	—	±10.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±2	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
2.5g	$S_{2.5g}$	444	480	516	mV/g
3.3g	$S_{3.3g}$	333	360	387	mV/g
6.7g	$S_{6.7g}$	167	180	193	mV/g
10g	S_{10g}	111	120	129	mV/g
Sensitivity[4]	S,T_A	—	±0.03	—	%/°C
Bandwidth Response					
X	f_{-3dB}	—	350	—	Hz
Z	f_{-3dB}	—	150	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	3.0	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
X	f_{GCELL}	—	6.0	—	kHz
Z	f_{GCELL}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 μA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Z_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	V_{XZ}	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 μF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 2.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (postillion) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

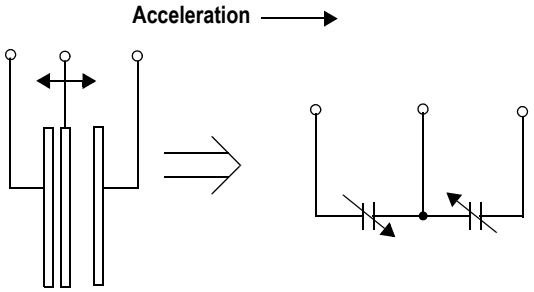

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 2.5g, 3.3g, 6.7g, or 10g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 2.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (480 mV/g).

Table 3. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	2.5g	480 mV/g
0	1	3.3g	360 mV/g
1	0	6.7g	180 mV/g
1	1	10g	120 mV/g

Sleep Mode

The 2 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3 μA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 2.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The 2 axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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Pin Descriptions

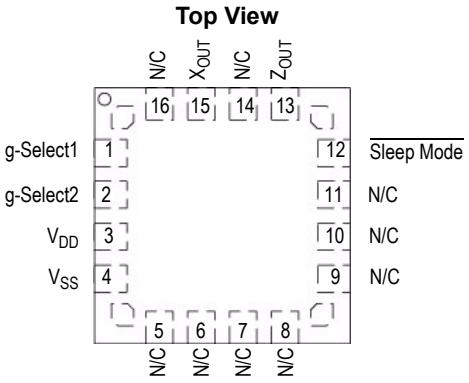

Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	$\overline{\text{Sleep Mode}}$	Logic input pin to enable product or Sleep Mode.
13	Z_{OUT}	Z direction output voltage.
14	N/C	No internal connection. Leave unconnected.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

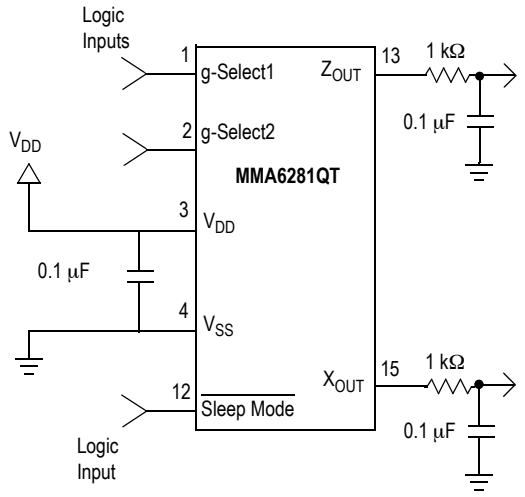

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

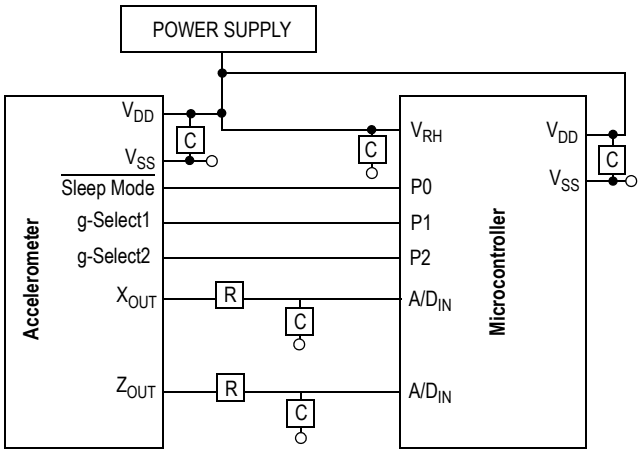

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF on V_{DD}-GND.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
7. Accelerometer and microcontroller should not be a high current path.
8. A/D sampling rate and any external power supply switching frequency should be selected such that they do not interfere with the internal accelerometer sampling frequency (11 kHz for the sampling frequency). This will prevent aliasing errors.
9. PCB layout should not run traces or vias under the QFN part. This could lead to ground shorting to the accelerometer flag.

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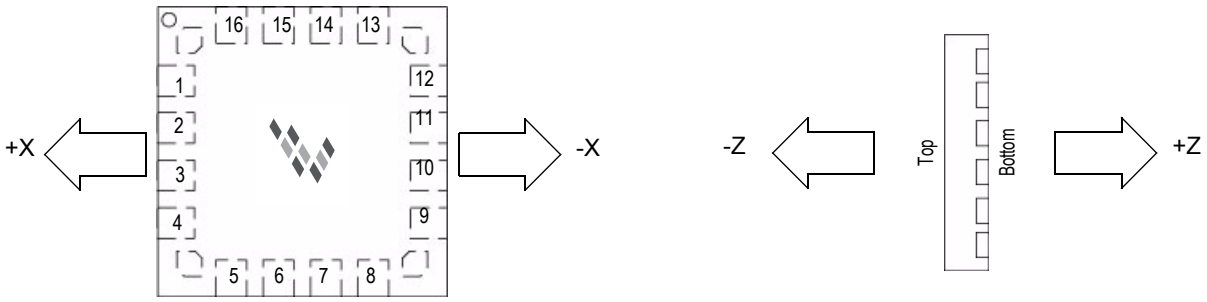
DYNAMIC ACCELERATION

Top View

Top View

Side View



16-Pin QFN Package

: Arrow indicates direction of mass movement.

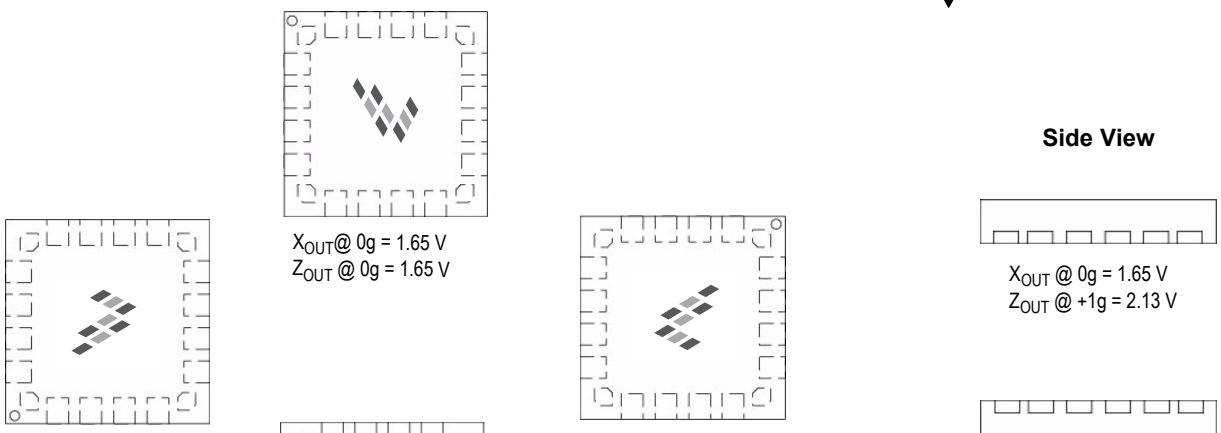
STATIC ACCELERATION

In 2.5g mode

Direction of Earth's gravity field.*

Top View

Side View



X_{OUT}@ 0g = 1.65 V
Z_{OUT} @ 0g = 1.65 V

X_{OUT} @ +1g = 2.13 V
Z_{OUT} @ 0g = 1.65 V

X_{OUT} @ -1g = 1.17 V
Z_{OUT} @ 0g = 1.65 V

X_{OUT} @ 0g = 1.65 V
Z_{OUT} @ +1g = 2.13 V

X_{OUT} @ 0g = 1.65 V
Z_{OUT} @ 0g = 1.65 V

X_{OUT} @ 0g = 1.65 V
Z_{OUT} @ -1g = 1.17 V

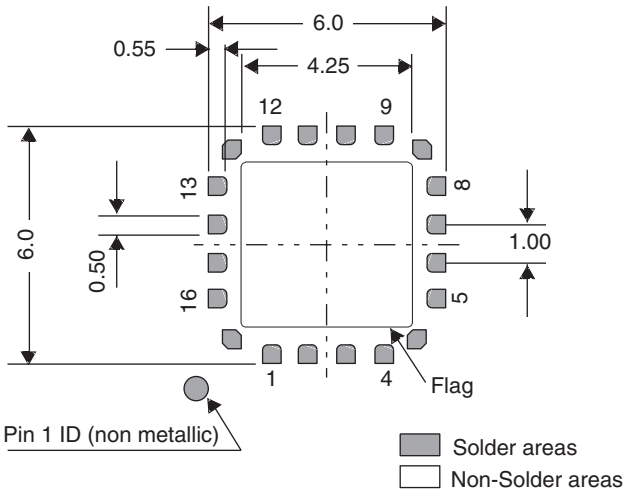
* When positioned as shown, the Earth's gravity will result in a positive 1g output.

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package.

With the correct footprint, the packages will self-align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.



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RoHS

±1.5g - 6g Three Axis Low-g Micromachined Accelerometer

The MMA7260QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (1.5g/2g/4g/6g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- High Sensitivity (800 mV/g @ 1.5g)
- Fast Turn On Time
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Pb-Free Terminations
- Environmentally Preferred Package
- Low Cost

Typical Applications

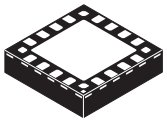
- HDD MP3 Player: Freefall Detection
- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Package Drawing**	**Package**
MMA7260QT	–20 to +85°C	1622-02	QFN-16, Tray
MMA7260QR2	–20 to +85°C	1622-02	QFN-16,Tape & Reel

MMA7260QT

MMA7260QT: XYZ AXIS ACCELEROMETER ±1.5g/2g/4g/6g

Bottom View



16 LEAD QFN CASE 1622-02

Top View

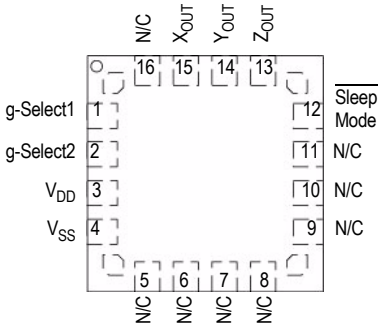


Figure 1. Pin Connections

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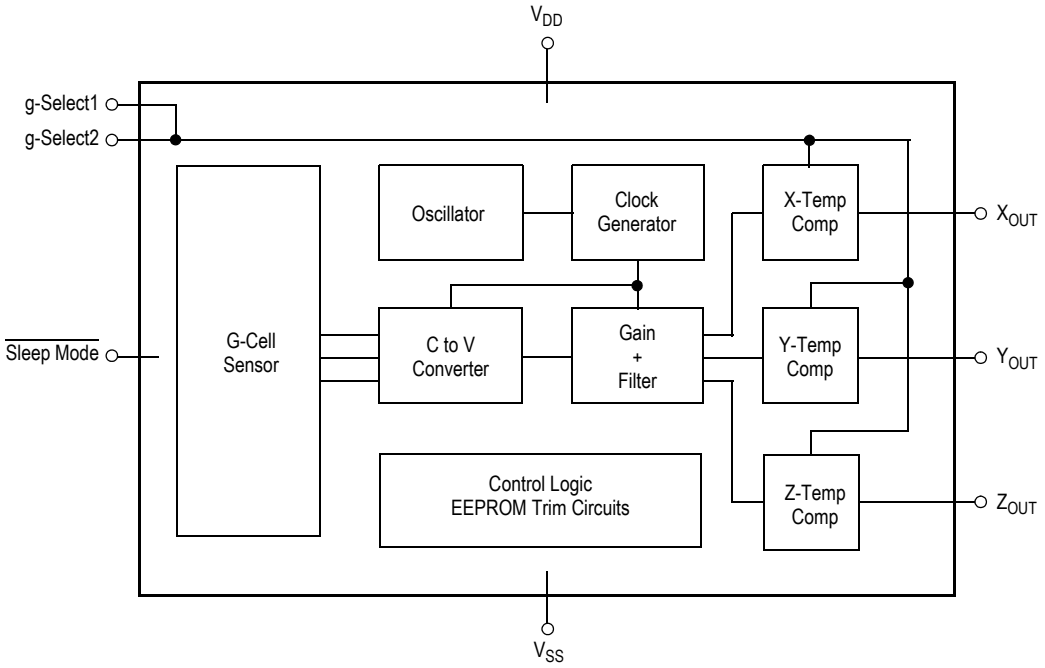

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	μA
Supply Current at Sleep Mode[4]	I_{DD}	—	3.0	10	μA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Y-Axis, Z-Axis					
g-Select1 & 2: 00	g_{FS}	—	±1.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±2.0	—	g
g-Select1 & 2: 01	g_{FS}	—	±4.0	—	g
g-Select1 & 2: 11	g_{FS}	—	±6.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±2.0	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
1.5g	$S_{1.5g}$	740	800	860	mV/g
2g	S_{2g}	555	600	645	mV/g
4g	S_{4g}	277.5	300	322.5	mV/g
6g	S_{6g}	185	200	215	mV/g
Sensitivity[4]	S,T_A	—	±0.03	—	%/°C
Bandwidth Response					
XY	f_{-3dB}	—	350	—	Hz
Z	f_{-3dB}	—	150	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	4.7	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
XY	f_{GCELL}	—	6.0	—	kHz
Z	f_{GCELL}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 μA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Y_{OUT}, Z_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	$V_{XY, XZ, YZ}$	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 μF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 1.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (polysilicon) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

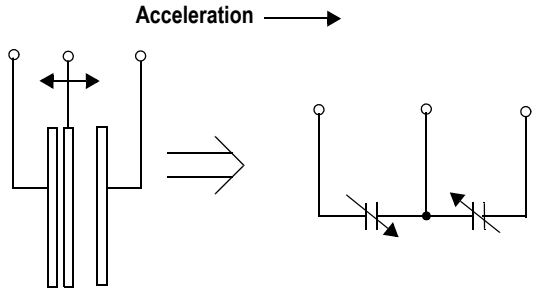

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 1.5g, 2g, 4g, or 6g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 1.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (800mV/g).

Table 3. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800 mV/g
0	1	2g	600 mV/g
1	0	4g	300 mV/g
1	1	6g	200 mV/g

Sleep Mode

The 3 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3 μA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 1.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The 3 axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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Pin Descriptions

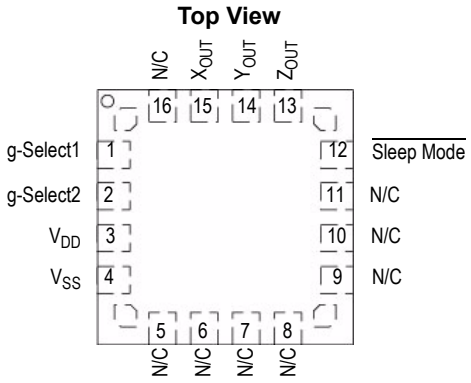

Figure 4. Pinout Description

Table 4. Pin Descriptions

Pin No.	Pin Name	Description
1	g-Select1	Logic input pin to select g level.
2	g-Select2	Logic input pin to select g level.
3	V_{DD}	Power Supply Input
4	V_{SS}	Power Supply Ground
5 - 7	N/C	No internal connection. Leave unconnected.
8 - 11	N/C	Unused for factory trim. Leave unconnected.
12	$\overline{\text{Sleep Mode}}$	Logic input pin to enable product or Sleep Mode.
13	Z_{OUT}	Z direction output voltage.
14	Y_{OUT}	Y direction output voltage.
15	X_{OUT}	X direction output voltage.
16	N/C	No internal connection. Leave unconnected.

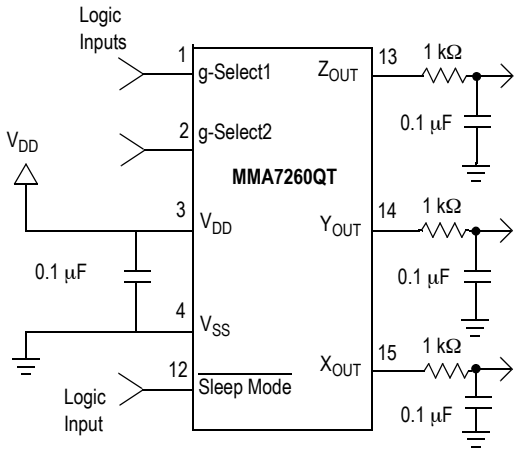

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

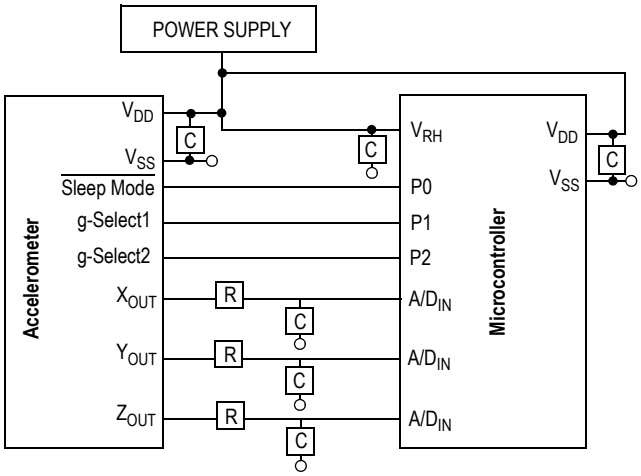

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
3. The flag underneath the package is internally connected to ground. It is not recommended for the flag to be soldered down.
4. Place a ground plane beneath the accelerometer to reduce noise, the ground plane should be attached to all of the open ended terminals shown in Figure 6.
5. Use an RC filter with 1.0 kΩ and 0.1 µF on the outputs of the accelerometer to minimize clock noise (from the switched capacitor filter circuit).
6. PCB layout of power and ground should not couple power supply noise.
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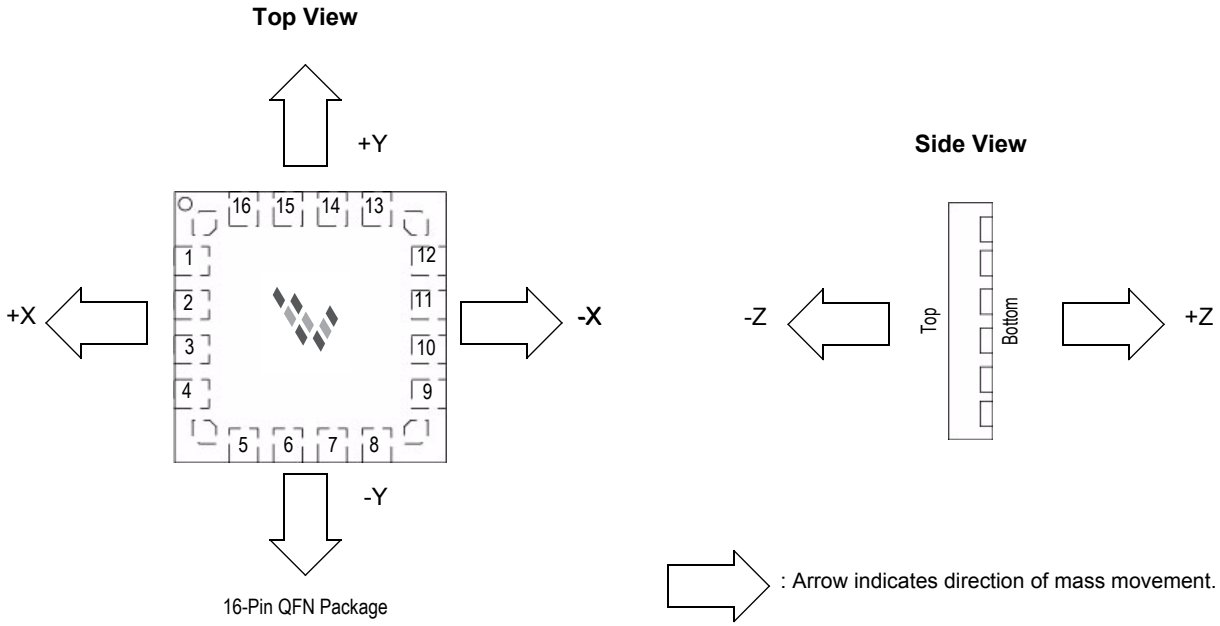
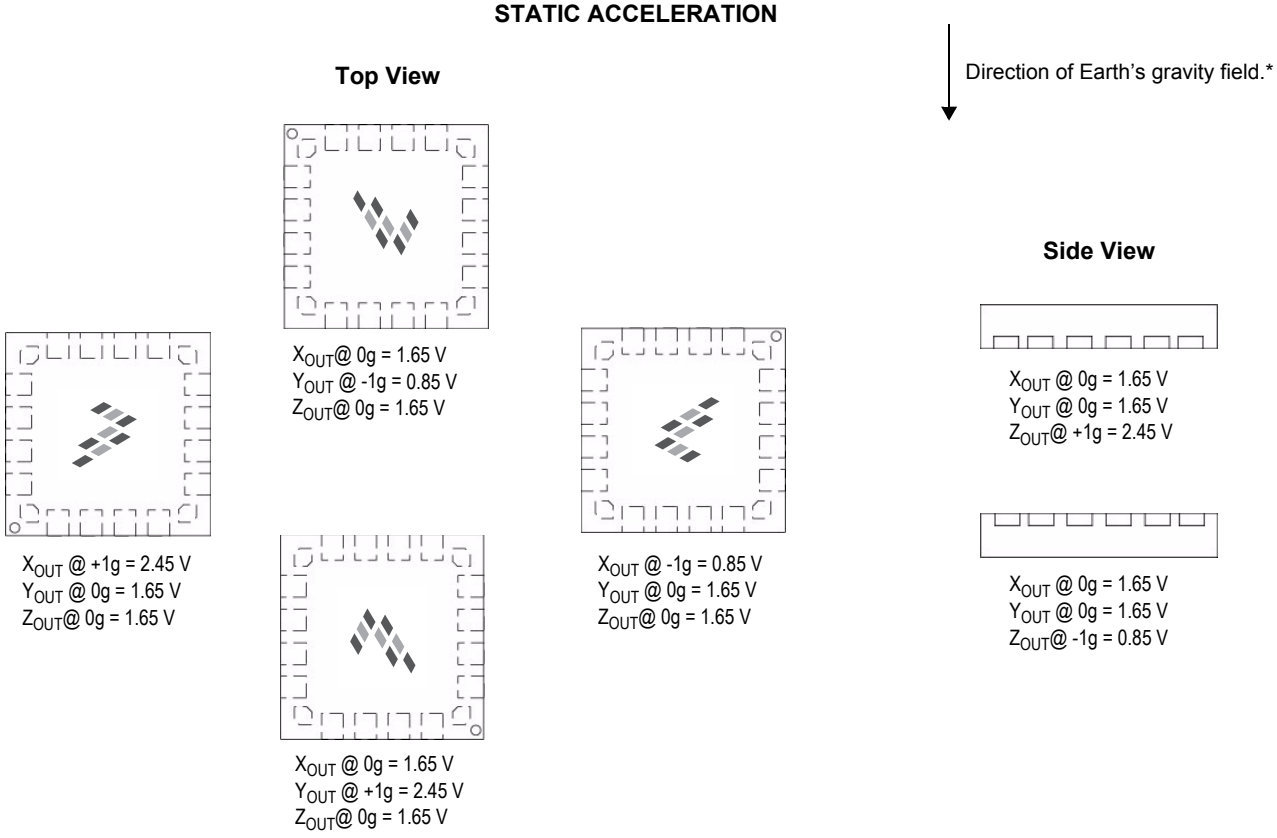
DYNAMIC ACCELERATION



STATIC ACCELERATION



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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

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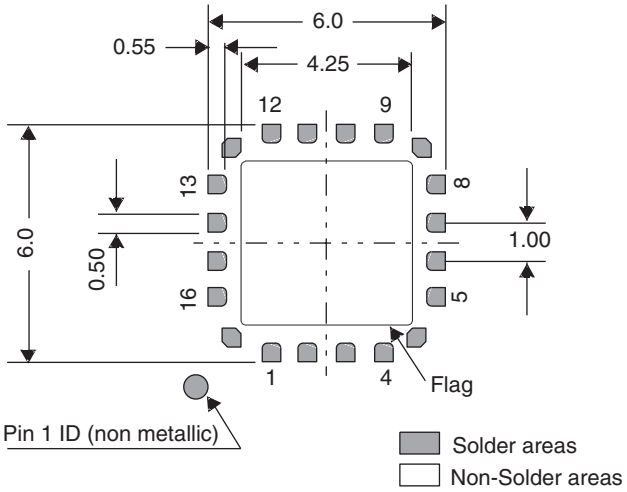

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RoHS

±2.5g - 10g Three Axis Low-g Micromachined Accelerometer

The MMA7261QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter, temperature compensation and g-Select which allows for the selection among 4 sensitivities. Zero-g offset full scale span and filter cut-off are factory set and require no external devices. Includes a Sleep Mode that makes it ideal for handheld battery powered electronics.

Features

- Selectable Sensitivity (2.5g/3.3g/6.7g/10g)
- Low Current Consumption: 500 μA
- Sleep Mode: 3 μA
- Low Voltage Operation: 2.2 V – 3.6 V
- 6mm x 6mm x 1.45mm QFN
- Fast Turn On Time
- High Sensitivity (2.5 g)
- Integral Signal Conditioning with Low Pass Filter
- Robust Design, High Shocks Survivability
- Environmentally Preferred Package
- Low Cost

Typical Applications

- HDD MP3 Player: Freefall Detection
- Laptop PC: Freefall Detection, Anti-Theft
- Cell Phone: Image Stability, Text Scroll, Motion Dialing, E-Compass
- Pedometer: Motion Sensing
- PDA: Text Scroll
- Navigation and Dead Reckoning: E-Compass Tilt Compensation
- Gaming: Tilt and Motion Sensing, Event Recorder
- Robotics: Motion Sensing

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Package Drawing**	**Package**
MMA7261QT	– 20 to +85°C	1622-02	QFN-16, Tray
MMA7261QR2	– 20 to +85°C	1622-02	QFN-16,Tape & Reel

MMA7261QT

MMA7261QT: XYZ AXIS ACCELEROMETER ±2.5g/3.3g/6.7g/10g

Bottom View

16-LEAD QFN CASE 1622-02

Top View

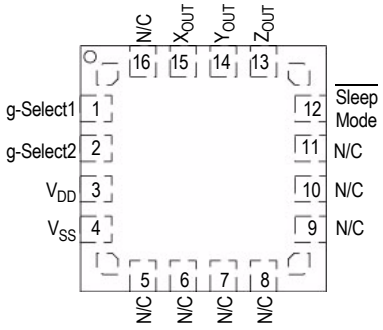

Figure 1. Pin Connections

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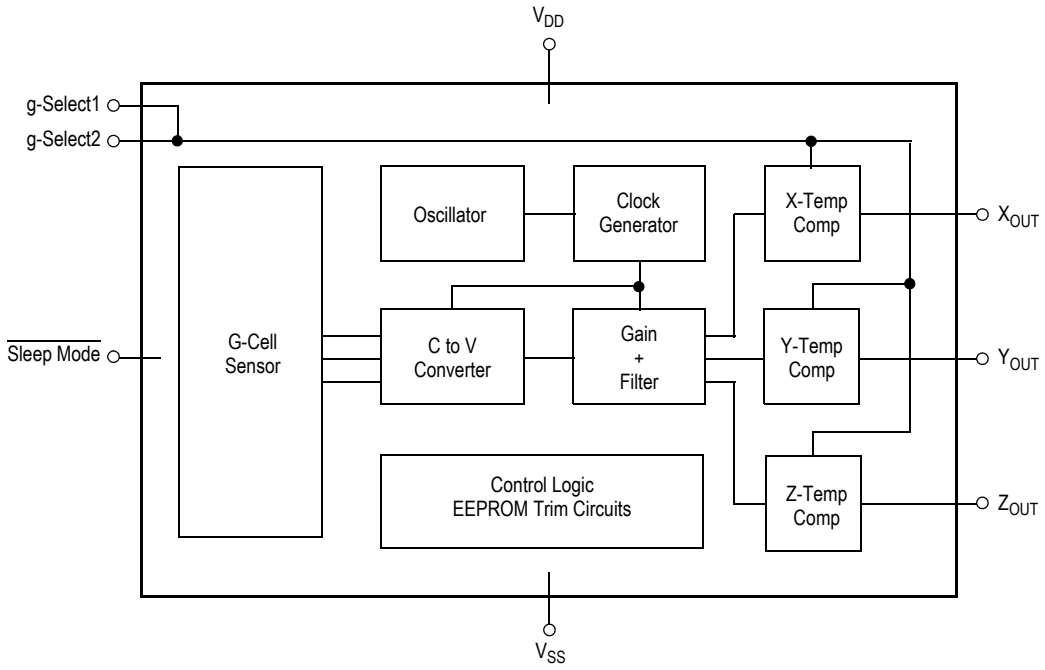

Figure 2. Simplified Accelerometer Functional Block Diagram

Table 1. Maximum Ratings
(Maximum ratings are the limits to which the device can be exposed without causing permanent damage.)

Rating	Symbol	Value	Unit
Maximum Acceleration (all axis)	g_{max}	±2000	g
Supply Voltage	V_{DD}	–0.3 to +3.6	V
Drop Test(1)	D_{drop}	1.8	m
Storage Temperature Range	T_{stg}	–40 to +125	°C

1. Dropped onto concrete surface from any axis.

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Although the Freescale accelerometer contains internal 2000 V ESD protection circuitry, extra precaution must be taken by the user to protect the chip from ESD. A charge of over 2000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the accelerometer, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

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Table 2. Operating Characteristics

Unless otherwise noted: –20°C ≤ T_A ≤ 85°C, 2.2 V ≤ V_{DD} ≤ 3.6 V, Acceleration = 0g, Loaded output[1]

Characteristic	Symbol	Min	Typ	Max	Unit
Operating Range[2]					
Supply Voltage[3]	V_{DD}	2.2	3.3	3.6	V
Supply Current	I_{DD}	—	500	800	μA
Supply Current at Sleep Mode[4]	I_{DD}	—	3	10	μA
Operating Temperature Range	T_A	–20	—	+85	°C
Acceleration Range, X-Axis, Y-Axis, Z-Axis					
g-Select1 & 2: 00	g_{FS}	—	±2.5	—	g
g-Select1 & 2: 10	g_{FS}	—	±3.3	—	g
g-Select1 & 2: 01	g_{FS}	—	±6.7	—	g
g-Select1 & 2: 11	g_{FS}	—	±10.0	—	g
Output Signal					
Zero g (T_A = 25°C, V_{DD} = 3.3 V)[5]	V_{OFF}	1.485	1.65	1.815	V
Zero g[4]	V_{OFF}, T_A	—	±5	—	mg/°C
Sensitivity (T_A = 25°C, V_{DD} = 3.3 V)					
2.5g	$S_{2.5g}$	444	480	516	mV/g
3.3g	$S_{3.3g}$	333	360	387	mV/g
6.7g	$S_{6.7g}$	167	180	193	mV/g
10g	S_{10g}	111	120	129	mV/g
Sensitivity[4]	S,T_A	—	±0.03	—	%/°C
Bandwidth Response					
XY	f_{-3dB}	—	350	—	Hz
Z	f_{-3dB}	—	150	—	Hz
Noise					
RMS (0.1 Hz – 1 kHz)[4]	n_{RMS}	—	4.7	—	mVrms
Power Spectral Density RMS (0.1 Hz – 1 kHz)[4]	n_{PSD}	—	350	—	$\mu g/\sqrt{Hz}$
Control Timing					
Power-Up Response Time[6]	$t_{RESPONSE}$	—	1.0	2.0	ms
Enable Response Time[7]	t_{ENABLE}	—	0.5	2.0	ms
Sensing Element Resonant Frequency					
XY	f_{GCELL}	—	6.0	—	kHz
Z	f_{GCELL}	—	3.4	—	kHz
Internal Sampling Frequency	f_{CLK}	—	11	—	kHz
Output Stage Performance					
Full-Scale Output Range (I_{OUT} = 30 μA)	V_{FSO}	V_{SS}+0.25	—	V_{DD}–0.25	V
Nonlinearity, X_{OUT}, Y_{OUT}, Z_{OUT}	NL_{OUT}	–1.0	—	+1.0	%FSO
Cross-Axis Sensitivity[8]	$V_{XY, XZ, YZ}$	—	—	5.0	%

1. For a loaded output, the measurements are observed after an RC filter consisting of a 1.0 kΩ resistor and a 0.1 μF capacitor on V_{DD}-GND.
2. These limits define the range of operation for which the part will meet specification.
3. Within the supply range of 2.2 and 3.6 V, the device operates as a fully calibrated linear accelerometer. Beyond these supply limits the device may operate as a linear device but is not guaranteed to be in calibration.
4. This value is measured with g-Select in 2.5g mode.
5. The device can measure both + and – acceleration. With no input acceleration the output is at midsupply. For positive acceleration the output will increase above V_{DD}/2. For negative acceleration, the output will decrease below V_{DD}/2.
6. The response time between 10% of full scale Vdd input voltage and 90% of the final operating output voltage.
7. The response time between 10% of full scale Sleep Mode input voltage and 90% of the final operating output voltage.
8. A measure of the device's ability to reject an acceleration applied 90° from the true axis of sensitivity.

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PRINCIPLE OF OPERATION

The Freescale accelerometer is a surface-micromachined integrated-circuit accelerometer.

The device consists of two surface micromachined capacitive sensing cells (g-cell) and a signal conditioning ASIC contained in a single integrated circuit package. The sensing elements are sealed hermetically at the wafer level using a bulk micromachined cap wafer.

The g-cell is a mechanical structure formed from semiconductor materials (postillion) using semiconductor processes (masking and etching). It can be modeled as a set of beams attached to a movable central mass that move between fixed beams. The movable beams can be deflected from their rest position by subjecting the system to an acceleration (Figure 3).

As the beams attached to the central mass move, the distance from them to the fixed beams on one side will increase by the same amount that the distance to the fixed beams on the other side decreases. The change in distance is a measure of acceleration.

The g-cell beams form two back-to-back capacitors (Figure 3). As the center beam moves with acceleration, the distance between the beams changes and each capacitor's value will change, ($C = A\varepsilon/D$). Where A is the area of the beam, ε is the dielectric constant, and D is the distance between the beams.

The ASIC uses switched capacitor techniques to measure the g-cell capacitors and extract the acceleration data from the difference between the two capacitors. The ASIC also signal conditions and filters (switched capacitor) the signal, providing a high level output voltage that is ratiometric and proportional to acceleration.

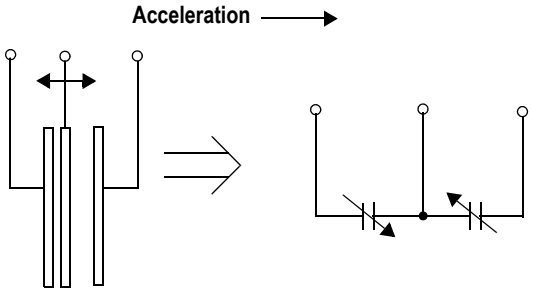

Figure 3. Simplified Transducer Physical Model

SPECIAL FEATURES

g-Select

The g-Select feature allows for the selection among 4 sensitivities present in the device. Depending on the logic input placed on pins 1 and 2, the device internal gain will be changed allowing it to function with a 2.5g, 3.3g, 6.7g, or 10g sensitivity (Table 3). This feature is ideal when a product has applications requiring different sensitivities for optimum performance. The sensitivity can be changed at anytime during the operation of the product. The g-Select1 and g-Select2 pins can be left unconnected for applications requiring only a 2.5g sensitivity as the device has an internal pull-down to keep it at that sensitivity (480mV/g).

Table 3. g-Select pin Descriptions

g-Select2	g-Select1	g-Range	Sensitivity
0	0	2.5g	480mV/g
0	1	3.3g	360mV/g
1	0	6.7g	180mV/g
1	1	10g	120mV/g

Sleep Mode

The 3 axis accelerometer provides a Sleep Mode that is ideal for battery operated products. When Sleep Mode is active, the device outputs are turned off, providing significant reduction of operating current. A low input signal on pin 12 (Sleep Mode) will place the device in this mode and reduce the current to 3uA typ. For lower power consumption, it is recommended to set g-Select1 and g-Select2 to 2.5g mode. By placing a high input signal on pin 12, the device will resume to normal mode of operation.

Filtering

The 3 axis accelerometer contains onboard single-pole switched capacitor filters. Because the filter is realized using switched capacitor techniques, there is no requirement for external passive components (resistors and capacitors) to set the cut-off frequency.

Ratiometricity

Ratiometricity simply means the output offset voltage and sensitivity will scale linearly with applied supply voltage. That is, as supply voltage is increased, the sensitivity and offset increase linearly; as supply voltage decreases, offset and sensitivity decrease linearly. This is a key feature when interfacing to a microcontroller or an A/D converter because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

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BASIC CONNECTIONS

Pin Descriptions

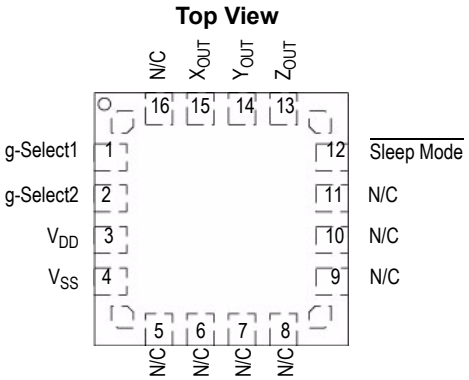

Figure 4. Pinout Description

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Pin No.	Pin Name	Description
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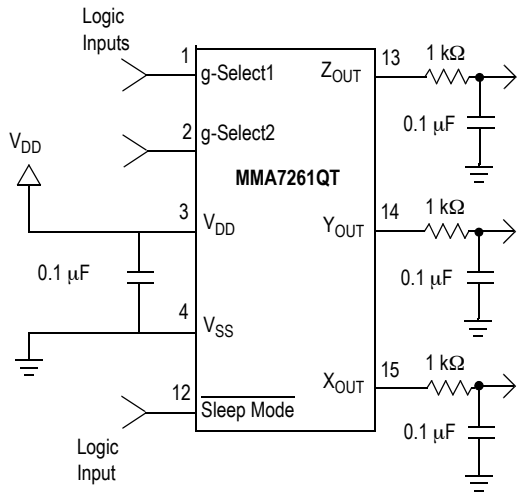

Figure 5. Accelerometer with Recommended Connection Diagram

PCB Layout

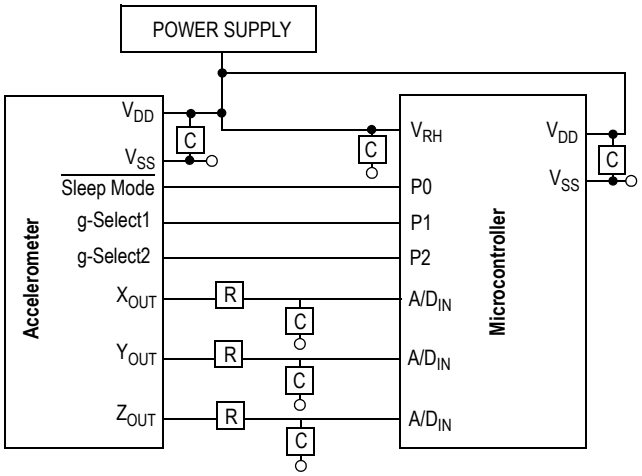

Figure 6. Recommended PCB Layout for Interfacing Accelerometer to Microcontroller

NOTES:

1. Use 0.1 µF capacitor on V_{DD} to decouple the power source. Do not exceed capacitor values of 2.2 or 3.3 µF on V_{DD}-GND.
2. Physical coupling distance of the accelerometer to the microcontroller should be minimal.
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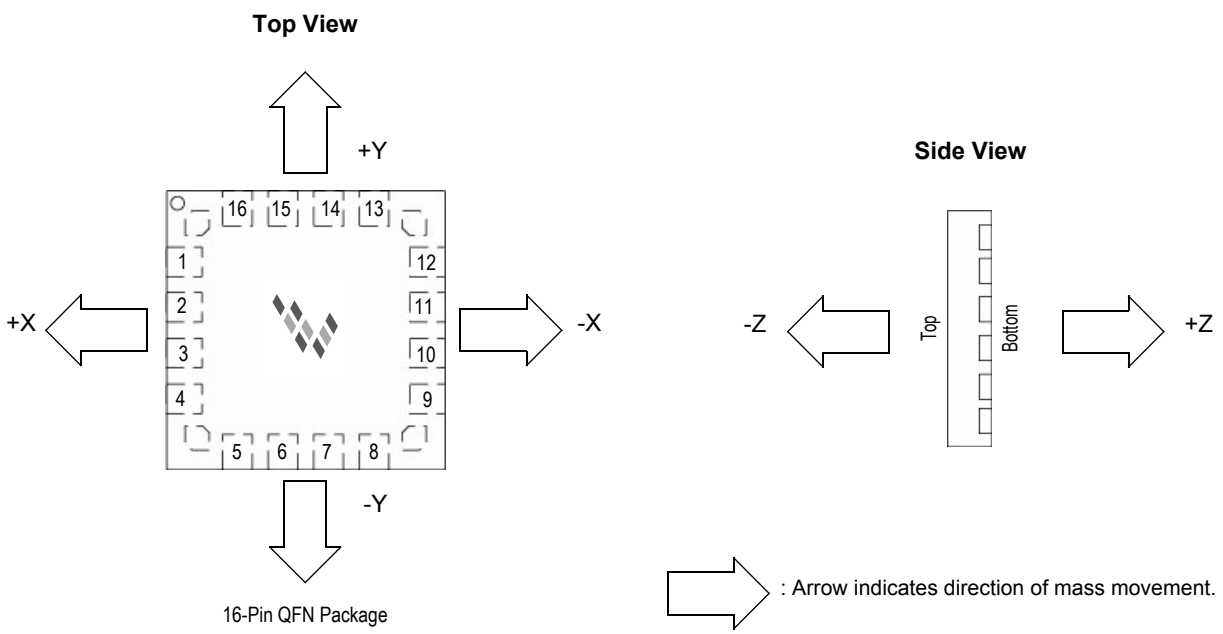
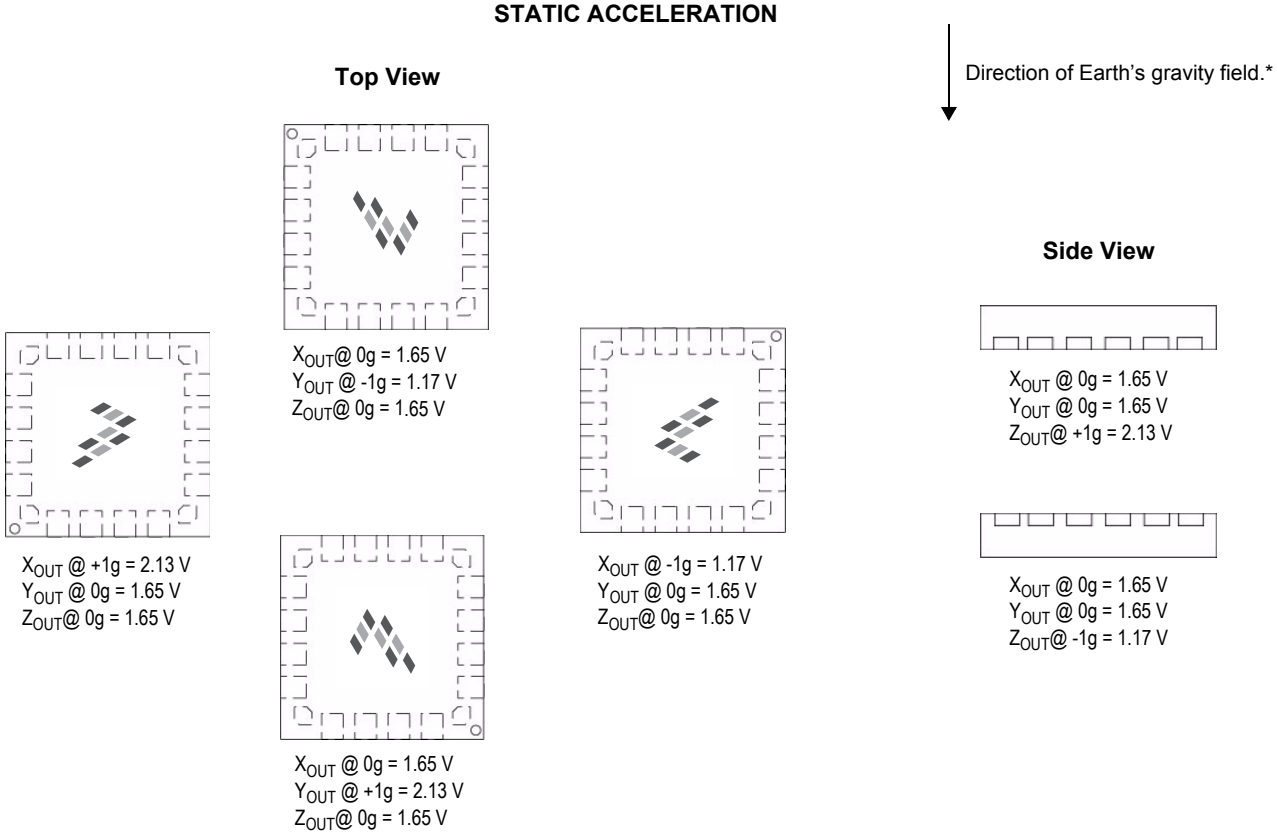
DYNAMIC ACCELERATION



16-Pin QFN Package

STATIC ACCELERATION



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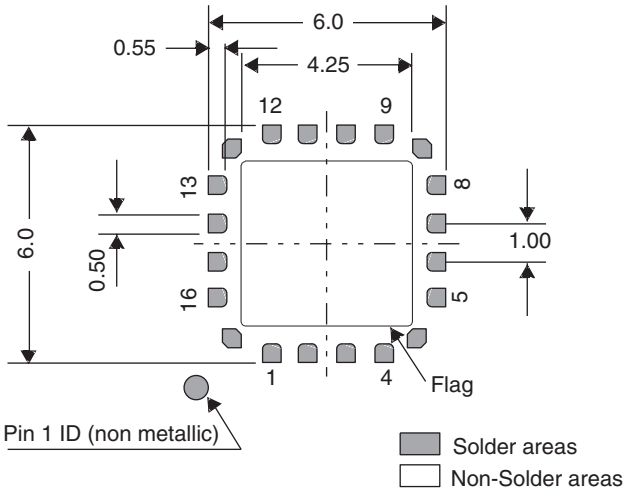

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Application Considerations for a Switched Capacitor Accelerometer

by: Wayne Chavez

INTRODUCTION

Today's low cost accelerometers are highly integrated devices employing features such as signal conditioning, filtering, offset compensation and self test. Combining this feature set with economical plastic packaging requires that the signal conditioning circuitry be as small as possible. One approach is to implement sampled data system and switched capacitor techniques as in the Freescale accelerometer.

As in all sampled data systems, precautions should be taken to avoid signal aliasing errors. This application note describes the accelerometer and how signal aliasing can be introduced and more importantly minimized.

BACKGROUND

What is aliasing? Simply put, aliasing is the effect of sampling a signal at an insufficient rate, thus creating another signal at a frequency that is the difference between the original signal frequency and the sampling rate. A graphical explanation of aliasing is offered in Figure 1. In this figure, the upper trace shows a 50 kHz sinusoidal waveform. Note that when sampled at a 45 kHz rate, denoted by the boxes, a sinusoidal pattern is formed. Lowpass filtering the sampled points, to create a continuous signal, produces the 5 kHz waveform shown in Figure 1 (lower). (The phase shift in the lower figure is due to the low-pass filter).

Aliased signals, like the one in Figure 1 (lower) are often unintentionally produced. Signal processing techniques are well understood and sampling rates are chosen appropriately (i.e. Nyquist criteria). However, the assumption is that the signals of interest are well characterized and have a limited bandwidth. This assumption is not always true, as in the case of wideband noise.

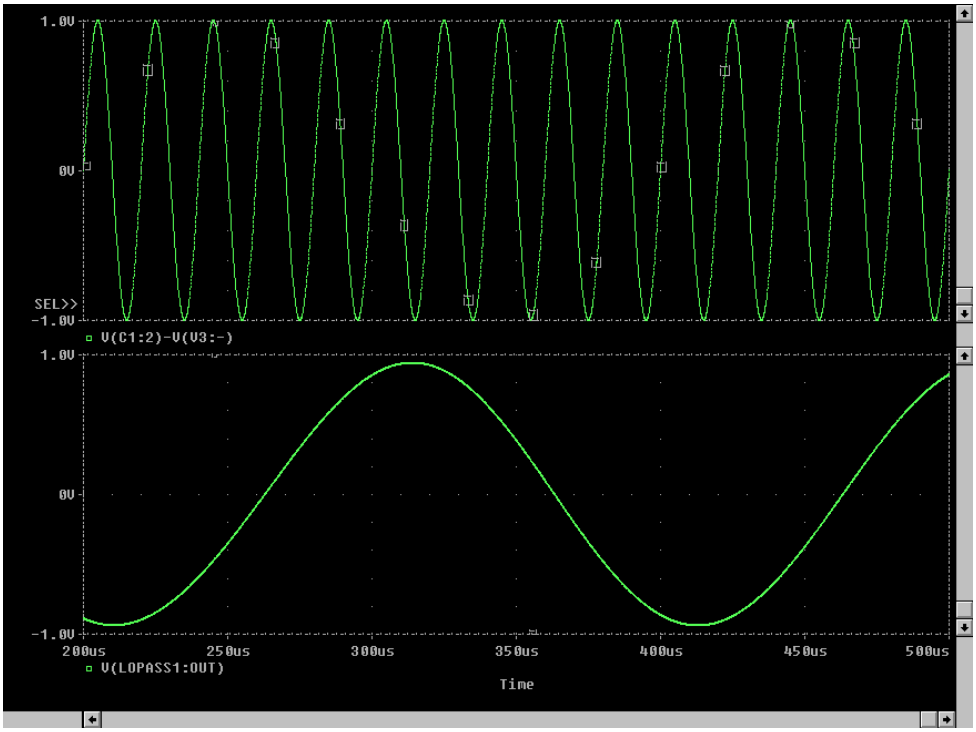

Figure 1. Aliased Signals

Given the brief example on how aliasing can occur, how does the accelerometer relate to aliasing? To answer this question, a brief summary on how the accelerometer works is in order.

The accelerometer is a two chip acceleration sensing solution. The first chip is the acceleration transducer, termed G-Cell, constructed by Micro Electro-Mechanical Systems (MEMS) technology. The G-Cell is a two capacitor element where the capacitors are in series and share a common center plate. The deflection in the center plate changes the capacitance of each capacitor which is measured by the second chip, termed control chip.

The control chip performs the signal conditioning (amplification, filtering, offset level shift) function in the system. This chip measures the G-Cell output using switched capacitor techniques. By the nature of switched cap techniques, the system is a sampled data system operating at sampling frequency f_s. The filter is switched capacitor, 4-pole Bessel implementation with a -3 dB frequency of 400 Hz.

As a sampled data system, the accelerometer is not immune to signal aliasing. However, given the accelerometer's internal filter, aliased signals will only appear in the output passband when input signals are in the range $| n \bullet f_s - f_{signal} | \leq f_{BW}$. Where f_s is the sampling rate, f_{Signal} is the input signal frequency, f_{BW} is the filter bandwidth and n is a positive integer to account for all harmonics. The graphical representation is shown in Figure 2. The bounds can be extended beyond f_{BW} to ensure an alias free output.

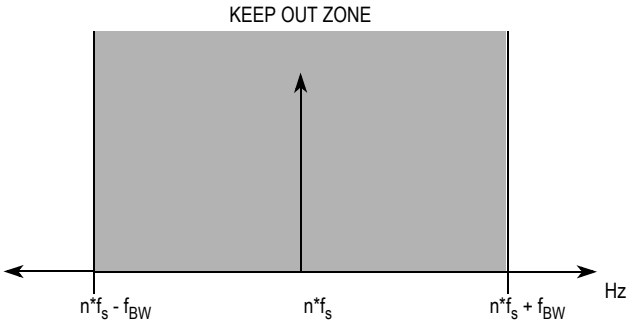

Figure 2. Input Signal Frequency Range Where a Signal Will Be Produced in the Output Passband

ACCELEROMETER INPUT SIGNALS

The accelerometer is a ratiometric electro-mechanical transducer. Therefore, the input signals to the device are the acceleration and the input power source.

The acceleration input is limited in frequency bandwidth by the geometry of the sensing, packaging, and mounting structures that define the resonant frequency and response. This response is in the range of 10 kHz, however, the practical range is less than 600 Hz for most mechanical systems. Therefore, aliasing an acceleration signal is unlikely.

The power input signal is ideally dc. However, depending on the application system architecture, the power supply line can be riddled with high frequency components. For example, dc to dc converters can operate with switching frequencies between 20 kHz and 200 kHz. This range encompasses the sampling rate of the accelerometer and point to the power source as the culprit in producing aliased signal.

DEMONSTRATION OF ALIASING

Under zero acceleration conditions a 100 mV_{rms} signal was injected onto the power supply line of 5.0 Vdc. The frequency of the injected signal was tuned in to produce an alias in the accelerometer's passband. Figure 3 and Figure 4 show the difference in output when a high frequency signal is not and is present on the V_{CC} pin of the accelerometer.

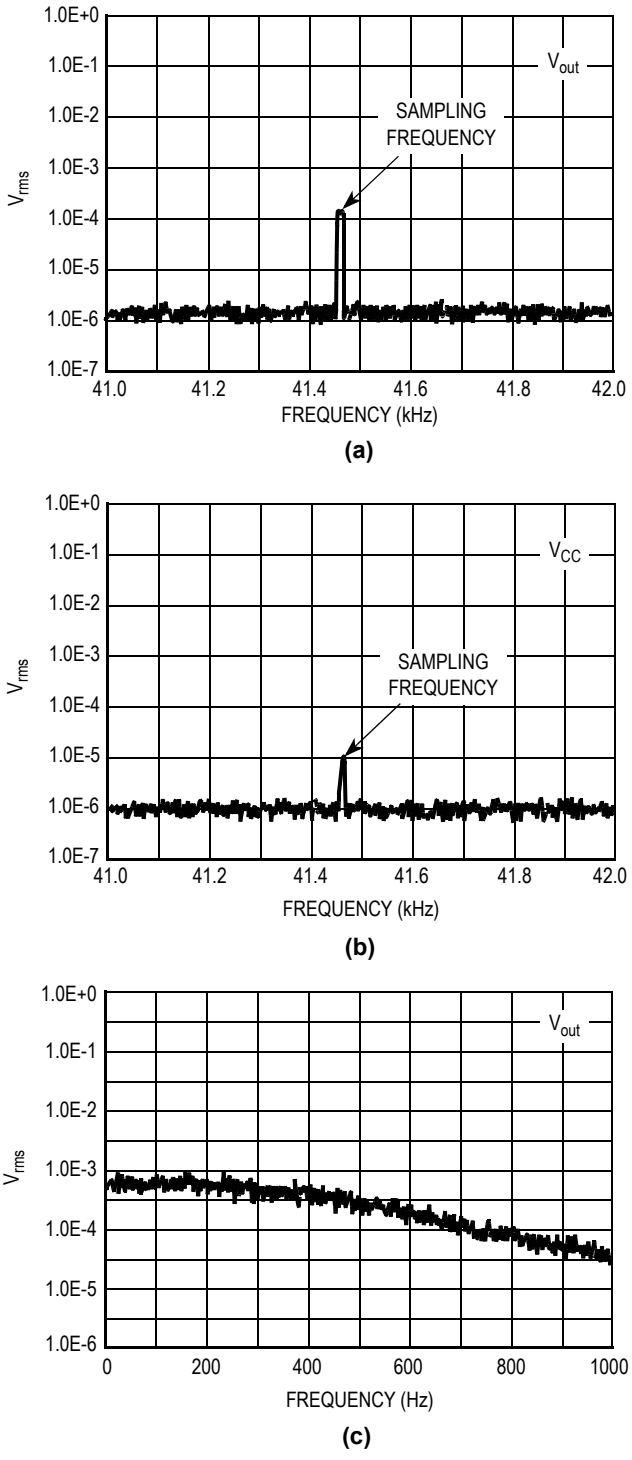

Figure 3. Normal Waveforms

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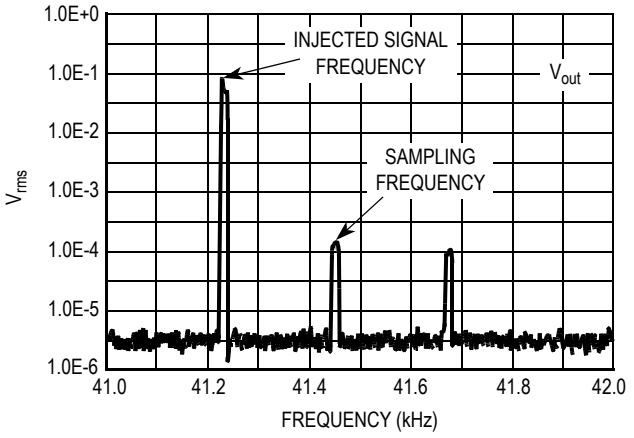
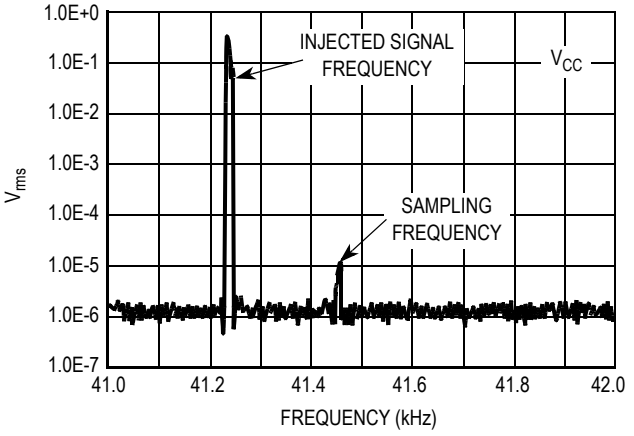
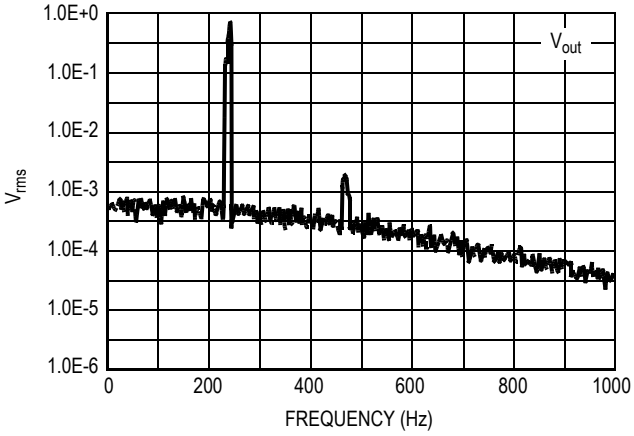


(a)



(b)



(c)

Figure 4. Aliasing Comparison

Points to Note:

- Under clean dc bias, V_{out} and V_{CC}, Figure 3a and Figure 3b have a signal component at the sampling rate. This is due to switched capacitor currents coupling through finite power supply source impedances and PCB paracitics.
- The low frequency output spectrum, Figure 3c, displays the internal lowpass filter characteristics. (The filter and sampling characteristics are sometimes useful in system debugging.)
- When an ac component is superimposed onto V_{CC} near the sampling frequency, as shown in Figure 4b, the output will contain the original signal plus a mirrored signal about the sampling frequency, shown in Figure 4a. Signals on the V_{CC} line will appear at the output due to the ratiometric characteristic of the accelerometer and will be one half the amplitude.
- As a result of sampling, the output waveform of Figure 4c is produced where the injected high frequency signal has now produced a signal in the passband.
- Harmonics of the aliased signal in the pass band are also shown in Figure 4c.
- Aliased signals in the passband will be amplified versions of the injected signals. This is due to the signal conditioning circuitry in the accelerometer that includes gain.

ALIASING AVOIDANCE KEYS

- Use a linear regulated power source when feasible. Linear regulators have excellent power supply rejection offering a stable dc source.
- If using a switching power supply, ensure that the switching frequency is not close to the accelerometer sampling frequency or its harmonics. Noting that the accelerometer will gain the aliasing signal, it is desirable to keep frequencies at least 4 kHz away from the sampling frequency and its harmonics. 4 kHz is one decade from the -3 dB frequency, therefore any signals will be sufficiently attenuated by the internal 4-pole lowpass filter.
- Proper bias decoupling will aid in noise reduction from other sources. With dense surface mount PCB assemblies, it is often difficult to place and route decoupling components. However, the accelerometer is not like a typical logic device. A little extra effort on decoupling goes a long way.
- Good PCB layout practices should always be followed. Proper system grounding is essential. Parasitic capacitance and inductance could prove to be troublesome, particularly during EMC testing. Signal harmonics and sub-harmonics play a significant role in introducing aliased signals. Clean layouts minimize the effects of parasitics and thus signal harmonics and sub-harmonics.

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Impact Measurement Using Accelerometers

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INTRODUCTION

This application note describes the concept of measuring impact of an object using an accelerometer, microcontroller hardware/software and a liquid crystal display. Due to the wide frequency response of the accelerometer from d.c. to 400 Hz, the device is able to measure both the static acceleration from the Earth's gravity and the shock or vibration from an impact. This design uses a 40g accelerometer and yields a minimum acceleration range of -40g to +40g.

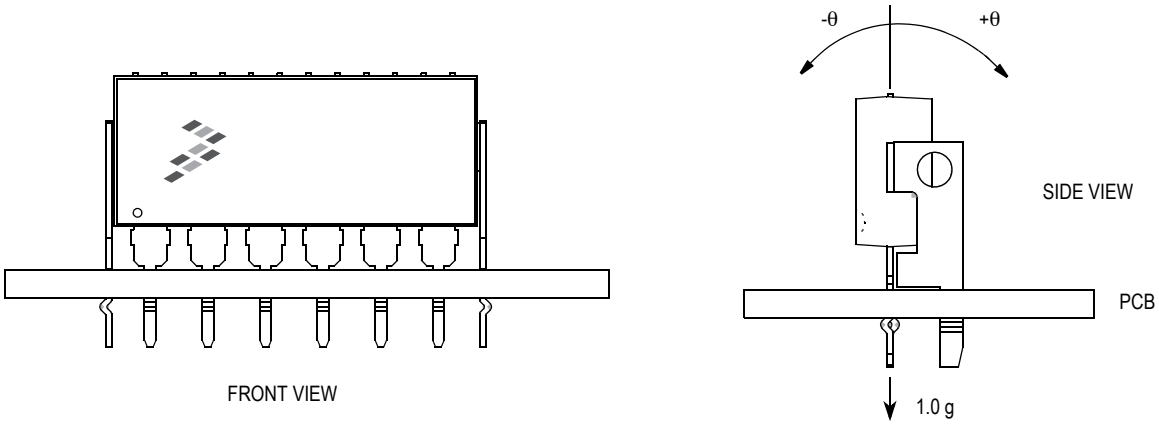

Figure 1. Orientation of Accelerometer

CONCEPT OF IMPACT MEASUREMENT

During an impact, the accelerometer will be oriented as shown in Figure 1 to measure the deceleration experienced by the object from dc to 400 Hz. Normally, the peak impact pulse is in the order of a few milliseconds. Figure 2 shows a typical crash waveform of a toy car having a stiff bumper.

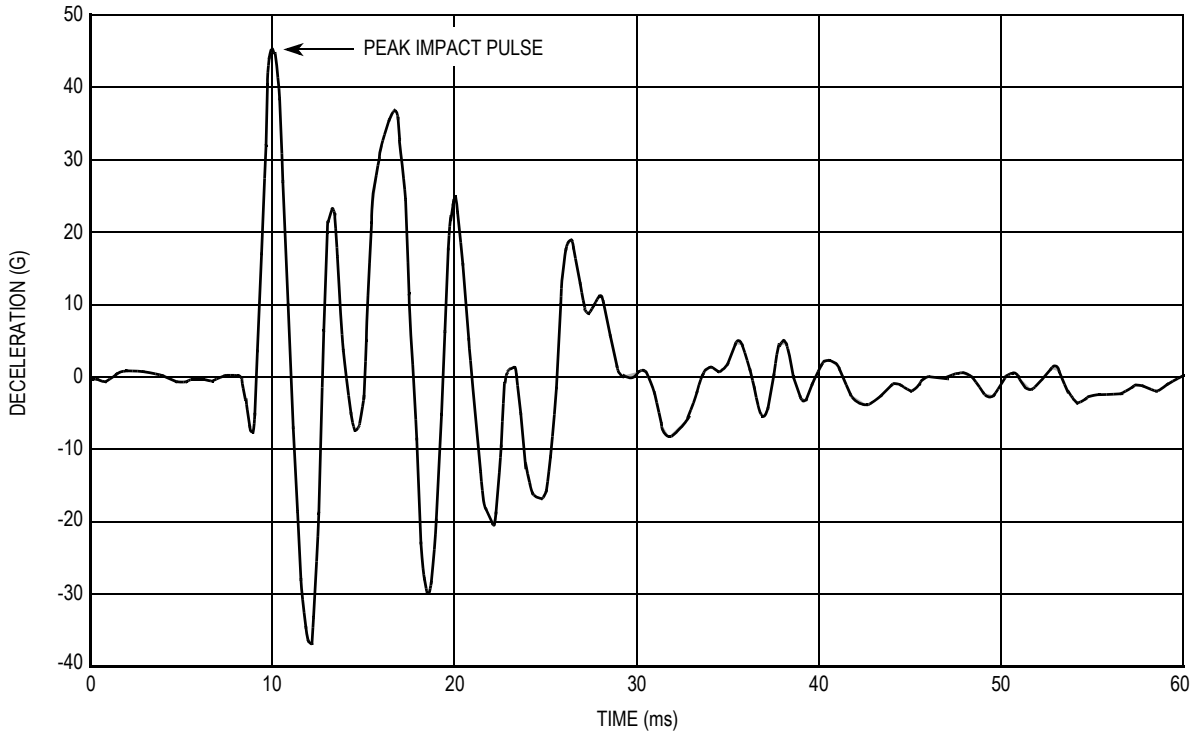

Figure 2. Typical Crash Pattern

HARDWARE DESCRIPTION AND OPERATION

Since the accelerometer is fully signal-conditioned by its internal op-amp and temperature compensation, the output of the accelerometer can be directly interfaced with an analog-to-digital (A/D) converter for digitization. A filter consists of one RC network and should be added if the connection between the output of the accelerometer and the A/D converter is a long track or cable. This stray capacitance may change the position of the internal pole which would drive the output amplifier of the accelerometer into oscillation or unstability. In this design, the cut-off frequency is chosen to be 15.9 kHz which also acts as an anti-alias filter for the A/D converter. The 3 dB frequency can be approximated by the following equation.

$$f_{-3db} = \frac{1}{2\pi RC}$$

Referring to the schematic, Figure 3, the accelerometer is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on-chip 8-bit analog-to-digital (A/D) converter. Typically, the accelerometer provides a signal output to the microprocessor of approximately 0.3 Vdc at -55g to 4.7 Vdc at +55g of acceleration. However, Freescale only guarantees the accuracy within ±40g range. Using the same reference voltage for the A/D converter and accelerometer minimizes the number of additional components, but does sacrifice resolution. The resolution is defined by the following:

$$\text{count} = \frac{V_{out}}{5} \times 255$$

The count at 0g = [2.5/5] × 255 ∝ 128

The count at +25g = [3.5/5] × 255 ∝ 179

The count at -25g = [1.5/5] × 255 ∝ 77

Therefore the resolution 0.5g/count

The output of the accelerometer is ratiometric to the voltage applied to it. The accelerometer and the reference voltages are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate. Other than the LCD, one light emitting diode (LED) are connected to the pulse length converter (PLM) of the microcontroller. This LED will light up for 3 seconds when an impact greater or equal to 7g is detected.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P-5 provides an undervoltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time bases functions, for instance calculation of pulse rate.

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SOFTWARE DESCRIPTION

Upon power-up of the system, the LCD will display CAL for approximately four seconds. During this period, the output of the accelerometer are sampled and averaged to obtain the zero offset voltage or zero acceleration. This value will be saved in the RAM which is used by the equation below to calculate the impact in term of g-force. One point to note is that the accelerometer should remain stationary during the zero calibration.

$$\text{Impact} = [\text{count} - \text{count}_{\text{offset}}] \times \text{resolution}$$

In this software program, the output of the accelerometer is calculated every 650 μs. During an impact, the peak deceleration is measured and displayed on the LCD for three seconds before resetting it to zero. In the mean time, if a higher impact is detected, the value on the LCD will be updated accordingly.

However, when a low g is detected (e.g. 1.0g), the value will not be displayed. Instead, more samples will be taken for further averaging to eliminate the random noise and high frequency component. Due to the fact that tilting is a low g and low frequency signal, large number of sampling is preferred to avoid unstable display. Moreover, the display value will not hold for three seconds as in the case of an impact.

Figure 4 is a flowchart for the program that controls the system.

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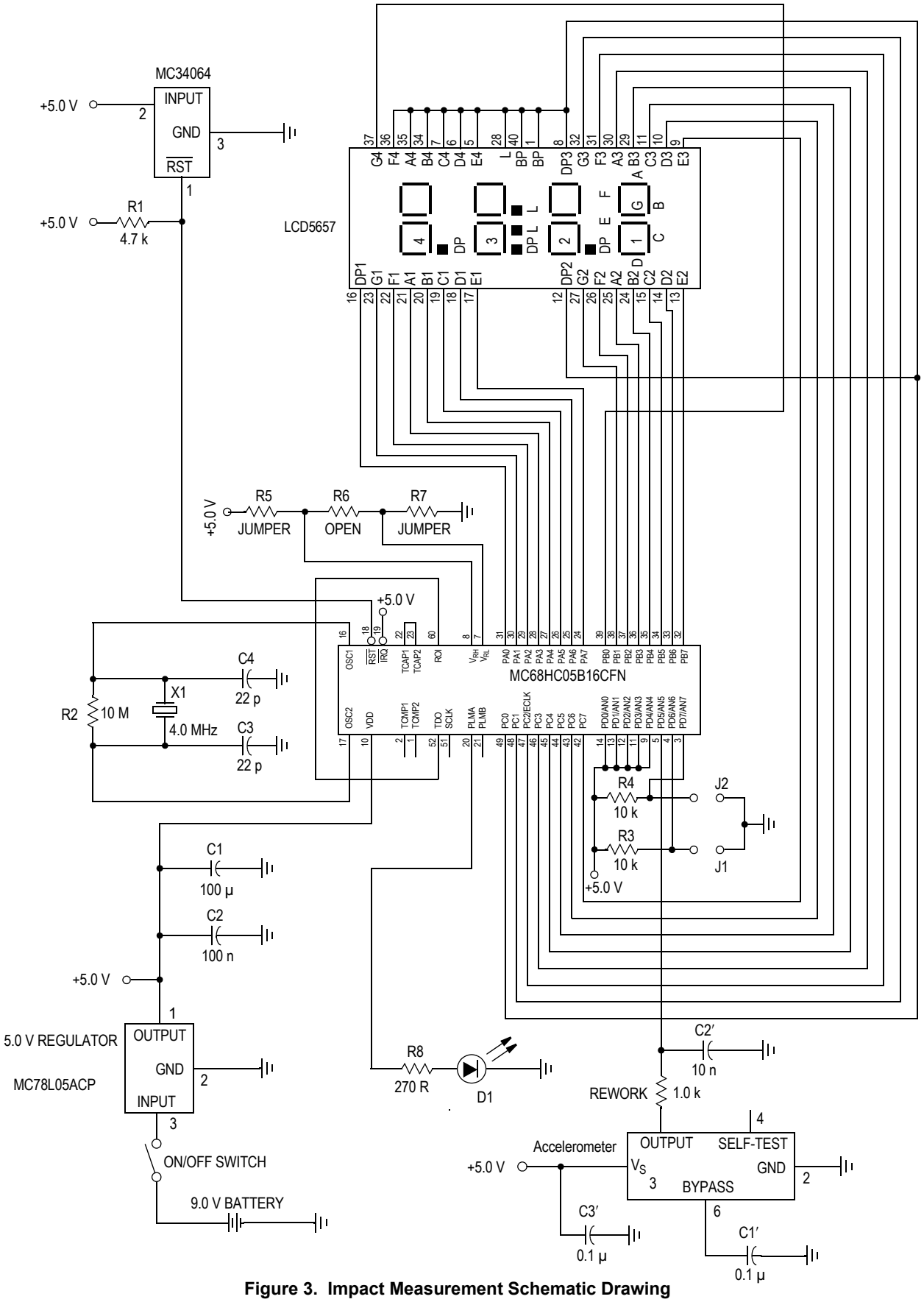

Figure 3. Impact Measurement Schematic Drawing

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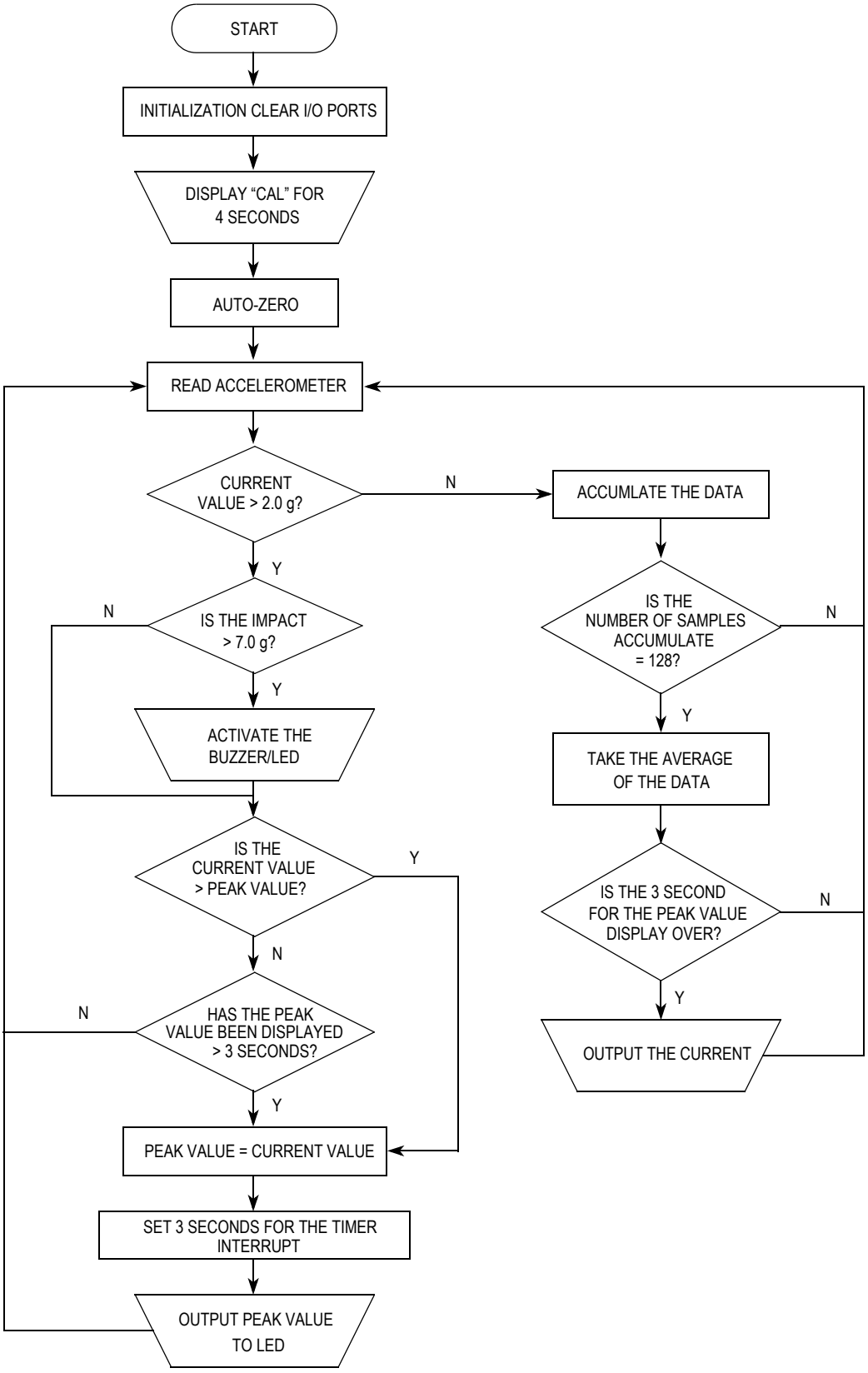

Figure 4. Main Program Flowchart

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
*****************************************************************************
*                                                                           *
*                    Accelerometer Demo Car Version 2.0                     *
*                                                                           *
*   The following code is written for MC68HC705B16 using MMDS05 software    *
*   Version 1.01                                                            *
*   CASM05 - Command line assembler Version 3.04                            *
*   P & E Microcomputer Systems, Inc.                                       *
*                                                                           *
*                         Written by : C.S. Chua                            *
*                             29 August 1996                                *
*                                                                           *
*                                                                           *
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*   which the failure of the Freescale product could create a situation     *
*   a situation where personal injury or death may occur. Should the buyer  *
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*   unauthorised application, buyer shall indemnify and hold Freescale and  *
*   its officers, employees, subsidiaries, affiliates, and distributors     *
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*   personal injury or death associated with such unintended or unauthorised *
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*                                                                           *
*****************************************************************************
*****************************************************************************
*                                                                           *
*                          Software Description                             *
*                                                                           *
*   This software is used to read the output of the accelerometer MMA2200W  *
*   and display it to a LCD as gravity force. It ranges from -55g to +55g   *
*   with 0g as zero acceleration or constant velocity. The resolution is    *
*   0.5g.                                                                   *
*                                                                           *
*   The program will read from the accelerometer and hold the maximum       *
*   deceleration value for about 3.0 seconds before resetting. At the same  *
*   time, the buzzer/LED is activated if the impact is more than 7.0g.      *
*   However, if the maximum deceleration changes before 3.0 seconds, it     *
*   will update the display using the new value. Note that positive value   *
*   implies deceleration whereas negative value implies acceleration        *
*                                                                           *
*****************************************************************************
*****************************************
*                                       *
*            Initialisation             *
*                                       *
*****************************************
PORTA       EQU     $00         ; Last digit

PORTB       EQU     $01         ; Second digit (and negative sign)
PORTC       EQU     $02         ; First digit (and decimal point)
ADDATA      EQU     $08         ; ADC Data
ADSTAT      EQU     $09         ; ADC Status
PLMA        EQU     $0A         ; Pulse Length Modulator (Output to Buzzer)
MISC        EQU     $0C         ; Miscellaneous Register (slow/fast mode)
TCONTROL    EQU     $12         ; Timer control register
TSTATUS     EQU     $13         ; Timer Status Register
OCMPHI1     EQU     $16         ; Output Compare Register 1 High Byte
```


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```
OCMPLO1       EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI        EQU     $18           ; Timer Count Register High Byte
TCNTLO        EQU     $19           ; Timer Count Register Low Byte
OCMPHI2       EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2       EQU     $1F           ; Output Compare Register 2 Low Byte
*****************************************
*                                       *
*           User-defined RAM            *
*                                       *
*****************************************
SIGN          EQU     $54           ; Acceleration (-) or deceleration (+)
PRESHI2       EQU     $55           ; MSB of accumulated acceleration
PRESHI        EQU     $56
PRESLO        EQU     $57           ; LSB of accumulated acceleration
PTEMPHI       EQU     $58           ; Acceleration High Byte (Temp storage)
PTEMPLO       EQU     $59           ; Acceleration Low Byte (Temp storage)
ACCHI         EQU     $5A           ; Temp storage of acc value (High byte)
ACCLO         EQU     $5B           ;                           (Low byte)
ADCOUNTER     EQU     $5C           ; Sampling Counter
AVERAGE_H     EQU     $5D           ; MSB of the accumulated data of low g
AVERAGE_M     EQU     $5E
AVERAGE_L     EQU     $5F           ; LSB of the accumulated data of low g
SHIFT_CNT     EQU     $60           ; Counter for shifting the accumulated data
AVE_CNT1      EQU     $61           ; Number of samples in the accumulated data
AVE_CNT2      EQU     $75
TEMPTCNTHI    EQU     $62           ; Temp storage for Timer count register
TEMPTCNTLO    EQU     $63           ; Temp storage for Timer count register
DECHI         EQU     $64           ; Decimal digit high byte
DECLO         EQU     $65           ; Decimal digit low byte
DCOFFSETHI    EQU     $66           ; DC offset of the output (high byte)
DCOFFSETLO    EQU     $67           ; DC offset of the output (low byte)
MAXACC        EQU     $68           ; Maximum acceleration
TEMPHI        EQU     $69
TEMPLO        EQU     $6A
TEMP1         EQU     $6B           ; Temporary location for ACC during delay
TEMP2         EQU     $6C           ; Temporary location for ACC during ISR
DIV_LO        EQU     $6D           ; No of sampling (low byte)
DIV_HI        EQU     $6E           ; No of sampling (high byte)
NO_SHIFT      EQU     $6F           ; No of right shift to get average value
ZERO_ACC      EQU     $70           ; Zero acceleration in no of ADC steps
HOLD_CNT      EQU     $71           ; Hold time counter
HOLD_DONE     EQU     $72           ; Hold time up flag
START_TIME    EQU     $73           ; Start of count down flag
RSHIFT        EQU     $74           ; No of shifting required for division
              ORG     $300          ; ROM space 0300 to 3DFE (15,104 bytes)
              DB      $FC           ; Display "0"
              DB      $30           ; Display "1"
              DB      $DA           ; Display "2"
              DB      $7A           ; Display "3"
              DB      $36           ; Display "4"
              DB      $6E           ; Display "5"
              DB      $EE           ; Display "6"
              DB      $38           ; Display "7"
              DB      $FE           ; Display "8"
              DB      $7E           ; Display "9"
HUNDREDHI     DB      $00           ; High byte of hundreds
HUNDREDLO     DB      $64           ; Low byte of hundreds
TENHI         DB      $00           ; High byte of tens
TENLO         DB      $0A           ; Low byte of tens
*****************************************
*                                       *
*   Program starts here upon hard reset  *
*                                       *
*****************************************
RESET         CLR     PORTC         ; Port C = 0
              CLR     PORTB         ; Port B = 0
              CLR     PORTA         ; Port A = 0
              LDA     #$FF
              STA     $06           ; Port C as output
              STA     $05           ; Port B as output
              STA     $04           ; Port A as output
              LDA     TSTATUS       ; Dummy read the timer status register
              CLR     OCMPHI2       ; so as to clear the OCF
              CLR     OCMPHI1
              LDA     OCMPLO2
              JSR     COMPRGT
              CLR     START_TIME
```

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```
            LDA     #$40            ; Enable the output compare interrupt
            STA     TCONTROL
            CLI                     ; Interrupt begins here
            LDA     #$CC            ; Port C = 1100 1100   Letter "C"
            STA     PORTC
            LDA     #$BE            ; Port B = 1011 1110   Letter "A"
            STA     PORTB
            LDA     #$C4            ; Port A = 1100 0100   Letter "L"
            STA     PORTA
            LDA     #16
IDLE        JSR     DLY20           ; Idling for a while (16*0.125 = 2 sec)
            DECA                    ; for the zero offset to stabilize
            BNE     IDLE            ; before perform auto-zero
            LDA     #$00            ; Sample the data 32,768 times and take
            STA     DIV_LO          ; the average 8000 H = 32,768
            LDA     #$80            ; Right shift of 15 equivalent to divide
            STA     DIV_HI          ; by 32,768
            LDA     #!15            ; Overall sampling time = 1.033 s)
            STA     NO_SHIFT
            JSR     READAD          ; Zero acceleration calibration
            LDX     #5              ; Calculate the zero offset
            LDA     PTEMPLO         ; DC offset = PTEMPLO * 5
            STA     ZERO_ACC
            MUL
            STA     DCOFFSETLO      ; Save the zero offset in the RAM
            TXA
            STA     DCOFFSETHI
            CLR     HOLD_CNT
            LDA     #$10          ; Sample the data 16 times and take
            STA     DIV_LO        ; the average 0100 H = 16
            LDA     #$00          ; Right shift of 4 equivalent to divide
            STA     DIV_HI        ; by 16
            LDA     #$4           ; Overall sampling time = 650 us
            STA     NO_SHIFT
            LDA     ZERO_ACC      ; Display 0.0g at the start
            STA     MAXACC
            JSR     ADTOLCD
            CLR     START_TIME
            CLR     AVE_CNT1
            CLR     AVE_CNT2
            CLR     SHIFT_CNT
            CLR     AVERAGE_L
            CLR     AVERAGE_M
            CLR     AVERAGE_H
REPEAT      JSR     READAD          ; Read acceleration from ADC
            LDA     ZERO_ACC
            ADD     #$04
            CMP     PTEMPLO
            BLO     CRASH           ; If the acceleration < 2.0g
            LDA     PTEMPLO         ; Accumulate the averaged results
            ADD     AVERAGE_L       ; for 128 times and take the averaging
            STA     AVERAGE_L       ; again to achieve more stable
            CLRA                    ; reading at low g
            ADC     AVERAGE_M
            STA     AVERAGE_M
            CLRA
            ADC     AVERAGE_H
            STA     AVERAGE_H
            LDA     #$01
            ADD     AVE_CNT1
            STA     AVE_CNT1
            CLRA
            ADC     AVE_CNT2
            STA     AVE_CNT2
            CMP     #$04
            BNE     REPEAT
            LDA     AVE_CNT1
            CMP     #$00
            BNE     REPEAT
SHIFTING    INC     SHIFT_CNT       ; Take the average of the 128 samples
            LSR     AVERAGE_H
            ROR     AVERAGE_M
            ROR     AVERAGE_L
            LDA     SHIFT_CNT
            CMP     #$0A
            BLO     SHIFTING
            LDA     AVERAGE_L
```

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```
            STA     PTEMPLO
            LDA     HOLD_CNT        ; Check if the hold time of crash data
            CMP     #$00            ; is up
            BNE     NON-CRASH
            LDA     PTEMPLO         ; If yes, display the current acceleration
            STA     MAXACC          ; value
            JSR     ADTOLCD
            BRA     NON-CRASH
CRASH       LDA     ZERO_ACC
            ADD     #$0E            ; If the crash is more than 7g
            CMP     PTEMPLO         ; 7g = 0E H * 0.5
            BHS     NO_INFLATE
            LDA     #$FF            ; activate the LED
            STA     PLMA
NO_INFLATE  JSR     MAXVALUE        ; Display the peak acceleration
            JSR     ADTOLCD
NON-CRASH   CLR     SHIFT_CNT
            CLR     AVE_CNT1
            CLR     AVE_CNT2
            CLR     AVERAGE_L
            CLR     AVERAGE_M
            CLR     AVERAGE_H
            BRA     REPEAT          ; Repeat the whole process
****************************************
*                                      *
*           Delay Subroutine           *
*     (162 * 0.7725 ms = 0.125 sec)    *
*                                      *
****************************************
DLY20       STA     TEMP1
            LDA     #!162             ; 1 unit = 0.7725 ms
OUTLP       CLRX
INNRLP      DECX
            BNE     INNRLP
            DECA
            BNE     OUTLP
            LDA     TEMP1
            RTS
****************************************
*                                      *
*     Reading the ADC data X times     *
*        and take the average          *
*   X is defined by DIV_HI and DIV_LO  *
*                                      *
****************************************
READAD      LDA     #$25
            STA     ADSTAT          ; AD status = 25H
            CLR     PRESHI2
            CLR     PRESHI          ; Clear the memory
            CLR     PRESLO
            CLRX
            CLR     ADCOUNTER
LOOP128     TXA
            CMP     #$FF
            BEQ     INC_COUNT
            BRA     CONT
INC_COUNT   INC     ADCOUNTER
CONT        LDA     ADCOUNTER       ; If ADCOUNTER = X
            CMP     DIV_HI          ; Clear bit = 0
            BEQ     CHECK_X         ; Branch to END100
            BRA     ENDREAD
CHECK_X     TXA
            CMP     DIV_LO
            BEQ     END128
ENDREAD     BRCLR   7,ADSTAT,ENDREAD ; Halt here till AD read is finished
            LDA     ADDATA          ; Read the AD register
            ADD     PRESLO          ; PRES = PRES + ADDATA
            STA     PRESLO
            CLRA
            ADC     PRESHI
            STA     PRESHI
            CLRA
            ADC     PRESHI2
            STA     PRESHI2
            INCX                    ; Increase the AD counter by 1
            BRA     LOOP128         ; Branch to Loop128
END128      CLR     RSHIFT          ; Reset the right shift counter
```

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```
DIVIDE      INC     RSHIFT          ; Increase the right counter
            LSR     PRESHI2
            ROR     PRESHI          ; Right shift the high byte
            ROR     PRESLO          ; Right shift the low byte
            LDA     RSHIFT
            CMP     NO_SHIFT        ; If the right shift counter >= NO_SHIFT
            BHS     ENDDIVIDE       ; End the shifting
            JMP     DIVIDE          ; otherwise continue the shifting
ENDDIVIDE   LDA     PRESLO
            STA     PTEMPLO
            RTS
****************************************
*                                      *
*       Timer service interrupt        *
*     Alternates the Port data and     *
*          backplane of LCD            *
*                                      *
****************************************
TIMERCMP    STA     TEMP2           ; Push Accumulator
            COM     PORTC           ; Port C = - (Port C)
            COM     PORTB           ; Port B = - (Port B)
            COM     PORTA           ; Port A = - (Port A)
            LDA     START_TIME      ; Start to count down the hold time
            CMP     #$FF            ; if START_TIME = FF
            BNE     SKIP_TIME
            JSR     CHECK_HOLD
SKIP_TIME   BSR     COMPRGT         ; Branch to subroutine compare register
            LDA     TEMP2           ; Pop Accumulator
            RTI
****************************************
*                                      *
*      Check whether the hold time     *
*        of crash impact is due        *
*                                      *
****************************************
CHECK_HOLD  DEC     HOLD_CNT
            LDA     HOLD_CNT
            CMP     #$00            ; Is the hold time up?
            BNE     NOT_YET
            LDA     #$00            ; If yes,
            STA     PLMA            ; stop buzzer
            LDA     #$FF            ; Set HOLD_DONE to FF indicate that the
            STA     HOLD_DONE       ; hold time is up
            CLR     START_TIME      ; Stop the counting down of hold time
NOT_YET     RTS
****************************************
*                                      *
*          Subroutine reset            *
*      the timer compare register      *
*                                      *
****************************************
COMPRGT     LDA     TCNTHI          ; Read Timer count register
            STA     TEMPTCNTHI      ; and store it in the RAM
            LDA     TCNTLO
            STA     TEMPTCNTLO
            ADD     #$4C            ; Add 1D4C H = 7500 periods
            STA     TEMPTCNTLO      ; with the current timer count
            LDA     TEMPTCNTHI      ; 1 period = 2 us
            ADC     #$1D
            STA     TEMPTCNTHI      ; Save the next count to the register
            STA     OCMPHI1
            LDA     TSTATUS         ; Clear the output compare flag
            LDA     TEMPTCNTLO      ; by access the timer status register
            STA     OCMPLO1         ; and then access the output compare
            RTS                     ; register
****************************************
*                                      *
*      Determine which is the next     *
*    acceleration value to be display  *
*                                      *
****************************************
MAXVALUE    LDA     PTEMPLO
            CMP     MAXACC          ; Compare the current acceleration with
            BLS     OLDMAX          ; the memory, branch if it is <= maxacc
            BRA     NEWMAX1
OLDMAX      LDA     HOLD_DONE       ; Decrease the Holdtime when
            CMP     #$FF            ; the maximum value remain unchanged
```

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```
            BEQ     NEWMAX1         ; Branch if the Holdtime is due
            LDA     MAXACC          ; otherwise use the current value
            BRA     NEWMAX2
NEWMAX1     LDA     #$C8            ; Hold time = 200 * 15 ms = 3 sec
            STA     HOLD_CNT        ; Reload the hold time for the next
            CLR     HOLD_DONE       ; maximum value
            LDA     #$FF
            STA     START_TIME      ; Start to count down the hold time
            LDA     PTEMPLO         ; Take the current value as maximum
NEWMAX2     STA     MAXACC
            RTS
****************************************
*                                      *
*     This subroutine is to convert    *
*        the AD data to the LCD        *
*    Save the data to be diaplayed     *
*             in MAXACC                *
*                                      *
****************************************
ADTOLCD     SEI                     ; Disable the Timer Interrupt !!
            LDA     #$00            ; Load 0000 into the memory
            STA     DECHI
            LDA     #$00
            STA     DECLO
            LDA     MAXACC
            LDX     #5
            MUL                     ; Acceleration = AD x 5
            ADD     DECLO           ; Acceleration is stored as DECHI
            STA     DECLO           ; and DECLO
            STA     ACCLO           ; Temporary storage
            LDA     #$00            ; Assume positive deceleration
            STA     SIGN            ; "00" positive ; "01" negative
            CLRA
            TXA
            ADC     DECHI
            STA     DECHI
            STA     ACCHI           ; Temporary storage
            LDA     DECLO
            SUB     DCOFFSETLO      ; Deceleration = Dec - DC offset
            STA     DECLO
            LDA     DECHI
            SBC     DCOFFSETHI
            STA     DECHI
            BCS     NEGATIVE        ; Branch if the result is negative
            BRA     SEARCH
NEGATIVE    LDA     DCOFFSETLO      ; Acceleration = DC offset - Dec
            SUB     ACCLO
            STA     DECLO
            LDA     DCOFFSETHI
            SBC     ACCHI
            STA     DECHI
            LDA     #$01            ; Assign a negative sign
            STA     SIGN
SEARCH      CLRX                    ; Start the search for hundred digit
LOOP100     LDA     DECLO           ; Acceleration = Acceleration - 100
            SUB     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            SBC     HUNDREDHI
            STA     DECHI
            INCX                    ; X = X + 1
            BCC     LOOP100         ; if acceleration >= 100, continue the
            DECX                    ; loop100, otherwise X = X - 1
            LDA     DECLO           ; Acceleration = Acceleration + 100
            ADD     HUNDREDLO
            STA     DECLO
            LDA     DECHI
            ADC     HUNDREDHI
            STA     DECHI
            TXA                     ; Check if the MSD is zero
            AND     #$FF
            BEQ     NOZERO          ; If MSD is zero, branch to NOZERO
            LDA     $0300,X         ; Output the first second digit
            STA     PORTC
            BRA     STARTTEN
NOZERO      LDA     #$00            ; Display blank if MSD is zero
            STA     PORTC
```

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```
STARTTEN    CLRX                    ; Start to search for ten digit
LOOP10      LDA     DECLO           ; acceleration = acceleration - 10
            SUB     TENLO
            STA     DECLO
            LDA     DECHI
            SBC     TENHI
            STA     DECHI
            INCX
            BCC     LOOP10          ; if acceleration >= 10 continue the
            DECX                    ; loop, otherwise end
            LDA     DECLO           ; acceleration = acceleration + 10
            ADD     TENLO
            STA     DECLO
            LDA     DECHI
            ADC     TENHI
            STA     DECHI
            LDA     $0300,X         ; Output the last second digit
            EOR     SIGN            ; Display the sign
            STA     PORTB
            CLRX                    ; Start to search for the last digit
            LDA     DECLO           ; declo = declo - 1
            TAX
            LDA     $0300,X         ; Output the last digit
            EOR     #$01            ; Add a decimal point in the display
            STA     PORTA
            CLI                     ; Enable Interrupt again !
            RTS
*****************************************
*                                       *
*   This subroutine provides services   *
*    for those unintended interrupts    *
*                                       *
*****************************************
SWI         RTI                     ; Software interrupt return
IRQ         RTI                     ; Hardware interrupt
TIMERCAP    RTI                     ; Timer input capture
TIMERROV    RTI                     ; Timer overflow
SCI         RTI                     ; Serial communication Interface
                                    ; Interrupt
            ORG     $3FF2           ; For 68HC05B16, the vector location
            FDB     SCI             ; starts at 3FF2
            FDB     TIMERROV        ; For 68HC05B5, the address starts
            FDB     TIMERCMP        ; 1FF2
            FDB     TIMERCAP
            FDB     IRQ
            FDB     SWI
            FDB     RESET
```

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Shock and Mute Pager Applications Using Accelerometer

by: C.S. Chua
Sensor Application Engineering, Singapore, A/P

INTRODUCTION

In the current design, whenever there is an incoming page, the buzzer will “beep” until any of the buttons is depressed. It can be quite annoying or embarrassing sometime when the button is not within your reach. This application note describes the concept of muting the “beeping” sound by tapping the pager lightly, which could be located in your pocket or handbag. This demo board uses an accelerometer, microcontroller hardware/software and a piezo audio transducer. Due to the wide frequency response of the accelerometer from d.c. to 400 Hz, the device is able to measure both the static acceleration from the Earth's gravity and the shock or vibration from an impact. This design uses a 40g accelerometer, which yields a minimum acceleration range of -40g to +40g.

CONCEPT OF TAP DETECTION

To measure the tapping of a pager, the accelerometer must be able to respond in the range of hundreds of hertz. During the tapping of a pager at the top surface, illustrated in Figure 1, the accelerometer will detect a negative shock level between -15g to -50g of force depending on the intensity. Similarly, if the tapping action comes from the bottom of the accelerometer, the output will be a positive value. Normally, the peak impact pulse is in the order of a few milliseconds. Figure 2 shows a typical waveform of the accelerometer under shock.

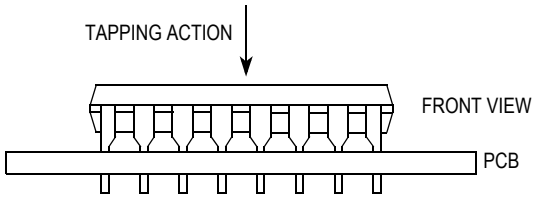

Figure 1. Tapping Action of Accelerometer

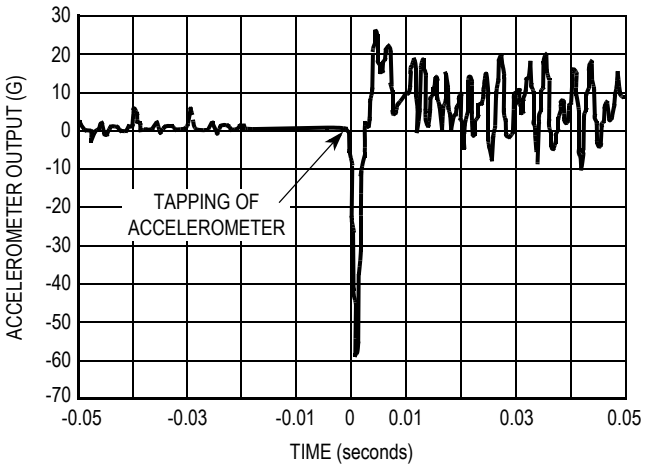

Figure 2. Typical Waveform of Accelerometer Under Tapping Action

Therefore, we could set a threshold level, either by hardware circuitry or software algorithm, to determine the tapping action and mute the “beeping.” In this design, a hardware solution is used because there will be minimal code added to the existing pager software. However, if a software solution is used, the user will be able to program the desire shock level.

HARDWARE DESCRIPTION AND OPERATION

Since MMA1201P is fully signal-conditioned by its internal op-amp and temperature compensation, the output of the accelerometer can be directly interfaced with a comparator. To simplify the hardware, only one direction (tapping on top of the sensor) is monitored. The comparator is configured in such a way that when the output voltage of the accelerometer is less than the threshold voltage or Vref (refer to Figure 3), the output of the comparator will give a logic 1, illustrated in Figure 4. To decrease the V_{REF} voltage or increase the threshold impact in magnitude, turn the trimmer R2 anti-clockwise.

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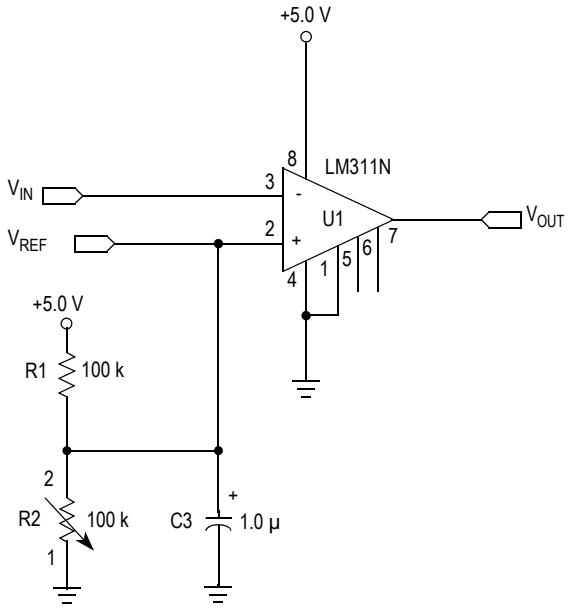

Figure 3. Comparator Circuitry

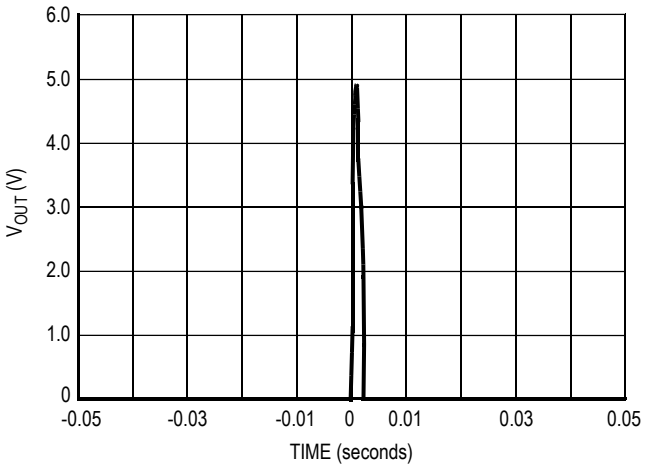

Figure 4. Comparator Output Waveform

For instance, if the threshold level is to be set to -20g, this will correspond to a Vref voltage of 1.7 V.

$$V_{REF} = V_{OFFSET} + \left(\frac{\Delta V}{\Delta G} \times G_{THRESHOLD}\right)$$

$$= 2.5 + (0.04 \times [-20])$$
$$= 1.7\ V$$

Under normal condition, V_{IN} (which is the output of the accelerometer) is at about 2.5 V. Since V_{IN} is higher than Vref, the output of the comparator is at logic 0. During any shock or impact which is greater than -20g in magnitude, the output voltage of the accelerometer will go below V_{REF}. In this case, the output logic of the comparator changes from 0 to 1.

When the pager is in silence mode, the vibrator produces an output of about ±2g. This will not trigger the comparator. Therefore, even in silence mode, the user can also tap the pager to stop the alert. Refer to Figure 5 for the vibrator waveform.

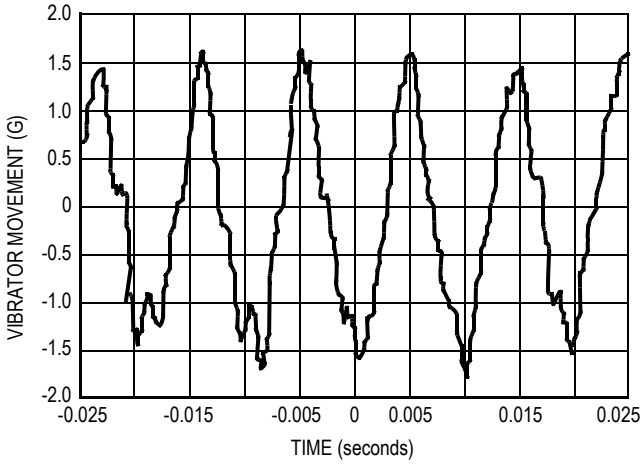

Figure 5. Vibrator Waveform

Figure 6 is a schematic drawing of the whole demo and Figure 7, Figure 8, and Figure 9 show the printed circuit board and component layout for the shock and mute pager. Table 1 is the corresponding part list.

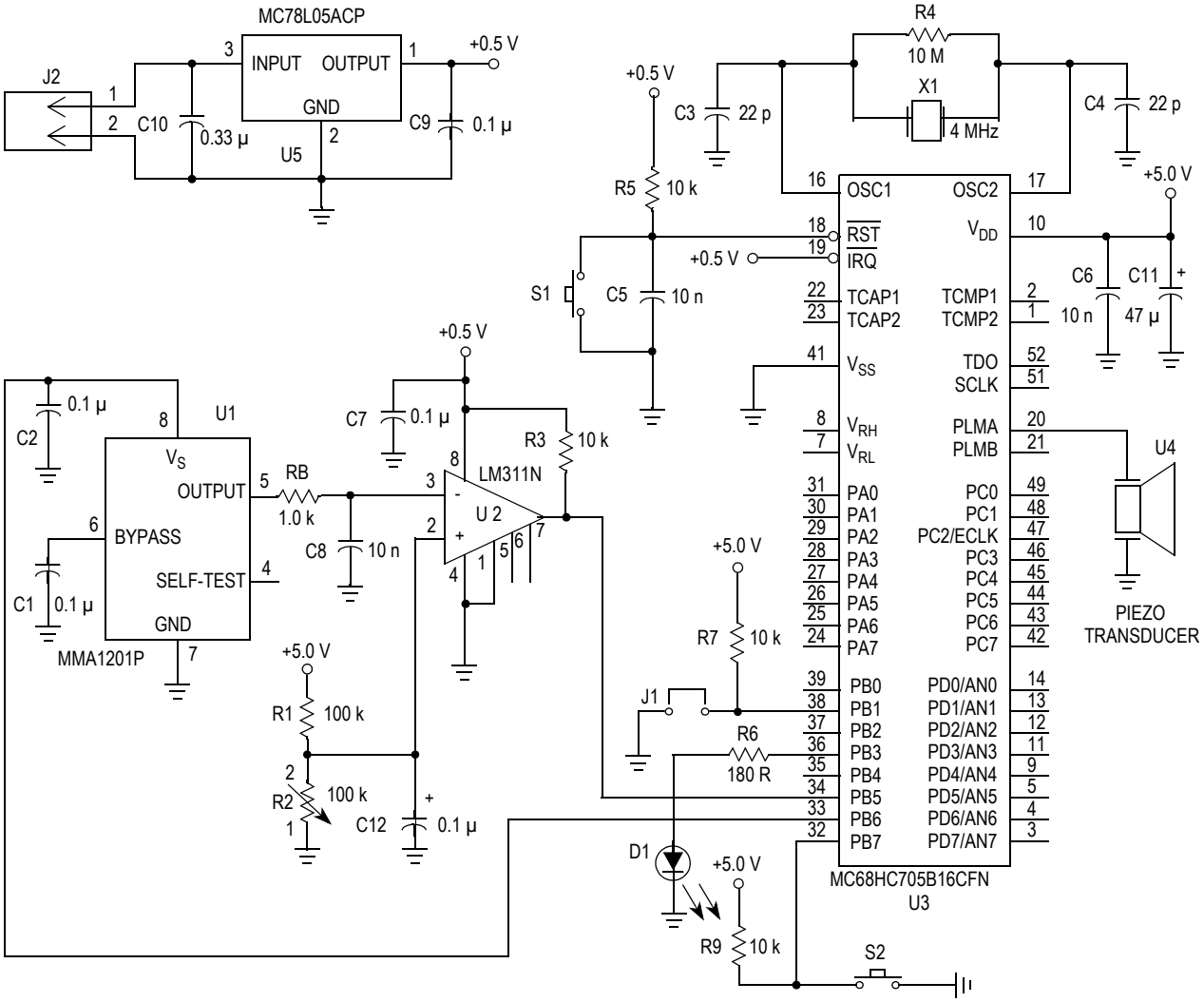

Figure 6. Overall Schematic Diagram of the Demo

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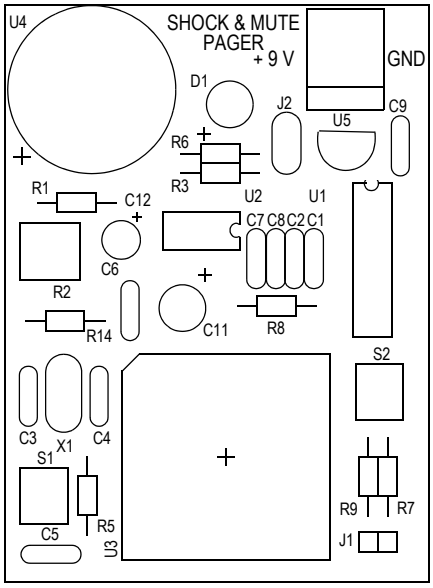

Figure 7. Silk Screen of the PCB

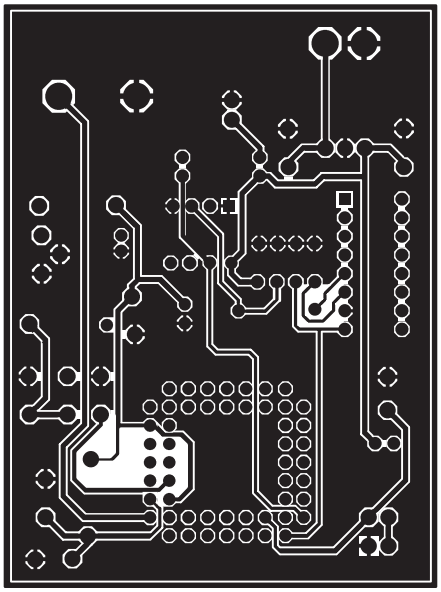

Figure 8. Solder Side of the PCB

Table 1. Bill of Material for the Shock and Mute Pager

Device Type	Qty.	Value	References
Ceramic Capacitor	4	0.1µ	C1, C2, C7, C9
Ceramic Capacitor	2	22p	C3, C4
Ceramic Capacitor	3	10n	C5, C6, C8
Solid Tantalum	1	0.33µ	C10
Electrolytic Capacitor	1	47µ	C11
Electrolytic Capacitor	1	1µ	C12
LED	1	5mm	D1
Header	1	2 way	J1
PCB Terminal Block	1	2 way	J2
Resistor ±5% 0.25W	1	100k	R1
Single Turn Trimmer	1	100k	R2
Resistor ±5% 0.25W	4	10k	R3, R5, R7, R9
Resistor ±5% 0.25W	1	10M	R4
Resistor ±5% 0.25W	1	180R	R6
Resistor ±5% 0.25W	1	1k	R8
Push Button	2	6mm	S1, S2
MMA1201P	1	—	U1
LM311N	1	—	U2
MC68HC705B16CFN	1	—	U3
Piezo Transducer	1	—	U4
MC78L05ACP	1	—	U5
Crystal	1	4MHz	X1

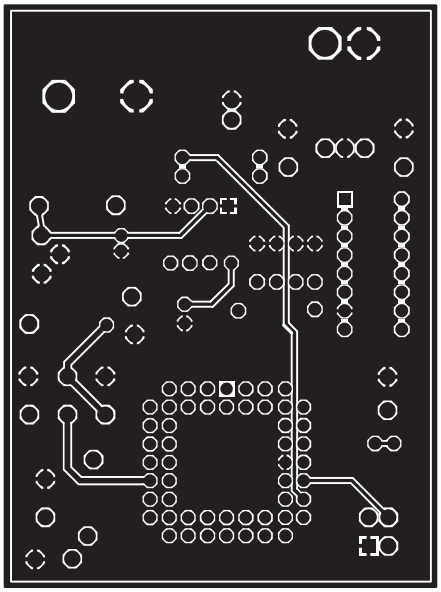

Figure 9. Component Side of the PCB

SOFTWARE DESCRIPTION

Upon powering up the system, the piezo audio transducer is activated simulating an incoming page, if the pager is in sound mode (jumper J1 in ON). Then, the accelerometer is powered up and the output of the comparator is sampled to obtain the logic level. The “beeping” will continue until the accelerometer senses an impact greater than the threshold level. Only then the alert is muted. However, when the pager is in silence mode (jumper J1 is OFF), indicated by the blinking red LED, the accelerometer is not activated. To stop the alert, press the push-button S2.

To repeat the whole process, simply push the reset switch S1.

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Figure 10 is a flowchart for the program that controls the system.

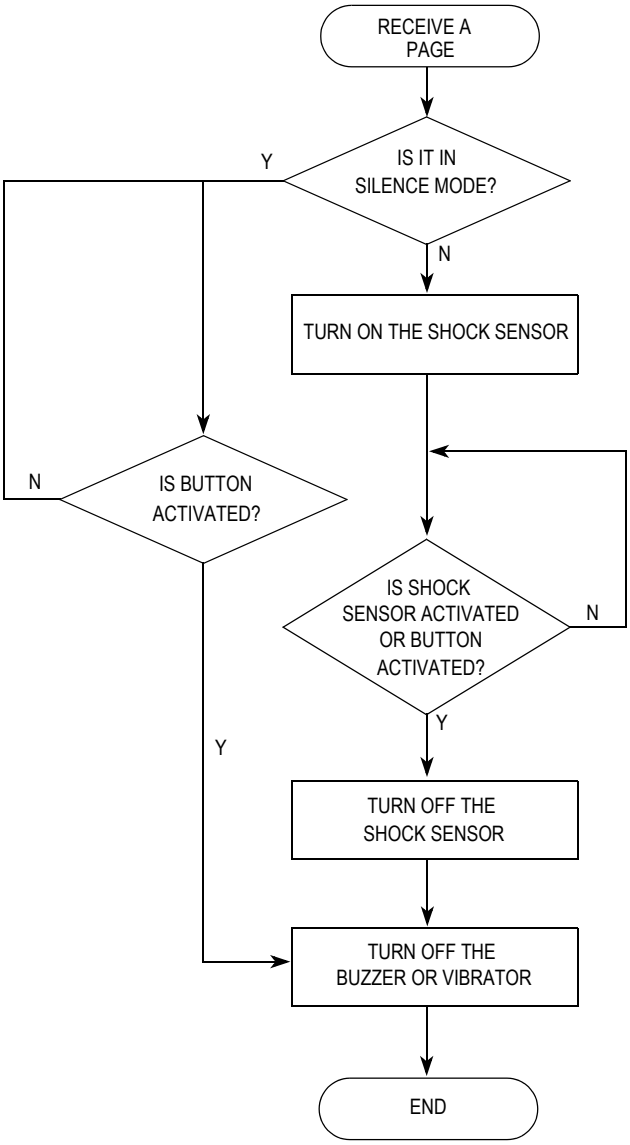

Figure 10. Main Program Flowchart

CONCLUSION

The shock and mute pager design uses a comparator to create a logic level output by comparing the accelerometer output voltage and a user-defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications, e.g. hard disk drive knock sensing, etc. The design presented here uses a comparator which yields excellent logic-level outputs and output transition speeds for many applications.

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SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
*****************************************************************************
*                                                                           *
*****************************************************************************
*                                                                           *
*                 Pager Shock & Mute Detection Version 1.0                  *
*                                                                           *
*   The following code is written for MC68HC705B16 using MMDS05 software    *
*   Version 1.01                                                            *
*   CASM05 - Command line assembler Version 3.04                            *
*   P & E Microcomputer Systems, Inc.                                       *
*                                                                           *
*                         Written by : C.S. Chua                            *
*                             9th January 1997                              *
*                                                                           *
*                           Software Description                            *
*                                                                           *
*   J1 ON - Sound mode                                                      *
*   Buzzer will turn off if the accelerometer is tapped or switch S2 is     *
*   depressed.                                                              *
*                                                                           *
*   J1 OFF - Silence mode                                                   *
*   LED will turn off if and only if S2 is depressed                        *
*                                                                           *
*****************************************************************************
*****************************************
*                                       *
*            I/O Declaration            *
*                                       *
*****************************************
PORTB         EQU     $01           ; Port B
PLMA          EQU     $0A           ; D/A to control buzzer
TCONTROL      EQU     $12           ; Timer control register
TSTATUS       EQU     $13           ; Timer Status Register
OCMPHI1       EQU     $16           ; Output Compare Register 1 High Byte
OCMPLO1       EQU     $17           ; Output Compare Register 1 Low Byte
TCNTHI        EQU     $18           ; Timer Count Register High Byte
TCNTLO        EQU     $19           ; Timer Count Register Low Byte
OCMPHI2       EQU     $1E           ; Output Compare Register 2 High Byte
OCMPLO2       EQU     $1F           ; Output Compare Register 2 Low Byte
*****************************************
*                                       *
*        RAM Area ($0050 - $0100)       *
*                                       *
*****************************************
              ORG     $50
STACK         RMB     4             ; Stack segment
TEMPTCNTLO    RMB     1             ; Temp. storage of timer result (LSB)
TEMPTCNTHI    RMB     1             ; Temp. storage of timer result (MSB)
*****************************************
*                                       *
*        ROM Area ($0300 - $3DFD)       *
*                                       *
*****************************************
              ORG     $300
*****************************************
*                                       *
*   Program starts here upon hard reset *
*                                       *
*****************************************
RESET         CLR     PORTB             ; Initialise Ports
              LDA     #%01001000        ; Configure Port B
              STA     $05
              LDA     TSTATUS           ; Dummy read the timer status register so as to clear the OCF
              CLR     OCMPHI2
              CLR     OCMPHI1
              LDA     OCMPLO2
              JSR     COMPRGT
              LDA     #$40              ; Enable the output compare interrupt
              STA     TCONTROL
              LDA     #10               ; Idle for a while before "beeping"
IDLE          JSR     DLY20
              DECA
              BNE     IDLE
              CLI                       ; Interrupt begins here
              BRSET   1,PORTB,SILENCE   ; Branch if J1 is off
              BSET    6,PORTB           ; Turn on accelerometer
              JSR     DLY20             ; Wait till the supply is stable
TEST          BRSET   5,PORTB,MUTE      ; Sample shock sensor for tapping
              BRCLR   7,PORTB,MUTE      ; Sample switch S2 for muting
              JMP     TEST
MUTE          BCLR    6,PORTB           ; Turn off accelerometer
              SEI
              CLR     PLMA              ; Turn off buzzer
```


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```
DONE          JMP      DONE              ; End
SILENCE       BRSET    7,PORTB,SILENCE   ; Sample switch S2 for stopping LED
              SEI
              BCLR     3,PORTB           ; Turn off LED
              JMP      DONE              ; End
*****************************************
*                                       *
*       Timer service interrupt         *
*       Alternates the PLMA data        *
*       and bit 3 of Port B             *
*                                       *
*****************************************
TIMERCMP      BSR      COMPRGT           ; Branch to subroutine compare register
              BRSET    1,PORTB,SKIPBUZZER  ; Branch if J1 is OFF
              LDA      PLMA
              EOR      #$80              ; Alternate the buzzer
              STA      PLMA
              RTI
SKIPBUZZER    BRSET    3,PORTB,OFF_LED   ; Alternate LED supply
              BSET     3,PORTB
              RTI
OFF_LED       BCLR     3,PORTB
              RTI
*****************************************
*                                       *
*           Subroutine reset            *
*      the timer compare register       *
*                                       *
*****************************************
COMPRGT       LDA      TCNTHI            ; Read Timer count register
              STA      TEMPTCNTHI        ; and store it in the RAM
              LDA      TCNTLO
              STA      TEMPTCNTLO
              ADD      #$50              ; Add C350 H = 50,000 periods
              STA      TEMPTCNTLO        ; with the current timer count
              LDA      TEMPTCNTHI        ; 1 period = 2 us
              ADC      #$C3
              STA      TEMPTCNTHI        ; Save the next count to the register
              STA      OCMPHI1
              LDA      TSTATUS           ; Clear the output compare flag
              LDA      TEMPTCNTLO        ; by access the timer status register
              STA      OCMPLO1           ; and then access the output compare register
              RTS
*****************************************
*                                       *
*       Delay Subroutine for 0.20 sec   *
*                                       *
*   Input: None                         *
*   Output: None                        *
*                                       *
*****************************************
DLY20         STA      STACK+2
              STX      STACK+3
              LDA      #!40           ; 1 unit = 0.7725 mS
OUTLP         CLRX
INNRLP        DECX
              BNE      INNRLP
              DECA
              BNE      OUTLP
              LDX      STACK+3
              LDA      STACK+2
              RTS
*****************************************
*                                       *
*   This subroutine provides services   *
*    for those unintended interrupts    *
*                                       *
*****************************************
SWI           RTI                     ; Software interrupt return
IRQ           RTI                     ; Hardware interrupt
TIMERCAP      RTI                     ; Timer input capture
TIMERROV      RTI                     ; Timer overflow interrupt
SCI           RTI                     ; Serial communication Interface Interrupt
              ORG      $3FF2          ; For 68HC05B16, the vector location
              FDB      SCI            ; starts at 3FF2
              FDB      TIMERROV       ; For 68HC05B5, the address starts at 1FF2
              FDB      TIMERCMP
              FDB      TIMERCAP
              FDB      IRQ
              FDB      SWI
              FDB      RESET
```

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Baseball Pitch Speedometer

by: **Carlos Miranda, Systems and Applications Engineer and**
David Heeley, Systems and Applications Mechanical Engineer

INTRODUCTION

The Baseball Pitch Speedometer, in its simplest form, consists of a target with acceleration sensors mounted on it, an MCU to process the sensors' outputs and calculate the ball speed, and a display to show the result. The actual implementation, shown in Figure 1, resembles a miniature pitching cage, that can be used for training and/or entertainment. The cage is approximately 6 ft. tall by 3 ft. wide by 6 ft. deep. The upper portion is wrapped in a nylon net to retain the baseballs as they rebound off the target. A natural rubber mat, backed by a shock resistant acrylic plate, serve as the target. Accelerometers, used to sense the ball impact, and buffers, used to drive the signal down the transmission line, are mounted on the back side of the target. The remainder of the electronics is contained in a display box on the top front side of the cage.

Accelerometers are sensors that measure the acceleration exerted on an object. They convert a physical quantity into an electrical output signal. Because acceleration is a vector quantity, defined by both magnitude and direction, an accelerometer's output signal typically has an offset voltage and can swing positive and negative relative to the offset, to account for both positive and negative acceleration. An example acceleration profile is shown in Figure 2. Because acceleration is defined as the rate of change of velocity with respect to time, the integration of acceleration as a function of time will yield a net change in velocity. By digitizing and numerically integrating the output signal of an accelerometer through the use of a microcontroller, *the area under the curve* could be computed. The result corresponds to the net change in velocity of the object under observation. This is the basic principle behind the Baseball Pitch Speedometer.

Figure 1. David Heeley, mechanical designer of the Baseball Pitch Speedometer Demo, tests his skills at Sensors Expo Boston '97.

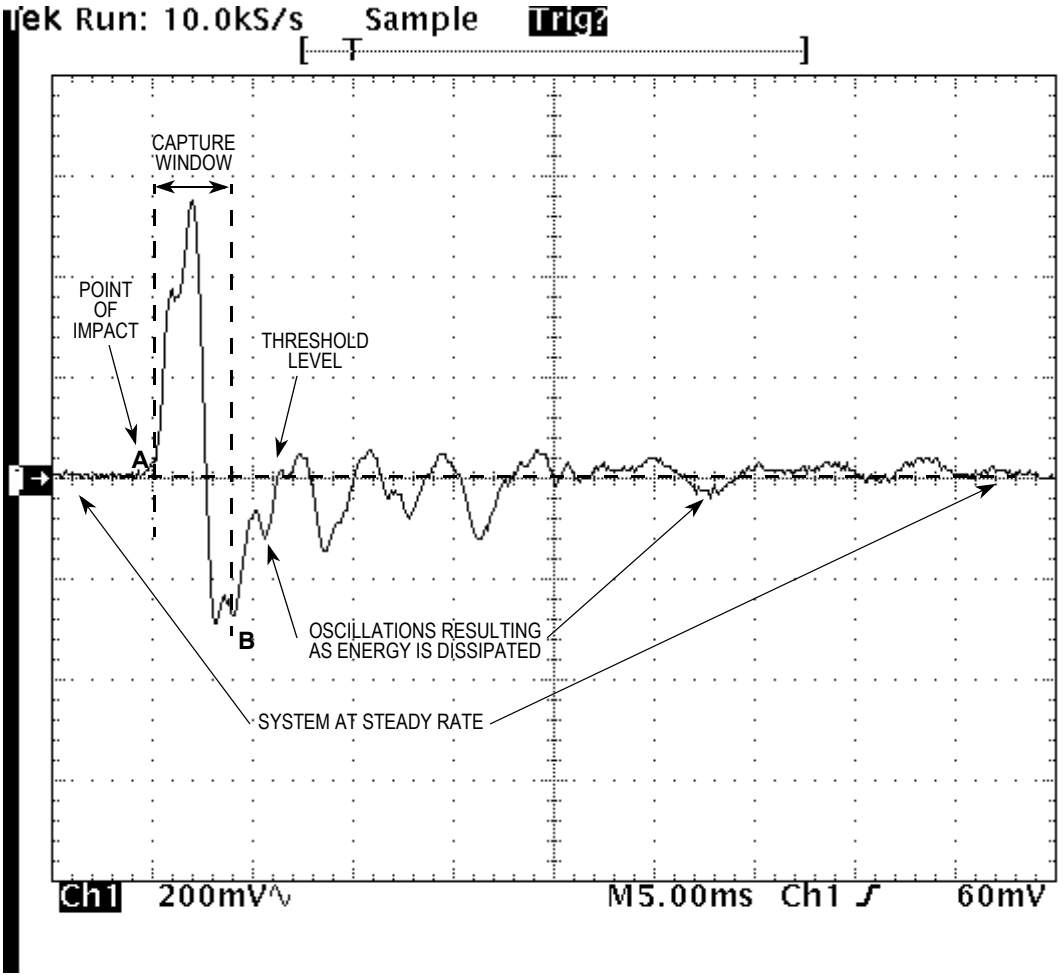

Figure 2. Typical Crash Pattern for the Baseball Pitch Speedometer Demo

THEORY OF OPERATION

When a ball is thrown against the target, the accelerometer senses the impact and produces an analog output signal, proportional to the acceleration measured, resulting in a crash signature. The amplitude and duration of the crash signature is a function of the velocity of the ball. How can this crash signature be correlated to the velocity of the baseball? By making use of the principle of conservation of momentum (see Equation 1). The principle of conservation of momentum states that the total momentum within a closed system remains constant. In our case, the system consists of the thrown ball and the target.

$$m_{ball} * V_{ball,initial} + m_{target} * V_{target,initial} = m_{ball} * V_{ball,final} + m_{target} * V_{target,final} \quad (1)$$

When the ball is thrown, it has a momentum equivalent to $m_{ball} * V_{ball,initial}$. The target initially has zero momentum since it is stationary. When the ball collides with the target, part of the momentum of the ball is transferred to the target, and the target will momentarily experience acceleration, velocity, and some finite, though small, displacement before dissipating the momentum and returning to a rest state. The other portion of momentum is retained by the ball as it bounces off the target, due to the elastic nature of the collision. By measuring the acceleration imparted on the target, its velocity is computed through integration. Ideally, if the mass of the ball, the mass of the target, and the final velocity of the ball are known, then the problem could be solved analytically and the initial velocity of the baseball determined.

The analysis of the crash phenomenon is, however, actually quite complex. Some factors that must be taken into account and that complicate the analysis greatly, are the spring constant and damping coefficient of the target. The target will be displaced during impact because it is anchored to the frame by a thick rubber mat. This action effectively causes the system to have a certain amount of spring. Also, though the mat is very dense, it will deform somewhat during impact and will act as shock absorber. In addition, the ball itself also has a spring constant and damping coefficient associated with it, since it bounces off the target and, though not noticeable by the naked eye, will deform during the impact. Finally, and of even greater significance, the mass of the ball, the mass of the target, and the final velocity of the ball are neither known nor measured. So how can the system work?

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The Baseball Pitch Speedometer works by exploiting the fact that the final velocity of the target will be, according to Eq. 1, linearly proportional to the initial velocity of the thrown ball. Therefore, by measuring the acceleration response of the system to various ball velocities, which can be measured by independent means such as a radar gun, the system could be calibrated and a linear model developed. To facilitate the characterization and calibration of the system, a pitching machine was used to ensure that the incident ball speed would be repeatable. It also eliminated potential error caused by the variability of location of impact on the target that would inevitably result from several manual throws. Figure 3shows a linear regression plot of the response of the system as a function of incident velocity. As is indicated by the plot, just a simple constant of proportionality could be used to correlate the measured acceleration response to the incident velocity of the ball, with fairly accurate results.

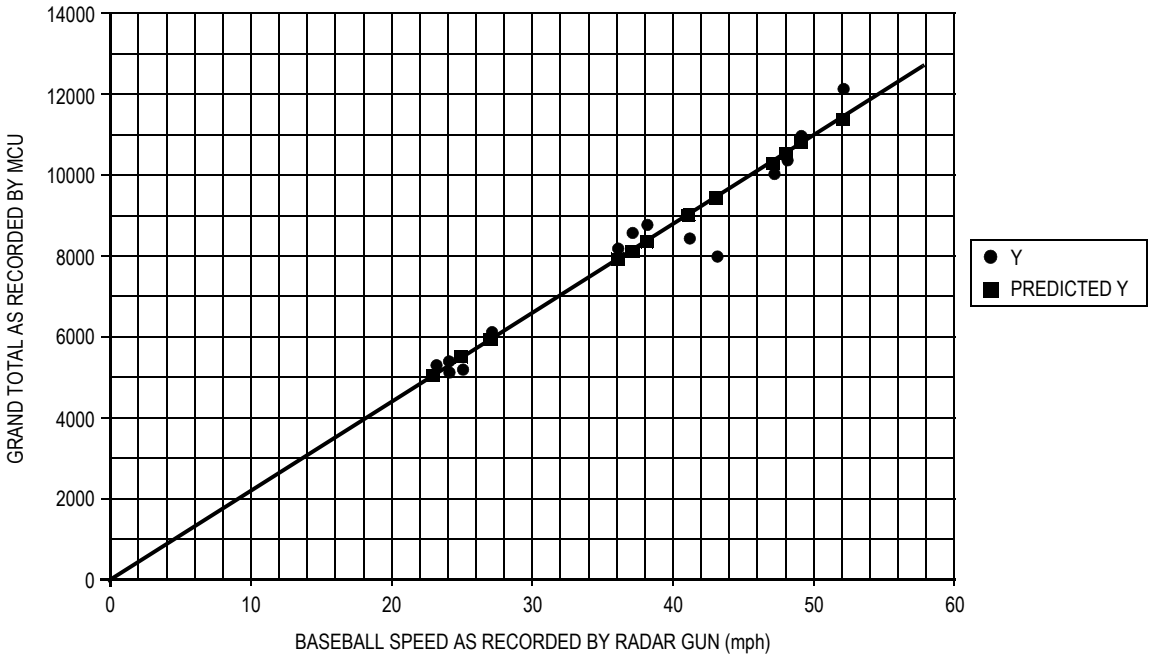

Figure 3. Baseball Pitch Speedometer Characterization Data

IMPLEMENTATION — HARDWARE

The target mat of the Baseball Pitch Speedometer has an area of approximately 9 ft^2 (3 by 3). Even though the rubber material used to construct the target is quite dense and heavy, the transmission of an impact is very poor if the ball strikes the target too far from the sensor. Therefore, to cover such a relatively large area it is necessary to use at least four devices; one centered in each quadrant of the square target. In addition, a shock resistant plate about a quarter inch thick is mounted behind the rubber mat. These features help make the response of the system more uniform and reduce errors that result from the variability of where the ball strikes the target.

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The bulk of the circuit hardware is contained in a display box mounted on the top front side of the cage. Since the accelerometers are physically located far away from the mother board (about 10 feet of wiring), op-amps were used to buffer the accelerometers' output and drive the transmission line. The four accelerometer signals are then simultaneously fed into a comparator network and four of the ADC inputs on an MC68HC11 microcontroller. The MC68HC11 was selected because it has the capability of converting four A/D channels in one conversion sequence and operates at a higher clock speed. These two features reduce the overall time interval between digitizations of the analog signal (that result from the minimum required time for proper A/D conversion and from software latency) thus allowing a more accurate representation of the acceleration waveform to be captured. The comparator network serves a similar purpose by eliminating the additional software algorithm and execution time that would be required to continually monitor the outputs of all four accelerometers and determine whether impact has occurred or not. By minimizing this delay (some is still present since the output signal must exceed a threshold, and a finite amount of time is required for this) more of the initial and more significant part of the signal is captured.

The comparator network employs four LM311's configured to provide an OR function, and a single output is fed into an input capture pin on the MCU. A potentiometer and filter capacitor are used to provide a stable reference threshold voltage to the comparator network. The threshold voltage is set as close as possible to the accelerometers' offset voltage to minimize the delay between ball impact and the triggering of the conversion sequence, but enough clearance must be provided to prevent false triggering due to noise. Because the comparator network is wired such that any one of the accelerometer outputs can trigger it, the threshold voltage must be higher than the highest accelerometer offset voltage. Hysteresis is not necessary for the comparator network, because once the MCU goes into the conversion sequence it ignores the input capture pin.

The system is powered using a commercially available 9 V supply. A Freescale MC7805 voltage regulator is used to provide a steady 5 Volt supply for the operation of the MCU, the accelerometers, the comparator network, and the op-amp buffers. The 9 V supply is directly connected to the common anode 8-segment LED displays. Each segment can draw as much as 30 mA of current. Therefore, to ensure proper operation, the power supply selected to build this circuit should be capable of supplying at least 600 mA. Ports B and C on the MCU are used to drive the LED displays. Each port output pin is connected via a resistor to the base of a BJT, which has the emitter tied to ground. A current limiting resistor is connected between the collector of each BJT and the cathode of the corresponding segment on the display. To minimize the amount of board space consumed by the output driving circuitry, MPQ3904s (quad packaged 2N3904s) were selected instead of the standard discrete 2N3904s. The zero bit on Port C is connected to a combination BJT and MOSFET circuit that drives the “Your Speed” and “Best Speed” LED's. The circuit is wired so that the LED's toggle, and only one can be ON at a time.

Figure 4 shows a schematic of the circuit used. Part (a) shows the accelerometers, the op-amps used to buffer the outputs and drive the transmission lines, the comparator network and the potentiometer used to set the detection threshold. Part (b) shows the MCU, with its minimal required supporting circuitry. Part (c) shows the voltage regulator, a mapping of the cathodes to the corresponding segments on the LED displays, the BJT switch circuitry used to drive the seven segment display LEDs (although not shown on the schematic, this circuit block is actually repeated 15 times), and finally, the circuitry used to drive the “Your Speed”/“Best Speed” LEDs.

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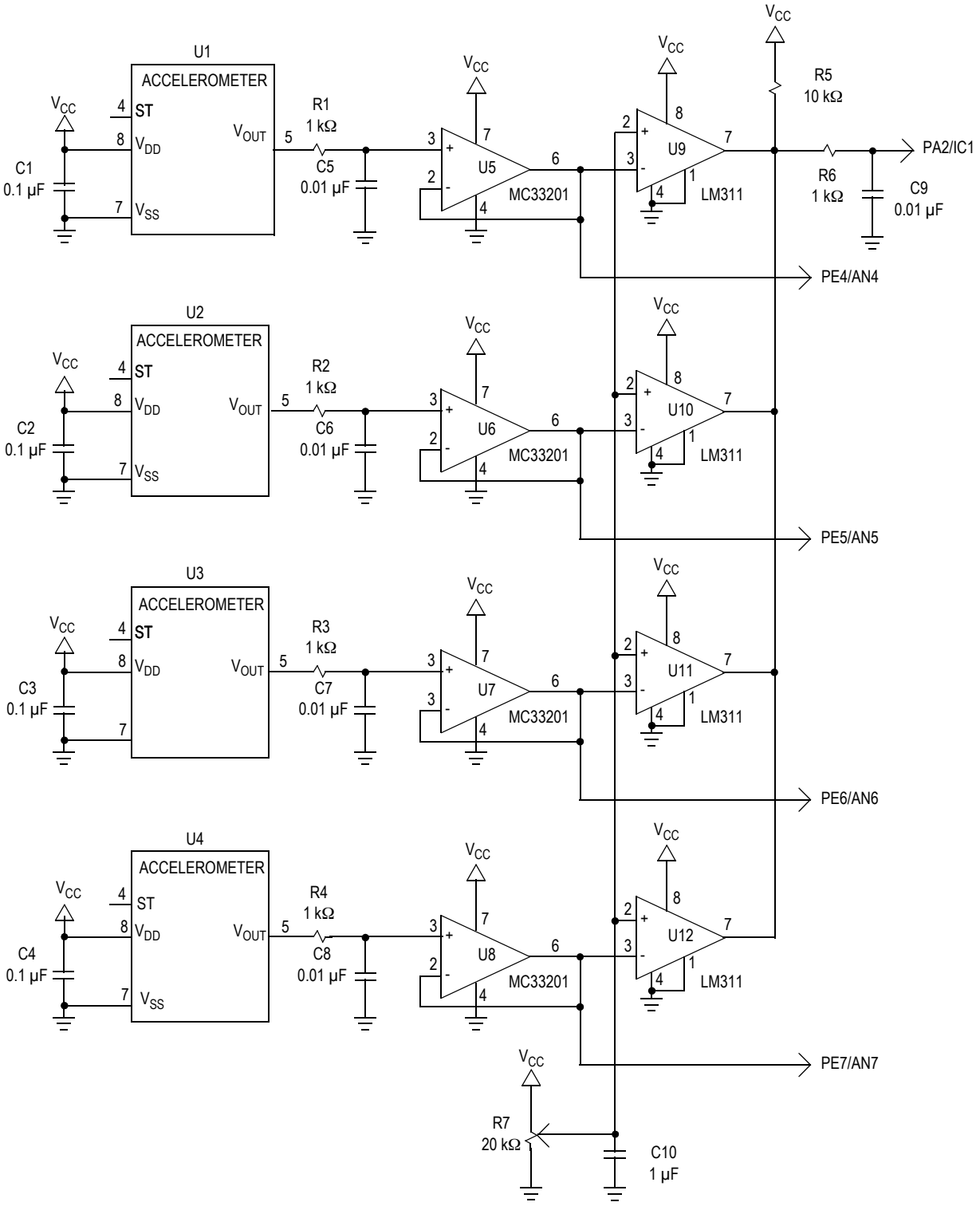

Figure 4a. Accelerometers, Buffer Op-Amps, and Comparator Network

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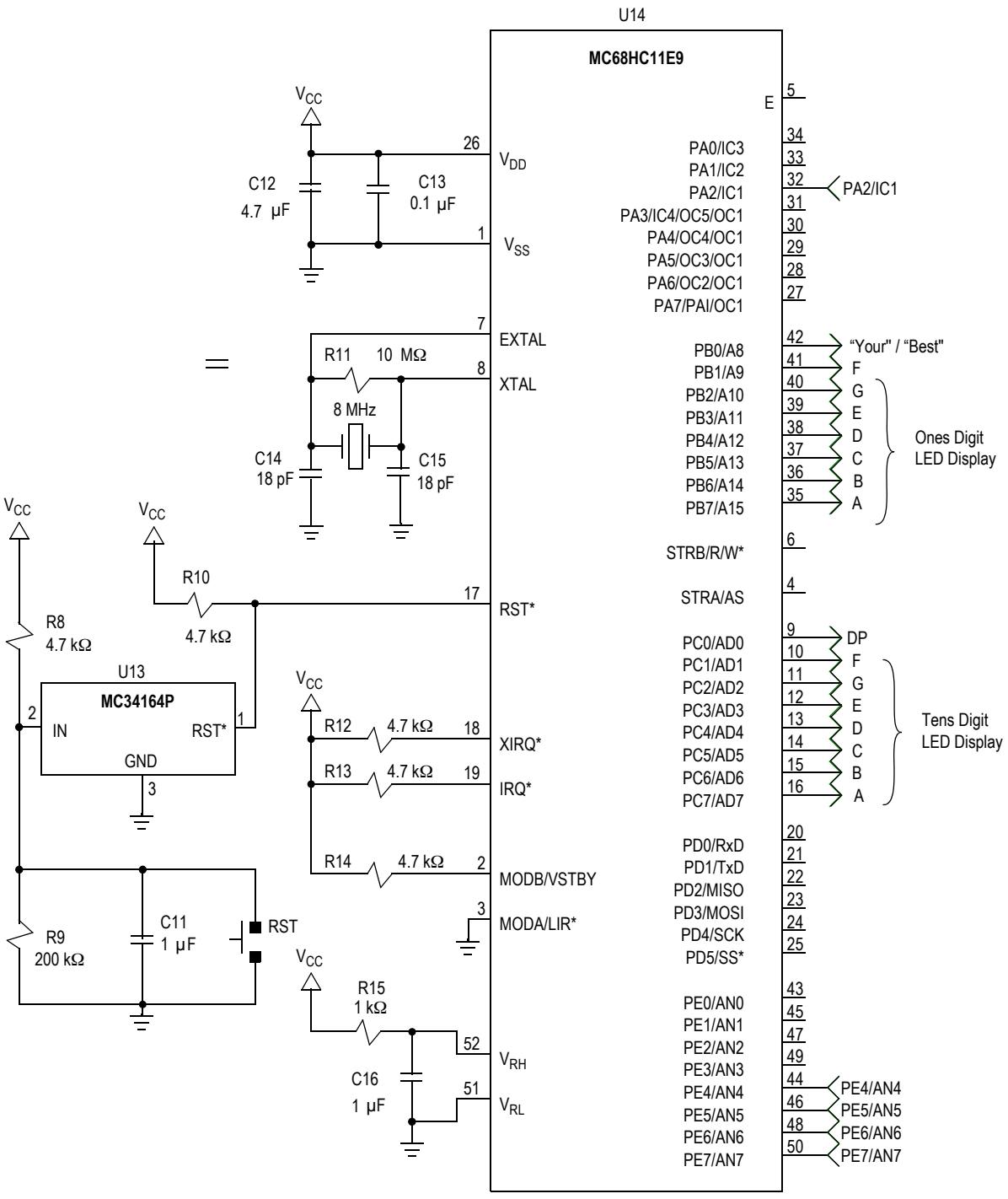

Figure 4b. MC68HC11E9 MCU with Supporting Circuitry

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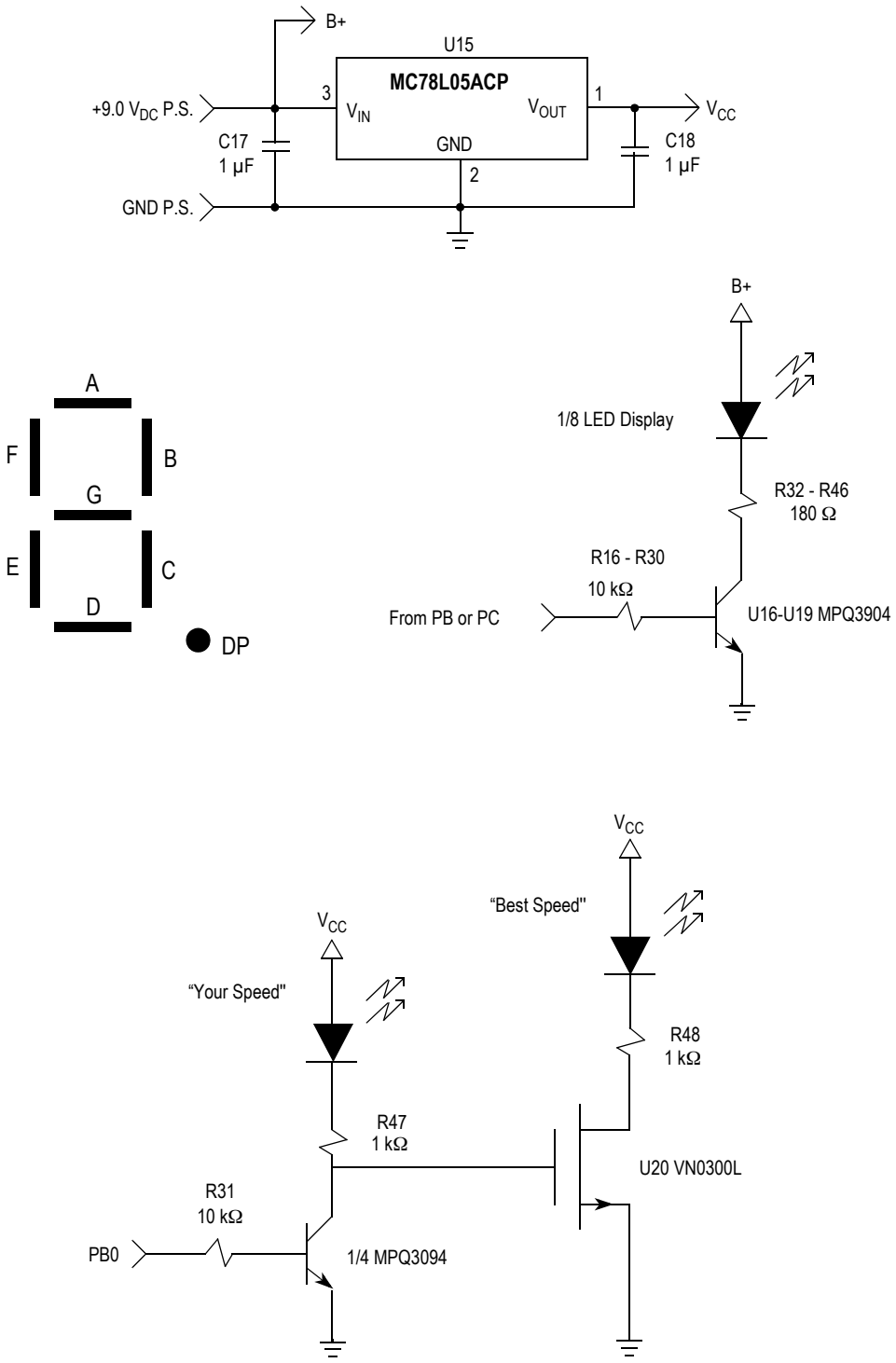

Figure 4c. Voltage Regulator, LED Segment Mapping, and LED Driving Circuitry

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IMPLEMENTATION — SOFTWARE

The operation of the Baseball Pitch Speedometer is very simple. Upon power on reset, the output LEDs are initialized to display 00 and “Best Speed.” The analog to digital converter is turned on and the offset voltages of the accelerometers are measured and stored. Finally, all the variables are initialized and the MCU goes into a dormant state, where it will wait for a negative edge input capture pulse to trigger it to begin processing the crash signal.

Once the input capture flag is set, the MCU will immediately begin the analog to digital conversion sequence. As it digitizes the crash signature, it will calculate the absolute difference between the current value and the stored offset voltage value. It will integrate by summing up all the differences. Figure 2 shows a typical crash signature of the Baseball Pitch Speedometer. As illustrated, starting at the point of impact (A), the acceleration will initially ramp up, reaching a maximum, then decrease as the target is displaced. Because the target is constrained to the frame structure, the acceleration will continue to decrease until it reaches a minimum (point B), which correspond to the travel stop of the target. It is difficult to determine exactly when point B will occur, because the amplitude and duration of the initial acceleration pulse will vary with ball speed. Therefore, the capture window duration is set so that it will encompass most typical crash signatures, while rejecting most of the secondary ripples that result as the energy is dissipated by the system.

After integrating the four signals, the results are added together to produce an overall sum. This procedure averages out the individual responses and reduces measurement error due to the variability of where the ball lands on the target. The MCU then divides the grand sum by an empirically predetermined constant of proportionality. The result will then go through a binary to BCD conversion algorithm. A look-up table is used to match the BCD numbers to their corresponding 7-segment display codes. The calculated speed is displayed on the two digit 8-segment displays (one segment corresponds to the decimal point), and the “Your Speed” LED is turned on while the “Best Speed” LED is turned off. After a duration of approximately five seconds, the LEDs are toggled and stored best speed is redisplayed. The five second delay is used to provide enough time for the user to check his/her speed and also to allow the target to return to a rest state. The system is now ready for another pitch. A complete listing of the software is presented in the Appendix.

CONCLUSION

The Baseball Pitch Speedometer works fairly well, with an accuracy of ±5 mph. The dynamic range of the system is also worthy of note, measuring speeds from less than 10 mph up to well above the 70 mph range. One key point to emphasize, is that the system is empirically calibrated, and so to maintain good accuracy the system should only be used with balls of mass equal to those used during calibration.

Although intended mainly for training and recreational purposes, the Baseball Pitch Speedometer demonstrates a very important concept concerning the use of accelerometers. Accelerometers can be used not only to detect that an event such as impact or motion has occurred, but more importantly they measure the intensity of such events. They can be used to discern between different crash levels and durations. This is very useful in applications where it is desired to have the system respond in accord with the magnitude of the input being monitored. An example application would be a smart air bag system, where the speed at which the bag inflates is proportional to the severity of the crash. The deployment rate of the airbag would be controlled so that it does not throw the occupant back against the seat, thus minimizing the possibility of injury to the occupant. Another application where this concept may be utilized is in car alarms, where the response may range from an increased state of readiness and monitoring, to a full alarm sequence depending on the intensity of the shock sensed by the accelerometer. This could be used to prevent unnecessary firing of the alarm in the event that an animal or person were to inadvertently bump or brush against the automobile.

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APPENDIX — ASSEMBLY CODE LISTING FOR BASEBALL PITCH SPEEDOMETER

```
* Baseball Pitch Speedometer - Rev. 1.0
*
* Program waits for detection of impact via the input capture pin and then reads four A/D channels.
* The area under the Acceleration vs. Time curve is found by subtracting the steady state offsets
* from the digitized readings and summing the results.  The sum is then divided by an empirically
* determined constant of proportionality, and the speed of the ball is displayed.
*
* Written by Carlos Miranda
* Systems and Applications
* Sensor Products Division
* Freescale Semiconductor Products Sector
* May 6, 1997
*
*
*****************************************************************************************************
*        Although the information contained herein, as well as any information provided relative       *
*        thereto, has been carefully reviewed and is believed accurate, Freescale assumes no            *
*        liability arising out of its application or use, neither does it convey any license under     *
*        its patent rights nor the rights of others.                                                   *
*****************************************************************************************************
* These equates assign memory addresses to variables.
EEPROM          EQU             $B600
CODEBGN         EQU             $B60D
REGOFF          EQU             $1000   ;Offset to access registers beyond direct addressing range.
PORTC           EQU             $03
PORTB           EQU             $04
DDRC            EQU             $07
TCTL2           EQU             $21
TFLG1           EQU             $23
ADCTL           EQU             $30
ADR1            EQU             $31
ADR2            EQU             $32
ADR3            EQU             $33
ADR4            EQU             $34
OPTION          EQU             $39
STACK           EQU             $01FF   ;Starting address for the Stack Pointer.
RAM             EQU             $0000
* These equates assign specific masks to variables to facilitate bit setting, clearing, etc.
ADPU            EQU             $80     ;Power up the analog to digital converter circuitry.
CSEL            EQU             $40     ;Select the internal system clock.
CCF             EQU             $80     ;Conversion complete flag.
IC1F            EQU             $04     ;Input Capture 1 flag.
IC1FLE          EQU             $20     ;Configure Input Capture 1 to detect falling edges only.
IC1FCLR         EQU             $FB     ;Clear the Input Capture 1 flag.
CHNLS47         EQU             $14     ;Select channels 4 through 7 with MULT option ON.
SAMPLES         EQU             $0200   ;Number of A/D samples taken.
OC1F            EQU             $80     ;Output Compare 1 flag.
OC1FCLR         EQU             $7F     ;Clear the Output Compare flag.
CURDLY          EQU             $0098   ;Timer cycles to create delay for displaying "Your Speed."
RAMBYTS         EQU             $19     ;Number of RAM variables to clear during initialization.
ALLONES         EQU             $FF
YOURSPD         EQU             $01
PRPFCTR         EQU             $00AD   ;This constant of proportionality was empirically determined.
* Variables used for computation.
                ORG             RAM
OFFSET1         RMB             1       ;One for each accelerometer.
OFFSET2         RMB             1
OFFSET3         RMB             1
OFFSET4         RMB             1
SUM1            RMB             2       ;Area under the acceleration vs. time curve.
SUM2            RMB             2
SUM3            RMB             2
SUM4            RMB             2
GRNDSUM         RMB             2
COUNT           RMB             2
CURBIN          RMB             1
TEMPBIN         RMB             1
BCD             RMB             2
CURDSPL         RMB             2
MAXBIN          RMB             1
MAXDSPL         RMB             2
* LED seven segment display patterns table.
                ORG             EEPROM
```


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```
                JMP             START
SEVSEG          FCB             %11111010
                FCB             %01100000
                FCB             %11011100
                FCB             %11110100
                FCB             %01100110
                FCB             %10110110
                FCB             %10111110
                FCB             %11100000
                FCB             %11111110
                FCB             %11100110
* This is the main program loop.
                ORG             CODEBGN
START           LDS             #STACK
                LDX             #REGOFF
                JSR             LEDINIT
                JSR             ADCINIT
                JSR             VARINIT
MAIN            JSR             CAPTURE
                JSR             COMPUTE
                JSR             BINTBCD
                JSR             OUTPUT
                BRA             MAIN
* This subroutine initializes ports B & C, and the LED display.
LEDINIT         PSHX
                PSHA
                LDX             #REGOFF
                BSET            DDRC,X,ALLONES          ;Configure port C as an output.
                LDAA            SEVSEG
                STAA            PORTB,X
                STAA            PORTC,X
                PULA
                PULX
                RTS
* This subroutine initializes the analog to digital converter.
ADCINIT         PSHX
                PSHA
                LDX             #REGOFF
                BSET            OPTION,X,ADPU           ;Turn on A/D converter via ADPU bit.
                BCLR            OPTION,X,CSEL           ;Select system e clock via CSEL bit.
                CLRA
DELAY           INCA
                BNE             DELAY
                PULA
                PULX
                RTS
* This subroutine clears all the memory variables.
VARINIT         PSHX
                LDX             #$0000
CLRVAR          CLR             OFFSET1,X
                INX
                CPX             #RAMBYTS                ;Number of RMB bytes.
                BLO             CLRVAR
DONECLR         LDX             #REGOFF
                LDAA            #CHNLS47                ;Measure the offset.
                STAA            ADCTL,X
OFSWAIT         BRCLR           ADCTL,X,CCF,OFSWAIT
                LDD             ADR1,X
                STD             OFFSET1
                LDD             ADR3,X
                STD             OFFSET3
                PULX
                RTS
* This subroutine waits for impact and computes the area under the curve.
CAPTURE         PSHX
                PSHA
                PSHB
                LDX             #REGOFF
                BSET            TCTL2,X,IC1FLE          ;Set IC1 to detect falling edge only.
                BCLR            TFLG1,X,IC1FCLR
MONITOR         BRCLR           TFLG1,X,IC1F,MONITOR
ADCREAD         LDAA            #CHNLS47                ;Select channels 4 - 7 for conversion.
                STAA            ADCTL,X
ADCWAIT         BRCLR           ADCTL,X,CCF,ADCWAIT
CALDLT1         LDAB            ADR1,X
```


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```
                SUBB                    OFFSET1
                BPL                     ADDSUM1
                COMB
                INCB
ADDSUM1         CLRA
                ADDD                    SUM1
                STD                     SUM1
CALDLT2         LDAB                    ADR2,X
                SUBB                    OFFSET2
                BPL                     ADDSUM2
                COMB
                INCB
ADDSUM2         CLRA
                ADDD                    SUM2
                STD                     SUM2
CALDLT3         LDAB                    ADR3,X
                SUBB                    OFFSET3
                BPL                     ADDSUM3
                COMB
                INCB
ADDSUM3         CLRA
                ADDD                    SUM3
                STD                     SUM3
CALDLT4         LDAB                    ADR4,X
                SUBB                    OFFSET4
                BPL                     ADDSUM4
                COMB
                INCB
ADDSUM4         CLRA
                ADDD                    SUM4
                STD                     SUM4
                LDD                     COUNT
                ADDD                    #$0001
                STD                     COUNT
                CPD                     #SAMPLES
                BLO                     ADCREAD
                PULB
                PULA
                PULX
                RTS
* This subroutine computes the ball speed by dividing the overall sum by a constant.
COMPUTE         PSHX
                PSHA
                PSHB
                LDD                     SUM1
                ADDD                    SUM2
                ADDD                    SUM3
                ADDD                    SUM4
                STD                     GRNDSUM
                LDX                     #PRPFCTR
                IDIV
                XGDX
                STAB                    CURBIN
                PULB
                PULA
                PULX
                RTS
* This subroutine converts from binary to BCD. (Limited to number up to 99 decimal.)
BINTBCD         PSHX
                PSHA
                PSHB
                LDX                     #$0000
                LDAA                    CURBIN
                STAA                    TEMPBIN
                CLRA
                CLRB
BINSHFT         LSL                     TEMPBIN
                ROLB
                LSLA
                CMPB                    #$10
                BLO                     CHKDONE
                INCA
                ANDB                    #$0F
CHKDONE         INX
                CPX                     #$0008
```


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```
                BEQ                     RAILAT9
CHKFIVE         CMPB                    #$05
                BLO                     BINSHFT
                ADDB                    #$03
                BRA                     BINSHFT
RAILAT9         CMPA                    #$09            ;Force the display to “99" if speed > 100 mph.
                BLS                     DONE
                LDD                     #$0909
DONE            STD                     BCD
                LDX                     #SEVSEG         ;This part finds the seven segment display codes.
                XGDX
                ADDB                    BCD
                XGDX
                LDAA                    $00,X
                STAA                    CURDSPL
                LDX                     #SEVSEG
                XGDX
                ADDB                    BCD+1
                XGDX
                LDAA                    $00,X
                STAA                    CURDSPL+1
                PULB
                PULA
                PULX
                RTS
* This subroutine displays the current speed for 5 seconds & then displays the maximum.
OUTPUT          PSHX
                PSHA
                PSHB
LDX             #REGOFF
                LDAA                    CURBIN
                CMPA                    MAXBIN
                BLS                     OLDMAX
                STAA                    MAXBIN
                LDD                     CURDSPL
                STD                     MAXDSPL
OLDMAX          LDD                     CURDSPL
                STD                     PORTC,X
                BSET                    PORTB,X,YOURSPD             ;Toggle the "YOUR"/“BEST” LEDs.
                LDD                     #$0000
LEDWAIT         BCLR                    TFLG1,X,OC1FCLR             ;Clear output compare 1 flag.
DSPLDLY         BRCLR                   TFLG1,X,OC1F,DSPLDLY
                ADDD                    #$0001
                CPD                     #CURDLY                     ;Decimal 152. (152 * 33ms = 5.0 sec)
                BLO                     LEDWAIT
                LDX                     #$0000
RECLEAR         CLR                     SUM1,X          ;Clear 12 RAM bytes beginning at address "SUM1".
                INX                                     ;Clears SUM1 thru SUM4, GRNDSUM, and COUNT.
                CPX                     #$000C
                BLO                     RECLEAR
                LDX                     #REGOFF
                LDD                     MAXDSPL
                STD                     PORTC,X         ;The "YOUR"/“BEST” LEDS are automatically toggled.
                PULB
                PULA
                PULX
                RTS
```

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Reducing Accelerometer Susceptibility to BCI

by: Brandon Loggins

INTRODUCTION

Automobile manufacturers require all system electronics to pass stringent electromagnetic compatibility (EMC) tests. Airbag systems are one of the systems that must perform adequately under EMC tests. There are different types of tests for EMC, one of which is testing the tolerance of the system to high frequency conducted emissions. One of the most stringent methods for EMC evaluation is the Bulk Current Injection (BCI) test. The entire airbag system must continue to function normally throughout the BCI test. This application note will discuss how to reduce susceptibility to BCI for the Freescale accelerometer but the information presented here can be applied to other electronic components in the system.

BCI TEST SETUP

The BCI test procedure follows a published SAE engineering standard, “Immunity to Radiated Electric Fields ~ Bulk Current Injection (BCI)”, or SAE J 1113/401. For an airbag module, this involves injecting the desired current into the wiring harness by controlling current in the injection probe. The test frequency can vary from one to several hundred MHz. There are at least 20 frequency steps per octave required for the test, but as many as 50 steps per octave can be used. The injection probe is placed on the harness in one of three distances from the airbag module connector: 120, 450 and 750 mm. There is a monitor pickup probe present to measure the amount of current being injected. It is placed 50 mm from the airbag module. This feeds back to the system to ensure that the desired test current is being injected on to the wiring harness. Figure 1 shows the setup for the BCI test. (For more details, see the SAE J 1113/401 Test Procedure).

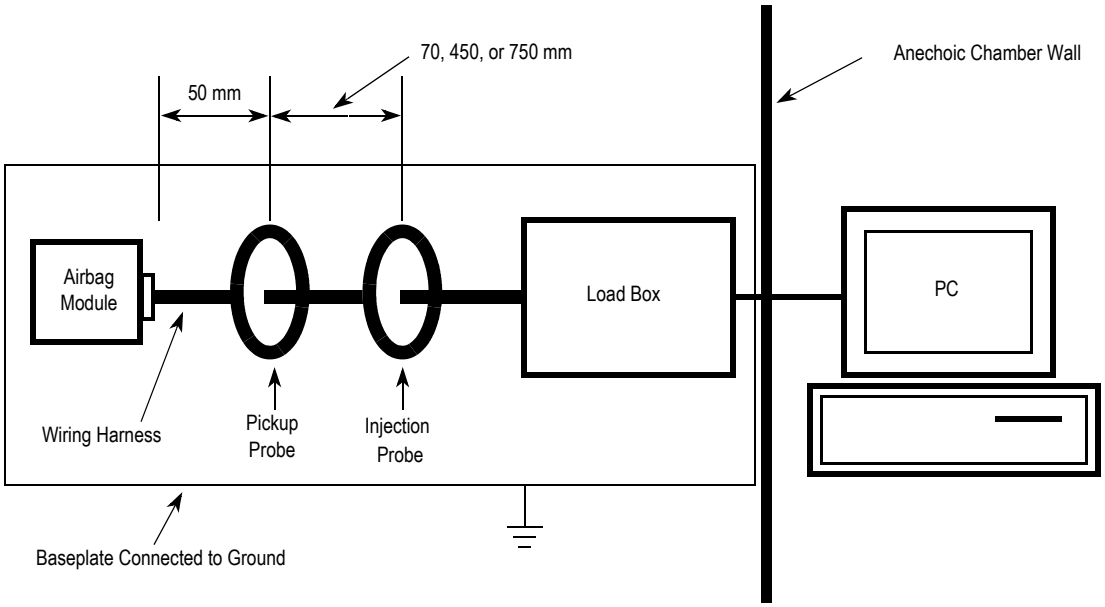

Figure 1. BCI Test Setup

The harness connects the airbag module to a load box. This load box provides simulated loads for terminating the remainder of the airbag system (firing ignitors, etc.). The data coming back is translated from J1850 to RS232 to be communicated to a dummy terminal on a PC. For safety reasons, this test is typically performed inside an anechoic chamber to shield high frequency emissions from equipment and humans.

BCI TEST PROCEDURE FOR THE MMA2202D ACCELEROMETER

The accelerometer is evaluated in the following manner. In an airbag system, the microcontroller's A/D converter digitizes the accelerometer output. The microcontroller sends this value to the communication ASIC which translates the logic from board level logic to RS232, then sends the value back along the wiring harness. Once through the chamber wall, the data is translated to RS232 and fed to a dummy terminal. On the terminal screen, the A/D codes for the accelerometer can be monitored for unexpected performance.

Ideally, when the accelerometer is at rest (no acceleration applied), the output should be at 0*g*, regardless of what EMC testing the system may be subjected to. Depending on the crash algorithm of the airbag module software, there is some allowable offset shift that can be tolerated. Higher shift in output could create errors in the crash analysis software, perhaps causing the airbags to unnecessarily deploy when there is not a crash or not deploy when there is a crash.

The accelerometer must be able to meet the airbag system requirements throughout BCI exposure. It has a sensitivity of 40 mV/g and an offset (0*g* output) of 2.50 V. During the BCI test, the accelerometer output should be 2.50 V at 0*g* with as little drift as possible. A typical airbag system may have software that can tolerate from as little as 0.5 *g* up to 2.0 *g*. of deviation from the offset. The system would then expect the accelerometer output to be within 40 mV of the offset during the entire BCI test. Therefore, at any given frequency of the BCI test, if the output deviates outside this expected window of drift, it fails the test.

MMA2202D ACCELEROMETER BCI TEST RESULTS

If a system has not been well designed for electromagnetic compatibility, the accelerometer, as well as other devices, can have performance problems. What has been found for the accelerometer is that in some system applications, it suffers from an offset shift when certain frequencies of BCI are applied. For example, in one airbag system being tested at a certain frequency, with the desired BCI current applied, the offset is found to shift down by 60 mV. This would equate to an error of 1.5 *g*. See Figure 2. At other frequencies, this shift is even higher. This DC shift plot was taken with an oscilloscope using a 20 MHz filter to remove the high frequency component of the signal. Probes are placed at the accelerometer in the system application. The plot shows the accelerometer output before and after BCI was applied (before and after the RF generator creating the high frequency signal was turned on).

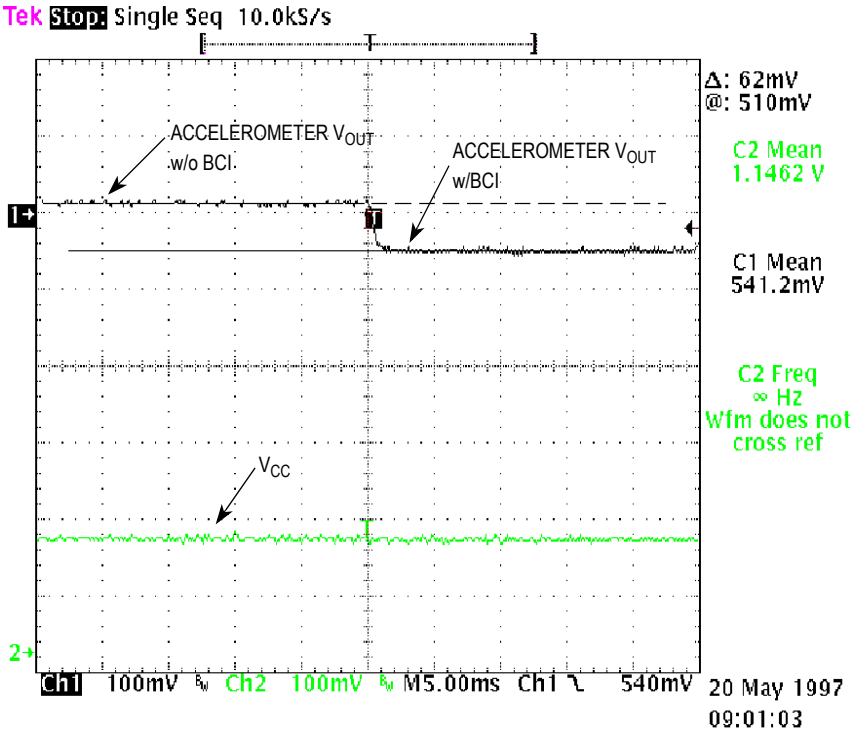

Figure 2. Accelerometer Tested Under High Frequency BCI

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This phenomenon has been determined to be system level related. PCB layout and grounding for the accelerometer will affect its performance. This was found by testing the accelerometer outside of the airbag module. The device was put on a test board by itself with only the supply decoupling capacitor of 0.1 μF connected to it. To simulate the effect of BCI on V_{CC}, a frequency generator was used to inject a known high frequency sinusoid that caused BCI failure on to the 5.0 V supply voltage. The device was first tested in small test board with ground provided by one wire back to the supply. This grounding reproduced the failure due to BCI seen at the module level. The test board was then mounted down to a ground plane provided by a copper plate and the accelerometer ground was soldered to the plate (providing a low impedance path to ground). With this setup, the offset shift did not occur.

If a system does not incorporate a good PCB layout providing a low impedance to ground, the accelerometer output may shift at certain high frequencies. This output offset shift was caused by a shift in the 0-5.0 V supply window. Because the accelerometer has a ratiometric output, its offset is dependent on the supply voltage. Any change in the supply voltage will result in the same proportional change in the output. For example, if the 5.0 V supply were to change by 10%, from 5.0 V to 5.5 V, the accelerometer offset will change by 10% also, from 2.5 V to 2.75 V. This phenomena would also occur if the ground were to shift. A 100 mV change in ground would result in a 50 mV change in the output. If the accelerometer does not have low impedance path to ground and parasitics from a poor ground are present as a result, the ground seen by the accelerometer may change over frequency. So, during a BCI test, if the 5.0 V supply does not shift but the output of the accelerometer does, the ground to the accelerometer may be moving.

It was found with some experimentation that the offset shift can be eliminated with proper board layout techniques as described below.

PROPER LAYOUT TECHNIQUES

Since the accelerometer is a sensitive analog device that relies on a clean supply to function within established parameters, there are some techniques that can be employed to minimize the effects of BCI on the accelerometer performance. PCB layout is paramount to reducing susceptibility to BCI.

- A low impedance path to ground will provide shunting of the high frequency interference and minimize its effect on the accelerometer. The best way to provide a good path is by putting a solid, unbroken ground plane in the PCB. This ground plane should be shunted to chassis ground at the module connector. This will ensure that the high frequency BCI will be shunted before interfering with accelerometer performance.
- All accelerometer pins that require ground connection should be tied together to a common ground.
- Traces attached directly to the connector pins can receive high RF noise, which can couple to nearby traces and components. Increasing series impedance of the traces helps reduce the couple or conducted noise. High frequency filters on the supply line and other susceptible lines may be required to filter out high frequency interference introduced by the BCI test. Signal lines that carry low current can tolerate series resistances of 100-200 Ω.
- Decoupling capacitors on every input line to the common ground plane will help shunt the high frequency away from the system. These should be placed near the connector.
- Signal trace lengths to and from the accelerometer should be kept at a minimum. The shorter the trace, the less chance it has of picking up high frequency BCI signals as it crosses the board. Trace lengths can be reduced by placing the accelerometer and the microcontroller as close together as possible. Signal and ground traces looping should be minimized.
- A decoupling capacitor on the accelerometer Vcc pin will also help minimize BCI effects. The recommended value is 0.1 μF. This capacitor should be placed as close as possible to the accelerometer to achieve the best results.
- To maximize ratiometricity, the accelerometer Vcc and the microcontroller A/D reference pin should be on the same trace. The accelerometer ground and the microcontroller ground should also share the same ground point. Therefore, when there is signal interference due to BCI, the A/D converter and the accelerometer will see the interference at the same level. This will result in the same digital code representation of acceleration without signal interference.
- A clean power supply to both the accelerometer and the microcontroller should be provided. Supply traces should avoid high current traces that might carry high RF currents during the BCI test. The traces should be as short as possible.
- The accelerometer should be placed on the opposite end of the PCB away from the connector. The farther the distance, the lower the chance high frequency RF from BCI will interfere with the accelerometer.
- The accelerometer should be placed away from high current paths that may carry high RF currents during the BCI test.

Automotive customers will continue to require airbag systems to have high standards for EMC. One way to test for EMC is perform the Bulk Current Injection test. Because of the high current involved, BCI is one of the most difficult EMC tests to pass. Being part of the airbag system, the accelerometer must continue to function normally under application of high frequency BCI. The accelerometer is highly sensitive to placement on the board and its connection to ground. Poor design will caused the device to fail the BCI test. The practice of good PCB layout, device placement and good grounding will allow the accelerometer to function within specification and pass the BCI test.

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Using an Accelerometer Evaluation Board

by: Leticia Gomez and Raul Figueroa
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INTRODUCTION

This application note describes the Accelerometer Evaluation Board. The accelerometer evaluation boards are small circuit boards intended to serve as aids in system designs with the capability for mounting and quickly evaluating the low g devices. It also provides a means for understanding the best mounting position and location of an accelerometer in your product.

CIRCUIT DESCRIPTION

Figure 2 and Figure 3 are circuit schematics of the single and dual-axis evaluation boards respectively. The recommended decoupling capacitor at the power source and recommended RC filter at the output, are included on the evaluation board. This RC filter at the output of the accelerometer minimizes clock noise that may be present from the switched capacitor filter circuit. No additional components are necessary to use the evaluation board.

Refer to the respective datasheet of the device being used for specifications and technical operation of a specific accelerometer.

POWER HEADER ON LOW G SINGLE AXIS EVALUATION BOARDS

The power header provides a means for connecting to the accelerometer analog output through a wire to another breadboard or system. Four through-hole sockets are included to allow access to the following signals: VDD, GND, ST and STATUS. These sockets can be used as test points or as means for connecting to other hardware.

The ON/OFF switch (S1) provides power to the accelerometer and helps preserve battery life if a battery is being used as the power source. S1 must be set towards the ON position for the accelerometer to function. The green LED (D1) is lit when power is supplied to the accelerometer.

A self-test pushbutton (S2) on the evaluation board is a self-test feature that provides verification of the mechanical and electrical integrity of the accelerometer. The STATUS pin is an output from the fault latch and is set high if one of the fault conditions exists. A second pressing of the pushbutton (S2) resets the fault latch, unless of course one or more fault conditions continue to exist.

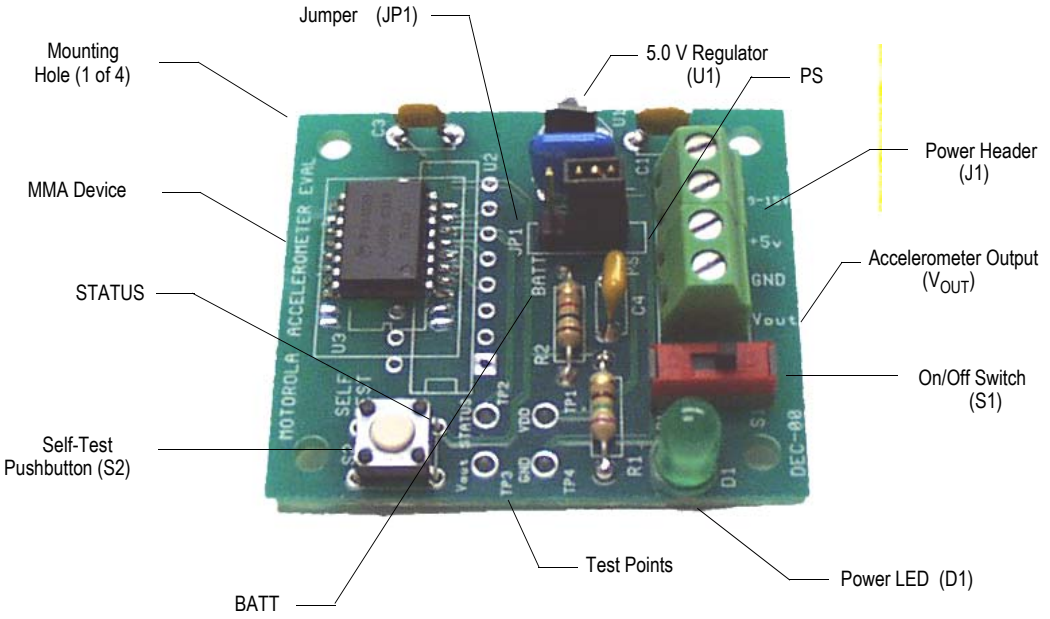

Figure 1. MMA1250D, MMA1260D, MMA1270D and MMA2260D Accelerometer Evaluation Board

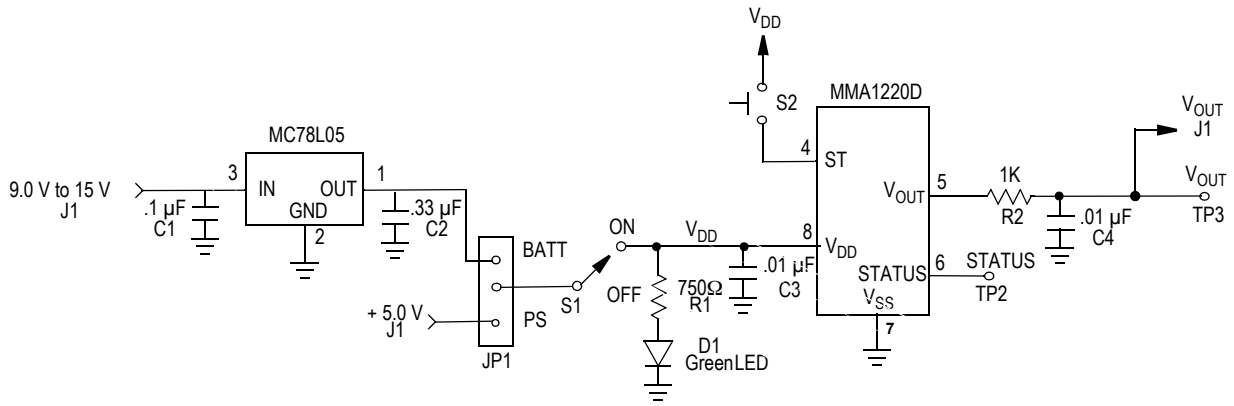

Figure 2. MMA1250D, MMA1260D, MMA1270D and MMA2260D Evaluation Board Circuit Schematics

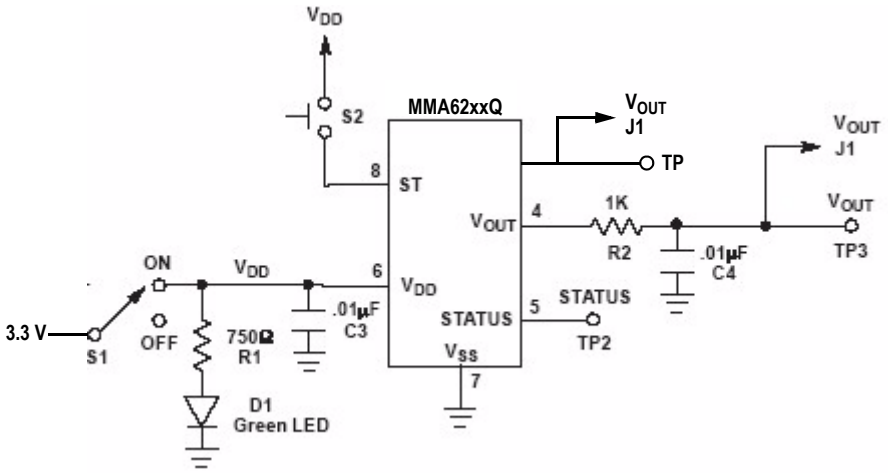

Figure 3. MMA6200Q Series Evaluation Board Circuit Schematic

OPTIONAL SOCKET MOUNTING

The board allows for direct mounting of a 16-pin DIP or SOIC package. For the SOIC device, a 20-pin test socket is used to allow for evaluation of more than one device without soldering directly to the board and potentially damaging the PCB. Care must be taken in placing the device correctly in the socket as four pins of the socket will not be used. With the board oriented as shown in Figure 3, Pin 1 should face downward and the device should be positioned toward the top of the test socket, thereby exposing the bottom four pins of the test socket. The socket is marked to help identify the four unused socket pins. Lids to secure the device in the socket are included with the board and delicately snap into place. The lids can be removed by applying pressure to the sides of the lid or by lifting the top and bottom snaps of the lid.

The evaluation board has a 4-pin header (J1 in Figure 1) for interfacing to a 5 volt power source or a 9 to 15 volt power source (for example, 9 V battery). Jumper JP1 (see Figure 1) must have the following placement: on PS if a 5 V supply is being used or on BATT if a 9 V to 15 V supply is used. A 5 V regulator (U1 in Figure 1) supplies the necessary power for the accelerometer in the BATT option.

Table 1. Pin Out Description

Pin	Name	Description
4	ST	Logic input pin to initiate self-test
5	V_{OUT}	Output voltage of the accelerometer
6	STATUS	Logic output pin to indicate fault
7	V_{SS}	Power supply ground
8	V_{DD}	Power supply input

Board Layout and Content

Figure 4 and Figure 5 show the layout used on the evaluation board. Through-hole mounting components have been selected to facilitate component replacement.

Mounting Considerations

System design and sensor mounting can affect the response of a sensor system. The placement of the sensor itself is critical to obtaining the desired measurements. It is important that the sensor be mounted as rigidly as possible to obtain accurate results. Since the thickness and mounting of the board varies, parasitic resonance may distort the sensor

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measurement. Hence, it is vital to fasten and secure to the largest mass structure of the system, i.e. the largest truss, the largest mass, the point closest to source of vibration. On the other hand, dampening of the sensor device can absorb much of the vibration and give false readings as well. The evaluation board has holes on the four corners of the board for mounting. It is important to maintain a secure mounting scheme to capture the true motion.

Orientation of the sensor is also crucial. For best results, align the sensitive axis of the accelerometer to the axis of vibration. In the case of the MMA1220D, the sensitive axis is perpendicular to the plane of the evaluation board.

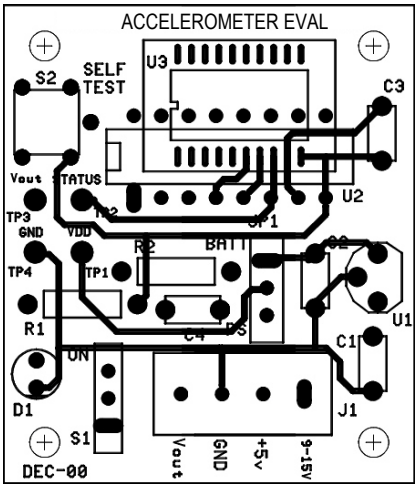

Figure 4. Board Layout (Component Side)

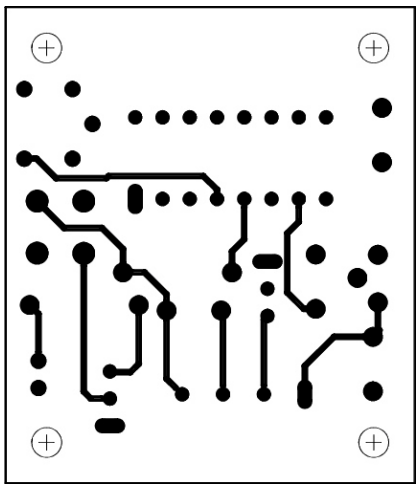

Figure 5. Board Layout (Back Side)

ORDERING INFORMATION

The Accelerometer Evaluation Boards are available to order as Evaluation Kits. Each kit includes an Evaluation Board with the accelerometer in an anti–static bag, a sensor repository CD that contains sensor brochures, data sheets, and the revised data book, and instructions for using the Evaluation Board.

Table 2 shows the kits that are available, or will be available soon. Check our website for availability.

SUMMARY

The Accelerometer Evaluation Board is a design-in tool for customers seeking to quickly evaluate an accelerometer in terms of output signal, device orientation, and mounting considerations. Both through-hole and surface mount packages can be evaluated. With the battery supply option and corner perforations, the board can easily be mounted on the end product; such as a motor or a piece of equipment. Easy access to the main pins allows for effortless interfacing to a microcontroller or other system electronics. The simplicity of this evaluation board provides reduced development time and assists in selecting the best accelerometer for the application.

Table 2. Evaluation Kits Order Information

Part Number	G Range	Axis
Kit1925MMA1250D	5.0g	Z
Kit1925MMA1260D	1.5g	Z
Kit1925MMA1270D	2.5g	Z
Kit1925MMA2260D	1.5g	X
Kit1925MMA6260Q	1.5g	XY, 50 Hz
Kit1925MMA6261Q	1.5g	XY, 300 Hz
Kit1925MMA6262Q	1.5g	XY, 150 Hz
Kit1925MMA6263Q	1.5g	XY, 900 Hz
Kit1925MMA6231Q	1.5g	XY, 300 Hz
Kit1925MMA6233Q	1.5g	XY, 900 Hz

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±1.5g Dual Axis Micromachined Accelerometer Power Supply Rejection Ratio (PSRR) Suggestions

by: Peter Schultz
Product Engineer

COMPONENT DESCRIPTION

The MMA6200Q series is a two axis (X and Y) accelerometer family with sensitivity parallel to the device's mounting plane. The device utilizes variable capacitance sensing elements and a two-channel interface IC all in a 16-pin QFN package.

This section provides a general description of the device power supply rejection ratio (PSRR), how it affects device performance, and suggestions for improvement.

INTRODUCTION TO POWER SUPPLY

Rejection Ratio

The power supply rejection ratio is a measure of how well the device rejects the noise on the power supply line. The MMA6200Q series is capable of being used in several different applications. In some cases it may be possible for supply line noise to adversely affect the output signal. This phenomenon can create large output signals when the supply line noise frequencies are roughly equal to the device's oscillator frequency and/or harmonics. The oscillator drives the g-cell sampling as well as the internal low pass filter. When the difference between the frequency of the noise on the supply and the oscillator frequency is less than the low pass filter cutoff frequency the aliased signal passes through the filter. This aliased signal is then amplified internally by the device creating an even more adverse effect. This noise at the output can be as much as ten times the amplitude of the input noise at the oscillator frequency or its harmonics.

IMPROVING THE POWER SUPPLY

Rejection Ratio

If the power supply contains noise approaching the oscillator frequency, large amounts of noise may be observed at the output of the device. This does not become an issue until the noise frequency is a little larger than the oscillator frequency; a little larger here meaning still within the internal low pass filter's bandwidth. In application a simple low pass filter at the input helped to resolve this issue by attenuating much of the offending noise before it enters the device.

A simple two element low pass filter at the input of the device, made up of a resistor in series with a capacitor in shunt with V_{dd}, works rather well (see Figure 1).

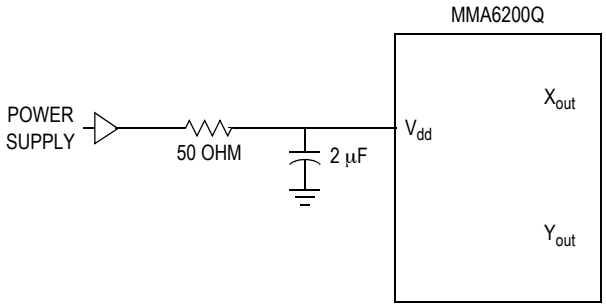

Figure 1. RC Input Loading for PSRR at V_{dd}

With this combination of a 50 ohm resistor and a 2 μF capacitor there is a large reduction in the PSRR, roughly 10X. This is now well below unity gain; meaning at the output of the device there is noticeably less noise than was supplied to the device, at the oscillator frequency and/or its harmonics. The first harmonic is at the oscillator frequency of roughly 15 KHz. The following illustration shows the effect on the PSRR when placing different values of capacitance at the input and retaining the 50 ohm resistor. There is six harmonics represented in the illustration the first of which is at about 15 KHz. These data points at the different harmonics represent the ratio of the output noise to the input noise. Depending on the application needs one can use this illustration to help determine the capacitive needs for the filter (see Figure 2). The plot is given in Log scale.

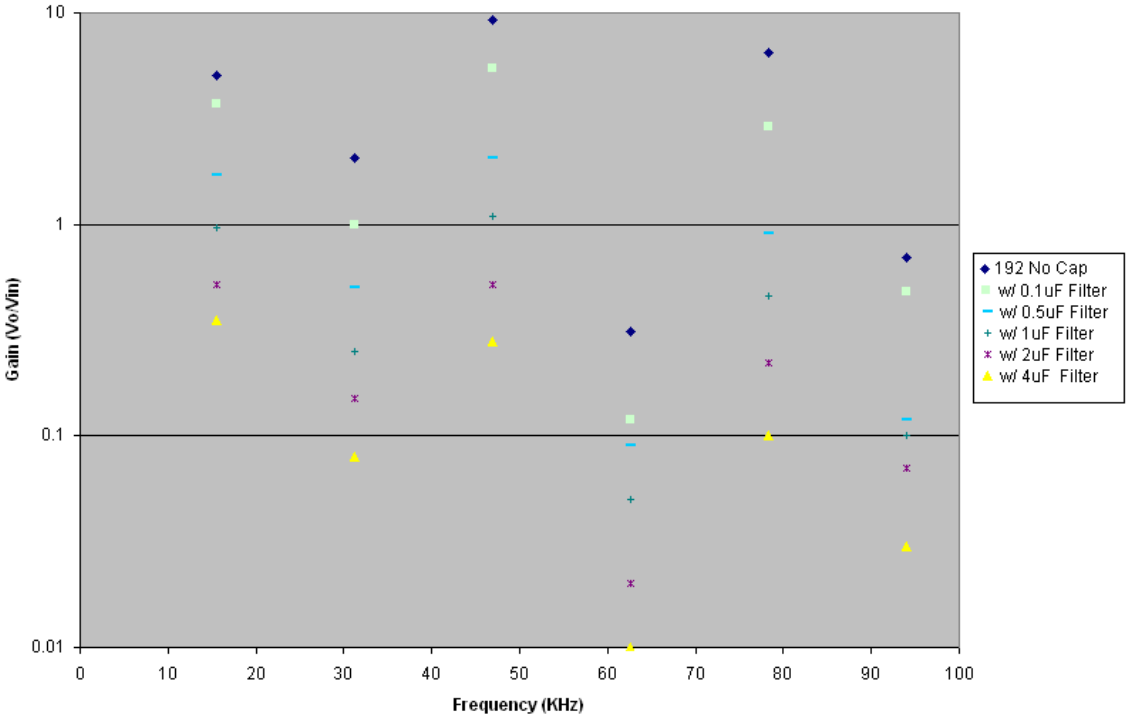

Figure 2. PSRR with 50 Ohm and Varying Input Capacitance

One can see the PSRR has improved by roughly a factor of 10 with a 2 μF capacitor at the input. Not only can the plot be used as a guide in the design of an input filter, it can also help put in perspective the possible amplitudes of the signal and about what frequencies they may occur. From looking at the plot one can see that for a capacitance of 1uF the gains at the two most predominate noise frequencies is unity. This means the aliased signals will not be larger in amplitude than the input noise that created it; giving the recommended smaller capacitance filter in the following illustration (see Figure 3).

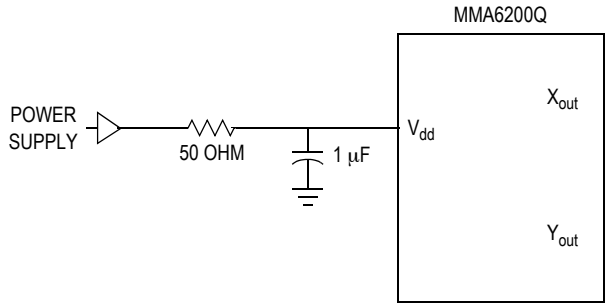

Figure 3. Recommended RC Input Loading for PSRR at V_{dd}

With cost as one of the deciding factors, this is a recommended filter design for reducing the PSRR. One should note however that variations in the individual devices and the different axes of the device produce plots that may look significantly different. The intent here is only to give an idea of the effects of different capacitances on the oscillator induced frequency gains. One must also remember to absorb any impedance the source may have into the RC filter as the source will also add its own impedance to the network.

If the series resistance and/or reactance is increased the amount of noise at the output will be decreased. The series reactance can be increased with the use of an inductor in series with the resistor (see Figure 4). This is more advantageous then adding more resistance due to the fact that it does not produce a large DC voltage drop.

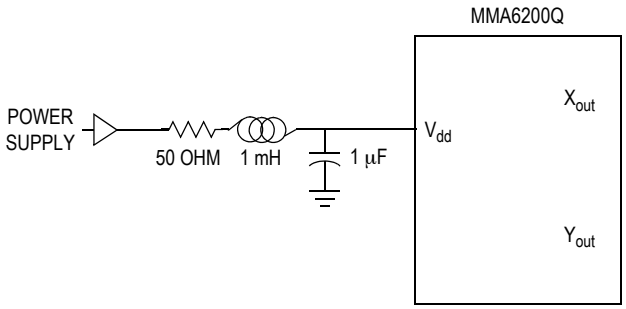

Figure 4. Recommended RCL Input Loading for PSRR at V_{dd}

The device was designed to operate with 3.3 Vdc at V_{dd}. If this input voltage is allowed to drop by more than half a volt the device may not operate correctly; hence the use of an inductor. With the use of an application board there was found to be greater than a factor of two drop in the output noise at the first harmonic with the use of the 1 mH inductor. The later harmonics incur a larger improvement due to the higher reactance of the inductor at the higher frequencies. As a result there was greater than a factor of eight improvement with the third and fifth harmonics. This RC and RLC circuit produced the following PSRR plot (see Figure 5).

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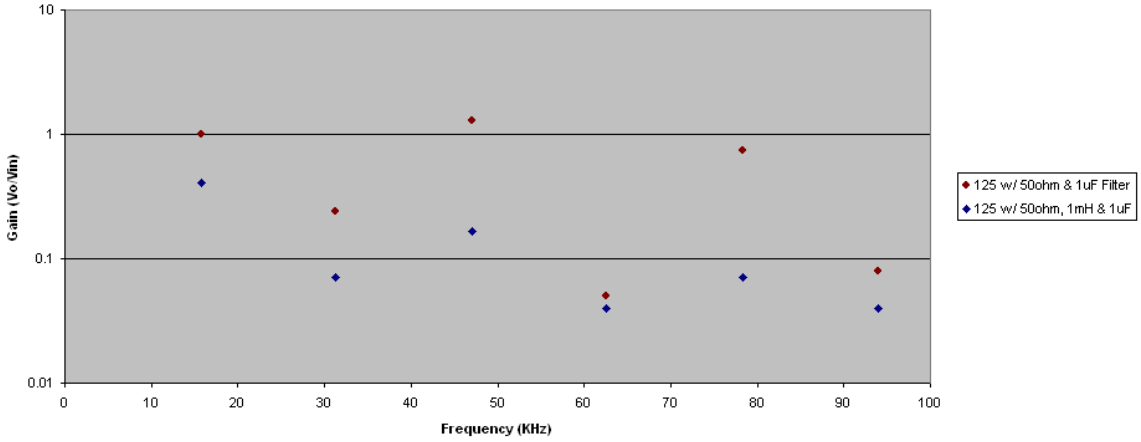

Figure 5. PSRR with RC and RLC Input Filter

If a smaller capacitance is desired in application with no inductor one can increase the value of just the series resistor. However one must take into consideration the tradeoffs involved. In order to get roughly the same improvement in the PSRR with a 0.5 μF capacitor as there was with the 50 ohm and 2 μF RC combination one must increase the series impedence to 150 ohms (see Figure 6).

This alternate RC circuit produces the following effect on the PSRR (see Figure 7). Notice the similarity in the gain when compared with the 50 ohm 2 μF filter. It is still well below unity for this configuration.

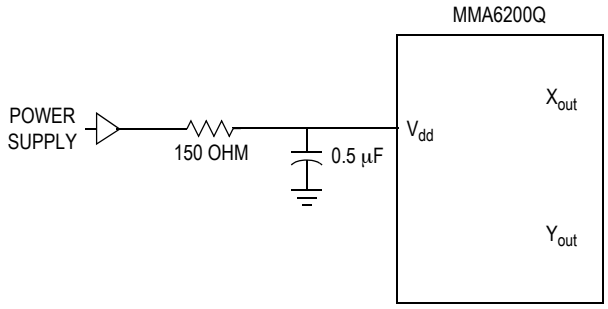

Figure 6. Alternate RC Input Loading for PSRR at V_{dd}

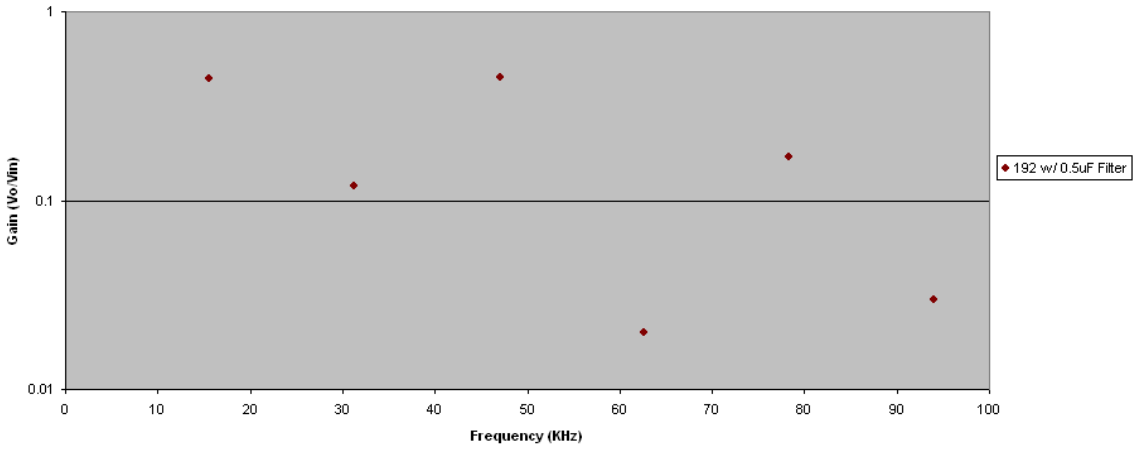

Figure 7. PSRR with 150 Ohm and 0.5 μF Input Capacitance

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As stated before this large value of resistance creates a DC voltage drop at the input of the device. However, it could be reduced some and still achieve less than unity gain. With the same voltage at the input of the filter the output voltage of the device is lowered. In this case it drops by roughly 5 percent. In turn, this loss in DC voltage also lowers the ratio-metric error. However if the voltage at Vdd is allowed to drop much lower than 2.7 volts the device may not operate at all. If cost and space permits, one should consider, as stated previously, the substitution of a series inductor in place of at least part of this series resistance. This can greatly decrease the DC voltage drop problem.

To get a 150 ohm impedance at the frequency of the first harmonic we have X = 2*pie*(15 KHz)*L = 150 ohm. Solving for L gives the somewhat large value of 1.6 mH for the inductor. A 1 mH inductor at 15 KHz has an impedance of about 95 ohms and these devices can be had in quantity (1000 or more) for less then twenty cents each.

CONCLUSION

The MMA6200Q series family of devices require external RC and possibly L components to correct power supply rejection ratio issues caused by noisy power supply lines. This may not be of concern in many applications; however, it may be in some. The preceding gives an introduction to power supply rejection ratio as well as some information to better understand this potential problem. Also included are some example filters, the effects on PSRR, as well as suggested choices.

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Measuring Tilt with Low-g Accelerometers

by: **Michelle Clifford and Leticia Gomez**
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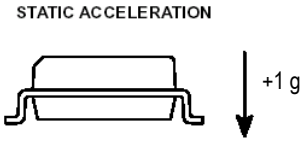
INTRODUCTION

This application note describes how accelerometers are used to measure the tilt of an object. Accelerometers can be used for measuring both dynamic and static measurements of acceleration. Tilt is a static measurement where gravity is the acceleration being measured. Therefore, to achieve the highest degree resolution of a tilt measurement, a low-g, high-sensitivity accelerometer is required. The Freescale MMA6200Q and MMA7260Q series accelerometers are good solutions for XY and XYZ tilt sensing. These devices provide a sensitivity of 800 mV/g in 3.3 V applications. The MMA2260D and MMA1260D are also good solutions for 5 V applications providing a sensitivity of 1200mV/g for X and Z, respectively. All of these accelerometers will experience acceleration in the range of +1g to -1g as the device is tilted from -90 degrees to +90 degrees.

1g = 9.8 m/s



MODULE

A simple tilt application can be implemented using an 8 or 10-bit microcontroller that has 1 or 2 ADC channels to input the analog output voltage of the accelerometers and general purpose I/O pins for displaying the degrees either on a PC through a communication protocol or on an LCD. See Figure 1 for a typical block diagram. Some applications may not require a display at all. These applications may only require an I/O channel to send a signal for turning on or off a device at a determined angle range.

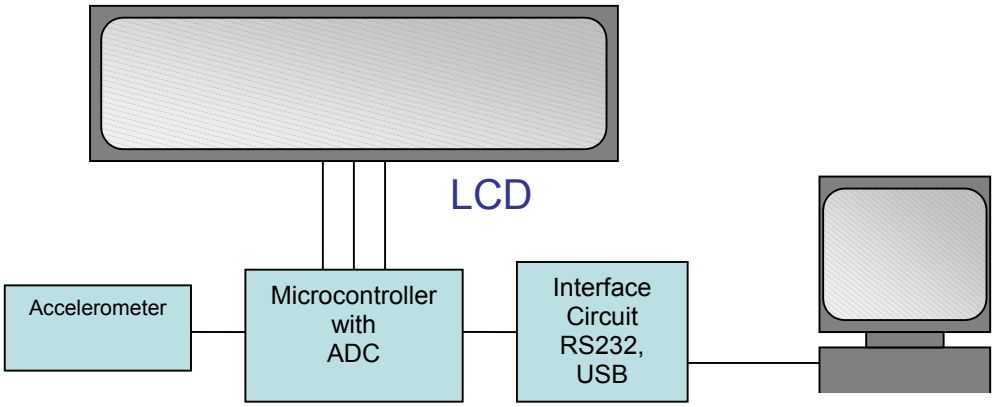


Figure 1. Typical Tilt Application Block Diagram

MOUNTING CONSIDERATIONS

Device selection depends on the angle of reference and how the device will be mounted in the end application. This will allow you to achieve the highest degree resolution for a given solution due to the nonlinearity of the technology. First, you need to know what the sensing axis is for the accelerometer. See Figure 2 to see where the sensing axes are for the MMA7260Q. To obtain the most resolution per degree of change, the IC should be mounted with the sensitive axis parallel to the plane of movement where the most sensitivity is desired. For example, if the degree range that an application will be measuring is only 0° to 45° and the PCB will be mounted perpendicular to gravity, then an X-Axis device

would be the best solution. If the degree range was 0° to 45° and the PCB will be mounted perpendicular to gravity, then a Z-Axis device would be the best solution. This is understood more when thinking about the output response signal of the device and the nonlinearity.

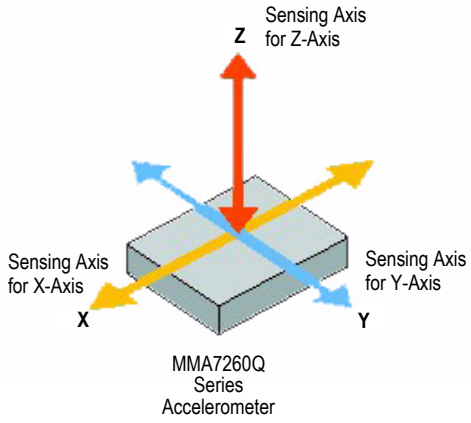


Figure 2. Sensing Axis for the MMA7260Q Accelerometer With X, Y, and Z-Axis for Sensing Acceleration

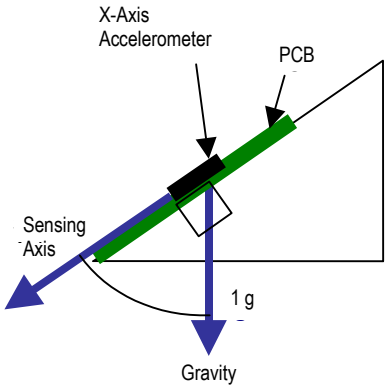


Figure 3. Gravity Component of a Tilted X-Axis Accelerometer

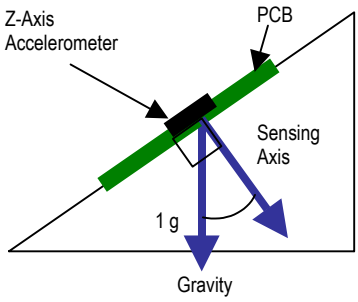


Figure 4. Gravity Component of a Tilted Z-Axis Accelerometer

NONLINEARITY

As seen in Figure 5, the typical output of capacitive, micro-machined accelerometers is more like a sine function. The figure shows the analog output voltage from the accelerometer for degrees of tilt from -90° to +90°. The change in degrees of tilt directly corresponds to a change in the acceleration due to a changing component of gravity acted on the accelerometer. The slope of the curve is actually the sensitivity of the device.

As the device is tilted from 0°, the sensitivity decreases. You see this in the graph as the slope of output voltage decreases for an increasing tilt towards 90°. Because of this nonlinearity, the degree resolution of the application must be determined at 0° and 90° to ensure the lowest resolution is still within the required application resolution. This will be explained more in the following section.

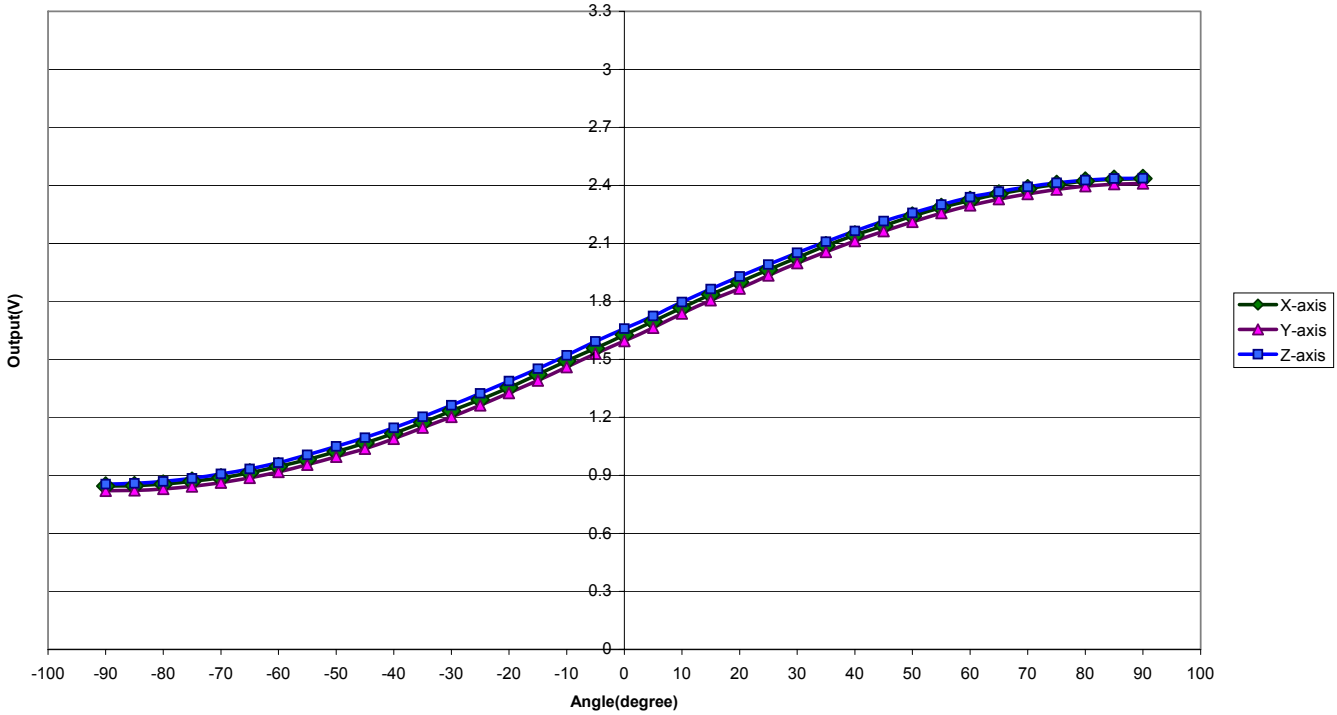


Figure 5. Typical Nonlinear Output of X, Y, and Z-Axis Accelerometers

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CALCULATING DEGREE OF TILT

In order to determine the angle of tilt, θ, the A/D values from the accelerometer are sampled by the ADC channel on the microcontroller. The acceleration is compared to the zero g offset to determine if it is a positive or negative acceleration, e.g., if value is greater than the offset then the acceleration is seeing a positive acceleration, so the offset is subtracted from the value and the resulting value is then used with a lookup table to determine the corresponding degree of tilt (See Table1 for a typical 8-bit lookup table), or the value is passed to a tilt algorithm. If the acceleration is negative, then the value is subtracted from the offset to determine the amount of negative acceleration and then passed to the lookup table or algorithm. One solution can measure 0° to 90° of tilt with a single axis accelerometer, or another solution can measure 360° of tilt with two axis configuration (XY, X and Z), or a single axis configuration (e.g. X or Z), where values in two directions are converted to degrees and compared to determine the quadrant that they are in. A tilt solution can be solved by either implementing an arccosine function, an arcsine function, or a look-up table depending on the power of the microcontroller and the accuracy required by the application. For simplicity, we will use the equation: θ = arcsin(x). The arcsin(y) can determine the range from 0° to 180°, but it cannot discriminate the angles in range from 0° to 360°, e.g. arcsin(45°) = arcsin(135°). However, the sign of x and y can be used to determine which quadrant the angle is in. By this means, we can calculate the angle β in one quadrant (0-90°) using arcsin(y) and then determine θ in the determined quadrant.

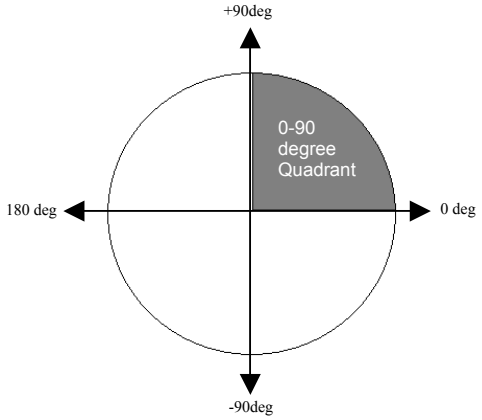

Figure 6. The Quadrants of a 360 Degree Rotation

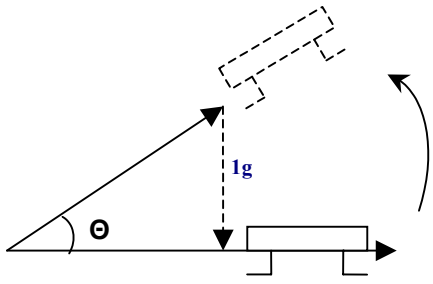

Figure 7. An Example of Tilt in the First Quadrant

[1] $$V_{OUT} = V_{OFFSET} + \left(\frac{\Delta V}{\Delta g} \times 1.0g \times \sin\theta\right)$$

where: V_{OUT} = Accelerometer Output in Volts
V_{OFF} = Accelerometer 0g Offset
$\Delta V/\Delta g$ = Sensitivity
1g = Earth's Gravity
θ = Angle of Tilt

Solving for the angle:

[2] $$\theta = \arcsin\left(\frac{V_{OUT} - V_{OFFSET}}{\frac{\Delta V}{\Delta g}}\right)$$

This equation can be used with the MMA6260Q as an example:

$$V_{OUT} = 1650mV + 800mV \times \sin\theta$$

Where the angle can be solved by

$$\theta = \arcsin\left(\frac{V_{OUT} - 1650mV}{800mV/g}\right)$$

From this equation, you can see that at 0° the accelerometer output voltage would be 1650mV and at 90° the accelerometer output would be 2450mV.

INTERFACING TO ADC

An 8-Bit ADC

An 8-bit ADC cuts 3.3V supply into 255 steps of 12.9mV for each step. Therefore, by taking one ADC reading of the MMA6260Q at 0g (0°of tilt for an x-axis device) and 1g (90° of tilt for an x-axis device), would result in the following:

0°: 1650mV + 12.9mV = 1662.9mV,
which is 0.92° resolution

90°: 2450mV+ 12.9mV = 2462.9mV,
which is 6.51° resolution

Due to the nonlinearity discussed earlier, you will see that the accelerometer is most sensitive when the sensing axis is closer to 0°, and less sensitive when closer to 90°. Therefore, the system provides a 0.92 degree resolution at the highest sensitivity point (0 degrees), and a 6.51 degree resolution at the lowest sensitivity point (90°).

A 10-Bit ADC

A 10-bit ADC cuts 3.3V supply into 1023 steps of 3.2mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an x-axis device), would now result in the following:

0°: 1650mV + 3.2mV = 1653.2mV

90° 2450mV + 3.2mV = 2453.2mV

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This results in a 0.229 degree resolution at the highest sensitivity point (0°) and a 3.26 degree resolution at the lowest sensitivity point (90°).

A 12-Bit ADC

A 12-bit ADC cuts 3.3V supply into 4095 steps of 0.8mV for each step. Therefore, by taking one ADC reading of the MMA6260Q again at 0g (0° of tilt for an x-axis device), would now result in the following:

0°: 1650mV + 0.8mV = 1650.8mV

90°: 2450mV + 0.8mV = 2450.8mV

This results in a 0.057 degree resolution at the highest sensitivity point (0°) and 1.63 degree resolution at the lowest sensitivity point (90°). However, for 0.8mV changes, the noise factor becomes the factor to consider during design. How much noise the system has will depend on how much resolution you can get with a higher bit count.

TILT APPLICATIONS

There are many applications where tilt measurements are required or will enhance its functionality. In the cell phone market and handheld electronics market, tilt applications can be used for controlling menu options, e-compass compensation, image rotation, or function selection in response to different tilt measurements. In the medical markets, tilt is used for making blood pressure monitors more accurate. They can also be used for feedback for tilting hospital beds or chairs. A tilt controller can also be used for an easier way to control this type of equipment. Accelerometers for tilt measurements can also be designed into a multitude of products, such as game controllers, virtual reality input devices, HDD portable products, computer mouse, cameras, projectors, washing machines, and personal navigation systems.

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Table 1. 8-Bit Lookup Table for Determining Degree of Tilt

ADC Bits	Calculated Voltage	g	arcsine	arccos
66	-0.80	-1.00	-87.47	177.47
67	-0.79	-0.98	-79.39	169.39
68	-0.77	-0.97	-75.19	165.19
69	-0.76	-0.95	-71.93	161.93
70	-0.75	-0.93	-69.16	159.16
71	-0.73	-0.92	-66.70	156.70
72	-0.72	-0.90	-64.47	154.47
73	-0.71	-0.89	-62.40	152.40
74	-0.70	-0.87	-60.47	150.47
75	-0.68	-0.85	-58.65	148.65
76	-0.67	-0.84	-56.92	146.92
77	-0.66	-0.82	-55.26	145.26
78	-0.64	-0.81	-53.67	143.67
79	-0.63	-0.79	-52.14	142.14
80	-0.62	-0.77	-50.66	140.66
81	-0.61	-0.76	-49.23	139.23
82	-0.59	-0.74	-47.83	137.83
83	-0.58	-0.73	-46.48	136.48
84	-0.57	-0.71	-45.15	135.15
85	-0.55	-0.69	-43.86	133.86
86	-0.54	-0.68	-42.59	132.59
87	-0.53	-0.66	-41.35	131.35
88	-0.52	-0.64	-40.13	130.13
89	-0.50	-0.63	-38.93	128.93
90	-0.49	-0.61	-37.76	127.76
91	-0.48	-0.60	-36.60	126.60
92	-0.46	-0.58	-35.46	125.46
93	-0.45	-0.56	-34.33	124.33
94	-0.44	-0.55	-33.22	123.22
95	-0.43	-0.53	-32.12	122.12
96	-0.41	-0.52	-31.04	121.04
97	-0.40	-0.50	-29.97	119.97
98	-0.39	-0.48	-28.91	118.91
99	-0.37	-0.47	-27.86	117.86
100	-0.36	-0.45	-26.82	116.82
101	-0.35	-0.44	-25.79	115.79
102	-0.34	-0.42	-24.77	114.77
103	-0.32	-0.40	-23.76	113.76
104	-0.31	-0.39	-22.75	112.75
105	-0.30	-0.37	-21.75	111.75
106	-0.28	-0.35	-20.76	110.76
107	-0.27	-0.34	-19.78	109.78
108	-0.26	-0.32	-18.80	108.80
109	-0.24	-0.31	-17.83	107.83
110	-0.23	-0.29	-16.86	106.86
111	-0.22	-0.27	-15.90	105.90
112	-0.21	-0.26	-14.94	104.94
113	-0.19	-0.24	-13.99	103.99
114	-0.18	-0.23	-13.04	103.04
115	-0.17	-0.21	-12.09	102.09
116	-0.15	-0.19	-11.15	101.15
117	-0.14	-0.18	-10.21	100.21
118	-0.13	-0.16	-9.27	99.27
119	-0.12	-0.15	-8.34	98.34
120	-0.10	-0.13	-7.41	97.41
121	-0.09	-0.11	-6.48	96.48
122	-0.08	-0.10	-5.55	95.55
123	-0.06	-0.08	-4.62	94.62
124	-0.05	-0.06	-3.70	93.70
125	-0.04	-0.05	-2.77	92.77
126	-0.03	-0.03	-1.85	91.85
127	-0.01	-0.02	-0.92	90.92
128	0.00	0.00	0.00	90.00
129	0.01	0.02	0.92	89.08
130	0.03	0.03	1.85	88.15
131	0.04	0.05	2.77	87.23
132	0.05	0.06	3.70	86.30
133	0.06	0.08	4.62	85.38
134	0.08	0.10	5.55	84.45
135	0.09	0.11	6.48	83.52
136	0.10	0.13	7.41	82.59
137	0.12	0.15	8.34	81.66
138	0.13	0.16	9.27	80.73
139	0.14	0.18	10.21	79.79
140	0.15	0.19	11.15	78.85
141	0.17	0.21	12.09	77.91
142	0.18	0.23	13.04	76.96
143	0.19	0.24	13.99	76.01
144	0.21	0.26	14.94	75.06
145	0.22	0.27	15.90	74.10
146	0.23	0.29	16.86	73.14
147	0.24	0.31	17.83	72.17
148	0.26	0.32	18.80	71.20
149	0.27	0.34	19.78	70.22
150	0.28	0.35	20.76	69.24
151	0.30	0.37	21.75	68.25
152	0.31	0.39	22.75	67.25
153	0.32	0.40	23.76	66.24
154	0.34	0.42	24.77	65.23
155	0.35	0.44	25.79	64.21
156	0.36	0.45	26.82	63.18
157	0.37	0.47	27.86	62.14
158	0.39	0.48	28.91	61.09
159	0.40	0.50	29.97	60.03
160	0.41	0.52	31.04	58.96
161	0.43	0.53	32.12	57.88
162	0.44	0.55	33.22	56.78
163	0.45	0.56	34.33	55.67
164	0.46	0.58	35.46	54.54
165	0.48	0.60	36.60	53.40
166	0.49	0.61	37.76	52.24
167	0.50	0.63	38.93	51.07
168	0.52	0.64	40.13	49.87
169	0.53	0.66	41.35	48.65
170	0.54	0.68	42.59	47.41
171	0.55	0.69	43.86	46.14
172	0.57	0.71	45.15	44.85
173	0.58	0.73	46.48	43.52
174	0.59	0.74	47.83	42.17
175	0.61	0.76	49.23	40.77
176	0.62	0.77	50.66	39.34
177	0.63	0.79	52.14	37.86
178	0.64	0.81	53.67	36.33
179	0.66	0.82	55.26	34.74
180	0.67	0.84	56.92	33.08
181	0.68	0.85	58.65	31.35
182	0.70	0.87	60.47	29.53
183	0.71	0.89	62.40	27.60
184	0.72	0.90	64.47	25.53
185	0.73	0.92	66.70	23.30
186	0.75	0.93	69.16	20.84
187	0.76	0.95	71.93	18.07
188	0.77	0.97	75.19	14.81
189	0.79	0.98	79.39	10.61
190	0.80	1.00	87.47	2.53

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Using the Multi-Axis g-Select Evaluation Boards

by: Michelle Clifford and John Young
Applications Engineers
Tempe, AZ

INTRODUCTION

This application note describes the Accelerometer Evaluation Boards for Freescale's multi-axis g-Select accelerometers.

Accelerometer Part Number(1)	Selectable g-ranges	Axis	Evaluation Kit Part Number(2)
MMA7260QT/R2	1.5g, 2g, 4g, 6g	XYZ-Axis	KIT3109MMA7260QE
MMA7261QT/R2	2.5g, 3.3g, 6.7g, 10g	XYZ-Axis	KIT3109MMA7261QE
MMA6270QT/R2	1.5g, 2g, 4g, 6g	XY-Axis	KIT3109MMA6270QE
MMA6271QT/R2	2.5g, 3.3g, 6.7g, 10g	XY-Axis	KIT3109MMA6271QE
MMA6280QT/R2	1.5g, 2g, 4g, 6g	XZ-Axis	KIT3109MMA6280QE
MMA6281QT/R2	2.5g, 3.3g, 6.7g, 10g	XZ-Axis	KIT3109MMA6281QE

NOTES:
1. The "T" signifies parts shipped in trays. "R2" signifies parts shipped in tape and reel.
2. The "E" signifies a RoHS compliant development tool.

The Accelerometer Evaluation Boards are small circuit boards intended to be used for evaluating the accelerometers and developing prototypes quickly without requiring a PCB to be designed to accommodate for the small profile QFN package. It also provides a means for understanding the best mounting position and location of an accelerometer in your product with provided board mounting points.

KIT3109 CIRCUIT DESCRIPTION

Figures 11 thru 13 are general circuit schematics of the evaluation boards. The recommended decoupling capacitor at the power source and recommended RC filter at each accelerometer output, are included on the evaluation board. For a complete description of the operation of the accelerometer, refer to the respective datasheet. There is an RC filter at each of the three accelerometer outputs in order to minimize clock noise that may be present from the switched capacitor filter circuit. No additional components are necessary to use the evaluation board.

The evaluation boards have pads for interfacing to a 3.3 V power source or battery. The pads on the side of the board also provide a means for connecting to the accelerometer analog output by soldering a wire from the evaluation board to another breadboard or system. The ON/OFF switch enables the power to the accelerometer and helps preserve battery life if a battery is being used as the power source. **S1** must be set towards the ON position for the accelerometer to function. The green LED labeled PWR is lit when power is supplied to the accelerometer.

G-SELECT DIPSWITCH SETTINGS

The g-Select is a powerful feature on this series of accelerometers allowing each single device to measure 4 different ranges of acceleration (see Table 1 and Table 2). The g-Select allows one device to provide multiple applications in one package. By adjusting the dip-switches on the evaluation board, the accelerometer can toggle between the different g-Ranges with the same accelerometer part. In application designs, the g-Select pins would be connected to I/O pins of a microcontroller. The following tables outline the g-Ranges that the values of the g-Select pins correspond to.

Table 1. g-Select Pin Descriptions for MMA7260QT, MMA6270QT, and MMA6280QT

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800 mV/g
0	1	2g	600 mV/g
1	0	4g	300 mV/g
1	1	6g	200 mV/g

Table 2. g-Select Pin Descriptions for MMA7261QT, MMA6271QT, and MMA6281QT

g-Select2	g-Select1	g-Range	Sensitivity
0	0	2.5g	480 mV/g
0	1	3.3g	360 mV/g
1	0	6.6g	180 mV/g
1	1	10g	120 mV/g

SLEEP MODE FUNCTION

The g-Select series accelerometers feature a sleep mode function, activated by a sleep mode option on the device's pinout. The sleep mode pin is an active high pin, enabling the device "on" when V_{DD} is applied to that pin (pin 12).

This is selectable on the evaluation board using either the INPUT/OUTPUT sleep mode Pad or the dip switch that is provided. When the dip switch is activated, the device is enabled. The same occurs with the Sleep Mode Pad. When the user attaches a 3.3 V or V_{DD} voltage to this, the device will be enabled. A V_{CC} connection to this pin will place the device in standby mode. If the device is enabled, the LED labeled sleep mode will be lit.

The sleep mode allows the accelerometer to operate on standby at 3 μA supply current. Regular operation uses 500 μA of supply current.

NOTE

Power Consumption is 3 μA during Sleep mode operation, and 500 μA during normal operation. Note that when verifying this information during prototyping, it is necessary to remove the LEDs from the Evaluation Board. These have been designed in to provide a clear indication of the part's states, but draw additional current as all items share the common input voltage terminal.

QUICK STARTUP GUIDE

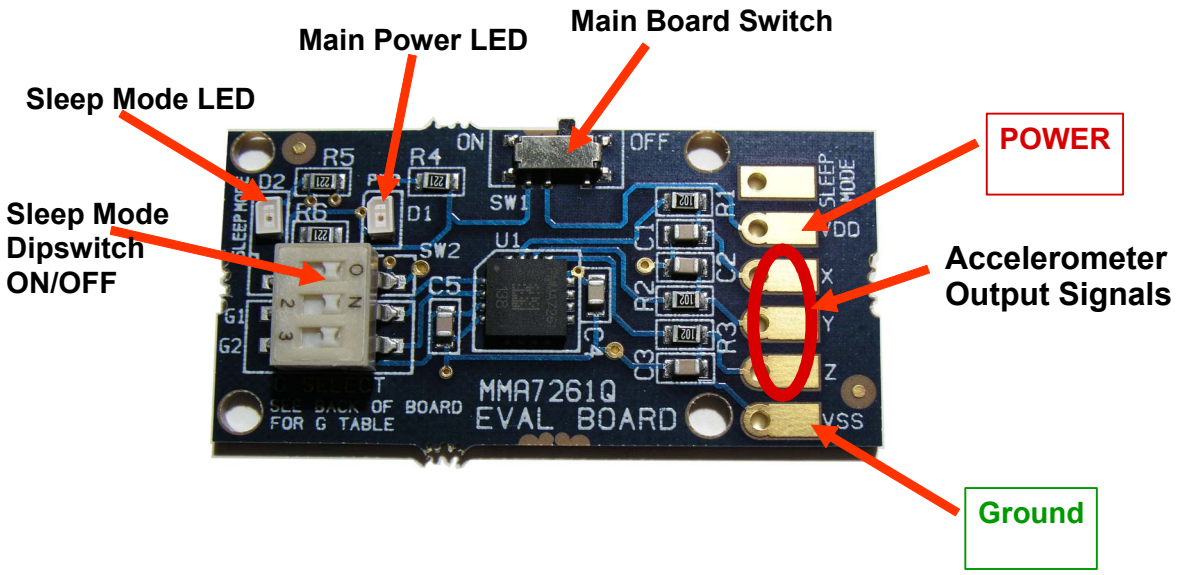

Figure 1. Evaluation Board Components for KIT3109

1. Connect the external power source to the Evaluation board. The 3.3 V input is connected to the POWER (V_{DD}) and Ground (V_{SS}) using the solder pads.
2. Note that the Main Power LED will turn on when the Main Board Switch is thrown.
3. Next use a ***pointed object*** to turn the Sleep Mode Dipswitch to the 'ON' position.
   - You will notice that the Sleep Mode LED will light up once the Sleep Mode Dip Switch is turned to the "ON" position. This means that the device will have X, Y, and Z outputs on the output pads. Sleep mode will actually be disabled and the device is now active.
   - When "OFF", no output voltages should be seen, and the LED will be off. This will mean the board is in Sleep Mode, in low power consumption.
4. Start to measure the voltages on the X, Y, and Z axes. Solder these pads to your microcontroller A/D terminals or other measuring devices.

The evaluation board has pads for interfacing to a 3.3 V power source or battery. The pads on the side of the board also provide a means for connecting to the accelerometer analog output by soldering a wire from the evaluation board to another breadboard or system. The ON/OFF switch provides power to the accelerometer and helps preserve battery life if a battery is being used as the power source. **S1** must be set towards the ON position for the accelerometer to function. The green LED labeled *PWR* is lit when power is supplied to the accelerometer.

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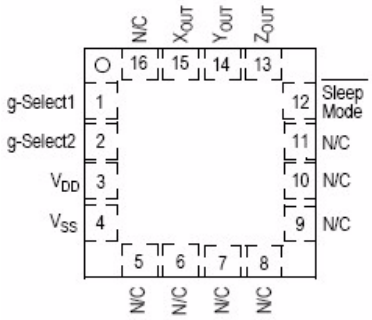

Figure 2. Pin Connections for MMA7260QT and MMA7261QT

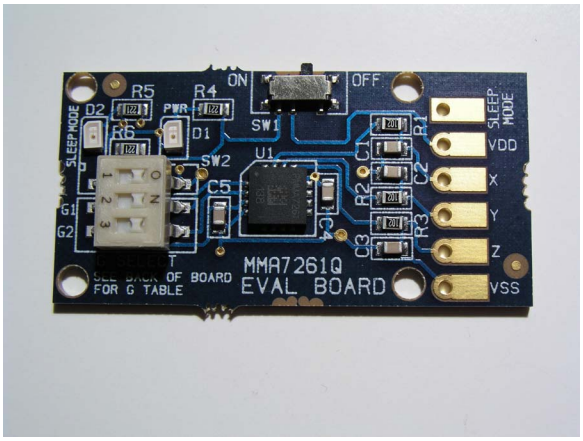

Figure 3. Photo of MMA7261QT Evaluation Board (similar to MMA7260QT Evaluation Board)

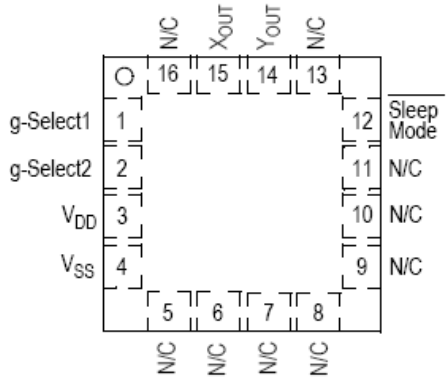

Figure 4. Pin Connections for MMA6270QT and MMA6271QT

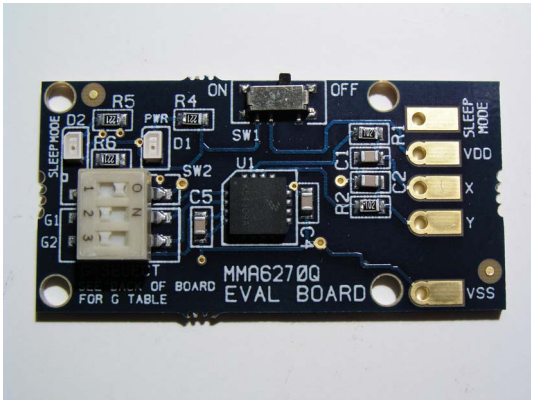

Figure 5. Photo of MMA6270QT Evaluation Board (similar to MMA6271QT Evaluation Board)

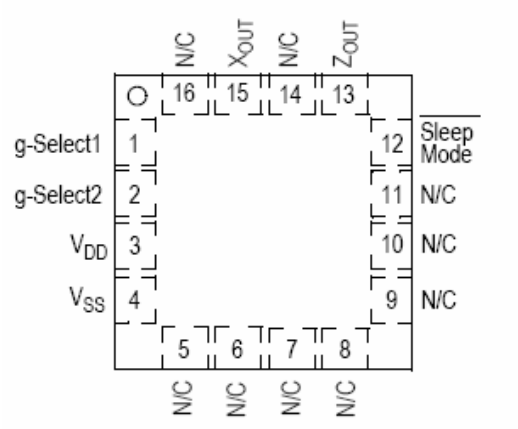

Figure 6. Pin Connections for the MMA6280QT and MMA6281QT

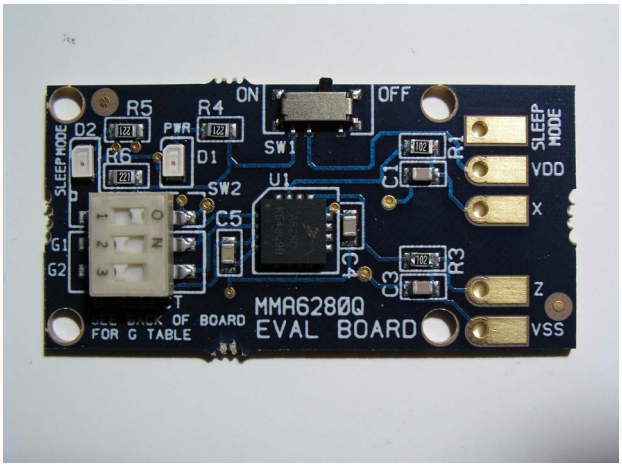

Figure 7. Photo of MMA6280QT Evaluation Board (similar to MMA6281QT Evaluation Board)

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APPENDIX 2

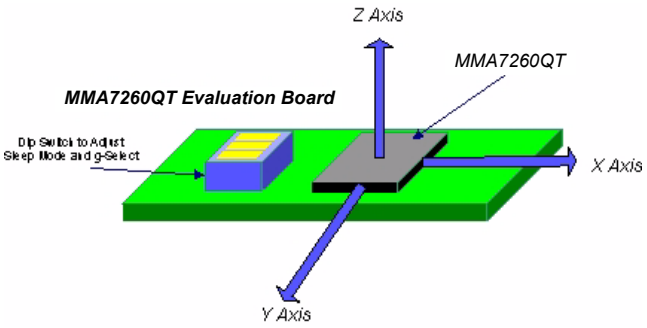

Figure 8. Board Orientation Corresponding for the Three Axes of the MMA7260QT and MMA7261QT

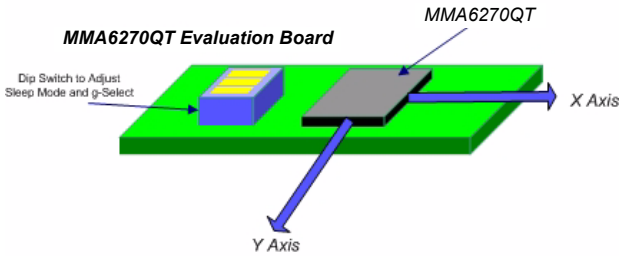

Figure 9. Board Orientation for the MMA6270QT and MMA6271QT

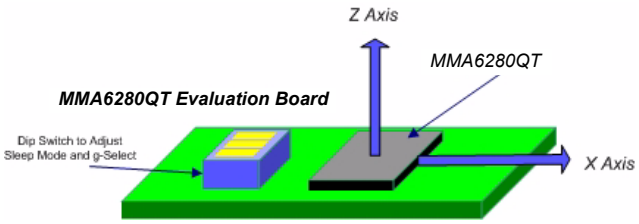

Figure 10. Board Orientation for the MMA6280QT and MMA6281QT

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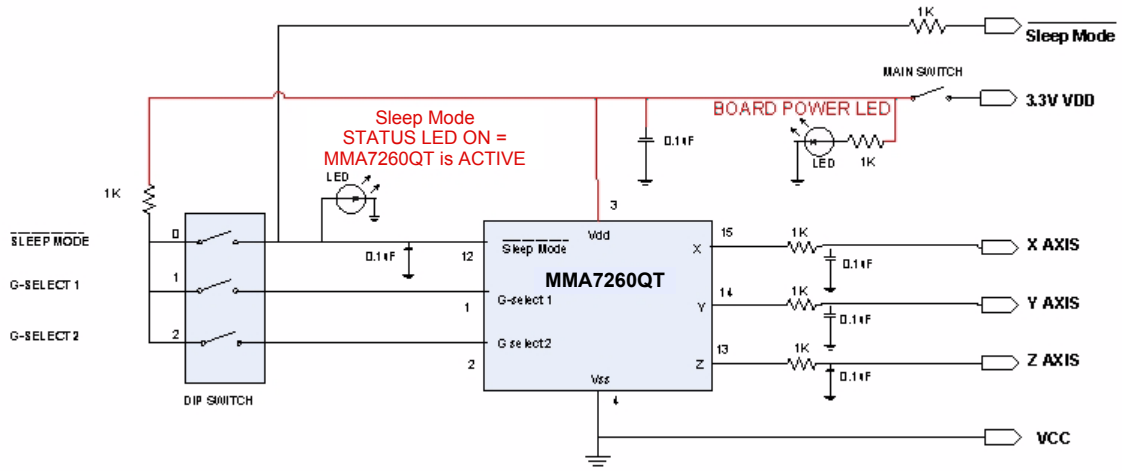

Figure 11. Circuit Schematic of the MMA7260QT or MMA7261QT Evaluation Board

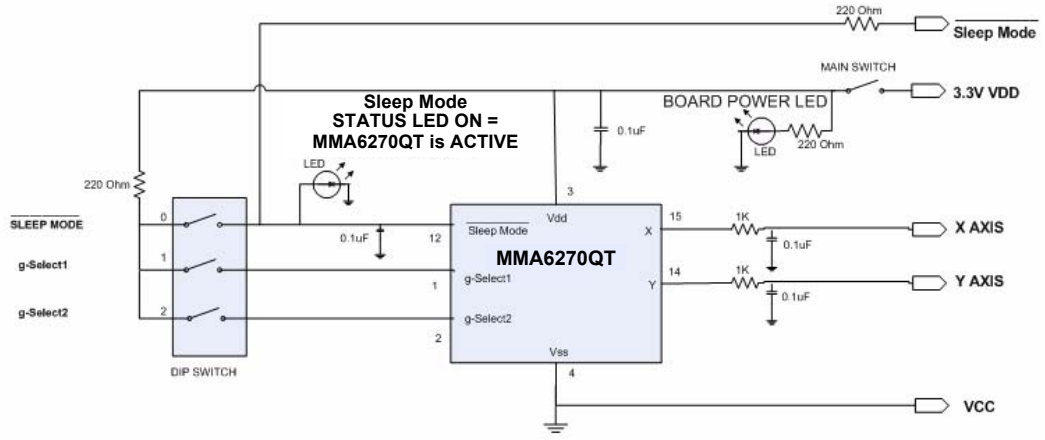

Figure 12. Circuit Schematic of the MMA6270QT or MMA6271QT Evaluation Board

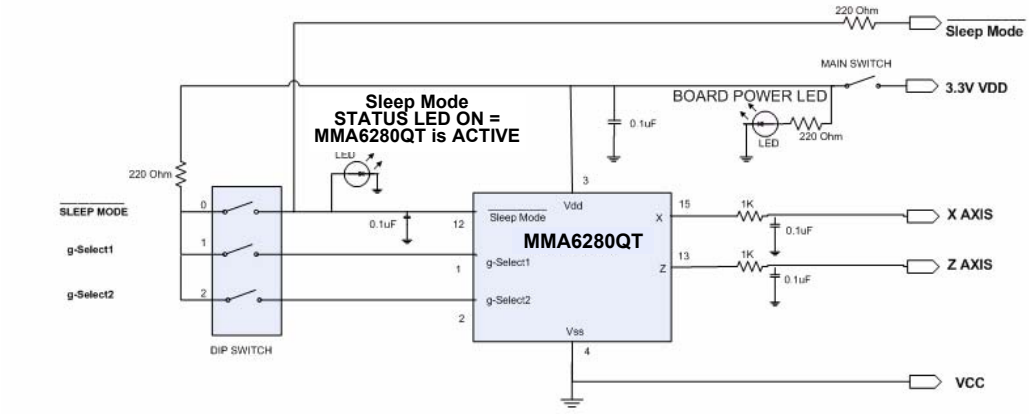

Figure 13. Circuit Schematic of the MMA6280QT or MMA6281QT Evaluation Board

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Table 3. Description of Output/Input Pads

Output/Input Pads	Description
Sleep Mode	Used for an external source to enable/disable Sleep Mode
3.3 V V_{DD}	Input voltage $V_{DD}$for Power Supply
X axis	Analog Voltage output of X axis
Y axis	Analog Voltage output of Y axis
YZ axis	Analog Voltage output of YZ axis
Z axis	Analog Voltage output of Z axis
V_{SS}	Ground Pin for Power Supply

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APPENDIX 4

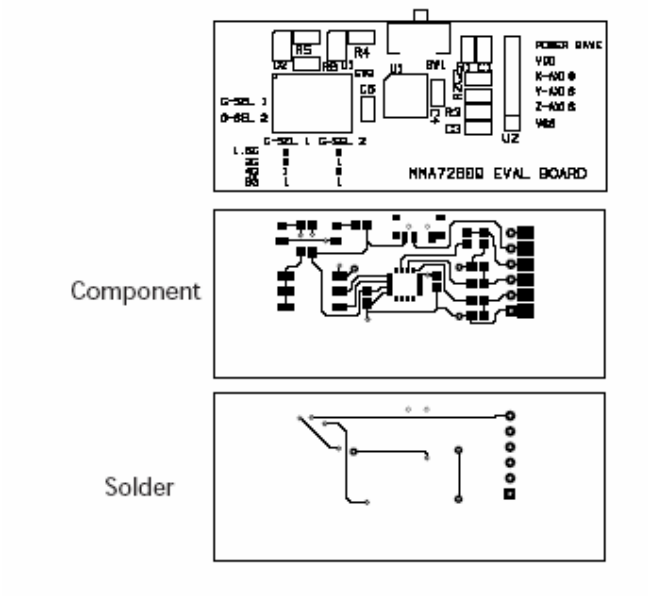

Figure 14. MMA7260QT Board Layout for Component, Top Layer, and Bottom Layer

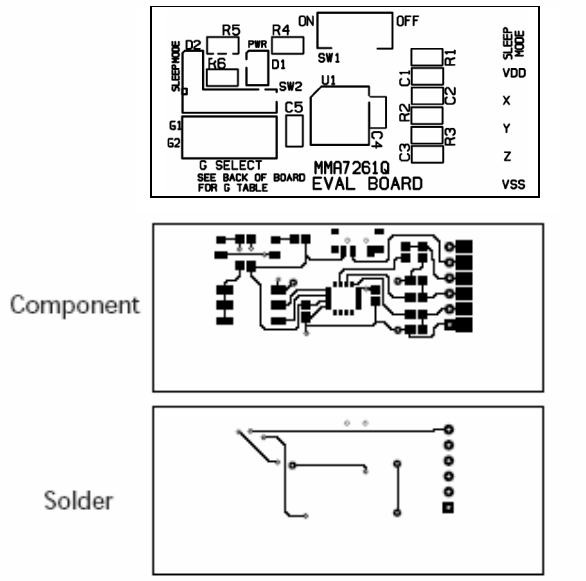

Figure 15. MMA7261QT Board Layout for Component, Top Layer, and Bottom Layer

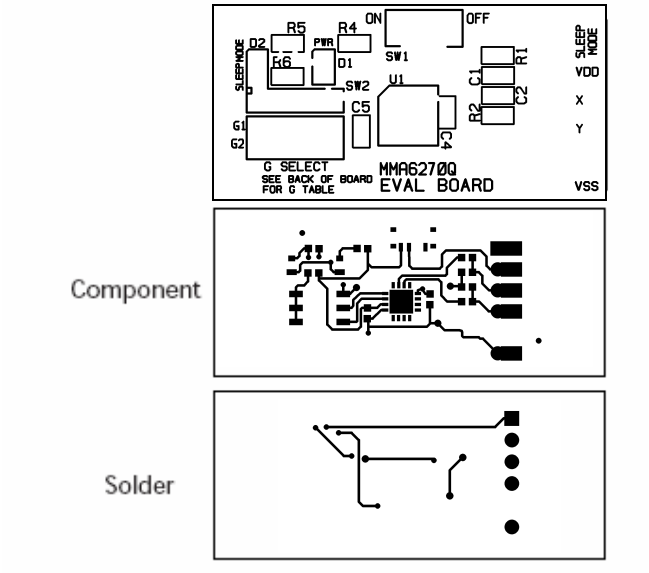

Figure 16. MMA6270QT Board Layout for Component, Top Layer, and Bottom Layer

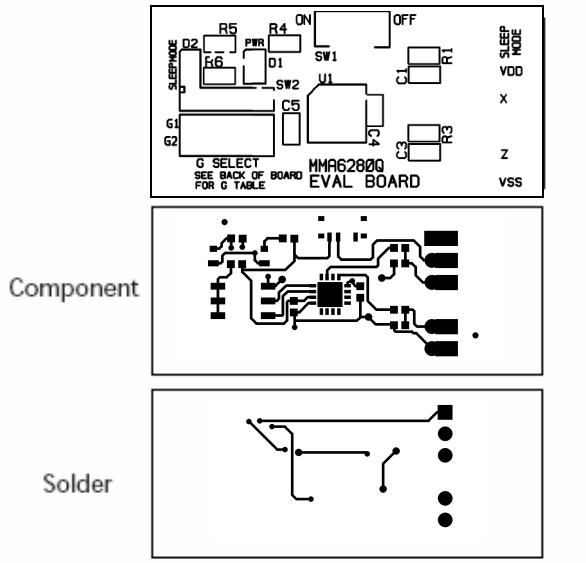

Figure 17. MMA6280QT Board Layout for Component, Top Layer, and Bottom Layer

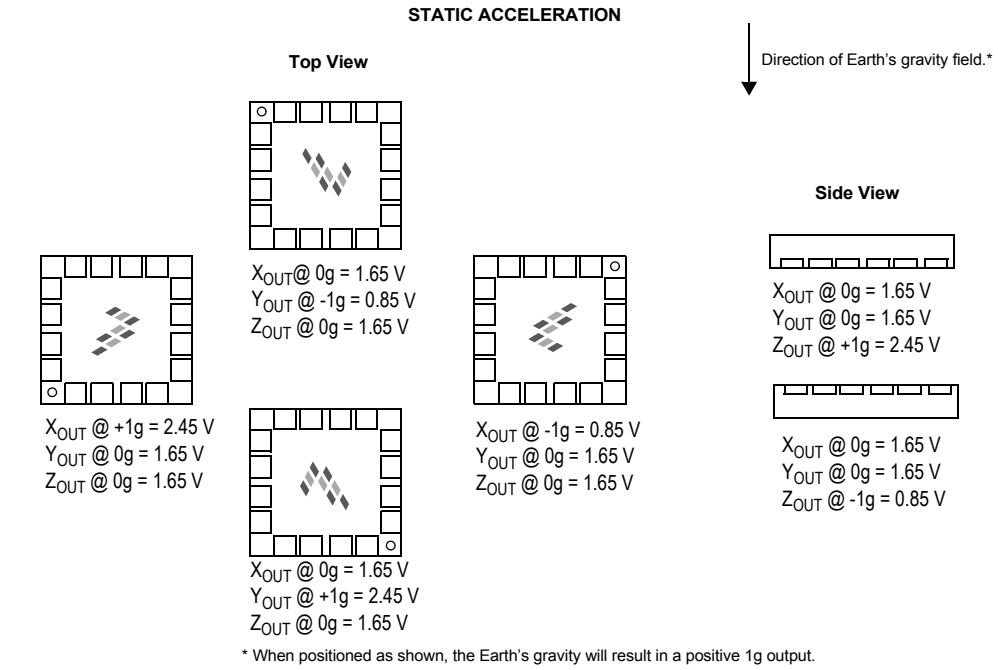

Figure 18. Orientation and Output Values for MMA7260QT, MMA6270QT and MMA6280QT

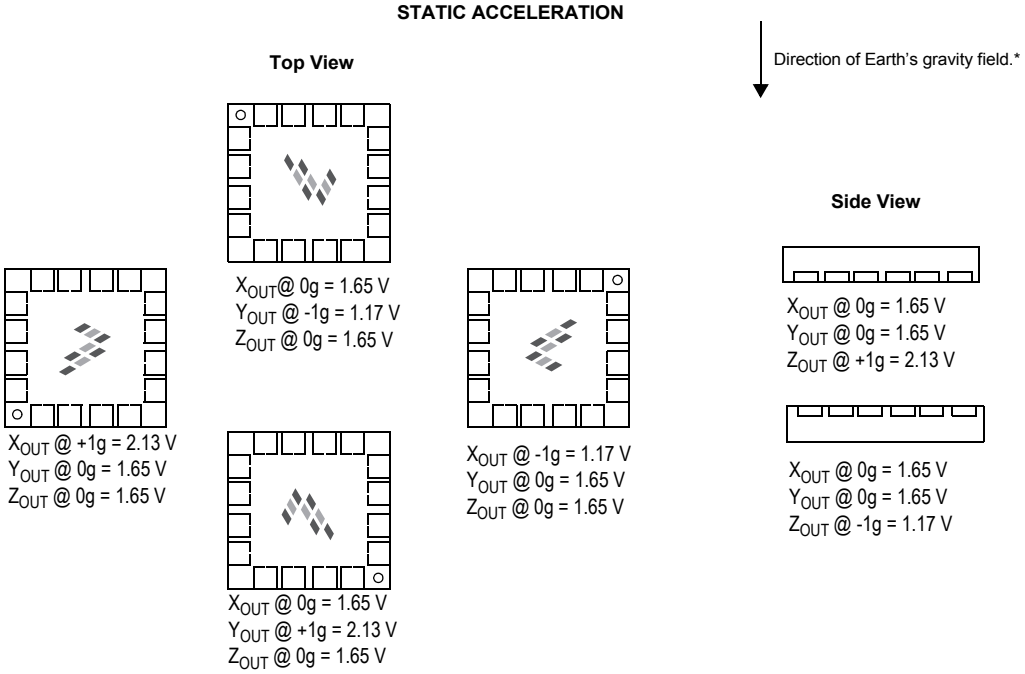

Figure 19. Orientation and Output Values for MMA7261QT

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Soldering the QFN Stacked Die Sensors to PC Board

by: Dave Mahadevan and Russell Shumway
Sensor and Analog Products
Tempe, Arizona

INTRODUCTION

The third generation of inertial sensors (accelerometers) uses the Quad Flat No-Lead (QFN) platform with stacked die configuration to minimize the footprint. This application note describes suggested methods of soldering these devices to the PC board. Figure 1 shows the top and bottom view of QFN 16 lead, 6 x 6 mm individual sensor devices and the device soldered to the board.

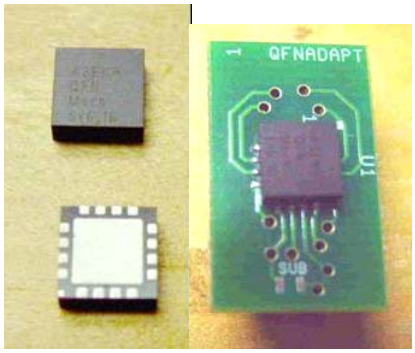


Figure 1. QFN 16-Lead, 6 x 6 mm Stacked Die Sensor

Overview of Soldering Considerations

Information provided here is based on experiments executed on QFN devices. They do not represent exact conditions present at a customer site. Hence, information herein should be used as a guidance only and process and design optimizations are recommended to develop an application specific solution.

Solder Joint Reliability (SJR) testing is performed to determine a measure of board level reliability when exposed to thermal cycling. Freescale typically accepts a minimum of 2000 cycles regardless of end application. For automotive applications, the widely accepted temperature range for testing is -40°C to +125°C. For these automotive applications, it is recommended to solder the exposed pad to PCB for greater board level reliability. It may not be necessary to solder mount the exposed pad of the QFN for commercial applications to reach acceptable performance. Commercial temperature cycling conditions vary widely but Freescale typically tests SJR at 0°C to +100°C and can meet target performance levels without soldering the exposed pad. Please refer to the product specific data sheets for recommendations on soldering the exposed pad as they will supersede general guidelines found in this document.

Freescale QFN sensors are compliant with Restrictions on Hazardous Substances (RoHS), having halide free molding compound (green) and lead-free terminations. These terminations are compatible with tin-lead (Sn-Pb) as well as tin-silver-copper (Sn-Ag-Cu) solder paste soldering processes. Reflow profiles applicable to those processes can be used successfully for soldering the devices. This document provides a suggested reflow profile for JEDEC compliant for the lead-free soldering process as well as the footprint information for the QFN device.

Test Procedure

The test board panel design for QFN stacked die package incorporates input from customers as to thickness, trace material, and layers of construction. This was accomplished to simulate as nearly as possible, the same conditions the package will be subjected to by customers. Solder paste printing at the board level is a critical factor in solder-joint reliability for QFN and all leadless devices. The final stencil used had a thickness of 6 mils (150 microns). The I/O pad openings (for the so-called *leads*) were 1:1 with the PCB pad size. The exposed flag region for the stencil was pulled away from the I/O to reduce the likelihood for solder bridging or scavenging. Because the evaluation was to only determine the solder joints, good electrical dies were required.

Mechanical dies to simulate the actual thermal cycling conditions were used in assembly. To check for solder failure, an electrical opening was viewed as a sign. Hence, all the leads were shorted. For redundancy, two wire bonds were provided for each joint. Temperature range for the experimental cycling was from -40°C to +125°C, as noted per automotive conditions, with 15 minute dwells at extreme and 15 minute ramps between extremes. The chamber of various packages and test boards were temperature profiled for stability.

Resistance measurements through the daisy chain nets were monitored on a continuous basis. Event detectors measured the resistance with a setup point of 300 Ω being the failure criterion [IPC-SM-785]. The start resistance for the QFN packages through the daisy chain was on the order of 1 Ω. When the event detectors recorded a failure, the net failing was identified and documented. Results indicated the first failure (with exposed flags soldered down) was more than 2000 temperature cycles.

Footprint and Reflow Profiles

Figure 2 provides the JEDEC compliant reflow conditions. Actual reflow mounting profile will vary with application and solder paste selection. Freescale uses the JEDEC compliant reflow in reliability testing of new product qualifications. Figure 3 illustrates the footprint of the QFN 16 lead 6 x 6 mm package for solder paste printing purposes.

Summary

There are many new applications being designed using QFN stacked die accelerometers. This document suggests soldering methods for those devices.

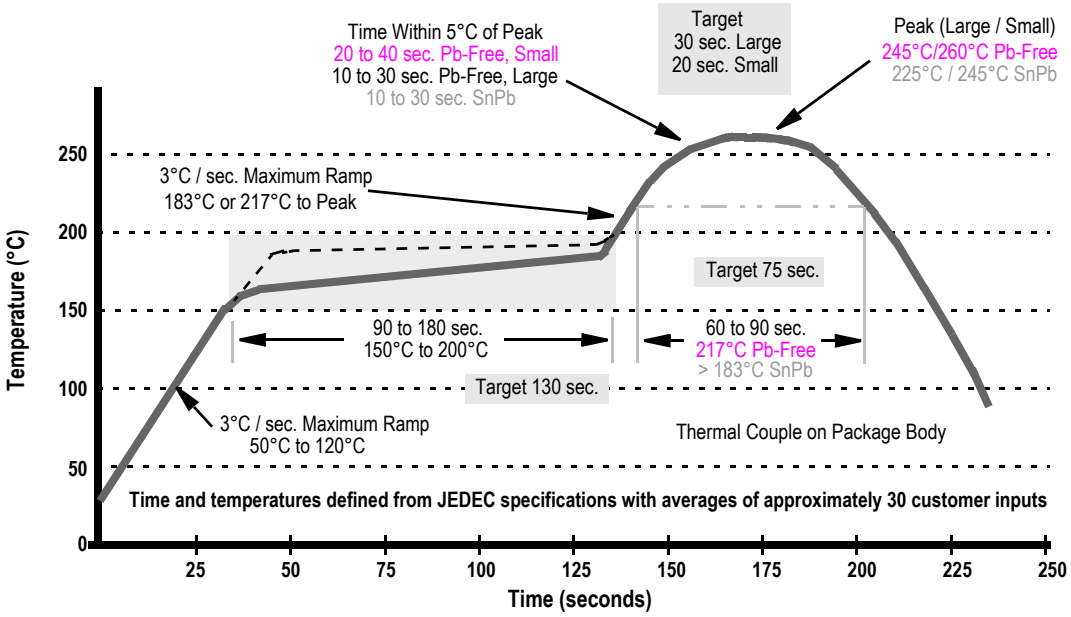
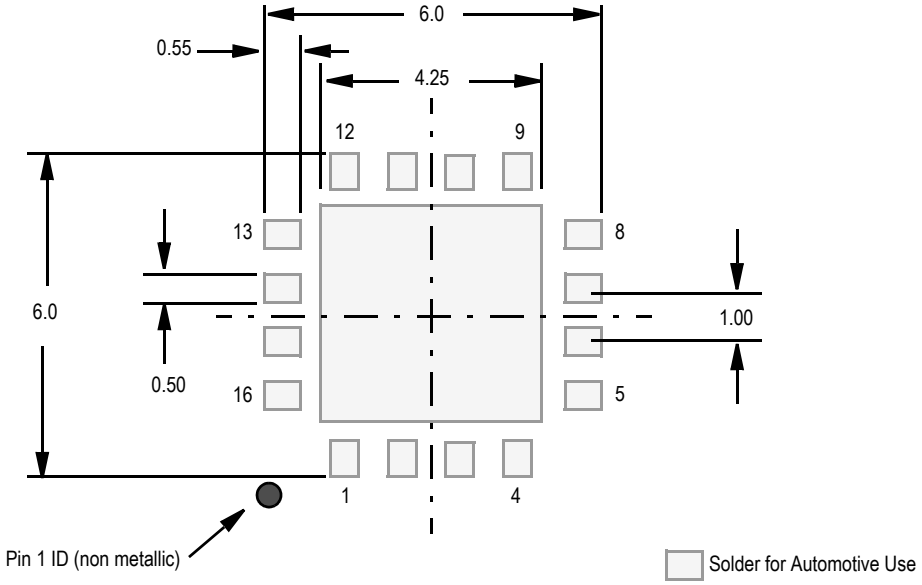


Figure 2. Reflow Profile for Sn-Pb and Sn-Ag-CU Solder Paste Soldering Processes



Note: The die-pad (flag) should be soldered down for automotive use. All dimensions are in mm.

Figure 3. Footprint for 16-Lead OFN, 6 x 6 mm

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Using the Sensing Triple Axis Reference Board (STAR)

by: John Young and Michelle Clifford
Sensor and Analog Products
Tempe, AZ

INTRODUCTION

The Sensing Triple Axis Reference Board (STAR) is a Freescale demonstration tool that is designed to allow visualization of key accelerometer applications in the consumer industry. In the past few years, accelerometers have changed dramatically during this entrance to the consumer market with increased sensitivity, reduced power consumption, and reduced package size. In addition, there has been development of accelerometer applications in many new markets. The MMA7260Q leaps forward in these requirements in addition to new functionality such as a g-Select feature and low power supply to allow system developer's more opportunities for integration of the five measurements of Freescale accelerometers (See AN1986).

MMA7260Q

The STAR board is a demonstration tool for the MMA7260Q, a 3-Axis Low-g accelerometer. The MMA7260Q has many unique features that make it an ideal solution for many consumer applications such as freefall protection for laptops and MP3 players, tilt detection for e-compass compensation and cell phone scrolling, motion detection for handheld games and game controllers, position sensing for g-mice, shock detection for warranty monitors, and vibration for out of balance detection.

Features such as low power, low current, and sleep mode with a quick turn on time allow the battery life to be extended in end applications. The 3-axis sensing in a small QFN package requires only 6 mm x 6 mm board space, with a profile of 1.45 mm, allowing for easy integration into many small handheld electronics.

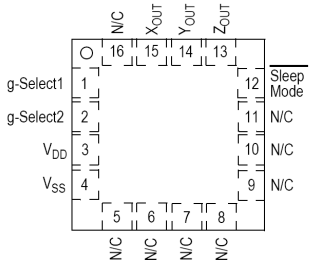

Figure 1. Pin Connections for the MMA7260Q

g-SELECT

The MMA7260Q has a unique feature that allows the range of g-force to be determined by changing inputs to the Quad Flat No-Lead (QFN) package. Table 1 below shows the configurable settings for the accelerometer, allowing multiple g-ranges.

Table 1. Configurable Setting for Accelerometer

g-Select2	g-Select1	g-Range	Sensitivity
0	0	1.5g	800 mV/g
0	1	2g	600 mV/g
1	0	4g	300 mV/g
1	1	6g	200 mV/g

The dip switches located on the (STAR) Board allow for the manual setting of the g-range. The ON position indicates a logic "1" which is equal to Vdd of the MMA7260Q. The OFF position is a logic "0" or Vss of the MMA7260Q. For a final design, the g-Select is best configured to additional I/O of a chosen microcontroller. Therefore, the sensitivity of the device could be easily changed with a quick change in the software. In addition, the software can be configured so that different sensitivities can be used for several applications, where the MCU drives the g-Select during different modes of operation.

MICROCONTROLLER

The MC68HC908KX8, an 8-bit MCU with 8-bit ADCs, was selected to sample the MMA7260Q 3-axis signals. An SCI for the serial communication, four 8-bit ADC channels to process the 3 analog signals, and 8 Kbytes of FLASH memory to save calibration data and other software configuration data also make it a suitable solution.

The MCU sends data via RS232 port to a CPU for further processing and graphical display of the acceleration data. In stand alone operation, the MCU can store acceleration, motion, or position data to a set of external EEPROMs which can later be downloaded to an excel file through the serial connection using the demo software provided. During stand alone operation, there are Status LEDs and a Piezo-electric buzzer allowing the MCU to display program modes.

More information regarding the MCU can be found in the MC68HC908KX8, MC68HC908KX2 Technical Datasheet (Freescale document number MC68HC908KX8/D).

REFERENCE BOARD

The goal of the Mini-TRIAX was to provide a small board with the capability to demonstrate and evaluate many accelerometer applications. Many design considerations were taken in effect to have a small and versatile tool (board size is 1.850" x 1.50").

Table 2 provides a brief description of the components on the STAR board and Figure 2 showing the location on the board.

Table 2. Components on the Mini-TRIAX Board

Component	Component Function
MMA7260Q	3 axis Accelerometer part to give vibration and inertial readings to the board
MC68HC908KX8	8-Bit processor used on the board. It is featured in a dip socket rather than SMT so it can be removed by a user for reprogramming for final solution designing.
LM317-L	Adjustable Voltage regulator. This part allows for the regulation of power to all the components on the board. 3.6 V
LM2765M6	Charge pump. This allows the use of a small 3 V battery to provide power at a higher voltage to the necessary level for the other components. With this, a standard 3V, 2/3A battery can easily be purchased. It keeps the size small rather than using a large 9V battery & holder.
2/3A battery Holder	The power of the board is supplied by a 3 V 2/3 A or 123 battery. It is commercially available at any consumer battery stand. This is the holder.
DB9 Serial Connector	The Mini-TRIAX communicates using a RS232 port, and this is the connector used for the cable.
MAX3316CAE	RS232 Chipset. This part allows the interface between the MCU and the standard RS232 communications port.
CTX690CT-ND	This is the external canned clock oscillator that allows the MCU to communicate with the RS232 port. This clock is set for 14.7456 MHz
25LC640	This is one of two EEPROMs. They are used via SCI to store accelerometer values at 200 times a second to memory.
Dip Switch	The STAR contains a set of 2 dip switches that allow the user to use the function defined as ‘g-select’ on the MMA7260Q accelerometer. This enables the user to define the g-force range, from a 1.5 g device to a 2 g, 4 g, and 6 g device with two simple buttons.
Momentary switch	This enables the MCU to detect inputs to the STAR from the user during standalone mode, when the board is not connected via RS232.
Buzzer & LEDs	These provide status/outputs for the STAR. It notifies the user if the board is on, if a certain condition is satisfied, etc.

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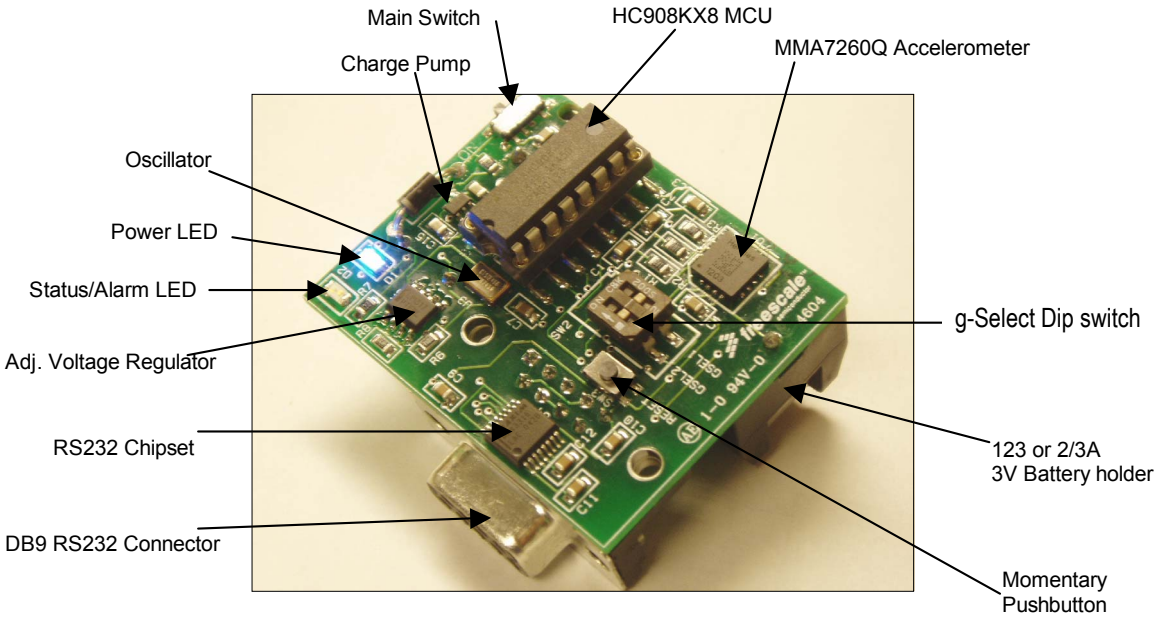

Figure 2. Location of Components on Board

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VOLTAGE/POWER

A 2/3 A battery was chosen as a power supply with its ability to supply 1400 mAH for the STAR. It was also a design consideration to reduce the size of the demonstration board. The 2/3 A battery is available at any commercial battery stand. The other options were two AA batteries or a 9 V battery, significantly larger in size when coupled with battery holders. As can be seen in Figure 2, a number of the components are driven at a 3.6 V supply. The MMA7260Q is optimal at 3.3 V so a slightly higher voltage was used to compensate for any small drop in voltage. The RS232 chipset was driven directly from the 3 V source due to the logic level thresholds of that particular device.

The 3.6 V supply is obtained from the 3 V battery by the use of a charge pump, the LM2765M6. This allows the doubling of voltage to 6 V. This is regulated back down to 3.6 V via the adjustable regulator LM317-L and supplied to the other ICs.

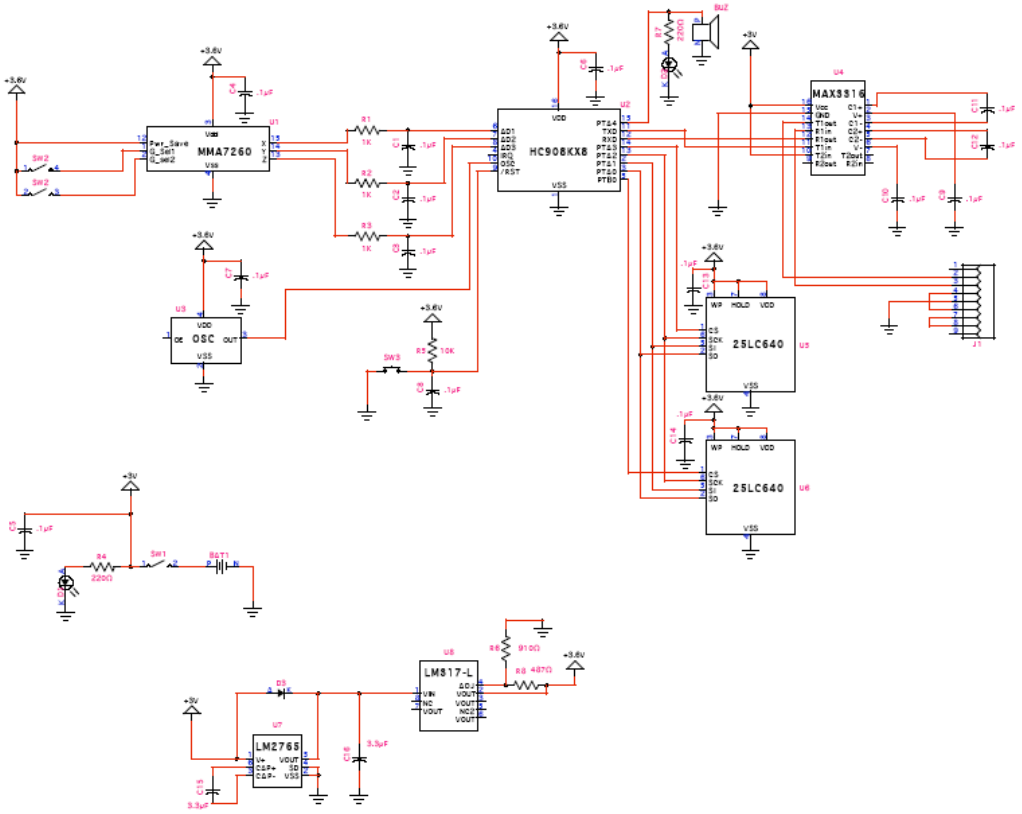

Figure 3. Schematic of Board

SOFTWARE

A software program was developed to provide an interface as well as a development system. The software can be used for displaying the 8-bit ADC values sent through the RS232 connection, or utilized for analyzing accelerometer data to demonstrate end applications. The software is sorted by various modules that showcase these possible end-applications for the MMA7260Q. This allows for developmental ideas for the MMA7260Q as a user can sample possible final products with a single reference/development tool. Some software modules such as free fall and battery saver can be initiated without the use of the PC connection, activated by a push button. The software available for the STAR board can be found on the Freescale Web site.

MODES OF OPERATION

The STAR board has three modes of operation - sending data to the PC for analysis or display, saving data to external memory (2 EEPROMs), or running a stand alone module. The stand alone modules contain demonstration tools such as freefall, battery saver, or shock alarm. The operation mode can be selected via the STAR's push button or by selecting a stand alone module on the PC software. In the push button operation mode, a user can push the STAR's tactile switch to select the most recent stand alone module. If the user depresses the same button for 20 seconds, it will cause the STAR to run the freefall stand alone module.

SUMMARY

The MMA7260Q has many unique features such as low power, low current, a quick turn on time, and 3-axis sensing with g-select all in a small QFN package. The STAR enables the user to quickly see many capabilities of the device along with application ideas to pursue. In addition, with data download capability, the STAR provides a quick way to prototype a software solution to gain a better understanding for the capability of the device.

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APPENDIX A

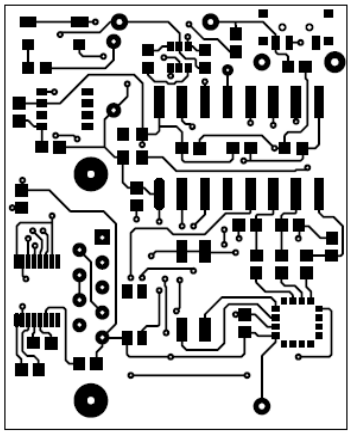

Figure 4. Component Layer of STAR Board

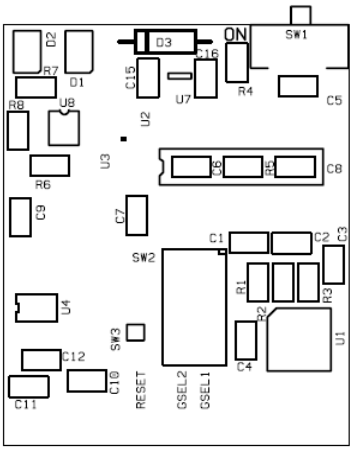

Figure 5. Component Silkscreen

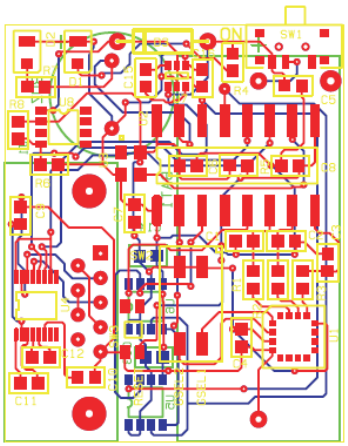

Figure 6. All Layers

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Detecting Freefall with Low-G Accelerometers

by: **Michelle Clifford**
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Tempe, AZ

INTRODUCTION

This application note describes the method of detecting freefall with Freescale's MMA7260Q 3-axis accelerometer. It will cover an overview of the application, the capability of the method, and considerations for developing a freefall detection system. The freefall algorithm was prototyped, tested, and characterized using the TRIAX2 and the STAR board Freescale development tools.

FREEFALL OVERVIEW

Using Freescale Accelerometers, the measurements of static acceleration from gravity and dynamic acceleration, due to a combination of gravity and motion, can be achieved. Freefall is a type of dynamic acceleration. Using the accelerometer to monitor the accelerations of a system, different freefall motions can be detected, called "freefall signatures". We have developed an algorithm to monitor the components of freefall signatures to determine when a freefall condition is met. There are three categories of a fall — linear, rotational, and projectile. A linear fall is defined as a linear translation of an object falling from any orientation, where the orientation does not change during the translation. A rotational fall is defined as a linear translation of an object falling from any orientation, where the orientation changes by the object rotating on an axis. A projectile fall is defined as a planar translation with two dimensions, vertical and horizontal, where the object is essentially thrown in the horizontal direction while falling in the vertical direction. A projectile fall typically ends with a similar signature of a rotational fall.

For a complete freefall solution, the output of accelerations from three axes (x, y, and z) are compared to all possible physical values of the accelerometer during static acceleration, when only gravity is acting on the device at different orientations when the device is not moving. During non-freefall conditions, the x y z coordinates described by the acceleration signals are only a subset of all possible values.

SYSTEM DESIGN

ACCELEROMETER

The MMA7260Q inertial sensor was designed specifically for the consumer products with a small package, low current, low voltage supply, small package, and three sensing axes in one package. The accelerometer is packaged as a low dimension Quad Flat No-Lead (QFN) RoHS compliant package that is 6 x 6 x 1.45 mm to reduce the overall real estate and to accommodate the limited board space available in smart portable electronics with HDD that would benefit from a freefall solution. The MMA7260Q also includes a g-select feature where two inputs control the sensitivity to enable selection of four g-ranges — 1.5g, 2g, 4g, and 6g. This feature enables the freefall application to be implemented by configuring the g-select to 1.5g to monitor freefall conditions with a timer interrupt. When not detecting freefall, other applications can be implemented by the MCU driving the g-select pins to change the g-range of the accelerometer for other application requirements as seen in Figure 1.

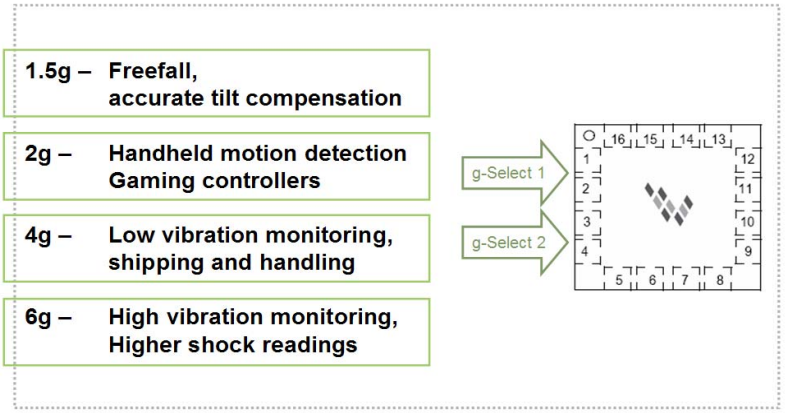


Figure 1. G-Select Enables Multiple Applications with One Accelerometer

MICROCONTROLLER

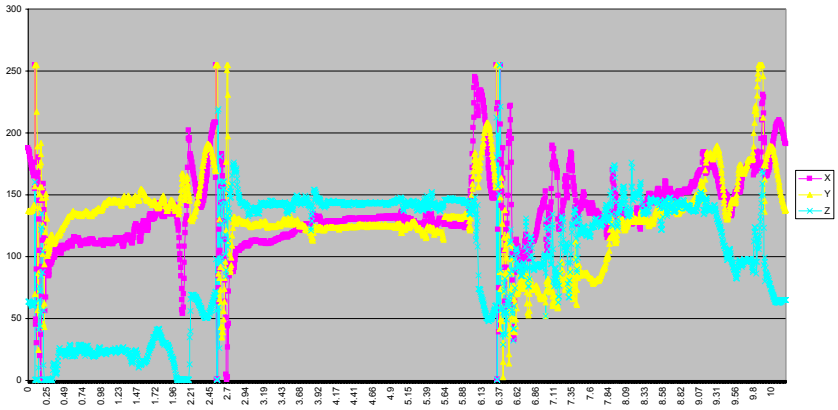
The Freefall detection demo was implemented on a low cost, 8-bit microcontroller with 8K of flash memory. These are the minimum processing requirements for running the freefall detection algorithm and sending a high/low signal to drive an LED or Piezohorn when freefall is detected. This ensures that freefall is quickly and reliably detected because there are no other processes running that may take precedence over the freefall detection algorithm. In most end products, there is a need for more complex MCUs or DSPs. In that case the freefall algorithm can be easily upgrade to one of these processors.

LINEAR FREEFALL

Linear freefall is the simplest of the three identified types of falls. Linear freefall is defined as a drop when the device was not previously moving, so there are no other forces acting on the device. Linear freefall is independent of the original orientation of the device. However, the requirement for linear freefall detection is that the orientation remains during the fall. If there is a dynamic change in the orientation, another freefall algorithm will be needed.

Figure 2. Linear Freefall is Defined as a Linear Translation to Earth's Surface without any Dynamic Change in Orientation

The linear freefall algorithm entails sampling the x-, y-, and z-axis output signals. If the acceleration on all three axes are determined to be at 0g with a predefined margin (i.e., ±5 bits when using an 8-bit ADC), for a set duration of time (5 samples in a row), then we are in a linear freefall condition.



Basic Software Algorithm Parameters

- Resolution of Analog to Digital converter: 8-bit (MC68HC908KX8)
- Accelerometer(s): MMA7260Q
- Processor speed/Sampling Rate: 50 Hz (200 samples per second)
- Averaging: None
- 0g Offset Calibration: YES
- Operating Temperature: approx 25°C

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S-FACTOR

At all times, the accelerometer will sense the acceleration of gravity. Depending on the orientation, each axis of the accelerometer will see a range of accelerations from 1g (when the axis is parallel to gravity) to 0g (when the axis is perpendicular to gravity). The S-factor is a way to consider the total acceleration acting on the device at once, acting for all axes combined.

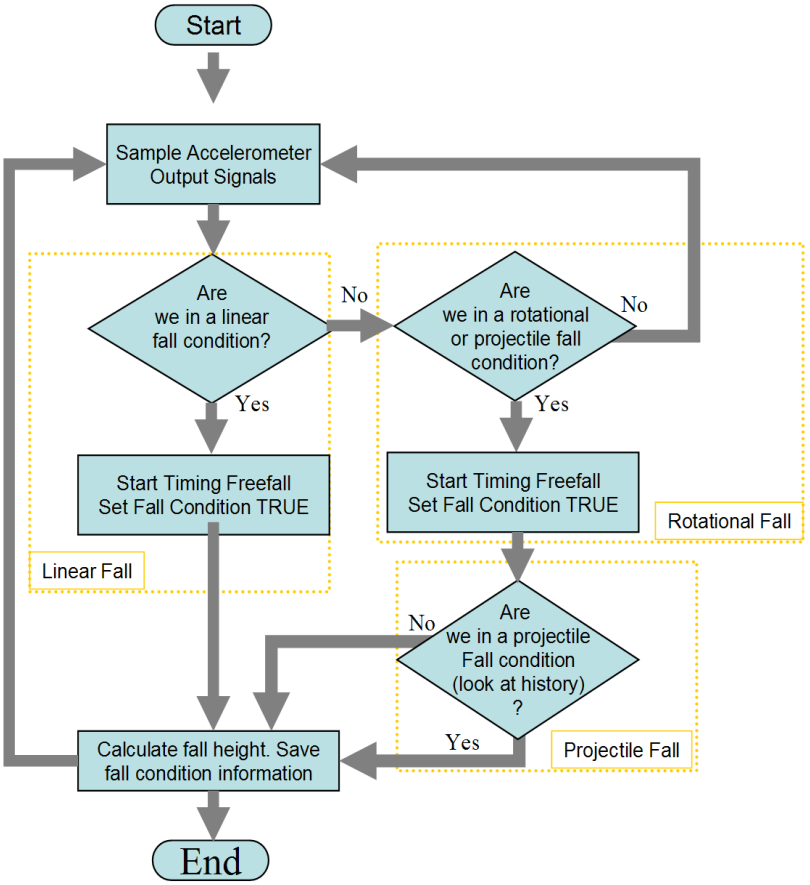
$$Sfactor = \sqrt{Xout^2 + Yout^2 + Zout^2}$$

When the accelerometer is held in any orientation, at least one of the sensing axes will be parallel with the acceleration of gravity. Therefore, at least one of the axes will be more than 0g. For example, when the accelerometer is tilted at an angle, a portion of the acceleration of gravity will be sensed. Therefore, the S-factor will always be equal to 1 when the accelerometer is static.

$$Sfactor = \sqrt{1^2 + 0^2 + 0^2}$$

During freefall, all 3 sensing axes converge to 0g. Since the S-factor is the total acceleration on all axes and all three axes are zero, the S-factor is 0. The S-factor will only be zero when freefall is occurring.

$$Sfactor = \sqrt{0^2 + 0^2 + 0^2}$$



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HEIGHT REQUIREMENTS FOR FREEFALL DETECTION

The height requirement for detecting freefall is directly dependent on the sampling rate of the software, the conversion time of the ADC, and the time segment given for sampling the freefall algorithm in the overall system. The freefall demo algorithm samples the data from x, y, and z output signals 256 times and takes the average for a steady value. The conversion of an ATD signal requires between 16 and 17 ADC clock cycles of the MC68HC908KX8 to complete. Conversion time in terms of the number of bus cycles is a function of CGMXCLK frequency, bus frequency, the ADIV prescaler bits, and the ADICLK bit. For example, with a CGMXCLK frequency of 8 MHz, bus frequency of 2 MHz, and fixed ADC clock frequency of 1 MHz, one conversion will take between 16 and 17 µs and there will be 32 bus cycles between each conversion. Therefore, the sample rate would be approximately 60 kHz. However, in most freefall applications, the fall protection mechanism is what takes over 95% of the fall time. For example, in a Hard drive protection application, the actual parking of the drive takes over 60 ms. Therefore, when designing a freefall protection algorithm, the typical height of a fall should be considered in addition to the limitation of the mechanical protection mechanism to determine what is more important in the solution — speed or accuracy.

TIME REQUIREMENTS FOR FREEFALL DETECTION

The time that an object will be in freefall when dropped from a typical drop height is useful for determining the maximum time allowed for the total freefall protection solution. The time required for an object to fall from a specific height is calculated using the kinematic equations of motion. For calculating a distance (height of the fall) with a known acceleration (gravity) from a static height (the initial velocity equals zero), we have the following equation:

$$d = v_i * t + ½ *a*t^2$$
$$= 0 + ½ *a*t^2$$

Since the distance is the known height of the fall and the acceleration of gravity is a known constant, the time can be calculated from the following translated equation:

$$t^2 = 2d/a$$

$$t = \sqrt{(2d)/a}$$

For example, if the typical height for an application is 700 mm, then the time needed for detecting freefall and protecting the device would be less than 400 ms.

$$t = [(2d)/a]$$
$$= [(2 \times 0.070 \text{ m}) / 9.8 \text{ m/s}^2]$$
$$= 0.3779 \text{ seconds}$$
$$= 400 \text{ ms}$$

Using this equation a time table can be formed so that the time a device is in freefall can be referenced (see Table 1) along with the time requirement for detecting freefall (see Table 2) to provide an understanding of how much time is available after the detection of freefall before impact occurs.

Table 1. Time in Freefall

Height of Fall (mm)	Time of Fall (ms)
5	31.944
10	45.175
50	101.02
100	142.86
200	202.03
300	247.44
400	285.71
500	319.44
600	349.93
700	377.96
800	404.06
900	428.57
1000	451.75

Table 2. Sampling Rate and Time to Detect Freefall

Sample/s	Samples in Algorithm	S/Sample	Time to Detect Freefall (ms)
200	1	0.005	5
500	1	0.002	2
1000	1	0.001	1
200	10	0.05	50
500	10	0.02	20
1000	10	0.01	10
200	20	0.1	100
500	20	0.04	40
1000	20	0.02	20

The time it takes for a system to detect freefall is directly related to the sampling rate of the system. If the analog to digital converter samples at 200 times per second, as in the Freescale Accelerometer demo board, then the system requires 100 ms before determining a freefall condition. If the system is able to sample at 1000 times per second, then a freefall condition can be detected in 10 ms. Another factor in the time required for freefall detection is the number of samples that are used in the freefall algorithm. For a simple linear freefall algorithm, only one sample is needed to determine freefall. However, to include detection for rotational and projectile freefall and increase the accuracy of freefall detection by looking at the conditions of the device before freefall, more samples may be needed before determining freefall. Table 2 shows the time required to detect freefall at the sampling rate of 200, 500, and 1000 samples per second along with 3 different levels of detection — simple freefall detection using 1 sample to determine freefall, and more complex algorithms which require 10 and 20 samples before determining freefall.

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RELIABILITY OF FREEFALL DETECTION

The reliability of freefall is dependent on the algorithm that is used and the calibration of the 0g offset of the device. The variation of the 0g offset for the MMA7260Q is shown in Figure 3. Depending on the range of the ADC bits in the algorithm logic, the reliability will be affected if the system is not calibrated for 0g on all axes. Our freefall solution recommends a 0g calibration for the highest reliability of freefall. As seen from Figure 1, the mean of the X, Y, and Z offset voltages is 1.654, 1.637, and 1.621, respectively. This variation between axes can be hard coded in the software; however, for six sigma reliability, the ranges for each axis would need to be considered.

Figure 3. MMA7260Q 0g Offset Data

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Another consideration is the operating temperature of the system. The characterization of freefall in this report was completed at room temperature, approximately 25°C. However, during the operation of some consumer electronics, the temperature increased beyond room temperature, so temperature drift may need to be considered. The operating temperature of the MMA7260Q is in the range of -20 to 80°C. Figure 4, Figure 5, and Figure 6 shows the temperature drift of the MMA7260Q in the operating temperature range. The changes in offset are small, so they should not alter the reliability of a freefall solution. However, a system characterization for temperature is still recommended.

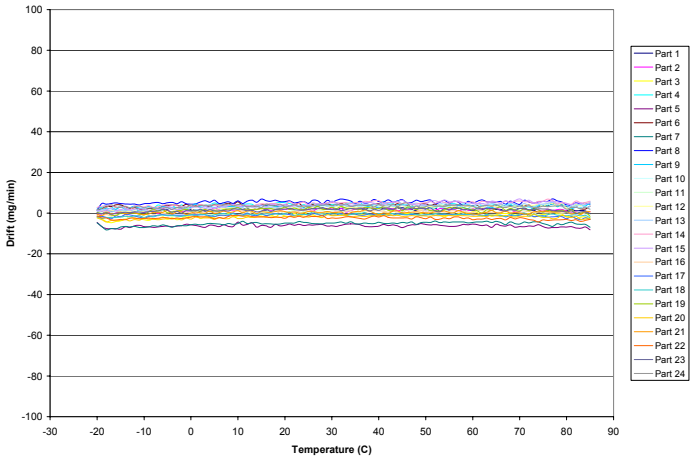

Figure 4. X-Offset Drift Over Temp (mg/min) at V_{DD} = 3.3 V

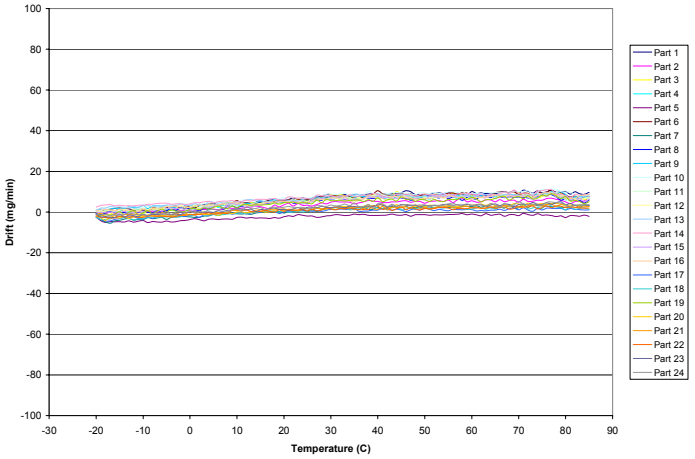

Figure 5. Y-Offset Drift Over Temp (mg/min) at V_{DD} = 3.3 V

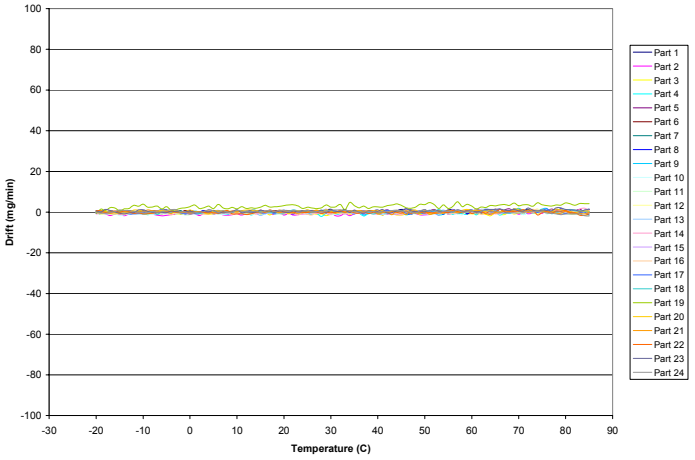

Figure 6. Z-Offset Drift Over Temp (mg/min) at V_{DD} = 3.3 V

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SHOCK PROTECTION IN ADDITION TO FREEFALL PROTECTION

Freefall detection is typically used for hard drive protection. However, freefall protection does not include protection from shock, which would not put the device into a freefall mode. Shock includes banging of the product itself, or using an external device to apply shock to the product, or excessive shaking of the product. Shock protection would have to be added in addition to freefall protection to ensure full protection on a hard drive during all types of excessive handing.

Table 3. Testing of the RD3112MMA7260Q

Trial	Orientation	Height of Fall	Freefall Detected
1	X-axis =1g	15 cm	Yes
2	X-axis =1g	10 cm	Yes
3	X-axis =1g	5 cm	Yes
4	Y-axis =1g	15 cm	Yes
5	Y-axis =1g	10 cm	Yes
6	Y-axis =1g	5 cm	Yes
7	Z-axis =1g	15 cm	Yes
8	Z-axis =1g	10 cm	Yes
9	Z-axis =1g	5 cm	Yes
10	X-axis = -1g	15 cm	Yes
11	X-axis = -1g	10 cm	Yes
12	X-axis = -1g	5 cm	Yes
13	Y-axis = -1g	15 cm	Yes
14	Y-axis = -1g	10 cm	Yes
15	Y-axis = -1g	5 cm	Yes
16	Z-axis = -1g	15 cm	Yes
17	Z-axis = -1g	10 cm	Yes
18	Z-axis = -1g	5 cm	Yes

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Using the Wireless Sensing Triple Axis Reference Design

RD3152MMA7260Q Reference Design (ZSTAR)

by: Pavel Lajšner and Radomír Kozub
Rožnov Czech System Center
Czech Republic

The Wireless Sensing Triple Axis Reference Design (ZSTAR) is a wireless successor of the popular STAR board described in AN3112 (RD3112MMA7260Q). It is an improved demonstration tool that is designed to allow visualization of key accelerometer applications in the consumer industry as well as the low-cost 2.4 GHz wireless solution based on the MC13191 transceiver.

The ZSTAR is a two-board design where a MMA7260QT triple axis accelerometer is controlled by an 8-bit MCU MC9S08QG8 and connected via a wireless link to a computer. The USB stick connects via the computer's USB slot. For the USB communication, a Full-Speed USB 2.0 8-bit microcontroller MCHC908JW32 is employed.

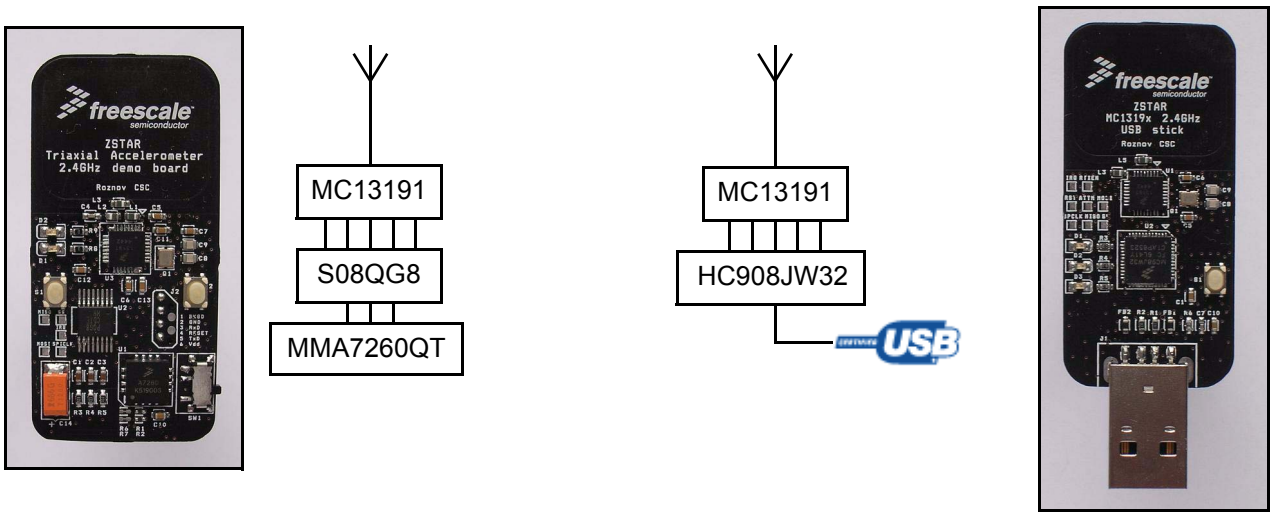

Figure 1. ZSTAR Design Overview

FEATURED PRODUCTS

This demo consists of several Freescale products. The main features are listed below.

Triple Axis Accelerometer MMA7260QT

The ZSTAR board is a demonstration tool for the MMA7260QT, a 3-Axis Low-g accelerometer. The MMA7260QT has many unique features that make it an ideal solution for many consumer applications such as freefall protection for laptops and MP3 players, tilt detection for e-compass compensation and cell phone scrolling, motion detection for handheld games and game controllers, position sensing for g-mice, shock detection for warranty monitors, and vibration for out of balance detection.

Features such as low power, low current, and sleep mode with a quick turn-on time allow the battery life to be extended in end applications. The 3-axis sensing in a small QFN package requires only 6 mm x 6 mm board space, with a profile of 1.45 mm, allowing for easy integration into many small handheld electronics.

There are several other derivatives of MMA7260QT:

- MMA7261Q XYZ triple axis accelerometer with selectable 2.5g to 10g range
- MMA6270Q XY dual axis accelerometer with selectable 1.5g to 6g range
- MMA6271Q XY dual axis accelerometer with selectable 2.5g to 10g range
- MMA6280Q XZ dual axis accelerometer with selectable 1.5g to 6g range
- MMA6281Q XZ dual axis accelerometer with selectable 2.5g to 10g range

All members of this sensor family are footprint (QFN package) compatible, which simplifies the evaluation and design of the target application.

Microcontroller MC9S08QG8

The MC9S08QG8 is a highly integrated member of Freescale's 8-bit family of microcontrollers based on the high-performance, low-power consumption HCS08 core. Integrating features normally found in larger, more expensive components, the MC9S08QG8 MCU includes a **background debugging system** and on-chip in-circuit emulation (ICE) with real-time bus capture, providing single-wire debugging and emulation interface. It also features a programmable 16-bit timer/pulse-width modulation (PWM) module (TPM) that is one of the most flexible and cost-effective of its kind.

The compact, tightly integrated MC9S08QG8 delivers a versatile combination and wealth of Freescale peripherals and the advanced features of the HCS08 core, including **extended battery life** with maximum performance down to 1.8 V, industry-leading Flash and innovative development support. The MC9S08QG8 is an excellent solution for power and size-sensitive applications, such as wireless communications and handheld devices, small appliances, Simple Media Access Controller (SMAC)-based applications and toys.

MC9S08QG8 Features

- Up to 20 MHz operating frequencies at >2.1 volts and 16 MHz at <2.1 volts
- 8 K Flash and 512 bytes RAM
- Support for up to 32 interrupt/reset sources
- 8-bit modulo timer module with 8-bit prescaler
- Enhanced 8-channel, 10-bit analog-to-digital converter (ADC)
- Analog comparator module
- Three communication interfaces: SCI, SPI and IIC

MC13191 2.4 GHz ISM Band Low Power Transceiver

The MC13191 is a short range, low power, 2.4 GHz Industrial, Scientific, and Medical (ISM) band transceiver. The MC13191 contains a complete packet data modem which is compliant with the IEEE® 802.15.4 Standard PHY (Physical) layer. This allows the development of proprietary point-to-point and star networks based on the 802.15.4 packet structure and modulation format. For full 802.15.4 compliance, the MC13192 and Freescale's 802.15.4 MAC software are required.

When combined with an appropriate microcontroller (MCU), the MC13191 provides a cost-effective solution for short-range data links and networks. Interfacing the MCU is accomplished by using a four wire serial peripheral interface (SPI) connection and an interrupt request output which allows for the use of a variety of processors. The software and processor can be scaled to fit applications ranging from simple point-to-point to star networks.

MC13192/MC13193 2.4 GHz Low Power Transceiver for the IEEE® 802.15.4 Standard

The MC13192 and MC13193 are short range, low power, 2.4 GHz Industrial, Scientific, and Medical (ISM) band transceivers. The MC13192/MC13193 contains a complete 802.15.4 physical layer (PHY) modem designed for the IEEE® 802.15.4 wireless standard which supports peer-to-peer, star, and mesh networking.

The MC13192 includes the 802.15.4 PHY/MAC for use with the HCS08 Family of MCUs. The MC13193 also includes the 802.15.4 PHY/MAC plus the ZigBee™ Protocol Stack for use with the HCS08 Family of MCUs. With the exception of the addition of the ZigBee™ Protocol Stack, the MC13193 functionality is the same as the MC13192.

When combined with an appropriate microcontroller (MCU), the MC13192/MC13193 provides a cost-effective solution for short-range data links and networks. Interfacing the MCU is accomplished by using a four wire serial peripheral interface (SPI) connection and an interrupt request output which allows for the use of a variety of processors. The software and processor can be scaled to fit applications ranging from simple point-to-point systems, through complete ZigBee™ networking.

Microcontroller MCHC908JW32

The MCHC908JW32 is a member of the low-cost, high-performance M68HC08 Family of 8-bit microcontroller units (MCUs). All MCUs in the family use the enhanced M68HC08 central processor unit (CPU08) and are available with a variety of modules, memory sizes and types, and package types.

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MCHC908JW32 Features

- Maximum internal bus frequency: 8 MHz at 3.5–5 V operating voltage
- Oscillators:
  - 4 MHz crystal oscillator clock input with 32 MHz internal phase-lock loop
  - Internal 88 kHz RC oscillator for timebase wakeup
- 32,768 bytes user program FLASH memory with security feature
- 1,024 bytes of on-chip RAM
- 29 general-purpose input/output (I/O) ports:
  - 8 keyboard interrupt with internal pull-up
  - 3 pins with direct LED drive
  - 2 pins with 10 mA current drive for PS/2 connection
- 16-bit, 2-channel timer interface module (TIM) with selectable input capture, output compare, PWM capability on each channel, and external clock input option
- Timebase module
- PS/2 clock generator module
- Serial Peripheral Interface (SPI) Module
- Universal Serial Bus (USB) 2.0 Full Speed functions:
  - 12 Mbps data rate
  - Endpoint 0 with 8-byte transmit buffer and 8-byte receive buffer
  - 64 bytes endpoint buffer to share among endpoints 1–4

ZSTAR REFERENCE BOARDS

The goal of the ZSTAR design was to provide a small portable board with the capability to demonstrate and evaluate various accelerometer applications that accommodate the low-cost low-power wireless connection. One of the considerations for design was to use a small and versatile tool (board size is 56 mm x 27 mm or 2.20" x 1.10"). The Sensor board includes two PCB 2.4 GHz antennas, CR2032 Lithium battery holder and the two pushbuttons. The USB stick board has the same two PCB 2.4 GHz antennas, one pushbutton and a USB type “A” plug.

Table 1 and Table 2 provide a brief description of the components on the ZSTAR boards and Figure 2 and Figure 3 show the location on the boards.

Table 1. ZSTAR Sensor Board Components

Component	Component Function
MMA7260QT	3-axis Accelerometer part to give vibration and inertial readings to the board
MC9S08QG8	8-bit microprocessor on the Sensor board, containing the SMAC stack, which can be reprogrammed on-board over the BDM (Background Debug Interface)
MC13191	2.4 GHz Low-Power RF Transceiver used for wireless transmission
Q1 Crystal	16.0 MHz crystal that accompanies MC13191 Transceiver
SW1 Main switch	Used to power on/off the Sensor board
S1 and S2 Pushbuttons	The pushbuttons are used when the Wireless mouse demonstration is active, acting as left and right mouse buttons.
D1 and D2 Status LEDs	These LEDs provide the user feedback about the Sensor board status, Transceiver or Sleep mode activity
Transmit and Receive PCB Antennas	These small footprint antennas are designed on the opposite sides of the PCB.
CR2032 Lithium Battery Holder	Provides the power for the Sensor board (on bottom side of the Sensor board). The footprint design allows to use CR2430, CR2450 or CR2477 battery holders when larger battery capacity is required.

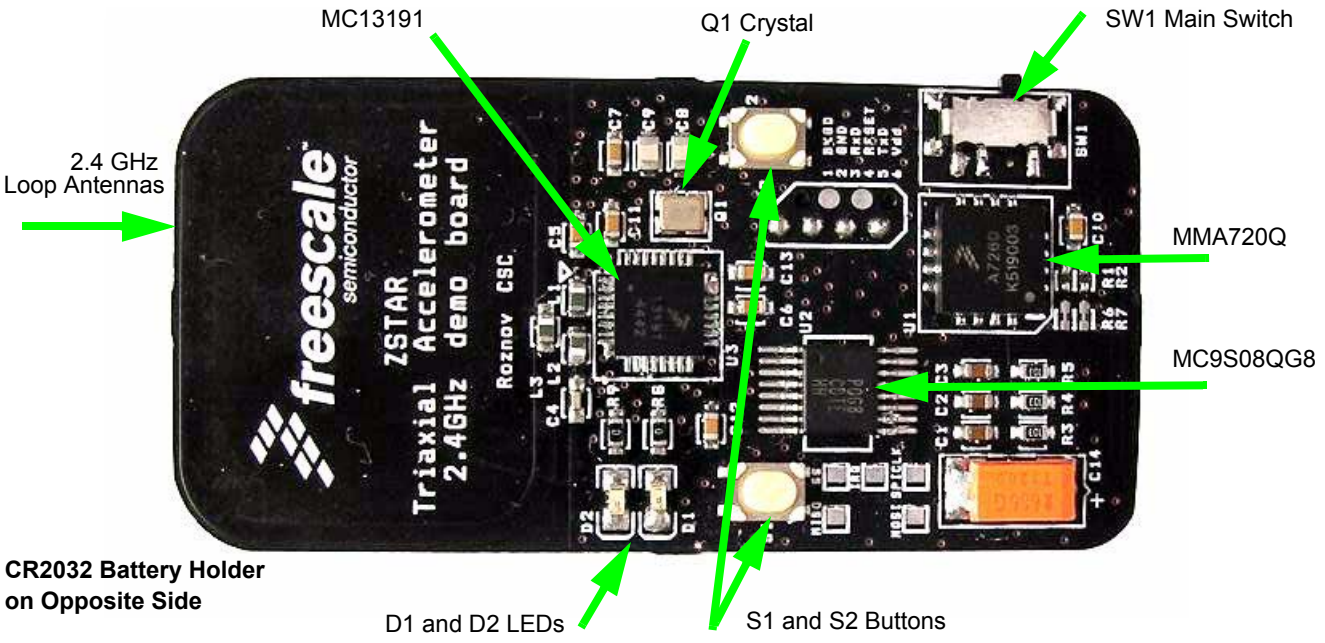

Figure 2. ZSTAR Sensor Board View

Table 2. ZSTAR USB Stick Board Components

Component	Component function
MCHC908JW32	8-bit microprocessor on the USB stick board, contains the SMAC stack and USB driver software. Its main job is bridging the received data from the Sensor board to the USB. Can be reprogrammed over the USB port.
MC13191	2.4 GHz Low-Power RF Transceiver used for wireless transmission
Q1 Crystal	16.0 MHz crystal that accompanies MC13191 Transceiver
Q2 Crystal	Q2 is the 6.0 MHz frequency reference for the MCHC908JW32 MCU
S1 Pushbutton	The pushbutton is used to change the operation mode of the USB stick (towards the PC).
D1, D2 and D3 Status LEDs	These LEDs provide the user feedback about the USB stick board status, Transceiver and USB activity
Transmit and Receive PCB Antennas	These small footprint antennas are designed on the opposite sides of the PCB
J1 USB type “A” plug	Provides the USB data connection and power from the USB slot
U3 and U4 Voltage regulator	U3 and U4 voltage regulators provide the regulated voltage for MC13191 and MCHC908JW32 out of 5.0 V voltage from USB port

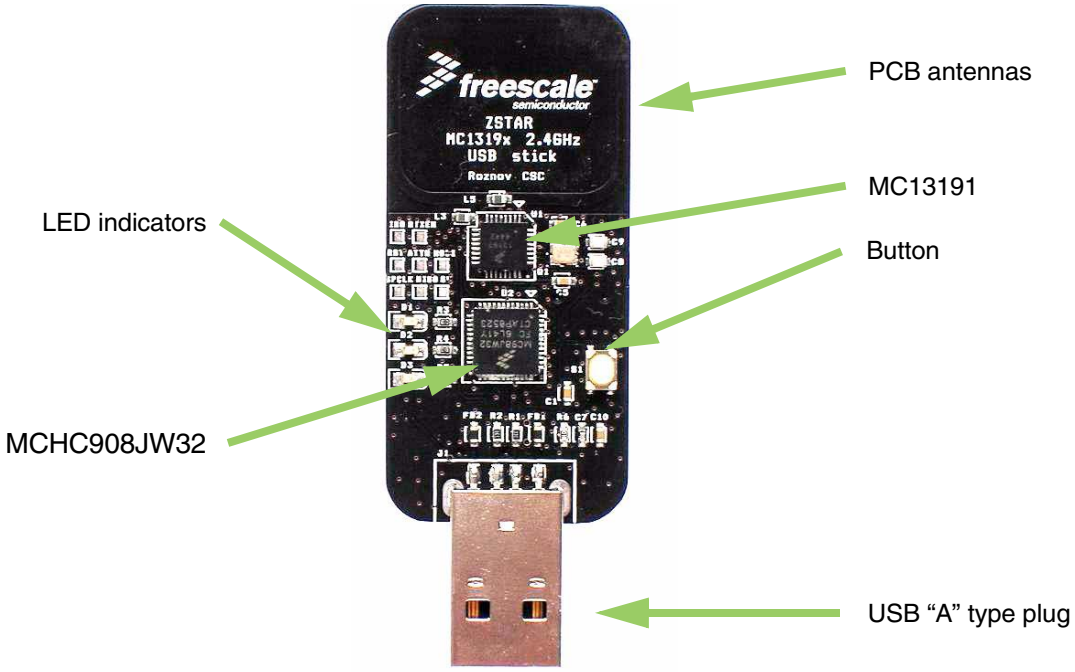

Figure 3. ZSTAR USB Stick Board View

SOFTWARE

This reference design contains two pieces of software. The first one is on the Sensor board MCU (MC9S08QG8). Its job is to collect sensor data from the MMA7260QT accelerometer, create a data packet and send it over the SMAC (Simple Media Access Controller) driver using the MC13191 RF Transceiver.

The sensor data is measured over three channels of the Analog-to-Digital converter, while another GPIO pin controls the sleep mode of the MMA7260QT accelerometer to conserve power.

Serial Peripheral Interface (SPI) is used for communication with the MC13191.

The overall application is powered from the coin-sized CR2032 Lithium battery that is located on the bottom side of the board. The overall average current consumption is below 1 mA with 20 data transmissions per second rate. This allows approximately 10 days of continuous operation at this real-time data rate.

The simple ZSTAR RF protocol also transfers the calibration data. These data are stored in non-volatile Flash memory and are transferred on request.

The software and hardware interface is shown in Figure 4.

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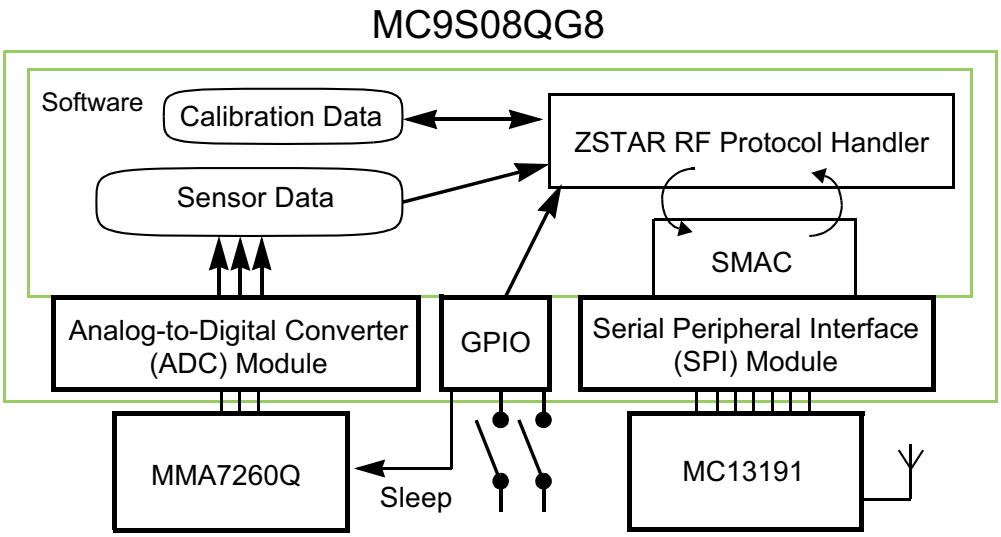

Figure 4. ZSTAR Sensor Board Software Overview

The second piece of software is contained within the USB stick board and its job is to create a “bridge” between the RF link and the USB connection. The sensor and keyboard data are received from the Sensor board and stored in the USB stick RAM memory. Another independent process is the USB protocol communication. Several options are possible. USB specifications define several ways of transferring data between the USB peripheral and the PC (called “profiles” or classes). In this demo two classes are demonstrated:

- Serial communication class (“virtual serial port”)
- HID (Human Interface Device) class

The Microsoft™ Windows 2000/XP operating system contains by default a driver support for these classes which makes this solution simple for demonstration purposes.

If the serial communication (virtual serial port) is demonstrated, the accelerometric data is available through the simple serial protocol compatible with the STAR demo. Thus most of the RD3112MMA7260QSW is usable also for data visualization.

On the other hand, if the HID class is demonstrated, the ZSTAR demo behaves as a mouse. By tilting the sensor board, the mouse cursor movement can be controlled.

The software and hardware interfacing is shown in Figure 5.

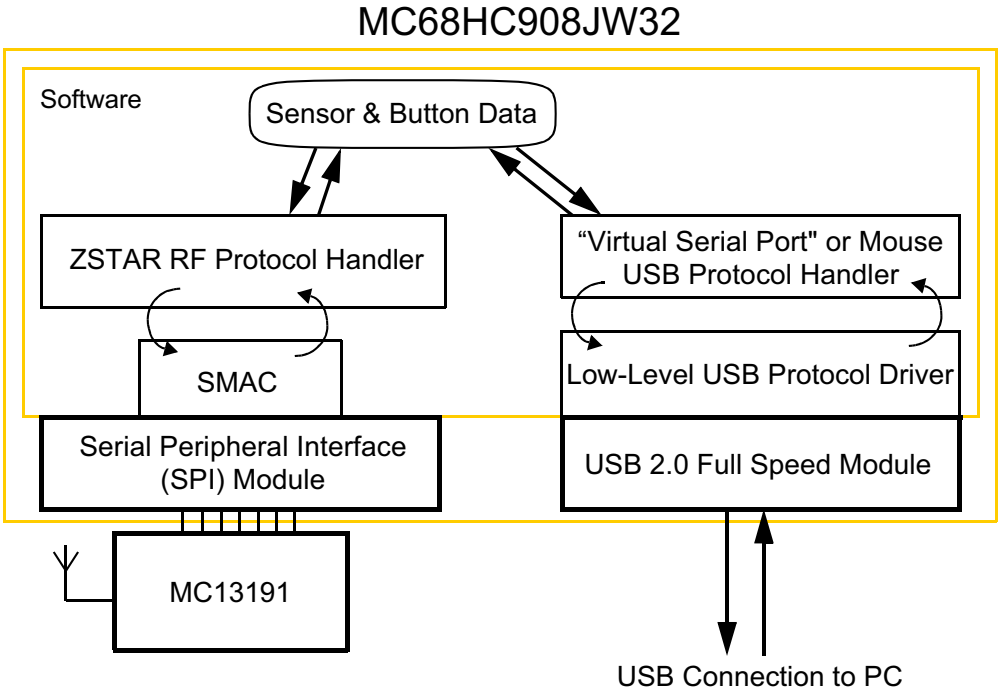

Figure 5. ZSTAR USB Stick Software Overview

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SUMMARY

Multi-axis sensing using an XYZ-axis low g acceleration sensor, MMA7260QT with selectable g-ranges of 1.5g/2g/4g/6g, is combined with the versatile MC9S08QG8 8-bit microcontroller.

2.4 GHz wireless communication is enabled by the latest RFCMOS technology. The MC13191 is a member of the pin-to-pin compatible series of Freescale's transceivers, including the MC13192 which supports the IEEE 802.15.4 protocol and the MC13193 which supports full ZigBee™ compliant applications.

The USB 2.0 with the 8-bit MCHC908JW32 full speed chip offers plug and play benefits.

RD3152MMA7260Q demonstrates:

- Consumer and industrial wireless sensing applications
- Accelerometer: MMA7260QT (MMA7261QT/MMA6270QT/MMA6271QT/MMA6280QT/MMA6281QT)
  - Package: Quad Flat No-Lead (QFN) 6 x 6 x 1.45 mm
  - Power: Low Voltage 2.2 V to 3.6 V
  - Low power consumption: 500 µA (3 µA in standby mode)
  - Selective g range:
    - 1.5g, 2g, 4g, 6g (MMA7260QT/MMA6270QT/MMA6280QT)
    - 2.5g, 3.3g, 6.7g, 10g (MMA7261QT/MMA6271QT/MMA6281QT)
  - Response time: 1 ms
- Microprocessor: MC9S08QG8
  - Versatile 8-bit microcontroller
- Wireless connectivity: ZigBee™ Transceivers (MC1319x)
- Microprocessor: MCHC908JW32 (USB 2.0 Full Speed)

References

AN3112 Using the Sensing Triple Axis Reference Board (STAR)

AN1986 Using the TRIAX Evaluation Board

AN3107 Measuring Tilt with Low-g Accelerometers

AN3109 Using the Multi-Axis g-Select Evaluation Boards

AN1611 Impact and Measurement Using Accelerometers

AN2731 Compact, Integrated Antennas: Designs and Applications for the MC13191 and MC13192

SMACRM Simple Media Access Controller (SMAC) User's Guide

AN2728 Demonstration Guide for SMAC Applications

AN2295 Developer's Serial Bootloader for M68HC08 and HCS08 MCUs

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APPENDIX A
ZSTAR BOARDS SCHEMATICS AND PCBs

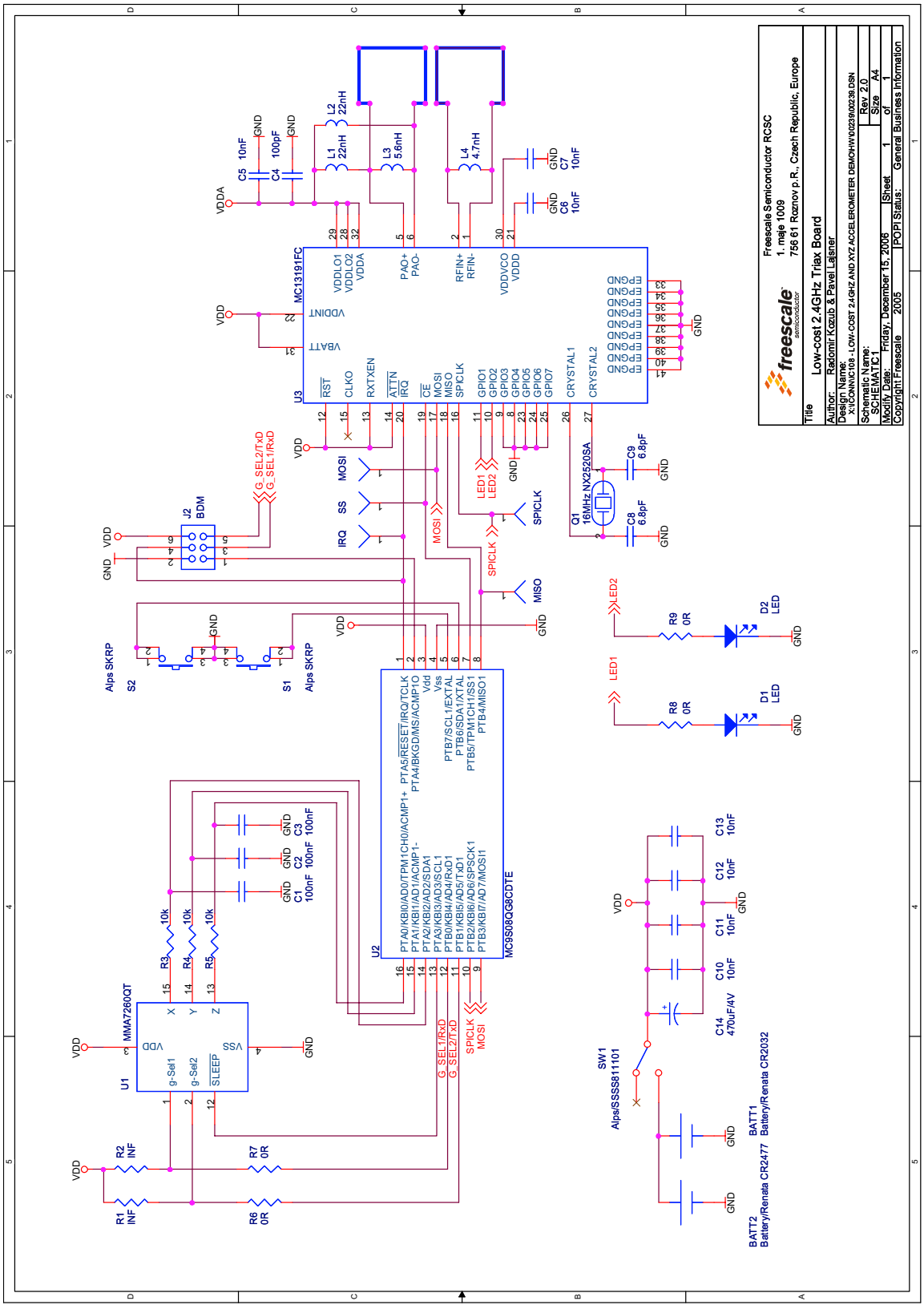

Figure 6. ZSTAR Sensor Board Schematics

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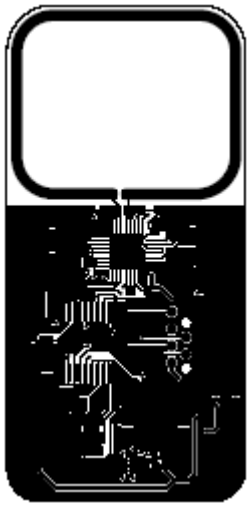

Figure 7. Top Layer of the Sensor Board

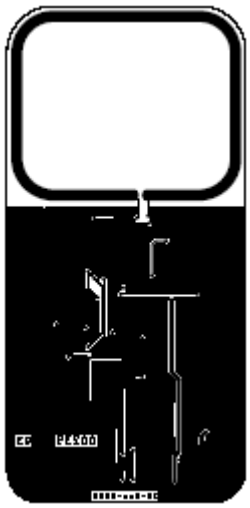

Figure 8. Bottom Layer of the Sensor Board

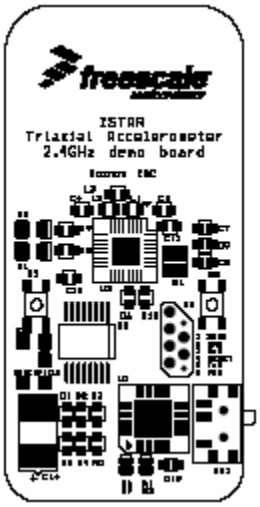

Figure 9. Top Component Placement of the Sensor Board

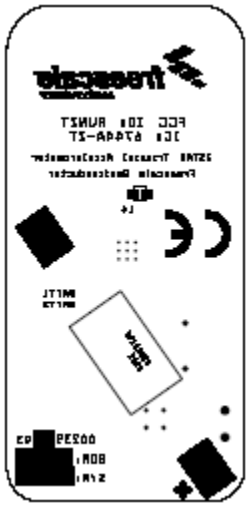

Figure 10. Bottom Component Placement of the Sensor Board

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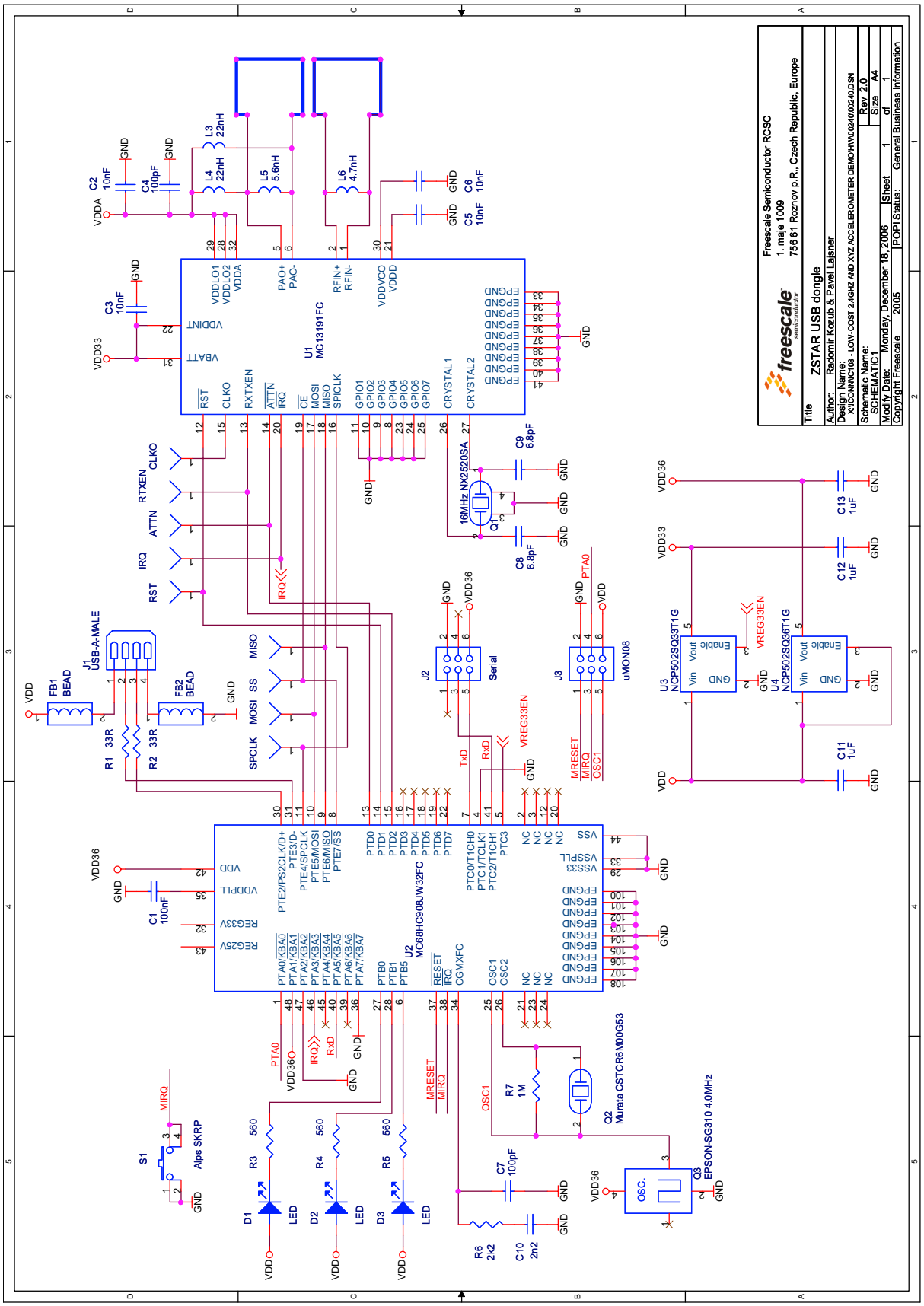

Figure 11. ZSTAR USB Stick Board Schematics

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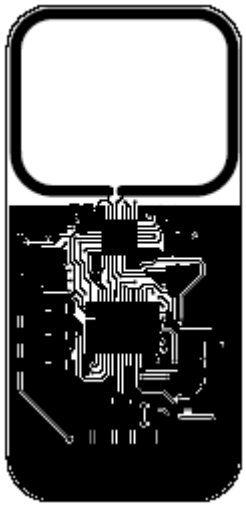

Figure 12. Top Layer of the USB Stick Board

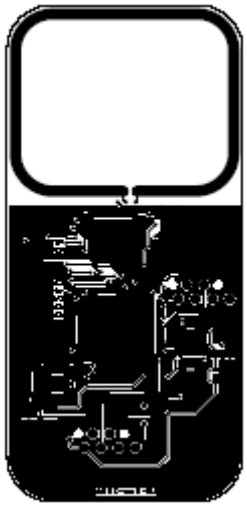

Figure 13. Bottom Layer of the USB Stick Board

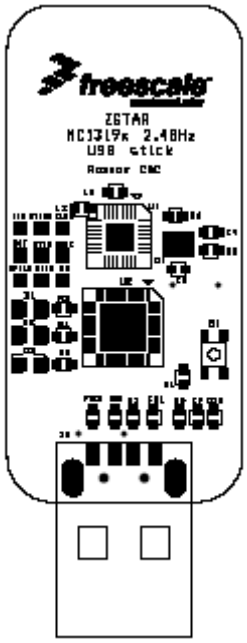

Figure 14. Top Component Placement of the USB Stick Board

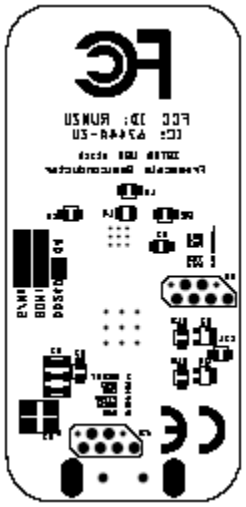

Figure 15. Bottom Component Placement of the USB Stick Board

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Using the Full-Speed USB Module on MC68HC908JW32

Including USB Basics, Driver Description, Software Examples, CDC — Virtual Serial COM, and HID Class

by: Radomir Kozub
Freescale Roznov pod Radhostem Czech Republic

The universal serial bus (USB) has become the most widespread periphery among PCs. Because embedded devices need to communicate with personal computers, USB is the ideal solution.

This document provides instructions for creating your first USB device. MC68HC908JW32 has an advanced USB 2.0 full-speed module that enables communication with a PC through USB with minimal software or hardware efforts. This document contains a description of MC68HC908JW32, suggestions for its use, and a discussion of USB basics. The embedded USB module speeds software design, and a description of the driver and examples for using it are included. In addition, this document discusses the communication device class (CDC) — virtual serial COM — that eases migration from UART to USB and human interface device (HID) class and contains an example of the implementation of a mouse.

1 MC68HC908JW32 USB Module Description

1.1 USB Module Features

The USB module complies with the *Universal Serial Bus Rev. 2.0 Specification* full-speed functions:

- 12 Mbps data rate
- On-chip 3.3 V regulator
- Endpoint 0 with an 8-byte transmit buffer and an 8-byte receive buffer
- Four data endpoints supported by a shared 64B in/out buffer
- Programmable endpoint type for four independent endpoints — interrupt or bulk
- USB device controller with protocol control supporting a single configuration, two interfaces with no alternative settings for either interface
- USB data control logic/packet identification and decoding/generation, CRC generation and checking, non-return-to-zero inserted (NRZI) encoding/decoding, bit-stuffing, sync detection, end-of-packet detection
- USB reset options: internal MCU reset generation and CPU interrupt request generation

1.2 USB Driver Files

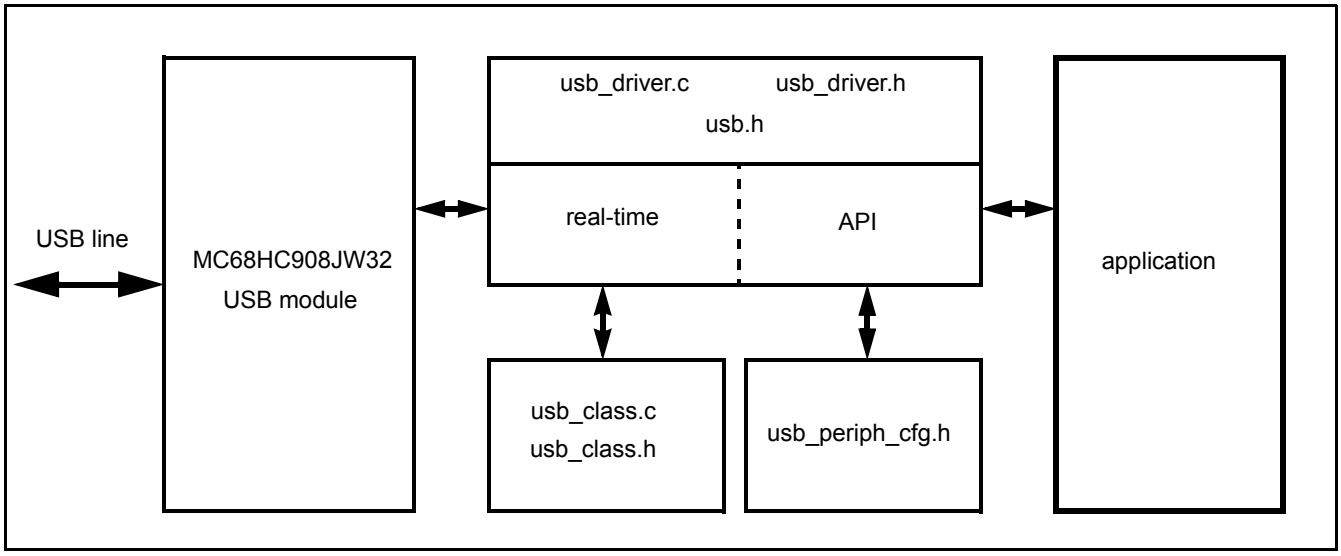

Figure 1. USB Driver Files Structure

The USB driver resides in usb_driver.c, usb_driver.h, usb.h. These files should not be changed.

The static settings by macro constants of the USB module for an application are defined in the usb_periph_cfg.h file. Most of these initializations, stated in usb_periph_cfg.h, are used in the driver usb_driver.c file for initializing the USB module (endpoint parameters, buffers, interrupts, etc.), and also for code tailoring during compilation time (conditional code). Section 1, "MC68HC908JW32 USB Module Description," and Section 2, "USB Interrupts," describe all the necessary static settings.

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The usb.h file contains data structures defined in *Universal Serial Bus Rev. 2.0 Specification* that are used mostly in the driver, such as the device, configuration, endpoint and interface descriptor format, setup packet data structure, etc.

Driver code is in the usb_driver.c file. By using macro constants from usb_periph_cfg.h, the source code is tailored during the compile time and no changes are needed.

In the HID example, you can find the application dependent files *usb_hid.c* and *usb_hid.h* (USB class files) where all the needed descriptors lie. User code must be placed there to manage vendor and device specific requests.

1.3 Electrical Basics

USB is a host-controlled serial bus that uses a star topology. All communication is initiated by the host — all devices are polled. Only one host exists in any USB system. USB devices are hubs or functions. Hubs provide additional attachment points to the USB host. Functions provide capabilities to the system, such as an ISDN connection, a digital joystick, or speakers.

The USB transfers signals and power over a four-wire cable with twisted pairs as specified in the *Universal Serial Bus Rev. 2.0 Specification*, Chapter 7.1.1.1. Data is signalled differentially over D+ and D–. A NRZI encoding scheme is used with a sync field to synchronize the host and receiver clocks. The other two wires, 5 V power lines Vbus and GND, are assigned to supply devices.

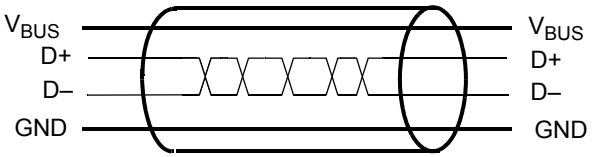

Figure 2. USB Lines — Data (D+, D–) and Power Supply (V_{Bus}, GND)

1.4 Power the Device by USB

One of the advantages of USB is bus-powered devices, which receive their power from the bus and require no external plug packs.

USB specification uses three types of USB functions:

- Low power bus-powered functions (max 100 mA)
- High power bus-powered functions (max 500 mA)
- Self-powered functions (max 100 mA from the bus, rest from an external source)

More details can be found in the *Universal Serial Bus Rev. 2.0 Specification*, Chapter 7.2.1.

Because MC68HC908JW32 has an operating voltage range of 3.5 to 5.5 V, it can be powered directly by USB without using the LDO regulator (see Figure 3). When you plug a USB device into the USB connector, the MCU supply voltage raises and it starts to work. Then you can initialize the MCU and its USB module. When the USB module is ready, enable a speed select pullup resistor (R_{PU}) to let the host know that the device is attached to the bus.

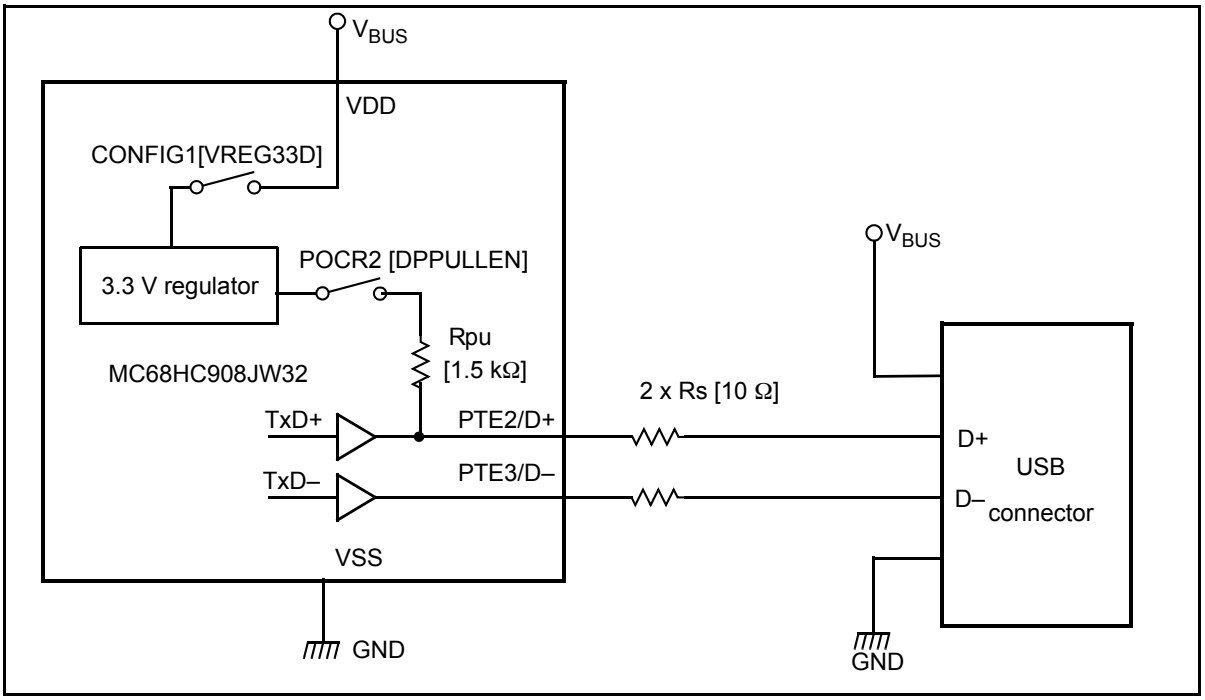

Figure 3. Connecting MC68HC908JW32 to USB

1.5 USB Speed Selection

Chapter four in *Universal Serial Bus Rev. 2.0 Specification* describes three data rates:

- The USB high-speed signaling bit rate is 480 Mbps
- The USB full-speed signaling bit rate is 12 Mbps
- A limited capability low-speed signaling mode is also defined at 1.5 Mbps

USB lines are terminated at the hub and function ends as shown in Figure 4. Full-speed, high-speed, and low-speed devices are differentiated by the position of the pullup resistor on the downstream end of the cable. Full-speed and high-speed devices are terminated with the pullup resistor Rpu (1.5 kΩ) on the D+ line to 3.3 V. Low-speed devices have a pullup resistor on the D– line. Both full-speed and high-speed devices have a pullup resistor on the D+ line and they are differentiated by a high-speed chirp during reset.

MC68HC908JW32 USB module supports only full-speed; therefore, this discussion concerns the full-speed mode only.

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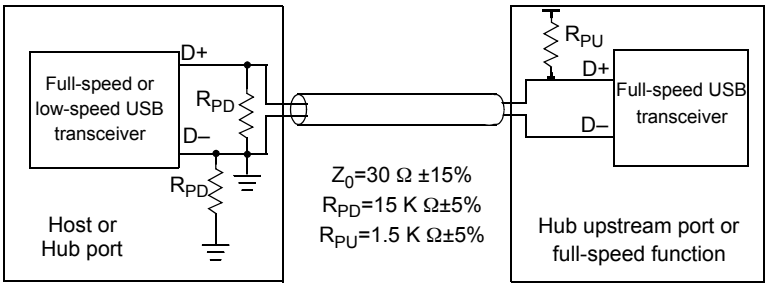

Figure 4. Full-speed Device Cable and Resistors Connection

MC68HC908JW32 has an integrated voltage regulator that provides 3.3 V output. It can be connected through an integrated pullup resistor to the D+ line (see Figure 3).

The 3.3 V voltage regulator can switched on or off by the CONFIG1[VREG33D] bit. The integrated pullup resistor (1.5 kΩ) between the 3.3 V output and the D+ line can be enabled or disabled by the POCR[DPPULLEN] bit.

If no pullup resistor is connected to the D+ or D– lines, the USB assumes nothing is connected to the bus.

1.5.1 Programming

As discussed in Section 1.2, all static settings used in the driver are set up by macro constants in the usb_periph_cfg.h file.

The 3.3 V voltage regulator is enabled by default on the MC68HC908JW32. To disable it, comment out the macro constant below. The voltage regulator will be disabled within:

```
#define USB_3V3REGULATOR_DIS  0x02
```

The internal pullup resistor (D+ to 3.3 V) is disabled by default. To enable it, define the macro constant:

```
#define USB_PULLUP_ENA 0x01
```

in usb_periph_cfg.h

Both settings are employed within the USB_Init() function in usb_driver.c. After the MCU reset, all module setup is done in this function also. See Section 2.1 for more discussion.

Call the function USB_Deinit() to disable the D+ pullup resistor. This will signal the host that the USB function was deasserted.

1.6 Endpoint and Pipe

The MC68HC908JW32 USB module contains five endpoints: EP0, EP1, EP2, EP3, and EP4. Endpoints are a source or sink of data located at the end of a logical communication channel, known as a pipe, to the USB function. A host can send or receive data to or from an endpoint. Each endpoint can be a source or a sink of data. Each endpoint has its own buffer of defined length.

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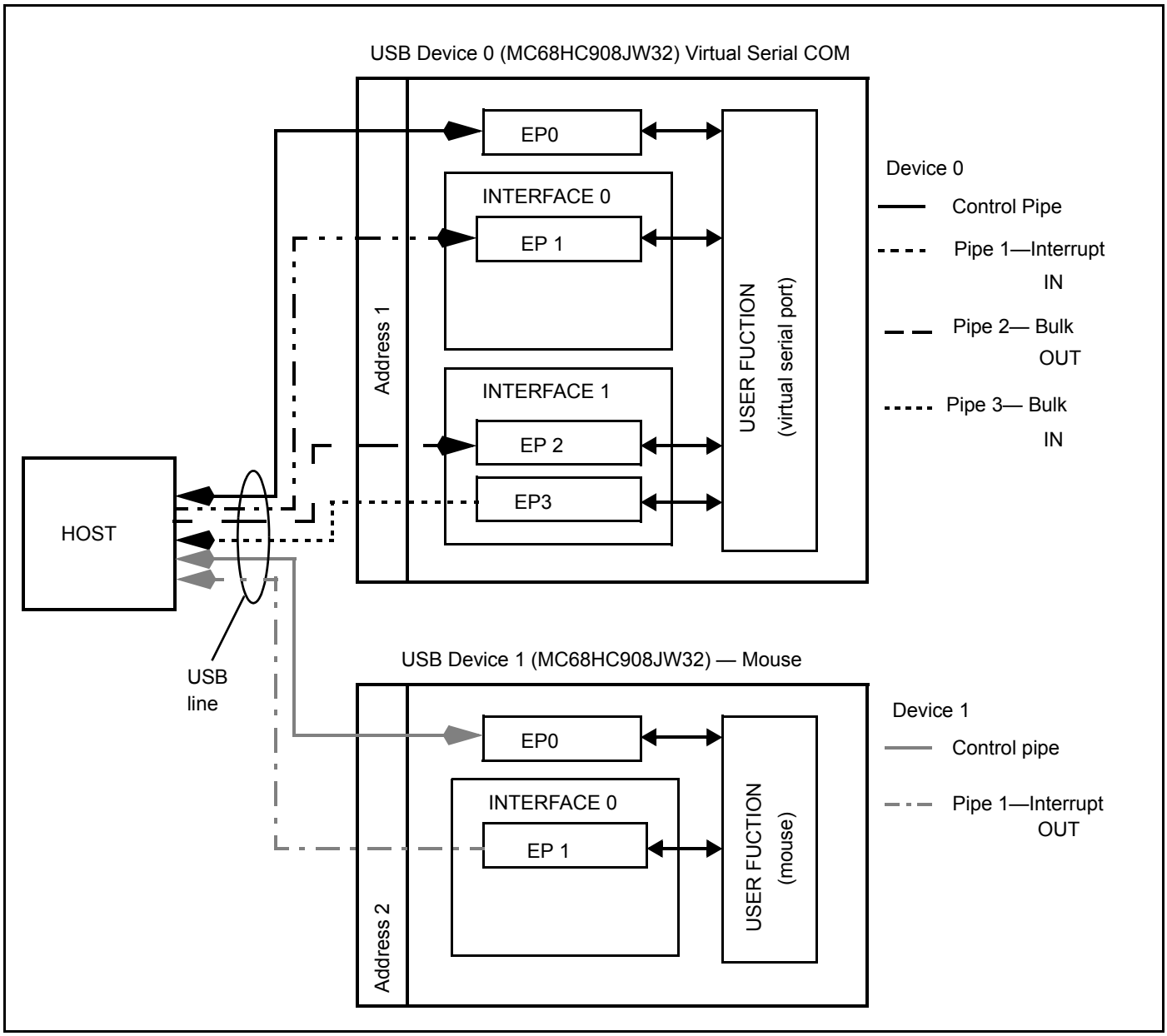

Figure 5. USB Logical Structure — Endpoints and Pipes

Each endpoint used in the USB device is logically connected to the host by a pipe. The pipe is a logical communication channel between the USB host and device. It has a set of parameters associated with it, such as dataflow direction (IN, OUT), transfer type (bulk, interrupt) or maximal packet size.

As shown in Figure 5, each USB device contains a control pipe. On the MC68HC908JW32, the default control pipe is made up of a bidirectional endpoint zero, EP0. It uses control transfer, both IN/OUT directions, and has a dedicated 8-byte bidirectional buffer and packet size at address $0040–$0047. EP0 is the only bidirectional endpoint on the MC68HC908JW32. EP0 does not need to be set because the setting is always the same and creates the control pipe. EP0 is set in the USB_Enable() function. Also, the EP0 data transfer interrupt is enabled by default.

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The endpoints and their pipes have a set of parameters that must be defined before communicating over the USB module. Most of them are set in USB endpoint control and status register, UEPxCSR. Parameters cannot be changed after the USB module is enabled as the bits have no effect.

1.6.1 Endpoint Direction

Endpoints EP1 to EP3 must have their data direction set as either IN or OUT, as opposed to bidirectional EP0. An IN endpoint has logical data flow from the USB device to the host, however an OUT endpoint receives data from the host. Endpoint direction is set by bit UEPxCSR[DIR] before the USB module is enabled and cannot be changed later.

1.6.1.1 Programming

Endpoints EP1 to EP3 direction macro constants must be initialized by one of the predefined values (EP_DIR_IN, EP_DIR_OUT) in the usb_periph_cfg.h file. These macro statements are employed in the USB_Enable() function. The endpoint should have the same direction in the endpoint descriptor:

```
#define EP1_DIR              EP_DIR_IN
#define EP2_DIR              EP_DIR_OUT
```

These definitions are also used in the compilation time to select the correct interrupt service routine in usb_driver.c if the interrupt service routine (ISR) is enabled.

1.6.2 Endpoint Mode

Endpoints EP1 to EP3 are data endpoints used to transfer data from the USB device to the USB host and vice versa. Using bits UEPxCSR[MODE], you can set the endpoints as bulk or interrupt (the endpoint will use a bulk or interrupt data transfer). Other transfer types such as control and isochronous, are not allowed. As the host polls the USB devices, the interrupt endpoint must wait until the host asks it. Interrupt transfer guarantees communication latency; however, bulk transfer uses spare unallocated bandwidth on the bus after all other transactions have been allocated. After the USB module is enabled, the transfer type cannot be changed.

Table 1. Endpoint Mode Selection

MODE[1:0]	Endpoint Type
00	Disable
10	Bulk
11	Interrupt

EP0 is dedicated to control transfer and a different setting is not possible.

1.6.2.1 Programming

Each endpoint mode macro constant (EP1_MODE), except EP0, must be initialized by one of the predefined values: EP_MODE_INT, EP_MODE_BULK or EP_MODE_DISABLE, in the usb_periph_cfg.h. Macro constants are employed in the USB_Enable() function to fill the UEPxCSR

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registers. These macro statements might also be used in the USB descriptors. The endpoint mode must be the same as that defined in the endpoint descriptor.

```
#define EP1_MODE                EP_MODE_INT      // Endpoint 1 will be initialized by EP1_MODE
#define EP2_MODE                EP_MODE_BULK
#define EP3_MODE                EP_MODE_DISABLE
#define EP4_MODE                EP_MODE_DISABLE
```

1.6.3 Buffer Size

EP1 to EP3 share one 64-byte IN/OUT buffer located at address $1000–$103F. Certain parts of the buffer space must be allocated to each used endpoint by the UEPxCSR[SIZE] bits.

Table 2. Endpoint Buffer Size Selection

SIZE[1:0]	Buffer Size
00	8 Bytes
01	16 Bytes
10	32 Bytes
11	64 Bytes

In registers UEP12BPR and UEP34BPR you must set the endpoint buffer base address within the buffer. See the MC68HC908JW32 USB module user's guide.

1.6.3.1 Programming

Each EP1 to EP3 buffer size macro constant (EP1_BUF_SIZE_BITMAP) should be initialized by one of the predefined values (EP_BUFFER_SIZE_0, EP_BUFFER_SIZE_8, EP_BUFFER_SIZE_16, EP_BUFFER_SIZE_32, EP_BUFFER_SIZE_64) in the usb_periph_cfg.h file as seen below:

```
#define EP1_BUF_SIZE_BITMAP     EP_BUFFER_SIZE_8 // endpoint 1 has an 8 byte buffer
#define EP2_BUF_SIZE_BITMAP     EP_BUFFER_SIZE_16
#define EP3_BUF_SIZE_BITMAP     EP_BUFFER_SIZE_16
#define EP4_BUF_SIZE_BITMAP     EP_BUFFER_SIZE_0 // disabled endpoint has zero length buffer
```

These macro constants initialize the UEPxCSR registers within the USB_Enable() function. Also, the endpoint buffer size constants (EPx_BUF_SIZE_BITMAP) are used directly to calculate endpoint buffer base addresses loaded into UEP12BPR and UEP34BPR registers within USB_Enable(). EP1 always has its buffer base address pointer set to $1000. EP2 has its buffer base address pointer set to the value $1000 + EP1_BUFFER_SIZE, and so on.

EPx_BUFFER_SIZE macro constants are calculated from EP1_BUF_SIZE_BITMAP by a preprocessor in the usb_periph_cfg.h file, and must be used in the USB driver functions as endpoint max packet length, and also in USB descriptors as packet length. The buffer size assigned to the endpoint is required to match the size defined in the endpoint descriptor.

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1.7 STALL

Setting the STALL bit will cause an endpoint to send a STALL handshake when polled by either an IN or OUT token from the USB host. A STALL handshake is issued to the host if the endpoint is halted or some request is not supported (EP0 only). Refer to the MC68HC908JW32 Data Sheet for details on latching halt state on an endpoint. A STALL is not a static setting of the USB module, it is used in runtime.

Use the macro constant USB_WRSTALL_EPx(x) to set/clear the STALL bit.

2 USB Interrupts

The MC68HC908JW32 has two interrupt sources for the USB module. USB endpoint interrupt is called if a successful transaction is finished between host and function endpoint. It is primarily used during data transfer.

USB system interrupt is concerned more with the states of the USB module or line. It can be generated from different sources — reset, suspend, resume, by an SOF and setup packet or config change request. Each source of the USB status interrupt has its own interrupt enable and interrupt flag bits. You must define the macro constant described in the subsequent sections to let the driver enable the interrupt (within USB_Enable()), and add service code to the interrupt service routine (ISR). In the ISR the interrupt flag is cleared and the call back function is called. You must write your own call back functions.

2.1 USB System Interrupts

2.1.1 USB Line Reset State

The USB host issues the reset state on the USB line by pulling the D+ line to logic zero for at least 2.5 µs (10 ms required).

Reset state is generated online by the host to put the function into a default state during the enumeration process after power up. The reset state is detected by the USB module. The MC68HC908JW32 MCU has two options for managing it:

If bit CONFIG2[URSTD] is logic 0, the default state after MCU reset, the USB line reset state recognized by the USB module will generate an internal reset of the MCU.

If bit CONFIG2[URSTD] is logic 1, then the USB line reset generates an interrupt request to the CPU.

To disable the MCU internal reset and enable a CPU interrupt request, define a macro constant

```
#define USB_CHIP_RESET_DIS    0x01      in file usb_periph_cfg.h
```

If a USB line reset generates interrupt request, you must enable or disable the USB RESET interrupt by setting or clearing bit USIMR[USBRESETIE]. The USB RESET interrupt will be enabled within the USB_Enable() function and the service code will be added to the ISR if the macro constant

```
#define USB_USBRSTIE_ENA     1    is defined in the file usb_periph_cfg.h
```

In the ISR USB_SYS_ISR, the flag USBSR[USBRST] is cleared and the callback function USB_ResertCB() is called.

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2.1.2 Suspend and Resume

If USB lines are idle for at least 3 ms, the USB module detects a suspend state**.** When the function detects a suspend state it has 7 ms to decrease power consumption, for example, switch off all peripherals, stop the PLL to decrease MCU bus clock, or go into stop mode. Stop the USB module clock by clearing bit USIMR[USBCLKEN] before putting the MCU into a stop. The maximum suspend current is proportional to the allowed function load that is stated in the descriptor. For a 100 mA load device, the maximum suspend current is 500 µA. By defining the macro constant

```
#define USB_SUSPNDIE_ENA     1    in file usb_periph_cfg.h
```

the SUSPNDIE interrupt is enabled within USB_Enable(). Callback function USB_SuspendCB() is called and the SUSPND flag is cleared during an interrupt service routine. You must write the USB_SuspendCB() function. The suspend state is used when the host goes to sleep and wants to prevent the battery from discharging through the USB module.

The device will resume from the suspend state when it receives any non-idle signalling during suspend mode. If the macro constant

```
#define USB_RESUMEFIE_ENA    1
```

is defined in file usb_periph_cfg.h then bit USBSR[RESUMEF] is set and the RESUME interrupt is enabled within the USB_Enable() function. USB_ResumeCB() function is called and the resume flag RESUMEF is cleared during an interrupt service routine. You must write the USB_ResumeCB() function.

The USB function can force a resume state onto the USB bus data lines to initiate a remote wakeup by setting bit USBCR[RESUME]. The resume state is issued only if the function is in suspend mode and the remote wakeup feature is enabled by the SET_FEATURE command. Use the macro statement USB_RESUME() to force the resume state on the USB line.

2.1.3 Config Change

CONFIG CHANGE interrupt is enabled by setting bit USIMR[CONFIG_CHGIE]. To do that, define

```
#define USB_CONFIGCHGIE_ENA  1
```

in file usb_periph_cfg.h and the interrupt will be enabled within the USB_Enable() function.

During enumeration, CONFIG_CHANGE is the last step to have a function ready from the USB point of view. In the configuration descriptor there is a configuration value to which the device is set by a SET_CONFIG request. When a SET_CONFIG request is received, a CONFIG CHANGE interrupt is generated. Callback function USB_ConfigChngCB(uchar cfgNum) is called and USBSR[CONFIG_CHG] is cleared.

When the USB device is configured, the function can start communicating over the USB.

2.1.4 SOF

Start of frame (SOF) packet is issued on full-speed USB every 1 ms. The MC68HC908JW32 USB module can recognize it and generate a START OF FRAME interrupt. Define the macro constant

```
#define USB_SOFIE_ENA        1
```

in the usb_periph_cfg.h file to enable a SOF interrupt in the USB_Enable() function.

Although the SOF packet contains an 11-bit length frame number data (see Section 4.1), the USB module does not provide this data. In the SOF ISR, the USB_SofCB() function is called and the SOF flag cleared.

2.1.5 Setup

When a setup token packet is received and the standard request is not managed by the USB module request processor, then the setup flag USBRST[SETUP] is set and an interrupt is generated if bit USIMR[SETUPIE] is set. The SETUP interrupt will be enabled within the USB_Enable() function if the macro constant

```
#define USB_SETUPIE_ENA      1
```

is defined in the usb_periph_cfg.h file, otherwise it is disabled.

More information can be found in Section 4.2, “Control Transfer.”

2.2 USB Endpoint Interrupt

If the endpoint successfully receives data (PID and CRC are correct), that data is then transferred to the buffer RAM, an ACK packet is generated, the packet size is reported to the UEPxDSR register, and the TRFC flag is set.

If the TCxIE flag is set then an endpoint interrupt is generated when the TRFC flag is set.

Within the USB_Enable() function the TCxIE flags are set to all active endpoints. The endpoint ISR is also added during compile time.

As EP0 cannot be disabled, bit TC0IE is set by default in the USB_Enable() function.

3 Descriptors

A USB device is described by a hierarchy of descriptors: type of device, class, power consumption, number of interfaces, endpoints, packet length, identification number of vendor and device, strings with readable information on the device, etc. A descriptor is a data structure with a defined format that is sent to the host during enumeration to let the host know everything about the device plugged into the USB port. There are three basic descriptor types: standard, vendor, and class specific descriptors. Each descriptor begins with a byte-wide field that contains the total number of bytes in the descriptor, followed by a byte-wide field that identifies the descriptor type. Chapter 9.5 of the *Universal Serial Bus Rev. 2.0 Specification* contains a discussion of descriptors.

Each device must provide some standard descriptors — device, configuration, interface, and endpoint. String descriptors are not mandatory. Standard descriptor structures are defined in the usb.h file.

According to the *Universal Serial Bus Rev. 2.0 Specification*, each USB function can have only one device descriptor, a few configuration and interface descriptors with alternative settings, and endpoints; however, the MC68HC908JW32 USB module allows only one configuration, two interfaces with no alternate settings, and a maximum four endpoints.

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Memory organization is important. PCs use little endian memories, however the Freescale 8-bit MCU uses big endian. This must be considered if you create descriptor data structures in C language. Change byte order of word time items in a structure. You can use the CHNG_ENDIAN(x) macro for the 16-bit long types, and CHNG_ENDIANL(x) for the 32-bit long types. Also, be careful parsing standard requests. Macros are stored in the usb.h file.

Example of device, configuration, interface, HID, and endpoint descriptors of a three button mouse:

```
1   const DeviceDscStrc device01 = { // device descriptor
2     sizeof(DeviceDscStrc), // length of this descriptor
3     DSC_DEVICE_TYPE,     // this descriptor is DEVICE
4     CHNG_ENDIAN(0x0200), //USB release num. in BCD 02.00 - word must change endian
5     0x00, // device Class Code CLASS_CDC_DEVICE
6     0x00, // device subclass code
7     0x00, // device protocol code
8     EP0_BUFFER_SIZE, // max. endpoint 0 buffer size -> always 8 see hw. spec
9     CHNG_ENDIAN(0x5538), // vendor id. - Freescale - again endian must be changed
10    CHNG_ENDIAN(0x1000), // product id
11    CHNG_ENDIAN(0x0000),// device release number
12    0x01,       // index of manufacturer string descriptor
13    0x02,       // index of product string descriptor
14    0x00,       // index of serial number string descriptor - zero - doesn't exist
15    0x01,       // number of possible configurations - always 1
16   };


1  const Config01_dsc_strc config01 = { // configuration descriptor
2     sizeof(ConfigDscStrc),   // length of descriptor
3     DSC_CONFIGURATION_TYPE,  // type of descriptor - configuration
4     CHNG_ENDIAN(sizeof(Config01_dsc_strc)), // length of config + interface +
5           // + HID + endpoint descriptors - all are transferred together
6     0x01, // number of interfaces used in function - at least one
7     0x01, // value to use as an argument to the SetConfiguration() request
8     0x00, // index of string descriptor describing this configuration
9     0xA0, // bits: 7-reserve(one), 6-self powered, 5-remote wakeup, 4-0-reserved
10    0x32, // // max. power consumption in this configuration 2mA unit -> 100mA
11
12   sizeof(IntfcDscStrc), // interface descriptor length
13    DSC_INTERFACE_TYPE, // type of descriptor
14    0, // number of this interface.
15    0, // value of alternate setting for the interface - must be zero - not allowed
16    1, // number of endpoints used by this interface
17    3, // class code HID CLASS
18    0,  // subclass code
19    2, // protocol code - MOUSE
20    0, // Index of string descriptor describing this interface
21
22   sizeof(HidDscStrc), // length of this descriptor
23    DSC_TYPE_HID, // HID descriptor type
24    CHNG_ENDIAN(0x0110), // HID Class Specification release number
25    0, // Hardware target country
26    1, // Number of HID class descriptors to follow
27    DSC_TYPE_REPORT, // Report descriptor type
28    CHNG_ENDIAN(sizeof(ReportDscStrc)), // Total length of Report descriptor
29    // ENDPOINT 01 IN descriptor interrupt
30   sizeof(EpDscStrc), // length od endpoint descriptor
31     DSC_ENDPOINT_TYPE, // descriptor type identifier
```


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```
32     EP01_IN_ADR, // address of endpoint - defined by number and direction!
33     (EP1_MODE>>6), // endpoint mode - use statement defined in usb_periph_cfg.h
34     CHNG_ENDIAN(EP1_BUFFER_SIZE), // buffer size - use statement from
                                     //usb_periph_cfg.h
35     0x0a, // interval for polling interrupt endpoint for data transfers
36   };
```

4 Endpoint Transfer Types

As discussed, USB is a host-centric bus. The host initiates all the transactions. Each transaction is build up from three packets: the token, data, and handshake packets. The MC68HC908JW32 USB module takes care of communication. You do not need to know anything about PIDs, addresses, or endpoints. You only provide the USB module data to send and get the received data. The handshake packet is also generated by the USB module. The *Universal Serial Bus Rev. 2.0 Specification* discusses the packets in more detail.

By setting the endpoint type, the pipe made up from the endpoint uses one of the protocols defined in *Universal Serial Bus Rev. 2.0 Specification* — control, bulk, interrupt, or isochronous transfer type. The MC68HC908JW32 has implemented control, bulk, and interrupt endpoints.

4.1 Packet Types

4.1.1 Token Packet

The token packet starts all communications on the USB. It is issued by the host and contains the packet identifier (PID), device address (ADDR), and endpoint number (ENDP) to identify a consignee.

The PID carries information on the type of token. These are:

- IN token — the host wants to receive data in the next packet
- OUT token — the host wants to send data to a device in the next packet
- SETUP token — to start control transfer
- SOF token — the start of a frame

CRC covers address and endpoint fields and is checked by hardware.

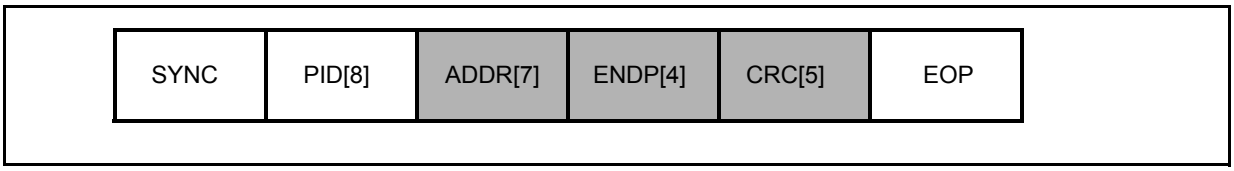

Figure 6. Token Packet Fields

4.1.2 Data Packet

A data packet is issued either by a device or by the host in accordance with the previous token packet. It contains PID and data parts. Types of PID are either Data1 or Data2 to distinguish odd and even data

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packets that are generated or checked by hardware. CRC protects all the data fields and is generated or checked by hardware also.

Maximum data payload for full-speed devices is 64 bytes.

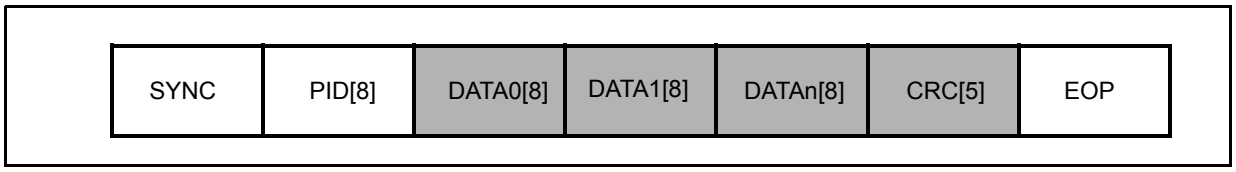

Figure 7. Data Packet Fields

4.1.3 Handshake Packet

Handshake packets report the status of a data transaction and can return values indicating the reception or rejection of data, halt conditions, or flow control. They are built only by PID.

There are three possible handshake packets:

- ACK — acknowledgment that the packet was successfully received
- NAK (Not Acknowledgment) — temporarily unable to send/receive data; there is no data to send concerning the interrupt transfer
- STALL — the endpoint is halted or a control pipe request is not supported, intervention from the host is required.

A handshake packet is issued or checked by hardware. If data is received correctly, the USB module issues an ACK. If the endpoint is busy and is not able to receive a data packet, or has nothing to send, hardware issues a NAK. If you halt the endpoint, hardware issues a STALL. If there is token or data error, hardware does not issue a response.

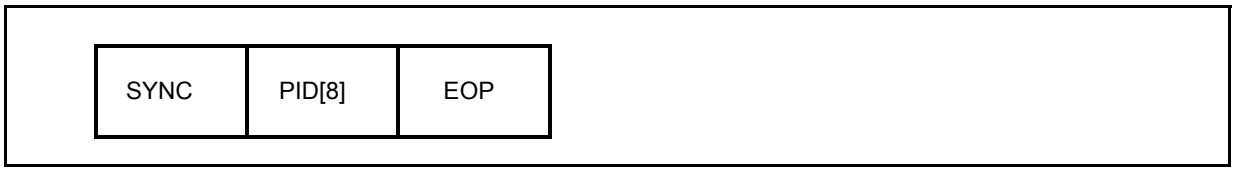

Figure 8. Handshake Packet Fields

4.1.4 SOF Packet

The start of frame transaction (SOF) packet consists of a PID indicating the packet type followed by an 11-bit frame number field. The packet is issued by the host at a nominal rate of once every 1.00 ms.

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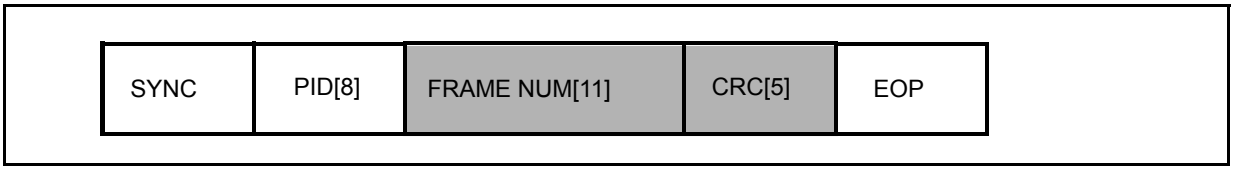

Figure 9. SOF Packet Fields

Table 3. Table of Possible PID

Packet type	PID name	Value
HANDSHAKE	ACK	0010B
	NAK	1010B
	STALL	1110B
DATA	DATA1	0011B
	DATA2	1011B
TOKEN	OUT	0001B
	IN	1001B
	SOF	0101B
	SETUP	1101B

4.2 Control Transfer

Control transfer is typically used to send different requests to a function: standard requests, vendor or device specific requests such as get descriptor, set address, set configuration, and so on. On the MC68HC908JW32, the control transfer is applicable only on the control pipe built by EP0 and where the packet is a maximum eight bytes long.

Control transfer consists of three stages:

- Setup stage that consists of token packet, data packet and handshake packet
- Multiple data stages in which one data stage consists of a token, data and handshake packet, and the last data stage has a data packet shorter than the maximal packet length
- Status stage confirms whether the previous setup and data stage finished successfully (see Figure 10 and Figure 11)

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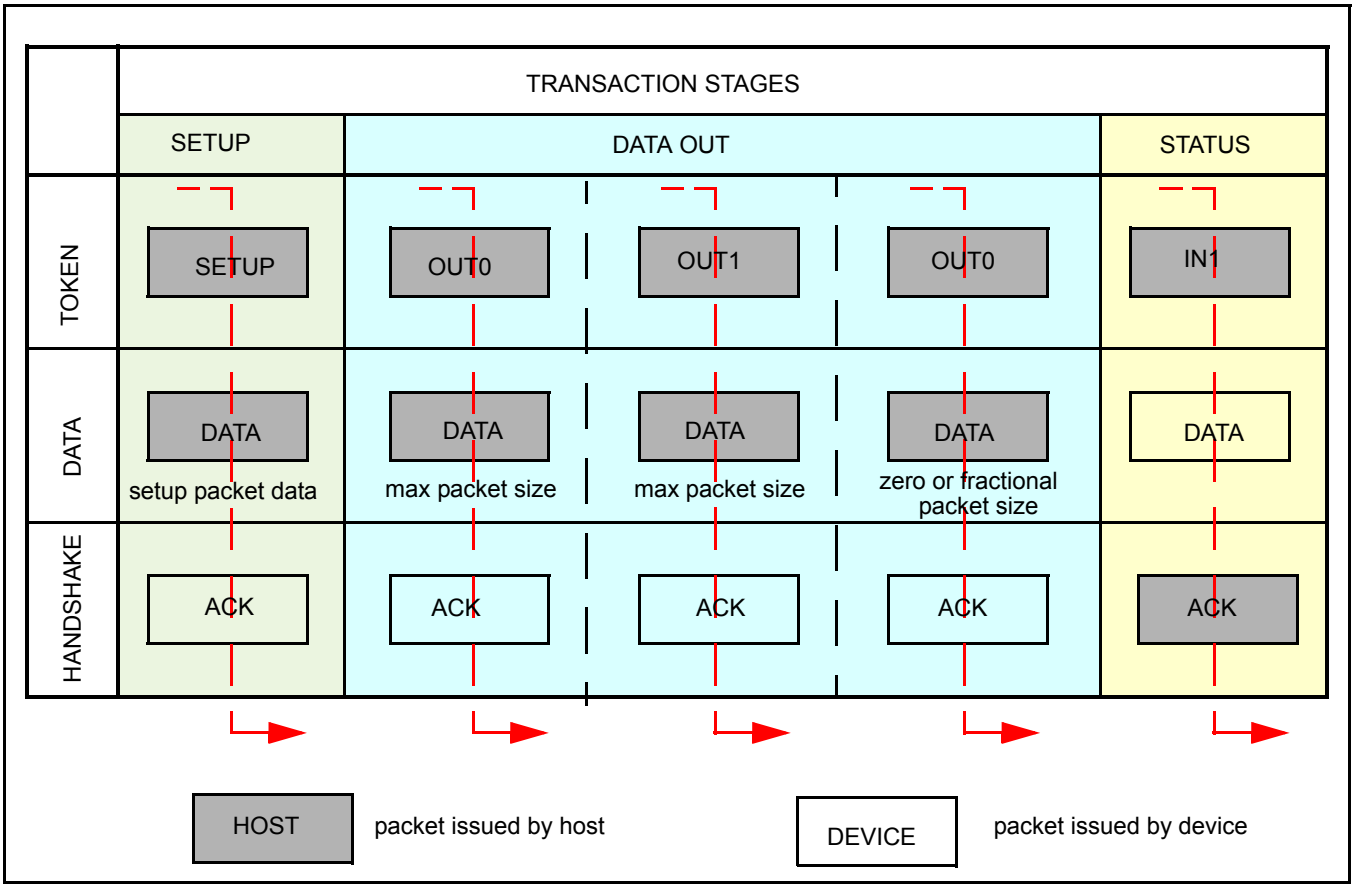

Figure 10. Control OUT Transaction — All Packets

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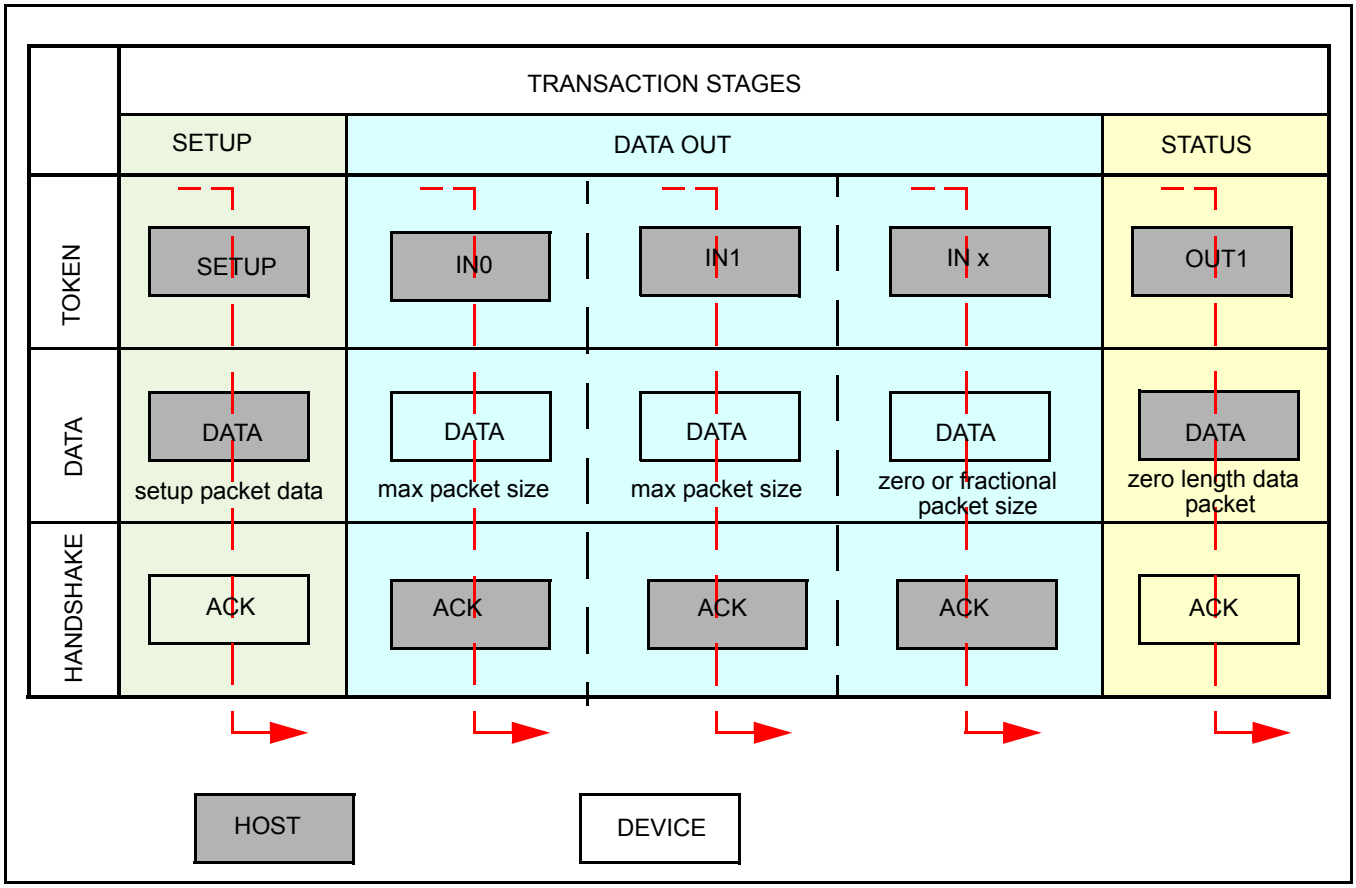

Figure 11. Control IN Transaction — All Packets

4.2.1 Setup Stage

The host initiates the control transfer by issuing two packets in the setup stage. The token packet carries the device address, endpoint number, and PID. The data packet has a setup packet format, which details the type of request. The setup packet structure SetupPcktStrc is defined in file usb.h. Chapter 9.3 of the *Universal Serial Bus Rev. 2.0 Specification* contains a more detailed description.

If the function receives setup data successfully, it responds with an ACK handshake packet. Handshake packets are generated by hardware and you need not give it any attention. If the function does not receive setup data, it does not send a handshake packet. Functions cannot issue a STALL or NAK packet in response to a setup request. CRC and PID checking are performed by hardware and user attention is not needed.

If CRC and PID are correct, you are notified by bits DVALID_IN, TRFC_IN and data is copied to the EP0 buffer.

Hardware also recognizes the token's PID as setup and generates the system interrupt — SETUP interrupt. You must parse the received data and prepare the USB module for the data stage.

If the data stage that follows is IN, you must prepare data to send. This is a typical situation if a GET_DESCRIPTOR standard request is received. You must fill your buffer with data and call the function:

```
uchar USB_TxBuff0(uchar* adr, uchar cnt)
```

adr is your buffer address and cnt is the number of bytes to send. The function returns number of bytes pending to transmit.

If the data stage that follows is OUT, you should prepare your buffer to receive data during the endpoint interrupt using the function:

```
void USB_RxBuff0(uchar* adr, uchar cnt)
```

adr is your buffer address , *cnt* is the number of bytes to receive.

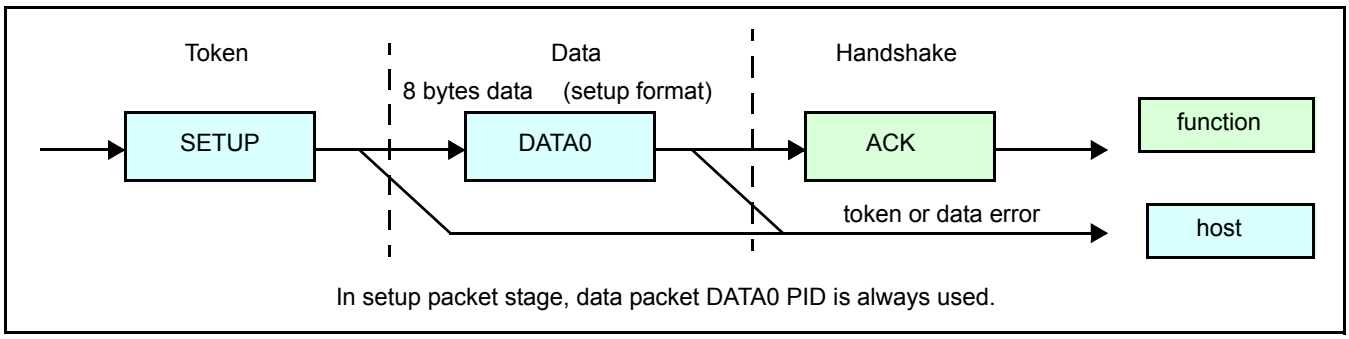

Figure 12. Control Transfer SETUP Stage

4.2.2 Data Stage (Optional)

If present, the data stage of a control transfer consists of one or more IN or OUT transactions and follows the same protocol rules as bulk transfer. All transactions in the data stage must be in the same direction, such as all INs or all OUTs. The amount of data to be sent during the data stage and its direction are specified during the setup stage. If the amount of data exceeds the maximal data packet size, the data is sent in multiple transactions (INs or OUTs) that carry the maximum packet size. Any remaining data is sent as a residual in the last transaction.

As mentioned above, the data stage can be IN or OUT.

IN: When the host is ready to receive control data from the function, it issues an IN token. If the function successfully receives the IN token it can either send data, send a STALL to indicate that the request is not supported, or send a NAK packet. A NAK packet indicates that function is either processing the last transaction or has no data to send. If an IN token has an error, the token is ignored. A multiple data stage is finished by sending a data packet shorter than the maximal packet size or a zero packet size.

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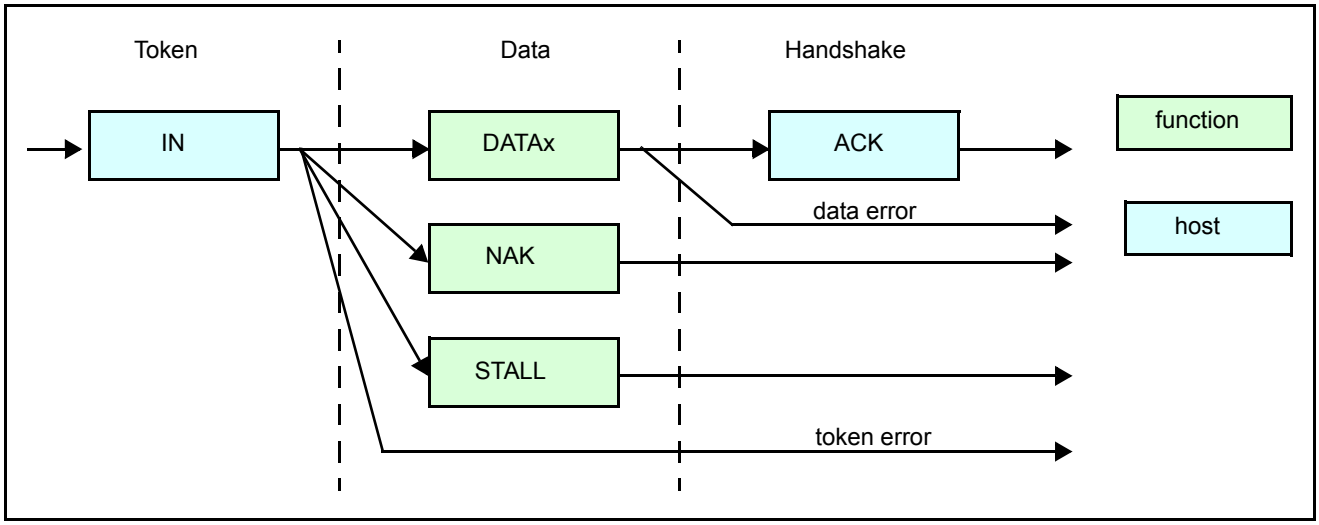

Figure 13. CONTROL Transfer — IN Data Stage

OUT: When the host wants to send control data to the function, it issues an OUT token and then a data packet. If the function receives a token and data successfully, it responds to the host with an ACK. If the function is processing previous data and the buffer is not empty, the function cannot receive any data and responds with a NAK to the host. A STALL is issued by the function to let the host know that the endpoint has an error and has halted. A multiple data stage is finished by sending a data packet shorter than the maximal packet size or a zero packet size.

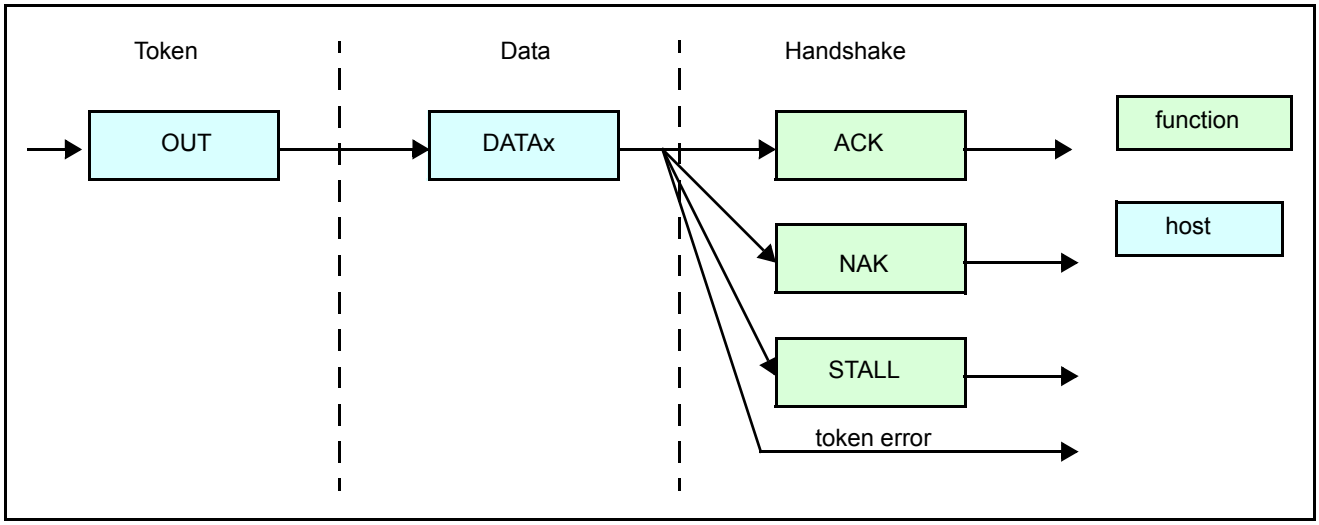

Figure 14. CONTROL Transfer — OUT Data Stage

4.2.3 Status Stage

The status stage reports to the host the outcome of the previous setup and data stages of the transfer. Three possible results may be returned:

- The transfer sequence completed successfully

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- The transfer failed
- The function has an error and is busy

Unlike a handshake packet, you must prepare the status stage handshake after the last data packet is received or sent. The status stage packet can be received or transmitted using the functions:

```
uchar USB_TxBuff0(uchar* adr, uchar cnt)
uchar USB_RxBuff0(uchar* adr, uchar cnt)
```

The status stage is different for the IN/OUT data stage:

OUT: If the previous data stage was IN and logical data flow was from the function to the host, the host must acknowledge successful receipt of this data by sending an OUT token followed by a zero length data packet. The function responds with either

- An ACK — the function has completed the command and is ready to accept a new command
- A NAK — the function is processing the command and that the host should continue the status stage
- A STALL — the function has an error that prevents it from completing the command.

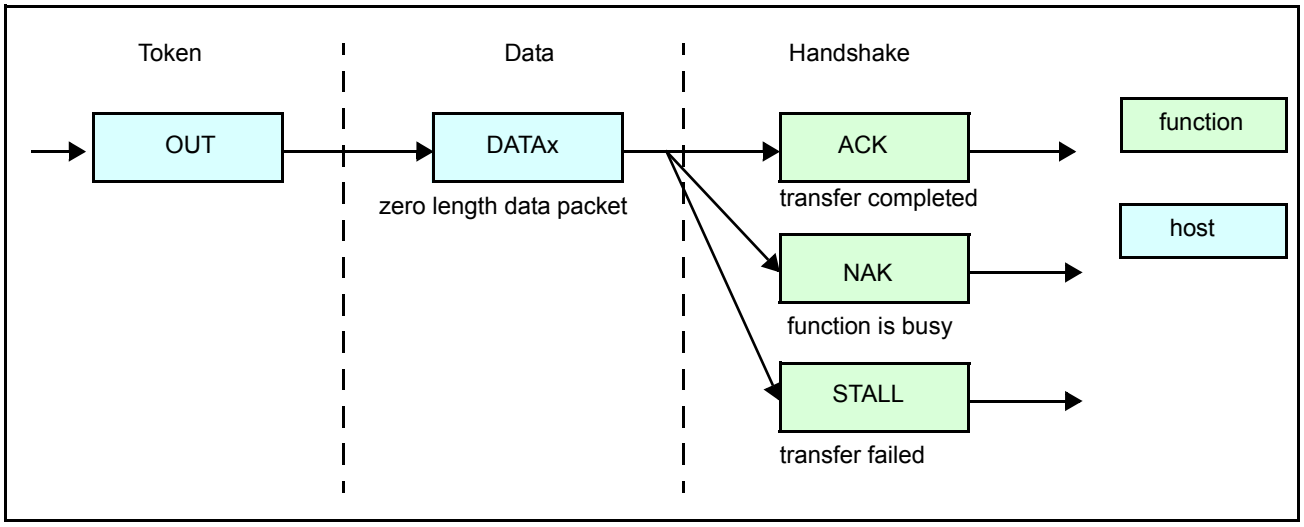

Figure 15. CONTROL Transfer — OUT Status Stage

IN: If the previous data stage was OUT and logical data flow was from the host to the function, the function must acknowledge successful receipt of this data by sending a zero length data packet as a response to the IN token. The USB driver uses the function USB_RxBuff0(DUMMY_ADR, 0) to send a zero data packet as a response to the IN token.

If the function is processing data, it can issue a NAK and the host will retry the status stage later. If the function detects any error during the token or data stages it responds with a STALL.

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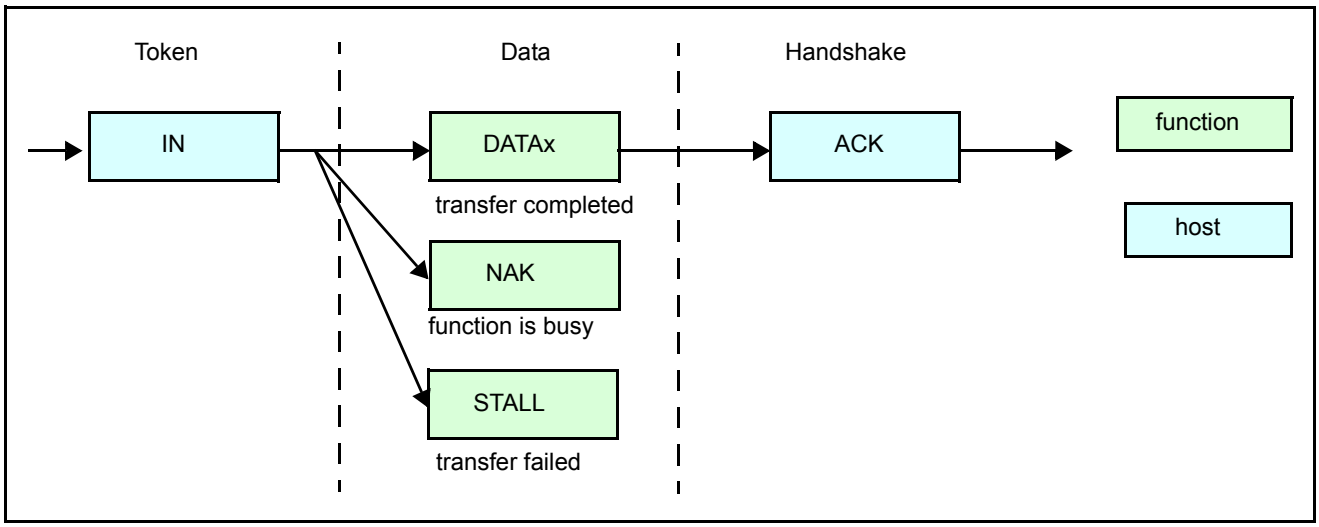

Figure 16. CONTROL Transfer — IN Status Stage

4.2.4 Programming Control Transfer

As discussed in Section 4.2, "Control Transfer," control transfer is mainly used to send different types of requests to the function. To simplify firmware, the MC68HC908JW32 has an integrated request processor in the USB module. The request processor automatically processes some standard USB requests without firmware attention (see MC68HC908JW32 Data Sheet table 11-2).

After the setup stage containing a SETUP token is successfully received, the MC68HC908JW32 request processor automatically processes some USB requests such as SET_ADDRESS and CLEAR_FEATURE. Only if GET_DESCRIPTOR or SYNC_FRAME standard requests, vendor, or class specific requests are received, is the status stage data packet loaded into the EP0 buffer and a SETUP interrupt generated.

The USB driver software parses the setup stage data packets and switches according to type of request, whilst also preparing the GET_DESCRIPTOR (DEVICE, CONFIGURATION and STRING) standard request response (see Figure 17).

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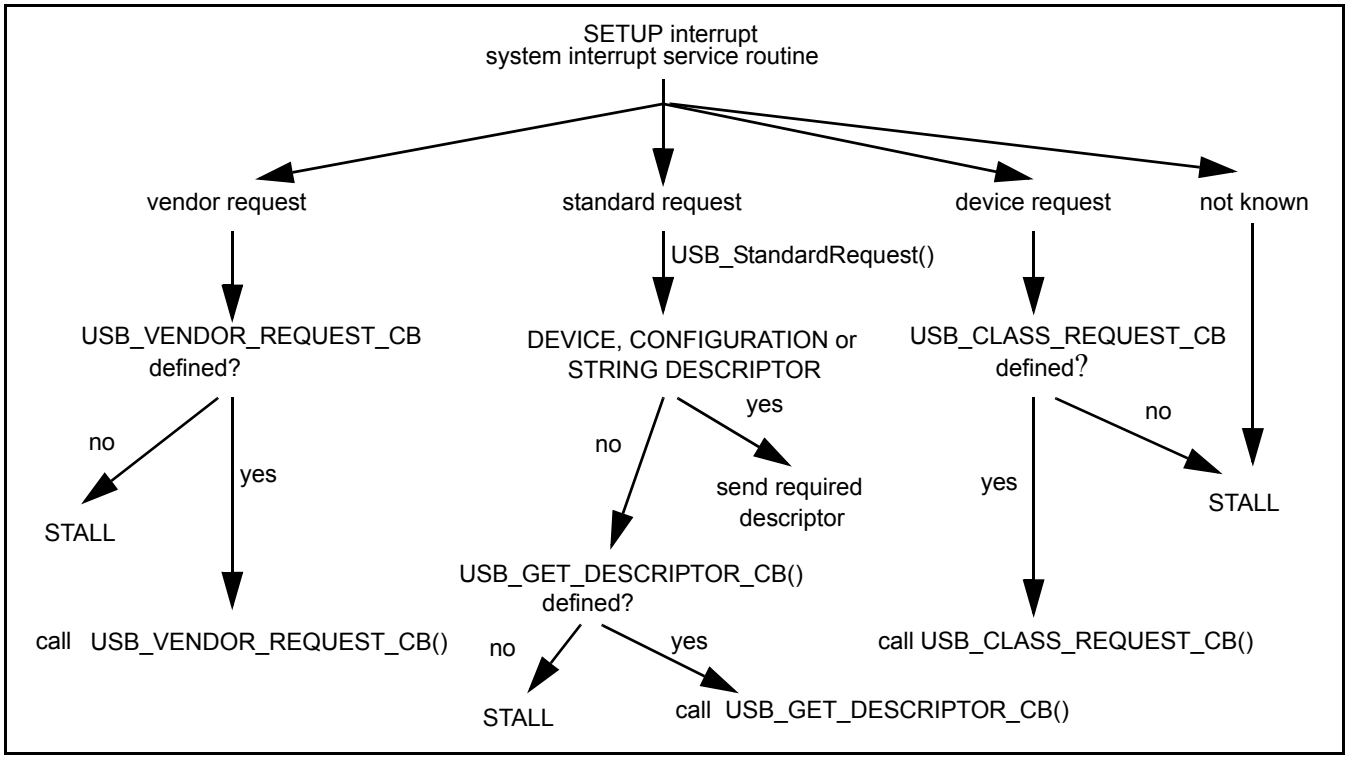

Figure 17. Parsing SETUP Stage Data Packet

If the request is a vendor type, then the function USB_VENDOR_REQUEST() is called, if defined. If you want to process any vendor requests you must write your own function USB_VendorRequest() function and define the macro constant

```
#define USB_VENDOR_REQUEST_CB  USB_VendorRequestCB
```

in file usb_periph_cfg.h to let the USB driver know what function to call. If the statement USB_VENDOR_REQUEST_CB is not defined as the function then vendor requests are responded with STALL.

Class requests are processed in the same way. If you want to process any class request, you must create the function USB_ClassRequest_CB() and define macro the constant

```
#define USB_CLASS_REQUEST_CB  USB_ClassRequestCB
```

in file usb_periph_cfg.h to let the USB driver use it. The standard requests can be only a GET_DESCRIPTOR subtype, as the USB module request processor responds to all the others. If a standard request is received then the USB_StandardRequest(void) function is called.

The function parses the GET_DESCRIPTOR request and if the DEVICE, CONFIGURATION or STRING descriptor is requested, USB firmware prepares the response. Otherwise, the USB_GET_DESCRIPTOR_CB() function is called, if defined.

To let the USB driver know where the descriptors are stored, define a pointer to the descriptors variable. There are macro statements prepared to create pointers to descriptors in flash memory (usb.h file).

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Use the macro statements

```
IDENT_CONFIG_DSC(config01);
IDENT_DEVICE_DSC(device01);
```

where config01 and device01 are the configuration and device descriptors structures.

These macros define the variables ptrToConfigDsc and ptrToDeviceDsc in Flash, and initialize them by the descriptors address. These variables are used in the USB driver software.

There is usually more than one string descriptor. Pointers to string descriptors must be stored in a table, which is an array of pointers to the string descriptors. The length of the string table must be defined in the usb_periph_cfg.h file as a macro constant

```
#define STRING_DSC_TAB_LEN   4
```

(there are four string descriptors). Another macro constant must name the string table, to let the USB driver know where the table lies

```
#define STRING_DSC_TAB  stringDscTab
```

If a GET_DESCRIPTOR command requires a descriptor other than a DEVICE, CONFIG or STRING, then you must a prepare response in the function USB_GetDescriptor_CB() and define macro constant

```
#define USB_GET_DESCRIPTOR_CB  USB_GetDescriptorCB
```

to let the USB driver call the callback function. If the request is unknown, then a STALL is issued.

The data stage is managed by the USB driver through code in the EP0 ISR and a pre-negotiated amount of data is transferred or received. When a data packet is shorter than the maximal packet length is transferred, the data stage is finished.

The status stage is also managed by the USB driver, so no user attention in needed.

4.3 Bulk Transfer

A bulk transaction type is characterized by the ability to guarantee error-free delivery of data between the host and the function by means of error detection and retry. Bulk transactions use a three-packet transaction consisting of token, data, and handshake packets as shown in Figure 18 and Figure 19.

OUT: If the host wants to send bulk data to the function, it issues an OUT token and then issues the data. If either the token or the data is corrupted, the function does not respond. If data is successfully received in the buffer, the function responds with an ACK handshake. If the endpoint buffer is full and the function is temporarily not able to receive data, it issues a NAK to let the host know it should try to send the bulk data later. If the function has a permanent error, it issues a STALL.

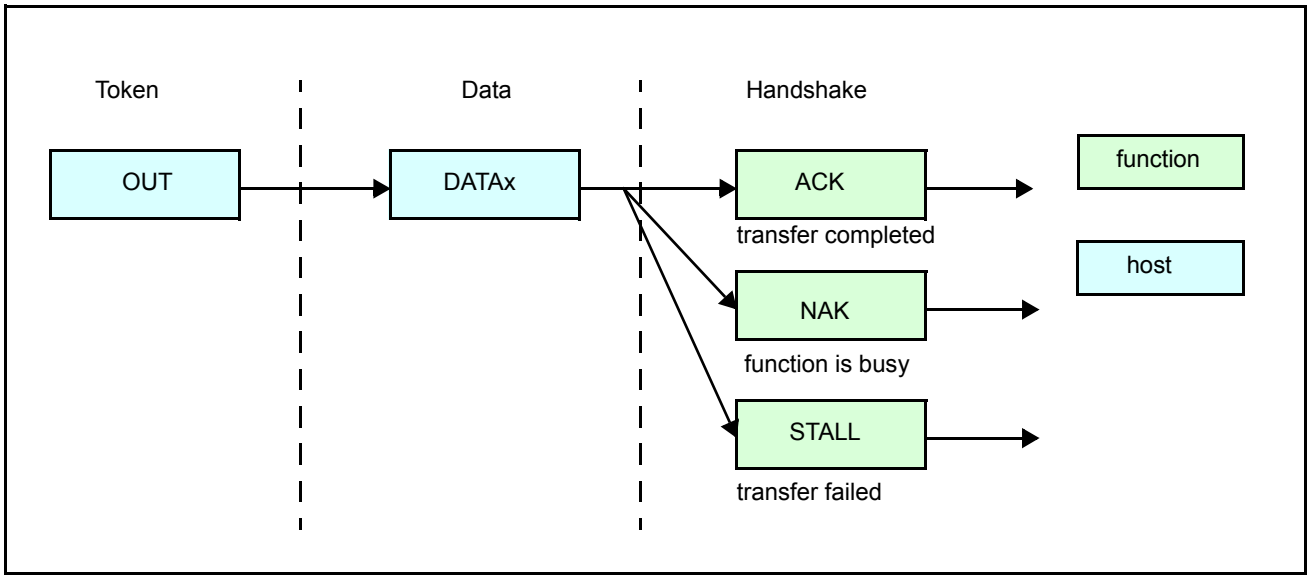

Figure 18. Bulk/Interrupt OUT Transfer — All Packets

IN: If the host is ready to receive data from a function, it issues an IN token. If the function is ready, it sends a data packet. If the function has a permanent error, it issues a STALL. If the function has nothing to send, it issues an NAK.

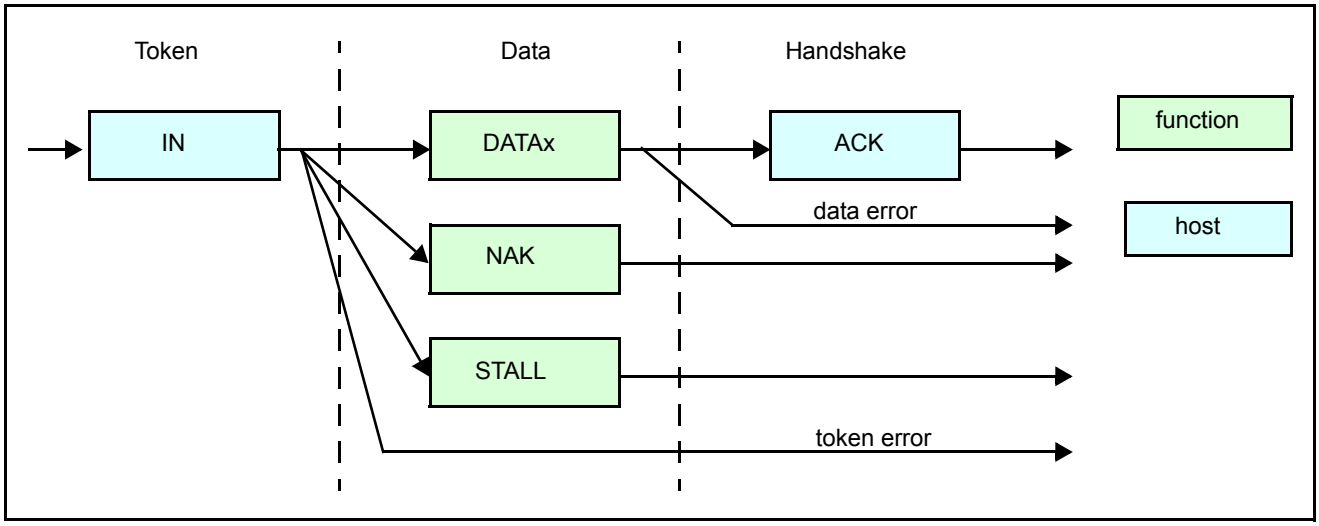

Figure 19. Bulk/Interrupt Transfer IN — All Packets

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4.4 Interrupt Transfer

Unlike bulk transfer, interrupt transfer assures guaranteed communication latency. If the function has data to send, it fills the buffer and waits for an IN data token which is issued in a pre-negotiated period by the endpoint descriptor.

Interrupt transactions may consist of IN or OUT transfers.

Upon receipt of an IN token, a function may return data, a NAK, or STALL. If the endpoint has no new data to return, the function returns a NAK handshake during the data phase. If the halt feature is set for the interrupt endpoint, the function will return a STALL handshake. If an interrupt is pending, the function returns the interrupt information as a data packet. In response to receipt of the data packet, the host issues either an ACK handshake if data was received error-free, or returns no handshake if the data packet was received corrupted.

If an OUT token packet followed by interrupt data packet is issued by the host, for example if the host wants to send interrupt data to the function, the function must respond with an ACK packet if the data was successfully received in the endpoint buffer; with a NAK if the endpoint buffer is full and the function is not able to receive other data; or with a STALL if the endpoint is halted. If an OUT token data is corrupted, the function does not respond.

4.4.1 Programming Bulk and Interrupt Transfer

Both bulk and interrupt transfers use the same functions to send or receive data. The only difference is the latency guarantee with interrupt transfer. The USB driver provides a few functions to send and receive data over USB. You can use either buffer transfer to send or receive data or a character approach — to send or receive characters.

Receive (OUT Direction):

For the buffer receive use the function

```
uchar USB_RxBuffx(uchar* adr, uchar cnt)
```

To receive data by the OUT endpoint, define your own buffer where the received bytes will be stored. The size of the buffer is arbitrary.

Parameters adr contains the start address of the user buffer and cnt passes the number of bytes to receive. When the function is called, it immediately copies any previously received data from the endpoint buffer to the user buffer. If the function copies all data from an endpoint buffer so that the endpoint buffer is empty, bit UEPxCSR[DVALID] is cleared to enable reception of the next data packet and the function ends.

The function returns remaining space in the user buffer in bytes. The function is non-blocking and the remaining requested bytes are transferred to the user buffer within the next endpoint complete transfer ISRs.

When the next data packet has been received by the endpoint buffer, an ACK handshake is issued by hardware and the interrupt service routine USB_EP_ISR is called. If there is any remaining space in the user buffer, the endpoint buffer copies the received data to the user buffer. If the endpoint buffer becomes empty, bit UEPxCSR[DVALID] is cleared to enable reception of other data.

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When some bytes remain in the endpoint buffer because the user buffer is full, (UEPxCSR[DVALID] = 1), then the next OUT data packet cannot be received and a NAK handshake packet is issued by hardware.

Another OUT data packet can be received after the endpoint buffer is empty.

You may also use the function

```
uchar USB_RxBuffPendingx(void)
```

which returns the number of bytes required to receive in the user buffer

```
uchar USB_GetRxReadyx(void)
```

which returns the number of data bytes pending in the endpoint buffer

Another possibility to receive data is “byte by byte”. You can use the blocking function

```
uchar USB_RxCharx(void)
```

The function waits until a previously called reception has finished (reception initiated by the USB_RxBuffx() function), and until there is at least one byte in the endpoint buffer (the function is blocking). Then the function returns the received byte and ends. If the endpoint buffer is empty and the function reads out the last pending byte, the function clears bit UEPxCSR[DVALID] to enable the next data reception.

It is useful to out if there is any byte pending in the endpoint buffer. The function uchar USB_GetRxEmptyx(void) returns the number of received bytes pending in the endpoint buffer.

Transmit (IN direction):

There are two possibilities for transmitting data over a USB with a blocking and a non-blocking function. Using the function uchar USB_TxBuffx(uchar* adr, uchar cnt) you can send a buffer. You must create the user buffer and fill it with data to transmit. Variable *adr* is the pointer to the user buffer and *cnt* passes the number of bytes to transmit.

The function returns the number of bytes pending in the user buffer for transmission.

When the function is called, it starts to copy data from the user buffer to the endpoint buffer. When all data is copied or the endpoint buffer is full, bit UEPxCSR[DVALID] is set, the buffer is primed to transmit data, and data is sent as soon as a data IN token is received. When the buffer has been successfully sent to the host and an ACK handshake received, an interrupt service routine (USB_EP_ISR) is called. If there is any data pending in the user buffer, it is copied to the endpoint buffer which is primed again to send it. The procedure is repeated until there are no bytes pending in the user buffer.

If there is no data to send (the endpoint buffer is not primed), the module responds with a NAK to all IN data tokens.

Function uchar USB_TxBuffPendingx(void) returns the number of bytes pending for transmission in the user buffer.

Function uchar USB_GetTxEmptyx(void) returns number of bytes available in the endpoint buffer.

A byte by byte approach should be used with the function uchar USB_TxCharx(uchar ch). In this function, ch contains the byte to be sent, which is copied to the endpoint buffer. When the endpoint buffer is full, bit UEPxCSR[DVALID] is set to arm the buffer. If you want to send a packet shorter than the endpoint buffer

size he should flush the buffer with the function uchar USB_TxFlushx(void).The function returns the number of sent bytes.

If you want to halt the endpoint, you may call the macro statement USB_WRSTALL_EPx(x) which will set/clear bit UEPxCSR[STALL].

5 Enumeration

Enumeration is the process in which the host determines the function parameter, such as the number of the endpoint, configuration, and class. The enumeration process on a standard Windows PC is:

1. Plug the function into the attached USB hub. The function is powered up and pulls the D+ line up via USB_Init(). The pullup must be enabled in USB_Init().
2. Host detects the D+ line and waits a further 100 ms to let the function finish the insertion process. During this time, you must initialize the MCU's PLL, USB module (USB_Enable()).
3. Host issues a reset state to the USB line. After reset, the function is in the default state.
4. Host sends a GET_DESCRIPTOR (device descriptor) request. When the first eight bytes of the device descriptor is received by the host, it issues a reset state.
5. Host issues a SET ADDRESS request, the function goes to the addressed state.
6. Host sends a GET_DESCRIPTOR (device descriptor) request again for all 18 bytes.
7. Host sends a GET_DESCRIPTOR (configuration descriptor) request of nine required bytes. Function returns nine bytes. The first nine bytes of the configuration descriptor contain information on the full size of the configuration descriptor.
8. Host sends a GET_DESCRIPTOR (configuration descriptor) and asks for 255 bytes so the function returns the whole configuration descriptor.
9. If there are any string descriptors defined, the host asks for them.
10. Host sends a SET_CONIGURATION request. If the host responds correctly, the function is configured and can be used. The host polls all working endpoints to allow transfer data.

6 HID Class—Mouse

One of the most simple USB devices is the human interface device (HID) such as a mouse or keyboard. This example describes a simple PC mouse. Windows will recognize a standard USB device and install it to Windows as a human interface device. You can check this in the device manager.

In Figure 5, device 1 represents a mouse. It consists of the EP0 control pipe and EP1— interrupt endpoint.

Control pipe EP0 is used during the enumeration process to send descriptors to the host. It uses control transfer.

In addition to the standard descriptors, such as device descriptor, configuration descriptor, interface and endpoint descriptor, the HID class devices also reports an HID and report descriptor. If the mouse wants to tell the computer that it has a pressed button or was moved, it sends a report. The structure of the report is flexible and it is configured in a report descriptor. As the USB_StandardRequest() function answers only standard descriptors, there is a possibility of answering all the non-standard and device-specific descriptors

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within the function USB_GET_DESCRIPTOR_CB(). It is your responsibility to write the USB_GET_DESCRIPTOR_CB() function. Chapter 6.2.2 of the *USB Device Class Definition for Human Interface Devices (HID)* contains a detailed description of this process.

The report descriptor below describes a simple mouse with a 4-byte report. The first byte is defined on lines 6 to 18 of the report descriptor and reports the mouse buttons. Within the first byte there are three defined bits — report count and report size on lines 13 and 14. The next five bits in lines 16 and 17 are not used here and are padding.

The axis of movement of the mouse are defined on lines 20, 21, and 22. Report values must lie in the interval –127 to 127 and are defined on lines 25 and 26 as three time 8-bytes.

```
1  const ReportDscStrc reportDsc =
2   {
3      0x0501,             // Usage Page(Generic Desktop)
4      0x0902,             // Usage (Mouse)
5      0xA101,             // Collection(Application)
6      0x0901,             // Usage(Pointer)
7      0xA100,             // Collection(Physical)
8      0x0509,             // Usage Page(Buttons)
9      0x1901,             // Usage Min(01)
10     0x2903,             // Usage Max(03)
11     0x1500,             // Logical Min(0)
12     0x2501,             // Logical Max(1)
13     0x9503,             // Report Count(3)
14     0x7501,             // Report Size(1)
15     0x8102,             // Input(Data,Variable,Absolute)
16     0x9501,             // Report Count(1)
17     0x7505,             // Report Size(5)
18     0x8101,             // Input(Constant)- Padding
19     0x0501,             // Usage Page(Generic Desktop)
20     0x0930,             // Usage(X)
21     0x0931,             // Usage(Y)
22     0x0938,             // Usage(WHEEL)
23     0x1581,             // Logical Min (-127)
24     0x257F,             // Logical Max(127)
25     0x7508,             // Report Size(8)
26     0x9503,             // Report Count(3)
27     0x8106,             // Input(Data,Variable,Relative)
28     0xC0,               // End Collection
29     0xC0,               // End Collection
30   };
```

For the report descriptor, the report structure looks like that below: variable but represents buttons press/release, x/y represent mouse movement <-127, 127>, and w represents wheel rotations <-127, 127>.

```
1  typedef struct
2   {
3     byte  but;          // buttons (bits 0, 1, 2)
4     byte  x;            // mouse movement X axis
5     byte  y;            // mouse movement X axis
6     byte  w;            // mouse wheel
7   }MouseReportStrc;
```

HID class functions should also respond to a few class specific requests such as GET_REPORT, SET_PROTOCOL, and GET_PROTOCOL. The function USB_CLASS_REQUEST_CB() must respond to these standard requests.

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EP1 sends reports to the host. EP1 is an interrupt endpoint so the host periodically polls the function through the IN data token. If the function detects any change such as a button press or movement, it should respond with a report data packet, otherwise the IN data token is NAK.

7 Communication Device Class (CDC)

In the past, the serial line known as UART was the major way of connecting embedded devices to a PC. Many new computers do not have COM ports, so USB is a good substitute. In situations when a PC application does not see the difference between a standard and the Virtual COM port, you can easily migrate from UART to USB by using the virtual serial COM port on the PC. There is also the standard Microsoft driver usbser.sys. This class is called abstract control model serial emulation and is described in Chapter 3.6.2.1 in *Universal Serial Bus Class Definitions for Communication Devices*.

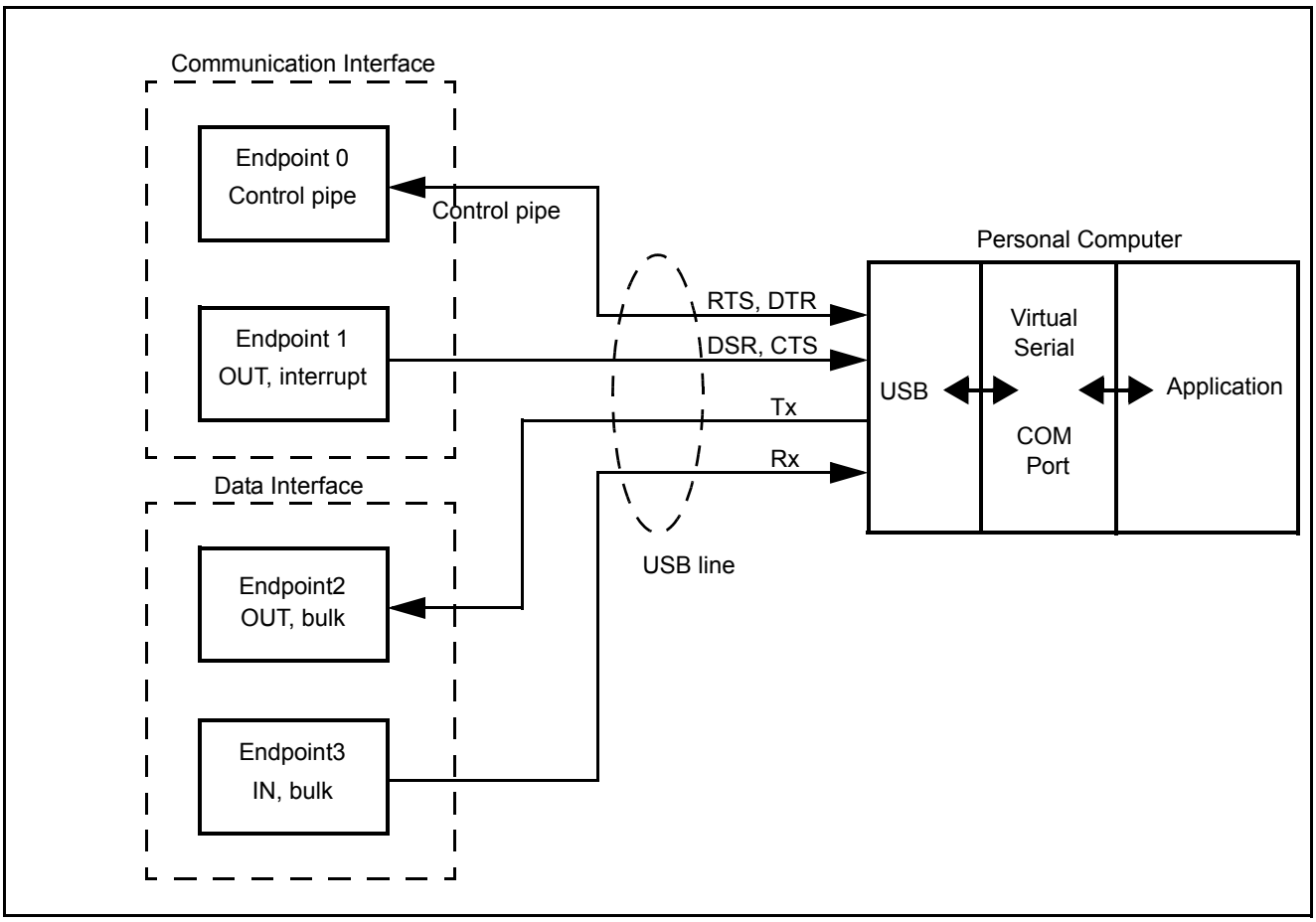

Figure 20. Virtual Serial COM Port

The virtual serial COM port is made up of two interfaces: the data class interface and the communication class interface. The communication class interface consists of at least two pipes: control pipe (EP0) for management, and OUT interrupt EP1 pipe for notification.

The control pipe is used for standard commands, such as GET_DESCRIPTOR and SET_ADDRESS, and class specific commands such as SEND_ENCAPSULATED_COMMAND,

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GET_ENCAPSULATED_RESPONSE (required), SET_CONTROL_LINE_STATE, GET_LINE_CODING, and SET_LINE_CODING.

SEND_ENCAPSULATED_COMMAND and GET_ENCAPSULATED_RESPONSE are device-specific commands that are used to send the AT commands over the USB. Implementation of those requests is required but we do not work with them when received.

SET_LINE_CODING and GET_LINE_CODING are device-specific requests that are transferred when a COM port on the PC is opened. In fact, this is only information on how the COM port is set and does not affect the speed or the setting of the USB communication. When a COM port is opened on the PC, the host asks the device how it is set with the request GET_LINE_CODING. When you change the baudrate, parity, or number of data bits for example, in the hyperterminal, the host sends the settings to the device with the request SET_LINE_CODING. The data packet has three bytes, with the structure below.

Structure of a line coding data packet

```
8   typedef struct
9   {
10     unsigned long   dwDTERate;    // data terminal rate, in bits per second
11     byte    bCharFormat;          // stop bits:
12                                   //    0 : 1 Stop bit
13                                   //    1 : 1.5 Stop bits
14                                   //    2 : 2 Stop bits
15
16     byte    bParityType;                 // parity:
17                                   //   0 : None
18                                   //   1 : Odd
19                                   //   2 : Even
20                                   //   3 : Mark
21                                   //   4 : Space
22     byte    bDataBits;               // data bits (5, 6, 7, 8 or 16)
23   } CdcLineCodingStrc;
```

The SET_CONTROL_LINE_STATE request is used to send the state of the RTS and DTR signals to the device. A data packet has 16 bits. Bit zero represents signal DTR. Bit 1 is RTS.

The second pipe in the communication class interface is the notification pipe. This is used to notify the host of the state of the device lines. It is not required, but this pipe should be an interrupt. Serial state notification should look like:

Table 4. Serial State Notification

bmRequestType	bNotification	wValue	wIndex	wLength	Data
10100001B	SERIAL_STATE	Zero	Interface	2	UART State

Where SERIAL_STATE has value 0x20.

UART state is a 16-bit variable:

D15..D7 Reserved for future use.

D6 Received data has been discarded due to overrun in the device.

D5 A parity error has occurred.

D4 A framing error has occurred.

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D3 State of the device ring detection signal.
D2 State of the device break detection signal.
D1 State of the device transmission carrier signal. This signal corresponds to RS-232 signal DSR.
D0 State of the device receiver carrier signal. This signal corresponds to RS-232 signal DCD.

Data interface has two endpoints: IN and OUT are both are bulk.

You can use function USB_TxBuffx(uchar* adr, uchar cnt) to send a buffer, or USB_TxCharx(uchar ch) to send data byte by byte. If you use the USB_TxCharx() function, you are filling the endpoint buffer which is send when full or you can send the buffer intermediately by USB_TxFlushx().

To receive the data, you may use USB_RxBuffx(uchar* adr, uchar cnt) to receive a defined amount of bytes, or USB_RxCharx() to pull out one byte from the endpoint buffer (if there is a received byte).

Code example (byte approach):

```
// RS 232 function
for(;;) {
   if(USB_GetRxReady2() > 0) // if there is any received byte
       receiveChar = USB_RxChar2(); // move it from endpoint 2 buffer to “receiveChar“

   if(USB_GetTxEmpty3()) { // if there is at least one free byte available in endpoint 3 buffer
      (void)USB_TxChar3(transmitChar); // write “transmitChar” byte to endpoint 3 buffer
      (void)USB_TxFlush3(); // let the USB module send endpoint 3 buffer to USB line
   }
}
```

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Wireless Sensing Triple Axis Reference Design

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Safety of Radio Frequency Energy

The manufacturer has evaluated the transmitter for safe operation for uncontrolled use in the general population. The measured power density at 1 cm is under the threshold established by the FCC and is not required to be tested for specific absorption rate. The manufacturer instructs the user that the transmitter should not be handled or placed near the body continuously for more than 30 minutes while operating.

USA:

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

– Reorient or relocate the receiving antenna.
– Increase the separation between the equipment and receiver.
– Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
– Consult the dealer or an experienced radio/TV technician for help.

This device complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) this device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

The antenna(s) used for this transmitter must not be co-located or operating in conjunction with any other antenna or transmitter.

Canada:

This digital apparatus complies with Canadian ICES-003.

Cet appareil numérique est conforme à la norme NMB-003 du Canada.

Europe:

Compliant (CE)

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Wireless Sensing Triple Axis Reference Design

Designer Reference Manual

by: Pavel Lajšner and Radomír Kozub
Freescale Czech Systems Laboratories
Rožnov pod Radhoštìm, Czech Republic

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http://www.freescale.com

The following revision history table summarizes changes contained in this document. For your convenience, the page number designators have been linked to the appropriate location.

Revision History

Date	Revision Level	Description	Page Number(s)
May, 2006	0.02	First draft	N/A
July 2006	0.9	Language correction, minor updates	N/A
September 2006	0.91	Extended 16-bit communication introduced (10-bit sampling on Sensor Board)	sections 3.2 and 5.4
October 2006	1	Updated FCC information	2
October 2006	2	Information detailed (temperature and bandgap reference voltage)	sections 3.2 and 5.3
January 2007	3	Replaced graphics, updated tables.	sections 3.4.4, 4.2.9, 4.3, and 6.1.1

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Chapter 1
Introduction

1.1 Introduction

This paper describes the design of a Wireless Sensing Triple Axis Reference Design (ZSTAR), a demo for wireless demonstration of the 3-axis accelerometer MMA7260QT Sensor from Freescale.

The reference design will enable you to see how Freescale's accelerometers can add additional functionality to applications in various industries. The accelerometer measurements can be grouped into 6 sensing functions - Fall, Tilt, Motion, Positioning, Shock and Vibration - for multifunctional applications.

The RD3152MMA7260Q development tool offers robust wireless communication using the powerful, easy-to-use 2.4GHz frequency MC13191 transceiver. Minor changes can be made with pin to pin compatibility allowing implementation of the MC13192 and MC13193 for ZigBee™ wireless applications.

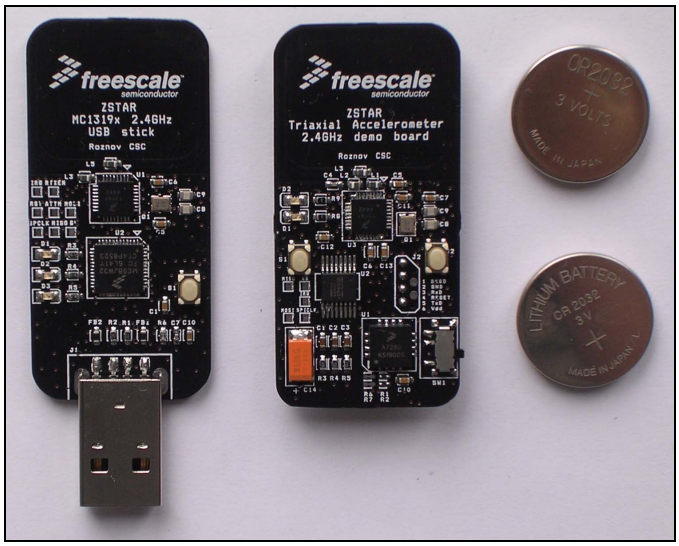

Figure 1-1. ZSTAR Demo photo (CR2032 batteries for comparison)

1.2 MMA7260QT 3-axis Accelerometer Sensor

The MMA7260QT low cost capacitive micromachined accelerometer features signal conditioning, a 1-pole low pass filter and temperature compensation, and g-select, which allows a selection from 4 sensitivities. Zero-g offset full scale span and filter cut-offs are factory set and require no external devices. This device includes a sleep mode making it ideal for handheld battery powered electronics.

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Chapter 2
Wireless Sensing Triple Axis Reference Design Introduction

2.1 Introduction

The Wireless Sensing Triple Axis Reference Design (ZSTAR) has been designed as a wireless complement to the previous STAR (Sensing Triple Axis Reference design) RD3112MMA7260Q demo. A 2.4GHz radio-frequency (RF) link based on the low-cost MC13191 family is used for connection from the Sensor to PC, allowing the visualization of key accelerometer applications.

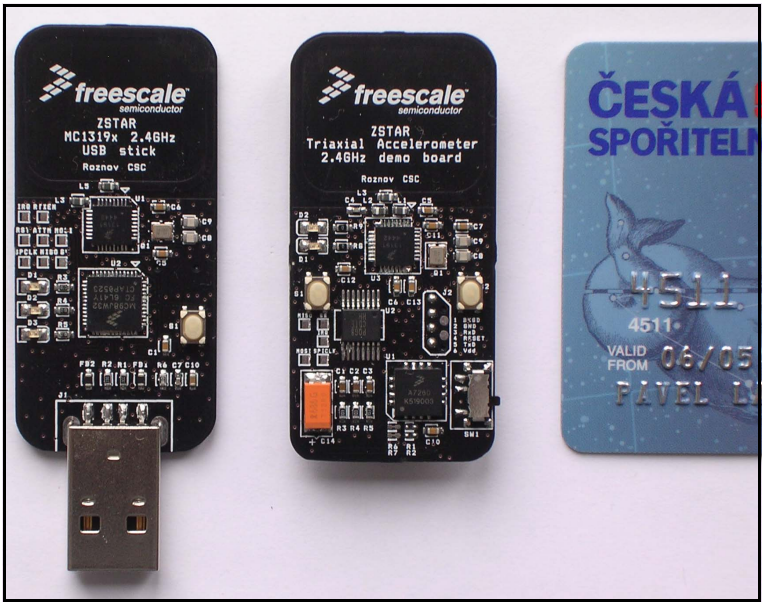

Figure 2-1. ZSTAR Demo Overview

The demo consists of the two boards:

- Sensor Board (or remote board) containing the MMA7260QT 3-axis accelerometer, S08 family MC9S08QG8 8-bit microcontroller and the 2.4GHz RF chip MC13191 for wireless communication.
- USB Stick, again with the MC13191 RF front-end, and the HC08 family MCHC908JW32 for the USB communication.

Both sides communicate over the RF medium utilizing the freely available software stack SMAC from Freescale.

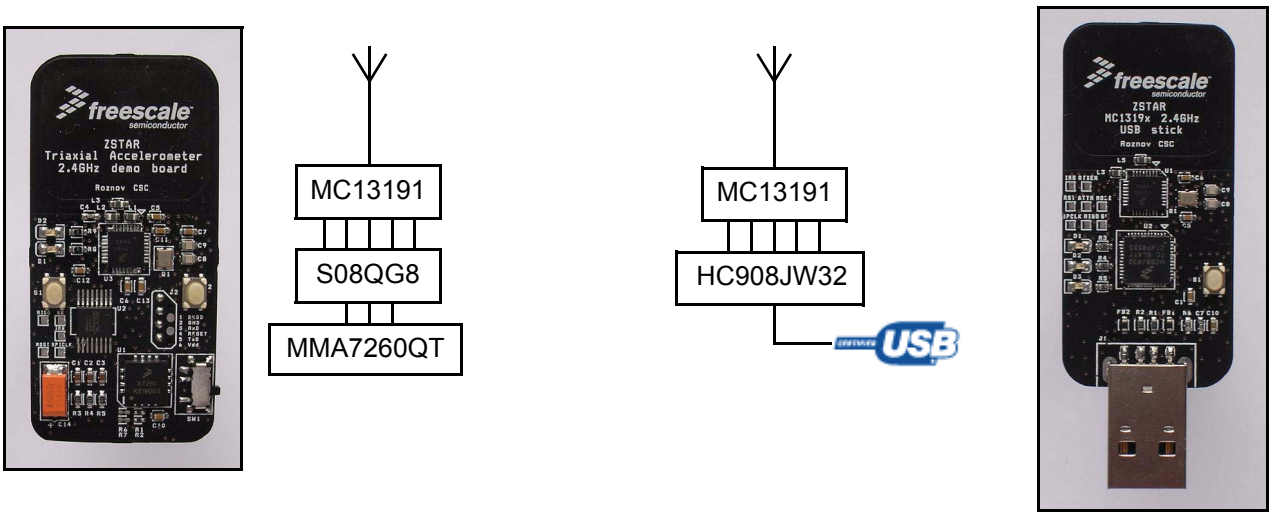

Figure 2-2. ZSTAR Block Diagram

2.2 Featured Products

This demo consists of several Freescale products whose main features are listed below.

2.2.1 Triple Axis Accelerometer MMA7260QT

The ZSTAR Board is a demonstration tool for the MMA7260QT, low-g accelerometer with selectable 1.5g to 6g range. The MMA7260QT has many unique features that make it an ideal solution for many consumer applications, such as freefall protection for laptops and MP3 players, tilt detection for e-compass compensation and mobile phone scrolling, motion detection for handheld games and game controllers, position sensing for g-mice, shock detection for warranty monitors, and vibration for out of balance detection.

Features such as low power, low current, and a sleep mode with a quick turn on time, allow the battery life to be extended in end applications. The 3-axis sensing in a small QFN package requires only a 6mm x 6mm board space, with a profile of 1.45mm, allowing easy integration into many small handheld electronics.

There are several other derivatives of the MMA7260QT:

- **MMA7261QT** XYZ-axis 2.5g/3.3g/6.7g/10g
- **MMA6270QT** XY-axis 1.5g/2g/4g/6g
- **MMA6271QT** XY-axis 2.5g/3.3g/6.7g/10g
- **MMA6280QT** XZ-axis 1.5g/2g/4g/6g
- **MMA6281QT** XZ-axis 2.5g/3.3g/6.7g/10g

All members of this Sensor family are footprint (QFN package) compatible which simplifies evaluation and design of the target application.

2.2.2 Microcontroller MC9S08QG8

The MC9S08QG8 is a highly integrated member of Freescale's 8-bit family of microcontrollers based on the high-performance, low-power consumption HCS08 core. Integrating features normally found in larger, more expensive components, the MC9S08QG8 MCU includes a **background debugging system** and on-chip in-circuit emulation (ICE) with real-time bus capture, providing a single-wire debugging and emulation interface. It also features a programmable 16-bit timer/pulse-width modulation (PWM) module (TPM), that is one of the most flexible and cost-effective of its kind.

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The compact, tightly integrated MC9S08QG8 delivers a versatile combination, from wealth of Freescale peripherals and the advanced features of the HCS08 core, including **extended battery life** with a maximum performance down to 1.8V, industry-leading Flash and innovative development support. The MC9S08QG8 is an excellent solution for power and size-sensitive applications, such as wireless communications and handheld devices, small appliances, Simple Media Access Controller (SMAC)-based applications and toys.

- MC9S08QG8 Features
  - Up to 20MHz operating frequencies at >2.1 volts and 16MHz at <2.1 volts
  - 8 K Flash and 512 bytes RAM
  - Support for up to 32 interrupt/reset sources
  - 8-bit modulo timer module with 8-bit prescaler
  - Enhanced 8-channel, 10-bit analog-to-digital converter (ADC)
  - Analog comparator module
  - Three communication interfaces: SCI, SPI and IIC

2.2.3 MC13191 2.4 GHz ISM Band Low Power Transceiver

The MC13191 is a short range, low power, 2.4 GHz Industrial, Scientific, and Medical (ISM) band transceivers. The MC13191 contains a complete packet data modem which is compliant with the IEEE® 802.15.4 Standard PHY (Physical) layer. This allows the development of proprietary point-to-point and star networks based on the 802.15.4 packet structure and modulation format. For full 802.15.4 compliance, the MC13192 and Freescale 802.15.4 MAC software are required.

When combined with an appropriate microcontroller (MCU), the MC13191 provides a cost-effective solution for short-range data links and networks. Interface with the MCU is accomplished using a four wire serial peripheral interface (SPI) connection and an interrupt request output, which allows the use of a variety of processors. The software and processor can be scaled to fit applications ranging from simple point-to-point to star networks.

2.2.4 Microcontroller MCHC908JW32

The MCHC908JW32 is a member of the low-cost, high-performance M68HC08 Family of 8-bit microcontroller units (MCU's). All MCU's in the family use the enhanced M68HC08 central processor unit (CPU08) and are available in a variety of modules, memory sizes and types, and package types.

- MCHC908JW32 Features
  - Maximum internal bus frequency: 8MHz at 3.5-5V operating voltage
  - Oscillators:
    - 4MHz crystal oscillator clock input with 32MHz internal phase-lock loop
    - Internal 88kHz RC oscillator for timebase wakeup
  - 32,768 bytes user program FLASH memory with security feature
  - 1,024 bytes of on-chip RAM
  - 29 general-purpose input/output (I/O) ports:
  - 8 keyboard interrupt with internal pull-up
    - 3 pins with direct LED drive
    - 2 pins with 10mA current drive for PS/2 connection
  - 16-bit, 2-channel timer interface module (TIM) with selectable input capture, output compare, PWM capability on each channel, and external clock input option
  - Timebase module
  - PS/2 clock generator module
  - Serial Peripheral Interface Module (SPI)
  - Universal Serial Bus (USB) 2.0 Full Speed functions:
    - 2 Mbps data rate
    - Endpoint 0 with an 8-byte transmit buffer and an 8-byte receive buffer
    - 64 bytes endpoint buffer to share amongst endpoints 1–4

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Chapter 3
Sensor Board Description

3.1 Board Overview

The Sensor Board utilizes a small footprint size dual-layer printed circuit board (PCB) containing all the necessary circuitry for MMA7260QT accelerometer sensing and transferring data over a radio frequency (RF).

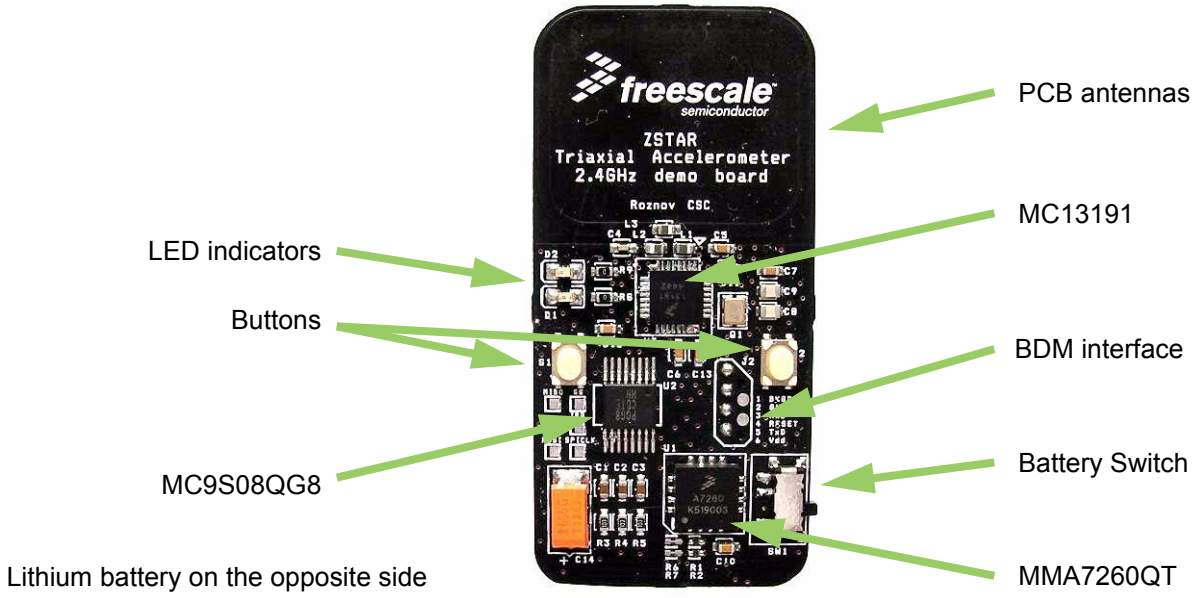

Figure 3-1. Sensor Board Overview

The board is powered by a Lithium coin-sized CR2032 battery with provisions also made for the larger capacity CR2477 size. The block diagram of the board is as follows:

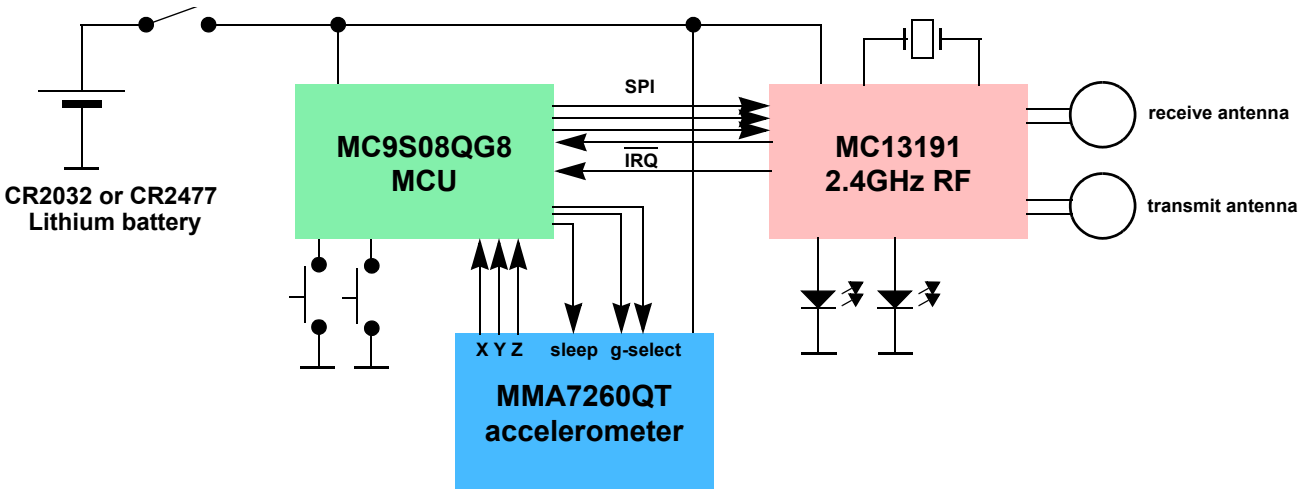

Figure 3-2. Sensor Board Block Diagram

Figure 3-3. shows in more detail, how different software and hardware modules co-operate with each other. The main task of the Sensor Board is to:

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- periodically wake-up from power saving mode
- measure all three XYZ acceleration values from the Sensor
- compose a data frame using simple ZSTAR RF Protocol
- use SMAC (Simple Media Access Controller) to send this data frame over the RF link
- wait for an acknowledgment from the other end (here, the USB Stick)
- go to sleep

This basic loop repeats roughly 30 times per second providing nearly a real-time response from the Sensor.

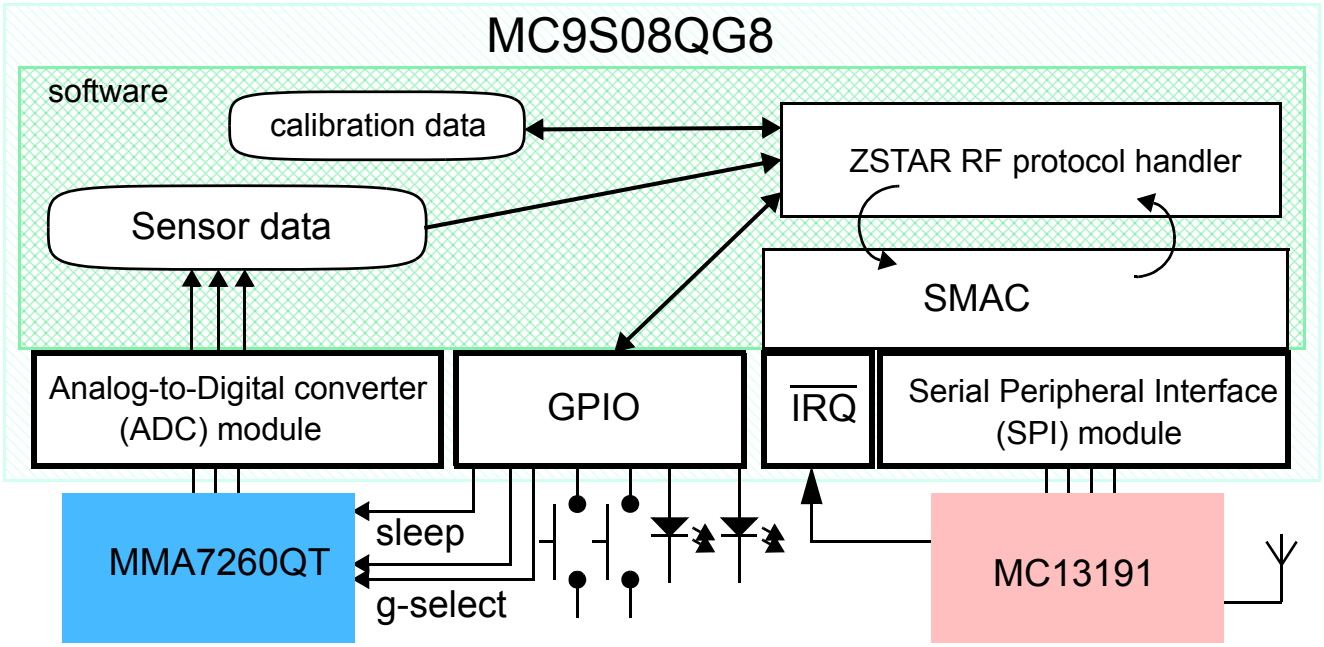

Figure 3-3. ZSTAR Sensor Board Software Overview

For the Sensor Board operation, several of the MC9S08QG8's hardware modules are used: Analog to Digital Converter (ADC), Synchronous Peripheral Interface (SPI), External Interrupt Request (IRQ) and General Purpose Input/Output (GPIO).

3.2 A/D Conversion of XYZ Levels

The 3-axis accelerometer Sensor MMA7260QT provides three separate analog levels for the X, Y and Z axis. These outputs are ratiometric which means that the output offset voltage and sensitivity will scale linearly with applied supply voltage. This is a key feature when interfacing to a microcontroller with A/D converter reference levels tied to a power supply, because it provides system level cancellation of supply induced errors in the analog to digital conversion process.

During the analog-to-digital conversion in the microcontroller, 10-bit resolution is used. MC9S08QG8 A/D channels 0, 1 and 2 are connected to X (channel 1), Y (channel 2) and Z (channel 0) outputs of the MMA7260QT. The microcontroller's `APCTL1` register enables these ADC channels for pin I/O control by the ADC module.

The `ADCCFG` register controls the selected mode of operation, clock source, clock divide, and configuration for low power or long sample time.

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3.2.1 ADC Module init

```
APCTL1 = 0b00000111; /* 0,1,2 channels are ADC */
ADCCFG = 0b01111000; /* set prescale to 8, ADICLK=BUS, 10-bit, high speed */
```

Actual ADC measurements are done in the main software loop. There is a macro (called POWSUM) that allows configuration of measurement to take several measurements of each channel during one loop, e.g. changing POWSUM to 3, 2^3 = 8, each channel will be measured 8 times, with POWSUM 6, each channel is measured 64 times. By default, POWSUM is 4, for 16 measurements of each channel. Before result values are provided, the accumulated values are left justified to the 16-bit range and inverted where necessary (may be required depending on the physical MMA7260QT device orientation relative to the earth's gravity).

Raw (i.e. not calibrated) values are actually sent, the calibration and calculation of an exact g value is done internally in the PC software.

3.2.2 ADC Measurement

The following routine is used for accelerometer measurement (together with temperature and bandgap voltage, refer to section 5.4.2.1):

```
unsigned int xx = 0;
unsigned int yy = 0;
unsigned int zz = 0;
unsigned int tt = 0;
unsigned int bb = 0;

unsigned int xxx, yyy, zzz, ttt, bbb;

#define POWSUM 4

 for (i = 0; i < (1 << POWSUM); i++)
 {
   ADCSC1 = 0x01;//read X channel
   while(!ADCSC1_COCO);
   xx += ADCR;

   ADCSC1 = 0x02;//read Y channel
   while(!ADCSC1_COCO);
   yy += ADCR;

   ADCSC1 = 0x00;//read Z channel
   while(!ADCSC1_COCO);
   zz += ADCR;

   ADCSC1 = 0x1A;//read temp sensor
   while(!ADCSC1_COCO);
   tt += ADCR;

   ADCSC1 = 0x1B;//read bandgap reference
   while(!ADCSC1_COCO);
   bb += ADCR;
 }

TRIAXSLEEP = 0;   /* go sleep for triax */

xxx.w = ~(xx << (16-(10+POWSUM)));
yyy.w = ~(yy << (16-(10+POWSUM)));
zzz.w =  (zz << (16-(10+POWSUM)));
ttt.w =  (tt << (16-(10+POWSUM)));
bbb.w =  (bb << (16-(10+POWSUM)));
```

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3.3 Power Management

A CR2032 (or CR2477) Lithium battery provides a fairly limited charge for such a realtime-like demo that demands frequent transmissions. Some sort of power management has to be implemented in order to keep the current consumption at a reasonable level.

Typically, current consumptions of Sensor Board components are as follows:

- 2.4GHz transceiver MC13191
  - in Hibernate mode, 2.3μA
  - in Doze mode, 35μA
  - in Idle mode, 500μA
  - in Transmit mode, 30mA
  - in Receive mode, 37mA
- 8-bit microcontroller MC9S08QG8
  - in Stop mode, 750nA
  - in Wait mode, 1mA
  - in Run mode, 3.5mA
- low-g triaxial Sensor MMA7260QT
  - in Sleep mode, 3μA
  - in Normal mode, 500μA

It is obvious that in a battery operated application care must be taken to ensure the lowest possible current consumption, especially when the maximum current (provided by the battery) is somehow limited. A CR2032 Lithium battery cannot provide current in the range of 40mA for long periods of time. To alleviate high current surges, an additional large capacitor has been designed - see 3.4.10 Power Supply.

For transmission and reception using the MC13191, a specific scheme has been used to ensure the battery is not depleted or overloaded. Targeting a 30 samples per second (33ms period) transmission rate, the following scheme for one transmission/sleep cycle is used for the data transfer:

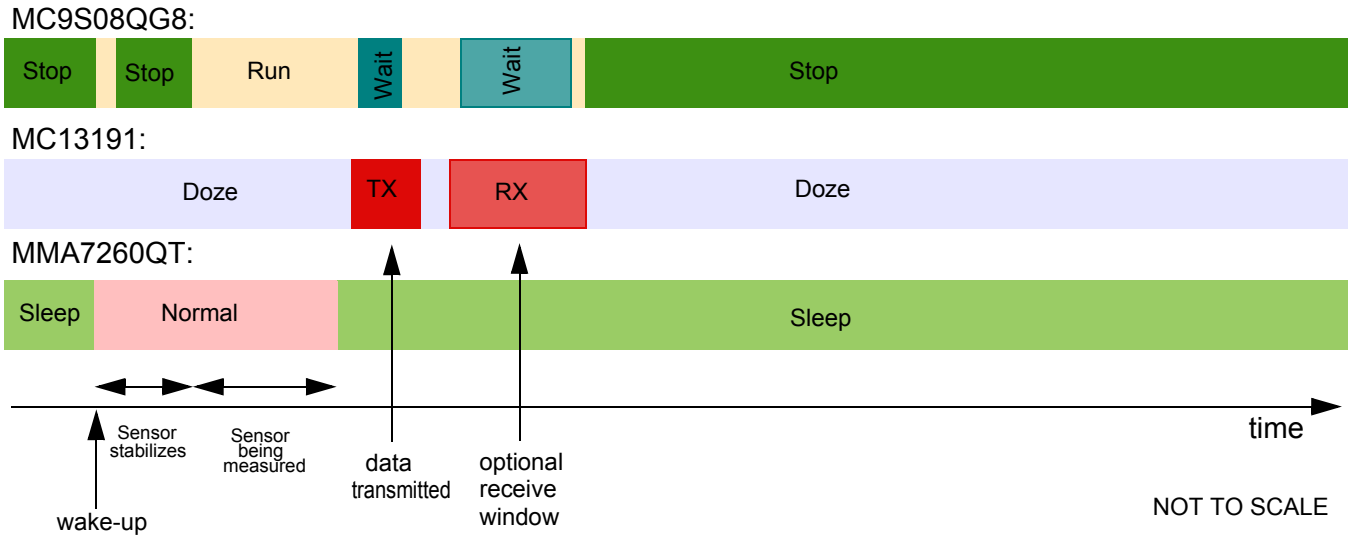

Figure 3-4. Transmission/Sleep Cycle Details

As shown on the previous diagram, all parts of the Sensor Board remain most of the time in Sleep/Doze/Stop modes, in which the total current consumption is below 10μA.

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During each loop, once the data has been acquired from the sensor, transmission over the MC13191 transceiver is initiated. The current consumption of the transmitter is ~30mA at that time, but only for a short period of time (typically ~600μs).

In order to keep the Sensor Board informed on the status of connection (for example, if the data-receiving side - USB Stick - is out of range, disconnected, etc.), the reception has to be turned on after the data has been transmitted. This is not really required within each loop cycle, and in the actual implementation only on every 8th loop the receive window opens (receiver is enabled to receive the acknowledgment). More in the 5.3 ZSTAR RF Protocol description.

The reception window is larger to fit any incoming receive data and the current consumption is also higher during reception, so this portion of current consumption would be one of the largest if the acknowledgment was received in every loop cycle.

The “optional receive” feature allows huge power savings, still keeping the reception of acknowledgment data from the data-receiving side.

Some further savings might be incorporated by utilizing the timer-triggered transceiver events that are described in the MC13191 Reference Manual.The MC13191, for example, latches a so-called time-stamp of each received frame. The data-receiving side may read this value and trigger the acknowledgment to be sent at exactly specified time after reception (also, a start of data frame transmission can be programmed as timer-triggered). The Sensor Board might then narrow its own receive window to perfectly match the expected time of the acknowledgment frame. For the simplicity of code, this has not been implemented in the current version of ZSTAR firmware.

3.3.1 MC13191 Power Management Features

MC13191 provides several power saving modes. One of them is called **Doze mode** in which the MC13191 crystal oscillator remains active. An internal timer comparator is functional too, providing a power efficient and accurately timed way of waking-up the application after a specified time.

This feature is fully utilized within the Sensor Board. The microcontroller calculates the time period for which the application should be in power saving mode, then fills in the timer comparator registers in the MC13191, and the microcontroller goes into Stop mode (MC13191 into Doze mode).

Once the timer reaches the pre-programmed time (a timer compare occurs), the MC13191’s IRQ signal is asserted which brings the microcontroller out of the Stop mode. There are various scaling possibilities that allow periods from a few μs up to 1073 seconds (~17 minutes) to be programmed, without intervention of the microcontroller.

3.4 ZSTAR Sensor Board Hardware Overview

This section describes the Sensor Board in terms of hardware design. The MC9S08QG8 microcontroller drives both the MMA7260QT Sensor and the MC13191 RF transceiver.

3.4.1 Analog Connections

The MMA7260QT Sensor is connected to AD0, AD1, and AD2 inputs to analog-to-digital converter via RC filters formed by R3, C3, R4, C2, R5, C1. These are recommended to minimize clock noise from the switched capacitor filter circuit inside the Sensor. Once the software filtering (also described in 3.2 A/D Conversion of XYZ Levels) is employed, these RC filters may be completely omitted.

3.4.2 g-select Connections

R1, R2, R6 and R7 components are made on the PCB. R1 and R2 are just footprints with no components assembled, while R6 and R7 are connected with copper trace allowing the user to disconnect (cut) these lines. By default, g-sel1 and g-sel2 MMA7260QT Sensor input pins (used to select the acceleration range) are connected to pins PTB0 and PTB1 of the microcontroller. The range can be controlled by software.

If user does not want to use this feature, the g-range can be selected by placing 0R resistors in the R1 and/or R2 positions. If no resistors are assembled, MMA7260QT internal pull-down resistors will automatically select the 1.5g range (both g-sel inputs low).

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Once R6 and R7 are cut, PTB0 and PTB1 (or their alternate SCI functionality of RxD1 and TxD1, or KBI or AD inputs) may be used. These signals are also routed to BDM connector, pins 3 and 5.

3.4.3 BDM (Background Debug Mode) Connections

A J2 connector is a non-standard footprint primarily intended for in-factory programming and testing via “spring-needle” type of connections. The J2 connector carries all standard signals for Background Debug Mode communication so if required, one may solder wires and a standard 2x3 pins 2.54mm (100mil) pitch header for regular BDM re-programming. The pin numbering is shown on Figure 3-5.

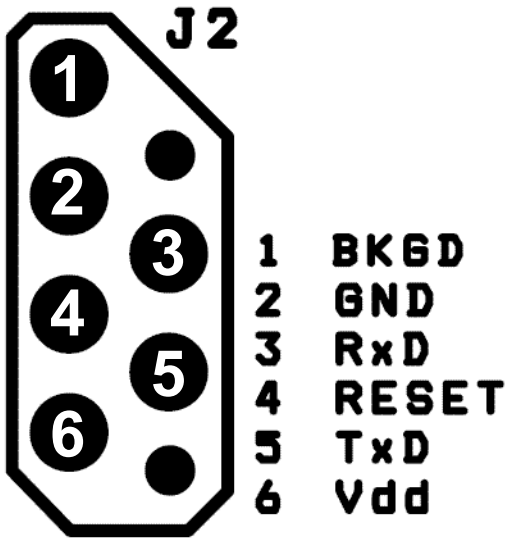

Figure 3-5. BDM Connector Layout

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3.4.4 Sensor Board schematics

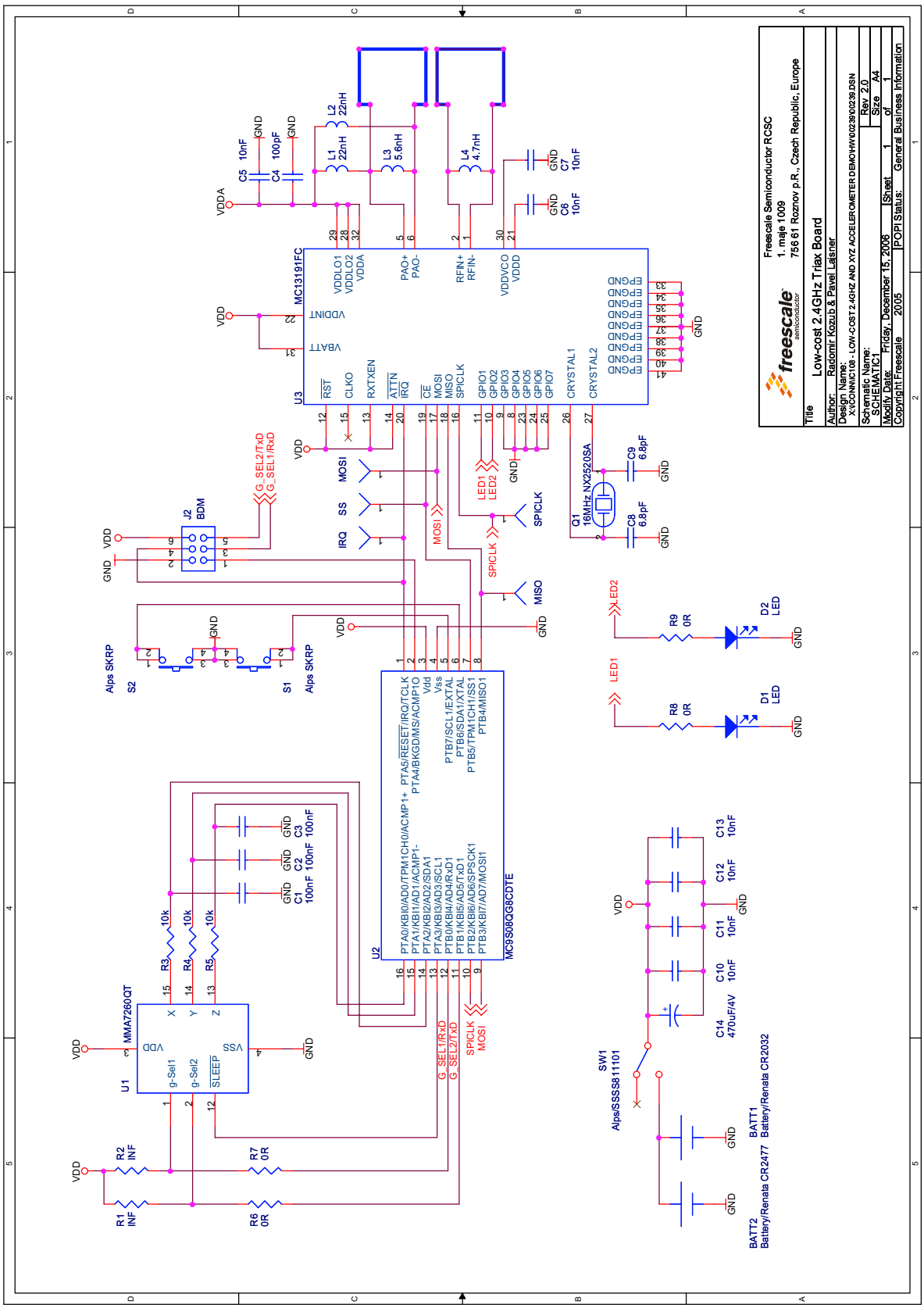

Figure 3-6. Sensor Board Schematics

3.4.5 Button Connections

Two buttons (S1 and S2) are connected directly to pins PTB6 and PTB7. Both have internal pull-up resistors, but are not part of the Keyboard Interrupt module, therefore don't allow a direct microcontroller wake-up from the Stop modes.

3.4.6 MC13191 to MC9S08QG8 Microcontroller Interface

In order to fit all the necessary circuitry onto a 16-pin microcontroller, the full recommended MC13191 interface had to be reduced. The full interface includes the following connections:

- 4-wire Synchronous Peripheral Interface (SPI) connection (MISO, MOSI, SPICLK, $\overline{CE}$)
- Interrupt Request signal ($\overline{IRQ}$)
- Attention ($\overline{ATTN}$) wake-up signal
- Receive/Transmit Enable (RXTXEN) signal
- External Reset ($\overline{RST}$) signal

SPI and **$\overline{IRQ}$** are vital for the communication and configuration of the MC13191. SPI is connected to the MC9S08QG8 SPI module (pins PTB4/MISO1, PTB3/MOSI1, PTB2/SPSCK1, and GPIO pin PTB5 for $\overline{CE}$).

Interrupt Request ($\overline{IRQ}$) is connected to the microcontroller $\overline{IRQ}$ pin sharing its alternate $\overline{RESET}$ function when BDM communication is active.

Attention ($\overline{ATTN}$) signal is intended to externally wake-up the MC13191 from Doze and Hibernate modes. Since this feature is not used and exit from the Doze mode is done using a timer compare event, the $\overline{ATTN}$ pin is not routed to the microcontroller and needs to be connected to V_{dd}.

Receive/Transmit Enable (RXTXEN) signal is used to control transitions to/from receive and transmit modes. Since this can be accomplished just by software programming and/or timer compare events, this connection to the microcontroller may also be omitted, saving an additional pin. RXTXEN is connected to V_{dd}.

External Reset ($\overline{RST}$) signal places the transceiver in a complete reset condition (Off mode and power down). Alternative Software reset is also possible and since Off mode (the one with the lowest possible power consumption) is not required too, $\overline{RST}$ is connected to V_{dd} too.

3.4.7 MC13191 RF Interface

The RF interface (antennas) were designed with the cost and board size in mind. Among several designs, the PCB layout antennas were in the main consideration (cost). Of several PCB antenna designs available for the 2.4GHz band (F-antenna, dipole, loop), the loop antenna has been selected mainly because of the size required on the PCB.

The MC13191 transceiver is designed with separated RF IN (receive) and PA OUT (transmit) paths. To avoid the need for an antenna switch, two separate antennas need to be used. Both ZSTAR boards (USB Stick and Sensor Board) use the same antenna layout, there are two antennas on the PCB, just on the opposite sides of the PCB.

The antenna is designed as a rectangle, 20x24mm (780x940mils), made of 1.25mm (50mils) wide trace of copper. The corners are rounded with a 3.8mm (150mils) radius.

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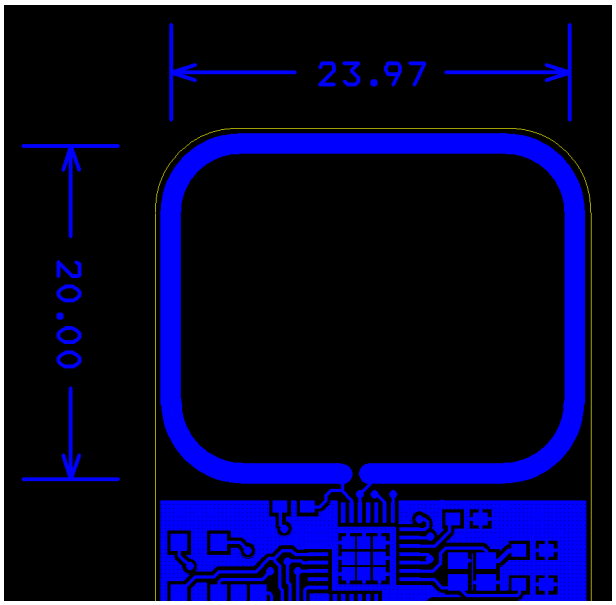

Figure 3-7. ZSTAR Antenna Layout

The matching is provided by L3 (transmit antenna) and L4 (receive antenna) coils. L1 and L2 coils bias the transmitter output transistors to the V_{DDA} level.

The inductors used in this design are from TDK:

L3 (5.6nH) MLG1608B5N6DT

L4 (4.7nH) MLG1608B4N7ST

L1, L2 (22nH) MLG1608B22NJT

3.4.8 Clocking Options of MC9S08QG8

Due to the availability of accurate timing provided by the MC13191 transceiver, an internal oscillator (ICG) in the MC9S08QG8 is used as the main clock source for the microcontroller. The protocol related timing is derived from MC13191 timers, the microcontroller itself is clocked from an internal oscillator, leaving the oscillator pins as GPIO. This is highly beneficial to the limited pin count microcontroller.

3.4.9 LED Indicators Connections

The MC13191 allows extension to the number of general I/O pins by 7 additional GPIO connections. Two of these (GPIO1 and GPIO2) are used for LED indicators. R8 and R9 are their current limiting resistors, and in the actual design orange LED's are used, with a threshold voltage around 2.0-2.5V.

The remaining unused GPIO3-GPIO7 signals are connected to ground, improving the physical PCB layout of the MC13191.

3.4.10 Power Supply

The Sensor Board is powered by a Lithium coin-sized battery. The primary choice was the popular CR2032, with a PCB layout provision made for the CR2477 size. This bigger battery holds roughly 4 times more charge (~1000mAh), but it is not as popular as CR2032 size.

A surface mounted SMTU series battery holder from Renata™ is placed on the underside of the PCB. The SMTU series holders provide (by mechanical construction) battery reverse protection, so no additional circuitry is required. Slide switch SW1 disconnects the battery from the application when not in use.

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A large tantalum capacitor (C14, 470μF/4V) improves the response of the power supply to current peaks caused by reception or transmission. Coin-sized Lithium CR2032 batteries are targeted at a maximum continuous discharge current in the range of 3mA. Such a large capacitor helps to supply enough current to the MC13191 during a receive/transmit without significant V_{dd} voltage drops.

3.5 Bill of Materials

Table 3-1. Sensor Board Bill of Materials

Item	Quantity	Reference	Part	Manufacturer	Manufacturer order code
1	1	BATT1	battery holder CR2032	Renata	SMTU 2032-1
2	3	C1,C2,C3	100nF	TDK	C1608JB1H104K
3	1	C4	100pF	TDK	C1608CH1H101J
4	7	C5,C6,C7,C10, C11,C12,C13	10nF	TDK	C1608CH1E103J
5	2	C8,C9	6.8pF	TDK	C1608CH1H070D
6	1	L3	5.6nH	TDK	MLG1608B5N6DT
7	1	L4	4.7nH	TDK	MLG1608B4N7ST
8	2	D1,D2	Kingbright KP-1608SEC	Kingbright	KP-1608SEC
9	1	J2	BDM + serial	N/A	
10	2	L1,L2	22nH	TDK	MLG1608B22NJT
11	1	Q1	16MHz NX2520SA	NDK	NX2520SA 16MHz EXS00A-02940 Specification n° EXS10B-07228
12	2	R1,R2	N/A	N/A	
13	3	R3,R4,R5	10k	resistor 0603 package	
14	2	R6,R7	N/A	N/A	
15	2	R8,R9	0R	resistor 0603 package	
16	1	SW1	slide switch Alps/SSSS811101	Alps	SSSS811101
17	2	S1,S2	switch SKRP	Alps	SKRPADE010 (or SKRPACE010 or SKRPABE010)
18	1	U1	MMA7260QT	Freescale	MMA7260QT (MMA7260QR2 for tape and reel)
19	1	U2	MC9S08QG8CDTE	Freescale	MC9S08QG8CDTE
20	1	U3	MC13191FC	Freescale	MC13191FC (MC13191FCR2 for tape and reel)
21	1	C14	470uF/4V	Vishay	594D477X9004C2T

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Chapter 4
USB Stick Board Description

4.1 Board Overview

The USB Stick board utilizes the same small footprint as Sensor Board and is also a dual-layer printed circuit board (PCB). It contains the minimalistic design of the MC13191 RF transceiver connected through an 8-bit MCHC908JW32 microcontroller to the USB. It's main task is to receive data from the Sensor Board and transfer it to the PC over the USB link.

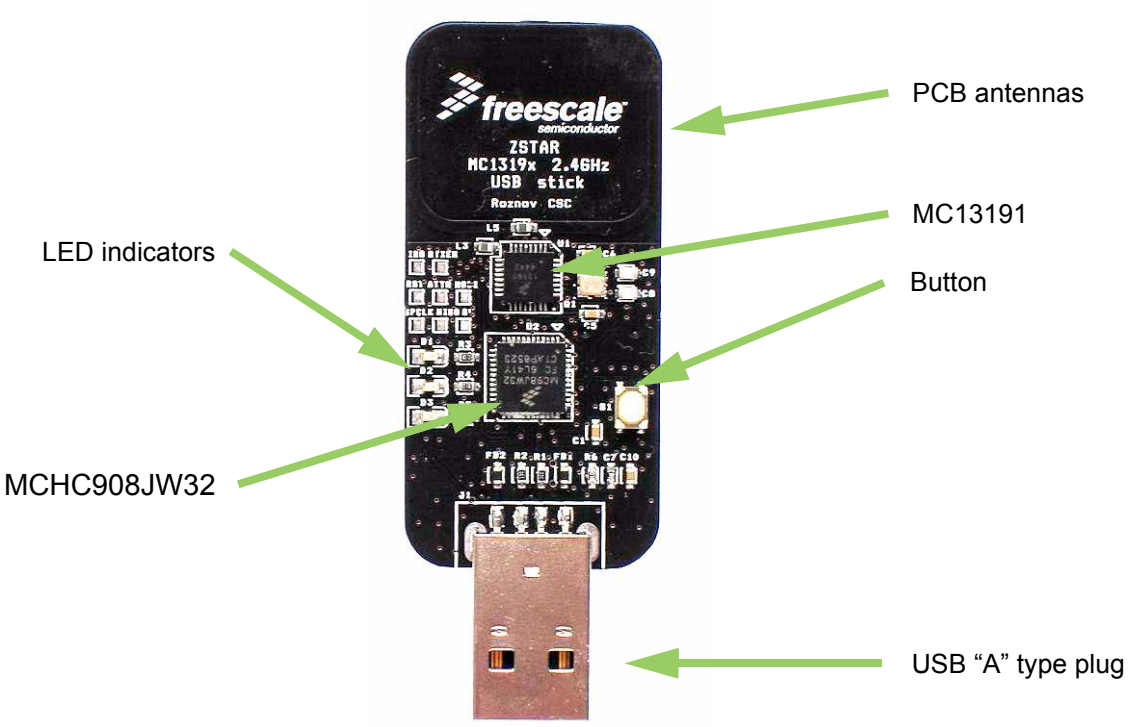

Figure 4-1. USB Stick Board Overview

The USB stick board is powered from the USB. The block diagram of the board is as follows:

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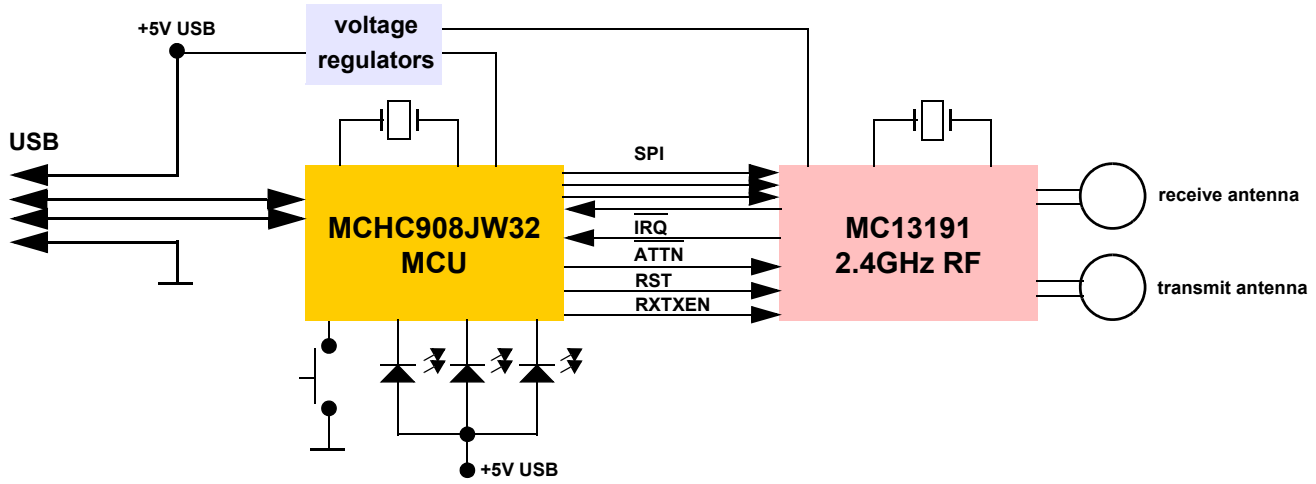

Figure 4-2. USB Stick Board Block Diagram

Figure 4-3. shows, in more detail, how different software and hardware modules co-operate with each other. There are two main tasks of the USB Stick board:

- receive the data from the MC13191 transceiver and store it in RAM buffer
- handle the USB module communication, decode and provide the data from the RAM buffer

These two are somewhat independent and the only common point between them is the accelerometer and button data buffer in RAM. The RF software communicates with the Sensor Board and retrieves the latest accelerometer data. This is stored in RAM and can be independently read by the PC application via the USB link. The protocol employed on the PC side is just a subset of the simple STAR protocol used in the original RD3112MMA7260Q demo. The protocol is described in section 5.4 STAR Protocol and ZSTAR Extensions (Over USB).

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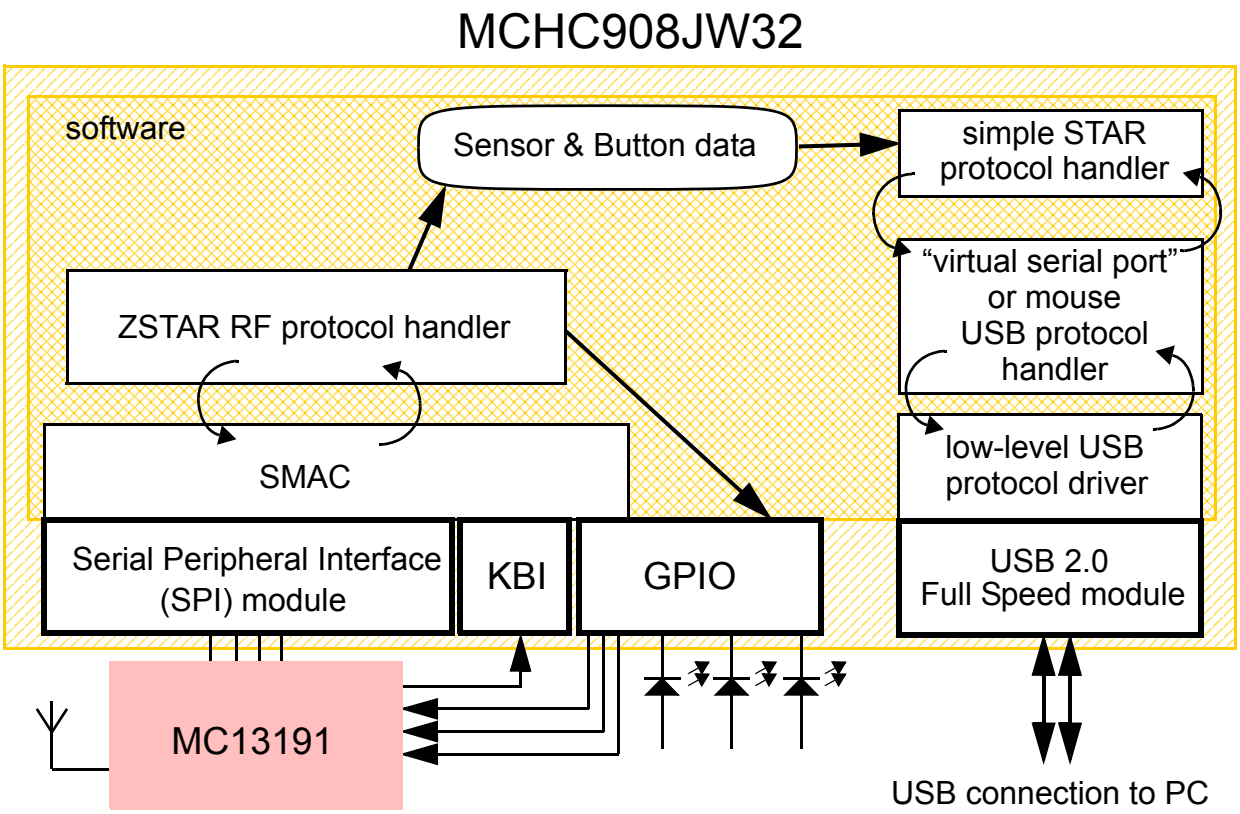

Figure 4-3. ZSTAR USB Stick Board Software Overview

For the USB Stick board operation, several MCHC908JW32 hardware modules are used: USB 2.0 Full-speed (USB), Synchronous Peripheral Interface (SPI), Keyboard Interrupt (KBI) and a General Purpose Input/Output (GPIO).

4.2 ZSTAR USB Stick Board Hardware Overview

This section describes the USB Stick board in terms of the hardware design. The MCHC908JW32 microcontroller drives the MC13191 RF transceiver and communicates over USB with PC.

4.2.1 USB Connections

Two USB communication lines are connected directly via R1 to PTE2/D+ and R2 to PTE3/D- microcontroller pins. There, R1 and R2 resistors define the output impedance of both drivers (Z_{DRV} as per chapter 7 of the USB 2.0 specifications).

Terminating the D+ line with a 1.5kΩ pull-up resistor (required for Full-speed signalling) is internal in the MCHC908JW32.

A USB "A" type SMT Plug is designed at the edge of the USB Stick board allowing the stick to be connected directly into a USB hub without the need for a cable.

4.2.2 Power Supply

The USB Stick board is a Low-power Bus-powered Function (as defined in chapter 7.2.1.3 of USB 2.0 specifications). This means that a maximum of one unit load (100mA) may be drawn by the USB Stick board. Ferrite beads are included on the VBUS and GND USB connections to minimize EMI. The recommended type is a **GLF1608T100M** or similar from TDK.

V_{BUS} voltage is defined as a minimum 4.4V and a maximum 5.25V on a Low-power Bus-powered Function.

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The MC13191 RF transceiver requires a maximum power supply voltage of 3.4V and the MCHC908JW32 microcontroller could not guarantee an internal 3.3V regulator working at such a low power supply. Therefore, two separate voltage regulators need to be implemented, and in addition, the voltage levels have to be close enough to avoid the need for level shifters (for the MC13191 to MCHC908JW32 Microcontroller Interface).

4.2.2.1 Fixed Voltage Regulators

Two voltage levels (3.3V for MC13191 and 3.6V for MCHC908JW32) were selected. For these levels, a low-cost, small footprint fixed regulator exists. The **NCP502/A** series regulators from ON Semiconductor™ were successfully implemented.

The **NCP502/A** series voltage regulator is an 80mA CMOS fixed linear regulator designed primarily for handheld communication equipment and portable battery powered applications which require a low quiescent current.

Each device contains a voltage reference unit, an error amplifier, a PMOS power transistor, resistors for setting the output voltage, current limit, and temperature limit protection circuits. The **NCP502/A** has been designed to be used with low cost ceramic capacitors. The device is housed in a micro-miniature SC70-5 surface mount package. Standard voltage versions are 1.5 V, 1.8 V, 2.5 V, 2.7 V, 2.8 V, 3.0 V, 3.3 V, 3.5 V, 3.6 V and 5.0 V. Other voltages are available in 100 mV steps.

Typically, a low-cost 1μF ceramic capacitor is recommended for input and output decoupling. 0603-sized SMD TDK capacitor **C1608X5R1A105K** was used.

Enable Operation - Enable pin of 3.3V regulator (for MC13191) is connected to PTC3 pin of the microcontroller. This way, the microcontroller may completely turn off the RF part of the application to minimize power consumption in USB suspend modes.

Alternatively, power down of the MC13191 RF transceiver may be done by forcing it into Off mode by pulling the $\overline{\text{RST}}$ pin low.

4.2.3 MC13191 to MCHC908JW32 Microcontroller Interface

On the USB Stick board the full recommended MC13191 interface has been used. This includes the following connections:

- 4-wire Synchronous Peripheral Interface (SPI) connection (MISO, MOSI, SPICLK, $\overline{\text{CE}}$)
- Interrupt Request signal ($\overline{\text{IRQ}}$)
- Attention ($\overline{\text{ATTN}}$) wake-up signal
- Receive/Transmit Enable (RXTXEN) signal
- External Reset ($\overline{\text{RST}}$) signal

The SPI connection is connected to the MCHC908JW32 SPI module signals (MISO, MOSI, SPCLK, $\overline{\text{SS}}$).

The $\overline{\text{IRQ}}$ signal is routed to the PTA3/$\overline{\text{KBA3}}$ Keyboard interrupt module pin instead of the MCHC908JW32 $\overline{\text{IRQ}}$ pin, which is left for the MON08 Interface and the Button Connection. The reason for re-routing this signal is that V_{TST} ($1.5xV_{DD}$, up to 8V) is applied to the microcontroller's $\overline{\text{IRQ}}$ during programming, therefore some additional jumper configuration would be required to disconnect this voltage from the MC13191. Here, the $\overline{\text{IRQ}}$'s MON08 function is only shared with the button under the condition that the button is not pressed during programming.

The remaining three signals ($\overline{\text{ATTN}}$, RXTXEN and $\overline{\text{RST}}$) are connected to GPIO signals of port D (PTD0, PTD2 and PTD1).

4.2.4 Oscillator and Clocking Options

The MCHC908JW32 microcontroller requires a stable clock, mainly for the Full-speed USB module operations. USB specifications define an overall 2500ppm (0.25%) accuracy. Basically, any generic 4MHz crystal is sufficient for such accuracy. The main issue with 4MHz crystals are their physical size. Due to the nature of crystal resonating elements, the 4MHz crystals are simply far too big for the USB Stick in the ZSTAR demo.

Another option is a SAW resonator (e.g. **CERALOCK™** series from Murata). These are usually sorted and selected by the manufacturer to fit the USB 2.0 Full-speed accuracy required. Today, only 6, 12, 24 and 48MHz versions are available from Murata. A 6MHz version (manufacturer order code **CSTCR6M00G15**) has been used in the USB Stick design, although the 6MHz frequency is outside the MCHC908JW32 microcontroller specifications.

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Provision is also made on the PCB (Q3 component) for an Epson **SG-310** series (or compatible) Crystal Oscillator (active output). Here, a 4MHz version oscillator is contained in a small 3.2x2.5mm package.

4.2.5 LED Indicators Connections

The MCHC908JW32 microcontroller allows a direct drive of LED's on its three pins. PTB0, PTB1 and PTB5 are high-current open-drain outputs, so the LED's D1, D2 and D3 are connected to these high-current outputs.

4.2.6 Button Connection

One button is implemented on the USB Stick board. It is connected to the $\overline{\text{IRQ}}$ microcontroller pin that has internal pull-up and allows an easy software interrupt.

4.2.7 MON08 Interface

For MCHC908JW32 in-circuit programming, a MON08 interface is required. Several pins must be connected to specific voltage levels in order for the MCHC908JW32 to enter the Monitor mode. The details are described in the MCHC908JW32 data sheet, Chapter 7 Monitor ROM (MON).

To minimize the number of MON08 connections, several pins are hardwired to specific voltage levels directly on the USB Stick board. Namely, PTA1 to V_{dd}, PTA2 and PTC1 to GND.

Pins PTA0, $\overline{\text{RST}}$, $\overline{\text{IRQ}}$ and OSC1, together with the power supply lines, are routed to PCB pads MON08 connector (J3).

There is no standard physical connector to be soldered onto the J3 footprint. The J3 connector pads are used during manufacturing for the initial in-circuit programming. Further re-programming of the USB Stick may be done using an AN2295 Bootloader as described in section 5.5.

4.2.8 Optional Serial Interface

For the purpose of evaluating the USB functions of the MCHC908JW32 microcontroller, a few other pins were routed to an additional PCB pads connector (J2). The two TIM timer pins are connected to J2 allowing emulation of SCI, IIC or such like serial interfaces in software. A simple example of a USB to UART converter software is a part of the Appendix A References.

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4.2.9 USB Stick Schematics

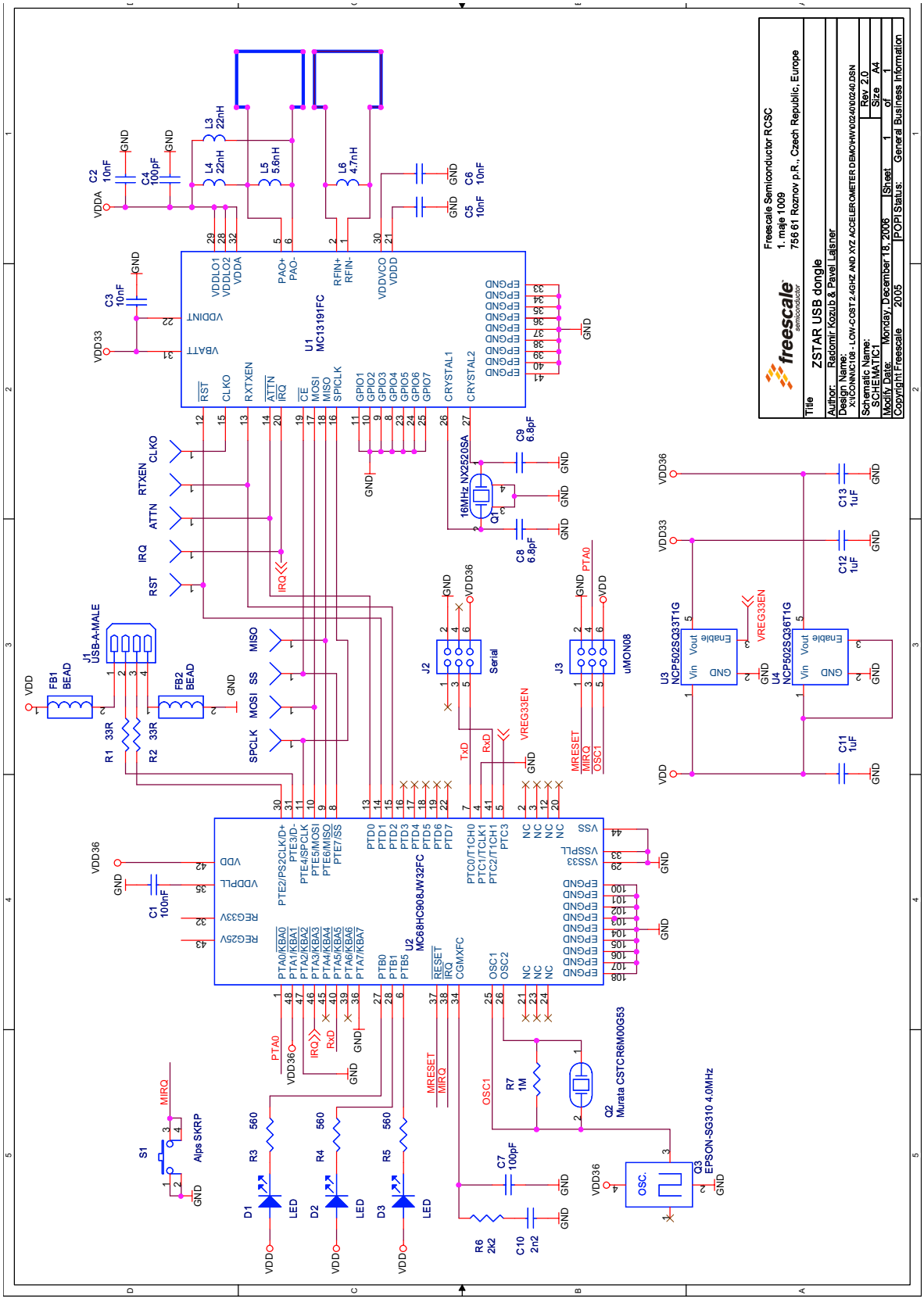

Figure 4-4. USB Stick Schematics

4.3 Bill of Materials

Table 4-1. USB Stick BIll of Materials

Item	Quantity	Reference	Part	Manufacturer	Manufacturer order code
1	1	C1	100nF	TDK	C1608CH1E104J
2	4	C2,C3,C5,C6	10nF	TDK	C1608CH1E103J
3	2	C4,C7	100pF	TDK	C1608CH1H101J
4	2	C8,C9	6.8pF	TDK	C1608CH1H070D
5	1	C10	2n2	TDK	C1608CH1H222J
6	3	C11,C12,C13	1uF	TDK	C1608JB1C105K
7	3	D1,D2,D3	Kingbright KP-1608SEC	Kingbright	KP-1608SEC
8	2	FB1,FB2	Ferrite bead	TDK	GLF1608T100M
9	1	J1	USB-A-MALE	Molex	48037-1000
10	1	J2	Serial	N/A	
11	2	L3,L4	22nH	TDK	MLG1608B22NJT
12	1	L6	4.7nH	TDK	MLG1608B4N7ST
13	1	L5	5.6nH	TDK	MLG1608B5N6DT
14	1	Q1	16MHz NX2520SA	NDK	NX2520SA 16MHz EXS00A-02940 Specification n° EXS10B-07228
15	1	Q2	Murata CSTCR6M00G15	Murata	CSTCR6M00G15
16	2	R1,R2	33R	resistor 0603 package	
17	3	R3,R4,R5	560R	resistor 0603 package	
18	1	R6	1k	resistor 0603 package	
19	1	R7	1M	resistor 0603 package	
20	1	U1	MC13191FC	Freescale	MC13191FC
21	1	U2	MCHC908JW32FC	Freescale	MCHC908JW32FC
22	1	U3	NCP502SQ33T1G	ON Semi	NCP502SQ33T1G
23	1	U4	NCP502SQ36T1G	ON Semi	NCP502SQ36T1G
24	1	S1	switch SKRP	Alps	SKRPADE010 (or SKRPACE010 or SKRPABE010)

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Chapter 5
Software Design

5.1 Introduction

This section describes the design of the ZSTAR software blocks. The software description comprises these topics:

- SMAC (Simple Media Access Controller) modifications description
- 'Air' ZSTAR RF Protocol protocol description
- Serial STAR Protocol and ZSTAR Extensions (Over USB) protocol description
- AN2295 Bootloader (over USB) implementation notes

5.2 SMAC (Simple Media Access Controller)

The SMAC is a simple ANSI C based code stack available as sample source code which can be used to develop proprietary RF transceiver applications using the MC13191.

5.2.1 SMAC Features

- Compact footprint:
  - 2K FLASH
  - 10 bytes (+ maximum packet length) RAM
  - As low as 16kHz bus clock
- Can be used to demonstrate coin cell operation for a remote control
- MC13191 compatible
- Very-low power, proprietary, bi-directional RF communication link
- ANSI C source code targeted at the HCS08 core and portable to almost any CPU core (including 4-bit)
- Low priority IRQ
- Sample application included, extremely easy to use
- Liberally commented
- CodeWarrior Experimental edition for support

5.2.2 Modifications of SMAC for ZSTAR Demo

The development of the ZSTAR software is based on the free SMAC stack available from Freescale. The SMAC version used was 4.1a. Two sorts of modifications were made since the original version did not support the HC08 family or the MC9S08QG8 derivative of the 9S08 family. All changes are made using conditional compile options, using `ZSTARQG8` and `ZSTARJW32` definitions.

A fully detailed description of the SMAC is in the SMAC Reference Manual (SMACRM.pdf), available together with SMAC source code.

5.2.2.1 MC9S08QG8 SMAC Modifications (Sensor Board)

Here the modifications of the SMAC are very minimal, since the core, peripherals and naming conventions are the same as in the MC9S08GB/GT code (originally in the SMAC 4.1a code).

The main changes are listed below:

`drivers.c:`

- `void MC13192Wake (void)` function not implemented, $\overline{\text{ATTN}}$ pin not connected to the microcontroller.

- `void RTXENDeAssert(void)` and `void RTXENAssert(void)` functions not implemented, RXTXEN pin not connected to the microcontroller.

`mcu_hw_config.c:`

- A set of functions
  `void SetGPIO(unsigned char gpio);`
  `void ClearGPIO(unsigned char gpio);`
  `void ToggleGPIO(unsigned char gpio);`
  added for the purpose of driving LED's connected to the MC13191 GPIO pins.
- `void UseExternalClock(void)` and void `UseMcuClock(void)` functions not implemented, no external clock available to the microcontroller.
- $\overline{\text{RESET}}$ pin handling in `void MC13192Restart(void)` and `void MC13192ContReset(void)` functions omitted since the $\overline{\text{RESET}}$ pin is not connected to the microcontroller.
- $\overline{\text{RESET}}$, $\overline{\text{ATTN}}$ and RXTXEN pins handling in `void GPIOInit(void)` and `void MCUInit(void)` functions omitted since these pins are not connected to the microcontroller.
- LED toggling added into `void MCUInit(void)` during the waiting for MC13191 to initialize.

`device_header.h:`

- Several SPI, TPM and SOPT definitions added at the top of the standard <mc9s08qg8.h> header file.

created `port_config_ZSTARQG8.h` file with target specific defines (GPIO assignments, etc.)

5.2.2.2 MCHC908JW32 SMAC Modifications (USB Stick)

There are several modifications of SMAC required to

1. compile for the HC08 family member MCHC908JW32
2. reflect that the MC13191 connects to the microcontroller in a slightly different way (as described in chapter 4.2.3 MC13191 to MCHC908JW32 Microcontroller Interface) - namely, MC13191's $\overline{\text{IRQ}}$ pin.

The 9S08 to HC908 porting required slight changes in the following files:

`mcu_spi_config.c:`

- `void SPIInit(void)` function modified to initialize the HC908 SPI module.

`mcu_spi_config.h:`

- `SPIWaitTransferDone(), SPIClearRecieveStatReg(), SPIClearRecieveDataReg(), SPISendChar(u8Char)` and `SPIRead()` macros changed to work with the HC908 SPI module.

Further changes are relevant to the ZSTAR JW32 platform and specific connections:

`drivers.h:`

- `CLEAR_IRQ_FLAG` macro changed to reflect KBI module serving IRQ requests from MC13191.

`mcu_hw_config.c:`

- `void UseExternalClock(void)` and void `UseMcuClock(void)` functions no implemented, no external clock available to the microcontroller.
- LED toggling added into `void MCUInit(void)` during waiting for MC13191 to initialize.
- `UINT8 IRQPinLow(void)` function returns the state of the pin PTA3/KBI3 instead of the IRQ pin.

`mcu_hw_config.h:`

- `IRQFLAG, IRQACK(), IRQInit() and IRQPinEnable()` macros changed to reflect KBI module serving IRQ requests from the MC13191.

`device_header.h:`

- Several KBI definitions added at the top of the standard <mc68hc908jw32.h> header file.

created `port_config_ZSTARJW32.h` file with target specific defines (GPIO assignments, etc.)

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5.2.2.3 Generic SMAC Modifications (USB Stick + Sensor Board)

Several modifications of SMAC have been made in order to improve the behavior with some older MC13191 silicon versions. Namely a software time-out functions (using microcontroller's TIM/TPM timer functions) have been added into `UINT8 PDDataRequest(tTxPacket *psPacket)` and `UINT8 PLMEEnergyDetect (void)` functions in `simple_phy.c` file.

Both functions wait for the `gu8RTxMode` variable to change to `IDLE_MODE`. This variable should change in the `void interrupt IRQIsr(void)` function once the execution of a specified task (in MC13191) finishes. Under some rare circumstances, an IRQ event (and also an `IRQIsr()` interrupt) does not occur, so this software workaround has been implemented to avoid a software lock-up.

5.3 ZSTAR RF Protocol

ZSTAR uses a simple protocol for an RF transfer of information between Sensor Board and USB receiver. Acceleration (X, Y and Z axis), temperature, bandgap voltage, button and calibration data can be accessed. The protocol is built on top of SMAC (Simple Media Access Controller) drivers that are available for the MC13191 transceivers family. The protocol is bidirectional allowing the set up of independent connections amongst numerous pairs of ZSTAR demos.

All data is transferred in so-called Zpackets. This protocol is primarily targeted at simple demo purposes, allowing a fast transfer of the accelerometer data in short packets with minimum overheads and with minimum battery loads (most of the receive windows eliminated, short transmit packets, etc.).

5.3.1 Zpacket Format

The ZSTAR Zpacket is contained inside the MC13191 standard packet structure, which is consistent with the IEEE 802.15.4 Standard. The SMAC library transparently adds a 16 bit Packet control field (see chapter 7.2.1.1 of IEEE 802.15.4 Standard specifications) to differentiate packets from ZigBee and other standards.

The Zpacket becomes a payload data for the SMAC standard packet and contains the following fields:

- Network Number
- RX Strength
- Zcommand
- Zdata

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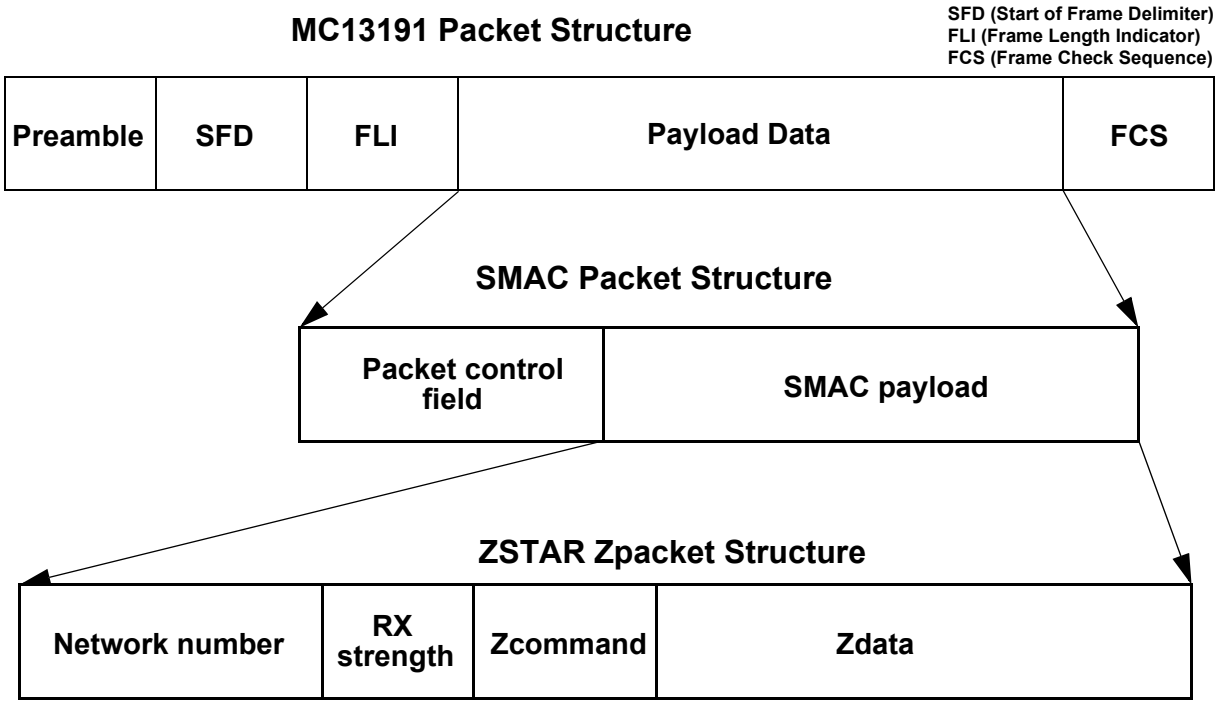

Figure 5-1. Zpacket Format

5.3.1.1 Network Number

The network number is randomly generated at the beginning of the connection between the USB Stick and the Sensor Board. It is used to determine between various connections. Packets with different Network numbers are simply ignored.

This field is 16 bits long.

5.3.1.2 RX Strength

This field reports the strength of the last received packet on the other end of the connection. This value simply tells us how well the other side receives 'our packets'. This can be used by transmission power management functions to change the transmission power if the other party receives packets with enough strength.

The values reported are retrieved using the `MLMELinkQuality()` SMAC primitive.

This field is 8 bits long.

5.3.1.3 Zcommand

The ZSTAR demo protocol uses a few simple commands to establish and maintain the data flow between the Sensor Board and USB Stick.

The command is carried in Zcommand field and is 8 bits long. The commands are defined as listed in Table 5-1.

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Table 5-1. ZSTAR Zcommand List

ZCommand	ZCommand code	Direction	Zdata
ZSTAR_BROADCAST	‘b’ (0x62)	USB Stick to Sensor Board	none
ZSTAR_ACK	‘a’ {0x61)	USB Stick to Sensor Board	none
ZSTAR_CALIB	‘k’ (0x6B)	USB Stick to Sensor Board	calibration data to Sensor Board
ZSTAR_STATUS	‘s’ (0x73)	USB Stick to Sensor Board	g-range selection data to Sensor Board
ZSTAR_CONNECT	‘c’ (0x63)	Sensor Board to USB Stick	calibration data from Sensor Board
ZSTAR_DATA	‘d’ (0x64)	Sensor Board to USB Stick	accelerometer values, temperature and bandgap voltage, button levels, g-range selection

5.3.1.4 Zdata

The Zdata field follows the Zcommand field and may be empty if the actual command doesn’t require any additional data. The data format is dependent on the Zcommand. A detailed description is in the next chapter.

5.3.2 ZSTAR Protocol Zcommand Description

5.3.2.1 ZSTAR_BROADCAST

This command is sent when the USB Stick tries to establish connection with the Sensor Board. The USB Stick first generates a new random network number which is then ‘broadcast’ to any Sensor Board that is not yet connected to a USB Stick. The USB Stick transmits this command on a free channel, while the Sensor Board searches all available channels. Once a Sensor Board receives this command, it responds with a ZSTAR_CONNECT.

5.3.2.2 ZSTAR_CONNECT

This command is a reply to ZSTAR_BROADCAST, ZSTAR_CALIB or ZSTAR_STATUS commands sent by the USB Stick. The Zdata field contains the calibration data stored in the Sensor Board, in the following format:

Zdata bytes:	0 1	2 3	4 5	6 7	8 9	10 11
	Xvalue (0g)	Xvalue (1g)	Yvalue (0g)	Yvalue (1g)	Zvalue (0g)	Zvalue (1g)

Figure 5-2. ZSTAR_CONNECT Zdata Format

5.3.2.3 ZSTAR_DATA

Once the connection is established, the Sensor Board starts to periodically transmit accelerometer, button, temperature, battery voltage and g-range status data towards the USB Stick.

The Zdata field contains 10 bytes; actual X, Y and Z accelerometer data, temperature value and bandgap reference voltage together with a byte containing status information.

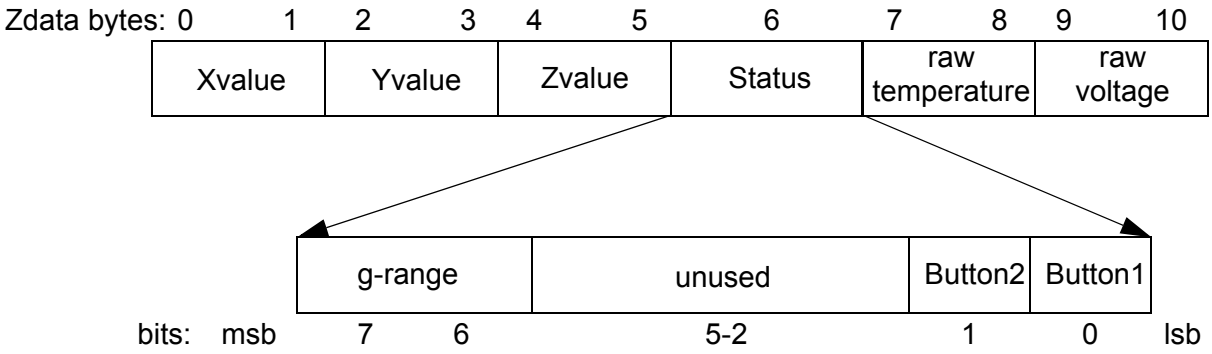

Figure 5-3. ZSTAR_DATA Zdata Format

Each transmission of a ZSTAR_DATA packet is acknowledged by a ZSTAR_ACK packet from the USB Stick, although the Sensor Board does not always open the reception window to receive this acknowledgement, in order to save the battery charge.

5.3.2.4 ZSTAR_ACK

This command is sent as the data acknowledgement so the Sensor Board board knows that the connection is still alive. If the receive window is opened by the Sensor Board and the ZSTAR_ACK has not been received, the operation (periodic transmission of a ZSTAR_DATA packet) continues but the Sensor Board will try to receive an acknowledgement more frequently. If the acknowledgement is not received several times, the connection is dropped and the Sensor Board will try to re-establish the connection again. The USB Stick will recognize this situation once several ZSTAR_DATA packets have not been received.

5.3.2.5 ZSTAR_CALIB

This command carries the calibration data provided by the USB Stick for the Sensor Board and is sent instead of a ZSTAR_ACK packet. The calibration data is intended to be stored in Flash memory of the Sensor Board. Since the Sensor Board does not receive after every ZSTAR_DATA packet, the USB Stick keeps sending a ZSTAR_CALIB until the Sensor Board confirms reception using a new ZSTAR_CONNECT packet.

5.3.2.6 ZSTAR_STATUS

This command carries the g-range data provided by the USB Stick for the Sensor Board and is sent instead of a ZSTAR_ACK packet. The g-range data is intended to switch the g-range of accelerometer Sensor. Since the Sensor Board does not receive after every ZSTAR_DATA packet, the USB Stick keeps sending a ZSTAR_STATUS until the Sensor Board confirms reception using a new ZSTAR_CONNECT packet.

5.4 STAR Protocol and ZSTAR Extensions (Over USB)

The ZSTAR demo uses a subset of the original STAR demo protocol commands. This way, most of the software originally developed for the RD3112MMA7260Q (STAR) is also usable with the ZSTAR.

The STAR demo communicates over the RS232 serial line with a simple text-based protocol. The same protocol is used in ZSTAR for communication between the USB Stick and a PC (over a virtual serial port). The PC application sees the same interface (serial port) and the same protocol as if a STAR demo was connected.

5.4.1 Communication Handshake ‘R’ (0x52)

Initially, a handshake (commands needed to test/establish the connection between the PC and the ZSTAR demo) is conducted. This is accomplished by the PC sending an ‘R’ command, the ZSTAR demo responding with ‘N’. In this way, the PC application sees that the demo is ready for communication. Communication is reset, and any debug or system modes are disabled.

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All subsequent commands will carry only 8-bit values (backward compatibility).

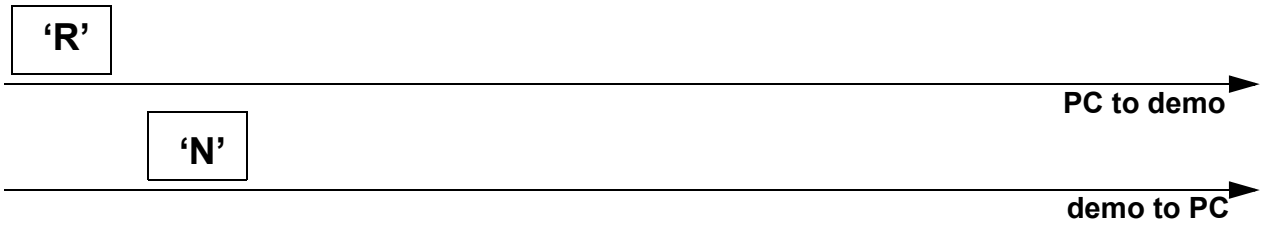

Figure 5-4. Communication Handshake 'R' (0x52)

5.4.1.1 Extended Communication Handshake 'r' (0x72)

To determine whether a ZSTAR or STAR demo is connected, Only the ZSTAR demo implements an Extended Handshake Communication command. Once the PC sends the 'r' command, the ZSTAR demo responds with a 'Z'.

All subsequent commands will carry left justified 16-bit values (extended values). The communication uses big endianism, i.e. more significant byte first.

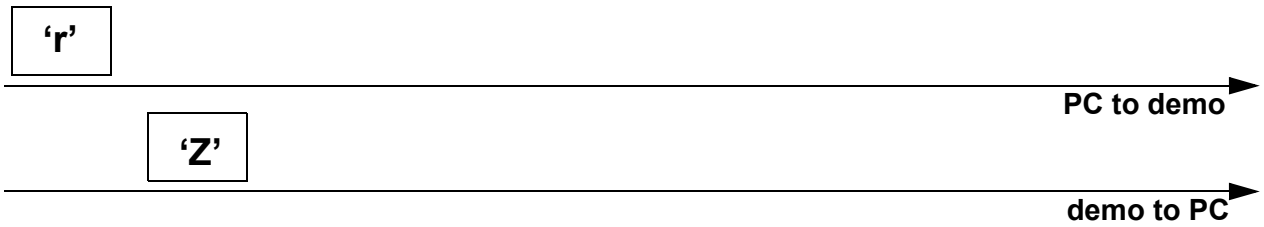

Figure 5-5. Extended Communication Handshake 'r' (0x72)

5.4.2 Accelerometer Data Transfer 'V' (0x56)

The PC sends the Values 'V' command, the demo responds with 6 bytes (or 9 bytes in 16-bit mode) in the following sequence:

'x', X-value, 'y', Y-value, 'z', Z-value, simply an 'x' character followed by the actual X-axis accelerometer binary value, then a 'y' followed by the actual Y-axis accelerometer binary value and a 'z' followed by the actual Z-axis accelerometer binary value. Since the ZSTAR demo caches the last (over the air) transmitted values, these values are immediately provided to the PC.

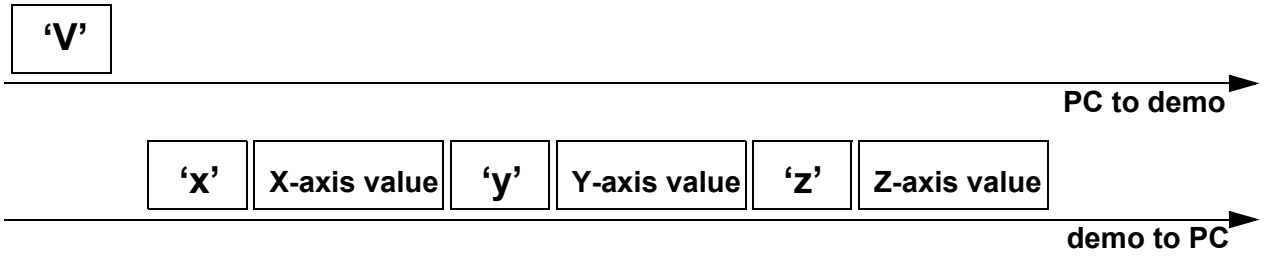

Figure 5-6. Accelerometer Data Transfer 'V' (0x56)

5.4.2.1 Extended Accelerometer Data Transfer 'v' (0x76)

The ZSTAR demo also has two buttons designed on the Sensor Board. The microcontroller on the Sensor Board is also capable of measuring internal bandgap voltage reference and temperature. To acquire the actual state of these values, the original 'V' command has been extended to a 'v' command, that provides the same information, followed by an 's' character and a binary byte containing the actual state. The least two significant bits are used, the others are reserved. If a button is pressed, the actual

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bit is set to ‘1’, and if depressed, the bit is ‘0’. The status data are followed by a ‘t’ character with raw temperature value and finally a ‘b’ character followed by raw bandgap voltage value.

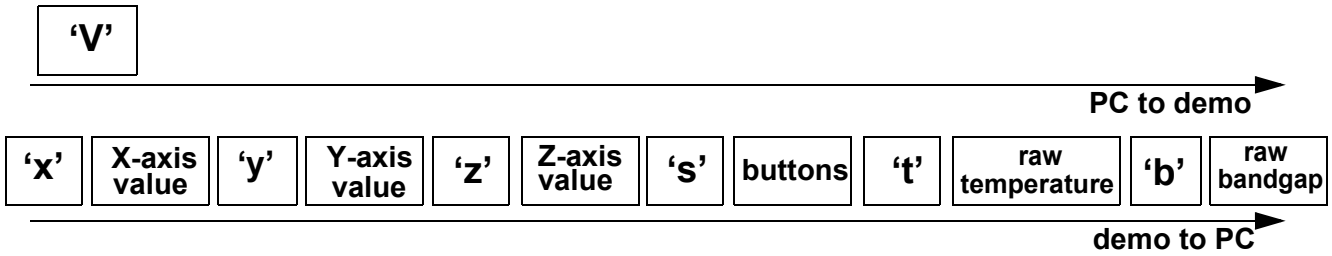

Figure 5-7. Extended Accelerometer Data Transfer ‘v’ (0x76)

Battery voltage can be calculated from raw bandgap:

$$V_{batt} = \frac{65536}{rawbgap} ¥ 1.20V$$

This is assuming a 16-bit format for rawbgap.

Temperature can be obtained out of bandgap reference voltage and raw temperature value.

First, voltage of temperature sensor is calculated:

$$V_{temp} = \frac{rawtemperature}{rawbgap} ¥ 1.20V$$

If temperature is above 25°C (i.e., voltage above 0.7012V), temperature is:

$$temperature = 25 - \left(\frac{V_{temp} - 0.7012}{0.001646}\right)$$

For temperature below 25°C:

$$temperature = 25 - \left(\frac{V_{temp} - 0.7012}{0.001769}\right)$$

5.4.3 Calibration Data ‘K’ (0x4B)

The calibration data is the accelerometer values for specific g (acceleration) levels. The values for 0g and 1g (earth’s gravity) are provided for each axis. The values are stored in the Flash memory of the Sensor Board and are transferred to the USB Stick once the air connection is established (as described in chapter 5.3.2.2 ZSTAR_CONNECT). These values are stored in the USB Stick for retrieval by the PC using the ‘K’ command.

The PC sends the Calibration data ‘K’ command, the demo responds with 9 bytes (or 15 bytes in 16-bit mode) in the following sequence:

'X', Xval0, Xval1, 'Y', Yval0, Yval1, Z', Zval0, Zval1, simply an ‘X’ character followed by the 0g and 1g X-axis calibration accelerometer binary values, and the same for Y- and Z-axis.

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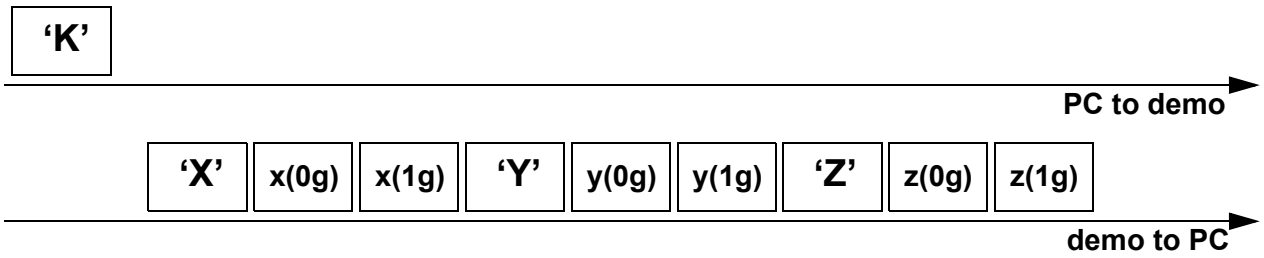

Figure 5-8. Calibration Data ‘K’ (0x4B)

5.4.4 Calibration Process ‘k’ (0x6B)

The calibration process is initiated by a ‘k’ command from the PC, followed by 6 bytes (or 12 bytes in 16-bit mode) of calibration data. These are to be stored in the Flash memory of the Sensor Board being used. More in chapter 5.3.2.5 ZSTAR_CALIB.

The calibration data is just 6 bytes (or 12 bytes in 16-bit mode) in the following sequence:

Xval0, Xval1, Yval0, Yval1, Zval0, Zval1 - 0g and 1g calibration accelerometer binary values for X-, Y- and Z-axis. No response from the demo is provided. Verification of the calibration data stored can be done using the Calibration Data ‘K’ (0x4B) command.

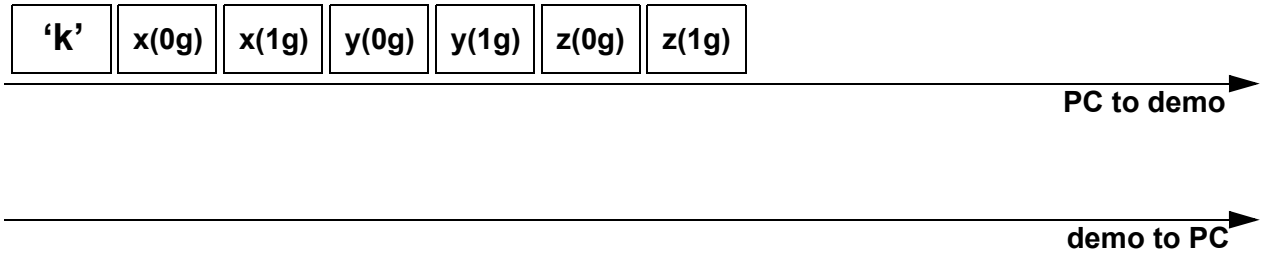

Figure 5-9. Calibration Process ‘k’ (0x6B)

5.4.4.1 Remaining STAR Demo Commands

The remaining STAR commands, such as 'F', 'G', 'H', '0', '1', '2', '3' and 'E' are not yet implemented in the ZSTAR demo.

5.4.5 Additional ZSTAR Commands

5.4.5.1 g-select Reading ‘G’ (0x47)

The ZSTAR demo allows dynamic selection of the g-range for the accelerometer Sensor (see details in chapter 3.4.2 g-select Connections), thus additional commands are implemented to read and change the g-range.

When the PC issues a ‘G’ command, the ZSTAR demo responds with the g-range actually selected. A ‘0’, ‘1’, ‘2’ or ‘3’ character is returned where ‘0’ is for the 1.5g range, ‘1’ for 2.0g , ‘2’ for 4.0g and ‘3’ for the 6.0g range. If a different sensor is implemented on the Sensor Board, like MMA7261QT, the g-range is 2.5g, 3.3g, 6.7g and 10g respectively.

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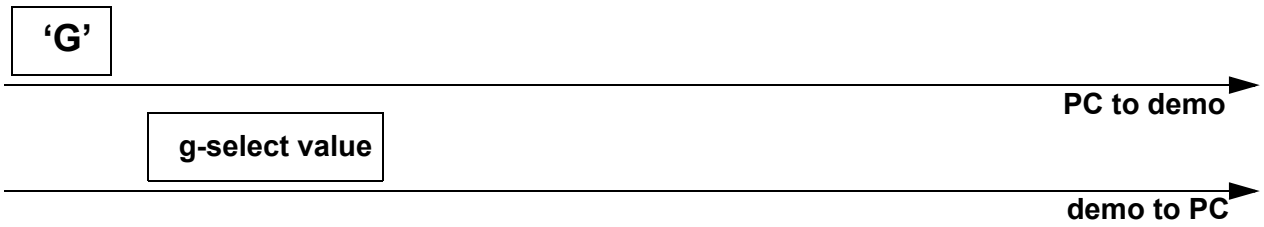

Figure 5-10. g-select Reading 'G' (0x47)

5.4.5.2 g-select Setting 'g' (0x67)

To select the g-range of the sensor on the ZSTAR Sensor Board, a 'g' command is issued. It needs to be followed by the required g-range ('0', '1', '2' or '3'). The USB Stick board then communicates this selection to the Sensor Board over the air (see more in 5.3.2.6 ZSTAR_STATUS).

No response from the demo is provided. To verify which g-range has been selected, the g-select Reading 'G' (0x47) command can be used.

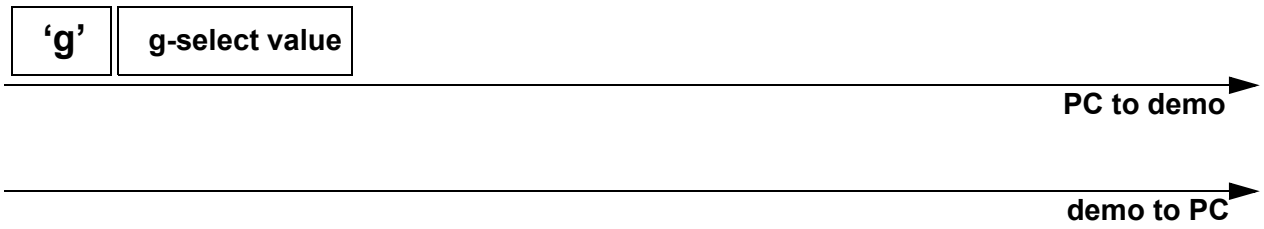

Figure 5-11. g-select Setting 'g' (0x67)

5.4.5.3 Info 'I' (0x49)

The Info command 'I' has only been added to determine which version, compile date, and author of the USB Stick software has been implemented. The demo returns a plain text information, and this command is usually issued over terminal (e.g. HyperTerminal) software.

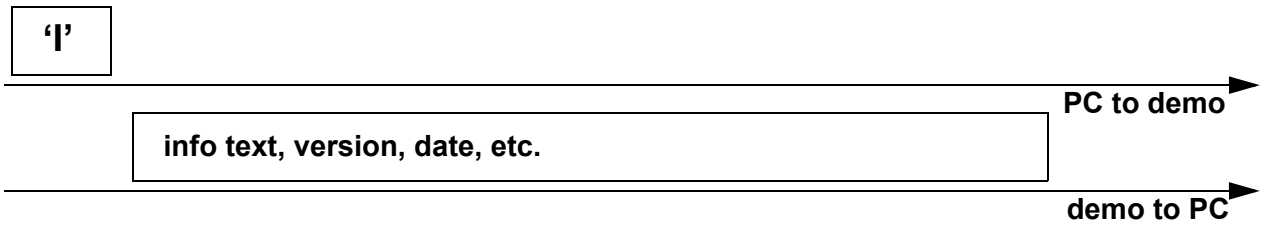

Figure 5-12. Info 'I' (0x49)

5.4.5.4 Debug on 'U' (0x55) and Debug Off 'u' (0x75)

Various debug information can be observed after issuing a 'U' command, usually in terminal (e.g. HyperTerminal) software. Mainly, information on the air protocol is displayed in text, information on the detected channel energy during the surveying for a free channel is shown, channel numbers, and, once the connection is established, the network number. The received level of packets from the Sensor Board and the reported USB Stick packet level are shown, as well as command names, etc. This can be useful in determining the communication range between the USB Stick and the Sensor Board.

The debug information is no longer displayed after issuing a 'u' command or Communication Handshake 'R' (0x52).

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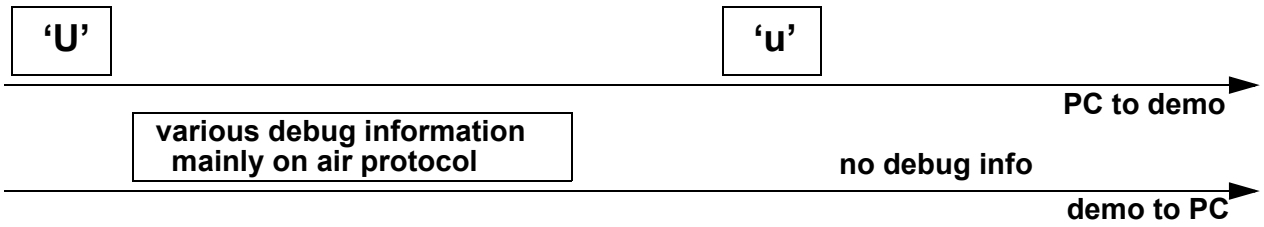

Figure 5-13. Debug on 'U' (0x55) and Debug Off 'u' (0x75)

5.4.6 Further Debug and Test Commands

5.4.6.1 Forced Channel Number Selection

In order to allow effective testing and debugging, additional commands have been added. If, before a connection between the USB Stick and Sensor Board is established, any hexadecimal number command ('0' through '9' or 'A' through 'F') is sent, the connection will be established on this specific channel number (0 to 15). Any new channel can be selected, sending the new channel number command. The selection becomes effective when the new connection is being established.

The return to the automatic mode (where a random channel with the minimum energy is selected) can be forced only by a complete software reset (i.e. removing the USB Stick from the USB slot).

5.4.6.2 Semiautomatic Self-Calibration

For the purpose of easier semiautomatic calibration of the ZSTAR demo, the additional Calibration command 'Q' (0x51) has been added. This command is usually issued over terminal (e.g. HyperTerminal) software.

A user is required to place the Sensor Board into three specific positions, in which the earth's gravity will induce a maximum acceleration in each of X, Y, and Z axes. Before issuing the first 'Q' command, the Sensor Board must be placed flat, i.e., with Z-axis aiming toward the earth. For the second issue of 'Q' calibration command, the board's X-axis has to aim toward the earth. The board should be placed on its right edge. Next, the Y-axis is calibrated, with the board placed on its top edge. Finally, after issuing the fourth 'Q' command, the calibration data are sent to the Sensor Board, actually using ZSTAR_CALIB command. The text help is provided during the self-calibration process.

5.5 Bootloader

There's bootloader software implemented in MCHC908JW32 microcontroller. The bootloader is based on AN2295 Application note - Developer's Serial Bootloader for M68HC08 and HCS08 MCUs and AN2295SW related software. The original AN2295 bootloader targets serial connections between the PC and applications, and since the MCHC908JW32 implements a virtual serial port application, the USB version of the AN2295 bootloader has been created to allow reprogramming of Flash memory in the USB Stick.

The USB virtual serial port software is fully described in AN3153 Application note - Using the Full-Speed USB Module on the MCHC908JW32. The MCHC908JW32 bootloader implements the same virtual serial port but under a different PID (the PC sees that serial port as a different application from ZSTAR).

The bootloader drivers installation guide can be found in section 6.1.2 AN2295 Bootloader Drivers installation.

5.5.1 Bootloading Procedure

1. Find on the installation CD the folder with binaries:

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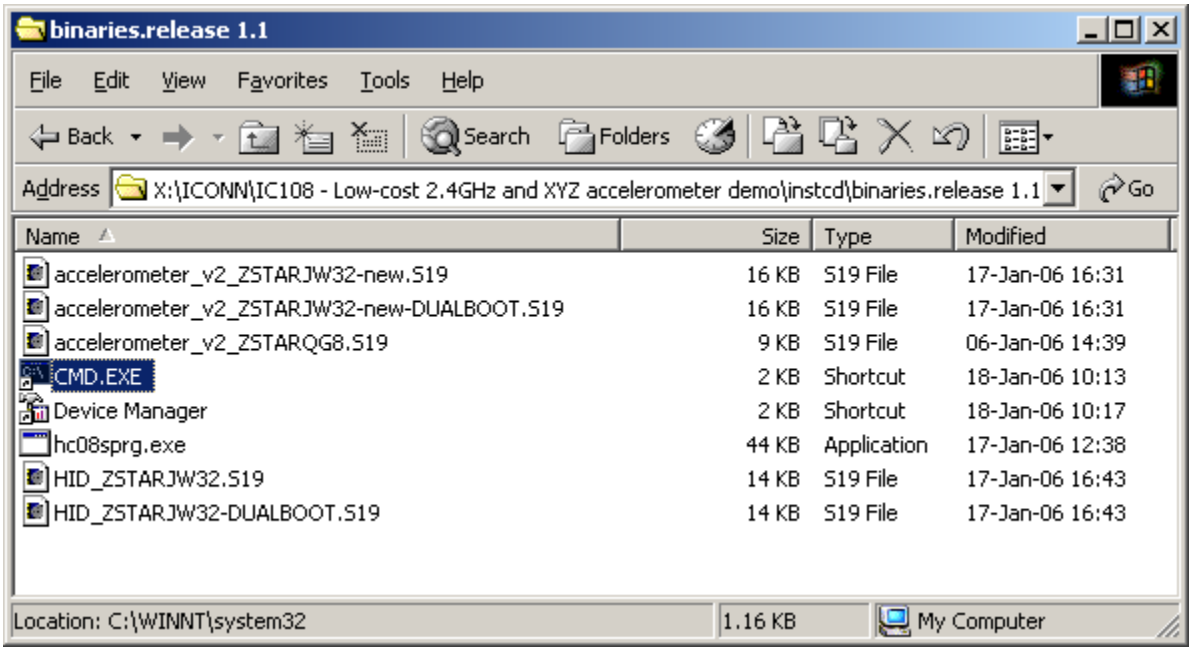
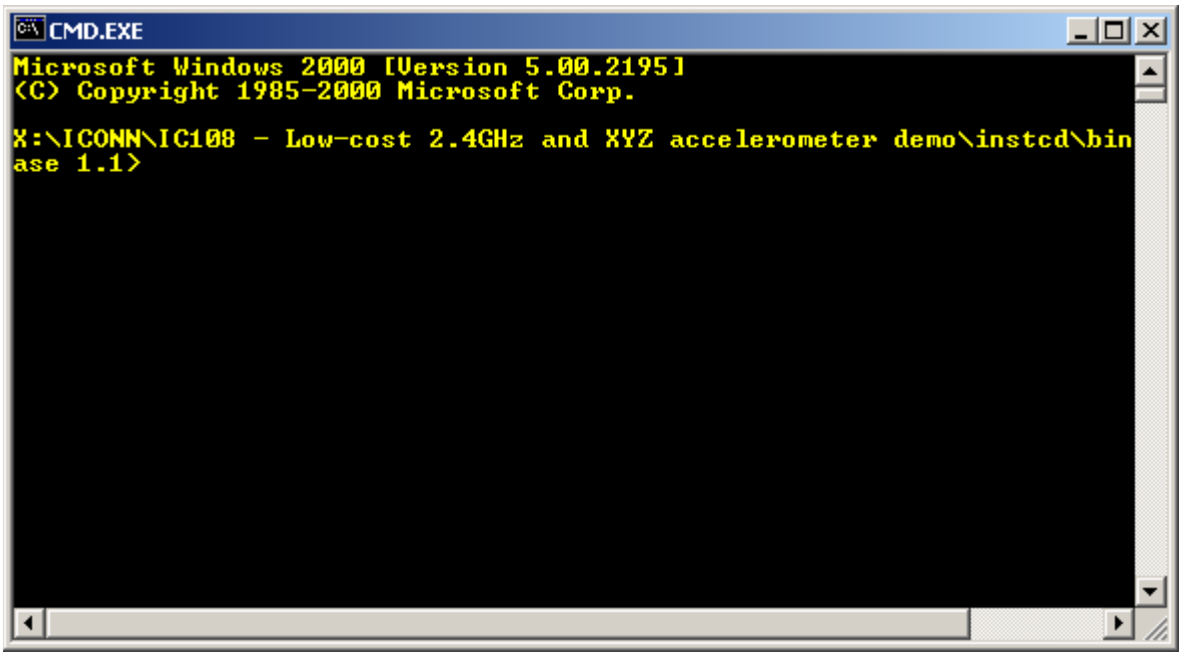


2. Start (double-click) the CMD.EXE shortcut, a command line window should appear:



3. Now type: hc08sprg [bootloader com port number] [binary (S file) that you want to bootload], just like this:

```
hc08sprg.exe com8 accelerometer_v2_ZSTARJW32-new-DUALBOOT.S19
```

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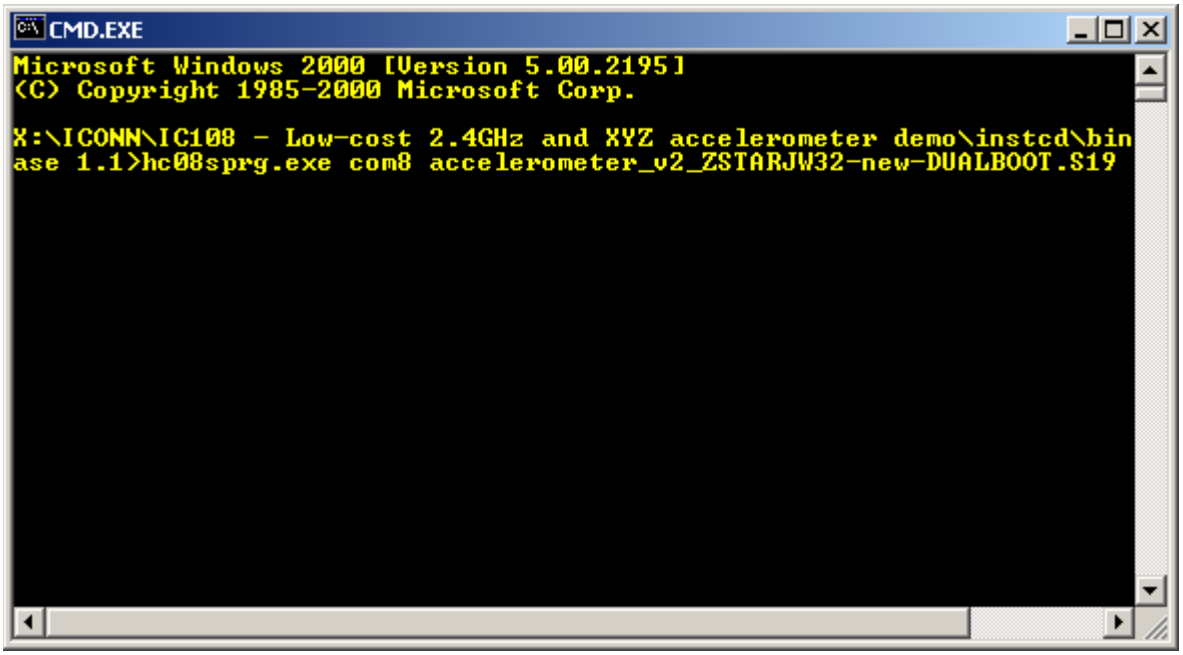
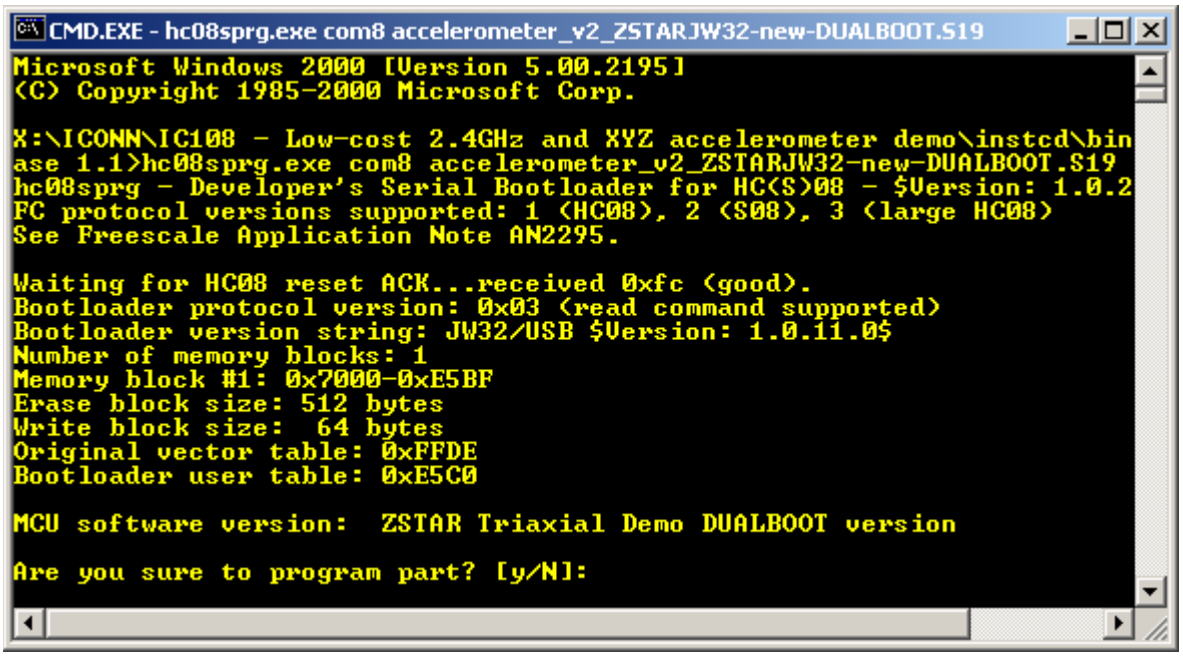
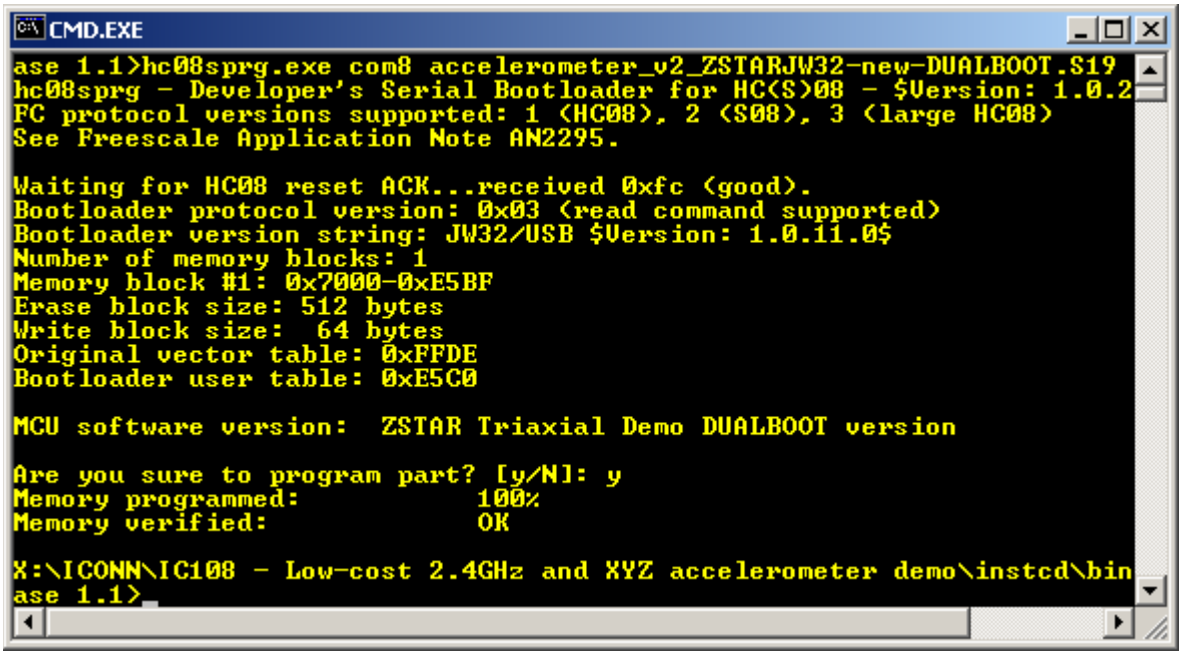


4. Press ENTER and initial bootloader communication will start:



If this screen does not appear, remove the USB stick and start from the beginning.

5. Just confirm with Y, and the binary will be loaded onto the USB stick:



The bootloader disappears (in Device Manager) and the newly loaded software starts to execute.

Using this procedure the software in the USB Stick can be changed anytime.

5.5.2 Dualboot Guidelines

NOTE

The USB Stick already comes from the factory with two dualboot-aware applications pre-programmed.

USB Stick and AN2295 Bootloader software provide a way of having two different software (devices) in one USB Stick. In order to do this, two dualboot-aware versions of the software needs to be consecutively bootloaded onto the USB Stick:

Follow the sequence of instructions in the 5.5.1 Bootloading Procedure for two dualboot versions of software:

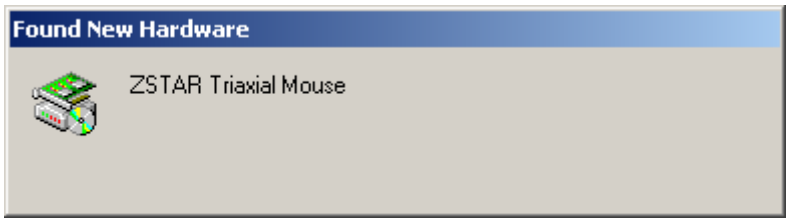
1. First bootload `accelerometer_v2_ZSTARJW32-new-DUALBOOT.S19.`

After bootloading, ZSTAR Triaxial Demo (COM1) should appear in Device Manager.

2. Next, remove the USB stick again, press the button, re-insert the stick and bootload

`HID_ZSTARJW32-DUALBOOT.S19 software in.`

After bootloading, a new device (ZSTAR Triaxial Mouse) should appear:



The 'tilt' mouse will install automatically and also appear in the Device Manager:

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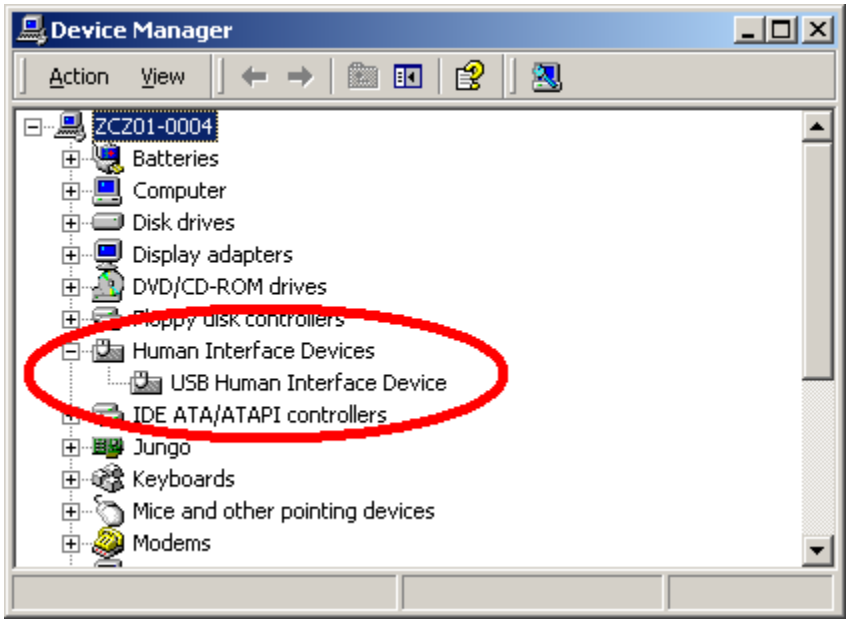

5.5.2.1 Dualboot Applications Switching

Having both dualboot-aware applications programmed in the USB Stick, they can be switched just by quickly pressing the button (having the USB Stick inserted into the USB slot). The applications will appear and disappear accordingly.

The 'tilt' mouse application in order to work must have Sensor Board calibrated correctly (e.g. using RD3152MMA7260Q_SW.exe or 5.4.6.2 Semiautomatic Self-Calibration procedure).

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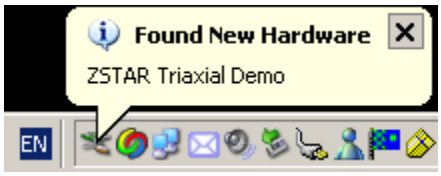
Chapter 6
Application Setup

6.1 ZSTAR Installation Procedure

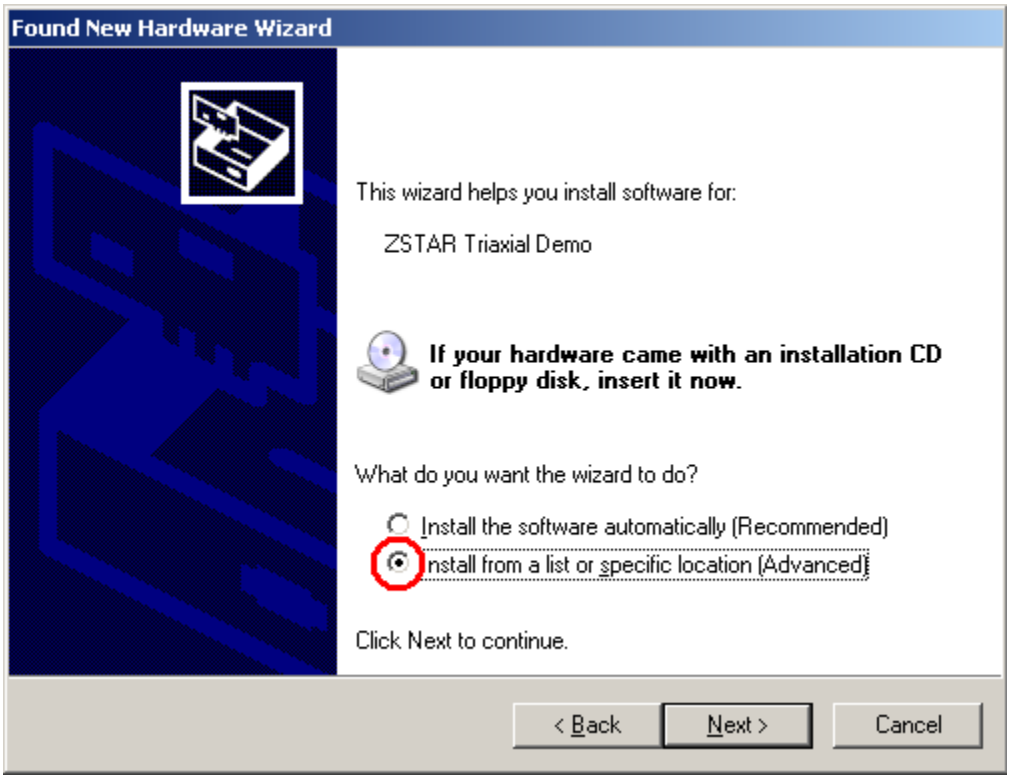
6.1.1 USB Stick Installation

First of the all, we have to install the USB Stick to your PC. Please follow the next steps.

1. Plug the USB Stick into a USB slot.The ‘Found New Hardware’ announcement should appear:



2. Then the installation wizard starts for new hardware. Choose “Install from a list or special location“



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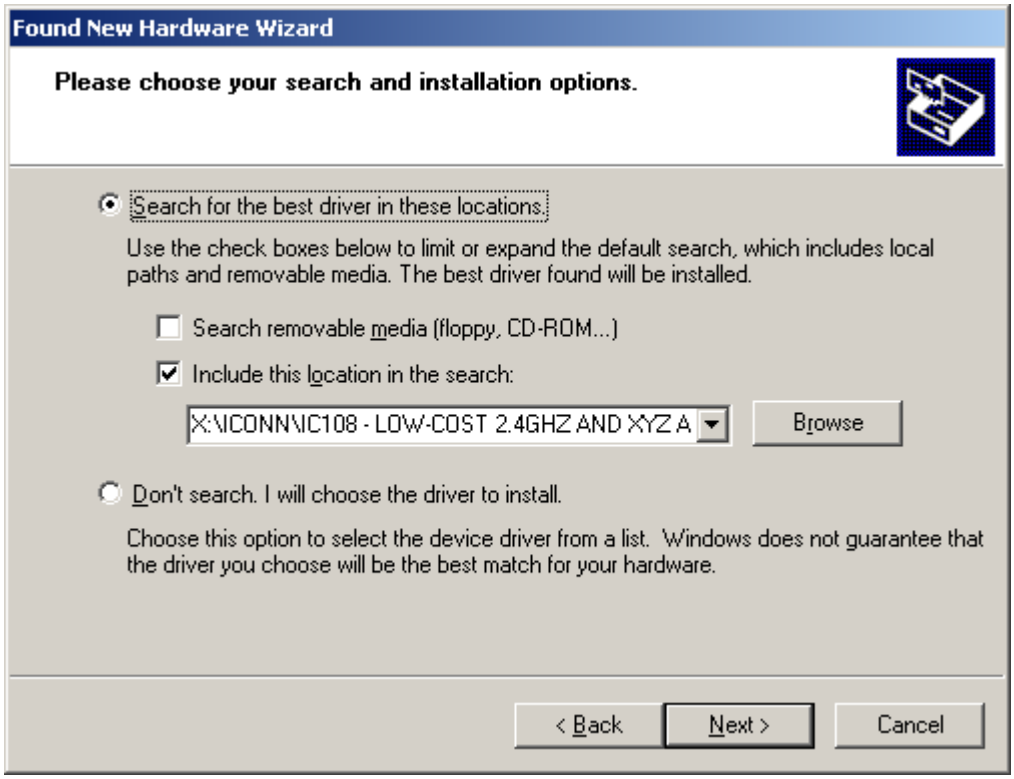
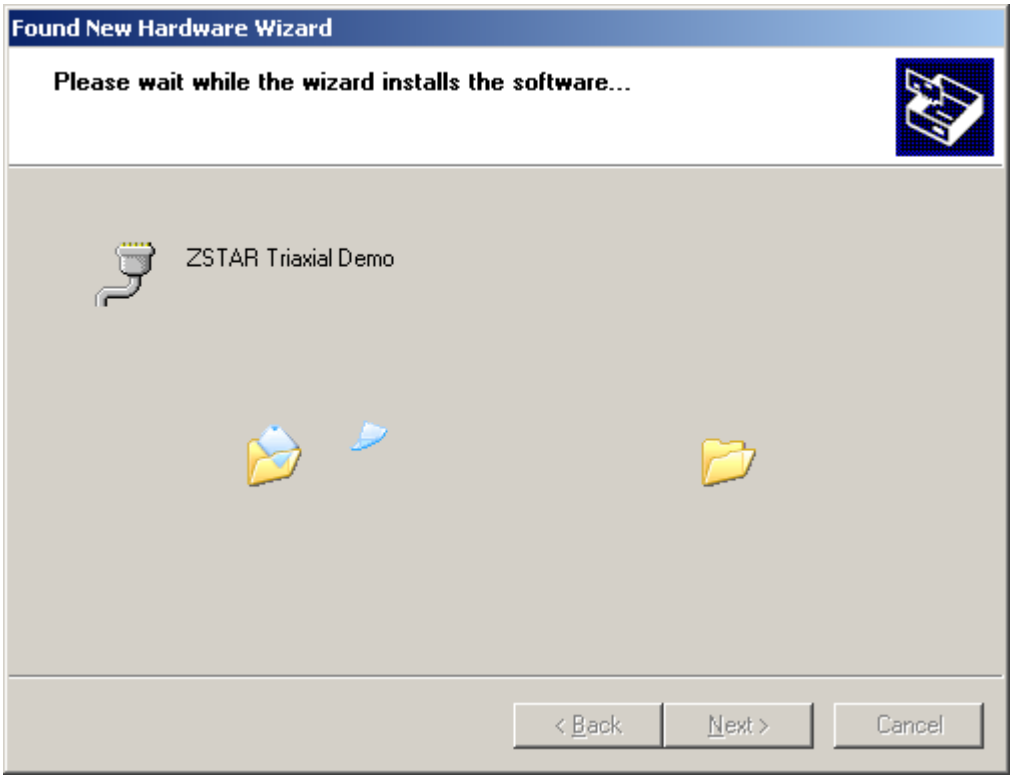
3. Point to the Installation CD as the driver path:



4. Installation should continue:



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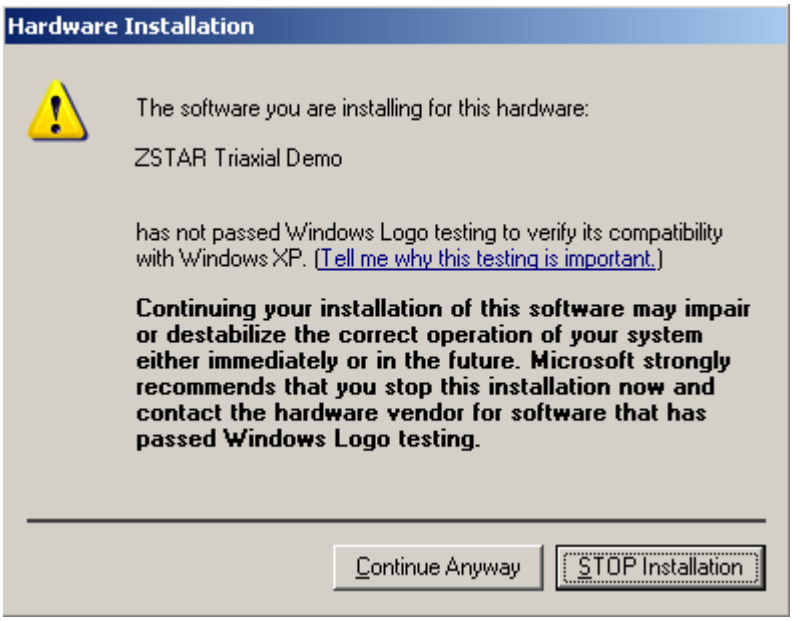
5. If you are asked to stop or continue installation because the drivers are not certified by Microsoft, select the “Continue Anyway” button.



6. Installation should successfully finish.

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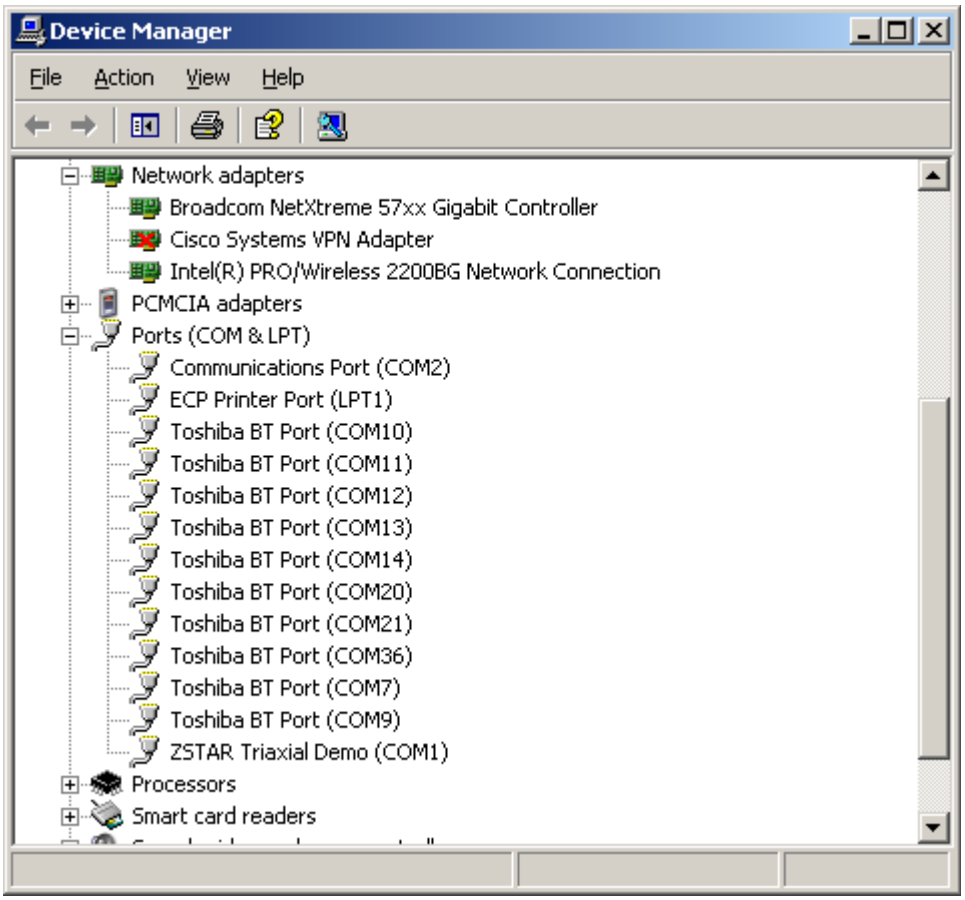
7. Check whether a new serial port (ZSTAR Triaxial Demo) has appeared in your Device Manager (Right click **My computer** on the Desktop > **Properties**, **Hardware** tab, **Device Manager** button):



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8. Launch the RD3152 software “RD3152MMA7260QSW.exe" and select the COM port number which you may have assigned in Device Manager.

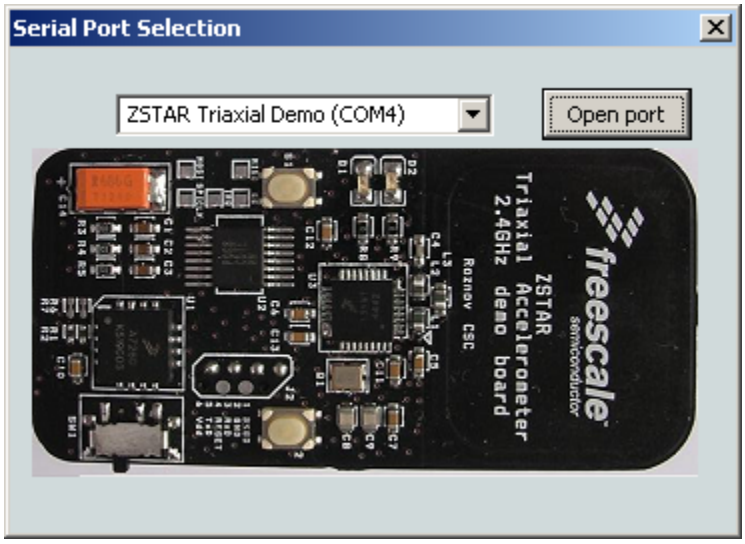

Figure 6-1.

If no error message appears, the COM port is opened correctly and software communicates with the USB Stick.

9. Now let’s go and check data from the ZSTAR Sensor Board.

Raw data, 2D/3D screen, or Scope work should be used for this purpose. While moving (turning, shaking) with a ZSTAR Sensor Board, data from the separate axis should change accordingly.

The RD3152MMA7260QSW calibration screen can be used for Sensor calibration (calibration data is stored in the Sensor Board).

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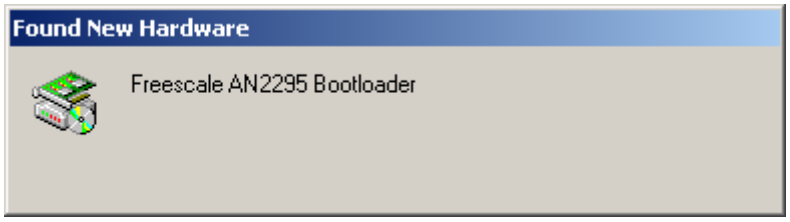
6.1.2 AN2295 Bootloader Drivers installation

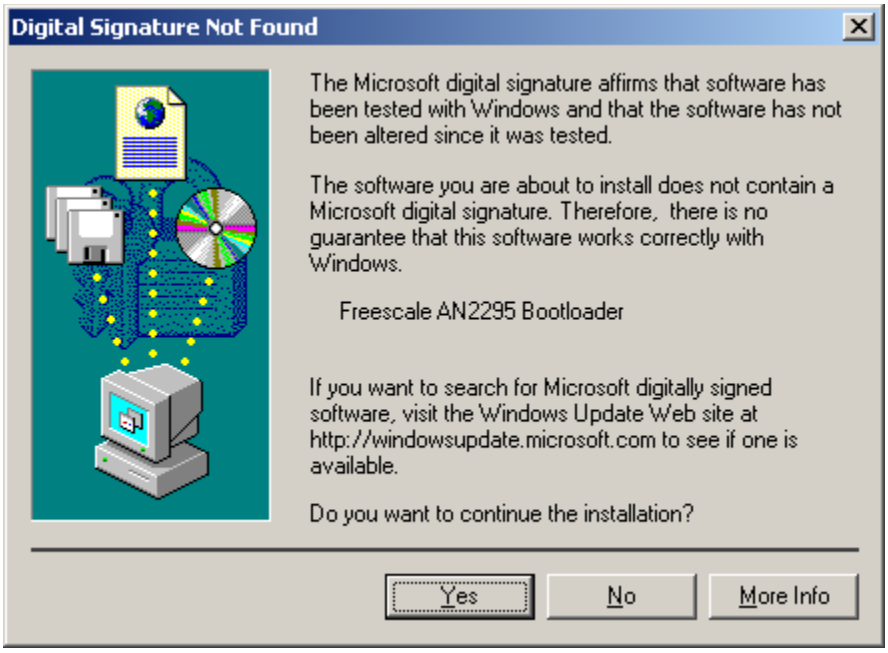
This procedure assumes that ZSTAR Demo drivers are already installed. The drivers are false common for the bootloader (= are already present in Windows folders). If not, the procedure will be identical to the ZSTAR drivers installation.

1. Press the Button on the USB Stick and insert it into a USB connector (keeping the button pressed when inserted).

The following window appears:



2. The PC searches for an appropriate driver (as the ZSTAR Demo, in some instances a folder with drivers (`zstar.inf` and `usbser-zstar.sys`) needs to be selected), then the following window should appear:



3. Just click Yes, and the bootloader port will be installed (as seen in the Device manager):
4. Right click **My computer** on the Desktop > **Properties**, **Hardware** tab, **Device Manager** button.

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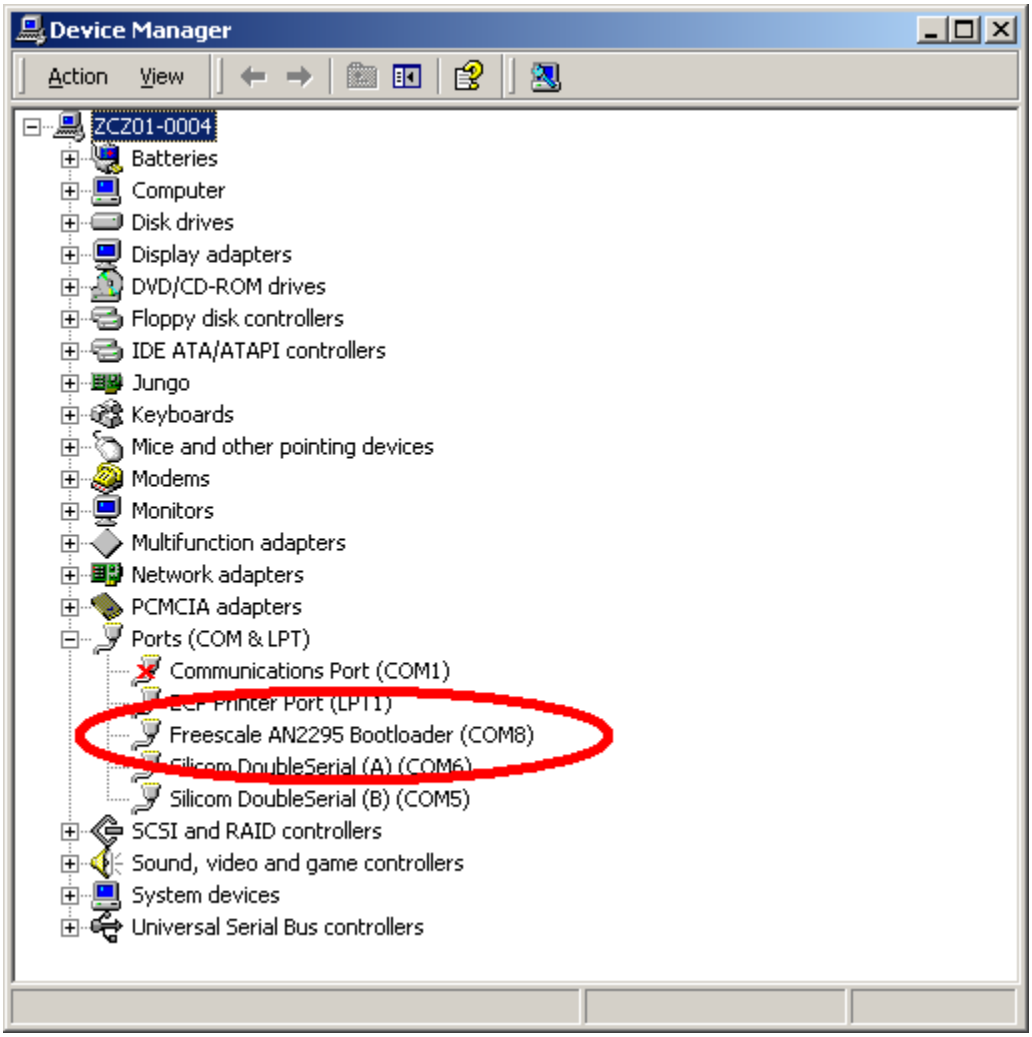
5. A similar setup should be observed:



6. Note down the COM port number (here, COM8); this is the port number of the Bootloader

Once the software in the USB stick needs to be updated, the Bootloader can be invoked anytime, just by pressing the button while inserting the USB Stick into the USB slot.

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Appendix A
References

The following documents can be found on the Freescale web site: http://www.freescale.com.

1. AN2295 Application note - Developer's Serial Bootloader for M68HC08 and HCS08 MCUs
2. AN3153 Application note - Using the Full-Speed USB Module on the MCHC908JW32
3. MC9S08QG8 data sheet
4. MCHC908JW32 data sheet
5. MMA7260QTT data sheet
6. MC13191 data sheet

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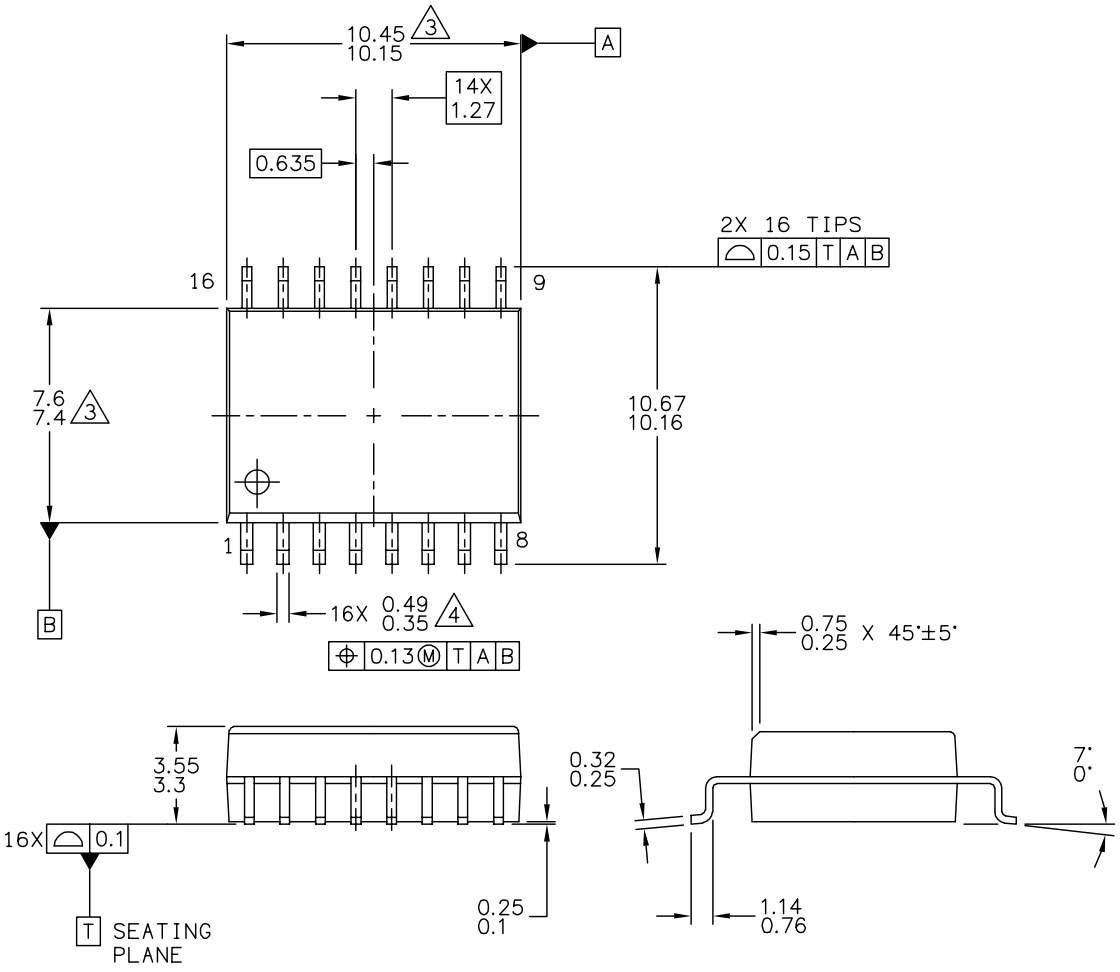
Package Dimensions



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TITLE: 16 LEAD SOIC ACCELEROMETER	DOCUMENT NO: 98ASB16926C	REV: C
	CASE NUMBER: 475-01	17 MAR 2005
	STANDARD: NON-JEDEC	

PAGE 1 OF 2

CASE 475-01
ISSUE C
16 LEAD SOIC

Package Dimensions

NOTES:

1. ALL DIMENSONS ARE IN MILLIMETERS.

2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.

3. THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.15 PER SIDE.

4. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION.
PROTRUSIONS SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.75

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASB16926C	REV: C
16 LEAD SOIC ACCELEROMETER	CASE NUMBER: 475–01	17 MAR 2005
	STANDARD: NON–JEDEC	

CASE 475-01
ISSUE C
16 LEAD SOIC

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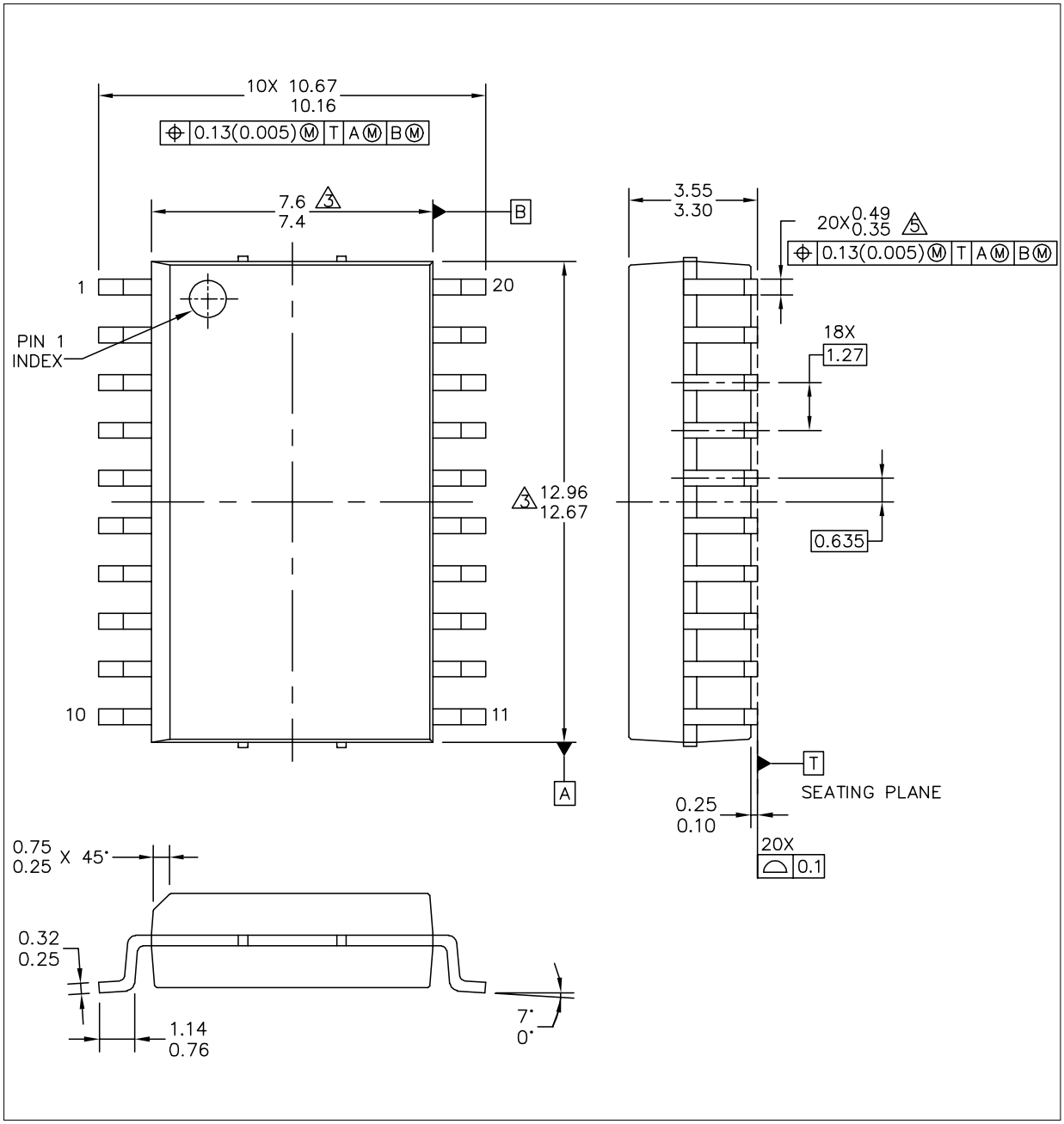
Package Dimensions



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	CASE NUMBER: 475A–02	06 JUL 2006
	STANDARD: NON–JEDEC	

PAGE 1 OF 2

CASE 475A-02
ISSUE C
20 LEAD SOIC

Package Dimensions

NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
2. DIMENSIONS ARE IN MILLIMETERS.
3. THIS DIMENSION DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15(0.006) PER SIDE.
5. THIS DIMENSION DOES NOT INCLUDE DAM BAR PROTRUSION ALLOWABLE DAM BAR PROTRUSION SHALL BE 0.13(0.005) TOTAL IN EXCESS OF THIS DIMENSION AT MAXIMUM MATERIAL CONDITION.

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE: 20LD SOIC W/B, 1.27 PITCH 7.5 X 12.8, ACCLEROMETER CASE–OUTLINE	DOCUMENT NO: 98ASB17933C	REV: C
	CASE NUMBER: 475A–02	06 JUL 2006
	STANDARD: NON–JEDEC	

CASE 475A-02
ISSUE C
20 LEAD SOIC

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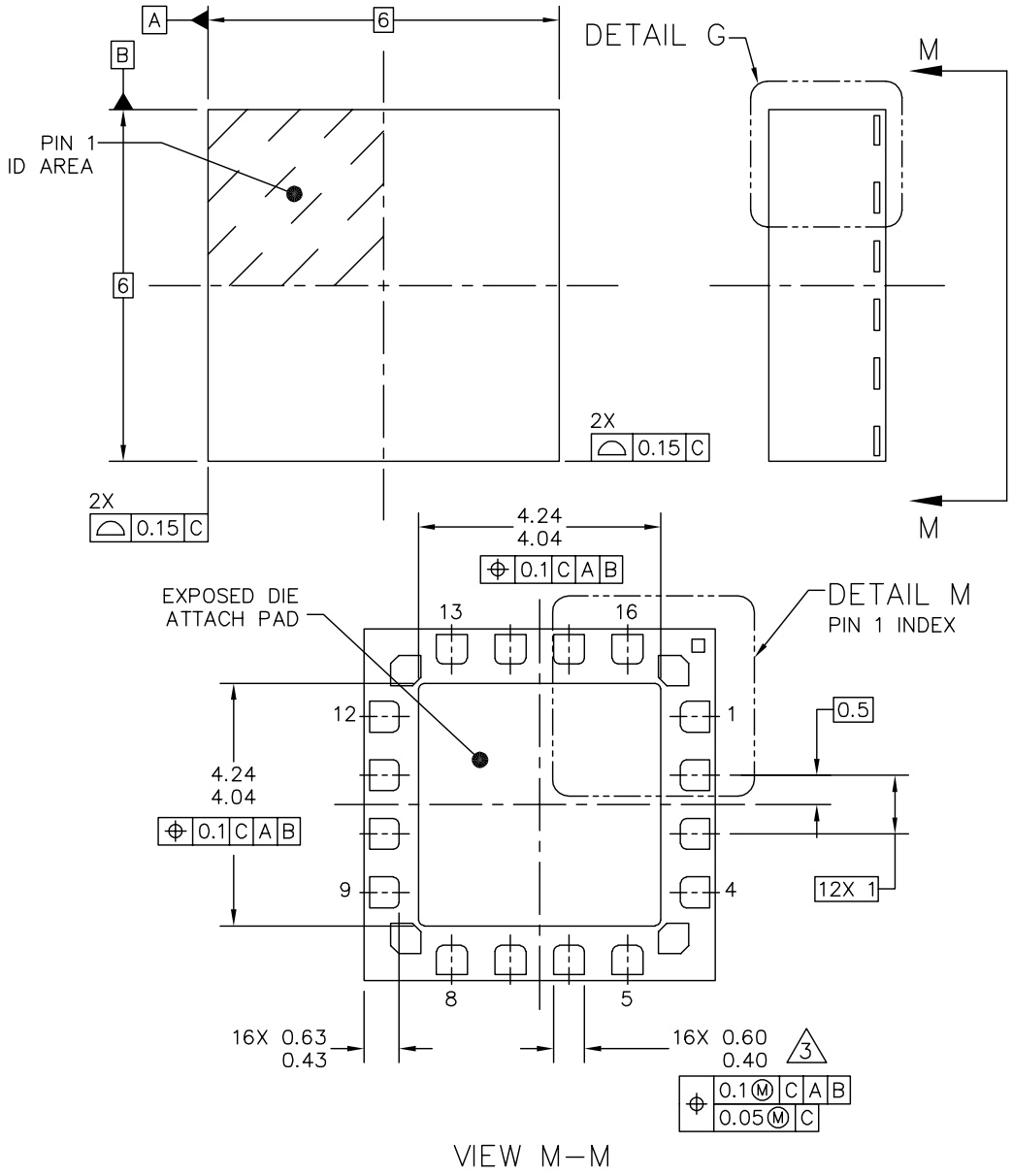
Package Dimensions



VIEW M–M

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TITLE: QUAD FLAT NON–LEADED PACKAGE (QFN) FOR SENSORS 16 TERMINAL, 1.0 PITCH (6 X 6 X 1.98)	DOCUMENT NO: 98ASA10571D	REV: B
	CASE NUMBER: 1477–02	27 SEP 2006
	STANDARD: NON–JEDEC	

PAGE 1 OF 3

CASE 1477-02
ISSUE B
16-LEAD QFN

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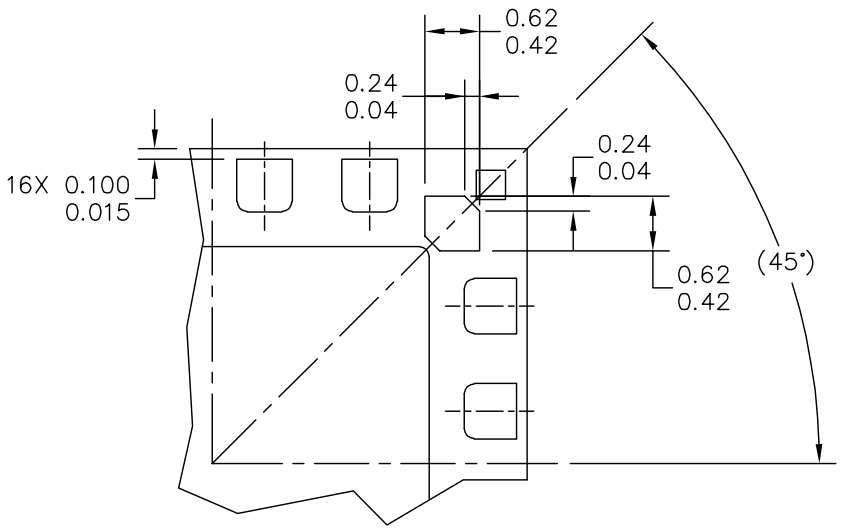
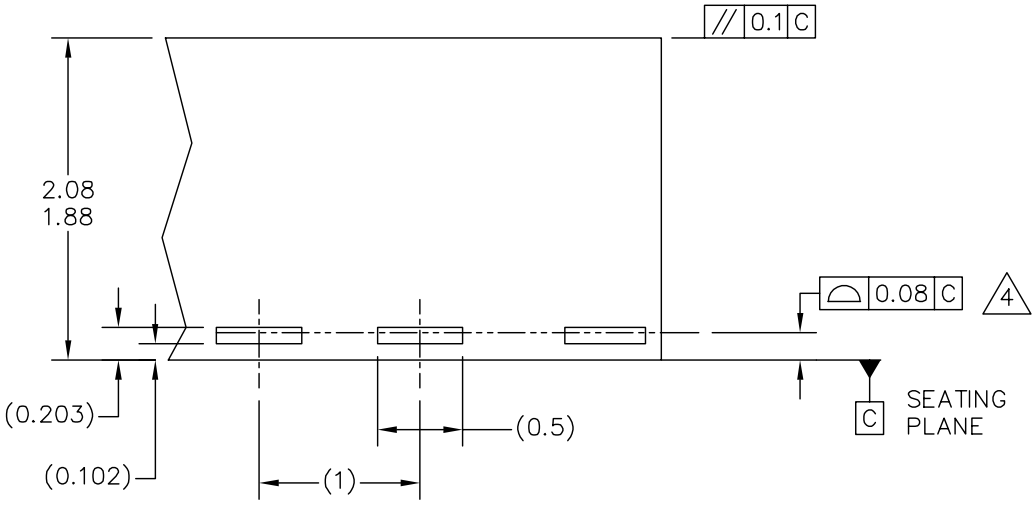
Package Dimensions



DETAIL M



DETAIL G
VIEW ROTATED 90° CW

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	CASE NUMBER: 1477-02	27 SEP 2006
	STANDARD: NON-JEDEC	

CASE 1477-02
ISSUE B
16-LEAD QFN

NOTES:

1. ALL DIMENSIONS ARE IN MILLMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. THIS DIMENSION APPLIES TO METALLIZED TERMINAL AND IS MEASURED BETWEEN 0.25MM AND 0.30MM FROM TERMINAL TIP.
4. COPLANARITY APPLIES TO THE EXPOSED HEAT SLUG, TERMINALS AND CORNER PADS.
5. RADIUS ON TERMINAL IS OPTIONAL.
6. MINIMUM METAL GAP SHOULD BE 0.2MM EXCEPT GAP BETWEEN CORNER PADS AND THE EXPOSED HEAT SLUG.

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CASE 1477-02
ISSUE B
16-LEAD QFN

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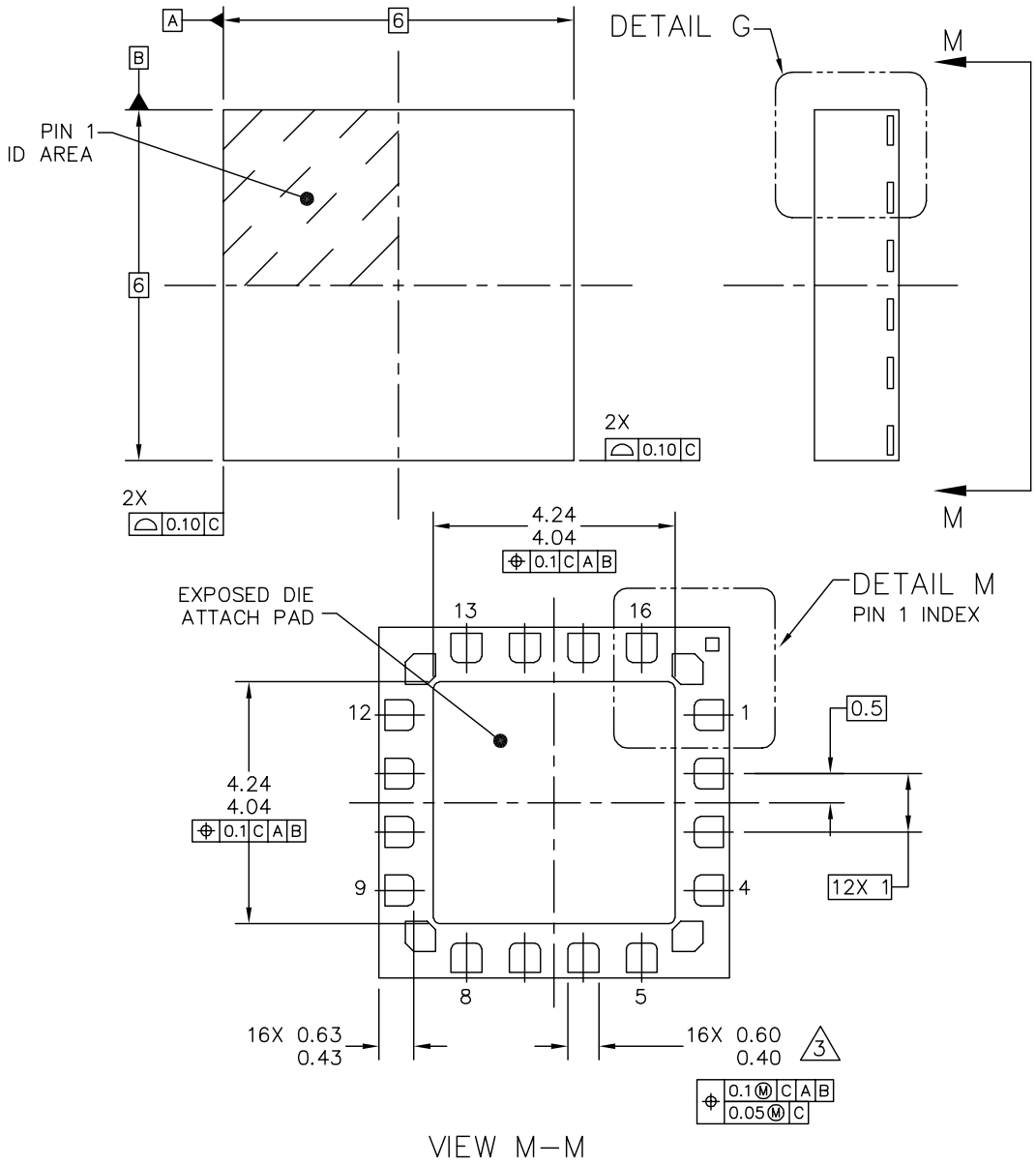
Package Dimensions



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ISSUE B
16-LEAD QFN

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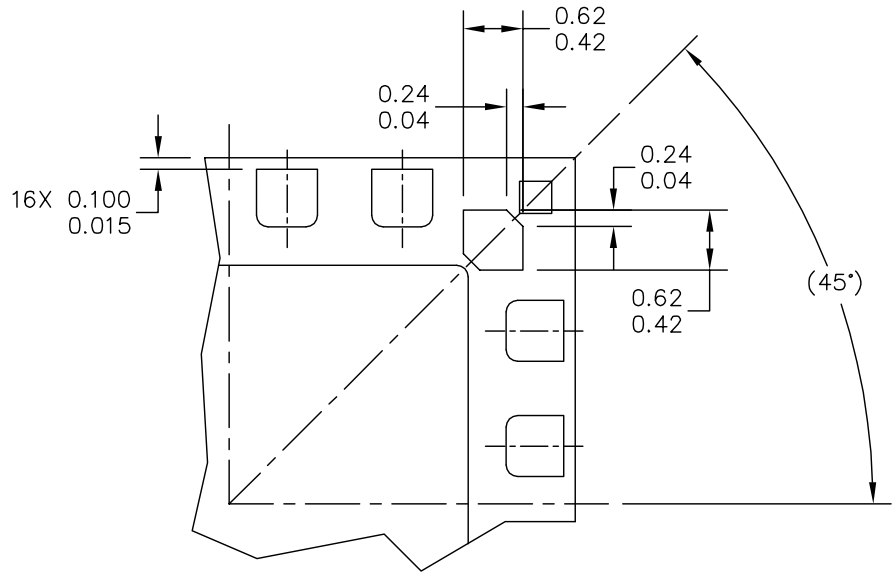
Package Dimensions



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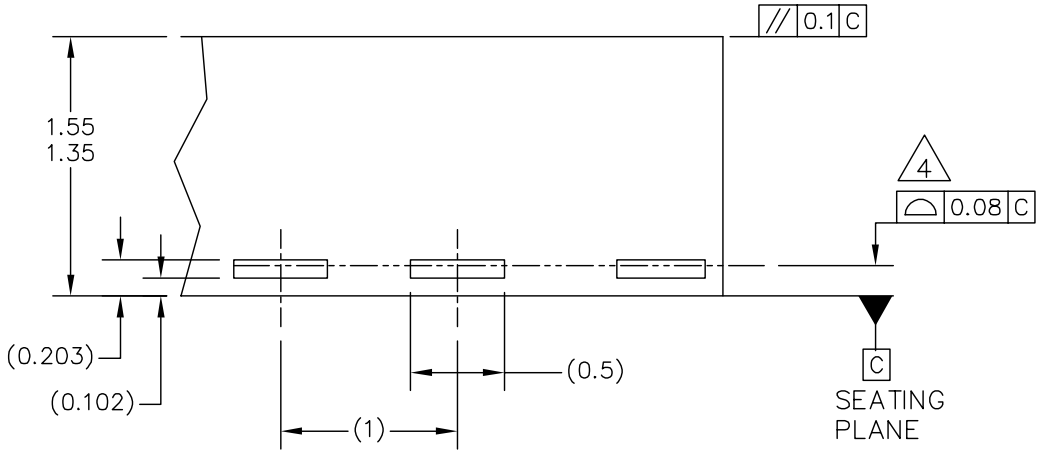

DETAIL G
VIEW ROTATED 90° CW

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TITLE: QUAD FLAT NON-LEADED PACKAGE (QFN) FOR SENSORS 16 TERMINAL, 1.0 PITCH (6 X 6 X 1.45)	DOCUMENT NO: 98ASA10651D	REV: B
	CASE NUMBER: 1622-02	27 SEP 2006
	STANDARD: NON-JEDEC	

CASE 1622-02
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16-LEAD QFN

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	CASE NUMBER: 1622–02	27 SEP 2006
	STANDARD: NON–JEDEC	

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Accelerometer Glossary of Terms

Acceleration	Change in velocity per unit time.
Acceleration Vector	Vector describing the net acceleration acting upon the device.
Frequency Bandwidth	The accelerometer output frequency range.
g	A unit of acceleration equal to the average force of gravity occurring at the earth's surface. A g is approximately equal to 32.17 ft/s^2 or 9.807 m/s^2.
Nonlinearity	The maximum deviation of the accelerometer output from a point-to-point straight line fitted to a plot of acceleration vs. output voltage. This is determined as the percentage of the full-scale output (FSO) voltage at full-scale acceleration (40g).
Ratiometric	The variation of the accelerometer's output offset and sensitivity linearly proportional to the variation of the power supply voltage.
Sensitivity	The change in output voltage per unit g of acceleration applied. This is specified in mV/g.
Sensitive Axis	The most sensitive axis of the accelerometer. On the DIP package, acceleration is in the direction perpendicular to the top of the package (positive acceleration going into the device). On the SIP package, acceleration is in the direction perpendicular to the pins.
Transverse Acceleration	Any acceleration applied 90° to the axis of sensitivity.
Transverse Sensitivity Error	The percentage of a transverse acceleration that appears at the output. For example, if the transverse sensitivity is 1%, then a +40 g transverse acceleration will cause a 0.4 g signal to appear on the output. Transverse sensitivity can result from sensitivity of the g-cell to transverse forces.

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Section Three

Pressure Sensor Overview

Freescale's pressure sensors are silicon micromachined, electromechanical devices featuring device uniformity and consistency, high reliability, accuracy, and repeatability at competitively low costs. With more than 25 years in pressure sensor engineering, technology development, and manufacturing, these pressure sensors have been designed into automotive, industrial, healthcare, commercial, and consumer products worldwide.

Pressure sensors operate in pressures up to 150 psi (1,000 kPa). For maximum versatility, Freescale pressure sensors are single silicon, piezoresistive devices with three levels of device sophistication. The basic sensor device provides uncompensated sensing, the next level adds device compensation, and the third and most value added pressure sensors, are the integrated devices. Compensated sensors are available in temperature compensated and calibrated configurations; integrated devices are available in temperature compensated, calibrated, and signal conditioned (or amplified) configurations. Each sensor family is available in gauge, absolute, and differential pressure references in a variety of packaging and porting options.

Pressure Sensor Products

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Mini Selector Guide

PRESSURE SENSORS

Integrated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Full Scale Span (Typ) (Vdc)	Sensitivity (mV/kPa)	Accuracy 0°C–85°C (% of VFSS)	Pressure Type(1)		
									A	D	G
MPX4080	11.6	80	321	815	600	4.3	54	±3.0		•	
MPX4100	15.2	105	422	1070	788	4.6	54	±1.8	•		
MPX4101	14.8	102	410	1040	765	4.6	54	±1.8	•		
MPXH6101	14.8	102	410	1040	765	4.6	54	±1.8	•		
MPX4105	15.2	105	422	1070	788	4.6	51	±1.8	•		
MPX4115	16.7	115	462	1174	863	4.6	46	±1.5	•		
MPX6115	16.7	115	462	1174	863	4.6	46	±1.5	•		
MPX4200	29	200	803	2040	1500	4.6	26	±1.5	•		
MPX4250	36 36	250 250	1000 1000	2550 2550	1880 1880	4.7 4.7	20 19	±1.5 ±1.4	•	•	•
MPXH6250	36	250	1000	2550	1880	4.7	19	±1.5	•		
MPXV4006	0.87	6	24	61	45	4.6	766	±5.0		•	V
MPXV5004	0.57	4	16	40	29	3.9	1000	±2.5		•	V
MPX5010	1.45	10	40	102	75	4.5	450	±5.0		•	V
MPX5050	7.25	50	201	510	375	4.5	90	±2.5		•	•
MPX5100	14.5 16.7	100 115	401 462	1020 1174	750 863	4.5 4.5	45 45	±2.5 ±2.5	•	•	•
MPX5500	72.5	500	2000	5100	3750	4.5	9	±2.5		•	•
MPX5700	102	700	2810	7140	5250	4.5	6	±2.5	•	•	•
MPX5999	150	1000	4150	10546	7757	4.5	5	±2.5		•	
MPXH6300	44	300	1200	3060	2250	4.7	16	±1.8	•		
MPXH6400	60	400	1600	4000	3000	4.7	12	±1.5	•		
MPXV7007	±1.0	±7	±28	±70	±53	4.0	286	±5.0		•	•
MPXV7025	±3.5	±25	±100	±254	±190	4.5	90	±5.0		•	•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

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PRESSURE SENSORS (continued)

Compensated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Offset (mV)	Full Scale Span (Typ) (mV)	Sensitivity (mV/kPa)	Pressure Type[1]		
									A	D	G
MPX2010	1.45	10	40	102	75	±1.0	25	2.5		•	•
MPX2053	7	50	201	510	375	±1.0	40	0.8		•	V
MPX2102	14.5 14.5	100 100	400 400	1020	750 750	±2.0 ±1.0	40 40	0.4 0.4	•	•	V V
MPX2202	29 29	200 200	800 800	2040	1500 1500	±1.0 ±1.0	40 40	0.2 0.2	•	•	V
MPX2050	7	50	201	510	375	±1.0	40	0.8		•	•
MPX2100	14.5 14.5	100 100	400 400	1020	750 750	±2.0 ±1.0	40 40	0.4 0.4	•	•	
MPX2200	29 29	200 200	800 800	2040	1500 1500	±1.0 ±1.0	40 40	0.2 0.2	•	•	V

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Compensated Medical Grade Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Supply Voltage (Typ) (Vdc)	Offset Maximum (mV)	Sensitivity (mV/kPa)	Pressure Type[1]		
									A	D	G
MPXC2011	1.45	10	40	102	75	10.0	1.0	n/a			•
MPX2300	5.8	40	161	408	300	6.0	0.75	5.0			•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Tire Pressure Monitoring Sensors

Product	Maximum Pressure Rating (PSI)	Maximum Operating Pressure (kPa)	Maximum Pressure Rating (BAR)	Full Scale Span Output (Digital)	Best Pressure Accuracy (-20°C)	Best Pressure Accuracy (+25°C to +70°C)	Best Temperature Accuracy (+25°C)	Supply Voltage (V)	Sensitivity (kPa/count)	Pressure Type[1]		
										A	D	G
MPXY8020A	92.4	637.5	6.4	8-bit	±15 kPa	±7.5 kPa	±4°C	2.1 to 3.6	2.5	•		
MPXY8021A	92.4	637.5	6.4	8-bit	±20 kPa	±7.5 kPa	±4°C	2.1 to 3.6	2.5	•		
MPXY8040A	130.5	900	9.0	8-bit	±25 kPa	±20 kPa	±4°C	2.1 to 3.6	5.0	•		

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

Uncompensated Pressure Sensors

Product Family	Pressure Rating Maximum (PSI)	Pressure Rating Maximum (kPa)	Pressure Rating Maximum (in H_2O)	Pressure Rating Maximum (cm H_2O)	Pressure Rating Maximum (mm Hg)	Offset (Typ) (mV)	Full Scale Span (Typ) (mV)	Sensitivity (mV/kPa)	Pressure Type[1]		
									A	D	G
MPX10	1.45	10	40	102	75	20	35	3.5		•	•
MPX12	1.45	10	40	102	75	20	55	3.5		•	•
MPX53	7	50	200	510	375	20	60	1.2		•	•

NOTES:
1. A = Absolute, D = Differential, G = Gauge, V = Vacuum

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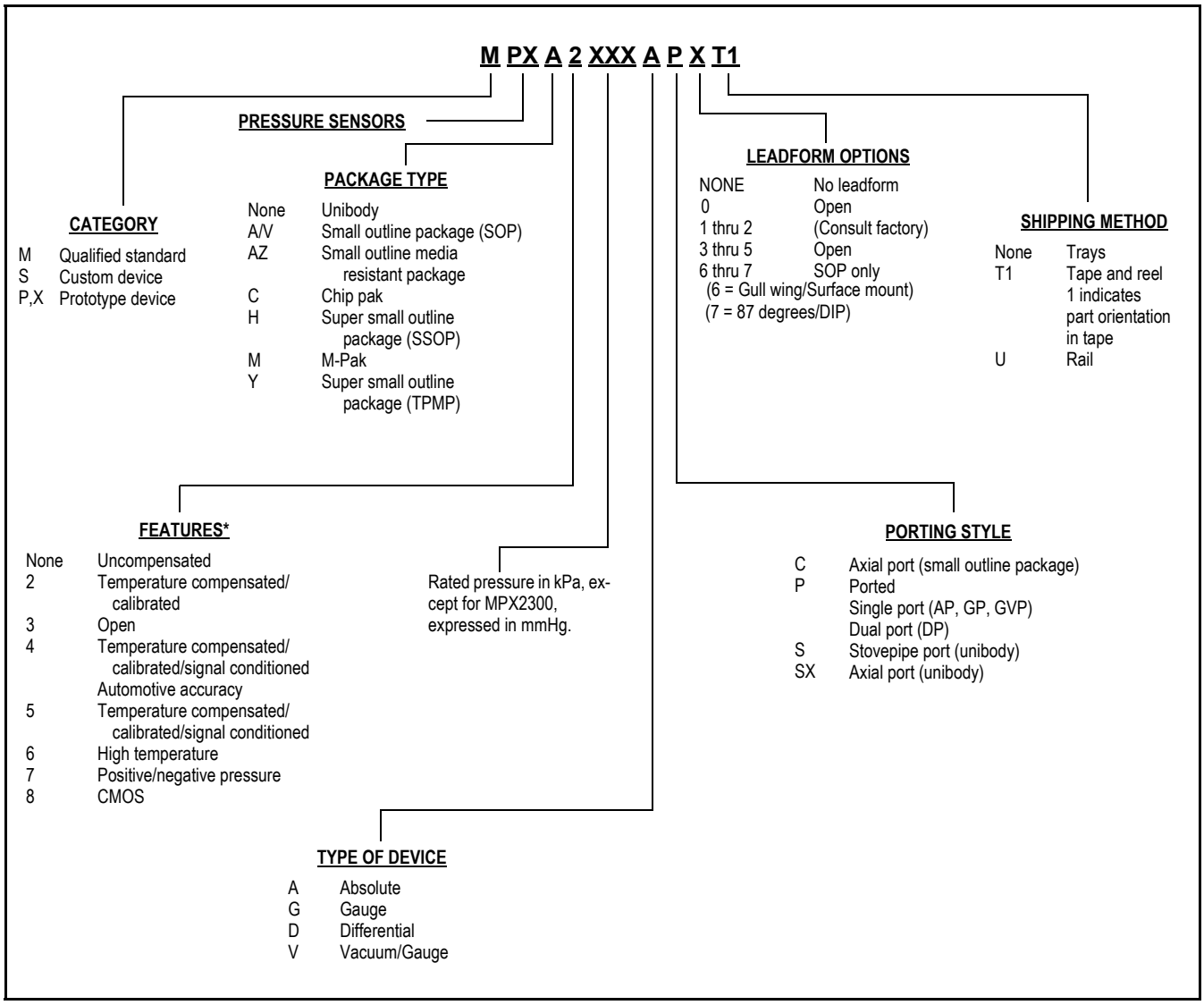
Device Numbering System for Pressure Sensors



Note: Actual product marking may be abbreviated due to space constraints but packaging label will reflect full part number.
*Only applies to qualified and prototype devices. This does not apply to custom devices.

Examples: MPX10DP 10 kPa uncompensated, differential device in minibody package, ported, no leadform, shipped in trays.
MPXA4115A6T1 115 kPa automotive temperature compensated and calibrated device with signal conditioning, SOP surface mount with gull wing leadform, shipped in tape and reel.

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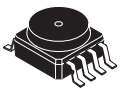
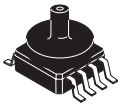
What Are the Pressure Packaging Options?

(Sizes not to scale)

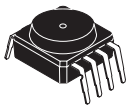
Preferred Pressure Sensor Packaging Options



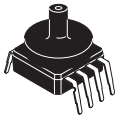
SOP
CASE 482
SUFFIX AG/G6



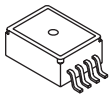
SOP AXIAL PORT
CASE 482A
SUFFIX AC6/GC6



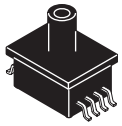
SOP
CASE 482B
SUFFIX G7U



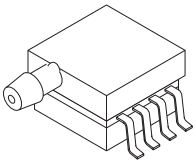
SOP AXIAL PORT
CASE 482C
SUFFIX GC7U



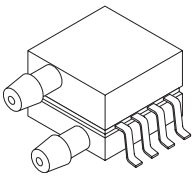
MPAK
CASE 1320
SUFFIX A/D



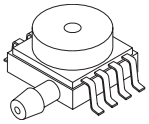
MPAK AXIAL PORT
CASE 1320A
SUFFIX AS/GS



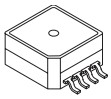
SOP SIDE PORT
CASE 1369
SUFFIX AP/GP



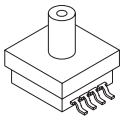
SOP DUAL PORT
CASE 1351
SUFFIX DP



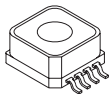
SOP VACUUM PORT
CASE 1368
SUFFIX GVP



SSOP
CASE 1317
SUFFIX A6

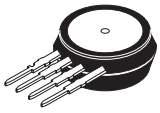


SSOP AXIAL PORT
CASE 1317A
SUFFIX AC6

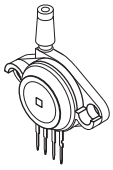


SSOP TIRE PRESSURE MONITOR
CASE 1352
SUFFIX A6

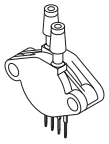
Pressure Sensor Packaging



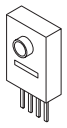
UNIBODY
BASIC ELEMENT
CASE 344
SUFFIX A/D



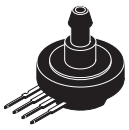
UNIBODY
SINGLE PORT
CASE 344B
SUFFIX AP/GP



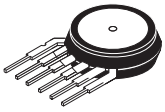
UNIBODY
DUAL PORT
CASE 344C
SUFFIX DP



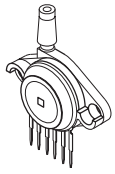
MEDICAL
CHIP PAK
CASE 423A
SUFFIX DT1



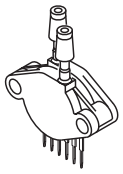
UNIBODY
STOVEPIPE PORT
CASE 344E
SUFFIX AS/GS



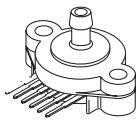
UNIBODY
BASIC ELEMENT
CASE 867
SUFFIX A/D



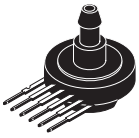
UNIBODY
SINGLE PORT
CASE 867B
SUFFIX AP/GP



UNIBODY
DUAL PORT
CASE 867C
SUFFIX DP



UNIBODY
AXIAL PORT
CASE 867F
SUFFIX ASX/GSX



UNIBODY
STOVEPIPE PORT
CASE 867E
SUFFIX AS/GS

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Orderable Part Numbers

PRESSURE SENSOR ORDERABLE PART NUMBERS

Uncompensated
MPX10D
MPX10DP
MPX10GP
MPX10GS
MPXV10GC6U
MPXV10GC7U
MPX12D
MPX12DP
MPX12GP
MPX53D
MPX53DP
MPX53GP
MPXM53GS
MPXM53GST1
MPXV53GC6U
MPXV53GC7U

Compensated
MPX2300DT1
MPX2301DT1
MPX2010D
MPX2010GP
MPX2010DP
MPX2010GS
MPX2010GSX
MPXM2010D
MPXM2010DT1
MPXM2010GS
MPXM2010GST1
MPXC2011DT1
MPXC2012DT1
MPXV2010GP
MPXV2010DP
MPX2053D
MPX2053GP
MPX2053DP
MPX2053GVP
MPXM2053D
MPXM2053DT1
MPXM2053GS
MPXM2053GST1
MPXV2053GP
MPXV2053DP
MPX2050D
MPX2050GP
MPX2050DP
MPX2050GSX

MPX2102D
MPX2102GP
MPX2102DP
MPX2102GVP
MPXM2102D
MPXM2102DT1
MPXM2102GS
MPXM2102GST1
MPXV2102GP
MPXV2102DP
MPX2102A
MPX2102AP
MPX2102ASX
MPXM2102A
MPXM2102AT1
MPXM2102AS
MPXM2102AST1
MPX2100D
MPX2100GP
MPX2100DP
MPX2100GVP
MPX2100A
MPX2100AP
MPX2100ASX
MPX2202D
MPX2202GP
MPX2202DP
MPXM2202D
MPXM2202DT1
MPXM2202GS
MPXM2202GST1
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MPXV2202DP
MPXV2202GC6T1
MPXV2202GC6U
MPX2202A
MPX2202AP
MPXM2202A
MPXM2202AT1
MPXM2202AS
MPXM2202AST1
MPX2200D
MPX2200GP
MPX2200DP
MPX2200GSX
MPX2200A
MPX2200AP

Integrated
MPXV5004GC6T1
MPXV5004GC6U
MPXV5004GC7U
MPXV5004G6U
MPXV5004G7U
MPXV5004GP
MPXV5004GP1
MPXV5004DP
MPXV5004GVP
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MPXV4006GC6U
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MPXV4006G7U
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MPX5010GSX
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MPXV5010GC7U
MPXV5010G6U
MPXV5010G7U
MPXV5010GP
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MPXV7025DP
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MPX5700D
MPX5700DP
MPX5700GP
MPX5700GP1
MPX5700GS
MPXY8020A6U
MPXY8020A6T1
MPXY8021A6U
MPXY8021A6T1
MPXY8040A6U
MPXY8040A6T1

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General Product Information

Performance, competitive price and application versatility are just a few of the Freescale pressure sensor advantages.

PRESSURE SENSOR APPLICATIONS VERSATILITY

For Freescale's pressure sensors, new applications emerge every day as engineers and designers realize that they can convert their expensive mechanical pressure sensors to Freescale's lower-cost, semiconductor-based devices. Applications include automotive and aviation, industrial, healthcare and medical products and systems.

PERFORMANCE

The performance of Freescale pressure sensors is based on its patented strain gauge design. Unlike the more conventional pressure sensors which utilize four closely matched resistors in a distributed Wheatstone bridge configuration, the device uses only a single piezoresistive element ion implanted on an etched silicon diaphragm to sense the stress induced on the diaphragm by an external pressure. The extremely linear output is an analog voltage that is proportional to pressure input and ratiometric with supply voltage. High sensitivity and excellent long-term repeatability make these sensors suitable for the most demanding applications.

ACCURACY

Computer controlled laser trimming of on-chip calibration and compensation resistors provide the most accurate pressure measurement over a wide temperature range. Temperature effect on span is typically ±0.5% of full scale over a temperature range from 0 to 85°C, while the effect on offset voltage over a similar temperature range is a maximum of only ±1 mV.

UNLIMITED VERSATILITY

Choice of Specifications

Freescale's pressure sensors are available in pressure ranges to fit a wide variety of automotive, healthcare, consumer and industrial applications.

Choice of Measurement

Devices are available for differential, absolute, or gauge pressure measurements.

Choice of Chip Complexity

Freescale's pressure sensors are available as the basic sensing element, with temperature compensation and calibration, or with full signal conditioning circuitry included on the chip. Uncompensated devices permit external compensation to any degree desired.

Choice of Packaging

Available as a basic element for custom mounting, or in conjunction with Freescale's designed ports, printed circuit board mounting is easy. Our Small Outline and Super Small Outline packaging options provide surface mount, low profile, and top piston fit package selections. Alternate packaging material, which has been designed to meet biocompatibility requirements, is also available.

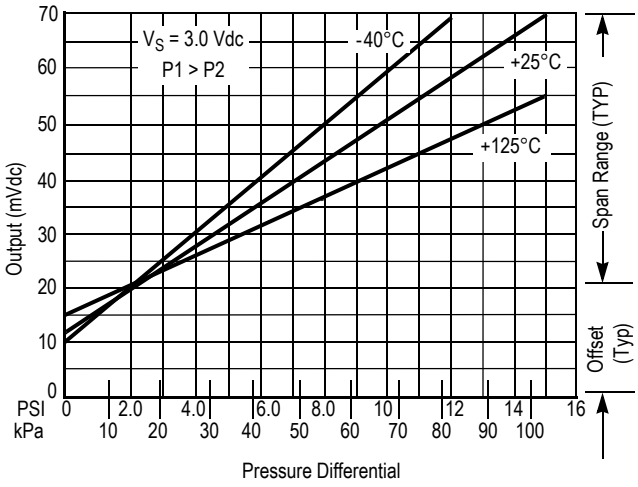
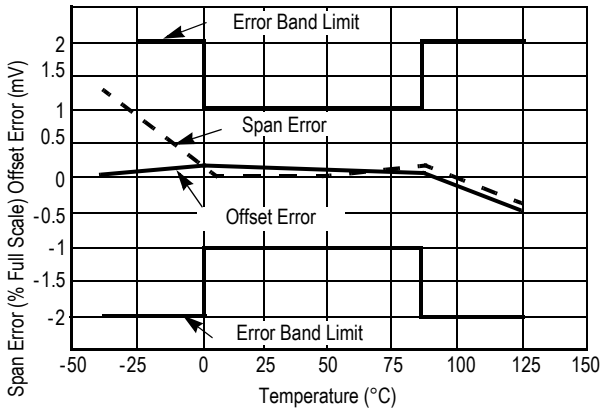


Figure 1. Typical Output versus Pressure Differential



Curves of span and offset errors indicate the accuracy resulting from on-chip compensation and laser trimming.

Figure 2. Temperature Error Band Limit and Typical Span and Offset Errors

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Freescale Pressure Sensors

INTRODUCTION

Freescale pressure sensors combine advanced piezoresistive sensor architecture with integrated circuit technology to offer a wide range of pressure sensing devices for automotive, medical, consumer and industrial applications. Selection versatility includes choice of:

Pressure Ranges in PSI

0 to 1.45, 0 to 6, 0 to 7.3, 0 to 14.5, 0 to 29, 0 to 75, 0 to 100, 0 to 150 psi.

Sensing Options

Uncompensated, Temperature Compensated/Calibrated, and Signal Conditioned (with on-chip amplifiers)

Application Measurements

Absolute, Differential, Gauge

Package Options

- Basic Element, Ported Elements for specific measurements
- Surface Mount and Through Hole, Low Profile packages

THE BASIC STRUCTURE

Freescale's pressure sensor is designed utilizing a monolithic silicon piezoresistor, which generates a changing output voltage with variations in applied pressure. The resistive element, which constitutes a strain gauge, is ion implanted on a thin silicon diaphragm.

Applying pressure to the diaphragm results in a resistance change in the strain gauge, which in turn causes a change in the output voltage in direct proportion to the applied pressure. The strain gauge is an integral part of the silicon diaphragm, hence there are no temperature effects due to differences in thermal expansion of the strain gauge and the diaphragm. The output parameters of the strain gauge itself are temperature dependent, however, requiring that the device be compensated if used over an extensive temperature range. Simple resistor networks can be used for narrow temperature ranges, i.e., 0°C to 85°C. For temperature ranges from -40°C to +125°C, more extensive compensation networks are necessary.

FREESCALE'S LOCALIZED SENSING ELEMENTS

Excitation current is passed longitudinally through the resistor (taps 1 and 3), and the pressure that stresses the diaphragm is applied at a right angle to the current flow. The stress establishes a transverse electric field in the resistor that is sensed as voltage at taps 2 and 4, which are located at the midpoint of the resistor (Figure 3b).

The transducer (Figure 3a) uses a single element eliminating the need to closely match the four stress and temperature sensitive resistors that form a distributed Wheatstone bridge design. At the same time, it greatly simplifies the additional circuitry necessary to accomplish calibration and temperature compensation. The offset does not depend on matched resistors but instead on how well the transverse voltage taps are aligned. This alignment is accomplished in a single photolithographic step, making it easy to control, and is only a positive voltage, simplifying schemes to zero the offset.

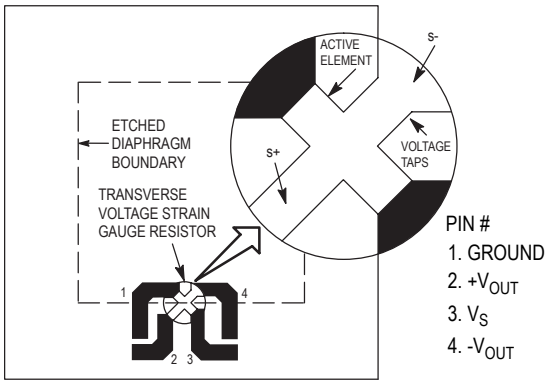

Figure 3a. X-ducer™ Sensor Element — Top View

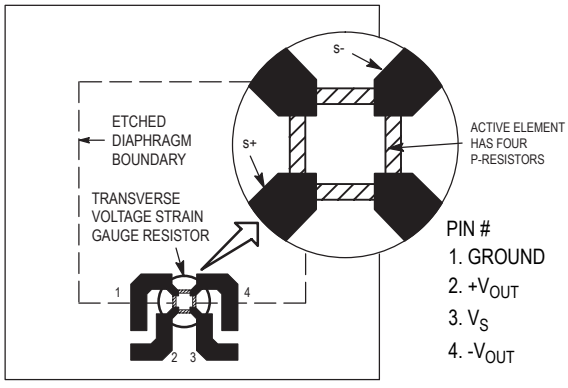

Figure 3b. Localized Sensing Element

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

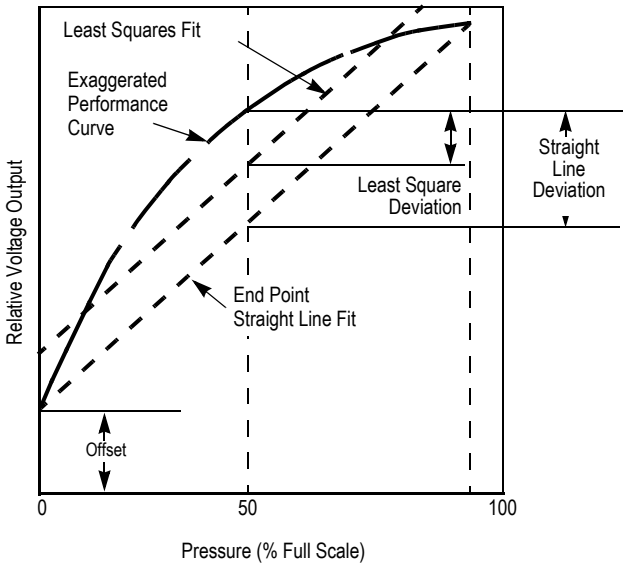


Figure 4. Linearity Specification Comparison

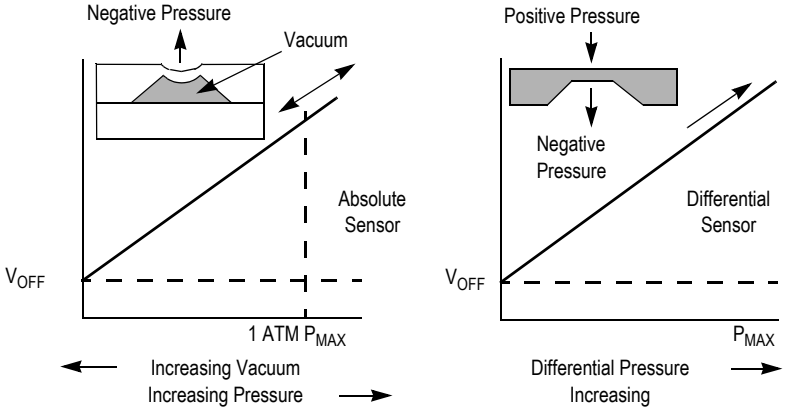
OPERATION

Freescale's pressure sensors provide three types of pressure measurement: Absolute Pressure, Differential Pressure and Gauge Pressure.

Absolute Pressure Sensors measure an external pressure relative to a zero-pressure reference (vacuum) sealed inside the reference chamber of the die during manufacture. This corresponds to a deflection of the diaphragm equal to approximately 14.5 psi (one atmosphere), generating a quiescent full-scale output for the MPXH6101A6T1 (14.5 psi) sensor, and a half-scale output for the MPX4200A (29 psi) device. Measurement of external pressure is accomplished by applying a relative negative pressure to the "Pressure" side of the sensor.

Differential Pressure Sensors measure the difference between pressures applied simultaneously to opposite sides of the diaphragm. A positive pressure applied to the "Pressure" side generates the same (positive) output as an equal negative pressure applied to the "Vacuum" side.

Gauge Pressure readings are a special case of differential measurements in which the pressure applied to the "Pressure" side is measured against the ambient atmospheric pressure applied to the "Vacuum" side through the vent hole in the chip of the differential pressure sensor elements.



Freescale sensing elements can withstand pressure inputs as high as four times their rated capacity, although accuracy at pressures exceeding the rated pressure will be reduced. When excessive pressure is reduced, the previous linearity is immediately restored.

Figure 5. Pressure Measurements

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TYPICAL ELECTRICAL CHARACTERISTIC CURVES

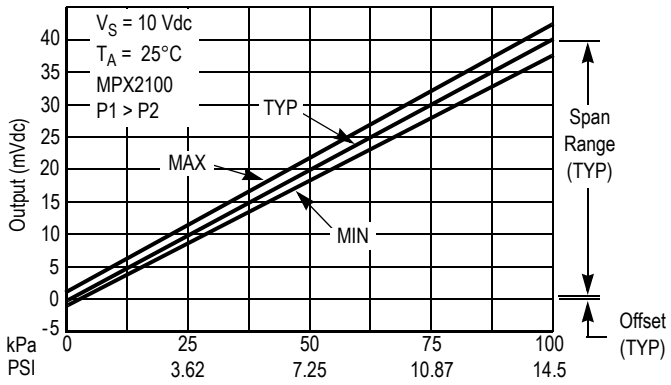

Figure 6. Output versus Pressure Differential

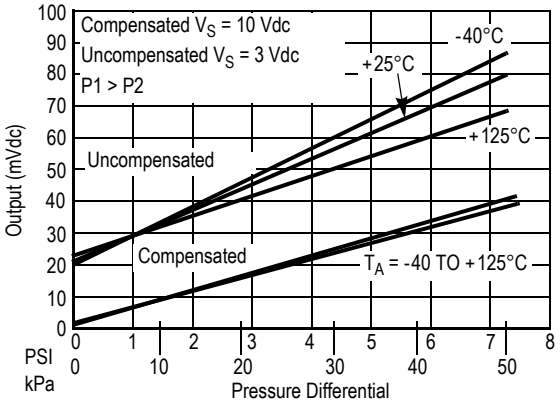

Figure 7. Typical-Output Voltage versus Pressure and Temperature for Compensated and Uncompensated Devices

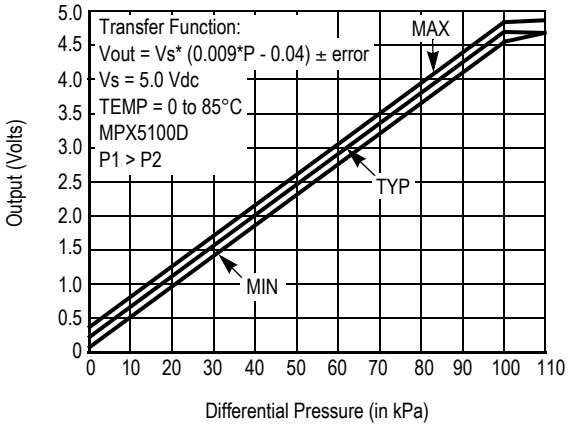

Figure 8. Signal Conditioned MPX5100

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UNIBODY CROSS-SECTIONAL DRAWINGS

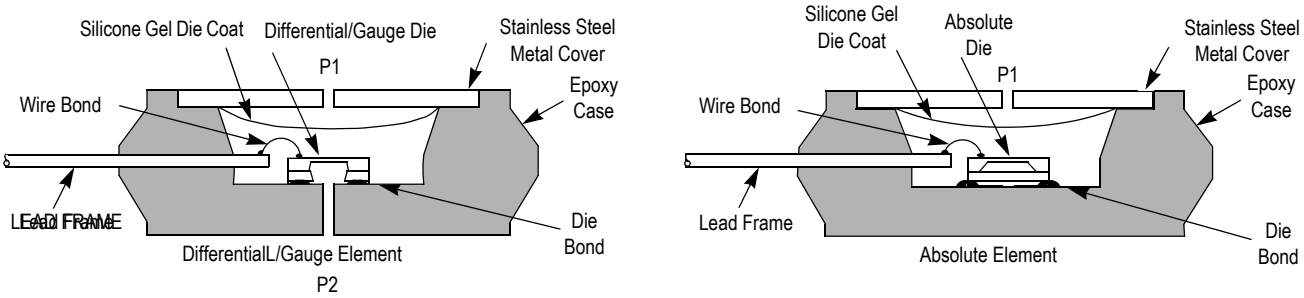

Figure 9. Cross-Sectional Diagrams (not to scale)

Figure 9 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

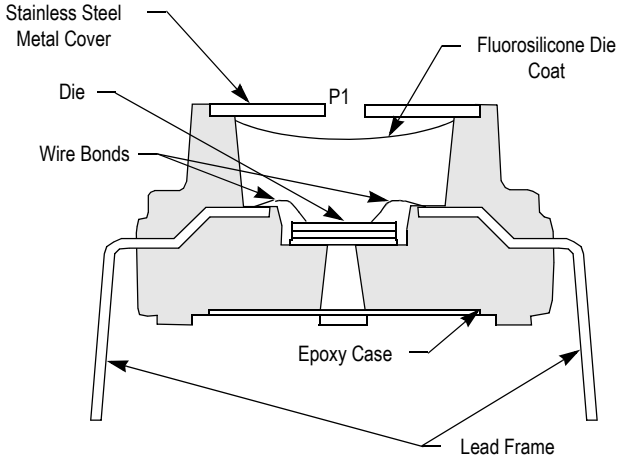

Figure 10. Cross-Sectional Diagram (not to scale)

Figure 10 illustrates the differential/gauge die in the basic chip carrier (Case 473). A silicone gel isolates the die surface and wirebonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

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Integration

ON-CHIP SIGNAL CONDITIONING

To make the designer's job even easier, Freescale's integrated devices carry sensor technology one step further. In addition to the on-chip temperature compensation and calibration offered currently on the 2000 series, amplifier signal conditioning has been integrated *on-chip* in the 4000, 5000 and 6000 series to allow interface directly to any microcomputer with an on-board A/D converter.

The signal conditioning is accomplished by means of a four-stage amplification network, incorporating linear bipolar processing, thin-film metallization techniques, and interactive laser trimming to provide the state-of-the-art in sensor technology.

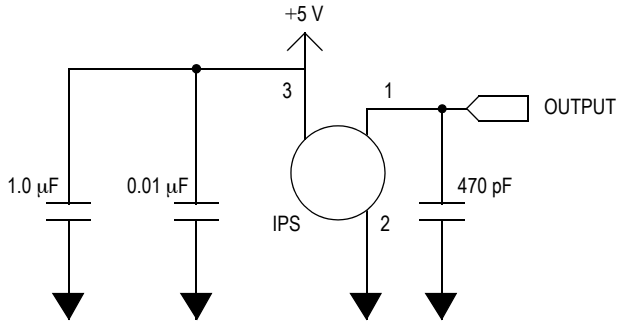

Figure 11. Recommended Power Supply Decoupling. For Output Filtering Recommendations (Refer to Application Note AN1646)

DESIGN CONSIDERATIONS FOR DIFFERENT LEVELS OF SENSOR INTEGRATION

	DESIGN ADVANTAGES	DESIGN CONSIDERATIONS
Uncompensated Sensors	High Sensitivity	Device-to-Device Variation in Offset and Span
	Lowest Device Cost	Temperature Compensation Circuitry Required
	Low-Level Output Allows Flexibility of Signal Conditioning	Requires Signal Conditioning/ Amplification of Output Signal
		Relatively Low Input Impedance (400 Ω Typical)
Temperature Compensated & Calibrated (2000 Series)	Reduced Device-to-Device Variations in Offset and Span	Lower Sensitivity Due to Span Compensation (Compared to Uncompensated)
	Reduced Temperature Drift in Offset and Span	Priced Higher than Uncompensated Device
	Reasonable Input Impedance (2K Ω Typical)	Requires Signal Conditioning/ Amplification of Output Signal
	Low Level Output Allows Flexibility in Signal Conditioning	
Integrated Pressure Sensors (4000, 5000 and 6000 Series)	No Amplification Needed Direct Interface to MPU	Priced Higher than Compensated/ Uncompensated Device
	Signal Conditioning, Calibration of Span and Offset, Temperature Compensation Included On-Chip	

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Sensor Applications

AUTOMOTIVE/AVIATION APPLICATIONS

- Fuel Level Indicator
- Altimeters
- Air Speed Indicator
- Ejection Seat Control
- Turbo Boost Control
- Manifold Vacuum Control
- Fuel Flow Metering
- Oil Filter Flow Indicator
- Oil Pressure Sensor
- Air Flow Measurement
- Anti-Start
- Breathalizer Systems
- Smart Suspension Systems
- Variometer-Hang glider & Sailplanes
- Automotive Speed Control

HEALTHCARE APPLICATIONS

- Blood Pressure
- Esophagus Pressure
- Heart Monitor
- Interoccular Pressure
- Saline Pumps
- Kidney Dialysis
- Blood Gas Analysis
- Blood Serum Analysis
- Seating Pressure (Paraplegic)
- Respiratory Control
- Intravenous Infusion Pump Control
- Hospital Beds
- Drug Delivery
- IUPC
- Patient Monitors

INDUSTRIAL/COMMERCIAL APPLICATIONS

- Electronic Fire Fighting Control
- Flow Control
- Barometer
- HVAC Systems
- Tire Pressure Monitoring
- Water Filtered Systems (Flow Rate Indicator)
- Air Filtered Systems (Flow Rate Indicator)
- Tactile Sensing for Robotic Systems
- Boiler Pressure Indicators
- End of Tape Readers
- Disc Drive Control/Protection Systems
- Ocean Wave Measurement
- Diving Regulators
- Oil Well Logging
- Building Automation (Balancing, Load Control, Windows)
- Fluid Dispensers
- Explosion Sensing - Shock Wave Monitors
- Load Cells
- Autoclave Release Control
- Soil Compaction Monitor - Construction
- Water Depth Finders (Industrial, Sport Fishing/Diving)
- Pneumatic Controls - Robotics
- Pinch Roller Pressure - Paper Feed
- Blower Failure Safety Switch - Computer
- Vacuum Cleaner Control
- Electronic Drum
- Pressure Controls Systems - Building, Domes
- Engine Dynamometer
- Water Level Monitoring
- Altimeters

Freescale has tested media tolerant sensor devices in selected solutions or environments and test results are based on particular conditions and procedures selected by Freescale. Customers are advised that the results may vary for actual services conditions. Customers are cautioned that they are responsible to determine the media compatibility of sensor devices in their applications and the foreseeable use and misuses of their applications.

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Pressure Sensor FAQ's

We have discovered that many of our customers have similar questions about certain aspects of our pressure sensor technology and operation. Here are the most frequently asked questions and answers that have been explained in relatively non-technical terms.

Q. How do I calculate total pressure error for my applications?

A. You can calculate total error in two fashions, worst case error and most probable error. Worst case error is taking all the individual errors and adding them up, while most probable error sums the squares of the individual errors and then take the square root of the total. In summary, Error (Worst Case) = E1 + E2 + E3 + ... + En, while Error (Most Probable) = SQRT[(E1)2 + (E2)2 + (E3)2 + ... (En)2]; Please note that not all errors may apply in your individual application.

Q. What is the media tolerance of our pressure sensors?

A. Most Freescale pressure sensors are specifically designed for dry air applications. However, Freescale now offers an MPXAZ series specifically designed for improved media resistance. This series incorporates a durable barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. NOTE: Applications exposing the sensor to media other than what has been specified could potentially limit the lifetime of the sensor. Please consult the Freescale factory for more information regarding media compatibility in your specific application.

Q. Can I pull a vacuum on P1?

A. Our pressure sensors are based on a silicon diaphragm and can tolerate a pressure that alternates from positive to negative. It is important that the applied pressure not rise above the overpressure specification in the positive or negative range.

Q. What will happen if I run the pressure sensor beyond the rated operating pressure?

A. For bare elements (uncompensated and compensated series devices), when you take the sensor higher than the rated pressure, the part will still provide an output increasing linearly with pressure. When you go below the minimum rated pressure, the output of the sensor will eventually go negative. Freescale, however, does not guarantee electrical specifications beyond the rated operating pressure range specified in the data sheet of each device. The integrated series devices will not function at all beyond the rated pressure of the part. These series of parts will saturate at near 4.8 V and 0.2 V and thus no further change in output will occur.

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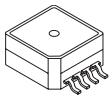
High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

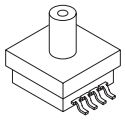
MP3H6115A SERIES

INTEGRATED PRESSURE SENSOR 15 TO 115 KPA (2.2 TO 16.7 PSI) 0.12 TO 2.8 VOLTS OUTPUT

SUPER SMALL OUTLINE PACKAGE



MP3H6115A6U/T1
CASE 1317-04



MP3H6115AC6U/T1
CASE 1317A-03

Freescale's MP3H6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MP3H6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Super Small Outline Package
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Application Examples

- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Device Barometers

PIN NUMBER			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

NOTE: Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the chamfered corner of the package.

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Marking
Basic Element	Absolute, Element Only	1317	MP3H6115A6U	Rails	MP3H6115A
	Absolute, Element Only	1317	MP3H6115A6T1	Tape and Reel	MP3H6115A
Ported Element	Absolute, Axial Port	1317A	MP3H6115AC6U	Rails	MP3H6115A
	Absolute, Axial Port	1317A	MP3H6115AC6T1	Tape and Reel	MP3H6115A

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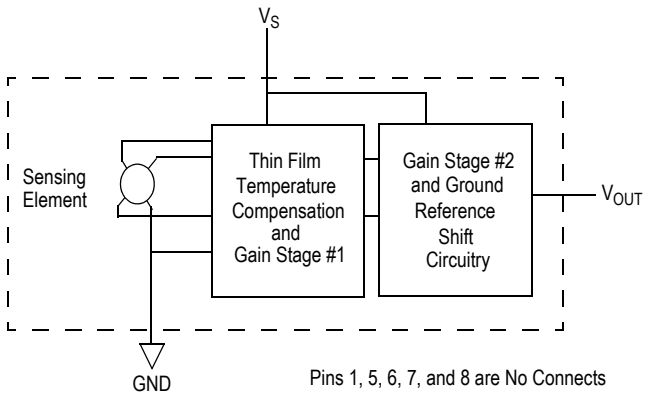

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics

(V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage(1)		V_S	2.7	3.0	3.3	Vdc
Supply Current		I_o	—	4.0	8.0	mAdc
Minimum Pressure Offset(2) @ V_S = 3.0 Volts	(0 to 85°C)	V_{off}	0.079	0.12	0.161	Vdc
Full Scale Output(3) @ V_S = 3.0 Volts	(0 to 85°C)	V_{FSO}	2.780	2.82	2.861	Vdc
Full Scale Span(4) @ V_S = 3.0 Volts	(0 to 85°C)	V_{FSS}	2.660	2.70	2.741	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	27	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

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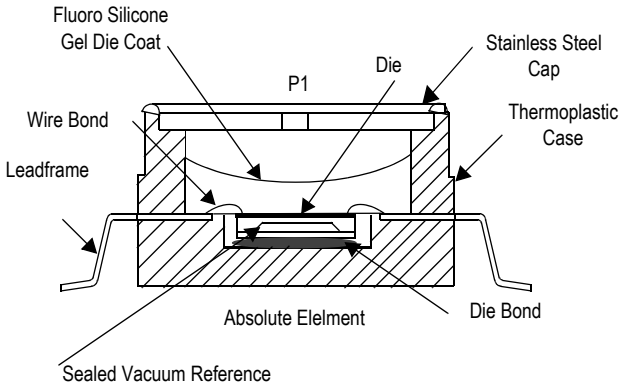

Figure 2. Cross Sectional Diagram SSOP (not to scale)

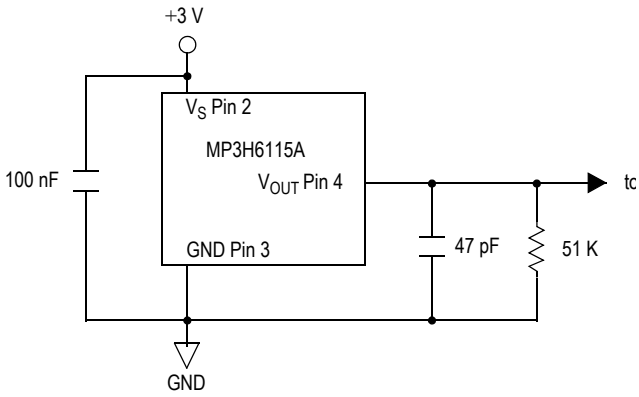

Figure 3. Typical Application Circuit (Output Source Current Operation)

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317).

Figure 3 shows a typical application circuit (output source current operation).

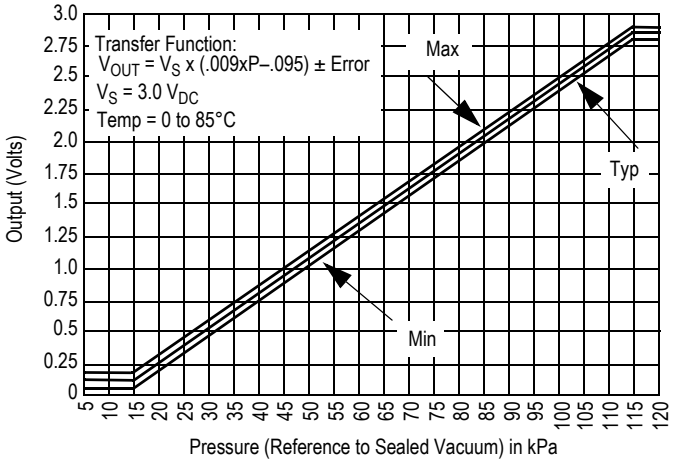

Figure 4. Output versus Pressure Differential

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MP3H6115A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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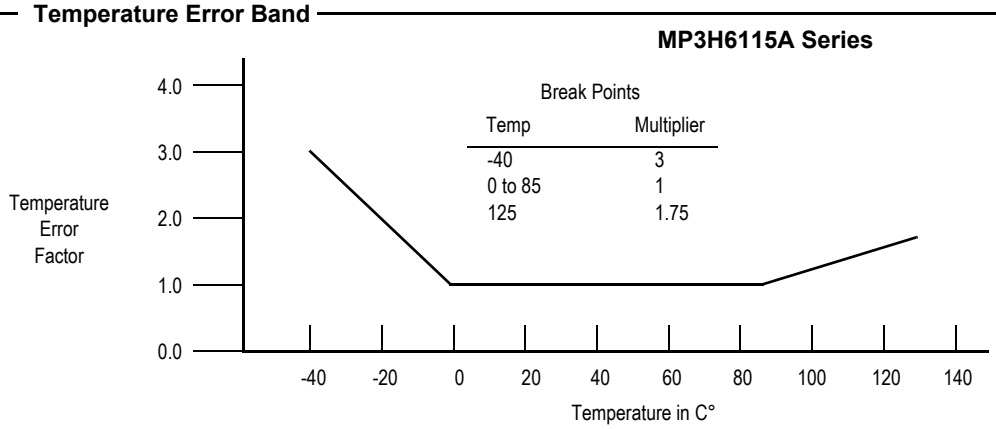
Transfer Function (MP3H6115A)

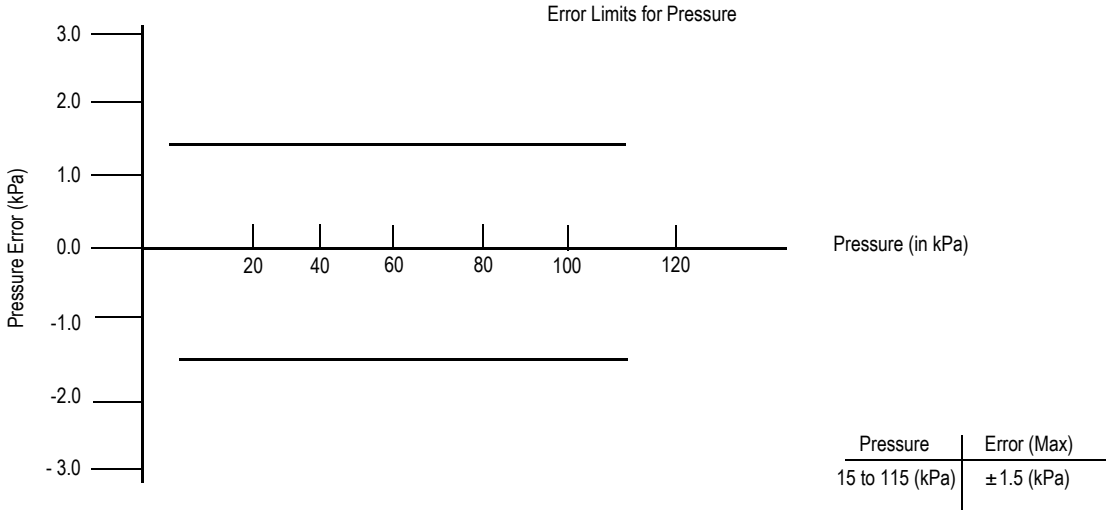
Normal Transfer Value: $V_{OUT} = V_S \times (0.009 \times P - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x 0.009 x V_S)
$V_S = 3.0 \pm 0.3\ V_{DC}$

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C

Pressure Error Band



Pressure	Error (Max)
15 to 115 (kPa)	±1.5 (kPa)

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MINIMUM RECOMMENDED FOOTPRINT FOR SUPER SMALL OUTLINE PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

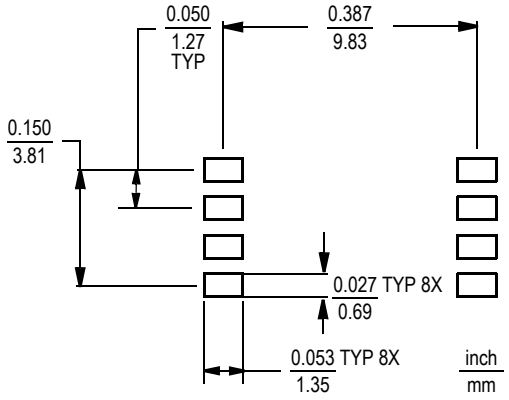

Figure 5. SSOP Footprint (Case 1317 and 1317A)

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200 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

MPMZ2202 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN (TYPICAL)

The MPMZ2202 device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

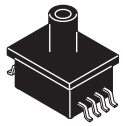
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape and Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options
- Increased media compatibility fluorocarbon gel

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

MPAK PACKAGE



MPMZ2202GS
CASE 1320A-02

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported	Gauge, Axial Port	1320A	MPMZ2202GS	Rails	MPMZ2202GS
	Gauge, Axial Port	1320A	MPMZ2202GST1	Tape & Reel	MPMZ2202GS

PIN NUMBER			
1	GND	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

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Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

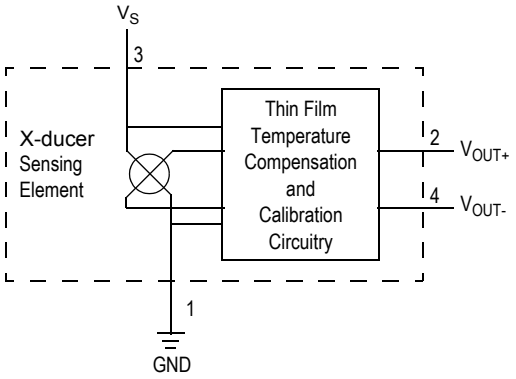

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	200	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	38.5	40	41.5	mV
Offset[4] MPMZ2202D/G Series	V_{OFF}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.2	—	mV/kPa
Linearity[5] MPMZ2202D/G Series	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 100 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2500	Ω
Output Impedance	Z_{OUT}	1400	—	3000	Ω
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

Operating characteristics, internal reliability and qualification tests are based on use of dry clean air as the pressure media. Media other than dry clean air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

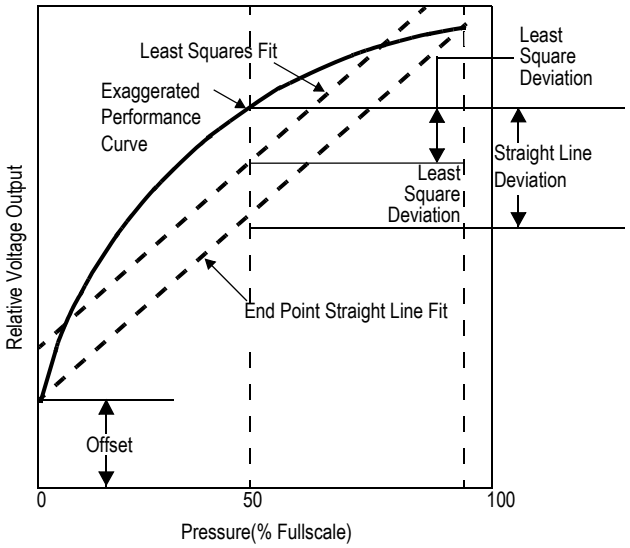

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPMZ2202 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

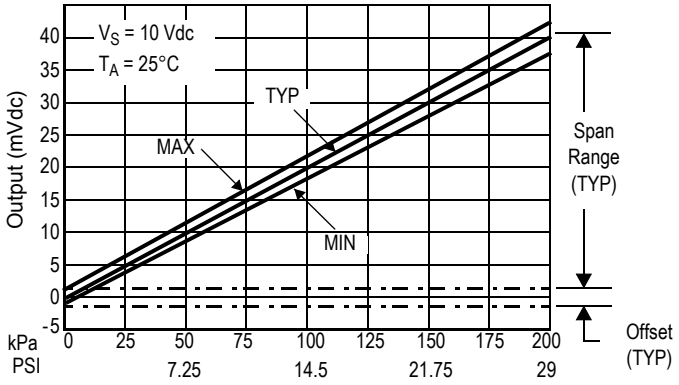

Figure 3. Output versus Pressure Differential

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10 kPa Uncompensated Silicon Pressure Sensors

MPVZ12 SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 10 kPA (0–1.45 psi)
55 mV FULL SCALE SPAN (TYPICAL)

The MPVZ12 series is a silicon piezoresistive pressure sensor providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design.

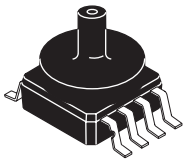
Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options
- Durable Epoxy Package
- Increased media compatibility fluorocarbon gel

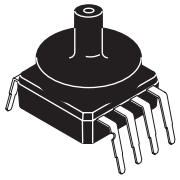
Application Examples

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

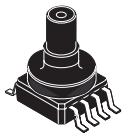
SMALL OUTLINE PACKAGE



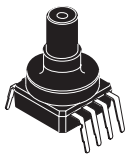
MPVZ12GC6U
CASE 482A-01



MPVZ12GC7U
CASE 482C-03



MPVZ12GW6U
CASE 1735-01



MPVZ12GW7U
CASE 1560-02

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**Order Number**	**Device Marking**
Ported	Gauge	482A	MPVZ12GC6U	MPVZ12G
		482C	MPVZ12GC7U	MPVZ12G
		1735	MPVZ12GW6U	MZ12GW
		1560	MPVZ12GW7U	MZ12GW

1. MPVZ12 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

PIN NUMBERS			
1	GND	5	N/C
2	$+V_{out}$	6	N/C
3	V_s	7	N/C
4	$-V_{out}$	8	N/C

NOTE: Pin 1 is noted by the notch in the lead.

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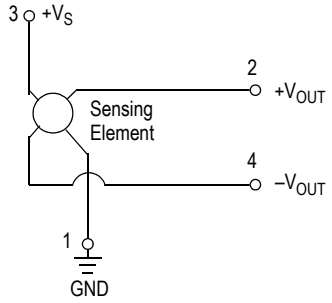

Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Burst Pressure (P1 > P2)	P_{BURST}	100	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	55	70	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	ΔV/ΔP	—	5.5	—	mV/kPa
Linearity(5)	—	–0.5	—	5.0	$\%V_{FSS}$
Pressure Hysteresis6 (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	μV/°C
Temperature Coefficient of Resistance(5)	TCR	0.28	—	0.34	$\%Z_{in}$/°C
Input Impedance	Z_{in}	400	—	550	W
Output Impedance	Z_{out}	750	—	1250	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time(7)	—	—	20	—	ms
Offset Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{IN} deviation with minimum rated pressure applied, over the temperature range of -40°C to ±125°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
8. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPVZ12 series over temperature.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2010D series sensor.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

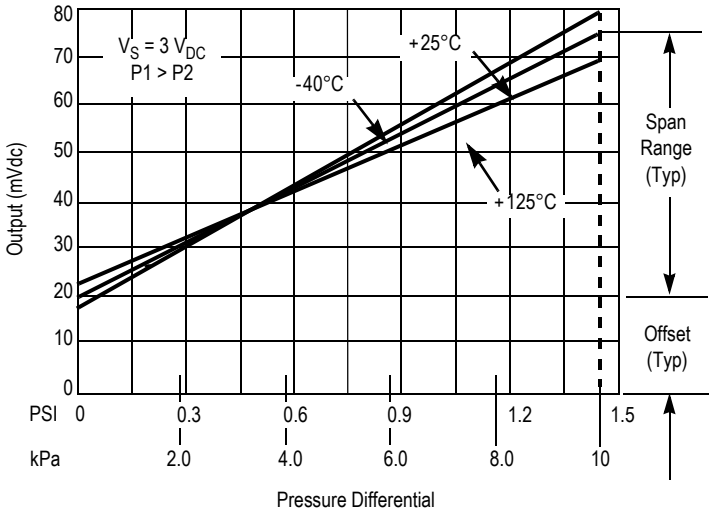

Figure 2. Output versus Pressure Differential

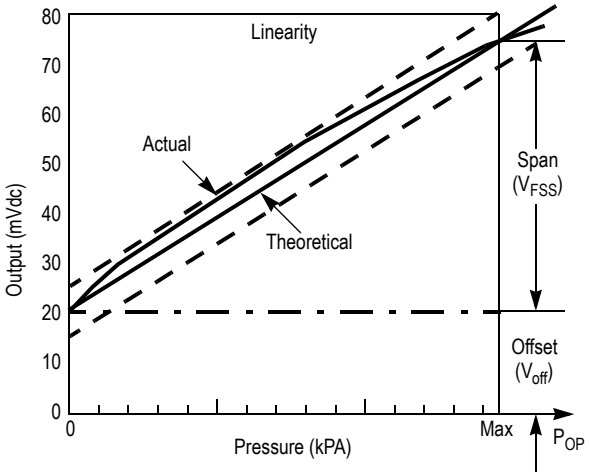

Figure 3. Linearity Specification Comparison

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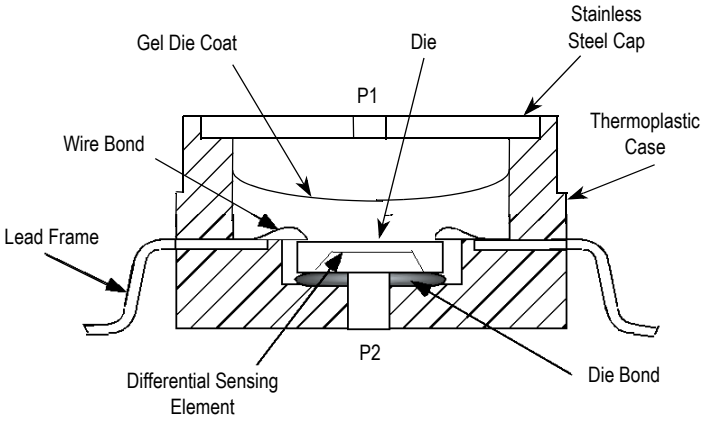

Figure 4. Cross-Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (applicable to cases 482, 1560 and 1735). A gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

Operating characteristics, internal reliability and qualification tests are based on use of dry clean air as the pressure media. Media other than dry clean air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing gel which isolates the die from the environment. The Freescale MPVZ12 series is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ12GC6U	482A	Top with Port Attached
MPVZ12GC7U	482C	Top with Port Attached
MPVZ12GW6U	1735	Top with Port Attached
MPVZ12GW7U	1560	Top with Port Attached

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200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPVZ2202 SERIES

**0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)**

The MPVZ2202 device series is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching and respiratory equipment.

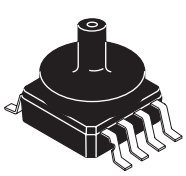
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Increased media compatibility fluorocarbon gel

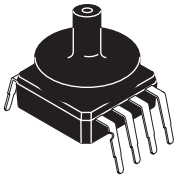
Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Respiratory Equipment

**SMALL OUTLINE PACKAGE
SURFACE MOUNT**



**MPVZ2202GC6T1
CASE 482A-01**



**MPVZ2202GC7U
CASE 482C-03**

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPVZ2202 SERIES)					
Ported Elements	Gauge, Vertical Port, Surface Mount	482A	MPVZ2202GC6T1	Tape and Reel	MPVZ2202G
	Gauge, Vertical Port, Through Hole	482C	MPVZ2202GC7U	Tube	MPVZ2202G

SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	V_S	8	N/C

1. Pin 1 is noted by the notch in the lead.

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Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

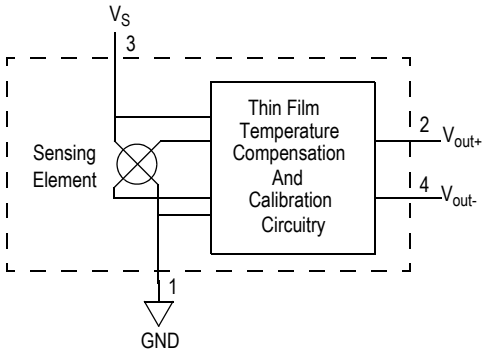

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	800	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics

(V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	200	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	38.5	40	41.5	mV
Offset[4]	V_{off}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.2	—	mV/kPa
Linearity[5] MPVZ2202D Serie	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 200 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

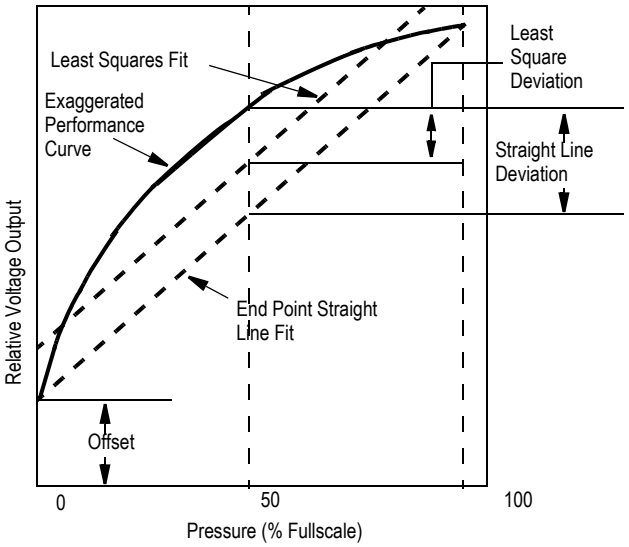

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPVZ2202 series at 25×C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

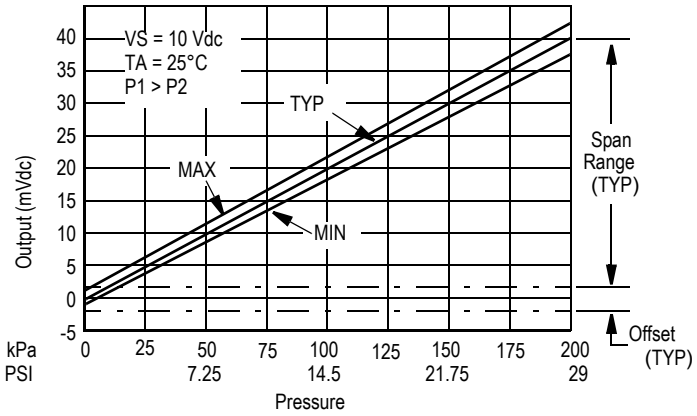

Figure 3. Output versus Pressure Differential

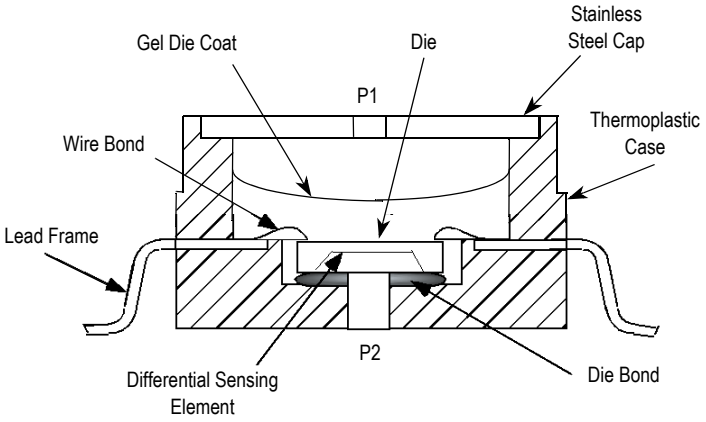

Figure 4. Cross-Sectional Diagram (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

Operating characteristics, internal reliability and qualification tests are based on use of dry clean air as the pressure media. Media other than dry clean air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ2202GC6T1	482A	Top with Port Attached
MPVZ2202GC7U	482C	Top with Port Attached

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPVZ4006G

INTEGRATED PRESSURE SENSOR
0 to 6 kPa (0 to 612 mm H_2O)
0.3 to 4.6 V OUTPUT

The MPVZ4006G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for the appliance, consumer, healthcare and industrial market. The analog output can be read directly into the A/D input of Freescale microcontrollers. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure. The axial port has been modified to accommodate industrial grade tubing.

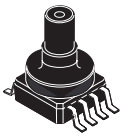
Features

- 2.5% Maximum Error over +10°C to +60°C with Auto Zero
- 5% Maximum Error over +10°C to +60°C without Auto Zero
- Durable Thermoplastic (PPS) Package
- Available in Surface Mount (SMT) or Through-Hole (DIP) Configurations

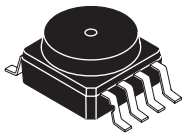
Application Examples

- Washing Machine Water Level Measurement (Reference AN1950)
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Appliance Liquid Level and Pressure Measurement
- Respiratory Equipment

SMALL OUTLINE PACKAGE SURFACE MOUNT

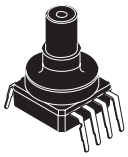


MPVZ4006GW6U
CASE 1735-01

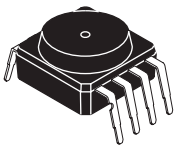


MPVZ4006G6U/T1
CASE 482-01

SMALL OUTLINE PACKAGE THROUGH-HOLE



MPVZ4006GW7U
CASE 1560-02



MPVZ4006G7U
CASE 482B-03

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Marking**
Ported Element	Surface Mount	1735-01	MPVZ4006GW6U	Rails	MZ4006GW
	Through-Hole	1560-02	MPVZ4006GW7U	Rails	MZ4006GW
	Surface Mount	482-01	MPVZ4006G6U	Rails	MZ4006G
	Surface Mount	482-01	MPVZ4006G6T1	Tape & Reel	MZ4006G
	Through-Hole	482B-03	MPVZ4006G7U	Rails	MZ4006G

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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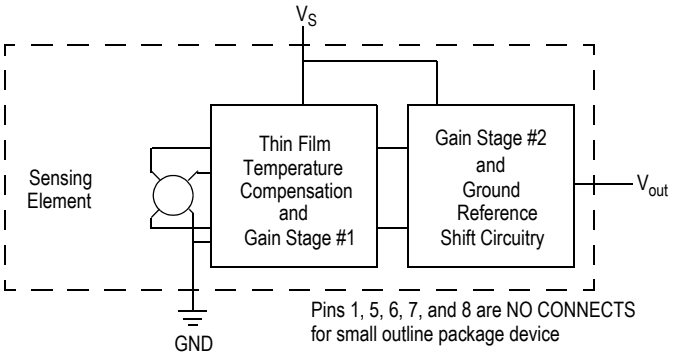

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	24	kPa
Storage Temperature	T_{stg}	-30° to +100°	°C
Operating Temperature	T_A	+10° to +60°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	6.0 612	kPa mm H_2O
Supply Voltage(1)	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_S	—	—	10	mAdc
Full Scale Output(2)	V_{FSS}	4.374	4.6	4.826	V
Offset(3)(5)	V_{off}	0.152	0.265	0.378	V
Sensitivity	V/P	—	766 7.511	—	mV/kPa mV/mm H_2O
Accuracy(4)(5) (10 to 60°C)	— —	— —	— —	±2.46 ±5.0	$\%V_{FSS}$ with auto zero $\%V_{FSS}$ without auto zero

1. Device is ratiometric within this specified excitation range.
2. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, -30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10° to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 10° to 60°C, relative to 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPVZ4006G, external mechanical stresses and mounting position can affect the zero pressure output reading. To obtain the 2.46% FSS accuracy, the device output must be “autozeroed" after installation. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations. The specified accuracy assumes a maximum temperature change of ±5°C between autozero and measurement.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION, AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPVZ4006G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 and Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

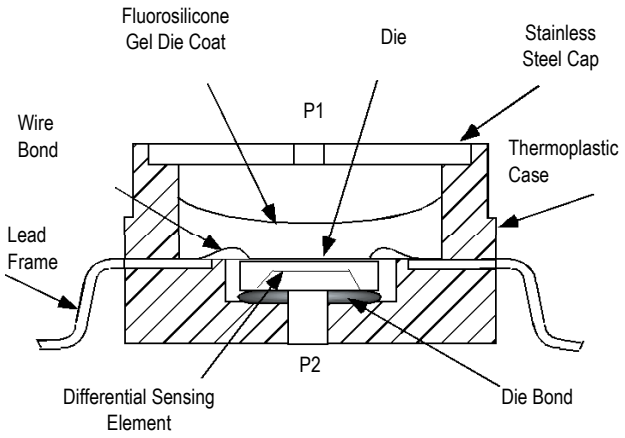

Figure 2. Cross Sectional Diagram SOP (Not to Scale)

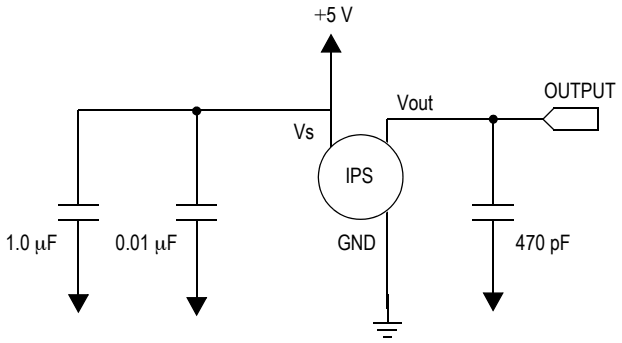

Figure 3. Recommended Power Supply Decoupling and Output Filtering Recommendations
(For additional output filtering, please refer to Application Note AN1646.)

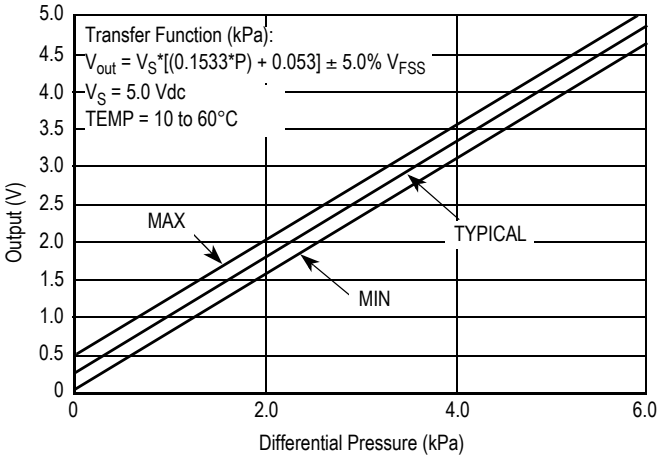

Figure 4. Output versus Pressure Differential at ±5.0% V_{FSS} (without auto zero, note 5 in Operating Characteristics)

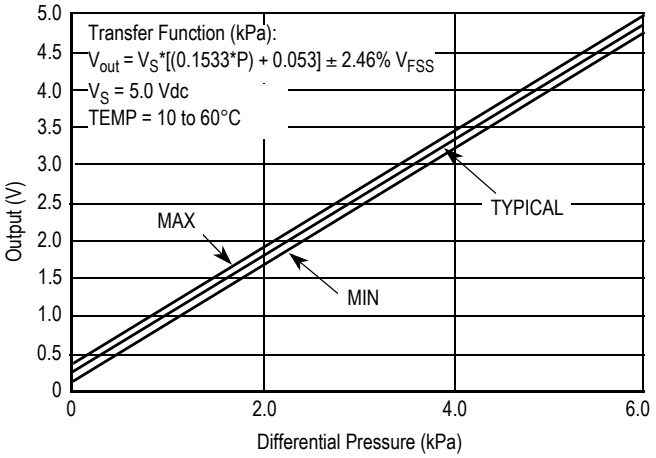

Figure 5. Output versus Pressure Differential at ±2.46% V_{FSS} (with auto zero, note 5 in Operating Characteristics)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing a gel die coat which isolates the die from the environment. The pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ4006GW6U	1735-01	Vertical Port Attached
MPVZ4006GW7U	1560-02	Vertical Port Attached
MPVZ4006G6U/T1	482-01	Stainless Steel Cap
MPVZ4006G7U	482B-03	Stainless Steel Cap

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

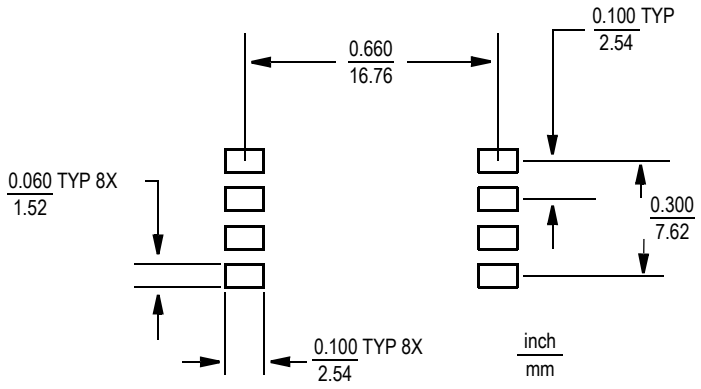

Figure 6. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPVZ5004G SERIES

INTEGRATED PRESSURE SENSOR
0 to 3.92 kPA
(0 to 400 mm H_2O)
1.0 to 4.9 V OUTPUT

The MPVZ5004G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for the appliance, consumer, healthcare and industrial market. The analog output can be read directly into the A/D input of Freescale microcontrollers. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure. The axial port has been modified to accommodate industrial grade tubing.

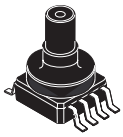
Features

- 1.5% Maximum Error for 0 to 100 mm H_2O over +10° to +60°C with Auto Zero
- 2.5% Maximum Error for 100 to 400 mm H_2O over +10° to +60°C with Auto Zero
- 6.25% Maximum Error for 0 to 400 mm H_2O over +10° to +60°C without Auto Zero
- Temperature Compensated over +10° to +60°C
- Available in Surface Mount (SMT) or Through-hole (DIP) Configurations

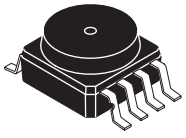
Application Examples

- Washing Machine Water Level Measurement (Reference AN1950)
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Appliance Liquid Level and Pressure Measurement
- Respiratory Equipment

SMALL OUTLINE PACKAGE SURFACE MOUNT

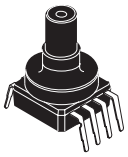


MPVZ5004GW6U
CASE 1735-01

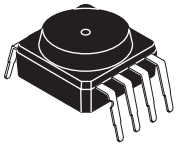


MPVZ5004G6U/T1
CASE 482-01

SMALL OUTLINE PACKAGE THROUGH-HOLE



MPVZ5004GW7U
CASE 1560-02



MPVZ5004G7U
CASE 482B-03

ORDERING INFORMATION

Device Type	Case No.	MPVZ Series Order No.	Packing Options	Device Marking
Surface Mount	1735-01	MPVZ5004GW6U	Rails	MZ5004GW
Through-Hole	1560-02	MPVZ5004GW7U	Rails	MZ5004GW
Surface Mount	482-01	MPVZ5004G6U	Rails	MZ5004G
Surface Mount	482-01	MPVZ5004G6T1	Tape & Reel	MZ5004G
Through-Hole	482B-03	MPVZ5004G7U	Rails	MZ5004G

PIN NUMBERS[1]

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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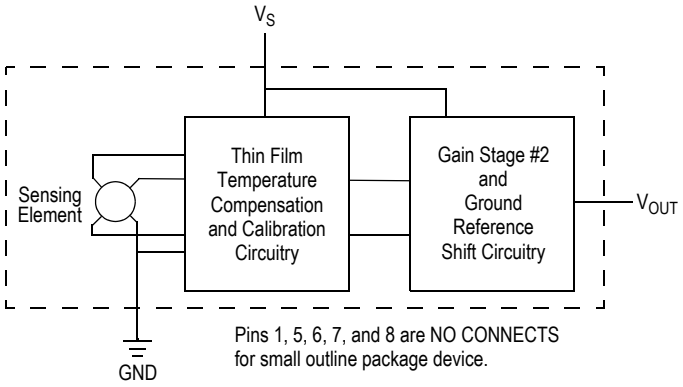

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	16	kPa
Storage Temperature	T_{STG}	–30 to +100	°C
Operating Temperature	T_A	0 to +85	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Pressure Range		P_{OP}	0	—	3.92 400	kPa mm H_2O
Supply Voltage(1)		V_S	4.75	5.0	5.25	V_{DC}
Supply Current		I_S	—	—	10	mAdc
Full Scale Span(2) @ V_S = 5.0 Volts		V_{FSS}	—	4.0	—	V
Offset(3) (4)		V_{OFF}	0.75	1.0	1.25	V
Sensitivity		V/P	—	1.0 9.8	—	V/kPa mV/mm H_2O
Accuracy(4) (5)	0 to 100 mm H_2O (10 to 60°C)	—	—	—	±1.5	$\%V_{FSS}$ with auto zero
	100 to 400 mm H_2O (10 to 60°C)	—	—	—	±2.5	$\%V_{FSS}$ with auto zero
	0 to 400 mm H_2O (10 to 60°C)	—	—	—	±6.25	$\%V_{FSS}$ without auto zero

1. Device is ratiometric within this specified excitation range.
2. Span is defined as the algebraic difference between the output voltage at specified pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, -30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10 to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 10 to 60°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPVZ5004G, external mechanical stresses and mounting position can affect the zero pressure output reading. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations. Reference AN1636 for specific information. The specified accuracy assumes a maximum temperature change of ± 5°C between autozero and measurement.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPVZ5004G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the MPVZ5004G to the A/D input of the microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 and Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3 The output will saturate outside of the specified pressure range.

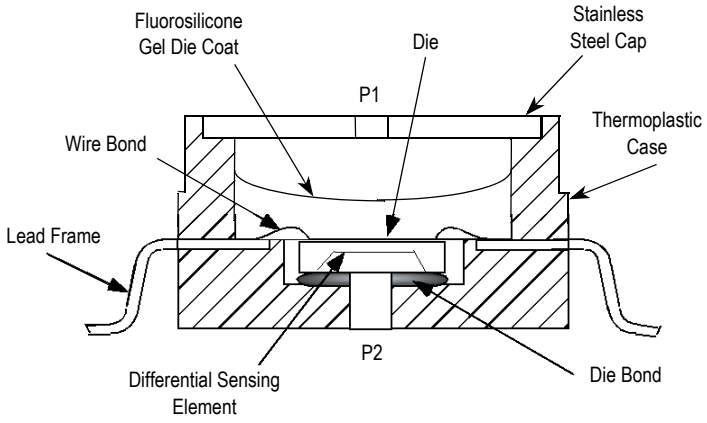

Figure 2. Cross-Sectional Diagram (Not to Scale)

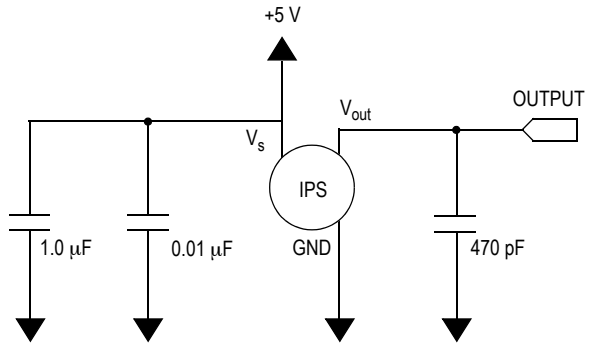

Figure 3. Recommended Power Supply Decoupling and Output Filtering.
(For additional output filtering, please refer to Application Note AN1646.)

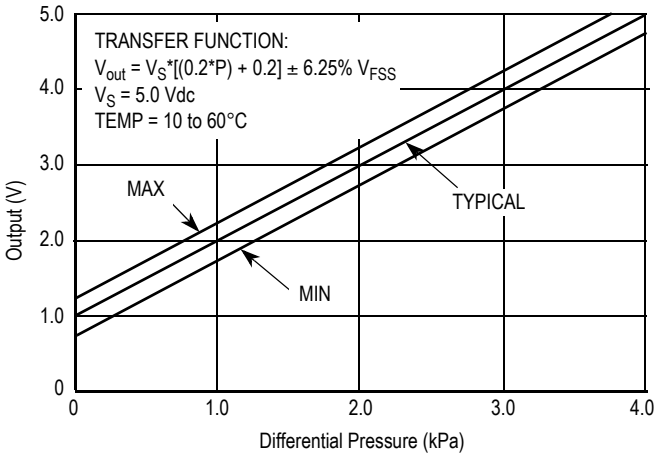

Figure 4. Output versus Pressure Differential at ±6.25% V_{FSS} (without auto zero, note 5 in Operating Characteristics)

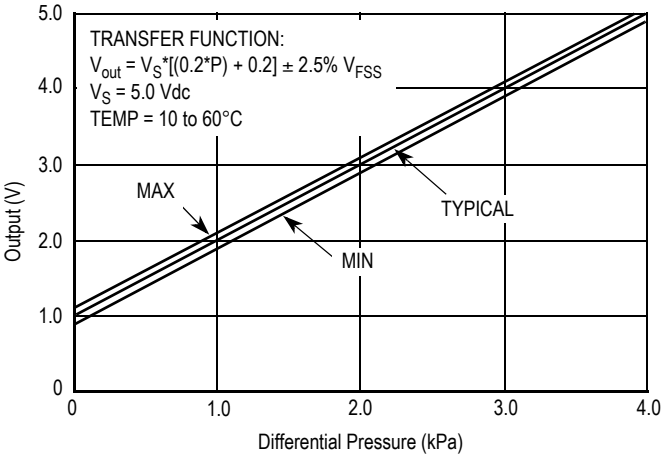

Figure 5. Output versus Pressure Differential at ±2.5% V_{FSS} (with auto zero, note 5 in Operating Characteristics)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale Semiconductor designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing a gel die coat which isolates the die from the environment. The Freescale Semiconductor pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below.

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ5004GW6U	1735-01	Vertical Port Attached
MPVZ5004GW7U	1560-02	Vertical Port Attached
MPVZ5004G6U/T1	482-01	Stainless Steel Cap
MPVZ5004G7U	482B-03	Stainless Steel Cap

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

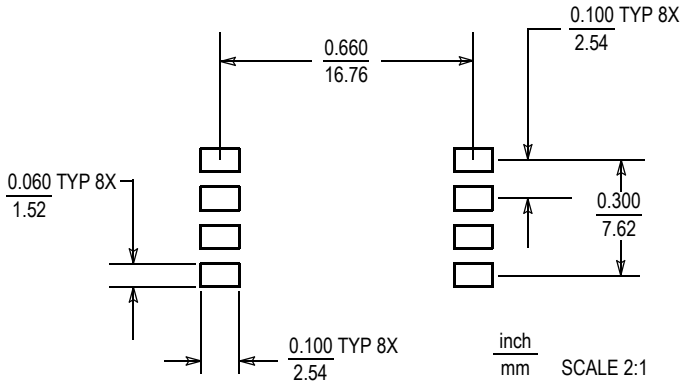

Figure 6. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPVZ5010G SERIES

INTEGRATED PRESSURE SENSOR
0 to 10 kPA (0 to 1019.78 mm H_2O)
0.2 to 4.7 V OUTPUT

The MPVZ5010G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for the appliance, consumer, healthcare, industrial and automotive market. The analog output can be read directly into the A/D input of Freescale microcontrollers. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure. The axial port has been modified to accommodate industrial grade tubing.

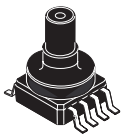
Features

- 5.0% Maximum Error over 0° to 85°C
- Temperature Compensated over -40° to +125°C
- Durable Thermoplastic (PPS) Package
- Available in Surface Mount (SMT) or Through-hole (DIP) Configurations

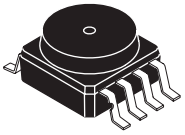
Application Examples

- Washing Machine Water Level Measurement (Reference AN1950)
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Appliance Liquid Level and Pressure Measurement
- Respiratory Equipment

SMALL OUTLINE PACKAGE SURFACE MOUNT

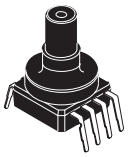


MPVZ5010GW6U
CASE 1735-01

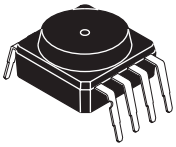


MPVZ5010G6U/T1
CASE 482-01

SMALL OUTLINE PACKAGE THROUGH-HOLE



MPVZ5010GW7U
CASE 1560-02



MPVZ5010G7U
CASE 482B-03

ORDERING INFORMATION				
Device Type	**Case No.**	**MPVZ Series Order No.**	**Packing Options**	**Device Marking**
Surface Mount	1735-01	MPVZ5010GW6U	Rails	MZ5010GW
Through-Hole	1560-02	MPVZ5010GW7U	Rails	MZ5010GW
Surface Mount	482-01	MPVZ5010G6U	Rails	MZ5010G
Surface Mount	482-01	MPVZ5010G6T1	Tape & Reel	MZ5010G
Through-Hole	482B-03	MPVZ5010G7U	Rails	MZ5010G

PIN NUMBERS[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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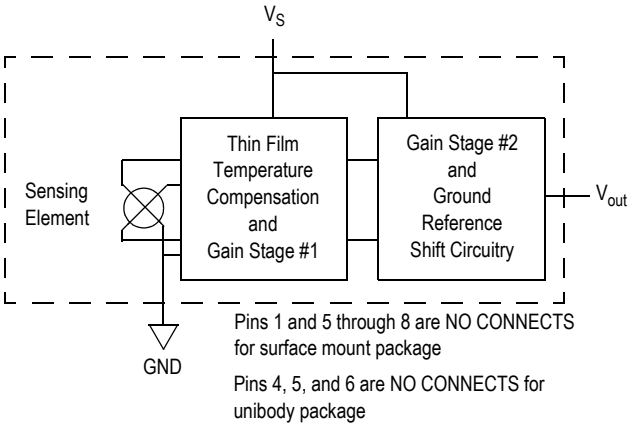

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	40	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	10 1019.78	kPa mm H_2O
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	5.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0	0.2	0.425	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.475	4.7	4.925	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.275	4.5	4.725	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	450 4.413	—	mV/kPa mV/mm H_2O
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPVZ5010G series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

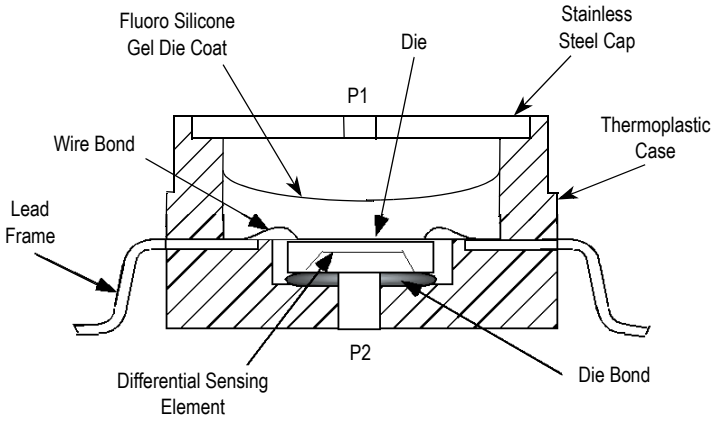

Figure 2. Cross-Sectional Diagram SOP (not to scale)

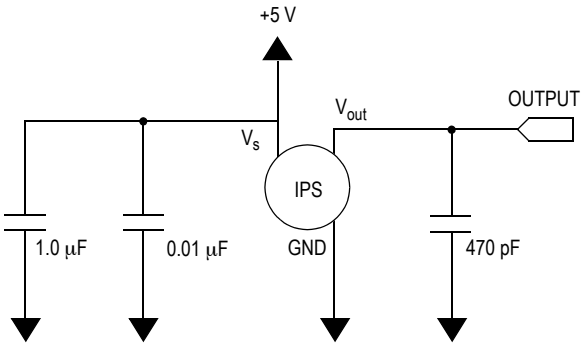

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

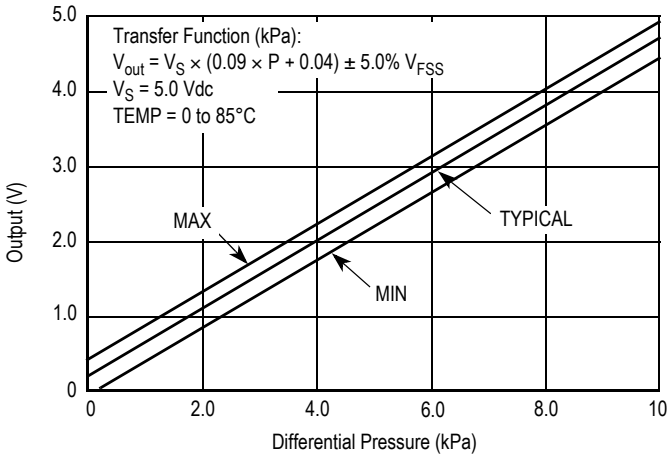

Figure 4. Output versus Pressure Differential

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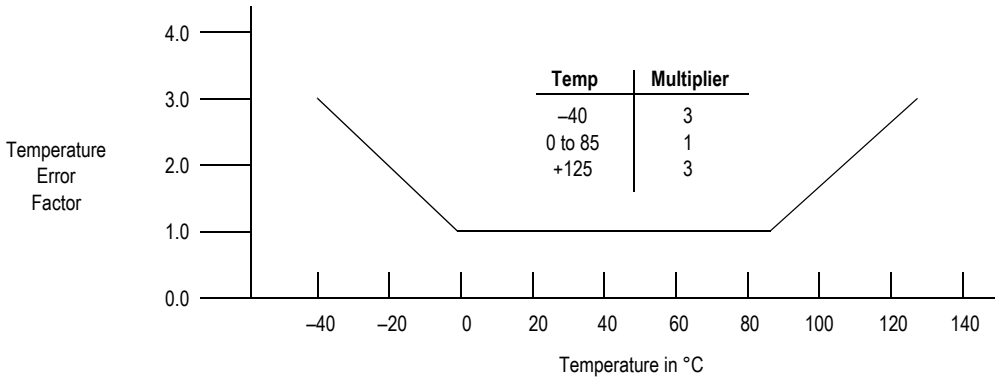
Transfer Function (MPVZ5010G)

Nominal Transfer Value: $V_{out} = V_S \times (0.09 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.09 x V_S)
$V_S = 5.0\ V \pm 0.25\ Vdc$
P = kPa

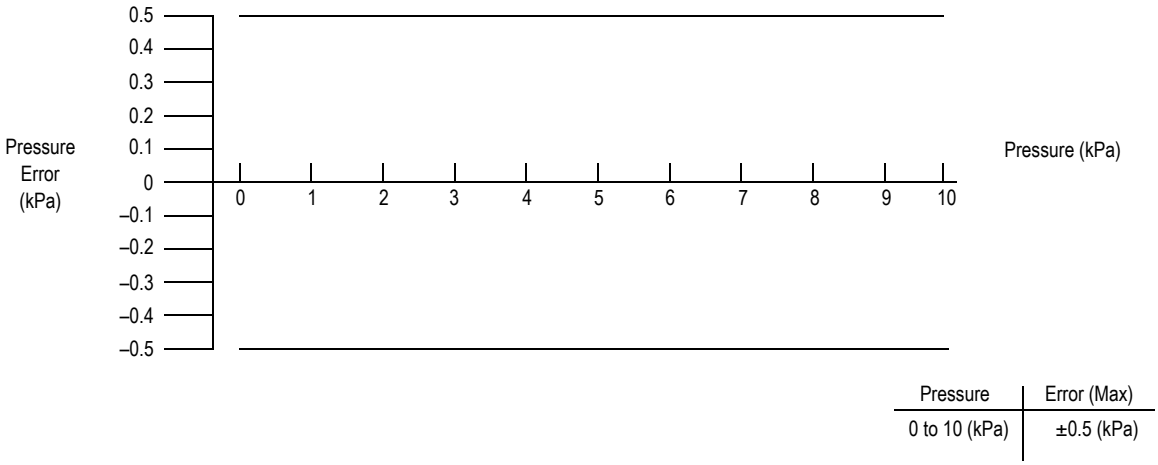
Temperature Error Band

MPVZ5010G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 10 (kPa)	±0.5 (kPa)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing a gel die coat which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ5010GW6U	1735-01	Vertical Port Attached
MPVZ5010GW7U	1560-02	Vertical Port Attached
MPVZ5010G6U/T1	482-01	Stainless Steel Cap
MPVZ5010G7U	482B-03	Stainless Steel Cap

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

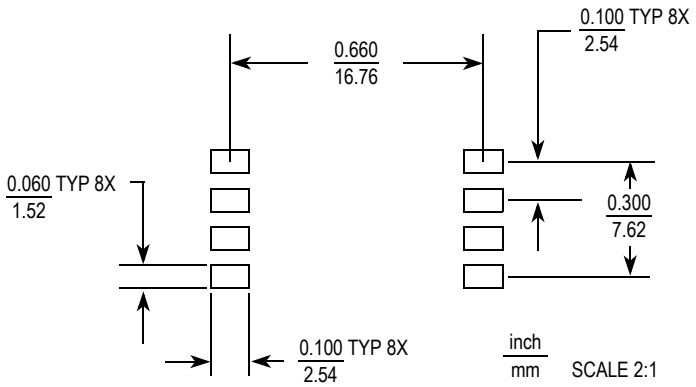

Figure 5. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPVZ5150 SERIES

INTEGRATED PRESSURE SENSOR
0 to 150 kPa (0 to 21.75 PSI)
0.2 to 4.7 V Output

The MPVZ5150 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

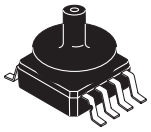
Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Easy-to-Use Chip Carrier Option
- Increased media compatibility fluorocarbon gel

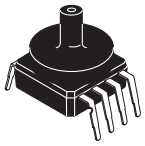
Typical Applications

- Level Indicators
- Process Control
- Pump/Motor Control
- Pressure Switching

SMALL OUTLINE PACKAGES



MPVZ5150GC6T1
CASE 482A-01



MPVZ5150GC7U
CASE 482C-03

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin1 is noted by the notch in the lead.

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
MPVZ5150 SERIES				
Ported Elements	Gauge, Axial Port, SMT	482A	MPVZ5150GC6T1	MPVZ5150G
	Gauge, Axial Port, DIP	482C	MPVZ5150GC7U	MPVZ5150G

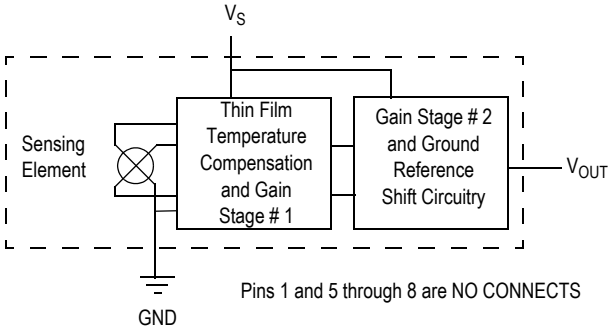


Figure 1. Fully Integrated Pressure Sensor Schematic

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TABLE 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40° to +125°C	°C
Operating Temperature	T_A	-40° to +125°C	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

TABLE 2. Operating Characteristics (V_S = 5.0 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	150	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	V_{DC}
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 V	(0 to 85°C)	V_{OFF}	0.088	0.200	0.313	V_{DC}
Full Scale Output(4) @ V_S = 5.0 V	Differential and Absolute (0 to 85°C)	V_{FSO}	4.588	4.700	4.813	V_{DC}
Full Scale Span(5) @ V_S = 5.0 V	Differential and Absolute (0 to 85°C)	V_{FSS}	—	4.500	—	V_{DC}
Accuracy(6)		—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	30	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1 kPa (kiloPascal) equals 0.145 PSI.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental changed in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-Up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 3 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. Operating characteristics, internal reliability and qualification tests are based on use of dry clean air as the pressure media. Media other than dry clean air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

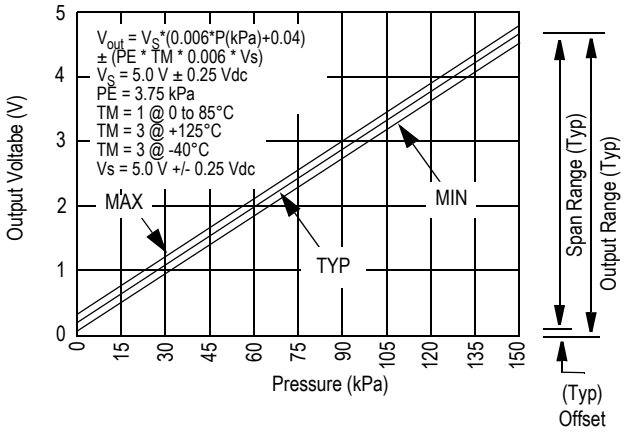

Figure 2. Output Vs. Pressure Differential

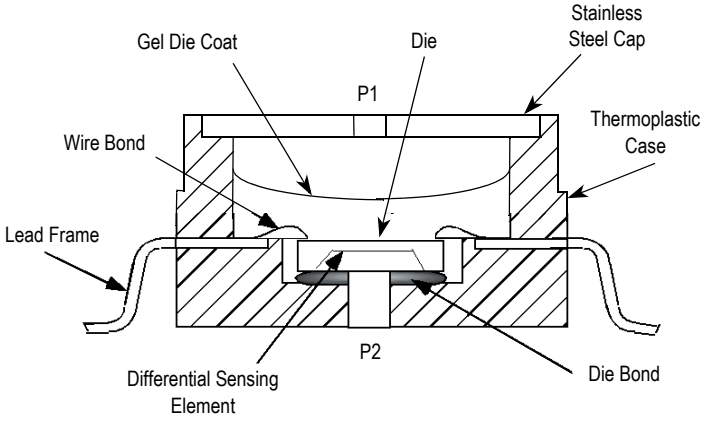

Figure 3. Cross Sectional Diagrams (Not to Scale)

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

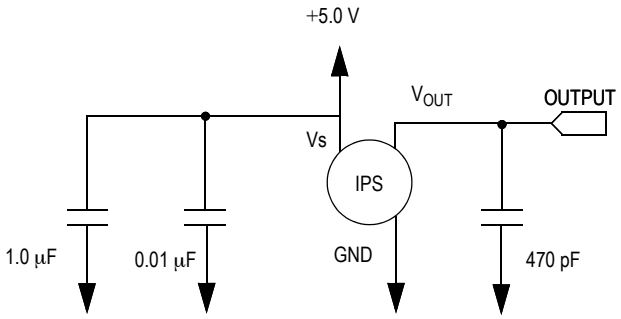

Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

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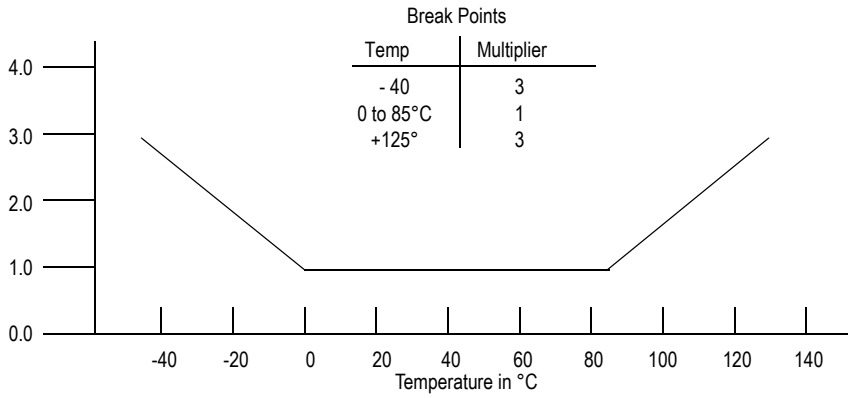
Transfer Function (MPVZ5150 Series)

Nominal Transfer Value: $V_{OUT} = V_S \times (0.006 \times P(kPa) + 0.04)$
$\pm$ (Pressure Error x Temp. Mult. x 0.006 x V_S)
$V_S = 5.0\ V \pm 0.25$ Vdc

Temperature Error Multiplier

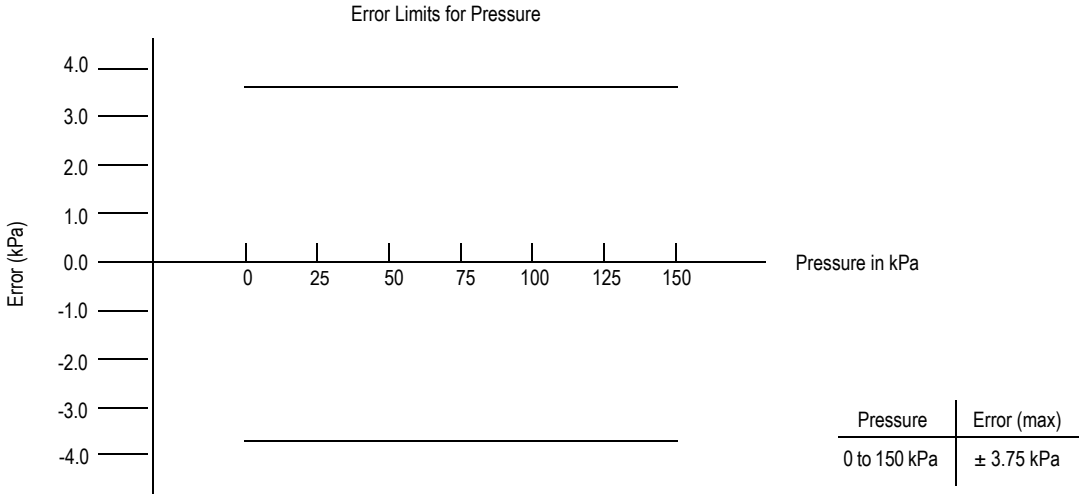
MPVZ5150 Series



Note: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band

MPVZ5150 Series



Pressure	Error (max)
0 to 150 kPa	± 3.75 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorocarbon gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using Table 3 below.

TABLE 3. PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Part Number	Case Type	Pressure (P1) Side Identifier
MPVZ5150GC6T1	482A	Top with Port Attached
MPVZ5150GC7U	482C	Top with Port Attached

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder.

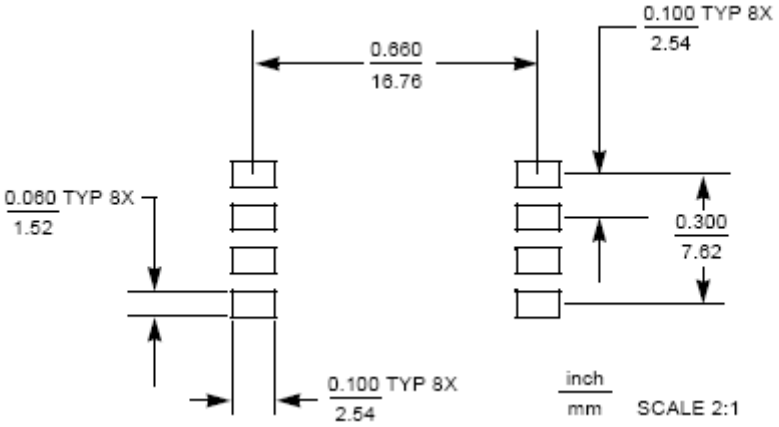


Figure 5. Small Outline Package Footprint

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10 kPa Uncompensated Silicon Pressure Sensors

The MPX10 and MPXV10GC series devices are silicon piezoresistive pressure sensors providing a very accurate and linear voltage output — directly proportional to the applied pressure. These standard, low cost, uncompensated sensors permit manufacturers to design and add their own external temperature compensation and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design. Figure 1 shows a schematic of the internal circuitry on the stand-alone pressure sensor chip.

Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

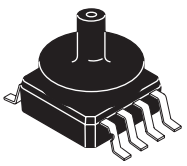
Functional Description

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

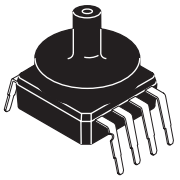
MPX10
MPXV10GC
SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 10 kPA (0–1.45 psi)
35 mV FULL SCALE SPAN
(TYPICAL)

SMALL OUTLINE PACKAGES



MPXV10GC6U
CASE 482A-01



MPXV10GC7U
CASE 482C-03

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**Order Number**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV10G SERIES)				
Ported Elements	Rails	482A	MPXV10GC6U	MPXV10G
	Tape and Reel	482A	MPXV10GC6T1	MPXV10G
	Rails	482C	MPXV10GC7U	MPXV10G
UNIBODY PACKAGE (MPX10 SERIES)				
Basic Element	Differential	344	MPX10D	MPX10D
Ported Elements	Differential	344C	MPX10DP	MPX10DP
	Gauge	344B	MPX10GP	MPX10GP
	Gauge	344E	MPX10GS	MPX10D

1. MPX10 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

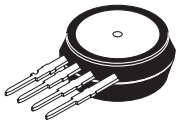
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND	5	N/C
2	$+V_{out}$	6	N/C
3	V_s	7	N/C
4	$-V_{out}$	8	N/C

NOTE: Pin 1 is noted by the notch in the lead.

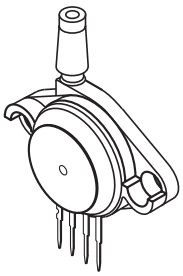
UNIBODY PACKAGE PIN NUMBERS			
1	GND	3	V_s
2	$+V_{out}$	4	$-V_{out}$

NOTE: Pin 1 is noted by the notch in the lead.

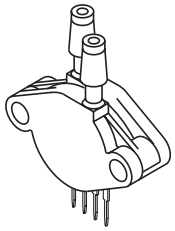
UNIBODY PACKAGES



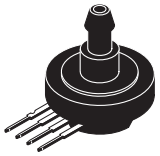
MPX10D
CASE 344-15



MPX10GP
CASE 344B-01



MPX10DP
CASE 344C-01



MPX10GS
CASE 344E-01

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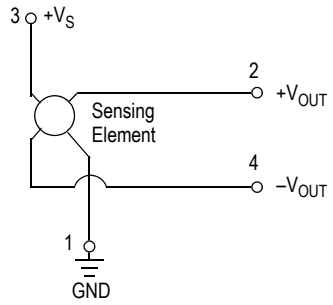

Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Burst Pressure (P > P2)	P_{BURST}	100	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Differential Pressure Range[1]	P_{OP}	0	—	10	kPa
Supply Voltage[2]	V_S	—	3.0	6.0	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	20	35	50	mV
Offset[4]	V_{OFF}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	3.5	—	mV/kPa
Linearity[5]	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span[5]	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset[5]	TCV_{OFF}	—	±15	—	µV/°C
Temperature Coefficient of Resistance[5]	TCR	0.28	—	0.34	$\%/Z_{IN}$/°C
Input Impedance	Z_{IN}	400	—	550	Ω
Output Impedance	Z_{OUT}	750	—	1250	Ω
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time[7]	—	—	20	—	ms
Offset Stability[8]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (VOFF) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{IN} deviation with minimum rated pressure applied, over the temperature range of -40°C to ±125°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
8. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX10 and MPXV10GC series over temperature.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2010D series sensor.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Application Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off} + \text{sensitivity} \times P$ over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: 1) end point straight line fit or 2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

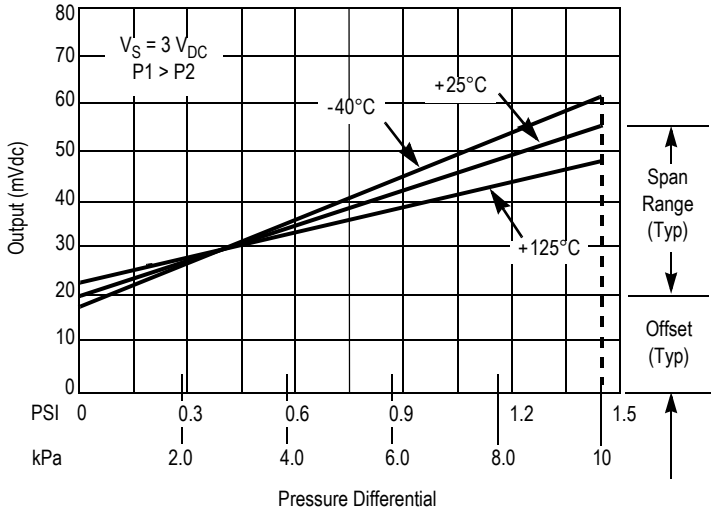

Figure 2. Output versus Pressure Differential

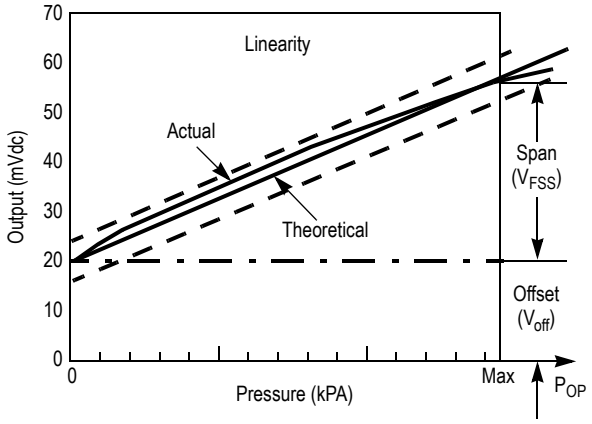

Figure 3. Linearity Specification Comparison

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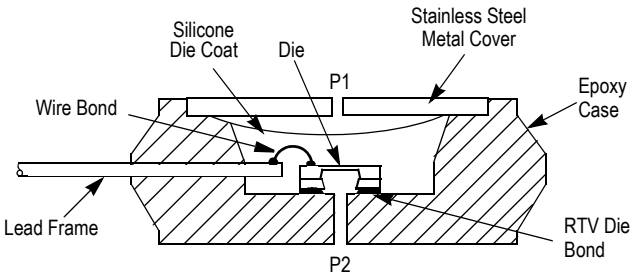

Figure 4. Unibody Package — Cross-Sectional Diagram (Not to Scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX10 and MPXV10GC series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Part Number	Case Type	Pressure (P1) Side Identifier
MPX10D	344	Stainless Steep Cap
MPX10DP	344C	Side with Part Marking
MPX10GP	344B	Side with Port Attached
MPX10GS	344E	Side with Port Attached
MPXV10GC6U	482A	Side with Part Marking
MPXV10GC7U	482C	Side with Part Marking

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10 kPa Uncompensated Silicon Pressure Sensors

MPX12 SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 10 kPA (0–1.45 psi)
55 mV FULL SCALE SPAN (TYPICAL)

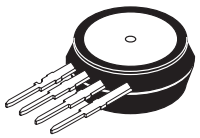
The MPX12 series device is a silicon piezoresistive pressure sensor providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design.

Features

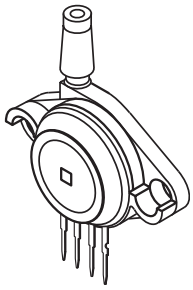
- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- Differential and Gauge Options
- Durable Epoxy Package

Application Examples

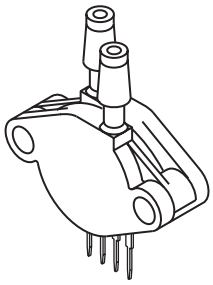
- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics



MPX12D
CASE 344-15



MPX12GP
CASE 344B-01



MPX12DP
CASE 344C-01

ORDERING INFORMATION(1)

Device Type	Options	Case No.	Order Number	Device Marking
Basic Element	Differential	344	MPX12D	MPX12D
Ported Elements	Differential	344C	MPX12DP	MPX12DP
	Gauge	344B	MPX12GP	MPX12GP

1. MPX12 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

PIN NUMBERS			
1	GND	3	V_{SS}
2	$+V_{out}$	4	$-V_{out}$

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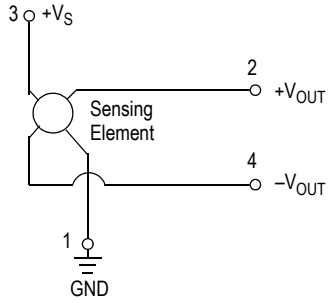

Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Burst Pressure (P1 > P2)	P_{BURST}	100	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	45	55	70	mV
Offset(4)	V_{off}	0	20	35	mV
Sensitivity	ΔV/ΔP	—	5.5	—	mV/kPa
Linearity(5)	—	–0.5	—	5.0	$\%V_{FSS}$
Pressure Hysteresis[6] (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)	TCV_{FSS}	–0.22	—	–0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset(5)	TCV_{off}	—	±15	—	μV/°C
Temperature Coefficient of Resistance(5)	TCR	0.28	—	0.34	$\%Z_{in}$/°C
Input Impedance	Z_{in}	400	—	550	W
Output Impedance	Z_{out}	750	—	1250	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time(7)	—	—	20	—	ms
Offset Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - TCR: Z_{IN} deviation with minimum rated pressure applied, over the temperature range of -40°C to ±125°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
8. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX12 series over temperature.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2010D series sensor.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

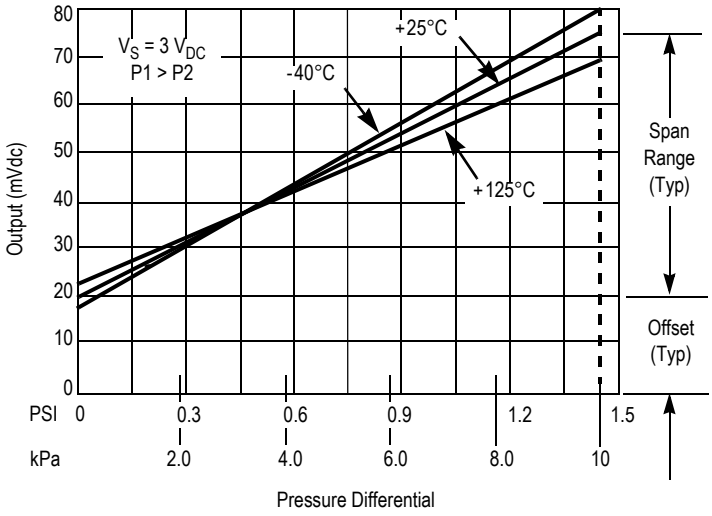

Figure 2. Output versus Pressure Differential

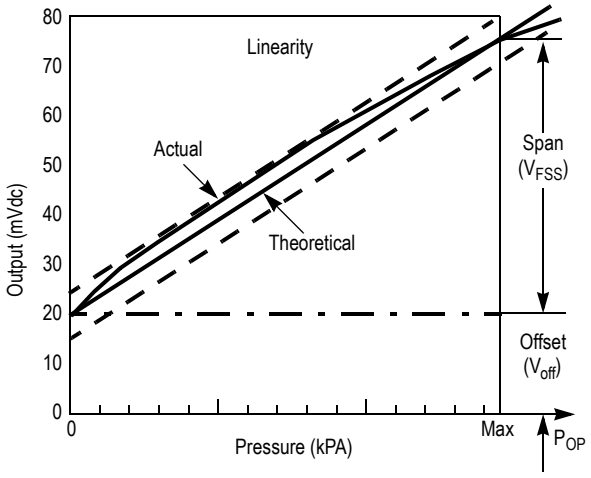

Figure 3. Linearity Specification Comparison

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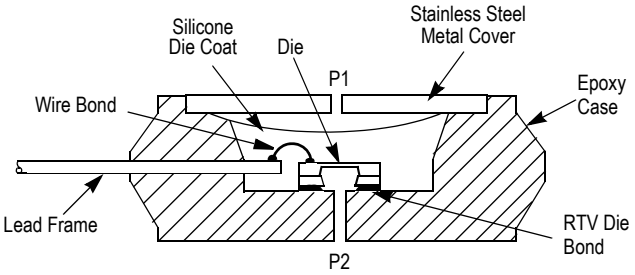

Figure 4. Unibody Package — Cross-Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX12 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application/

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table

Part Number	Case Type	Pressure (P1) Side Identifier
MPX12D	344	Stainless Steel Cap
MPX12DP	344C	Side with Part Marking
MPX12GP	344B	Side with Port Attached

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50 kPa Uncompensated Silicon Pressure Sensors

The MPX53/MPXV53GC series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output — directly proportional to the applied pressure. These standard, low cost, uncompensated sensors permit manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Freescale's single element strain gauge design.

Features

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options
- 60 mV Span (Typ)
- Differential and Gauge Options

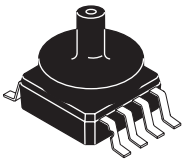
Typical Applications

- Air Movement Control
- Environmental Control Systems
- Level Indicators
- Leak Detection
- Medical Instrumentation
- Industrial Controls
- Pneumatic Control Systems
- Robotics

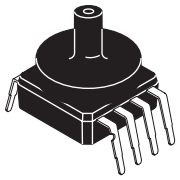
MPX53
MPXV53GC
SERIES

UNCOMPENSATED PRESSURE SENSOR
0 TO 50 kPA (0 – 7.25 psi)
60 mV FULL SCALE SPAN (TYPICAL)

SMALL OUTLINE PACKAGES



MPXV53GC6U
CASE 482A-01



MPXV53GC7U
CASE 482C-03

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE[1] (MPXV53 SERIES)					
Ported Elements	Gauge, Side Port, SMT	482A	MPXV53GC6T1	Tape & Rail	MPXV53G
		482A	MPXV53GC6U	Rails	MPXV53G
		482C	MPXV53GC7U	Rails	MPXV53G
UNIBODY PACKAGE[2] (MPX53 SERIES)					
Basic Element	Differential	344	MPX53D	—	MPX53D
Ported Elements	Differential	344C	MPX53DP	—	MPX53DP
	Gauge	344B	MPX53GP	—	MPX53GP

1. The MPXV53GC series pressure sensors are available with a pressure port, surface mount, or DIP leadforms and two packing options.
2. MPX53 series pressure sensors are available in differential and gauge configurations. Devices are available with basic element package or with pressure port fittings, providing printed circuit board mounting ease and barbed hose pressure.

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND[1]	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

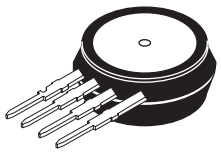
1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

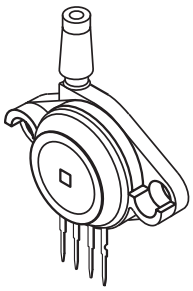
1	GND[1]	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

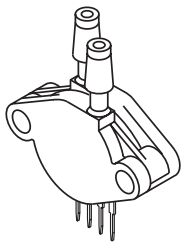
UNIBODY PACKAGES



MPX53D
CASE 344-15



MPX53GP
CASE 344B-01



MPX53DP
CASE 344C-01

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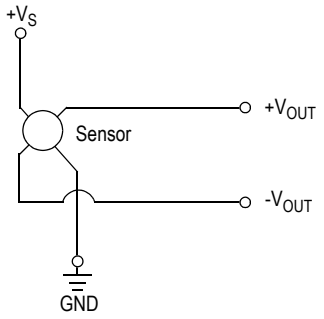

Figure 1. Uncompensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a schematic of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	200	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range[1]	P_{OP}	0	—	50	kPa
Supply Voltage[2]	V_S	—	3.0	6.0	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	45	60	90	mV
Offset[4]	V_{OFF}	0	20	35	mV
Sensitivity	$\Delta V/\Delta P$	—	1.2	—	mV/kPa
Linearity[5]	—	–0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span[5]	TCV_{FSS}	–0.22	—	-0.16	$\%V_{FSS}$/°C
Temperature Coefficient of Offset[5]	TCV_{OFF}	—	±15	—	µV/°C
Temperature Coefficient of Resistance[5]	TCR	0.31	—	0.37	$\%Z_{IN}$/°C
Input Impedance	Z_{IN}	355	—	505	Ω
Output Impedance	Z_{OUT}	750	—	1875	Ω
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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TEMPERATURE COMPENSATION

Figure 2 shows the typical output characteristics of the MPX53/MPXV53GC series over temperature.

The piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components, or by designing your system using the MPX2053 series sensors.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Freescale Application Note AN840.

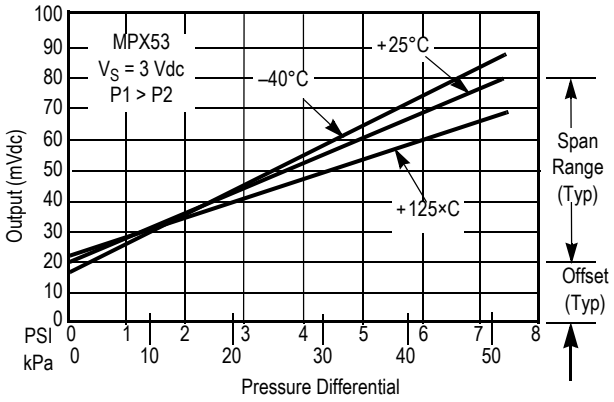

Figure 2. Output vs. Pressure Differential

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (see Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

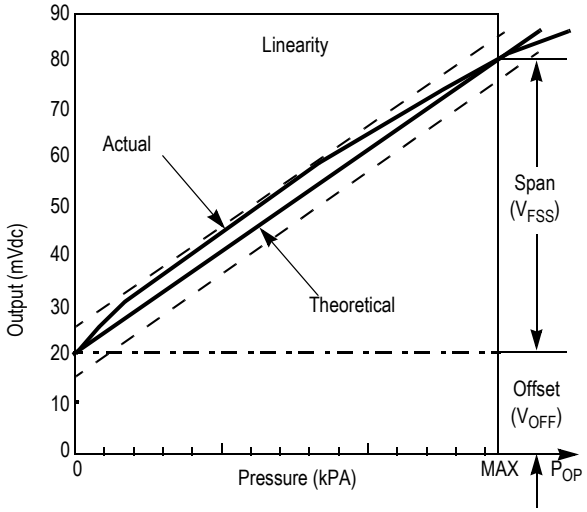

Figure 3. Linearity Specification Comparison

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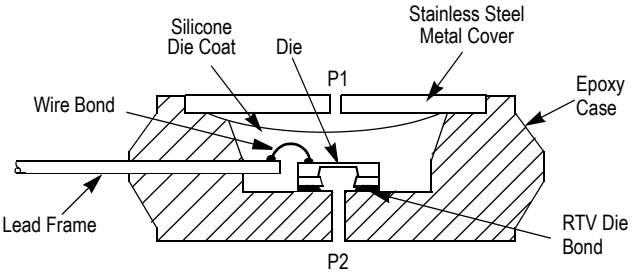

Figure 4. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 4 illustrates the differential or gauge configuration in the unibody chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX53/MPXV53GC series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Part Number	Case Type	Pressure (P1) Side Identifier
MPX53D	344	Stainless Steep Cap
MPX53DP	344C	Side with Port Marking
MPX53GP	344B	Side with Port Attached
MPX53GC Series	482A, 482C	Side with Port Attached

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10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPX2010
MPXV2010G
SERIES

COMPENSATED
PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
FULL SCALE SPAN: 25 mV

The MPX2010/MPXV2010G series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output directly proportional to the applied pressure. These sensors house a single monolithic silicon die with the strain gauge and thin film resistor network integrated on each chip. The sensor is laser trimmed for precise span, offset calibration and temperature compensation.

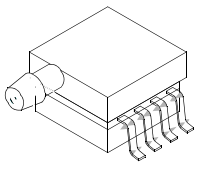
Features

- Temperature Compensated over 0°C to +85°C
- Ratiometric to Supply Voltage
- Differential and Gauge Options

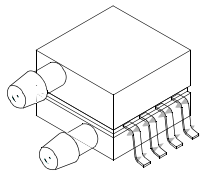
Typical Applications

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

SMALL OUTLINE PACKAGES



MPXV2010GP
CASE 1369-01



MPXV2010DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV2010G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2010GP	Trays	MPXV2010G
	Differential, Dual Port, SMT	1351	MPXV2010DP	Trays	MPXV2010G
UNIBODY PACKAGE (MPX2010 SERIES)					
Basic Element	Differential	344	MPX2010D	—	MPX2010D
Ported Elements	Differential, Dual Port	344C	MPX2010DP	—	MPX2010DP
	Gauge	344B	MPX2010GP	—	MPX2010GP
	Gauge, Axial	344E	MPX2010GS	—	MPX2010D
	Gauge, Axial PC Mount	344F	MPX2010GSX	—	MPX2010D

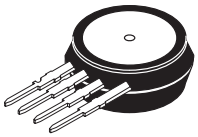
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

1. Pin 1 in noted by the notch in the lead.

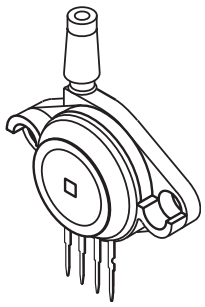
UNIBODY PACKAGE PIN NUMBERS			
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

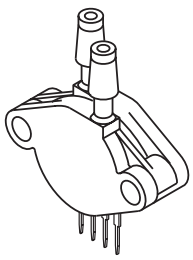
UNIBODY PACKAGES



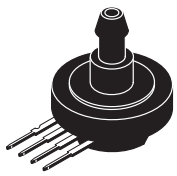
MPX2010GP
CASE 344-15



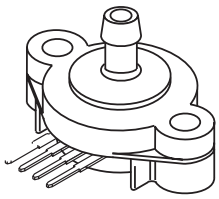
MPX2010GP
CASE 344B-01



MPX2010DP
CASE 344C-01



MPX2010GS
CASE 344E-01



MPX2010GSX
CASE 344F-01

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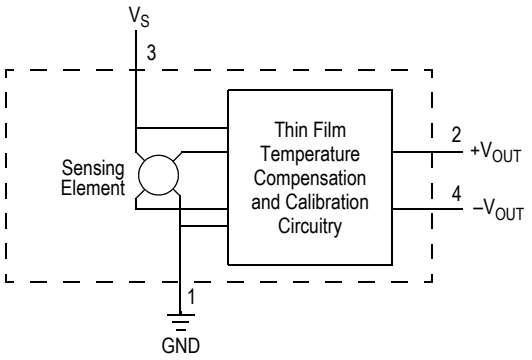

Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	75	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	10	16	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	24	25	26	mV
Offset(4)	V_{OFF}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	2.5	—	mV/kPa
Linearity(5)	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{OFF}	–1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2550	W
Output Impedance	Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

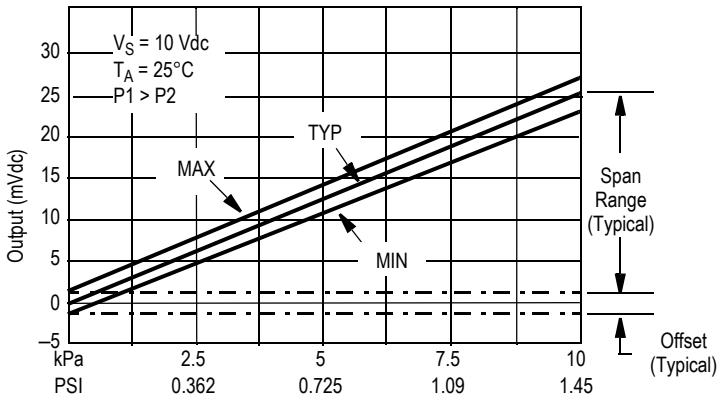

Figure 2. Output vs. Pressure Differential

Figure 2 shows the output characteristics of the MPX2010/MPXV2010G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics.

This performance over temperature is achieved by having both the shear stress strain gauge and the thin-film resistor circuitry on the same silicon diaphragm. Each chip is dynamically laser trimmed for precise span and offset calibration and temperature compensation.

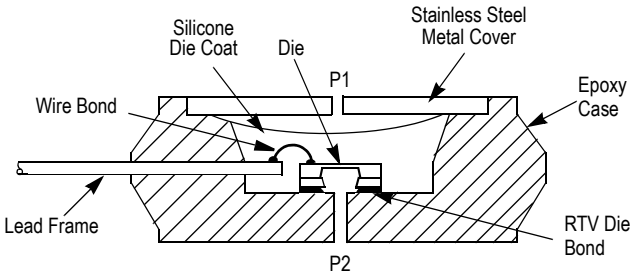

Figure 3. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2010/MPXV2010G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

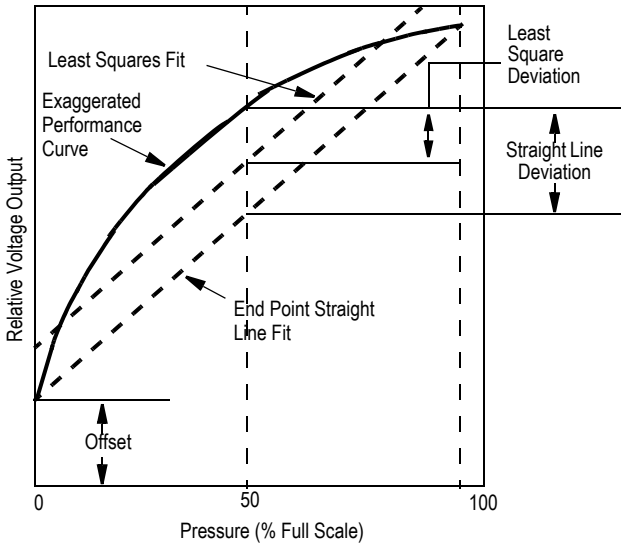

Figure 4. Linearity Specification Comparison

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2010D	344	Stainless Steep Cap
MPX2010DP	344C	Side with Part Marking
MPX2010GP	344B	Side with Port Attached
MPX2010GS	344E	Side with Port Attached
MPX2010GSX	344F	Side with Port Attached
MPXV2010GP	1369	Side with Port Attached
MPXV2010DP	1351	Side with Part Marking

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50 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

The MPX2053/MPXV2053G device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Ratiometric to Supply Voltage
- Differential and Gauge Options

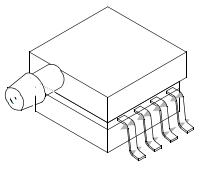
Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

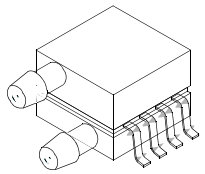
MPX2053
MPXV2053G
SERIES

0 TO 50 kPA (0 TO 7.25 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

SMALL OUTLINE PACKAGES



MPXV2053GP
CASE 1369-01



MPXV2053DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (**MPXV2053G** SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2053GP	Trays	MPXV2053G
	Differential Dual Port, SMT	1351	MPXV2053DP	Trays	MPXV2053G
UNIBODY PACKAGE (**MPX2053** SERIES)					
Basic Element	Differential	344	MPX2053D	—	MPX2053D
Ported Elements	Differential, Dual Port	344C	MPX2053DP	—	MPX20153DP
	Gauge	344B	MPX2053GP	—	MPX2053GP
	Gauge, Axial PC Mount	344F	MPX2053GSX	—	MPX2053D
	Gauge, Vacuum	344D	MPX2053GVP	—	MPX2053GVP

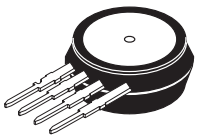
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

1. Pin 1 in noted by the notch in the lead.

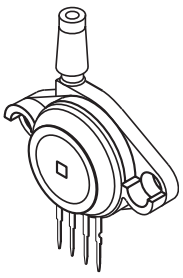
UNIBODY PACKAGE PIN NUMBERS			
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

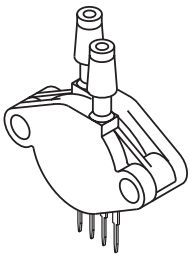
UNIBODY PACKAGES



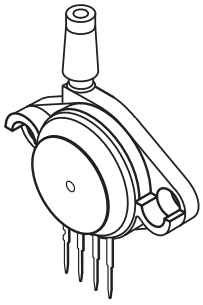
MPX2053GP
CASE 344-15



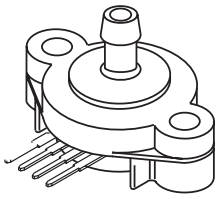
MPX2053GP
CASE 344B-01



MPX2053DP
CASE 344C-01



MPX2053GVP
CASE 344D-01



MPX2053GSX
CASE 344F-01

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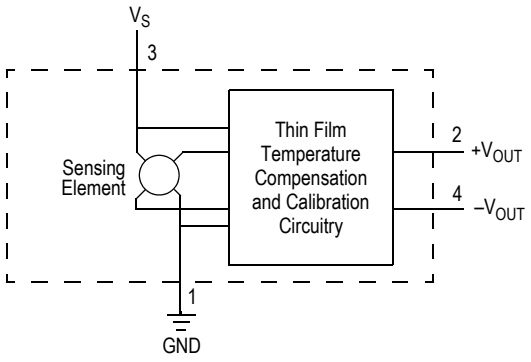

Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	20	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Units
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	10	16	V_{DC}
Supply Current	I_O	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	38.5	40	41.5	mV
Offset(4)	V_{OFF}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity(5)	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	–2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{OFF}	–1.0	—	1.0	mV
Input Impedance	Z_{IN}	1000	—	2550	W
Output Impedance	Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up Time	—	—	2.0	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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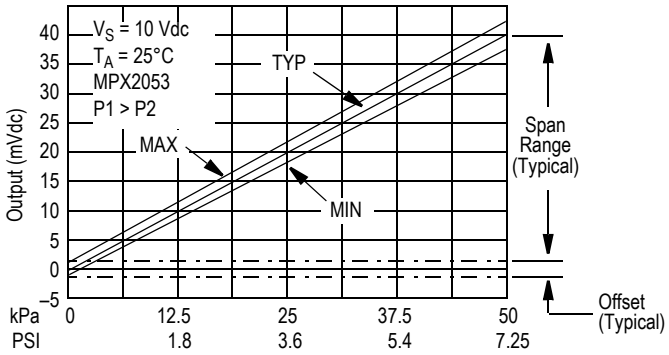

Figure 2. Output vs. Pressure Differential

Figure 2 shows the output characteristics of the MPX2053/MPXV2053G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics.

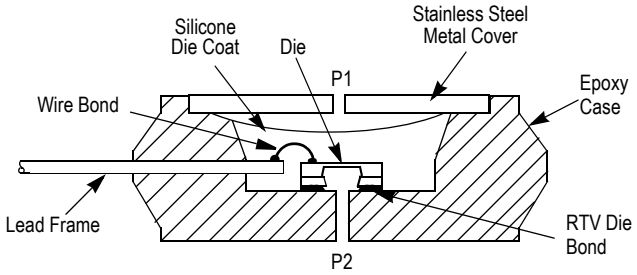

Figure 3. Unibody Package: Cross Sectional Diagram (Not to Scale)

Figure 3 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2053/MPXV2053G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 4) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale’s specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

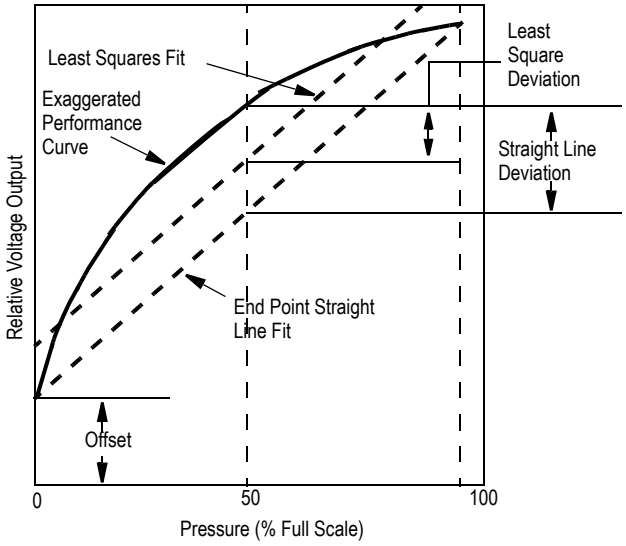

Figure 4. Linearity Specification Comparison

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2053D	344	Stainless Steep Cap
MPX2053DP	344C	Side with Part Marking
MPX2053GP	344B	Side with Port Attached
MPX2053GSX	344F	Side with Port Attached
MPXV2053GVP	344D	Stainless Steep Cap
MPXV2053GP	1369	Side with Port Attached
MPXV2053DP	1351	Side with Part Marking

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100 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPX2102
MPXV2102G
SERIES

0 TO 100 kPA (0 TO 14.5 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2102/MPXV2102G series device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

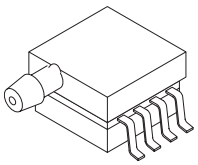
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage

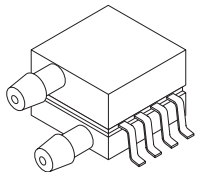
Application Examples

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

SMALL OUTLINE PACKAGES



MPX2102GP
CASE 1369-01



MPXV2102DP
CASE 1351-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV2102G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2102GP	Trays	MPXV2102G
	Differential, Dual Port, SMT	1351	MPXV2102DP	Trays	MPXV2102G
UNIBODY PACKAGE (MPX2102 SERIES)					
Basic Element	Absolute, Differential	344	MPX2102A MPX2102D	—	MPX2102A MPX2102D
Ported Elements	Differential, Dual Port	344C	MPX2102DP	—	MPX2102DP
	Absolute, Gauge	344B	MPX2102AP MPX2102GP	—	MPX2102AP MPX2102GP
	Absolute, Gauge Axial	344F	MPX2102ASX MPX2102GSX	—	MPX2102A MPX2102D
	Gauge, Vacuum	344D	MPX2102GVP	—	MPX2102GVP

SMALL OUTLINE PACKAGE PIN NUMBERS

1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	$-V_{OUT}$	8	N/C

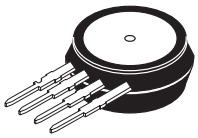
1. Pin 1 in noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS

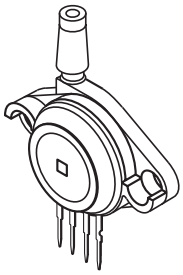
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

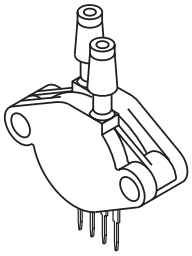
UNIBODY PACKAGES



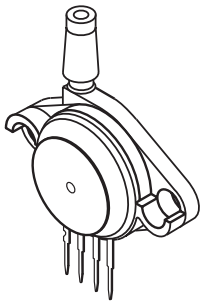
MPX2102A/D
CASE 344-15



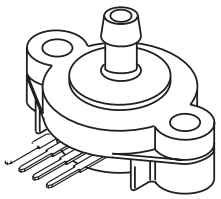
MPX2102AP/GP
CASE 344B-01



MPX2102DP
CASE 344C-01



MPX2102GVP
CASE 344D-01



MPX2102ASX/GSX
CASE 344F-01

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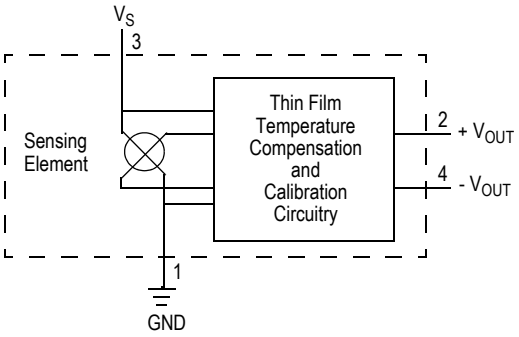

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VS. APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range[1]		P_{OP}	0	—	100	kPa
Supply Voltage[2]		V_S	—	10	16	V_{DC}
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span[3]		V_{FSS}	38.5	40	41.5	mV
Offset[4]	MPX2102D Series MPX2102A Series	V_{OFF}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.4	—	mV/kPa
Linearity[5]	MPX2102D Series MPX2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5](- 40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span[5]		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Coefficient of Offset[5]		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1000	—	2500	W
Output Impedance		Z_{OUT}	1400	—	3000	W
Response Time[6] (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up Time		—	—	20	—	ms
Offset Stability[7]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

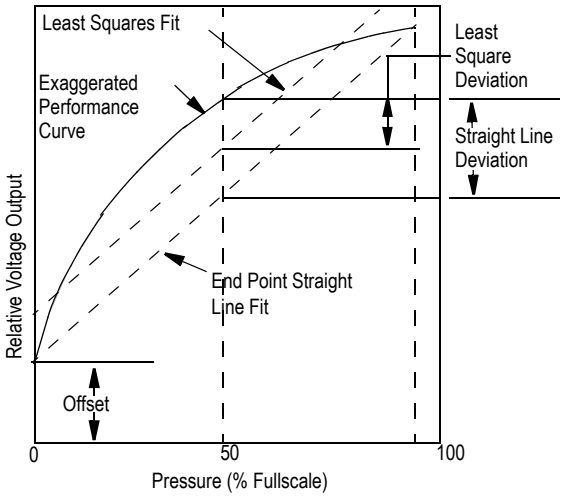

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2102/MPXV2102G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

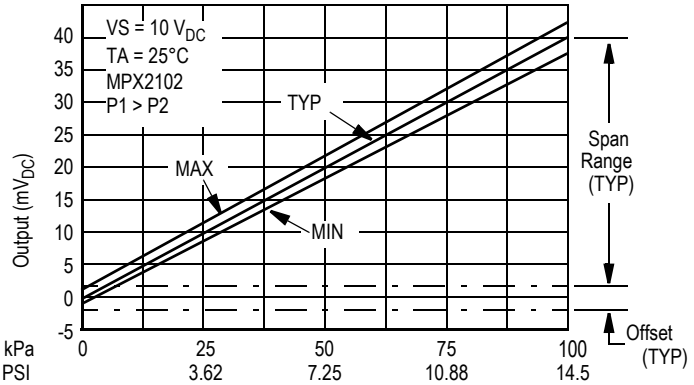

Figure 3. Output vs. Pressure Differential

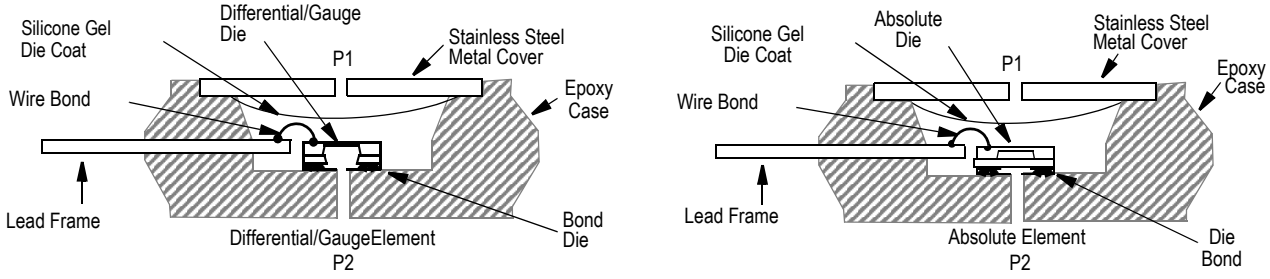

Figure 4. Cross Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2102/MPXV2102G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using Table 3.

Table 3. Pressure (P1) Side Delineation

Part Number		Case Type	Pressure (P1) Side Identifier
MPX2102A	MPX2102D	344	Stainless Steep Cap
MPX2102DP		344C	Side with Part Marking
MPX2102AP	MPX2102GP	344B	Side with Port Attached
MPX2102GVP		344D	Stainless Steep Cap
MPX2102ASX	MPX2102GSX	344F	Side with Port Marking
MPX2102GP		1369	Side with Port Attached
MPX2102DP		1351	Side with Part Marking

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200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPX2200 SERIES

0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)

The MPX2200 series device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

Features

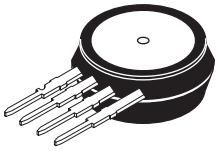
- Temperature Compensated Over 0°C to +85°C
- ±0.25% Linearity (MPX2200D)
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations

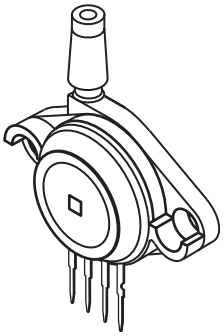
Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

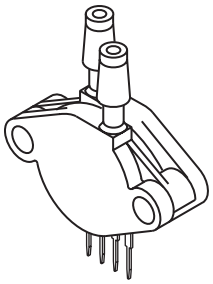
UNIBODY PACKAGES

MPX2200A/D
CASE 344-15

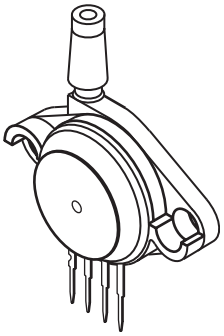




MPX2200AP/GP
CASE 344B-01



MPX2200DP
CASE 344C-01



MPX2200GVP
CASE 344D-01

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
Basic Element	Absolute, Differential	344	MPX2200A MPX2200D	MPX2200A MPX2200D
Ported Elements	Differential	344C	MPX2200DP	MPX2200DP
	Absolute, Gauge	344B	MPX2200AP MPX2200GP	MPX2200AP MPX2200GP
	Gauge, Vacuum	344D	MPX2200GVP	MPX2200GVP

1. MPX2200 series pressure sensors are available in absolute, differential and gauge configurations. Devicesare available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

PIN NUMBER			
1	GND[1]	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

1. Pin 1 in noted by the notch in the lead.

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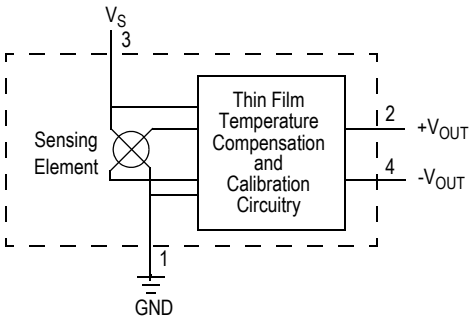

Figure 1. Temperature Compensation Pressure Sensor Schematic

VOLTAGE OUTPUT VS. APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	800	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage(2)		V_S	—	10	16	V_{DC}
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span(3)		V_{FSS}	38.5	40	41.5	mV
Offset(4)		V_{OFF}	-1.0	—	1.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(5)	MPX2200D Series MPX2200A Series	—	-0.25 -1.0	— —	0.25 1.0	$\%V_{FSSI}$
Pressure Hysteresis(5)(0 to 200 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5)(- 40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Coefficient of Full Scale Span(5)		TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Coefficient of Offset(5)		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1300	—	2500	W
Output Impedance		Z_{OUT}	1400	—	3000	W
Response Time(6) (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up Time		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
4. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure with the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

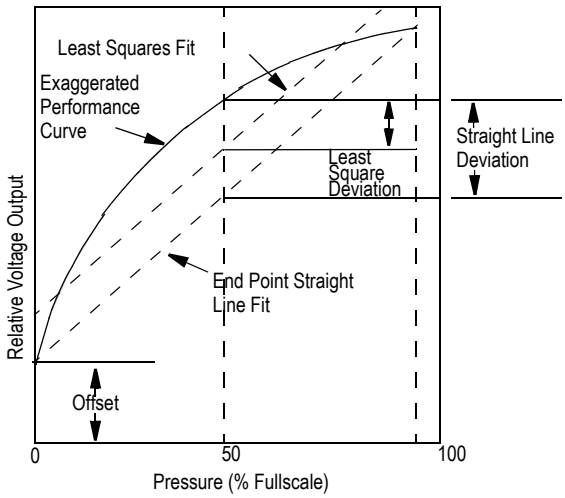

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2102/ MPXV2102G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

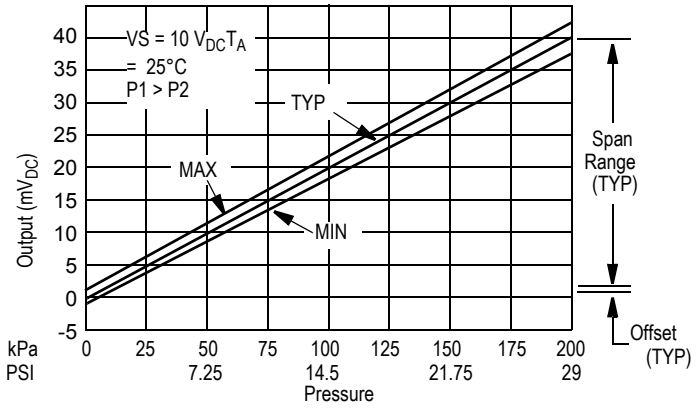

Figure 3. Output vs. Pressure Differential

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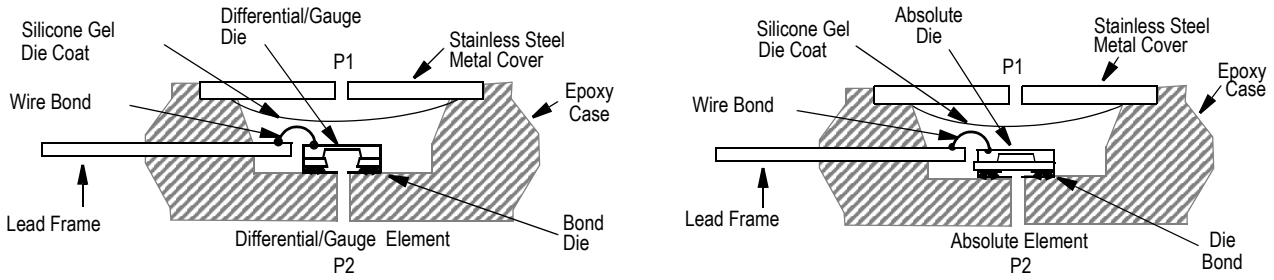

Figure 4. Cross Sectional Diagrams (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2200 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using Figure 3.

Table 3. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2200A/D	344	Stainless Steep Cap
MPX2200DP	344C	Side with Part Marking
MPX2200AP/GP	344B	Side with Port Attached
MPX2200GVP	344D	Stainless Steep Cap

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200 kPa On-Chip Temperature Compensated & Calibrated Pressure Sensors

MPX2202 SERIES

**0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN
(TYPICAL)**

The MPX2202/MPXV2202G device series is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

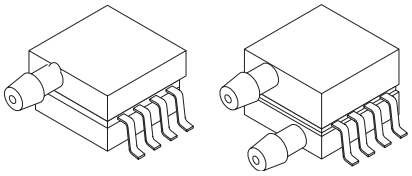
Features

- Temperature Compensated Over 0°C to +85°C
- Easy-to-Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

**SMALL OUTLINE PACKAGE
SURFACE MOUNT**



**MPXV2202GP
CASE 1369-01**

**MPXV2202DP
CASE 1351-01**

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPX2202G SERIES)					
Ported Elements	Gauge, Side Port, SMT	1369	MPXV2202GP	Trays	MPXV2202GP
	Differential, Dual Port, SMT	1351	MPXV2202DP	Trays	MPXV2202DP
UNIBODY PACKAGE (MPX2202 SERIES)					
Basic Element	Absolute, Differential	344	MPX2202A MPX2202D	—	MPX2202A MPX2202D
Ported Elements	Differential, Dual Port	344C	MPX2202DP	—	MPX2202DP
	Absolute, Gauge	344B	MPX2202AP MPX2202GP	—	MPX2202AP MPX2202GP
	Absolute, Gauge Axial	344F	MPX2202ASX	—	MPX2202A

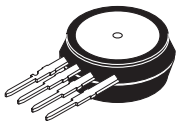
SMALL OUTLINE PACKAGE PIN NUMBERS			
1	GND(1)	5	N/C
2	$+V_{OUT}$	6	N/C
3	V_S	7	N/C
4	V_S	8	N/C

1. Pin 1 is noted by the notch in the lead.

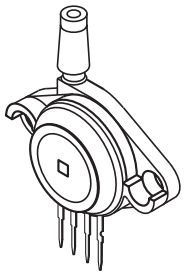
UNIBODY PACKAGE PIN NUMBERS			
1	GND(1)	3	V_S
2	$+V_{OUT}$	4	V_S

1. Pin 1 is noted by the notch in the lead.

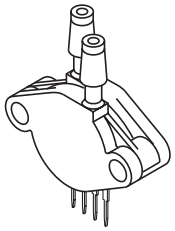
UNIBODY PACKAGES



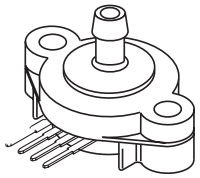
**MPX2202A/D
CASE 344-15**



**MPX2202AP/GP
CASE 344B-01**



**MPX2202DP
CASE 344C-01**



**MPX2202ASX
CASE 344F-01**

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Figure 1 illustrates a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

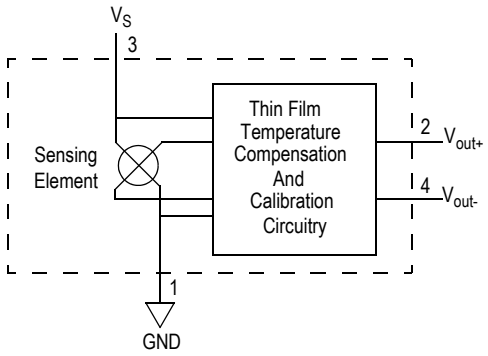

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The absolute sensor has a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure (P1) side.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure (P1) side relative to the vacuum (P2) side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum (P2) side relative to the pressure (P1) side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	800	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics

(V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristics		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	-	200	kPa
Supply Voltage[2]		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	-	mAdc
Full Scale Span[3]		V_{FSS}	38.5	40	41.5	mV
Offset[4]		V_{off}	-1.0	—	1.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity[5]	MPX2202D Series MPX2202A Series	—	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 200 kPa)		—	—	±0.1	-	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)		—	—	±0.5	-	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]		TCV_{off}	-1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	W
Output Impedance		Z_{out}	1400	—	3000	W
Response Time[6] (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up		—	—	20	—	ms
Offset Stability[7]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

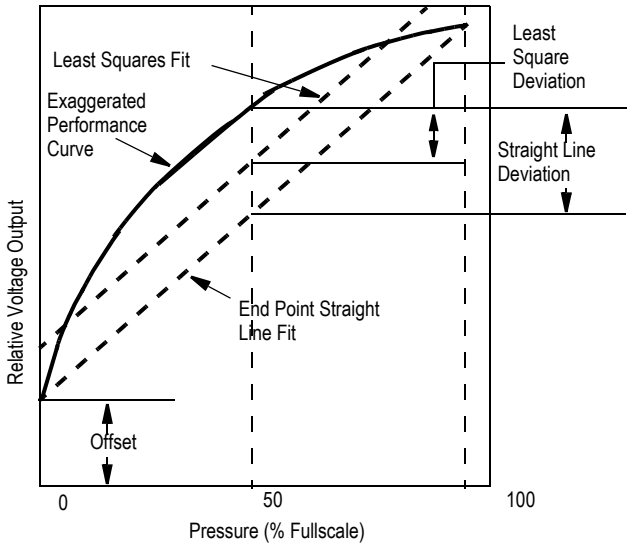

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the output characteristics of the MPX2202/ MPXV2202G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics.

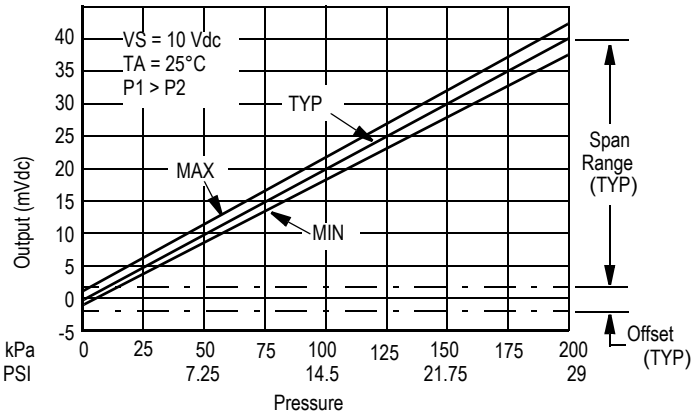

Figure 3. Output versus Pressure Differential

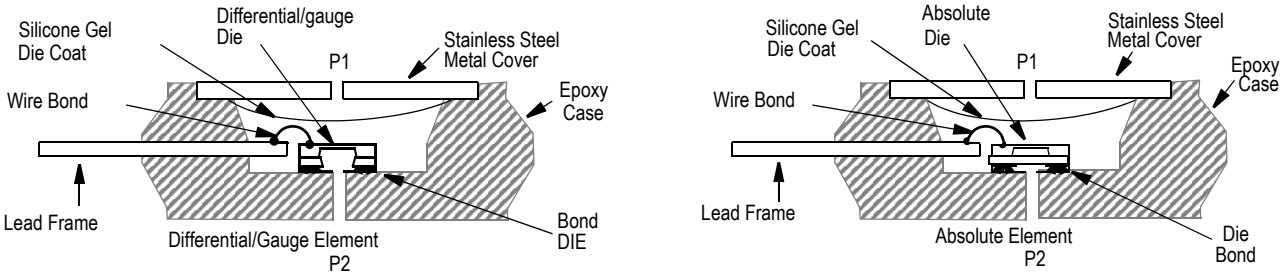

Figure 4. . Cross-Sectional Diagrams (Not to Scale)

Figure 4 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2202/MPXV2202G series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term reliability. Contact the factory for information regarding media compatibility in your application.

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing the silicone gel which isolates the die from the environment. The differential or gauge sensor is designed to operate with positive differential pressure applied, P1 > P2. The absolute sensor is designed for vacuum applied to P1 side.

The Pressure (P1) side may be identified by using the table below:

Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPX2202A/D	344	Stainless Steel Cap
MPX2202DP	344C	Side with Part Marking
MPX2202AP/GP	344B	Side with Port Attached
MPX2202ASX	344F	Side with Port Attached
MPXV2202GP	1369	Side with Port Attached
MPXV2202DP	1351	Side with Part Marking

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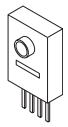
High Volume Pressure Sensor For Disposable Applications

MPX2300DT1
MPX2301DT1

PRESSURE SENSORS
0 TO 300 MM HG (0 TO 40 kPA)



MPX2300DT1/MPX2301DT1
CASE 423A-03

PIN NUMBER			
1	V_S	3	S-
2	S+	4	GND

Freescale Semiconductor, Inc. has developed a low-cost, high volume miniature pressure sensor package which is ideal as a sub-module component or a disposable unit. The unique concept of the Chip Pak allows great flexibility in system design while allowing an economic solution for the designer. This new chip carrier package uses Freescale's unique sensor die with its piezoresistive technology, along with the added feature of on-chip, thin-film temperature compensation and calibration.

NOTE: Freescale is also offering the Chip Pak package in application-specific configurations, which will have an “SPX” prefix, followed by a four-digit number, unique to the specific customer.

Features

- Low Cost
- Integrated Temperature Compensation and Calibration
- Ratiometric to Supply Voltage
- Polysulfone Case Material (Medical, Class V Approved)
- Provided in Easy-to-Use Tape and Reel

Typical Applications

- Medical Diagnostics
- Infusion Pumps
- Blood Pressure Monitors
- Pressure Catheter Applications
- Patient Monitoring

The MPX2300DT1/MPX2301DT1 silicon pressure sensors are available in tape and reel packaging

ORDERING INFORMATION

Device Type	Case No.	Device Description	Marking
MPX2300DT1	423A	Chip Pak, Full Gel	Date Code, Lot ID
MPX2301DT1	423A	Chip Pak, 1/3 Gel	Date Code, Lot ID

Packaging Information	Reel Size	Tape Width	Quantity
Tape and Reel	330 mm	24 mm	1000 pc/reel

NOTE: The die and wire bonds are exposed on the front side of the Chip Pak (pressure is applied to the backside of the device). Front side die and wire protection must be provided in the customer's housing. Use caution when handling the devices during all processes.

The MPX2300DT1/MPX2301DT1 Pressure Sensors have been designed for medical usage by combining the performance of Freescale's shear stress pressure sensor design and the use of biomedically approved materials. Materials with a proven history in medical situations have been chosen to provide a sensor that can be used with confidence in applications, such as invasive blood pressure monitoring. It can be sterilized using ethylene oxide. The portions of the pressure sensor that are required to be biomedically approved are the rigid housing and the gel coating.

The rigid housing is molded from a white, medical grade polysulfone that has passed extensive biological testing including: tissue culture test, rabbit implant, hemolysis, intracutaneous test in rabbits, and system toxicity, USP.

A silicone dielectric gel covers the silicon piezoresistive sensing element. The gel is a nontoxic, nonallergenic elastomer system which meets all USP XX Biological Testing Class V requirements. The properties of the gel allow it to transmit pressure uniformly to the diaphragm surface, while isolating the internal electrical connections from the corrosive effects of fluids, such as saline solution. The gel provides electrical isolation sufficient to withstand defibrillation testing, as specified in the proposed Association for the Advancement of Medical Instrumentation (AAMI) Standard for blood pressure transducers. A biomedically approved opaque filler in the gel prevents bright operating room lights from affecting the performance of the sensor. The MPX2301DT1 is a reduced gel option.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (Backside)	P_{max}	125	PSI
Storage Temperature	T_{stg}	-25 to +85	°C
Operating Temperature	T_A	+15 to +40	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (VS = 6 Vdc, TA = 25×C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	300	mm Hg
Supply Voltage(1)	V_S	—	6.0	10	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Zero Pressure Offset	V_{off}	-0.75	—	0.75	mV
Sensitivity	—	4.95	5.0	5.05	μV/V/mmHg
Full Scale Span(2)	V_{FSS}	2.976	3.006	3.036	mV
Linearity + Hysteresis(3)	—	-1.5	—	1.5	$\%V_{FSS}$
Accuracy(9) V_S = 6 V, P = 101 to 200 mmHg	—	-1.5	—	1.5	%
Accuracy(9) V_S = 6 V, P = 201 to 300 mmHg	—	-3.0	—	3.0	%
Temperature Effect on Sensitivity	TCS	-0.1	—	+0.1	%/°C
Temperature Effect on Full Scale Span(4)	TCV_{FSS}	-0.1	—	+0.1	%/°C
Temperature Effect on Offset(5)	TCV_{off}	-9.0	—	+9.0	μV/°C
Input Impedance	Z_{in}	1800	—	4500	W
Output Impedance	Z_{out}	270	—	330	W
R_{CAL} (150 kΩ)(6)	R_{CAL}	97	100	103	mm Hg
Response Time(7) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band	—	0	—	85	°C
Stability(8)	—	—	±0.5	—	$\%V_{FSS}$

1. Recommended voltage supply: 6 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +10 V may induce additional error due to device self-heating.
2. Measured at 6.0 Vdc excitation for 100 mmHg pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 200 mmHg.
4. Slope of end-point straight line fit to full scale span at 15°C and +40°C relative to +25°C.
5. Slope of end-point straight line fit to zero pressure offset at 15°C and +40°C relative to +25°C.
6. Offset measurement with respect to the measured sensitivity when a 150k ohm resistor is connected to V_S and S+ output.
7. For a 0 to 300 mm Hg pressure step change.
8. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   - 1000 temperature cycles, -40°C to +125°C.
   - 1.5 million pressure cycles, 0 to 300 mm Hg.

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX4080D series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

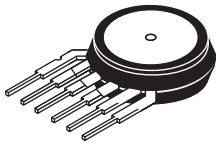
Features

- 3.0% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to 105°C
- Easy-to-Use, Durable Epoxy Unibody Package

ORDERING INFORMATION			
Device	**Device Type**	**Case No.**	**Device Marking**
MPX4080D	Differential	867	MPX4080D

MPX4080D

INTEGRATED PRESSURE SENSOR
0 TO 80 kPA (0 TO 11.6 psi)
0.58 TO 4.9 V OUTPUT



MPX4080D
CASE 867-08

PIN NUMBERS			
1	V_{out}	4	NC
2	GND	5	NC
3	V_S	6	NC

Note: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

Figure 1 shows a block diagram of the internal circuitry integrated on the pressure sensor chip.

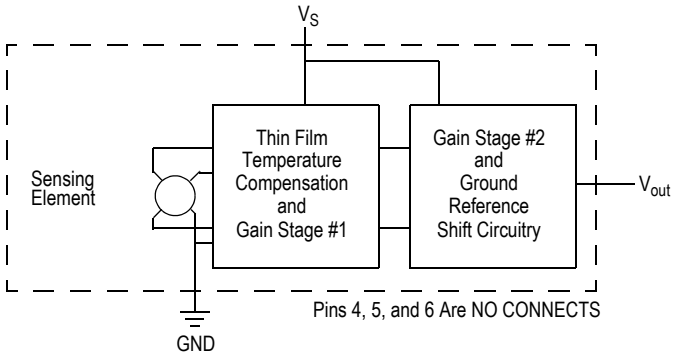


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings (1)

Rating		Symbol	Value	Unit
Maximum Pressure	(P1 > P2) (P2 > P1)	P_{max}	400 400	kPa
Storage Temperature		T_{stg}	-40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (VS = 5.1 Vdc, TA = 25×C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	80	kPa
Supply Voltage(2)	V_S	4.85	5.1	5.35	Vdc
Supply Current	I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3)(0 to 85°C) @ V_S = 5.1 V	V_{off}	0.478	0.575	0.672	Vdc
Full Scale Output(4)(0 to 85°C) @ V_S = 5.1 V	V_{FSO}	4.772	4.900	5.020	Vdc
Full Scale Span(5)(0 to 85°C) @ V_S = 5.1 V	V_{FSS}	—	4.325	—	Vdc
Accuracy(6)	—	—	—	3.0	$\%V_{FSS}$
Sensitivity	V/P	—	54	—	mV/kPa

1. 0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.

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Figure 2 shows the sensor output signal relative to differential pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

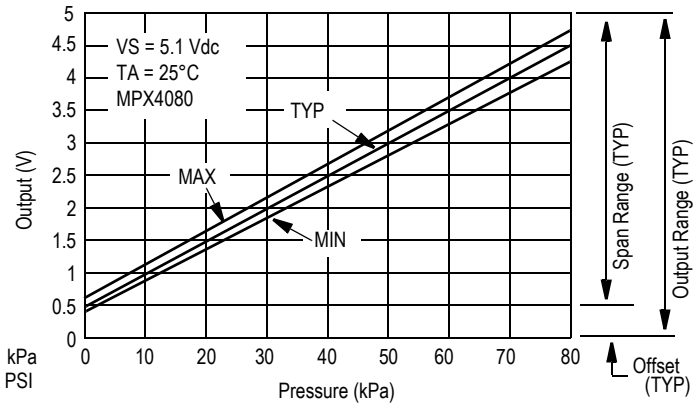

Figure 2. Output versus Pressure Differential

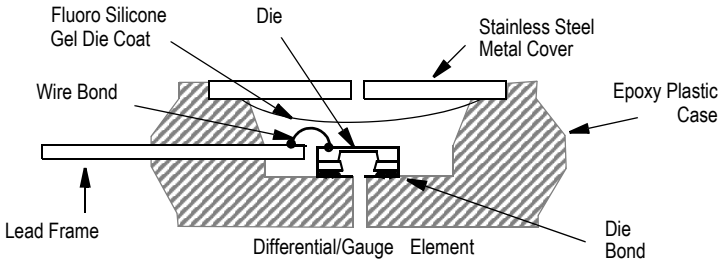

Figure 3. Cross-Sectional Diagrams (Not to Scale)

Figure 3 illustrates the differential sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4080D pressure sensor operating characteristics, internal reliability, and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

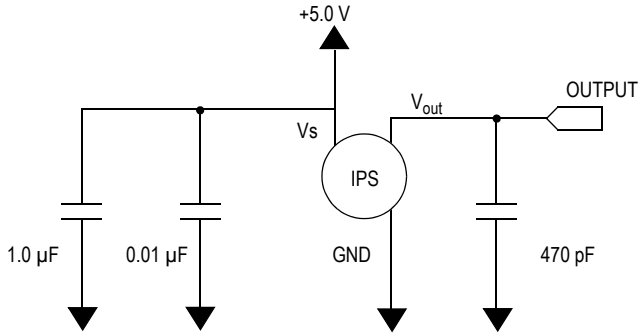

Figure 4. Recommended Power Supply Decoupling and Output Filter
(For additional output filtering information, refer to Application Note AN1646.)

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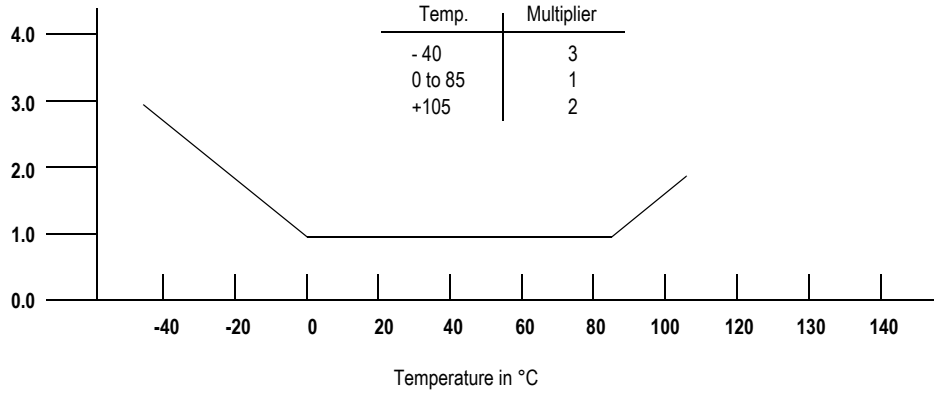
Transfer Function (MPX4080D)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 + 0.11280)$
$\pm$ (Pressure Error x Temp. Mult. x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25\ V$ P kPa

Temperature Error Multiplier

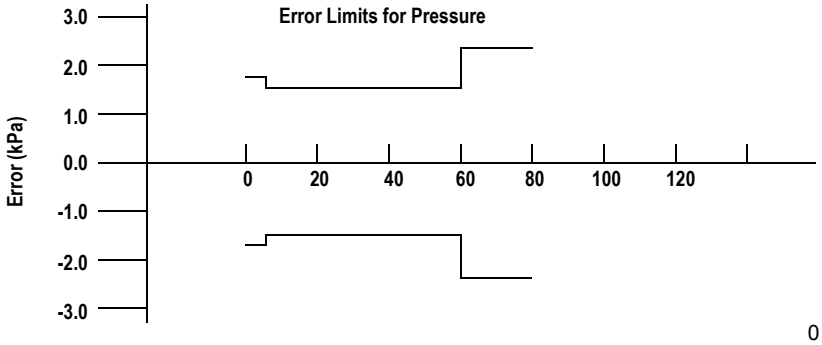
MPX4080D



Temp.	Multiplier
- 40	3
0 to 85	1
+105	2

NOTE: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 105°C.

Pressure Error Band



MPX4080D

Pressure	Error (max)
0 to 6 kPa	± 1.8 kPa
0 to 60 kPa	± 1.5 kPa
60 to 80 kPa	± 2.3 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

The two sides of the pressure sensor are designated as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side is identified by the stainless steel cap.

Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4100 SERIES

INTEGRATED PRESSURE SENSOR 20 TO 105 kPA (2.9 TO 15.2 psi) 0.3 TO 4.9 V OUTPUT

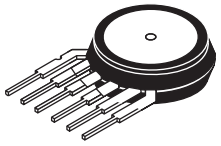
The MPX4100 series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the MAP sensor a logical and economical choice for automotive system designers.

Features

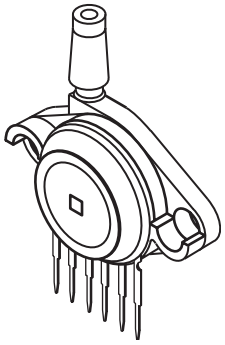
- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor Interfacing
- Temperature Compensated Over -40°C to +125°C
- Durable Epoxy Unibody Element
- Ideal for Non-Automotive Applications

Typical Applications

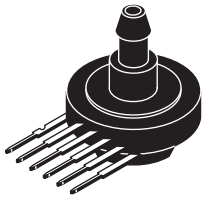
- Manifold Sensing for Automotive Systems



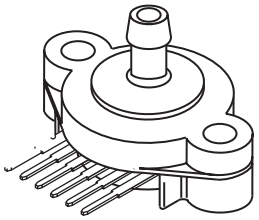
MPX4100A
CASE 867-08



MPX4100AP
CASE 867B-04



MPX4100AS
CASE 867E-03



MPX4100ASX
CASE 867F-03

ORDERING INFORMATION[1]				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
Basic Element	Absolute, Element Only	867-08	MPX4100A	MPX4100A
Ported Elements	Absolute, Ported	867B-04	MPX4100AP	MPX4100AP
	Absolute, Stove Pipe Port	867E-03	MPX4100AS	MPX4100A
	Absolute, Axial Port	867F-03	MPX4100ASX	MPX4100A

1. The MPX4100A series MAP silicon pressure sensors are available in the Basic Element, or with pressure port fittings that provide mounting ease and barbed hose connections.

PIN NUMBERS			
1	V_{OUT}	4	NC
2	GND	5	NC
3	V_S	6	NC

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The MPX4100 series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

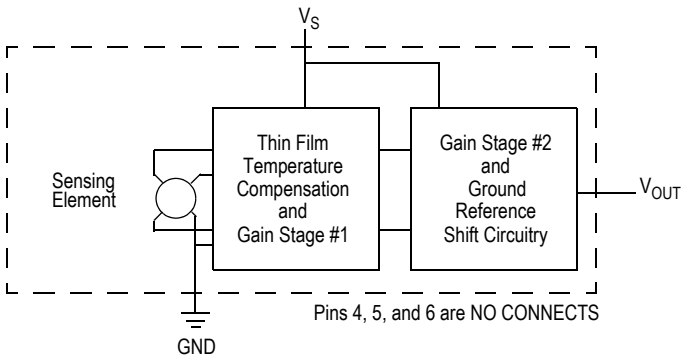

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. MAXIMUM RATINGS(1)

Rating	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. OPERATING CHARACTERISTICS (VS = 5.1 Vdc, TA = 25×C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[2]		P_{OP}	20	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.1 V	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output[4] @ V_S = 5.1 V	(0 to 85°C)	V_{FSO}	4.815	4.897	4.978	Vdc
Full Scale Span[5] @ V_S = 5.1 V	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. Decoupling circuit shown in Figure 3 required to meet electrical specifications.
2. 1.0 kPa (kiloPascal) equals 0.145 psi.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
10. Device is ratiometric within this specified excitation range.

Table 3. MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure[1]	—	—	—	690	kPa

1. Common mode pressures beyond specified may result in leakage at the case-to-lead interface.

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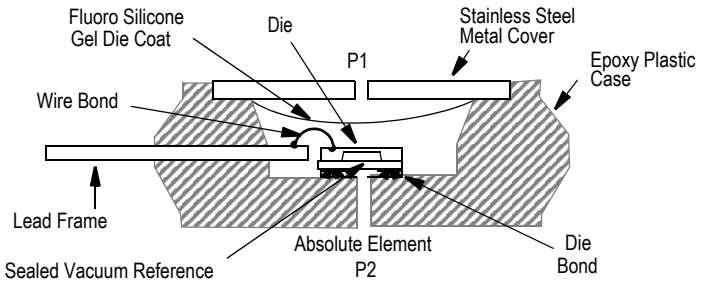

Figure 2. Cross-Sectional Diagram (Not to Scale)

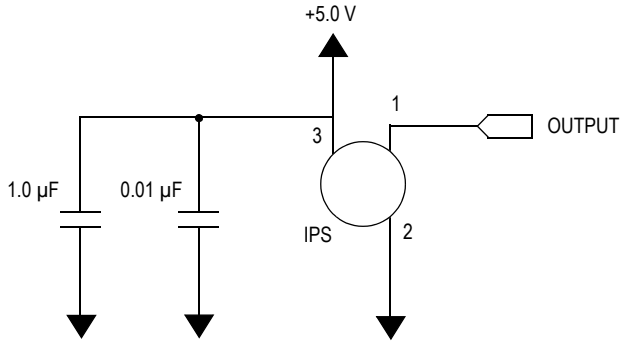

Figure 3. Recommended Power Supply Decoupling
(For output filtering recommendations, refer to Application Note AN1646.)

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4100A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

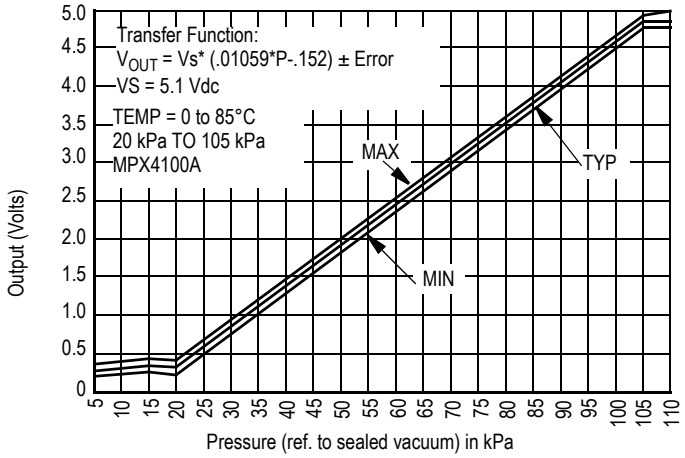

Figure 4. Output versus Absolute Pressure

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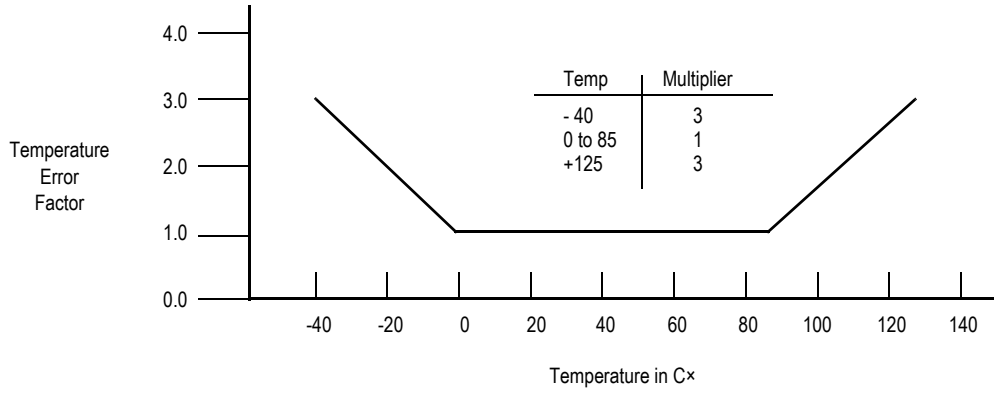
Transfer Function (MPX4100A)

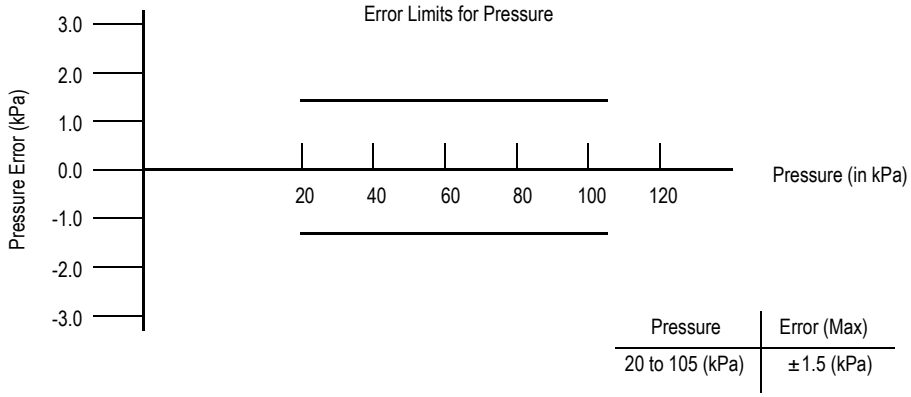
Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 - 0.1518)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25$ Vdc

Temperature Error Band

MPX4100A Series



Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

The two sides of the pressure sensor are designated as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel, which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4100A	867	Stainless Steel Cap
MPX4100AP	867B	Side with Port Marking
MPX4100AS	867E	Side with Port Attached
MPX4100ASX	867F	Side with Port Attached

Integrated Pressure Sensor

MPX4100A
MPXA4100A
SERIES

INTEGRATED
PRESSURE SENSOR
20 TO 105 kPa (2.9 TO 15.2 PSI)
0.3 TO 4.9 V OUTPUT

The Freescale MPX4100A/MPXA4100A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPX4100A/MPXA4100A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

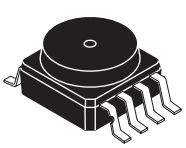
Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

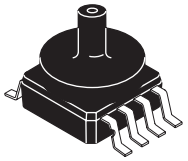
Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

SMALL OUTLINE PACKAGES



MPXA4100A6U/T1
CASE 482-01



MPXA4100AC6U
CASE 482A-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXA4100A SERIES)					
Basic Element	Absolute, Element Only	482	MPXA4100A6U	Rails	MPXA4100A
		482	MPXA4100A6T1	Tape & Reel	MPXA4100A
Ported Element	Absolute, Axial Port	482A	MPXA4100AC6U	Rails	MPXA4100A
UNIBODY PACKAGE (MPX4100A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4100A	—	MPX4100A
Ported Element	Absolute, Ported	867B	MPX4100AP	—	MPX4100AP
	Absolute, Stove Pipe Port	867E	MPX4100AS	—	MPX4100A

SMALL OUTLINE PACKAGE PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

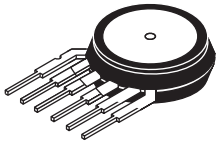
1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS(1)

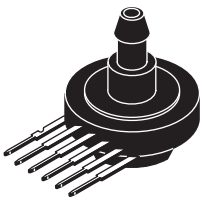
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

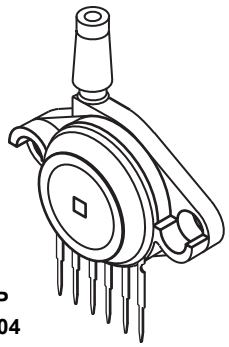
UNIBODY PACKAGES



MPX4100A
CASE 867-08



MPX4100AS
CASE 867E-03



MPX4100AP
CASE 867B-04

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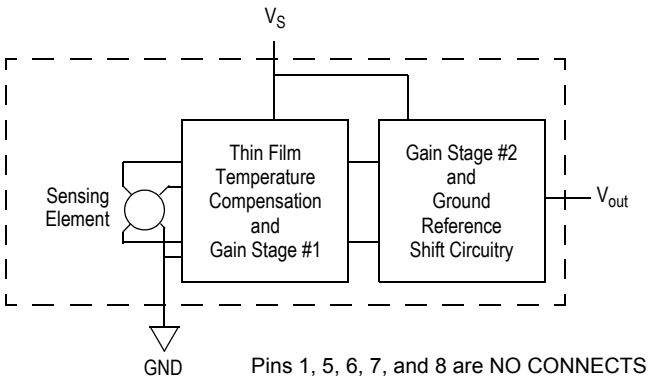

Figure 1. Fully Integrated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side (P1) relative to the vacuum side (P2). Similarly, output voltage increases as increasing vacuum is applied to the vacuum side (P2) relative to the pressure side (P1).

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Units
Pressure Range[1]		P_{OP}	20	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output[4] @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span[5] @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum related pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Small Outline Package (Case 482)	1.5	grams

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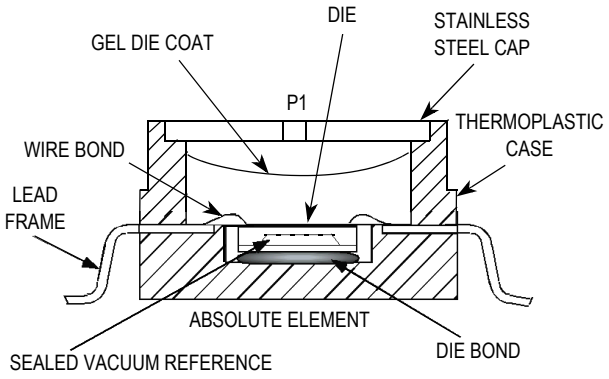

Figure 2. Cross Sectional Diagram SOP (not to scale)

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 482).

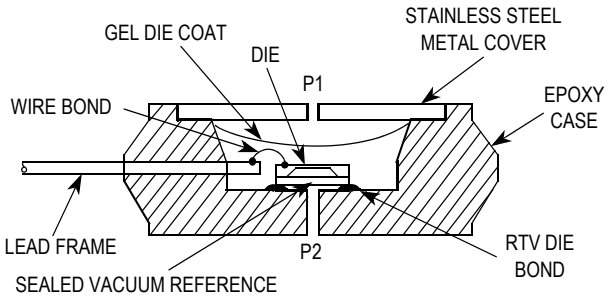

Figure 3. Cross Sectional Diagram (not to scale)

Figure 3 illustrates the absolute pressure sensing chip in the basic chip carrier (Case 867). A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

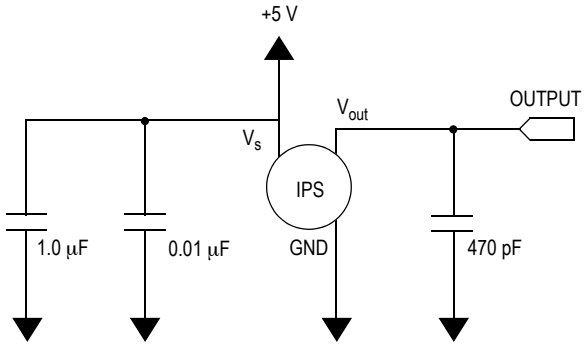

Figure 4. Recommended Power Supply Decoupling and Output Filtering (For additional output filtering, please refer to Application Note AN1646.)

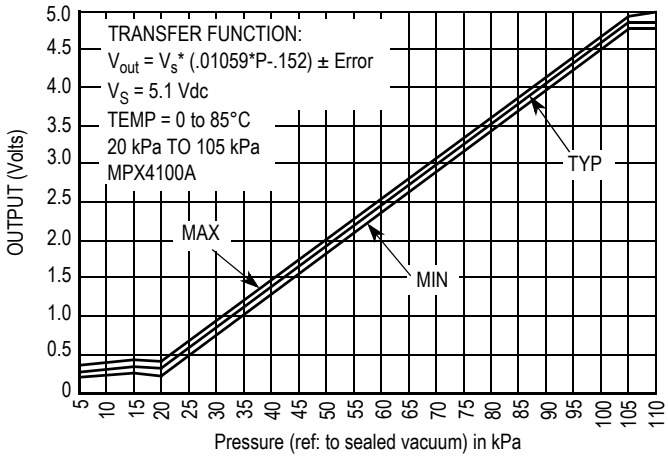

Figure 5. Output versus Absolute Pressure

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 5 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

The MPX4100A/MPXA4100A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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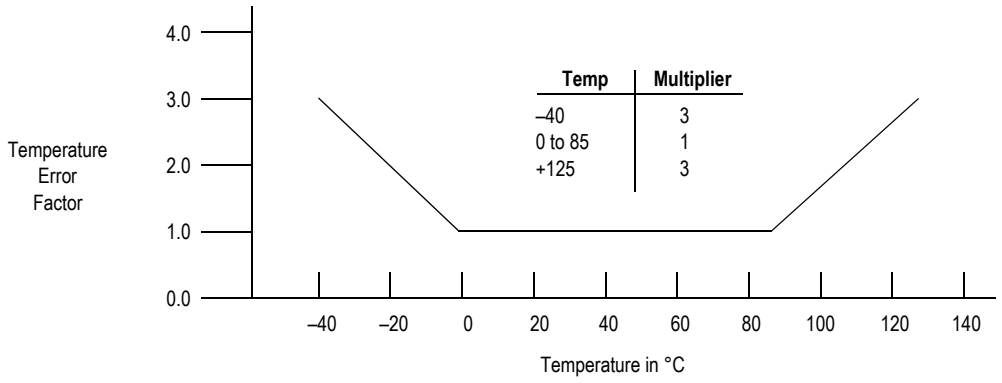
Transfer Function (MPX4100A, MPXA4100A)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 - 0.1518)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1 V \pm 0.25$ Vdc

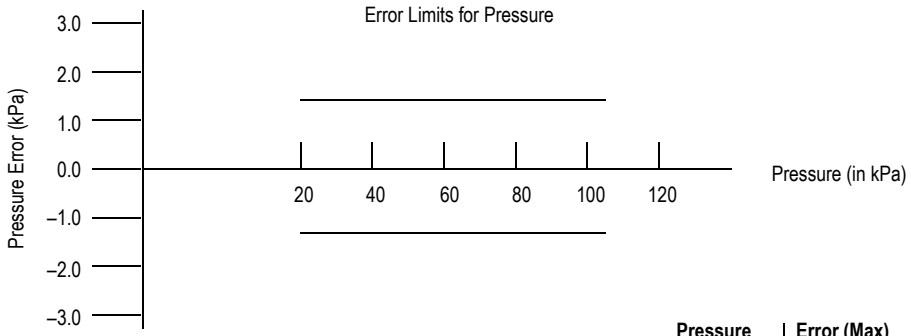
Temperature Error Band

MPX4100A, MPXA4100A Series



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 105 (kPa)	±1.5 (kPa)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the following table.

Table 4. Pressure (P1) Side Delineation

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4100A	867	Stainless Steep Cap
MPX4100AP	867B	Side with Port Marking
MPX4100AS	867E	Side with Port Attached
MPXA4100A6U/T1	482	Stainless Steel Cap
MPXA4100AC6U	482A	Side with Port Attached

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

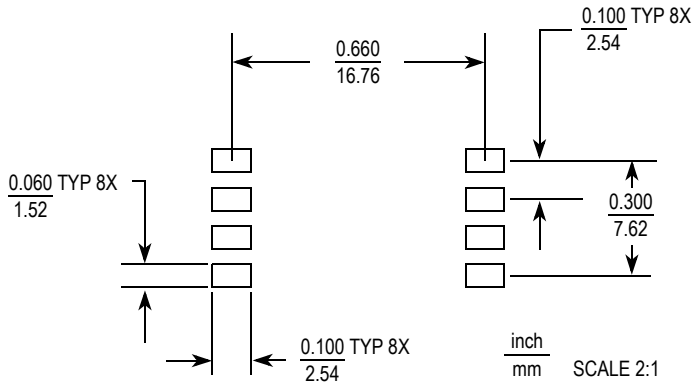

Figure 6. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4101A
MPXA4101A
MPXH6101A
SERIES

INTEGRATED PRESSURE SENSOR
15 TO 102 kPA
(2.18 TO 14.8 psi)
0.25 TO 4.95 V OUTPUT

The Freescale MPX4101A/MPXA4101A/MPXH6101A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPX4101A/MPXA4101A/MPXH6101A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

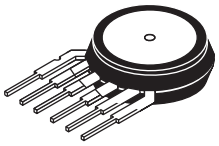
Features

- 1.72% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

Typical Applications

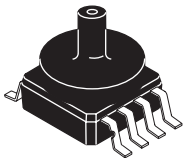
- Manifold Sensing for Automotive Systems
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

UNIBODY PACKAGE



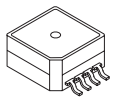
MPX4101A
CASE 867-O8

SMALL OUTLINE PACKAGE



MPXA4101AC6U
CASE 482A-01

SUPER SMALL OUTLINE PACKAGE



MPXH6101A6U/6T1
CASE 1317-04

UNIBODY PACKAGE PIN NUMBERS(1)			
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

SUPER SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
UNIBODY PACKAGE (MPX4101A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4101A	—	MPX4101A
SMALL OUTLINE PACKAGE (MPXA4101A SERIES)					
Ported Element	Absolute, Axial Port	482A	MPXA4101AC6U	Rails	MPXA4101A
SUPER SMALL OUTLINE PACKAGE (MPXA6101A SERIES)					
Basic Element	Absolute, Element Only	1317	MPXH6101A6U	Rails	MPXH6101A
	Absolute, Element Only	1317	MPXH6101A6T1	Tape and Reel	MPXH6101A

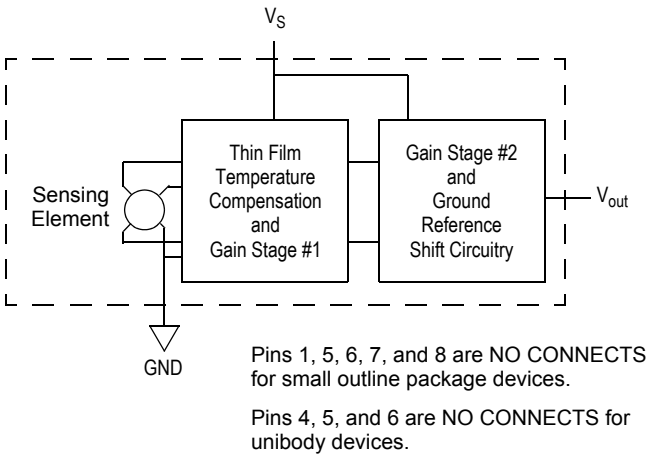


Figure 1. Temperature Compensated and Calibrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	15	—	102	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.171	0.252	0.333	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.7	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.72	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time[7]		t_R	—	15	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 2 illustrates an absolute sensing chip in the super small outline package (Case 1317).

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4101A/MPXA4101A/MPXH6101A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

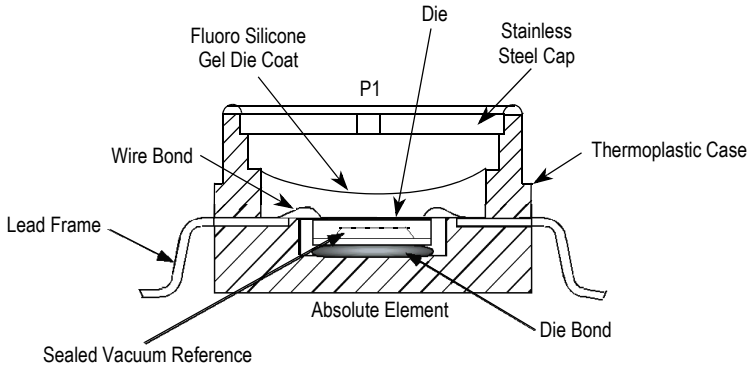

Figure 2. Cross Sectional Diagram SSOP (not to scale)

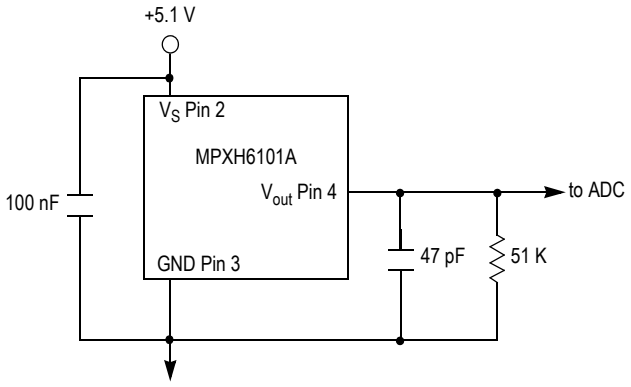

Figure 3. Recommended Power Supply Decoupling and Output Filtering

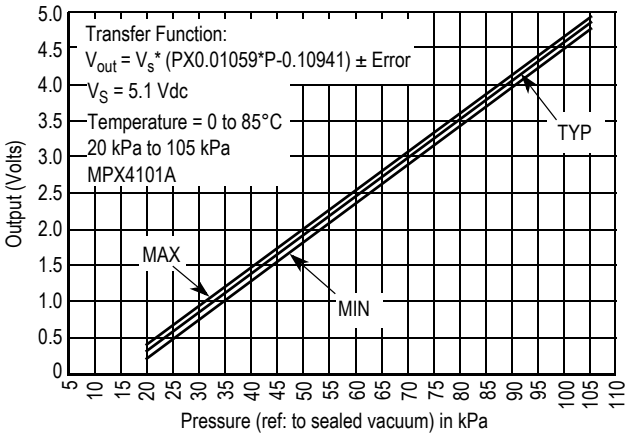

Figure 4. Output versus Absolute Pressure

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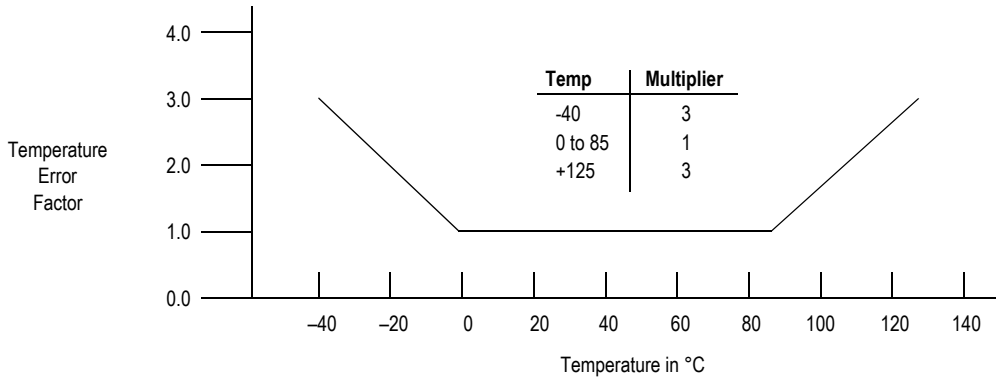
Transfer Function (MPX4101A, MPXA4101A, MPXH6101A)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 - 0.10941)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25\ Vdc$

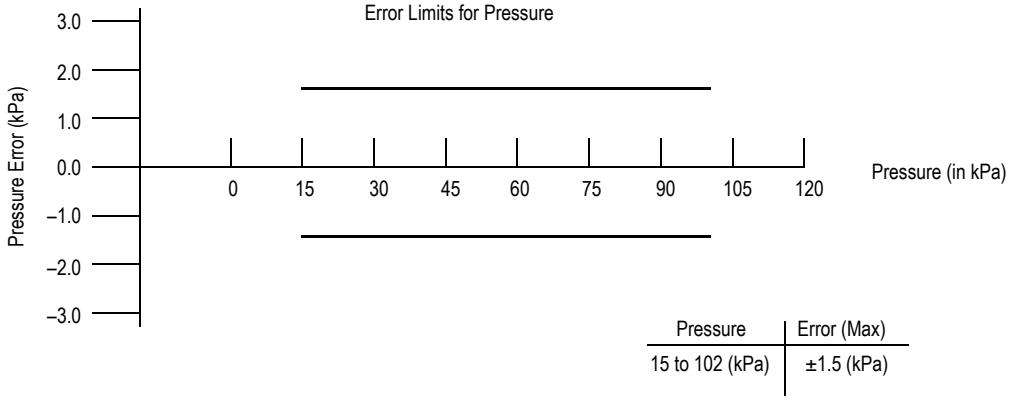
Temperature Error Band

MPX4101A, MPXA4101A MPXH6101A SERIES



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The Freescale pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX4101A	867	Stainless Steel Cap
MPXA4101AC6U	482A	Side with Port Attached
MPXH6101A6U	1317	Stainless Steel Cap
MPXH6101A6T1	1317	Stainless Steel Cap

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

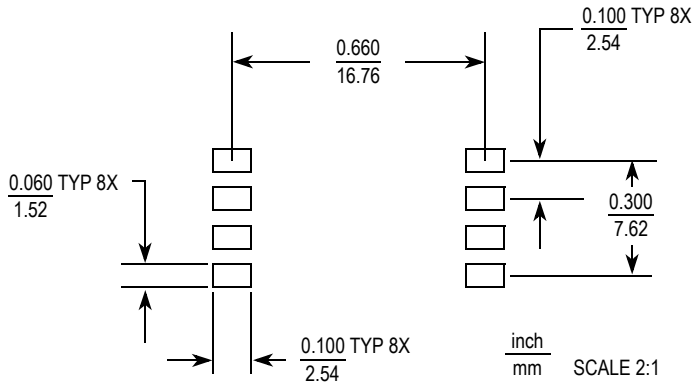

Figure 5. SOP Footprint (Case 482)

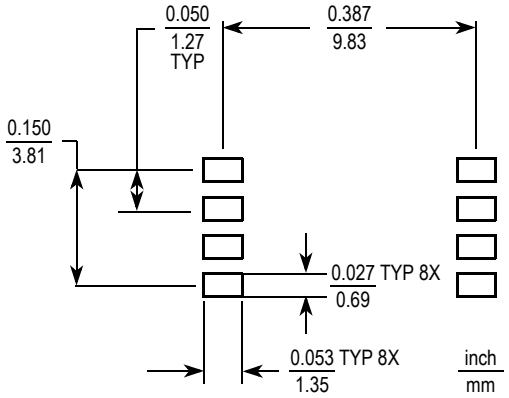

Figure 6. SSOP Footprint (Case 1317)

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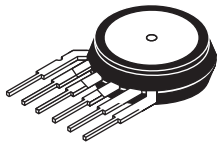
Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4105A SERIES

INTEGRATED PRESSURE SENSOR 15 TO 105 kPA (2.2 TO 15.2 psi) 0.3 TO 4.9 V OUTPUT

UNIBODY PACKAGE



MPX4105A
CASE 867-08

The Freescale MPX4105A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

Freescale's MAP sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for the automotive system designer.

The MPX4105A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Temperature Compensated Over –40 to +125°C
- Durable Epoxy Unibody Element

Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Also Ideal for Non-Automotive Applications

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Device Marking**
UNIBODY PACKAGE (MPX4105A SERIES)				
Basic Element	Absolute, Element	867	MPX4105A	MPX4105A

PIN NUMBERS(1)			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

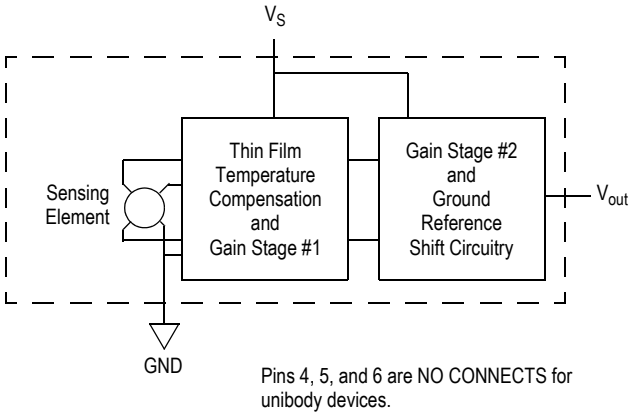


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	15	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3]	(0 to 85°C)	V_{off}	0.184	0.306	0.428	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.804	4.896	4.988	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	51	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	15	—-	ms
Offset Stability[9]		—	—	±0.65	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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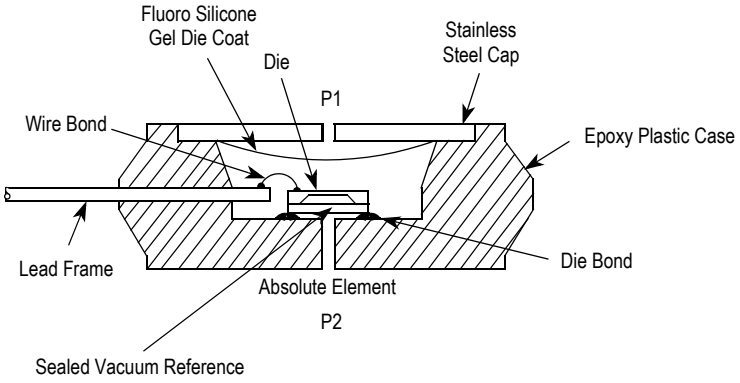

Figure 2. Cross Sectional Diagram (not to scale)

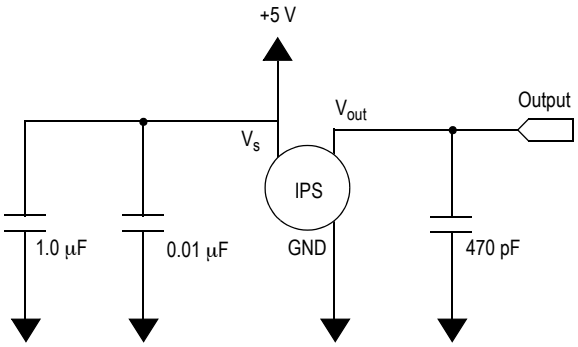

Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646)

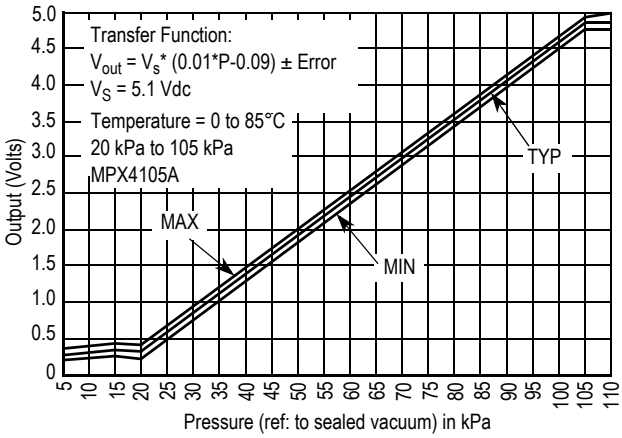

Figure 4. Output versus Absolute Pressure

Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 867).

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4105A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over a temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

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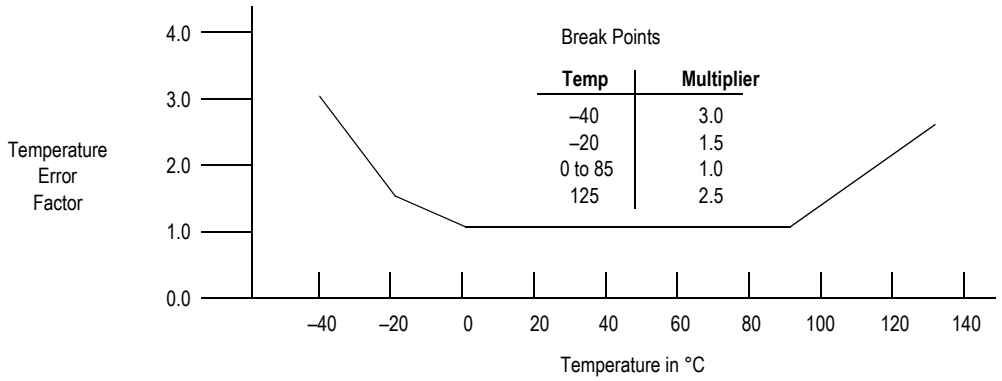
Transfer Function (MPX4105A)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01 - 0.09)$
$\pm$ (Pressure Error x Temp. Factor x 0.01 x V_S)
$V_S = 5.1\ V \pm 0.25\ Vdc$

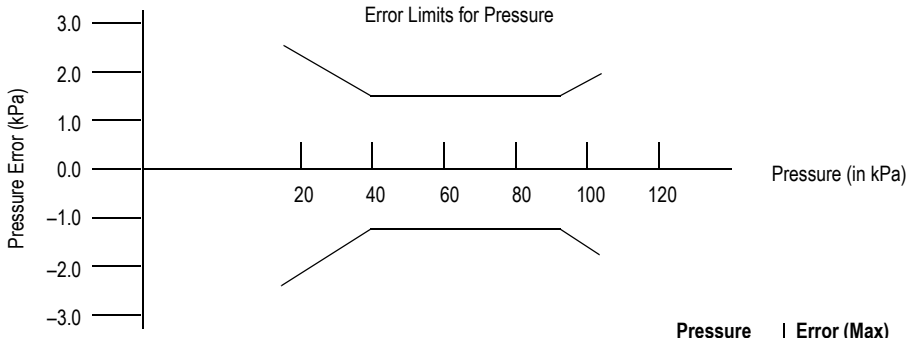
Temperature Error Band

MPX4105A Series



NOTE: The Temperature Multiplier is a linear response from –40°C to –20°C, –20°C to 0°C, and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
40 to 94 (kPa)	±1.5 (kPa)
15 (kPa)	±2.4 (kPa)
105 (kPa)	±1.8 (kPa)

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Integrated Silicon Pressure Sensor Altimeter/Barometer Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4115 SERIES

OPERATING OVERVIEW
INTEGRATED PRESSURE SENSOR
15 to 115kPa (2.18 to 16.7 psi)
0.2 to 4.8 Volts Output

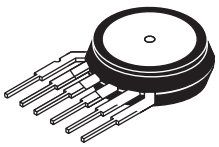
The MPX4115 series is designed to sense absolute air pressure in an altimeter or barometer (BAP) applications. Freescale's BAP sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and high reliability of on-chip integration makes the Freescale BAP sensor a logical and economical choice for application designers.

Features

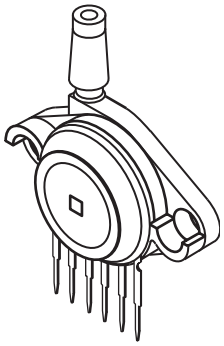
- 1.5% Maximum Error over 0° to 85°
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

Typical Applications

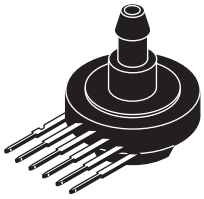
- Altimeter
- Baromete



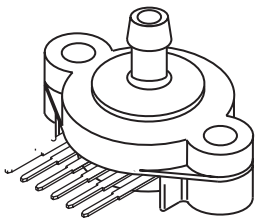
MPX4115A
CASE 867-08



MPX4115AP
CASE 867B-04



MPX4115AS
CASE 867E-03



MPX4115ASX
CASE 867F-03

ORDERING INFORMATION[1]				
Device	**Options**	**Case No.**	**MPX Series Order No.**	**Marking**
Basic Element	Absolute, Element Only	Case 867-08	MPX4115A	MPX4115A
Ported Elements	Absolute, Ported	Case 867B-04	MPX4115AP	MPX4115AP
	Absolute, Stove Pipe Port	Case 867E-03	MPX4115AS	MPX4115A
	Absolute, Axial Port	Case 867F-03	MPX4115ASX	MPX4115A

1. The MPX4115A BAP Sensor is available in the Basic Element package or with pressure port fittings that provide mounting ease and barbed hose connections.

PIN NUMBERS			
1	V_{OUT}[1]	4	N/C[2]
2	GND	5	N/C[2]
3	V_S	6	N/C[2]

1. Pin 1 is noted by the notch in the lead.
2. Pins 4, 5, and 6 are internal device connections. Pin 1 is noted by the notch in the Lead. Do not connect to external circuitry or ground.

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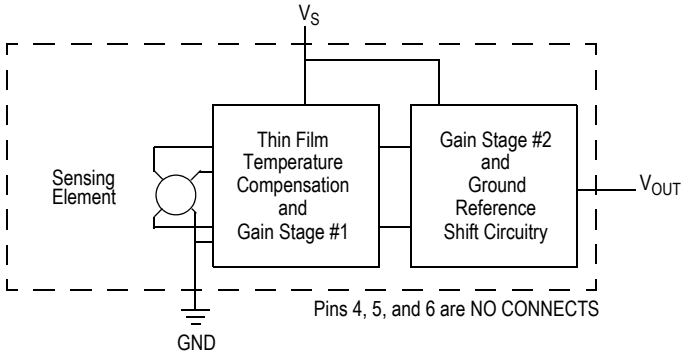

Figure 1. Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Unit
Overpressure(2) (P1 > P2)	P_{max}	400	kPa
Burst Pressure(2) (P1 > P2)	P_{burst}	1000	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C

1. T_C = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics

(V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2 Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	15	-	115	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{off}	0.135	0.204	0.273	Vdc
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.725	4.794	4.863	Vdc
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	46	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o+	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	mSec
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:

   Linearity:Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.

   Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.

   Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.

   TcSpan:Output deviation over the temperature range of 0° to 85°C, relative to 25°C.

   TcOffset:Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.

   Variation from Nominal:The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Common Mode Line Pressure(1)	—	—	—	690	kPa

1. Common mode pressures beyond what is specified may result in leakage at the case-to-lead interface.

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Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4115A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C. (The output will saturate outside of the specified pressure range.)

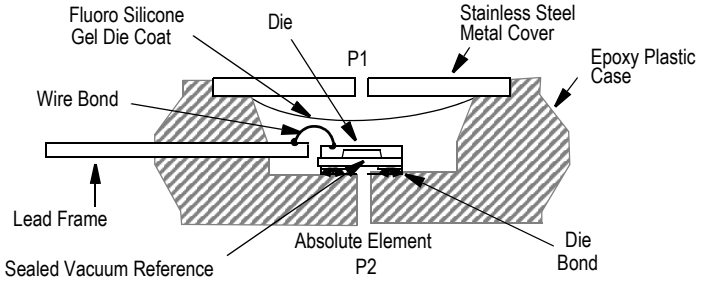

Figure 2. Cross-Sectional Diagram (Not to Scale)

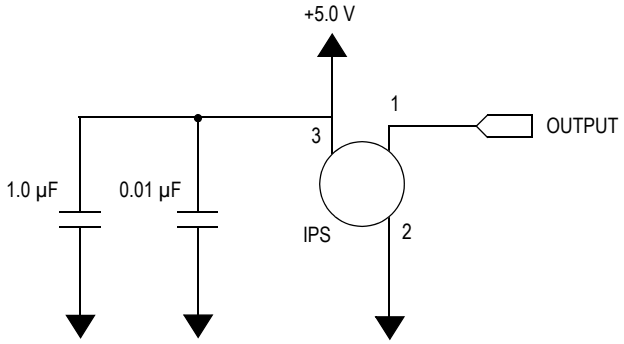

Figure 3. Recommended Power Supply Decoupling.
(For output filtering recommendations, please refer to Application Note AN1646.)

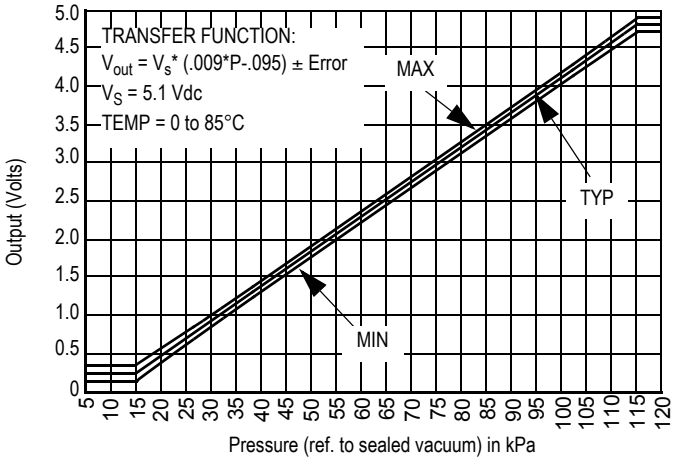

Figure 4. Output versus Absolute Pressure

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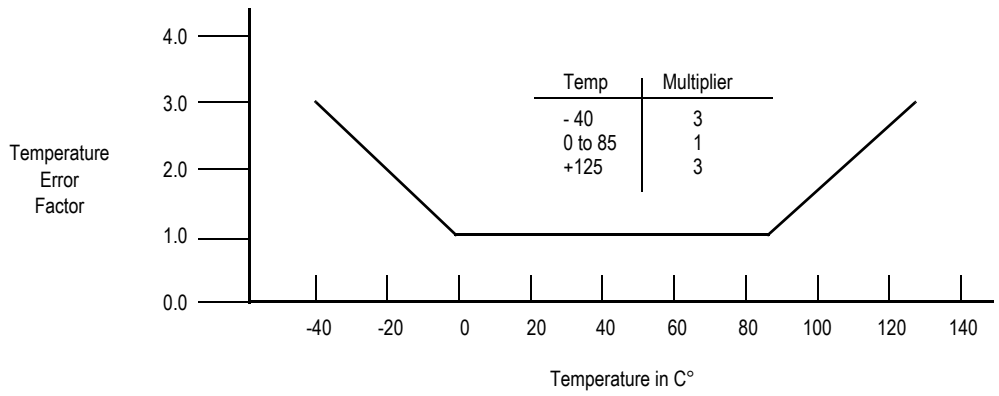
Transfer Function (MPX4115)

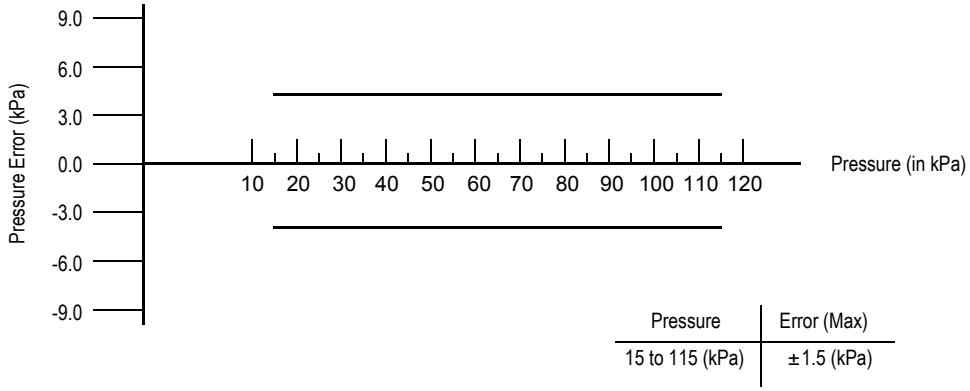
Nominal Transfer Value: $V_{out} = V_S (P \times 0.009 - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x 0.009 x V_S)
$V_S = 5.1\ V \pm 0.25$ Vdc

Temperature Error Band

MPX4115A Series



Pressure Error Band



Pressure	Error (Max)
15 to 115 (kPa)	±1.5 (kPa)

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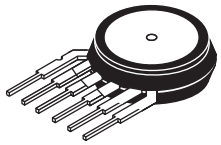
Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4200A SERIES

INTEGRATED PRESSURE SENSOR
20 to 200 kPa (2.9 to 29 psi)
0.3 to 4.9 V OUTPUT

UNIBODY PACKAGE



MPX4200A
CASE 867-08

The Freescale MPX4200A series Manifold Absolute Pressure (MAP) sensor for turbo boost engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

The MPX4200A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high level analog output signal and temperature compensation. The small form factor and reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for automotive system designers.

Features

- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over –40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

Typical Applications

- Manifold Sensing for Automotive Systems
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Also ideal for Non-Automotive Applications

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Device Marking**
UNIBODY PACKAGE (MPX4200A SERIES)				
Basic Element	Absolute, Element	867	MPX4200A	MPX4200A

PIN NUMBERS(1)			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

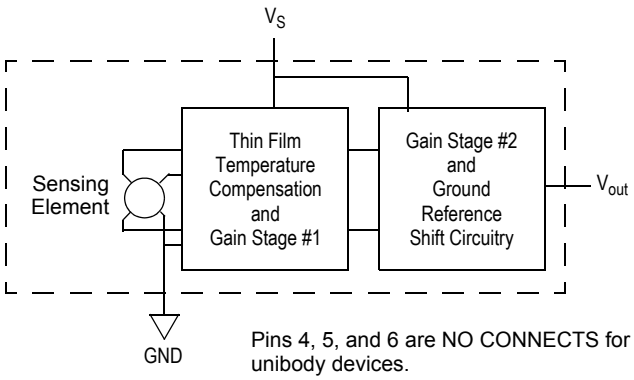


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	800	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	20	—	200	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.199	0.306	0.413	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.725	4.896	4.978	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.590	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	25.5	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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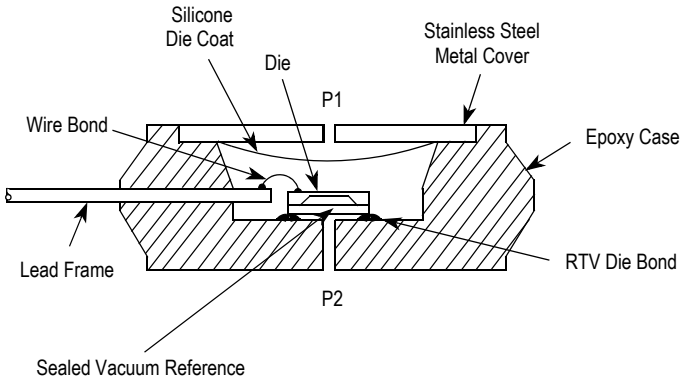

Figure 2. Cross Sectional Diagram (not to scale)

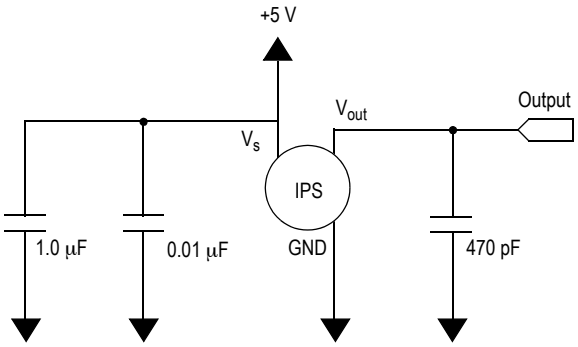

Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646)

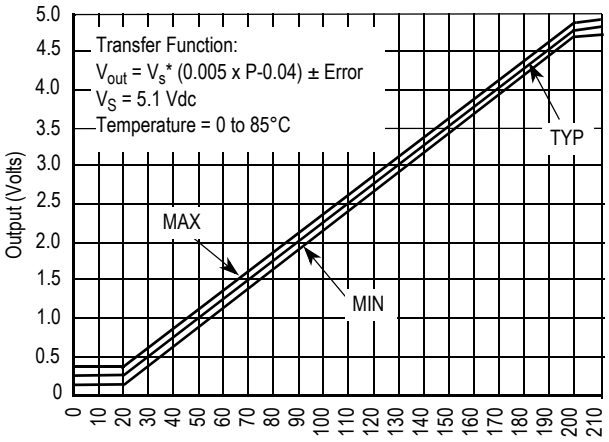

Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the absolute sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The MPX4200A series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over temperature range of 0° to 85°C. The output will saturate outside of the specified pressure range.

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Integrated Silicon Pressure Sensor Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4250A
MPXA4250A
SERIES

INTEGRATED
PRESSURE SENSOR
20 TO 250 kPA (2.9 TO 36.3 psi)
0.2 TO 4.9 V OUTPUT

The MPX4250A/MPXA4250A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

The MPX4250A/MPXA4250A series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for the automotive system engineer.

Features

- 1.5% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over -40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element or Thermoplastic Small Outline, Surface Mount Package
- Ideal for Non-Automotive Applications

Typical Applications

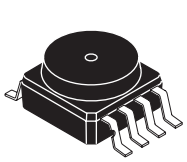
- Turbo Boost Engine Control
- Ideally Suited for Microprocessor or Microcontroller-Based Systems

ORDERING INFORMATION

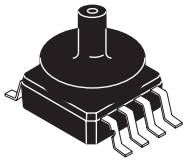
Device Type	Options	Case No.	MPX Series Order Number	Packing Options	Device Marking
SMALL OUTLINE PACKAGE(1) (MPXA4250A SERIES)					
Basic Elements	Absolute, Element Only	482	MPXA4250A6U	Rails	MPXA4250A
		482	MPXA4250A6T1	Tape & Reel	MPXA4250A
Ported Elements	Absolute, Axial Port	482A	MPXA4250AC6U	Rails	MPXA4250A
		482A	MPXA4250AC6T1	Tape & Reel	MPXA4250A
UNIBODY PACKAGE(2) (MPX4250A SERIES)					
Basic Element	Absolute, Element Only	867	MPX4250A	—	MPX4250A
Ported Elements	Absolute, Ported	867B	MPX4250AP	—	MPX4250AP

1. The MPXA4250A series pressure sensors are available in the basic element package or with pressure port fitting. Two packing options are offered for each type.
2. The MPX4250A series pressure sensors are available in the basic element package or with pressure port fittings providing mounting ease and barbed hose connections.

SMALL OUTLINE PACKAGES



MPXA4250A6U/6T1
CASE 482-01



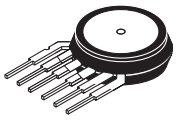
MPXA4250AC6U/C6T1
CASE 482A-01

SMALL OUTLINE PACKAGE PIN NUMBERS

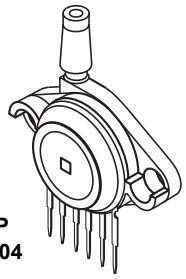
1	N/C(1), (2)	5(2)	N/C
2	V_S	6(2)	N/C
3	GND	7(2)	N/C
4	V_{OUT}	8	N/C

1. Pin 1 in noted by the notch in the lead.
2. Pins 1, 5, 6, and 7 are internal device connections. Do not connect to external circuitry or ground.

UNIBODY PACKAGES



MPX4250A
CASE 867-08



MPX4250AP
CASE 867B-04

UNIBODY PACKAGE PIN NUMBERS

1	V_{OUT}(1)	4	N/C(2)
2	GND	5	N/C(2)
3	V_S	6	N/C(2)

1. Pin 1 in noted by the notch in the lead.
2. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground.

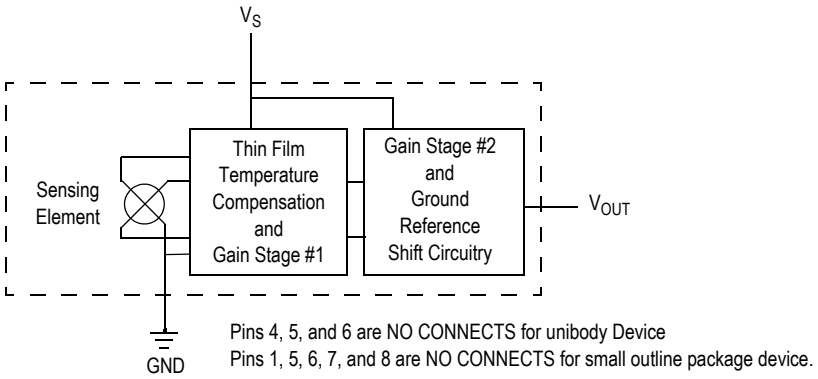


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure(2) (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. TC = 25°C unless otherwise noted.
2. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2, Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Units
Differential Pressure Range(1)		P_{OP}	20	—	250	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	V_{DC}
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.1 Volts	(0 to 85°C)	V_{OFF}	0.133	0.204	0.264	V_{DC}
Full Scale Output(4) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSO}	4.826	4.896	4.966	V_{DC}
Full Scale Span(5) @ V_S = 5.1 Volts	(0 to 85°C)	V_{FSS}	—	4.692	—	V_{DC}
Accuracy(6)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	20	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	msec
Output Source Current at Full Scale Output		I_O+	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	msec
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation at any temperature from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of VFSS, at 25°C.
7. Response Time is defined as the time form the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure is stabilized.
9. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	Grams
Weight, Small Outline Package (Case 482)	1.5	Grams

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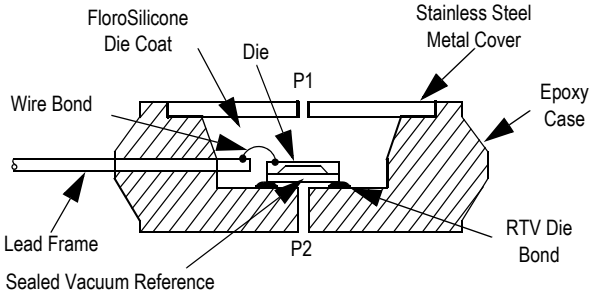

Figure 2. Cross Sectional Diagram (Not to Scale)

Figure 2 illustrates the absolute pressure sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250A/MPXA4250A series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability.

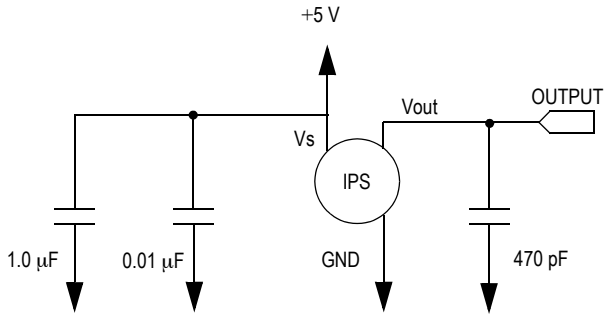

Figure 3. Recommended Power Supply Decoupling and Output Filtering

(For additional output filtering, please refer to Application Note AN1646.

Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

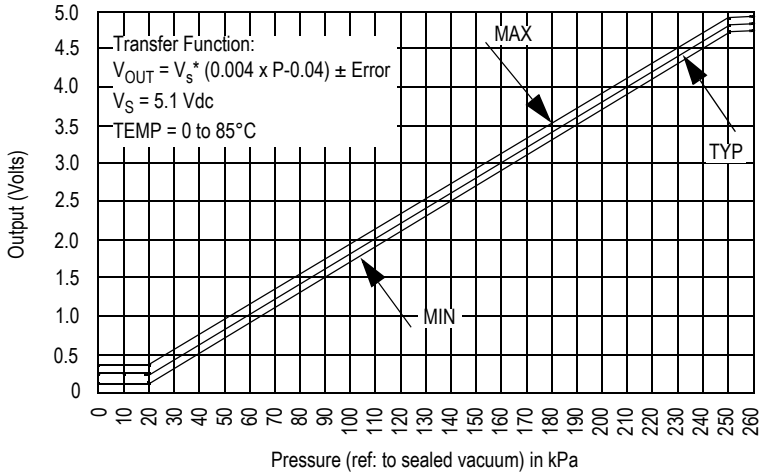

Figure 4. Output vs. Absolute Pressure

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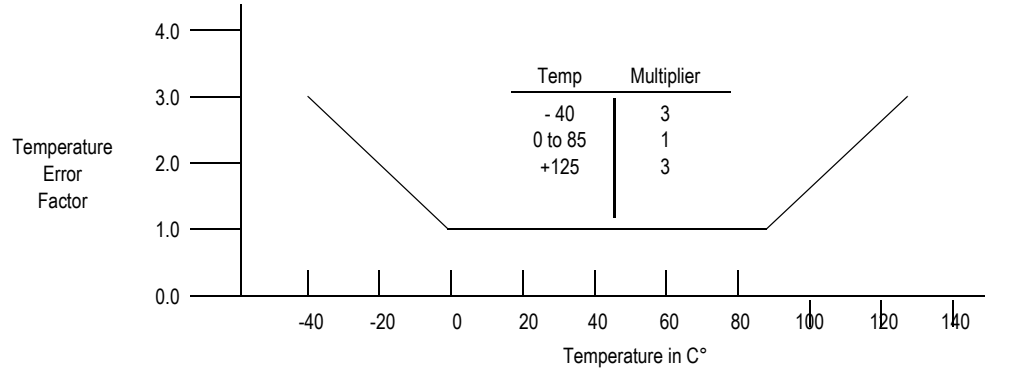
Transfer Function

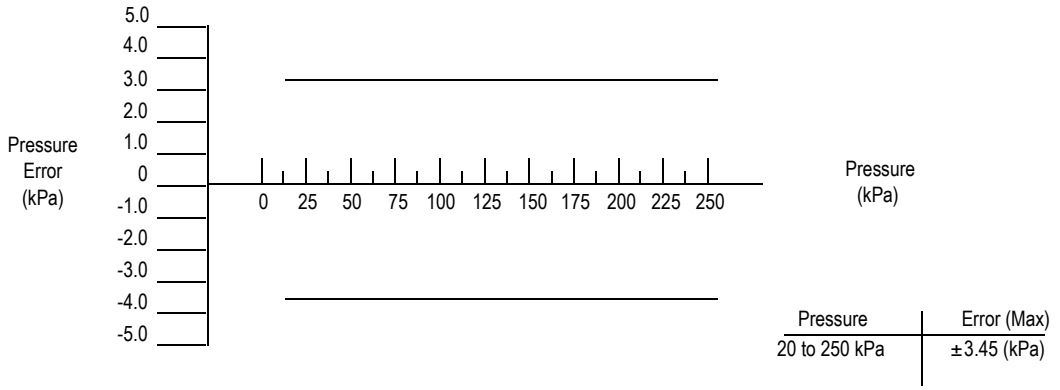
Nominal Transfer Value: $V_{OUT} = V_S (P \times 0.004 - 0.04)$
$\pm$ (Pressure Error $\times$ Temp. Factor $\times$ 0.004 $\times$ V_S)
$V_S = 5.1\ V \pm 0.25\ V_{DC}$

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0× to -40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 250 kPa	±3.45 (kPa)

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INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct Footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

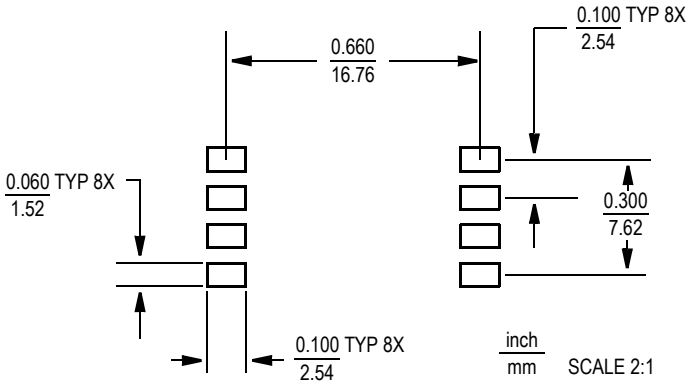

Figure 5. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX4250D SERIES

INTEGRATED PRESSURE SENSOR 0 TO 250 kPA (0 TO 36.3 psi) 0.2 TO 4.9 V OUTPUT

The MPX4250D series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for the automotive system engineer.

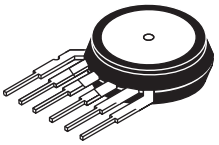
Features

- Differential and Gauge Applications Available
- 1.4% Maximum Error Over 0° to 85°C
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over –40° to +125°C
- Offers Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element

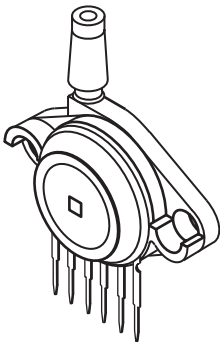
Typical Applications

- Ideally Suited for Microprocessor or Microcontroller-Based Systems

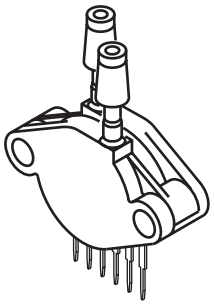
UNIBODY PACKAGES



BASIC CHIP CARRIER ELEMENT CASE 867-08 STYLE 1



GAUGE PORT OPTION CASE 867B-04 STYLE 1



DUAL PORT OPTION CASE 867C-05 STYLE 1

ORDERING INFORMATION[1]			
Device Type	**Case No.**	**MPX Series Order No.**	**Device Marking**
UNIBODY PACKAGE (MPX4250D SERIES)			
Basic Element	867	MPX4250D	MPX4250D
Gauge Ported Element	867B	MPX4250GP	MPX4250GP
Dual Ported Element	867C	MPX4250DP	MPX4250DP

1. The MPX4250D series silicon pressure sensors are available in the basic element package or with pressure port fittings that provide mounting ease and barbed hose connections.

PIN NUMBERS[1]			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

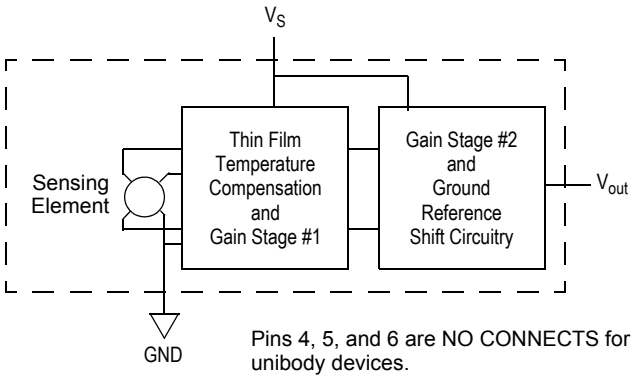


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	250	kPa
Supply Voltage(2)		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{off}	0.139	0.204	0.269	Vdc
Full Scale Output @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSO}	4.844	4.909	4.974	Vdc
Full Scale Span @ V_S = 5.1 Volts(5)	(0 to 85°C)	V_{FSS}	—	4.705	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±1.4	$\%V_{FSS}$
Sensitivity		$\Delta V/\Delta P$	—	18.8	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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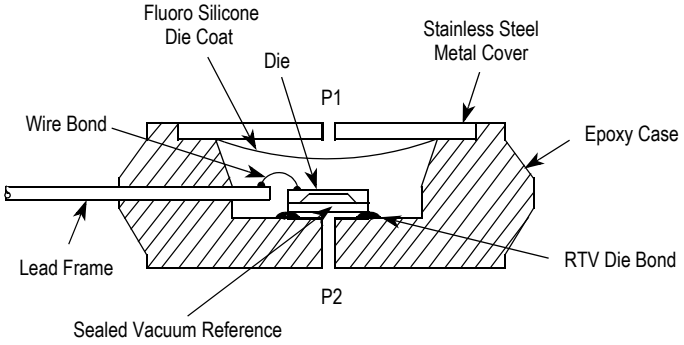

Figure 2. Cross Sectional Diagram (not to scale)

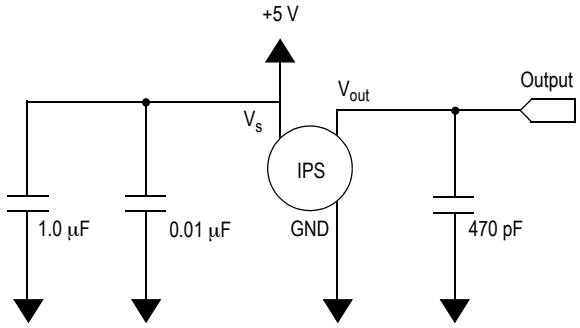

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1535)

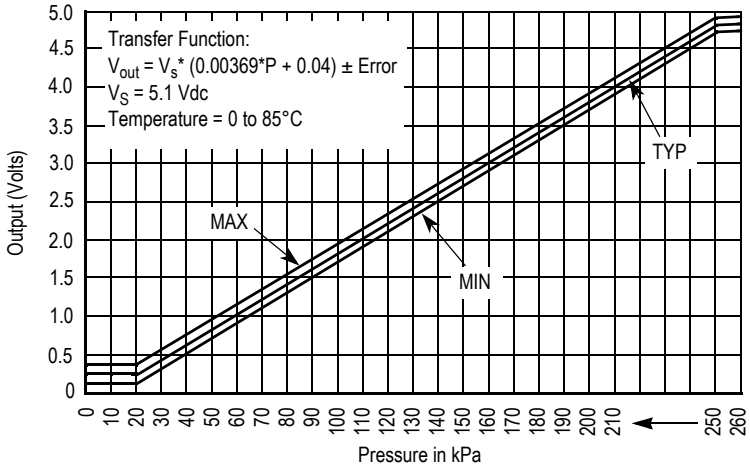

Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the differential/gauge pressure sensing chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX4250D series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

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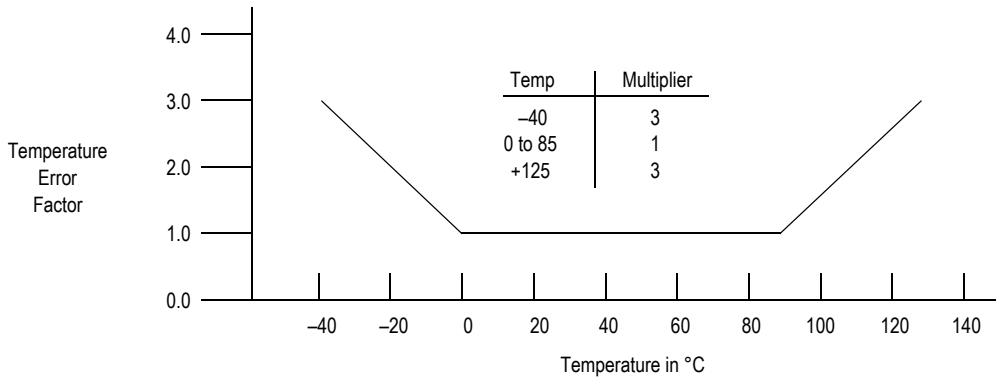
Transfer Function (MPX4250D)

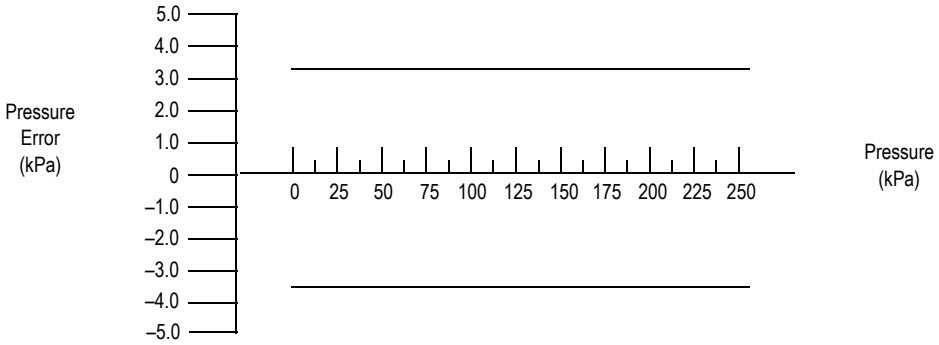
Nominal Transfer Value: $V_{out} = V_S \times (0.00369 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.00369 x V_S)
$V_S = 5.1 \pm 0.25$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 250 kPa	±3.45 kPa

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5010
MPXV5010G
SERIES

INTEGRATED
PRESSURE SENSOR
0 to 10 kPa (0 to 1.45 psi)
0.2 to 4.7 V OUTPUT

The MPX5010/MPXV5010G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

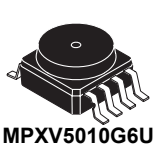
Features

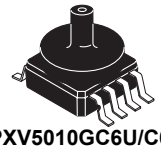
- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Epoxy Unibody and Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations
- Available in Surface Mount (SMT) or Through-hole (DIP) Configurations

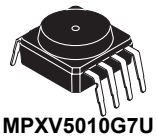
Application Examples

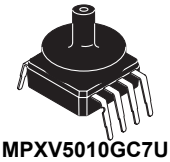
- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

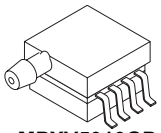
SMALL OUTLINE PACKAGE

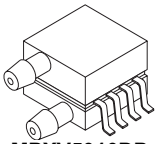

MPXV5010G6U
CASE 482-01


MPXV5010GC6U/C6T1
CASE 482A-01


MPXV5010G7U
CASE 482B-03


MPXV5010GC7U
CASE 482C-03


MPXV5010GP
CASE 1369-01


MPXV5010DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV5010G SERIES)					
Basic Elements	Gauge, Element Only, SMT	482	MPXV5010G6U	Rails	MPXV5010G
	Gauge, Element Only, DIP	482B	MPXV5010G7U	Rails	MPXV5010G
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV5010GC6U	Rails	MPXV5010G
	Gauge, Axial Port, DIP	482C	MPXV5010GC7U	Rails	MPXV5010G
	Gauge, Axial Port, SMT	482A	MPXV5010GC6T1	Tape & Reel	MPXV5010G
	Gauge, Side Port, SMT	1369	MPXV5010GP	Trays	MPXV5010G
	Gauge, Dual Port, SMT	1351	MPXV5010DP	Trays	MPXV5010G
UNIBODY PACKAGE (MPX2202 SERIES)					
Basic Element	Differential	867	MPX5010D	—	MPXV5010D
Ported Elements	Differential, Gauge	867C	MPX5010DP	—	MPXV5010DP
	Gauge	867B	MPX5010GP	—	MPXV5010GP
	Gauge, Axial	867E	MPX5010GS	—	MPXV5010D
	Gauge, Axial PC Mount	867F	MPX5010GSX	—	MPXV5010D

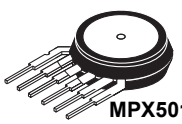
UNIBODY PACKAGE PIN NUMBERS[1]			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

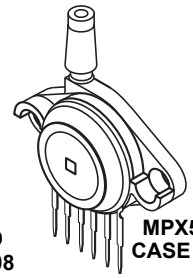
1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGE PIN NUMBERS[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGES


MPX5010D
CASE 867-08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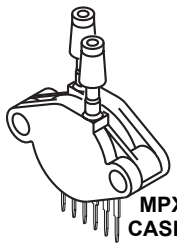
CASE 867B-04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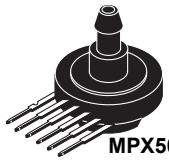
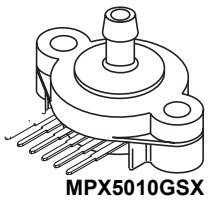
CASE 867C-05


MPX5010GS
CASE 867E-03


MPX5010GSX
CASE 867F-03

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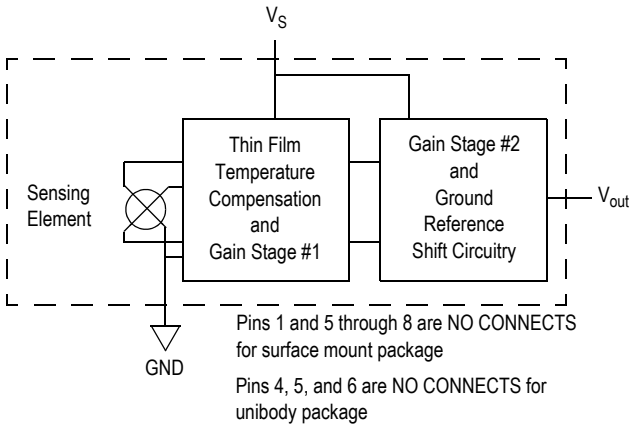

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	10	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	5.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0	0.2	0.425	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.475	4.7	4.925	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.275	4.5	4.725	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	450	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 482)	1.5	grams

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5010 and MPXV5010G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

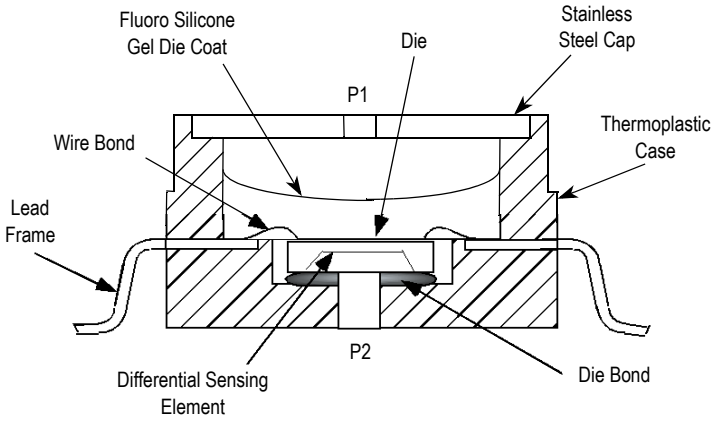

Figure 2. Cross-Sectional Diagram SOP (not to scale)

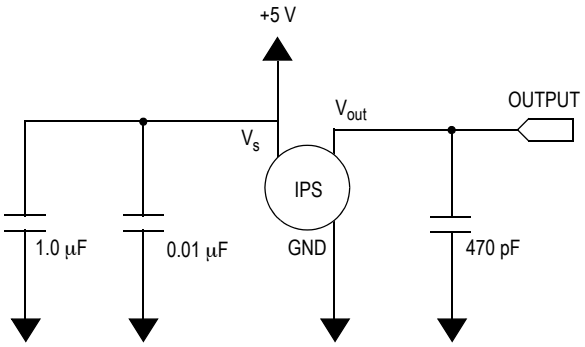

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

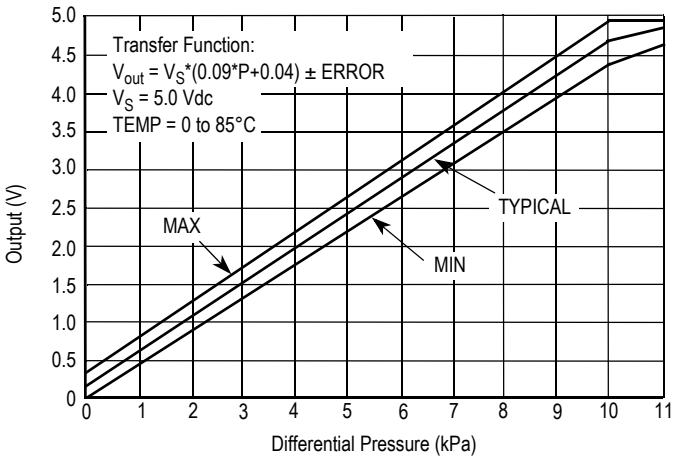

Figure 4. Output versus Pressure Differential

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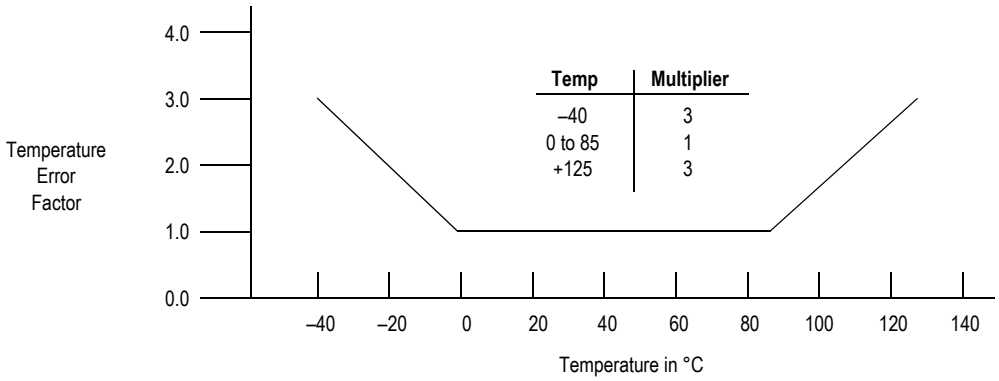
Transfer Function (MPX5010, MPXV5010G)

Nominal Transfer Value: $V_{out} = V_S \times (0.09 \times P + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.09 x V_S)
$V_S = 5.0\ V \pm 0.25\ Vdc$

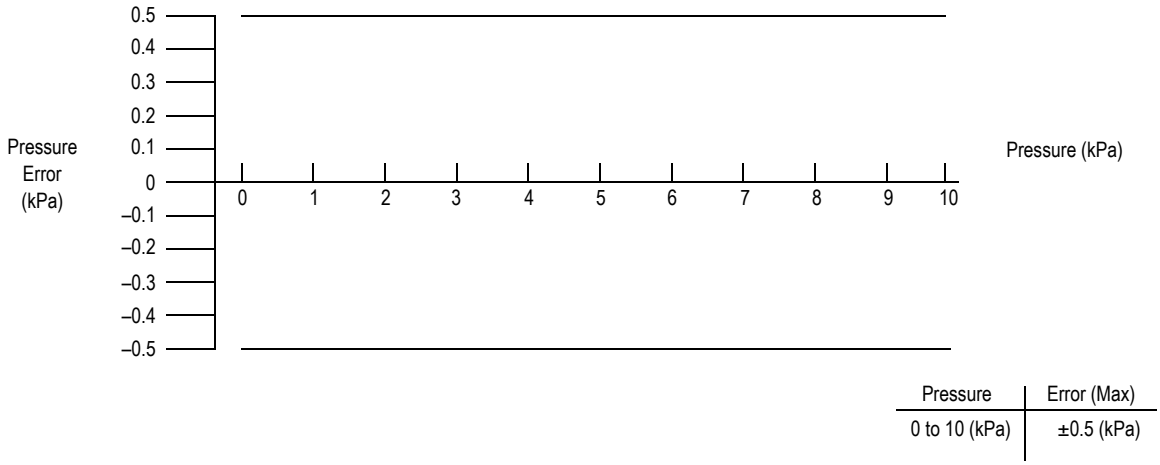
Temperature Error Band

MPX5010, MPXV5010G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 10 (kPa)	±0.5 (kPa)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5010D	867	Stainless Steel Cap
MPX5010DP	867C	Side with Part Marking
MPX5010GP	867B	Side with Port Attached
MPX5010GS	867E	Side with Port Attached
MPX5010GSX	867F	Side with Port Attached
MPXV5010G6U	482	Stainless Steel Cap
MPXV5010G7U	482B	Stainless Steel Cap
MPXV5010GC6U/T1	482A	Side with Port Attached
MPXV5010GC7U	482C	Side with Port Attached
MPXV5010GP	1369	Side with Port Attached
MPXV5010DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

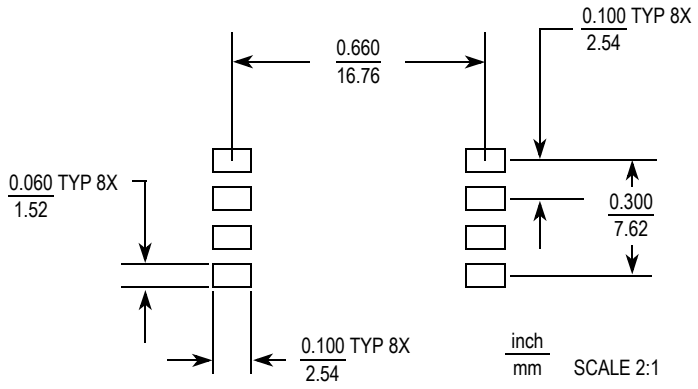

Figure 5. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5050
MPXV5050G
SERIES

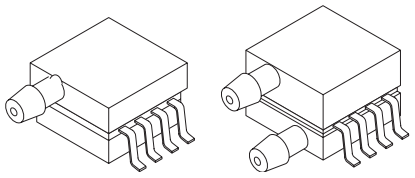
INTEGRATED
PRESSURE SENSOR
0 to 50 kPa (0 to 7.25 psi)
0.2 to 4.7 V Output

The MPX5050/MPXV5050G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

SMALL OUTLINE PACKAGE
SURFACE MOUNT



MPXV5050GP
CASE 1369-01

MPXV5050DP
CASE 1351-01

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE (MPXV5050G SERIES)					
Ported Elements	Side Port	1369	MPXV5050GP	Trays	MPXV5050G
	Dual Port	1351	MPXV5050DP	Trays	MPXV5050G
UNIBODY PACKAGE (MPX5050 SERIES)					
Basic Element	Differential	867	MPX5050D	—	MPX5050D
Ported Element	Differential Dual Ports	867C	MPX5050DP	—	MPX5050DP
	Gauge	867B	MPX5050GP	—	MPX5050GP

SMALL OUTLINE PACKAGE PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

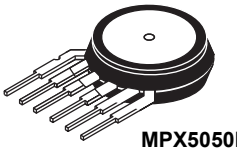
1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

UNIBODY PACKAGE PIN NUMBERS(1)

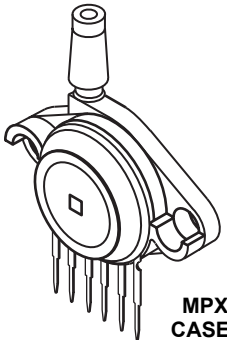
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

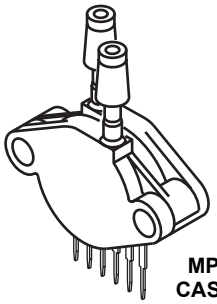
UNIBODY PACKAGES



MPX5050D
CASE 867-08



MPX5050GP
CASE 867B-04



MPX5050DP
CASE 857C-05

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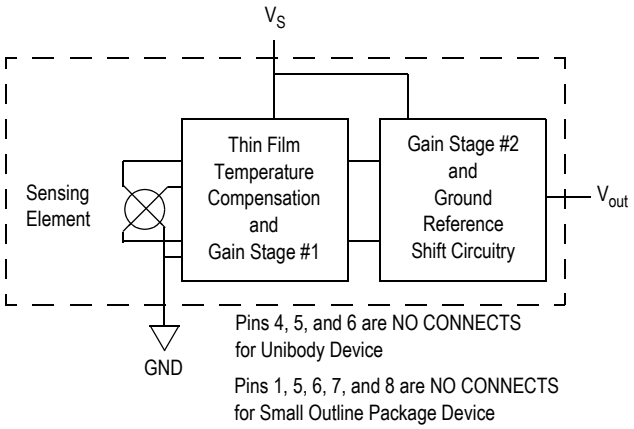

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. . Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	50	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	90	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 1369)	1.5	grams

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Figure 3 illustrates the Differential/Gauge Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5050/MPXV5050G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0× to 85×C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

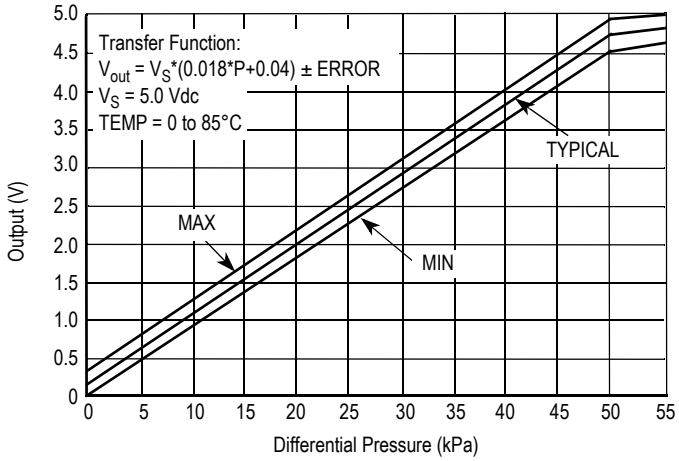

Figure 2. Output versus Pressure Differential

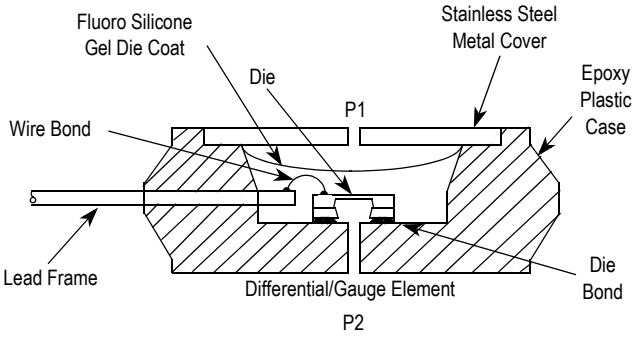

Figure 3. Cross-Sectional Diagram (not to scale)

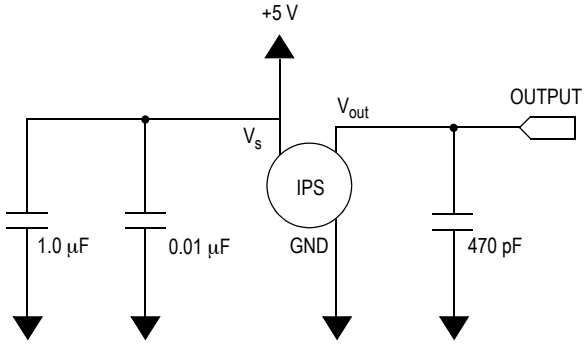

Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

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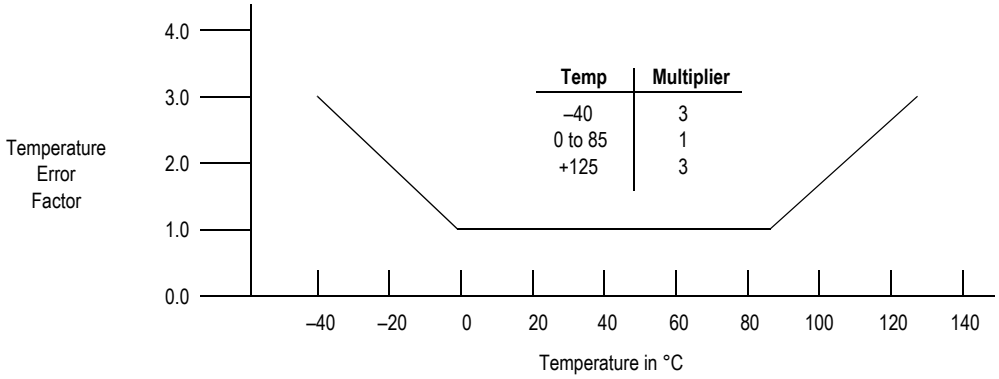
Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.018 + 0.04)$
$\pm$ (Pressure Error x Temp. Factor x 0.018 x V_S)
$V_S = 5.0\ V \pm 0.25\ Vdc$

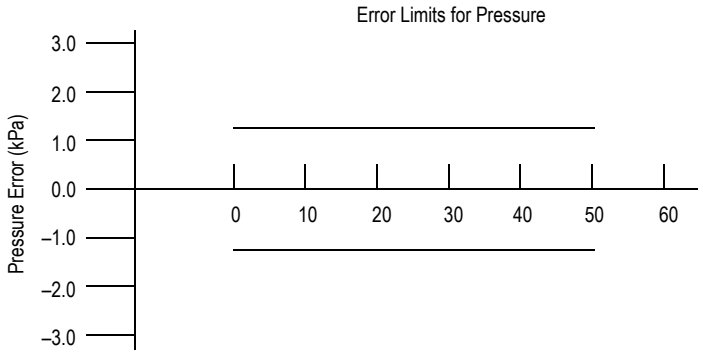
Temperature Error Band

MPX5050/MPXV5050G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
0 to 50 (kPa)	±1.25 (kPa)

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5050D	867	Stainless Steel Cap
MPX5050DP	867C	Side with Part Marking
MPX5050GP	867B	Side with Port Attached
MPXV5050GP	1369	Side with Port Attached
MPXV5050DP	1351	Side with Part Marking

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated, and Calibrated

MPX5100 SERIES

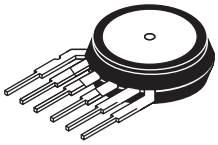
INTEGRATED PRESSURE SENSOR
0 to 100 kpa (0 to 14.5 psi)
15 to 115 kPa
(2.18 to 16.68 psi)
0.2 to 4.7 V Output

The MPX5100 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

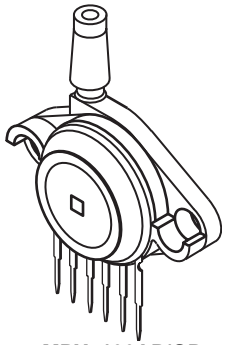
Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

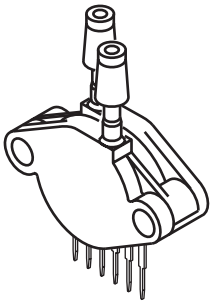
UNIBODY PACKAGES



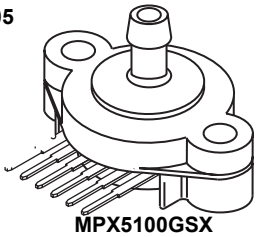
MPX5100A/D
CASE 867-08



MPX5100AP/GP
CASE 867B-04



MPX5100DP
CASE 867C-05



MPX5100GSX
CASE 867F-03

ORDERING INFORMATION				
Device Type	**Options**	**Case No.**	**MPX Series Order Number**	**Device Marking**
UNIBODY PACKAGE (MPX5100 SERIES)				
Basic Elements	Absolute	867	MPX5100A	MPX5100A
	Differential	867	MPX5100D	MPX5100D
Ported Elements	Differential Dual Ports	867C	MPX5100DP	MPX5100DP
	Absolute, Single Port	867B	MPX5100AP	MPX5100AP
	Gauge, Single Port	867B	MPX5100GP	MPX5100GP
	Gauge, Axial PC Mount	867F	MPX5100GSX	MPX5100GSX

PIN NUMBER(1)			
1	V_{OUT}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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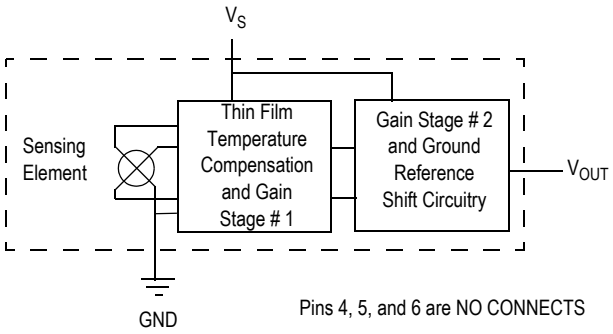

Figure 1. Fully Integrated Pressure Sensor Schematic

TABLE 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	-40° to +125°C	°C
Operating Temperature	T_A	-40° to +125°C	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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TABLE 2. Operating Characteristics (V_S = 5.0 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1] Gauge, Differential: MPX5100D Absolute: MPX5100A		P_{OP}	 0 15	 — —	 100 115	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	V_{DC}
Supply Current		I_O	—	7.0	10	mAdc
Minimum Pressure Offset[3] @ V_S = 5.0 V	(0 to 85°C)	V_{OFF}	0.088	0.20	0.313	V_{DC}
Full Scale Output[4] @ V_S = 5.0 V	Differential and Absolute (0 to 85°C) Vacuum	V_{FSO}	4.587 3.688	4.700 3.800	4.813 3.913	V_{DC}
Full Scale Span[5] @ V_S = 5.0 V	Differential and Absolute (0 to 85°C) Vacuum	V_{FSS}	— —	4.500 3.600	— —	V_{DC}
Accuracy[6]		—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	45	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 0.1 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{OFF}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental changed in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-Up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

TABLE 3. MECHANICAL CHARACTERISTICS

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0× to 85×C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPX5100 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

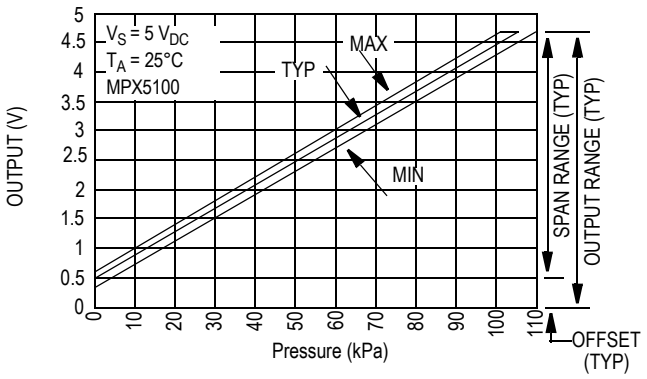

Figure 2. Output Vs. Pressure Differential

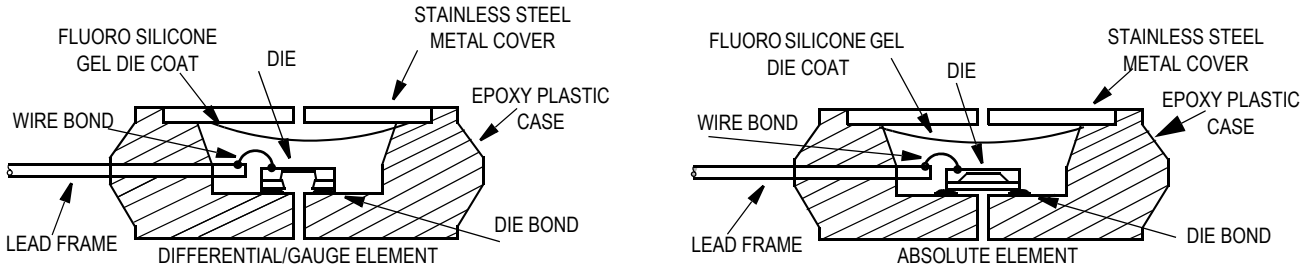

Figure 3. Cross Sectional Diagrams (Not to Scale)

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

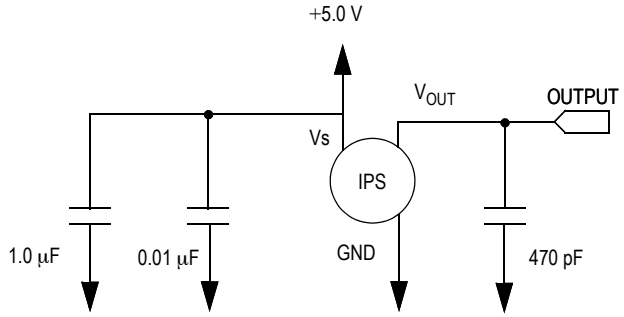

Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

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Transfer Function (MPX5100D, MPX5100G

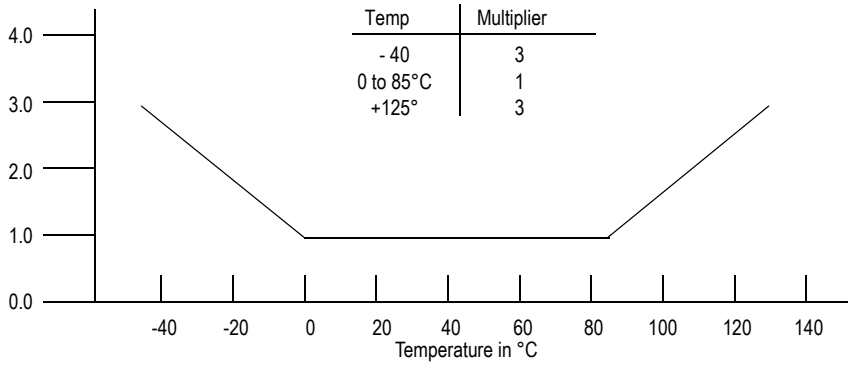
Nominal Transfer Value: VOUT = VS (P x 0.009 + 0.04)
± (Pressure Error x Temp. Mult. x 0.009 x VS)
VS = 5.0 V ±5% P kPa

Temperature Error Multiplier

MPX5100D Series

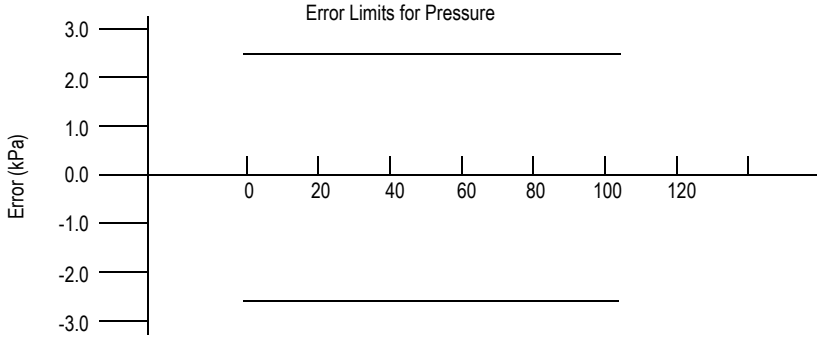
Break Points

Temp	Multiplier
- 40	3
0 to 85°C	1
+125°	3



Note: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



MPX5100D Series

Pressure	Error (max)
0 to 100 kPa	± 2.5 kPa

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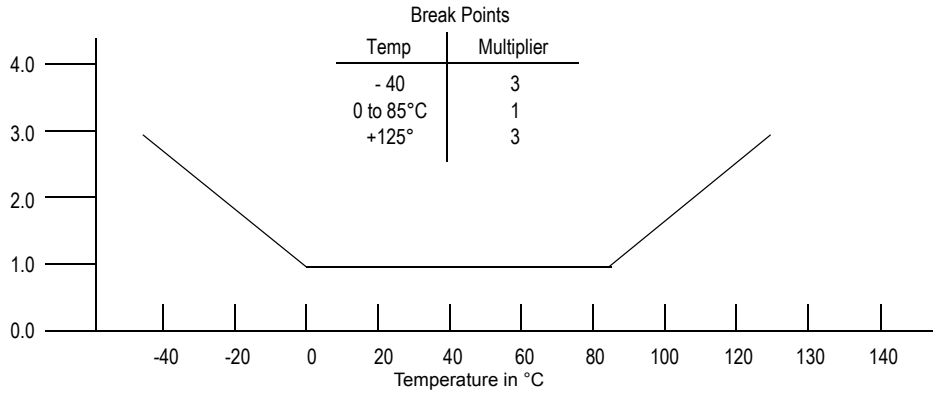
Transfer Function (MPX5100A

Nominal Transfer Value: $V_{OUT} = V_S$ (P x 0.009 + 0.095)
± (Pressure Error x Temp. Mult. x 0.009 x V_S)
V_S = 5.0 V ±5% P kPa

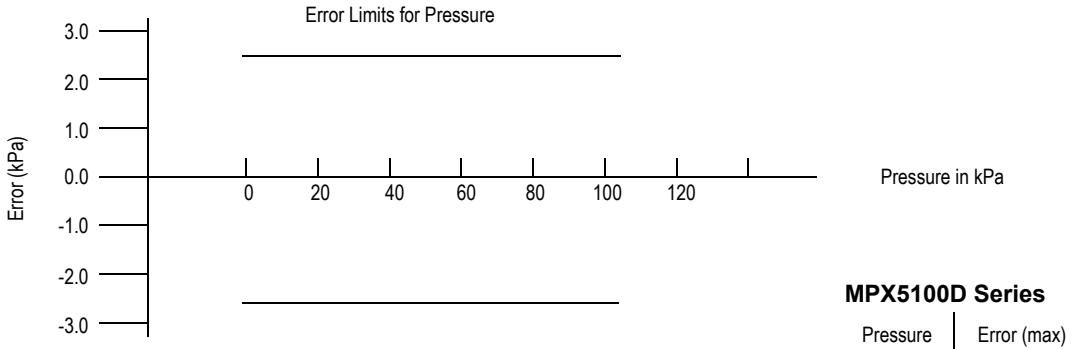
Temperature Error Multiplier

MPX5100A Series



Note: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



MPX5100D Series

Pressure	Error (max)
0 to 100 kPa	± 2.5 kPa

PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using Table 4 below:

TABLE 4. PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5100A, MPX5100D	867	Stainless Steel Cap
MPX5100DP	867C	Side with Part Marking
MPX5100AP, MPX5100GP	867B	Side with Port Attached
MPX5100GSX	867F	Side with Port Attached

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

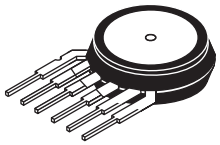
MPX5500 SERIES

INTEGRATED PRESSURE SENSOR
0 to 500 kPa (0 to 72.5 psi)
0.2 to 4.7 V Output

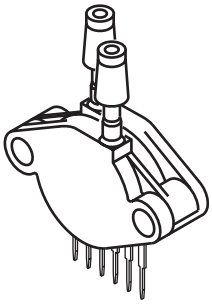
The MPX5500 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Available in Differential and Gauge Configurations



MPX5500D
CASE 867-08



MPX5500DP
CASE 867C-05

ORDERING INFORMATION				
Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5500D	MPX5500D
Ported Elements	Differential Dual Ports	867C	MPX5500DP	MPX5500DP

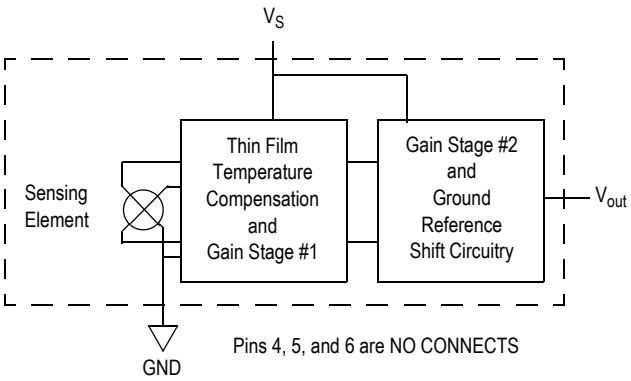


Figure 1. Fully Integrated Pressure Sensor Schematic

PIN NUMBERS[1]			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

1. Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	2000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Maximum Ratings apply to Case 867 only. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4. required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	500	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	(0 to 85°C)	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.70	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.50	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	9.0	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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Figure 3 illustrates the Differential/Gauge basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5500D in a high pressure, cyclic application, consult the factory.)

The MPX5500 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

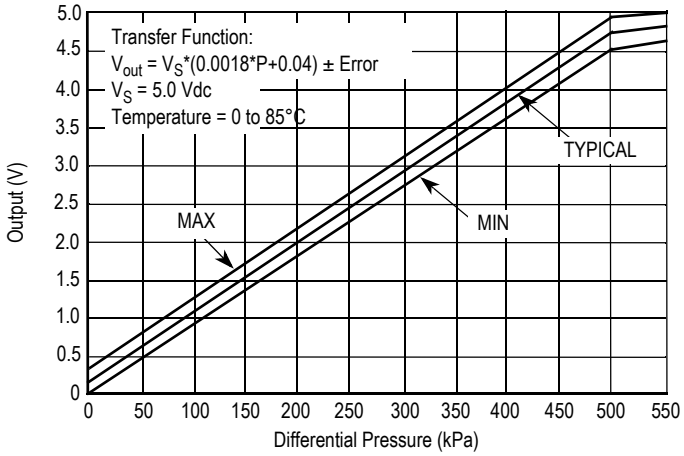

Figure 2. Output versus Pressure Differential

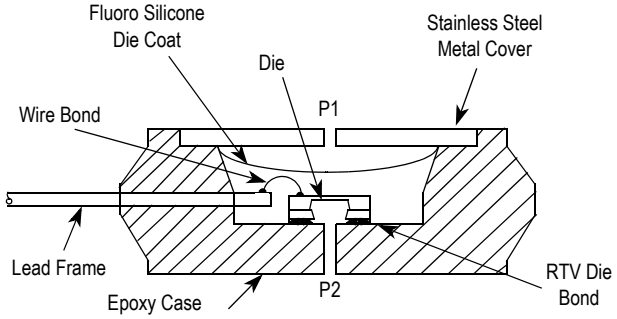

Figure 3. Cross-Sectional Diagrams (not to scale)

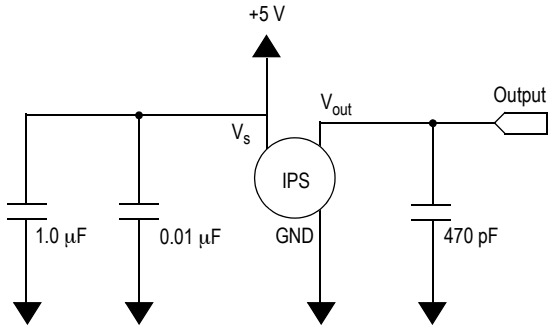

Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5500D	867	Stainless Steel Cap
MPX5500DP	867C	Side with Part Marking

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5700 SERIES

INTEGRATED PRESSURE SENSOR
0 to 700 kPa (0 to 101.5 psi)
15 to 700 kPa (2.18 to 101.5 psi)
0.2 to 4.7 V OUTPUT

The MPX5700 series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Available in Absolute, Differential and Gauge Configurations
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element

ORDERING INFORMATION

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5700D	MPX5700D
	Absolute	867	MPX5700A	MPX5700A
Ported Elements	Differential Dual Ports	867C	MPX5700DP	MPX5700DP
	Gauge	867B	MPX5700GP	MPX5700GP
	Gauge, Axial	867E	MPX5700GS	MPX5700D
	Absolute	867B	MPX5700AP	MPX5700AP
	Absolute, Axial	867E	MPX5700AS	MPX5700A
	Absolute, Axial PC Mount	867F	MPX5700ASX	MPX5700A

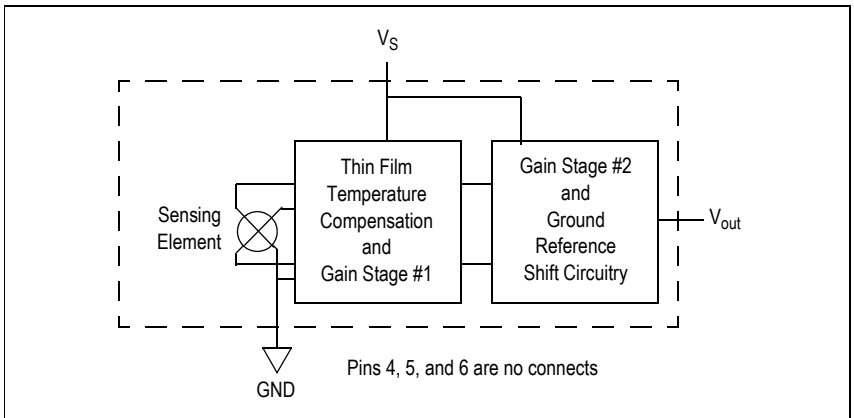
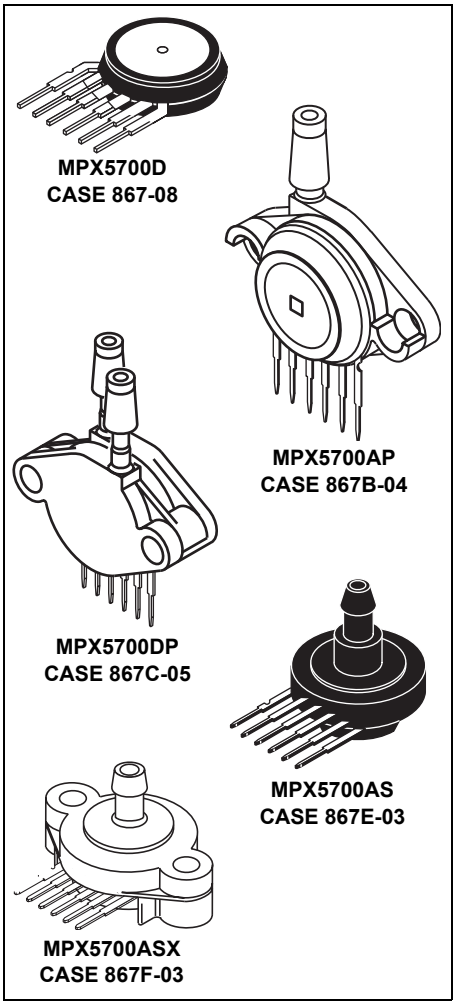


Figure 1. Fully Integrated Pressure Sensor Schematic



MPX5700D
CASE 867-08

MPX5700AP
CASE 867B-04

MPX5700DP
CASE 867C-05

MPX5700AS
CASE 867E-03

MPX5700ASX
CASE 867F-03

PIN NUMBERS			
1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

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Table 1. Maximum Ratings[1]

Parametrics	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	2800	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Maximum Ratings apply to Case 867 only. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]	Gauge, Differential: MPX5700D Absolute: MPX5700A	P_{OP}	0 15	— —	700 700	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	Gauge, Differential (0 to 85°C) Absolute (0 to 85°C)	V_{off}	0.088 0.184	0.2 —	0.313 0.409	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	6.4	—-	mV/kPa
Response Time[7]		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—-	mAdc
Warm-Up Time[8]		—	—	20	—-	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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Figure 3 illustrates both the Differential/Gauge and the Absolute Sensing Chip in the basic chip carrier (Case 867). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. (For use of the MPX5700D in a high-pressure cyclic application, consult the factory.)

The MPX5700 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

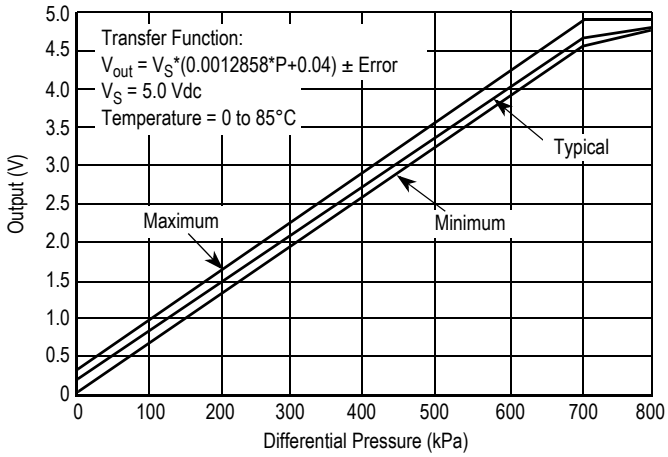

Figure 2. Output versus Pressure Differential

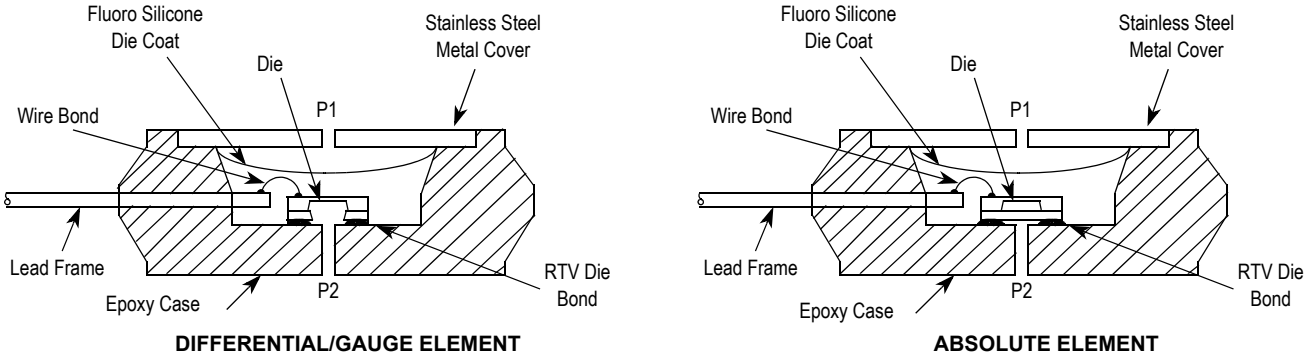

Figure 3. Cross-Sectional Diagrams (not to scale)

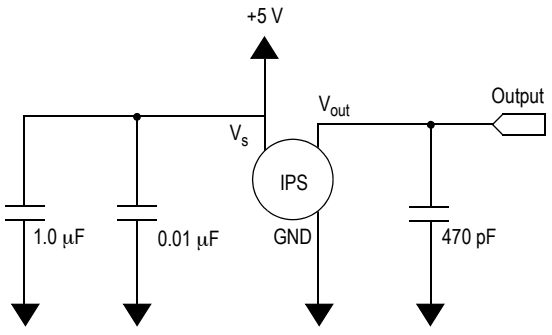

Figure 4. Recommended Power Supply Decoupling and Output Filtering (For additional output filtering, please refer to Application Note AN1646)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5700D, MPX5700A	867	Stainless Steel Cap
MPX5700DP	867C	Side with Part Marking
MPX5700GP, MPX5700AP	867B	Side with Port Attached
MPX5700GS, MPX5700AS	867E	Side with Port Attached
MPX5700ASX	867F	Side with Port Attached

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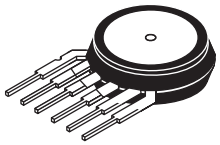
Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPX5999D SERIES

INTEGRATED PRESSURE SENSOR
0 to 1000 kPa (0 to 150 psi)
0.2 to 4.7 V OUTPUT



MPX5999D
CASE 867-08

The MPX5999D piezoresistive transducer is a state-of-the-art pressure sensor designed for a wide range of applications, but particularly for those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on the stand-alone sensing chip.

Features

- Temperature Compensated Over 0 to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element

ORDERING INFORMATION[1]

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5999D	MPX5999D

1. The MPX5999D pressure sensor is available as an element only.

PIN NUMBERS

1	V_{out}	4	N/C
2	GND	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

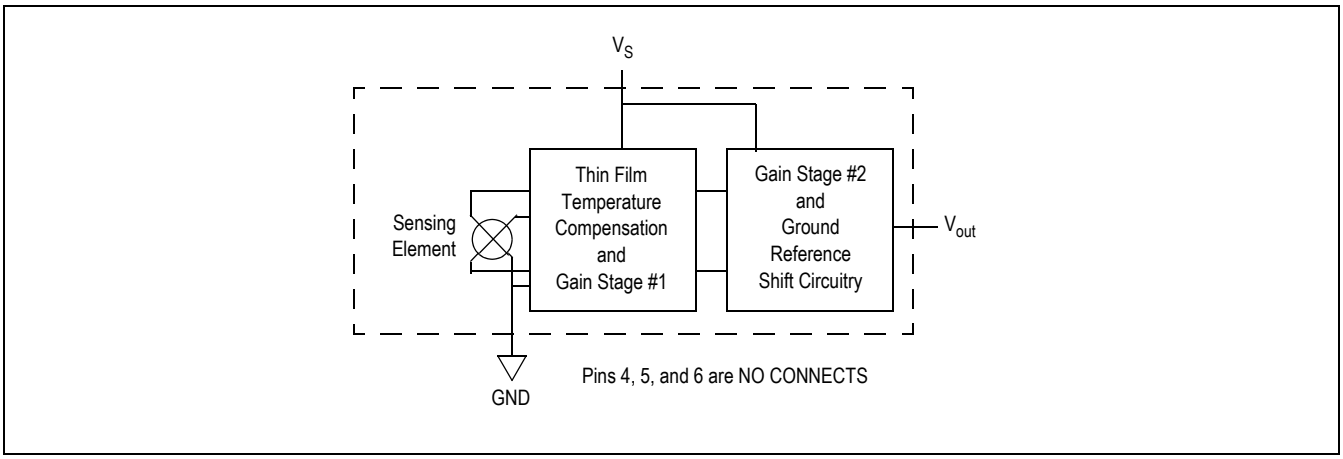


Figure 1. Fully Integrated Pressure Sensor Schematic

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Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure[2] (P2 ≤ 1 Atmosphere)	$P1_{max}$	4000	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Extended exposure at the specified limits may cause permanent damage or degradation to the device.
2. This sensor is designed for applications where P1 is always greater than, or equal to P2. P2 maximum is 500 kPa.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	1000	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_O	—	7.0	10	mAdc
Zero Pressure Offset[3]	(0 to 85°C)	V_{off}	0.088	0.2	0.313	Vdc
Full Scale Output[4]	(0 to 85°C)	V_{FSO}	4.587	4.7	4.813	Vdc
Full Scale Span[5]	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Sensitivity		V/P	—	4.5	—	mV/kPa
Accuracy[6]	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the device to meet the specified output voltage after the pressure has been stabilized.

Table 3. Mechanical Characteristics

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 4. The output will saturate outside of the specified pressure range.

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 3 illustrates the differential or gauge configuration in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX5999D pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 4 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

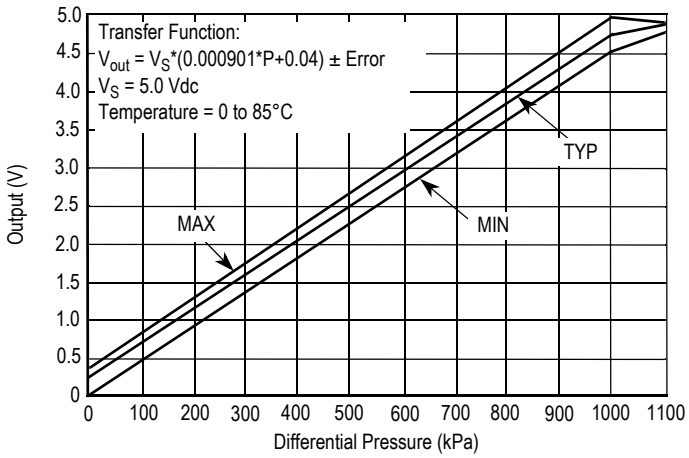

Figure 2. Output versus Pressure Differential

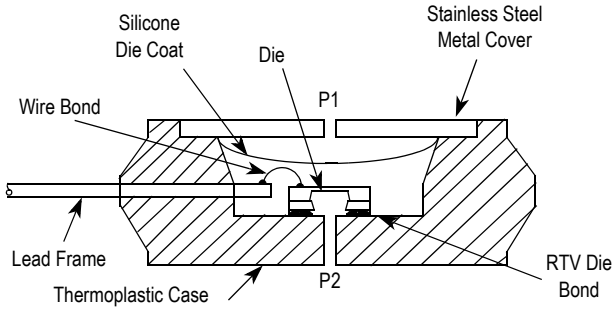

Figure 3. Cross-Sectional Diagrams (not to scale)

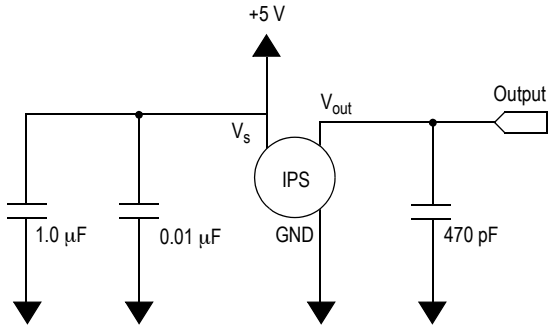

Figure 4. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluoro silicone gel which protects the die from harsh media. The Freescale MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX5999D	867	Stainless Steel Cap

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High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXA6115A
MPXH6115A
SERIES

INTEGRATED PRESSURE SENSOR
15 TO 115 kPA (2.2 TO 16.7 psi)
0.2 TO 4.8 V OUTPUT

The MPXA6115A/MPXH6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the pressure sensor a logical and economical choice for the system designer.

The MPXA6115A/MPXH6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

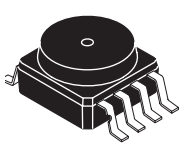
Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

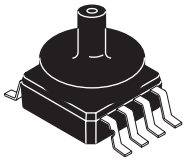
Typical Applications

- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Device Barometers

SMALL OUTLINE PACKAGE



MPXA6115A6U/6T1
CASE 482-01

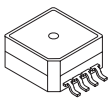


MPXA6115C6U/C6T1
CASE 482A-01

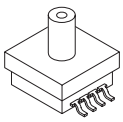
SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

SUPER SMALL OUTLINE PACKAGE



MPXH6115A6U/6T1
CASE 1317-04



MPXH6115AC6U/C6T1
CASE 1317A-03

SUPER SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	482	MPXA6115A6U	Rails	MPXA6115A
	Absolute, Element Only	482	MPXA6115A6T1	Tape & Reel	MPXA6115A
Ported Element	Absolute, Axial Port	482A	MPXA6115AC6U	Rails	MPXA6115A
	Absolute, Axial Port	482A	MPXA6115AC6T1	Tape & Reel	MPXA6115A
SUPER SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	1317	MPXH6115A6U	Rails	MPXH6115A
	Absolute, Element Only	1317	MPXH6115A6T1	Tape & Reel	MPXH6115A
Ported Element	Absolute, Axial Port	1317A	MPXH6115AC6U	Rails	MPXH6115A
	Absolute, Axial Port	1317A	MPXH6115AC6T1	Tape & Reel	MPXH6115A

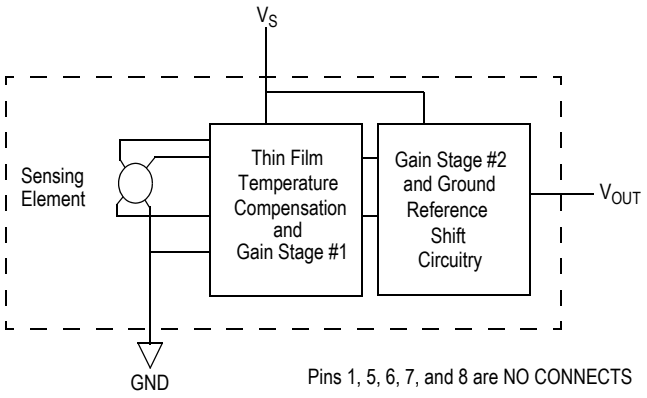


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	-	6.0	10	mAdc
Minimum Pressure Offset(2) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.133	0.200	0.268	Vdc
Full Scale Output(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.633	4.700	4.768	Vdc
Full Scale Span(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.433	4.500	4.568	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	45.9	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

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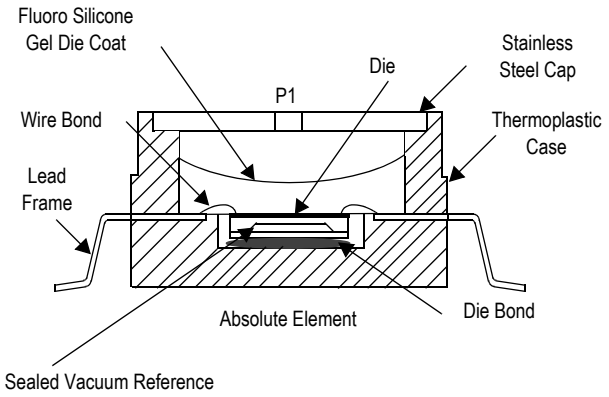

Figure 2. Cross Sectional Diagram SSOP (Not to Scale)

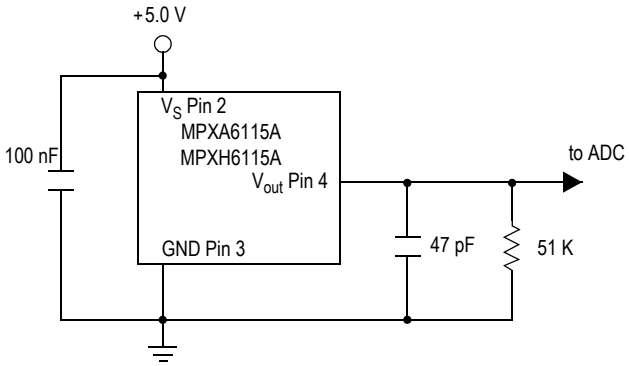

Figure 3. Typical Application Circuit (Output Source Current Operation)

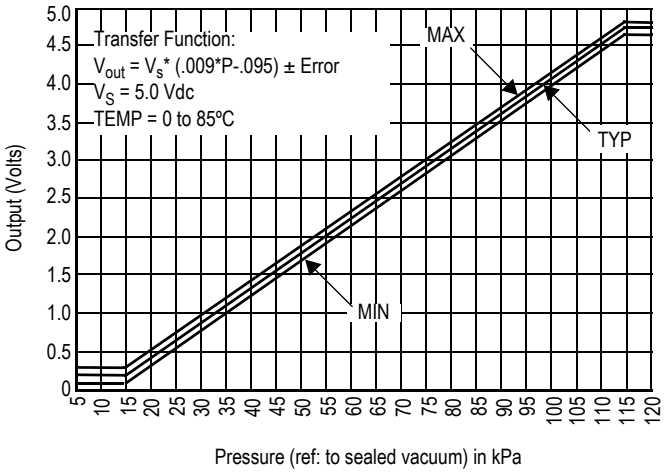

Figure 4. Output versus Absolute Pressure

Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317).

Figure 3 shows a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85×C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXA6115A/ MPXH6115A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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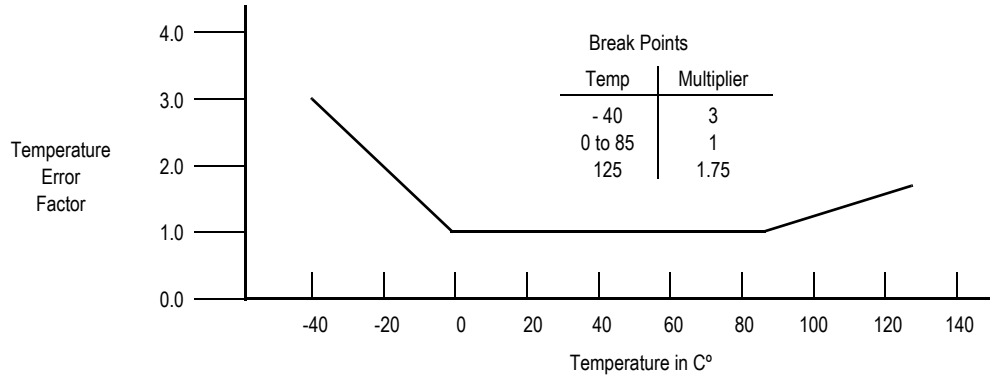
Transfer Function (MPXA6115A/MPXH6115A)

Nominal Transfer Value: Vout = VS x (0.009 x P - 0.095)
± (Pressure Error x Temp. Factor x 0.009 x VS)
VS = 5.0 ± 0.25 Vdc

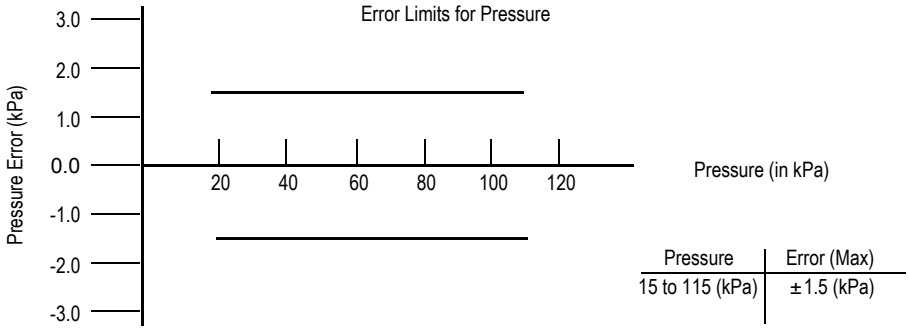
Temperature Error Band

MPXA6115A/MPXH6115A SERIES



NOTE: The Temperature Multiplier is a linear response from 0ºC to -40ºC and from 85ºC to 125ºC

Pressure Error Band



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MINIMUM RECOMMENDED FOOTPRINT FOR SMALL AND SUPER SMALL PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

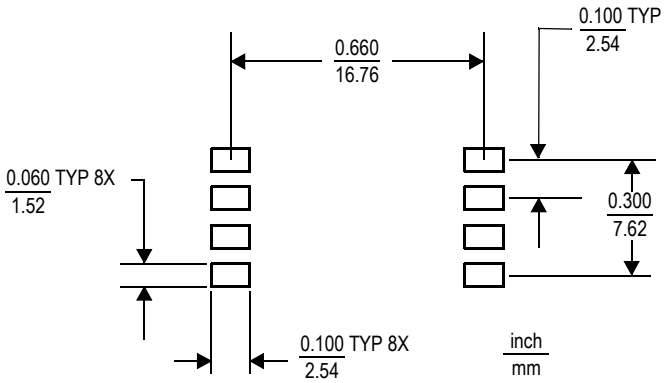

Figure 5. SOP Footprint (Case 482)

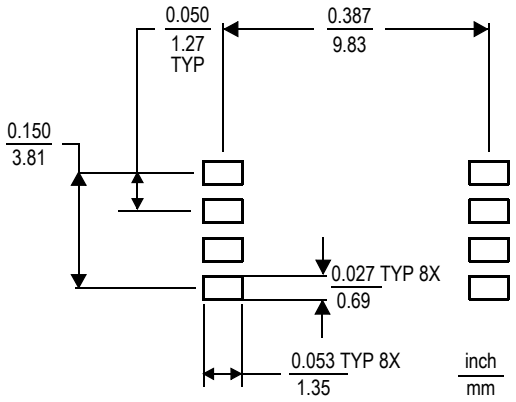

Figure 6. SSOP Footprint (Case 1317 and 1317A)

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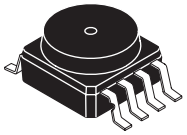
Integrated Silicon Pressure Sensor for Manifold Absolute Pressure Applications On-Chip Signal Conditioned, Temperature Compensated and Calibrated

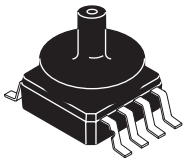
MPXAZ4100A SERIES

INTEGRATED PRESSURE SENSOR 20 TO 105 kPA (2.9 TO 15.2 psi) 0.3 TO 4.9 V OUTPUT

SMALL OUTLINE PACKAGES



MPXA4100A6U/6T1
CASE 482-01



MPXA4100AC6U/AC6T1
CASE 482A-01

The Freescale MPXAZ4100A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder. The small form factor and high reliability of on-chip integration makes the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPXAZ4100A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Resistant to high humidity and common automotive media
- 1.8% Maximum Error Over 0° to 85°C
- Specifically Designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally Suited for Microprocessor or Microcontroller Based Systems
- Temperature Compensated Over –40°C to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Manifold Sensing for Automotive Systems
- Also Ideal for Non-Automotive Applications

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXAZ4100A SERIES)					
Basic Elements	Absolute, Element Only	482	MPXAZ4100A6U	Rails	MPXAZ4100A
	Absolute, Element Only	482	MPXAZ4100A6T1	Tape & Reel	MPXAZ4100A
Ported Elements	Absolute, Axial Port	482A	MPXAZ4100AC6U	Rails	MPXAZ4100A
	Absolute, Axial Port	482A	MPXAZ4100AC6T1	Tape & Reel	MPXAZ4100A

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

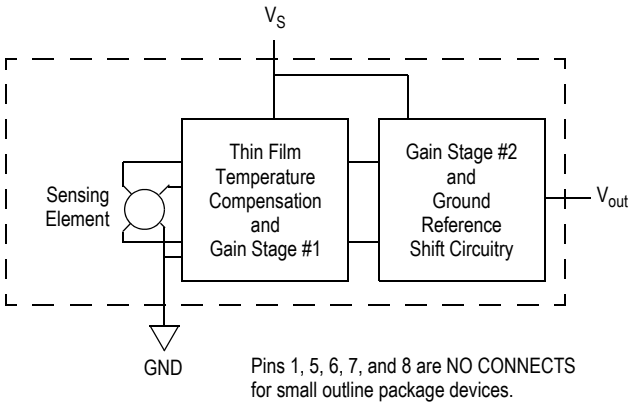


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	400	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	20	—	105	kPa
Supply Voltage[2]		V_S	4.85	5.1	5.35	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts[3]	(0 to 85°C)	V_{off}	0.225	0.306	0.388	Vdc
Full Scale Output @ V_S = 5.1 Volts[4]	(0 to 85°C)	V_{FSO}	4.870	4.951	5.032	Vdc
Full Scale Span @ V_S = 5.1 Volts[5]	(0 to 85°C)	V_{FSS}	—	4.59	—	Vdc
Accuracy[6]	(0 to 85°C)	—	—	—	±1.8	$\%V_{FSS}$
Sensitivity		V/P	—	54	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates an absolute sensing chip in the basic chip carrier (Case 482).

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The gel die coat and durable polymer package provide a media resistant barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. Contact the factory for more information regarding media compatibility in your specific application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

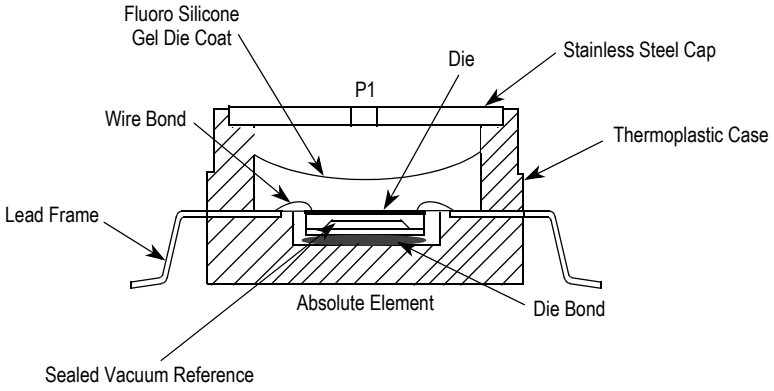

Figure 2. Cross Sectional Diagram SOP (not to scale)

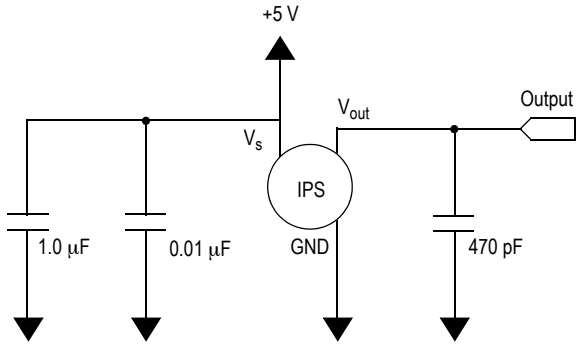

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

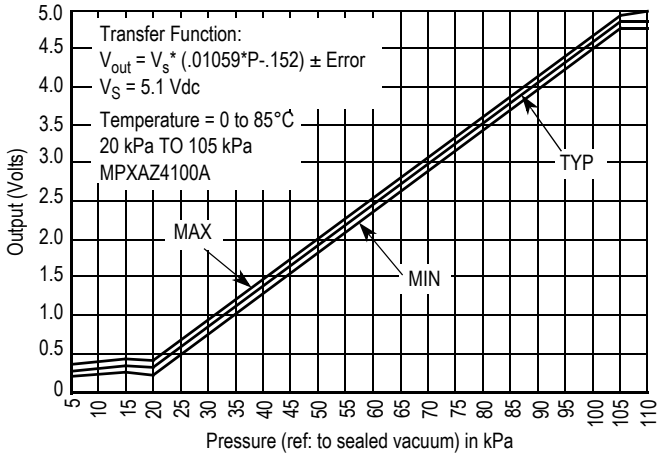

Figure 4. Output versus Absolute Pressure

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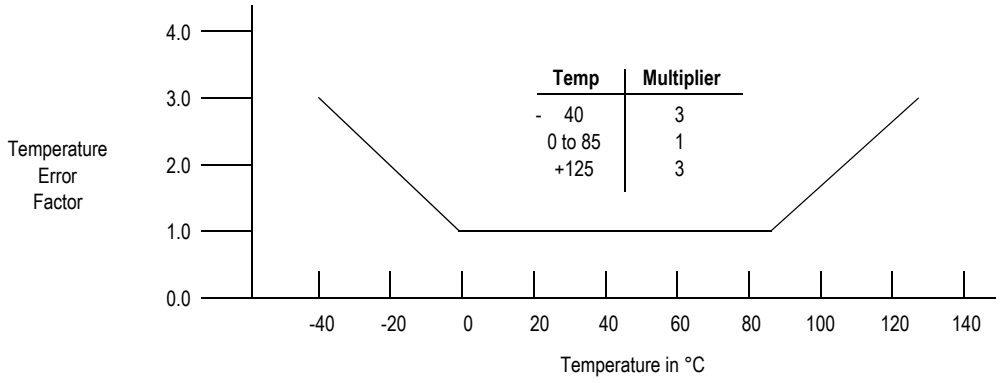
Transfer Function (MPXAZ4100A)

Nominal Transfer Value: $V_{out} = V_S (P \times 0.01059 - 0.1518)$
$\pm$ (Pressure Error x Temp. Factor x 0.01059 x V_S)
$V_S = 5.1\ V \pm 0.25\ Vdc$

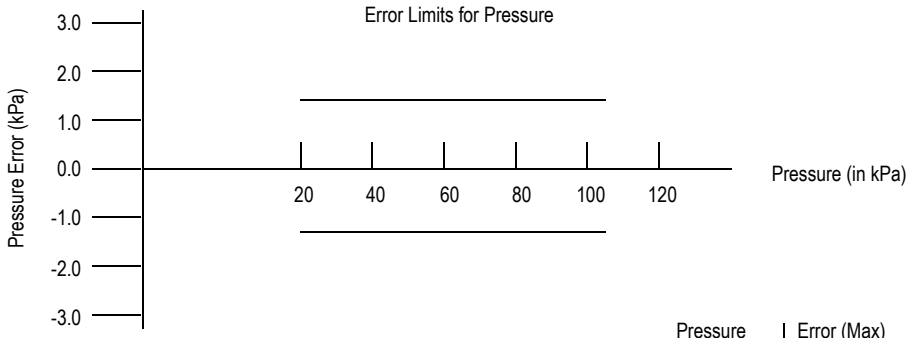
Temperature Error Band

MPXAZ4100A Series



NOTE: The Temperature Multiplier is a linear response from 0°C to-40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 105 (kPa)	±1.5 (kPa)

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INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

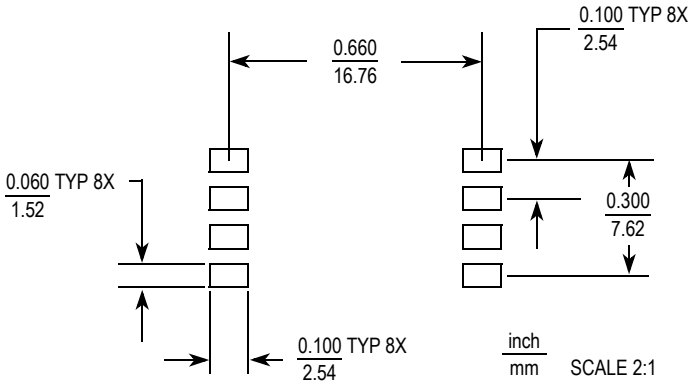

Figure 5. SOP Footprint (Case 482)

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Media Resistant and High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXAZ6115A
MPXHZ6115A
SERIES

INTEGRATED
PRESSURE SENSOR
15 TO 115 kPA (2.2 TO 16.7 psi)
0.2 TO 4.8 V OUTPUT

The MPXAZ6115A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The sensor's packaging has been designed to provide resistance to high humidity conditions as well as common automotive media. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXAZ6115A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

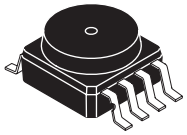
Features

- Resistant to High Humidity and Common Automotive Media
- Improved Accuracy at High Temperature
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

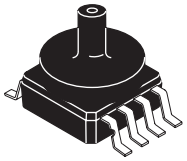
Typical Applications

- Aviation Altimeters
- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)
- Weather Station and Weather Reporting Devices

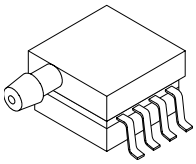
SMALL OUTLINE PACKAGE



MPXAZ6115A6U
CASE 482-01



MPXAZ6115AC6U
CASE 482A-01

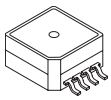


MPXAZ6115AP
CASE 1369-01

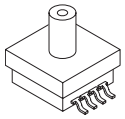
SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

SUPER SMALL OUTLINE PACKAGE



MPXHZ6115A6U
CASE 1317-04



MPXHZ6115AC6U
CASE 1317A-03

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	482	MPXAZ6115A6U	Rails	MPXAZ6115A
	Absolute, Element Only	482	MPXAZ6115A6T1	Tape & Reel	MPXAZ6115A
Ported Element	Absolute, Axial Port	482A	MPXAZ6115AC6U	Rails	MPXAZ6115A
	Absolute, Axial Port	482A	MPXAZ6115AC6T1	Tape & Reel	MPXAZ6115A
	Absolute, Side Port	1369	MPXAZ6115AP	Tray	MPXAZ6115A
	Absolute, Side Port	1369	MPXAZ6115APT1	Tape & Reel	MPXAZ6115A
SUPER SMALL OUTLINE PACKAGE					
Basic Element	Absolute, Element Only	1317	MPXHZ6115A6U	Rails	MPXHZ6115A
	Absolute, Element Only	1317	MPXHZ6115A6T1	Tape & Reel	MPXHZ6115A

ORDERING INFORMATION					
Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Ported Element	Absolute, Axial Port	1317A	MPXHZ6115AC6U	Rails	MPXHZ6115A
	Absolute, Axial Port	1317A	MPXHZ6115AC6T1	Tape & Reel	MPXHZ6115A

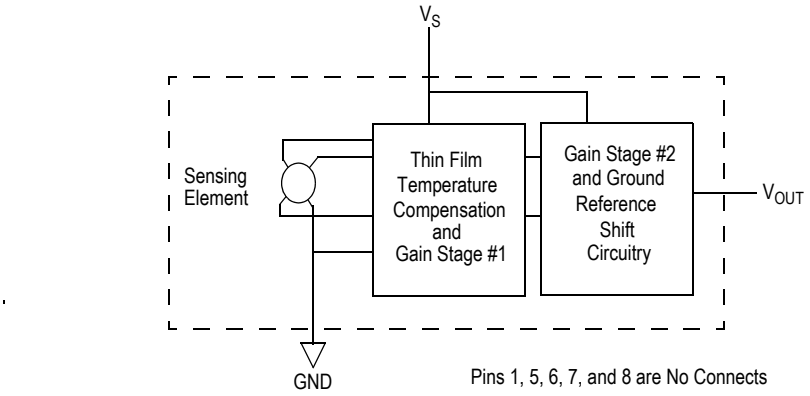


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	15	—	115	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset(2) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.133	0.200	0.268	Vdc
Full Scale Output(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.633	4.700	4.768	Vdc
Full Scale Span(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	4.433	4.500	4.568	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	45.9	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

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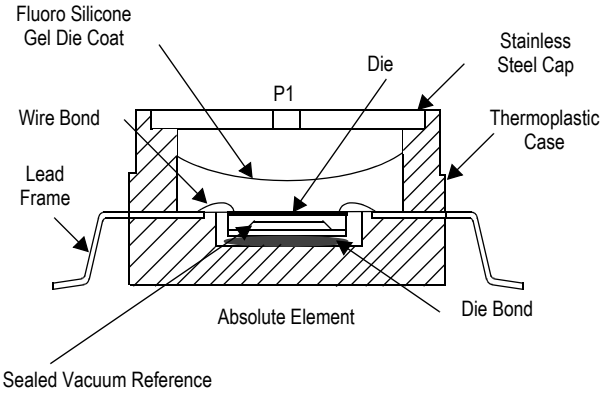

Figure 2. Cross Sectional Diagram SOP (Not to Scale)

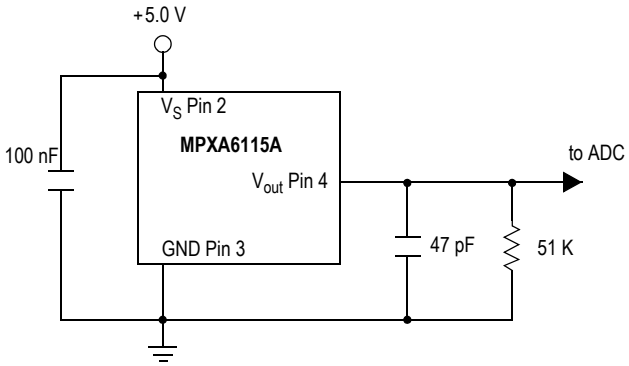

Figure 3. Typical Application Circuit (Output Source Current Operation)

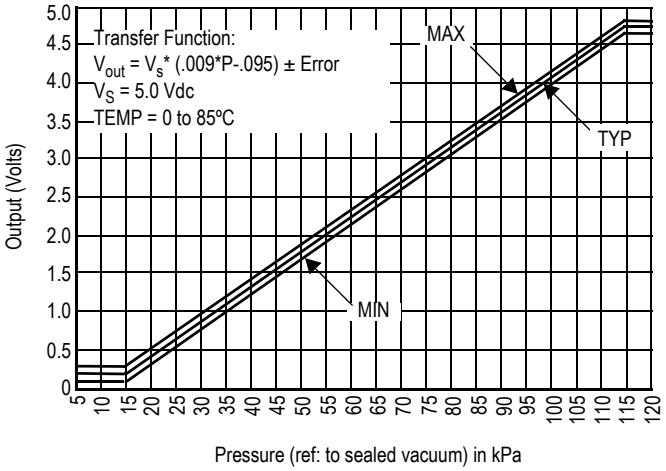

Figure 4. Output versus Absolute Pressure

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The gel die coat and durable polymer package provide a media resistant barrier that allows the sensor to operate reliably in high humidity conditions as well as environments containing common automotive media. Contact the factory for more information regarding media compatibility in your specific application.

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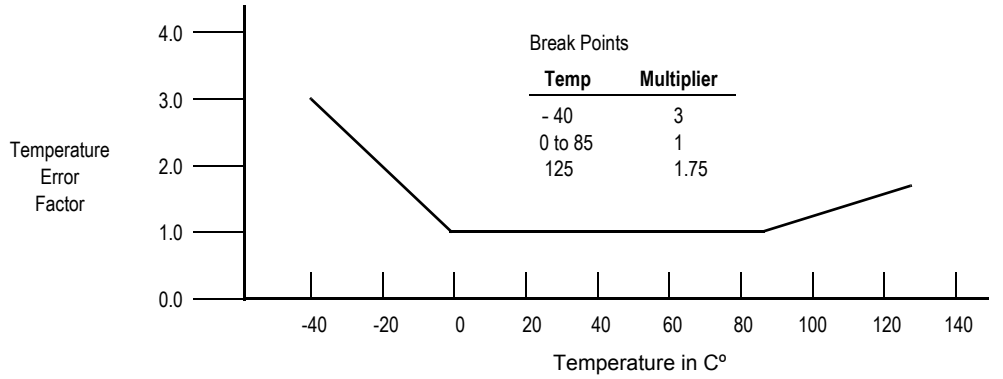
Transfer Function (MPXAZ6115A

Nominal Transfer Value: $V_{out} = V_S \times (0.009 \times P - 0.095)$
$\pm$ (Pressure Error x Temp. Factor x 0.009 x V_S)
$V_S = 5.0 \pm 0.25$ Vdc

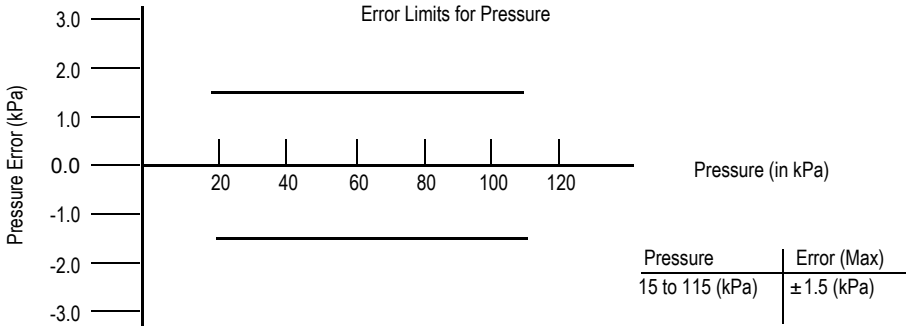
Temperature Error Band

MPXAZ6115A Series



NOTE: The Temperature Multiplier is a linear response from 0ºC to -40ºC and from 85ºC to 125ºC

Pressure Error Band



Pressure	Error (Max)
15 to 115 (kPa)	±1.5 (kPa)

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MINIMUM RECOMMENDED FOOTPRINT FOR SMALL AND SUPER SMALL PACKAGES

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

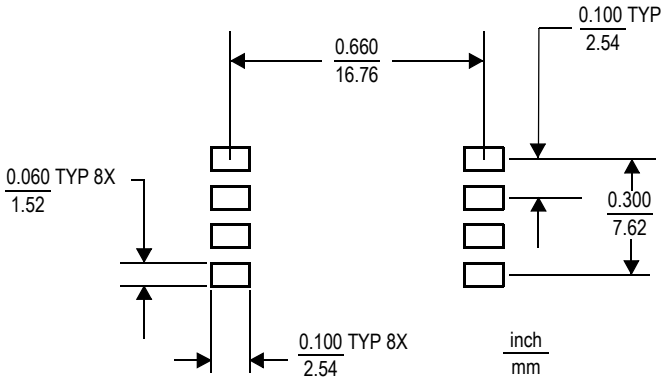

Figure 5. SOP Footprint (Case 482 and 482A)

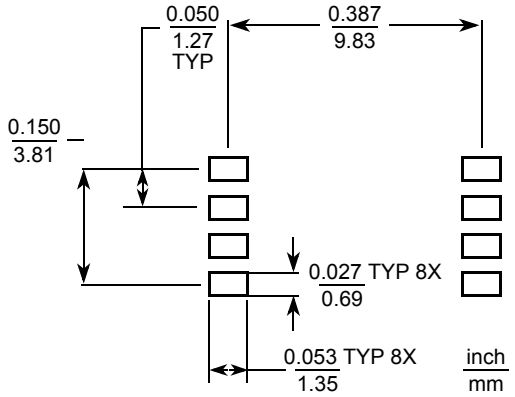

Figure 6. SSOP Footprint (Case 1317 and 1317A)

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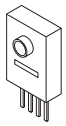
High Volume Sensor for Low Pressure Applications

MPXC2011DT1
MPXC2012DT1

PRESSURE SENSORS
0 to 75 mm HG
(0 TO 10 kPA

CHIP PAK PACKAGE



MPXC2011DT1/MPXC2012DT1
CASE 423A-03

PIN NUMBER			
1	GND	3	V_S
2	S+	4	S-

Freescale Semiconductor has developed a low cost, high volume, miniature pressure sensor package which is ideal as a sub-module component or a disposable unit. The unique concept of the Chip Pak allows great flexibility in system design while allowing an economic solution for the designer. This new chip carrier package uses Freescale Semiconductor's unique sensor die with its piezoresistive technology, along with the added feature of on-chip, thin-film temperature compensation and calibration.

NOTE: Freescale Semiconductor is also offering the Chip Pak package in application-specific configurations, which will have an “SPX” prefix, followed by a four-digit number, unique to the specific customer

Features

- Low Cost
- Integrated Temperature Compensation and Calibration
- Ratiometric to Supply Voltage
- Polysulfone Case Material (Medical, Class V Approved)
- Provided in Easy-to-Use Tape and Reel

Typical Applications

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

NOTE: The die and wire bonds are exposed on the front side of the Chip Pak (pressure is applied to the backside of the device). Front side die and wire protection must be provided in the customer's housing. Use caution when handling the devices during all processes.

Freescale Semiconductor's MPXC2011DT1/ MPXC2012DT1 Pressure Sensor has been designed for medical usage by combining the performance of Freescale Semiconductor's shear stress pressure sensor design and the use of biomedically approved materials. Materials with a proven history in medical situations have been chosen to provide a sensor that can be used with confidence in applications, such as invasive blood pressure monitoring. It can be sterilized using ethylene oxide. The portions of the pressure sensor that are required to be biomedically approved are the rigid housing and the gel coating.

The rigid housing is molded from a white, medical grade polysulfone that has passed extensive biological testing including: tissue culture test, rabbit implant, hemolysis, intracutaneous test in rabbits, and system toxicity, USP.

The MPXC2011DT1 contains a silicone dielectric gel which covers the silicon piezoresistive sensing element. The gel is a nontoxic, nonallergenic elastomer system which meets all USP XX Biological Testing Class V requirements. The properties of the gel allow it to transmit pressure uniformly to the diaphragm surface, while isolating the internal electrical connections from the corrosive effects of fluids, such as saline solution. The gel provides electrical isolation sufficient to withstand defibrillation testing, as specified in the proposed Association for the Advancement of Medical Instrumentation (AAMI) Standard for blood pressure transducers. A biomedically approved opaque filler in the gel prevents bright operating room lights from affecting the performance of the sensor.

The MPXC2012DT1 is a no-gel option.

ORDERING INFORMATION			
Device Order No.	**Case No.**	**Device Description**	**Device Marking**
MPXC2011DT1	423A	Chip Pak, 1/3 Gel	Date Code, Lot ID
MPXC2012DT1	423A	Chip Pak, No Gel	Date Code, Lot ID

Packaging Information	Reel Size	Tape Width	Quantity
Tape and Reel	330 mm	24 mm	1000 pc/reel

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Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (Backside)	P_{max}	75	kPa
Storage Temperature	T_{stg}	-25 to +85	°C
Operating Temperature	T_A	+15 to +40	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	10	kPa
Supply Voltage(2)	V_S	—	3	10	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	24	25	26	mV
Offset(4)	V_{off}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	2.5	—	mV/kPa
Linearity(5)	—	-1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (+15°C to +40°C)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1300	—	2550	W
Output Impedance	Z_{out}	1400	—	3000	W
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	v	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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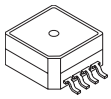
High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

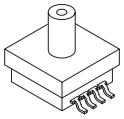
MPXH6250A SERIES

INTEGRATED PRESSURE SENSOR 20 to 250 kPa (3.0 to 36 psi) 0.3 to 4.9 V OUTPUT

SUPER SMALL OUTLINE PACKAGES



MPXH6250A6U/6T1
CASE 1317-04



MPXH6250AC6U/C6T1
CASE 1317A-03

The Freescale MPXH6250A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale MAP sensor a logical and economical choice for automotive system designers.

The MPXH6250A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Basic Element	Absolute, Element Only	1317	MPXH6250A6U	Rails	MPXH6250A
	Absolute, Element Only	1317	MPXH6250A6T1	Tape & Reel	MPXH6250A
Ported Element	Absolute, Axial Port	1317A	MPXH6250AC6U	Rails	MPXH6250A
	Absolute, Axial Port	1317A	MPXH6250AC6T1	Tape & Reel	MPXH6250A

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

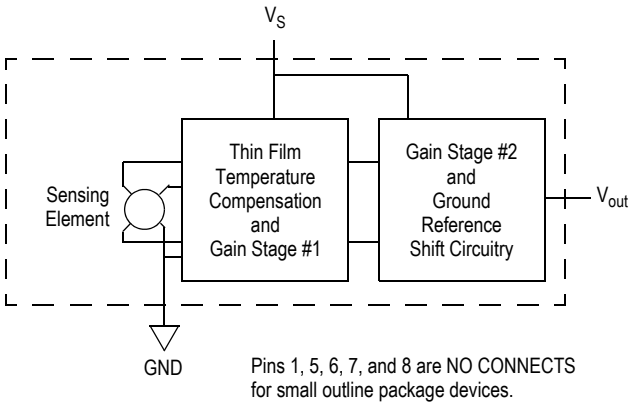


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	I_o–	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	250	kPa
Supply Voltage(1)		V_S	4.74	5.1	5.46	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(2)	(0 to 85°C)	V_{off}	0.133	0.204	0.274	Vdc
Full Scale Output @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{FSO}	4.826	4.896	4.966	Vdc
Full Scale Span @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSS}	4.552	4.692	4.833	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	20.4	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6250A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

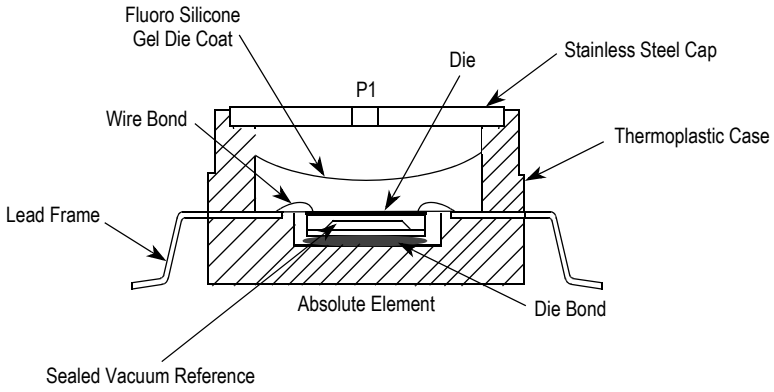

Figure 2. Cross Sectional Diagram SSOP (not to scale)

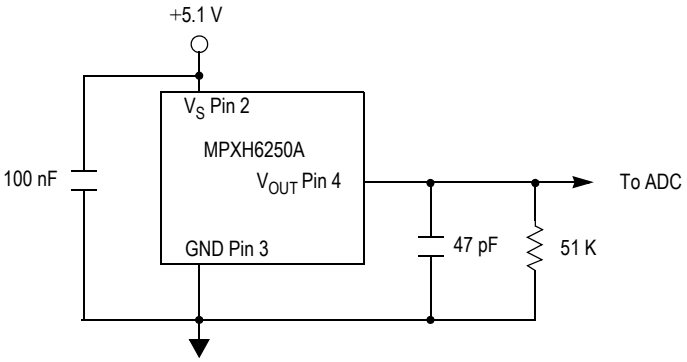

Figure 3. Typical Application Circuit (Output Source Current Operation)

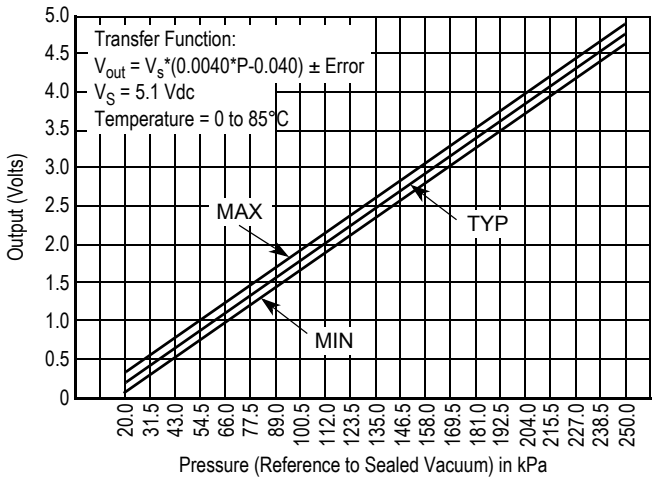

Figure 4. Output versus Absolute Pressure

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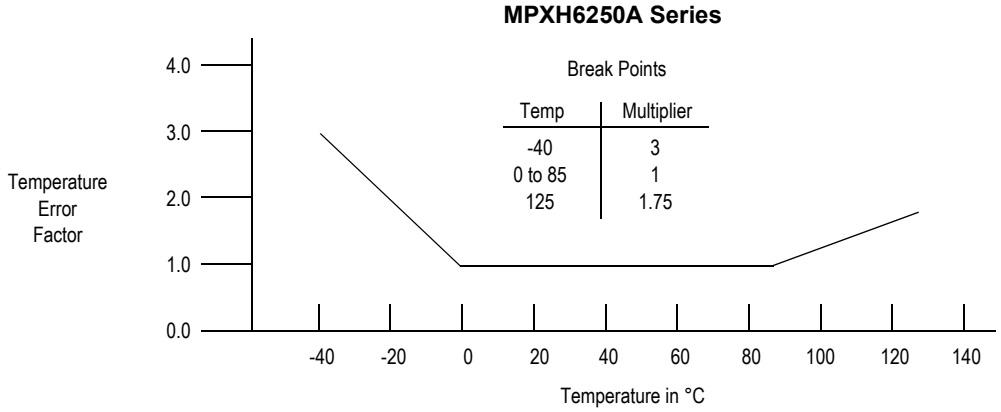
Transfer Function (MPXH6250A)

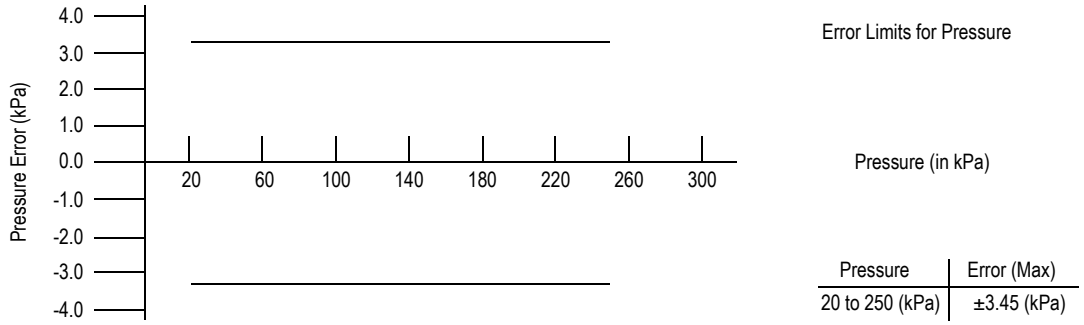
Nominal Transfer Value: $V_{out} = V_S \times (0.004 \times P - 0.040)$
$\pm$ (Pressure Error x Temp Factor x 0.004 x V_S)
$V_S = 5.1 \pm 0.36$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C.

Pressure Error Band



SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

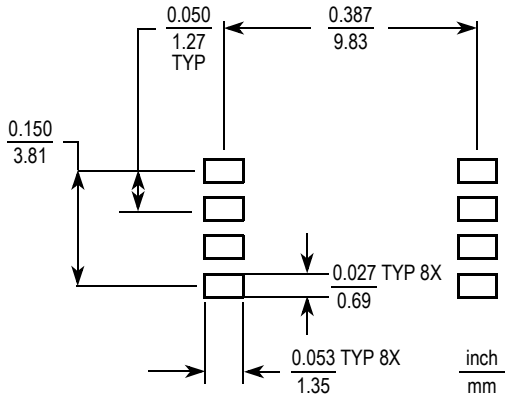


Figure 5. SSOP Footprint (Case 1317 and 1317A)

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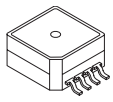
High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

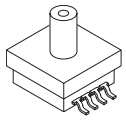
MPXH6300A SERIES

INTEGRATED PRESSURE SENSOR 20 to 304 kPa (3.0 to 42 psi) 0.3 to 4.9 V OUTPUT

SUPER SMALL OUTLINE PACKAGES



MPXH6300A6U/6T1
CASE 1317-04



MPXH6300AC6U/C6T1
CASE 1317A-03

The Freescale MPXH6300A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MPXH6300A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Application Examples

- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Basic Element	Absolute, Element Only	1317	MPXH63000A6U	Rails	MPXH6300A
	Absolute, Element Only	1317	MPXH6300A6T1	Tape & Reel	MPXH6300A
Ported Element	Absolute, Axial Port	1317A	MPXH6300AC6U	Rails	MPXH6300A
	Absolute, Axial Port	1317A	MPXH300AC6T1	Tape & Reel	MPXH6300A

PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

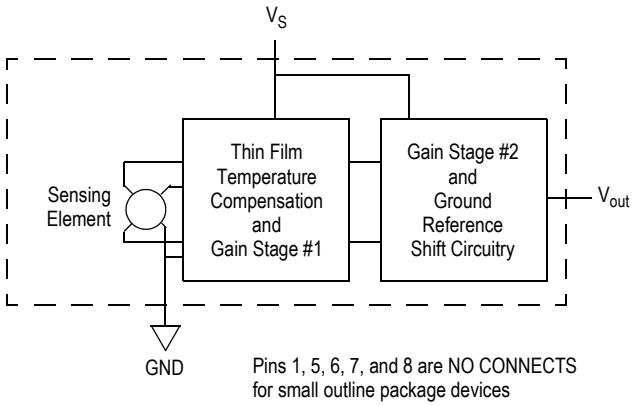


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1200	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	I_o–	–0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	304	kPa
Supply Voltage(1)		V_S	4.74	5.1	5.46	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(2)	(0 to 85°C)	V_{off}	0.241	0.306	0.371	Vdc
Full Scale Output @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{FSO}	4.847	4.912	4.977	Vdc
Full Scale Span @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSS}	4.476	4.606	4.736	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	16.2	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:

   Linearity:Output deviation from a straight line relationship with pressure over the specified pressure range.
   Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   TcSpan:Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   TcOffset:Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   Variation from Nominal:The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6300A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

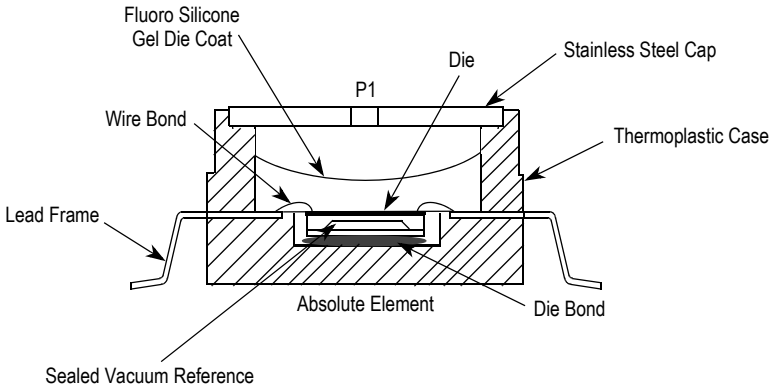

Figure 2. Cross Sectional Diagram SSOP (not to scale)

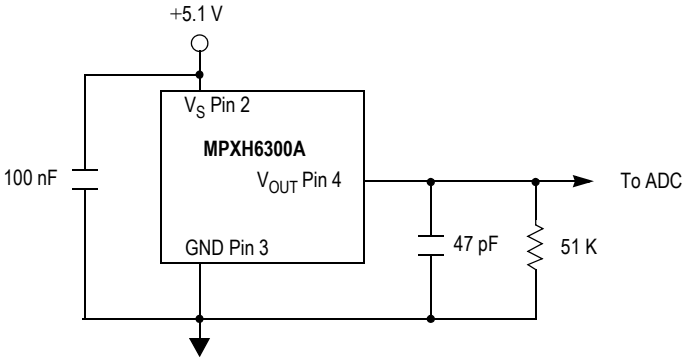

Figure 3. Typical Application Circuit (Output Source Current Operation)

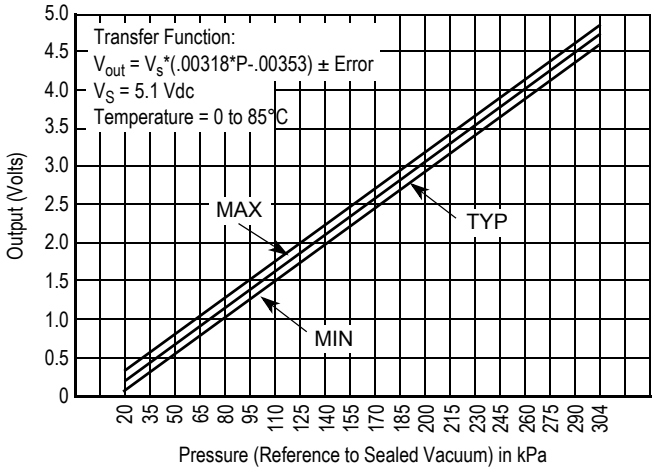

Figure 4. Output versus Absolute Pressure

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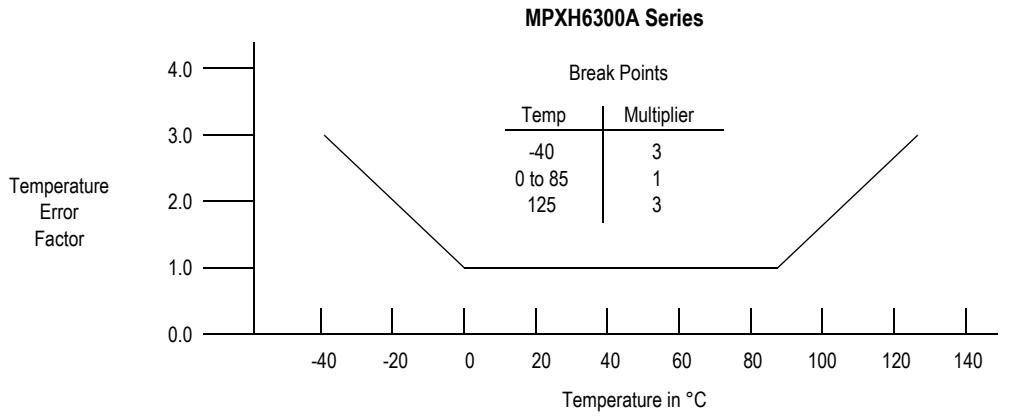
Transfer Function (MPXH6300A)

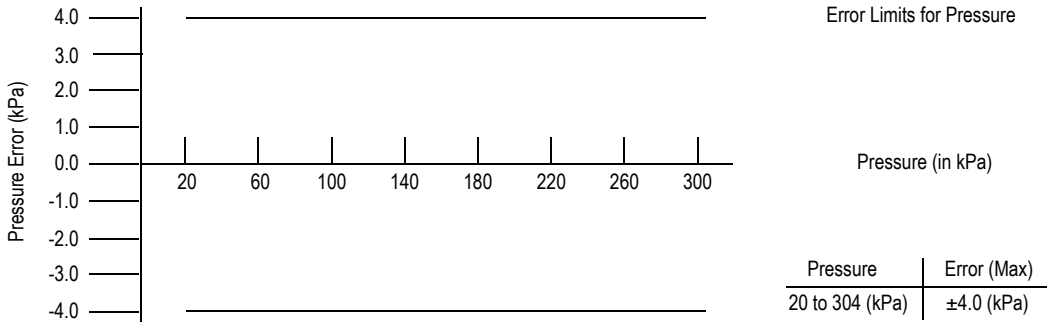
Nominal Transfer Value: $V_{out} = V_S \times (0.00318 \times P - 0.00353)$
$\pm$ (Pressure Error x Temp Factor x 0.00318 x V_S)
$V_S = 5.1 \pm 0.36$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
20 to 304 (kPa)	±4.0 (kPa)

SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

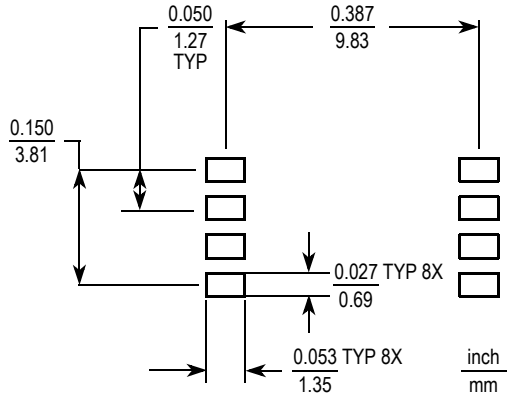


Figure 5. SSOP Footprint (Case 1317 and 1317A)

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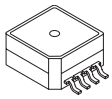
High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

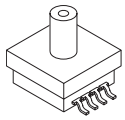
MPXH6400A SERIES

INTEGRATED PRESSURE SENSOR 20 TO 400 kPA (3.0 TO 58 psi) 0.2 TO 4.8 V OUTPUT (3.0 TO 58 psi)

SUPER SMALL OUTLINE PACKAGES



MPXH6400A6U/6T1
CASE 1317-04



MPXH6400AC6U/C6T1
CASE 1317A-03

The Freescale MPXH6400A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MPXH6400A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Manifold Absolute Pressure (MAP)

ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Basic Element	Absolute, Element Only	1317	MPXH6400A6U	Rails	MPXH6400A
	Absolute, Element Only	1317	MPXH6400A6T1	Tape & Reel	MPXH6400A
Ported Element	Absolute, Axial Port	1317A	MPXH6400AC6U	Rails	MPXH6400A
	Absolute, Axial Port	1317A	MPXH6400AC6T1	Tape & Reel	MPXH6400A

PIN NUMBERS(1)

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

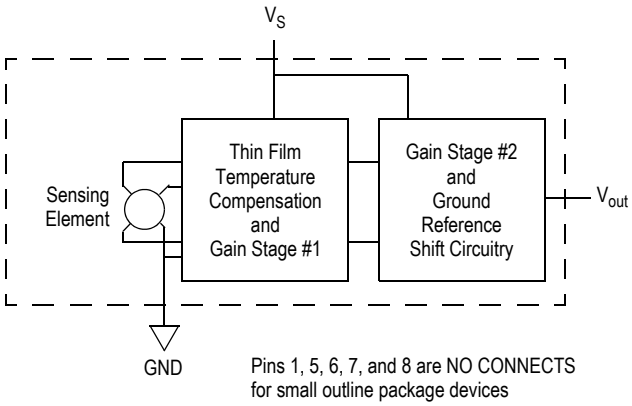


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	1600	kPa
Storage Temperature	T_{STG}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	I_o–	–0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	400	kPa
Supply Voltage(1)		V_S	4.64	5.0	5.36	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.1 Volts(2)	(0 to 85°C)	V_{off}	0.133	0.2	0.267	Vdc
Full Scale Output @ V_S = 5.1 Volts(3)	(0 to 85°C)	V_{FSO}	4.733	4.8	4.866	Vdc
Full Scale Span @ V_S = 5.1 Volts(4)	(0 to 85°C)	V_{FSS}	4.467	4.6	4.733	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	12.1	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates the absolute sensing chip in the basic Super Small Outline chip carrier (Case 1317). Figure 3 illustrates a typical application circuit (output source current operation).

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXH6400A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

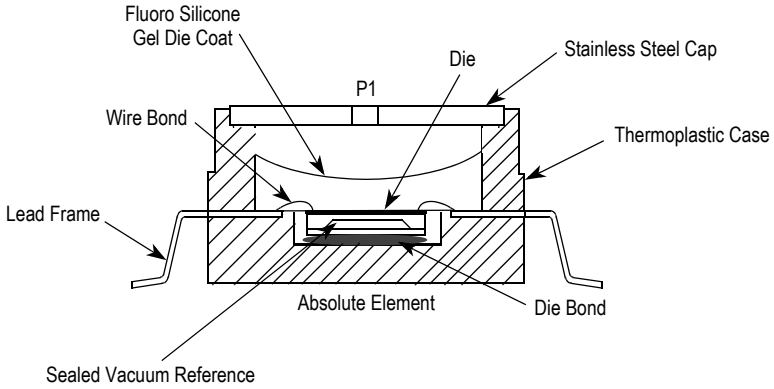

Figure 2. Cross Sectional Diagram SSOP (not to scale)

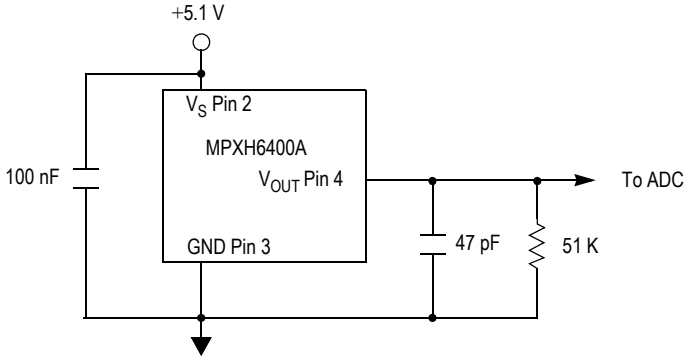

Figure 3. Typical Application Circuit (Output Source Current Operation)

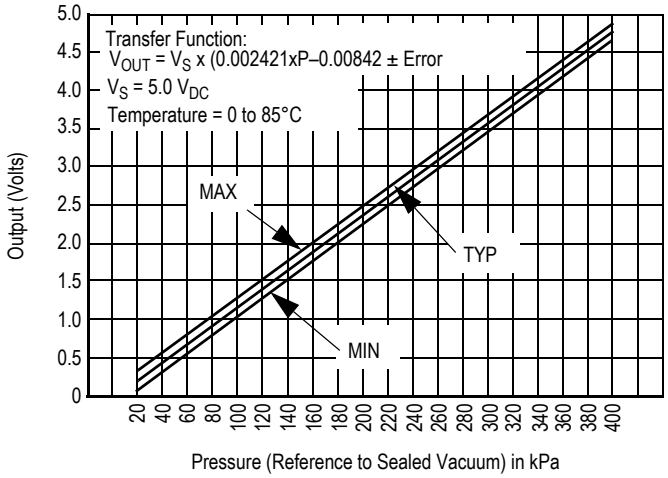

Figure 4. Output versus Absolute Pressure

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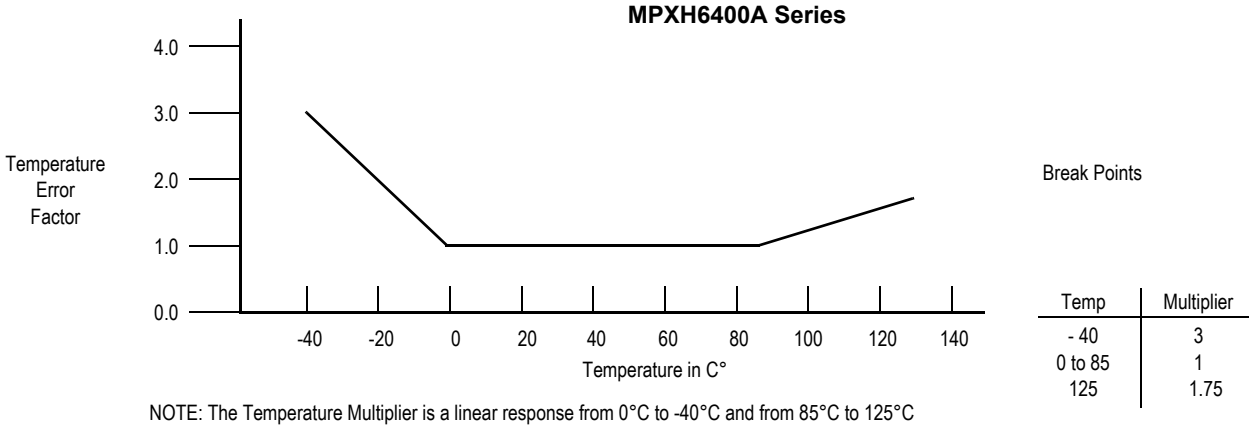
Transfer Function (MPXH6400A)

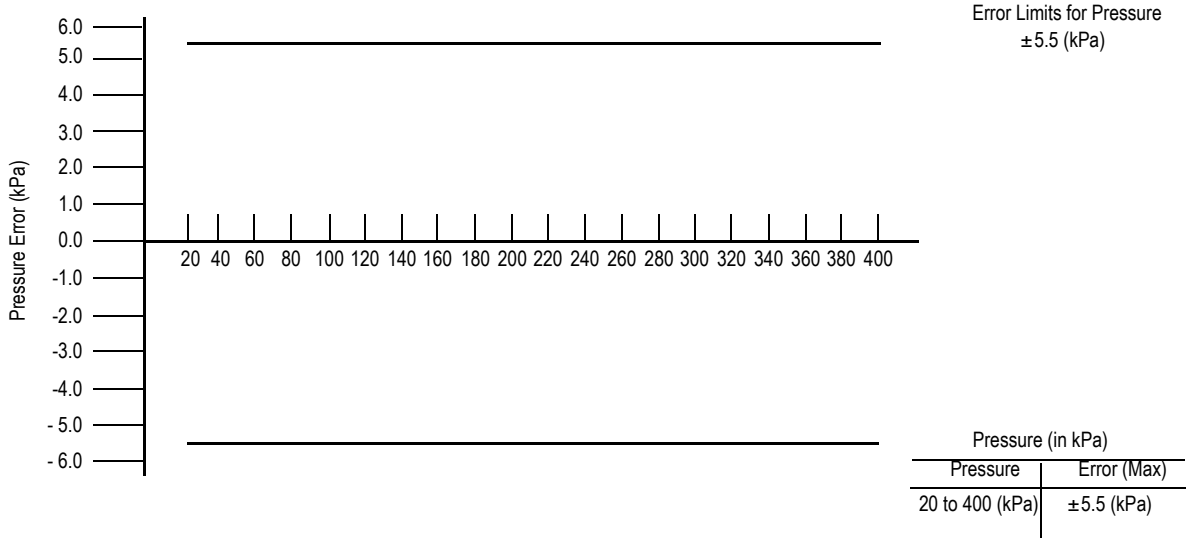
Normal Transfer Value: $V_{OUT} = V_S \times (0.002421 \times P - 0.0.00842)$
$\pm$ Pressure Error x Temp. Factor x 0.002421 x V_S
$V_S = 5.0 \pm 0.36\ V_{DC}$

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C

Pressure Error Band



SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

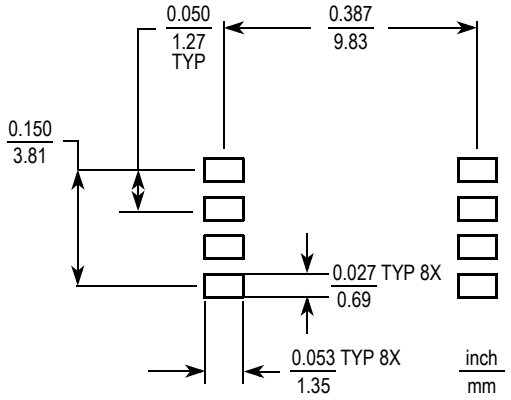


Figure 5. SSOP Footprint (Case 1317 and 1317A)

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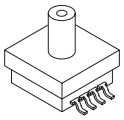
Media Resistant and High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXHZ6250A

INTEGRATED PRESSURE SENSOR
20 to 250 kPa (3.0 to 36 psi)
0.3 to 4.9 V OUTPUT

SUPER SMALL OUTLINE PACKAGE



MPXHZ6250AC6T1
CASE 1317A-03

The Freescale MPXHZ6250A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale sensor a logical and economical choice for automotive system designers.

The MPXHZ6250A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Liquified Petroleum Gas (LPG)

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported Element	Absolute, Axial Port	1317A	MPXHZ6250AC6T1	Tape & Reel	MPXHZ6250A

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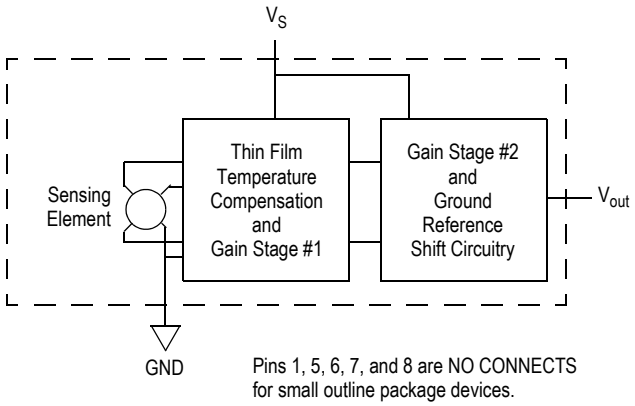

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{MAX}	1000	kPa
Storage Temperature	T_{STG}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	I_o–	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	250	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.0 Volts(2)	(0 to 85°C)	V_{off}	0.131	0.2	0.269	Vdc
Full Scale Output @ V_S = 5.0 Volts(3)	(0 to 85°C)	V_{FSO}	4.731	4.8	4.869	Vdc
Full Scale Span @ V_S = 5.0 Volts(4)	(0 to 85°C)	V_{FSS}	4.462	4.6	4.738	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	20	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
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   - TcSpan: Output deviation over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates a typical application circuit (output source current operation).

Figure 3 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXHZ6250A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

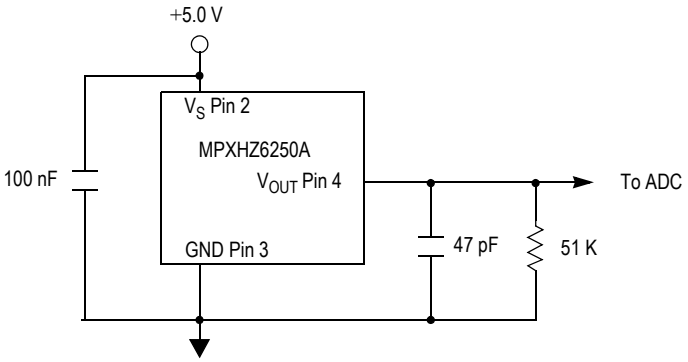

Figure 2. Typical Application Circuit (Output Source Current Operation)

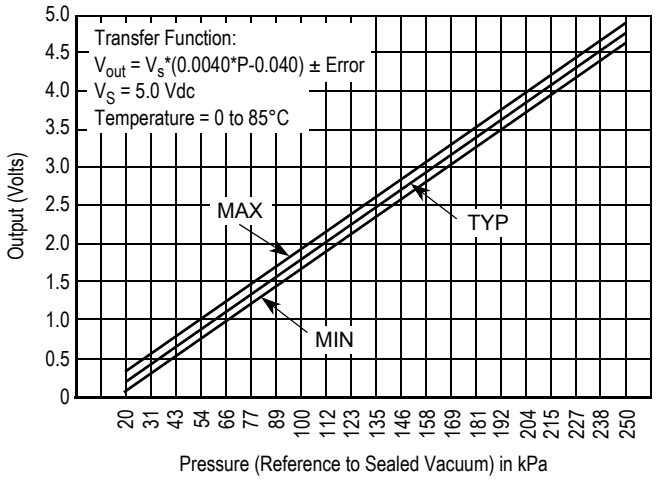

Figure 3. Output versus Absolute Pressure

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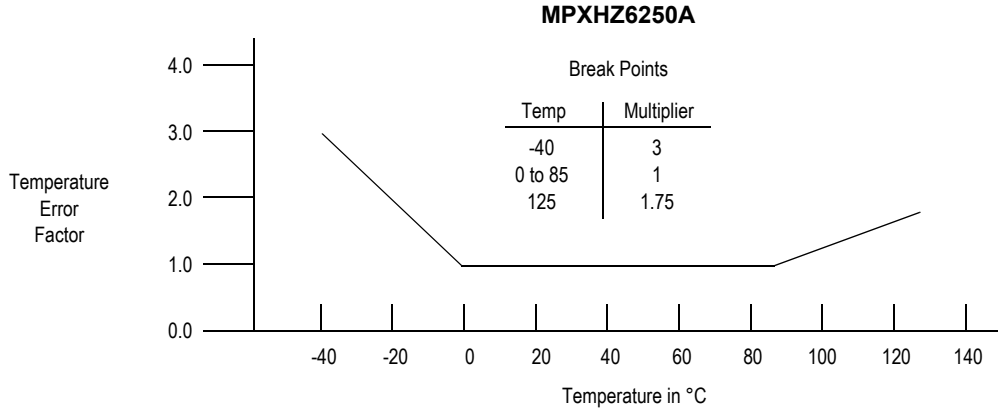
Transfer Function (MPXHZ6250A)

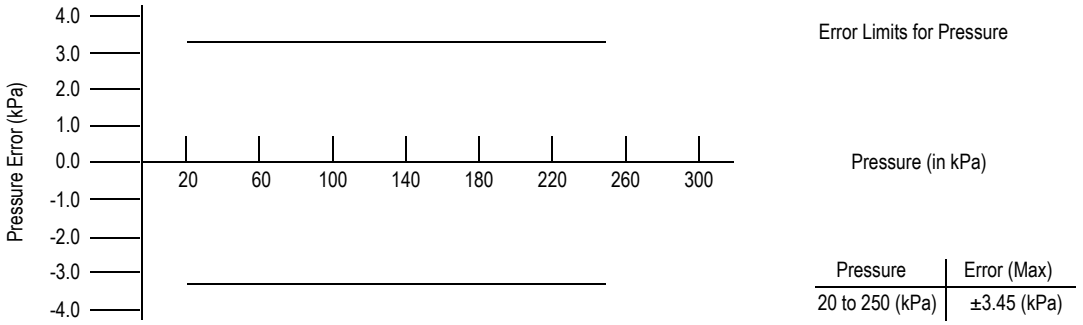
Nominal Transfer Value: $V_{out} = V_S \times (0.004 \times P - 0.040)$
$\pm$ (Pressure Error x Temp Factor x 0.004 x V_S)
$V_S = 5.0 \pm 0.36$ Vdc

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C.

Pressure Error Band



SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

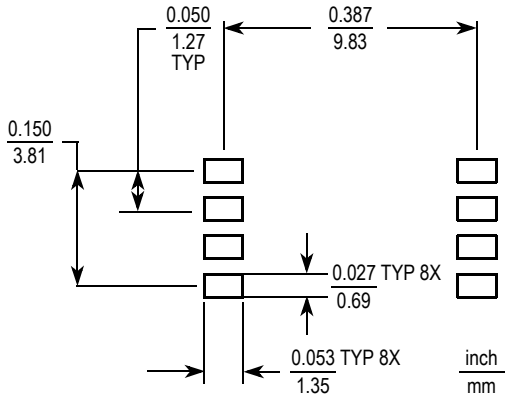


Figure 4. SSOP Footprint (Case 1317A)

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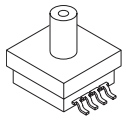
Media Resistant and High Temperature Accuracy Integrated Silicon Pressure Sensor for Measuring Absolute Pressure, On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXHZ6400A

INTEGRATED PRESSURE SENSOR 20 TO 400 kPA (3.0 TO 58 psi) 0.2 TO 4.8 V OUTPUT (3.0 TO 58 psi)

SUPER SMALL OUTLINE PACKAGE



MPXHZ6400AC6T1
CASE 1317A-03

The Freescale MPXHZ6400A series sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale pressure sensor a logical and economical choice for the system designer.

The MPXHZ6400A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- Available in Small and Super Small Outline Packages
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from –40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Industrial Controls
- Engine Control/Liquified Petroleum Gas (LPG)

PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

ORDERING INFORMATION					
Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Ported Element	Absolute, Axial Port	1317A	MPXHZ6400AC6T1	Tape & Reel	MPXHZ6400A

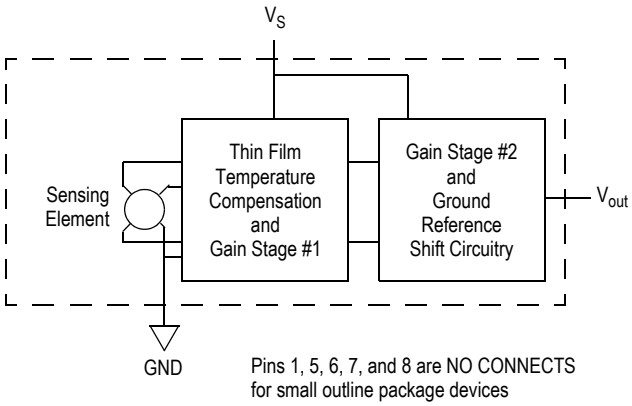


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{MAX}	1600	kPa
Storage Temperature	T_{STG}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset2	$I_o–$	–0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to GND or V_{out} to V_S in the application circuit.

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Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	20	—	400	kPa
Supply Voltage(1)		V_S	4.64	5.0	5.36	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Minimum Pressure Offset @ V_S = 5.0 Volts(2)	(0 to 85°C)	V_{off}	0.133	0.2	0.267	Vdc
Full Scale Output @ V_S = 5.0 Volts(3)	(0 to 85°C)	V_{FSO}	4.733	4.8	4.866	Vdc
Full Scale Span @ V_S = 5.0 Volts(4)	(0 to 85°C)	V_{FSS}	4.467	4.6	4.733	Vdc
Accuracy(5)	(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity		V/P	—	12.1	—	mV/kPa
Response Time(6)		t_R	—	1.0	—	ms
Warm-Up Time(7)		—	—	20	—	ms
Offset Stability(8)		—	—	±0.25	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
3. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
4. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
5. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:

   Linearity:Output deviation from a straight line relationship with pressure over the specified pressure range.

   Temperature Hysteresis:Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.

   Pressure Hysteresis:Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.

   TcSpan:Output deviation over the temperature range of 0 to 85°C, relative to 25°C.

   TcOffset:Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.

   Variation from Nominal:The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
8. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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Figure 2 illustrates a typical application circuit (output source current operation).

Figure 3 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXHZ6400A series pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

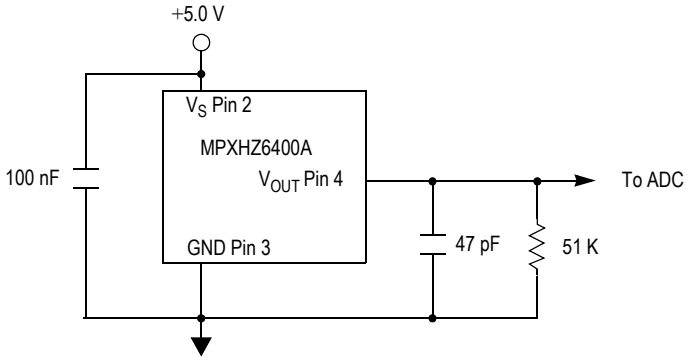

Figure 2. Typical Application Circuit (Output Source Current Operation)

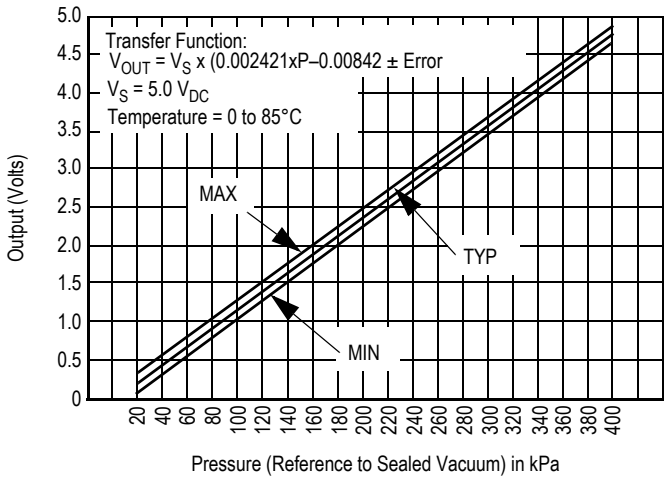

Figure 3. Output versus Absolute Pressure

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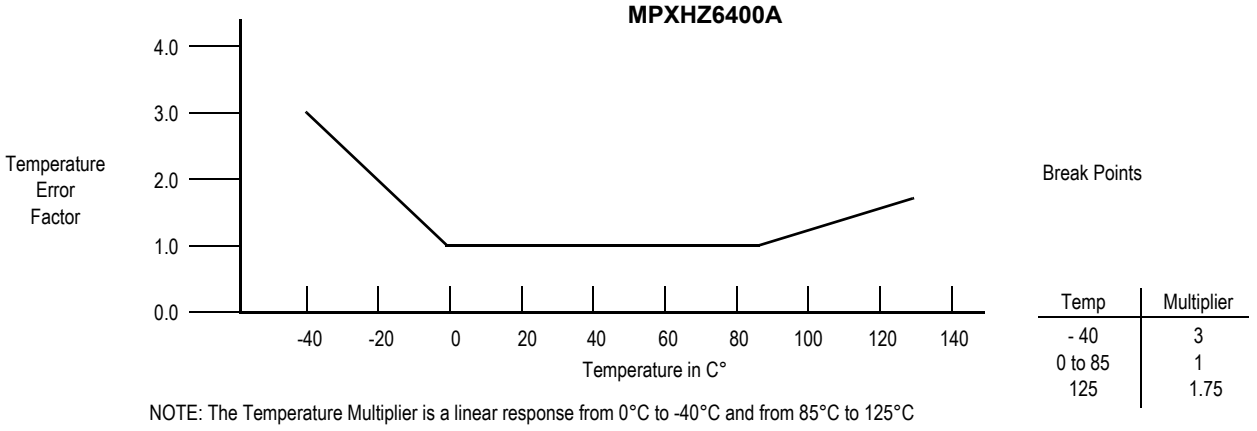
Transfer Function (MPXHZ6400A)

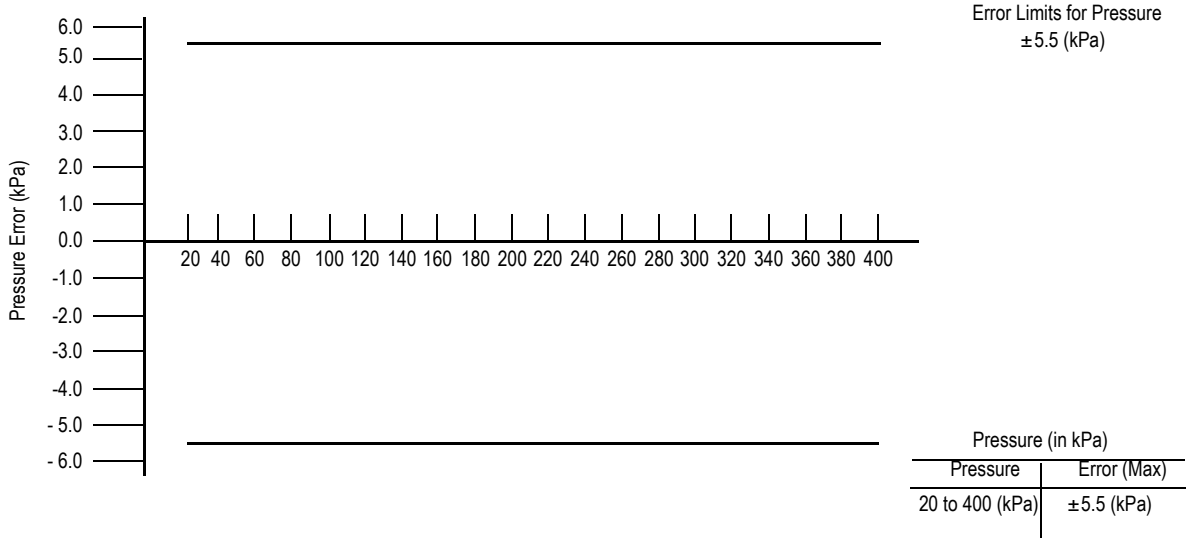
Normal Transfer Value: $V_{OUT} = V_S \times (0.002421 \times P - 0.0.00842)$
$\pm$ Pressure Error x Temp. Factor x 0.002421 x V_S
$V_S = 5.0 \pm 0.36\ V_{DC}$

Temperature Error Band



NOTE: The Temperature Multiplier is a linear response from 0°C to -40°C and from 85°C to 125°C

Pressure Error Band



SURFACE MOUNTING INFORMATION

Minimum Recommended Footprint for Super Small Outline Packages

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

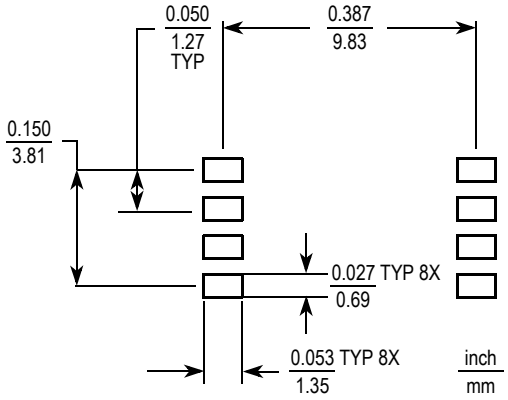


Figure 4. SSOP Footprint (Case 1317A)

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10 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPXM2010 SERIES

The MPXM2010 device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output – directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

FREESCALE PREFERRED DEVICE
0 to 10 kPa (0 to 1.45 psi)
25 mV FULL SCALE SPAN (TYPICAL)

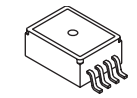
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported & Non Ported Options

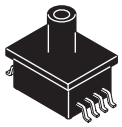
Application Examples

- Respiratory Diagnostics
- Air Movement Control
- Controllers
- Pressure Switching

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.



MPXM2010D/DT1
CASE 1320-02



MPXM2010GS/GST1
CASE 1320A-02

ORDERING INFORMATION		
Device Type/Order No.	**Options**	**Case No.**
MPXM2010D	Non-ported	1320
MPXM2010DT1	Non-ported, Tape and Reel	1320
MPXM2010GS	Ported	1320A
MPXM2010GST1	Ported, Tape and Reel	1320A

PIN NUMBERS			
1	GND	3	V_S
2	$+V_{out}$	4	$-V_{out}$

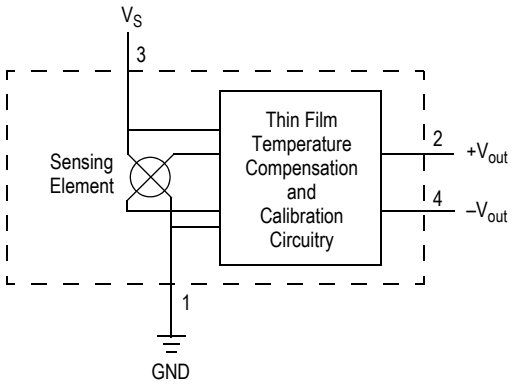


Figure 1. Fully Integrated Pressure Sensor Schematic

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VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

NOTE: **Preferred** devices are Freescale recommended choices for future use and best overall value.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{MAX}	75	kPa
Storage Temperature	T_{STG}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	10	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	24	25	26	mV
Offset[4]	V_{off}	–1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	2.5	—	mV/kPa
Linearity[5]	—	–1.0	—	1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 10 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (–40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	–1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	–1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2550	Ω
Output Impedance	Z_{out}	1400	—	3000	Ω
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Freescale's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

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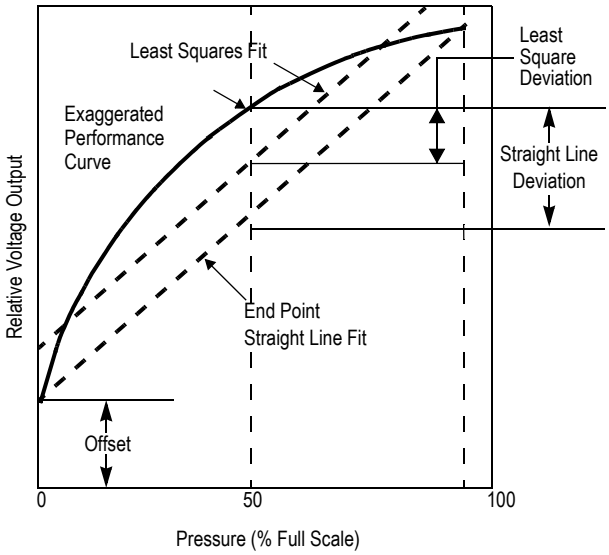

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2010 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

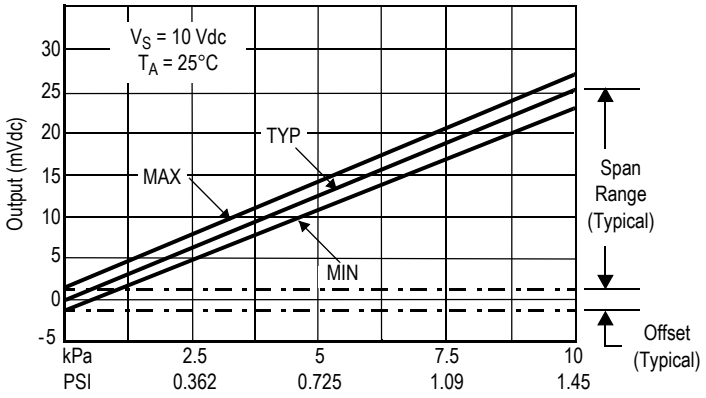

Figure 3. Output versus Pressure Differential

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50 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

MPXM2051G SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 50 kPA (0 TO 7.25 psi)
40 mV FULL SCALE SPAN (TYPICAL)

The MPXM2051G device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

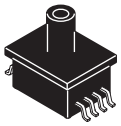
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

MPAK PACKAGES



MPXM2051GS/GST1
CASE 1320A-02

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported	Absolute, Axial Port	1320A	MPXM2051GS	Rails	MPXM2051G
	Absolute, Element Only	1320A	MPXM2051GST1	Tape & Reel	MPXM2051G

Pin Number			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

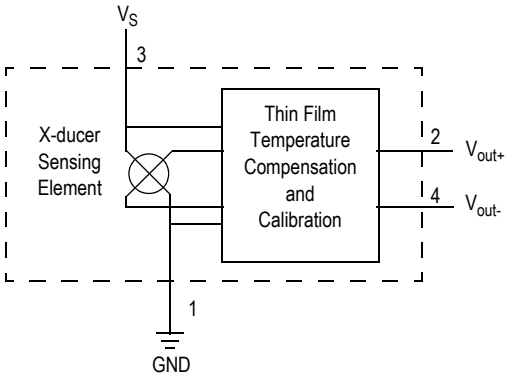


Figure 1. Temperature Compensated Pressure Sensor Schematic

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VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	200	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(2)	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(3)	V_{FSS}	38.5	40	41.5	mV
Offset(4)	V_{off}	-1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	0.8	—	mV/kPa
Linearity(5)	—	-0.3	—	0.3	$\%V_{FSS}$
Pressure Hysteresis(5) (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis(5) (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span(5)	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset(5)	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	Ω
Output Impedance	Z_{out}	1400	—	3000	Ω
Response Time(6) (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability(7)	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

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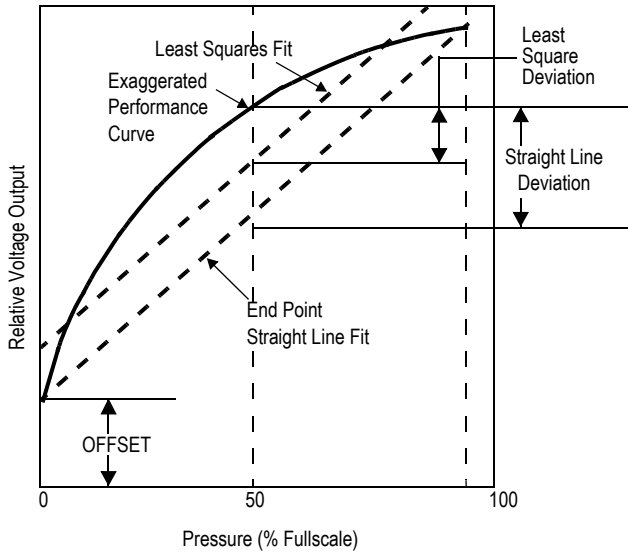

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2051G series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

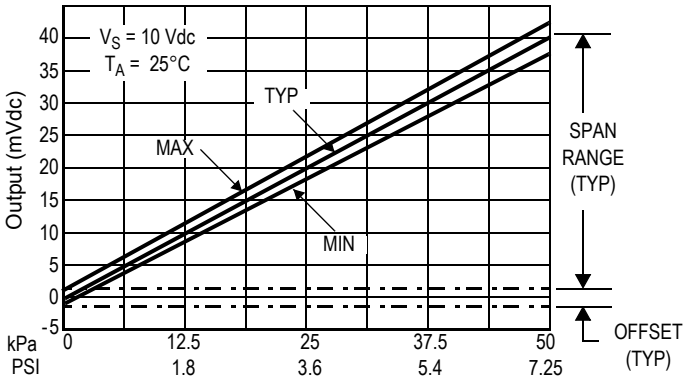

Figure 3. Output versus Pressure Differential

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50 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

MPXM2053 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 50 kPA (0 TO 7.25 psi)
40 mV FULL SCALE SPAN (TYPICAL)

The MPXM2053 device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

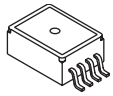
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

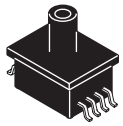
Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Non-Invasive Blood Pressure Measurement

MPAK PACKAGES



MPXM2053D/DT
CASE 1320-02



MPXM2053GS/GST1
CASE 1320A-02

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Non-ported	Absolute, Element Only	1320	MPXM2053D	Rails	MPXM2053D
	Absolute, Axial Port	1320	MPXM2053DT1	Tape & Reel	MPXM2053D
Ported	Absolute, Axial Port	1320A	MPXM2053GS	Rails	MPXM2053G
	Absolute, Element Only	1320A	MPXM2053GST1	Tape & Reel	MPXM2053G

Pin Number			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

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Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

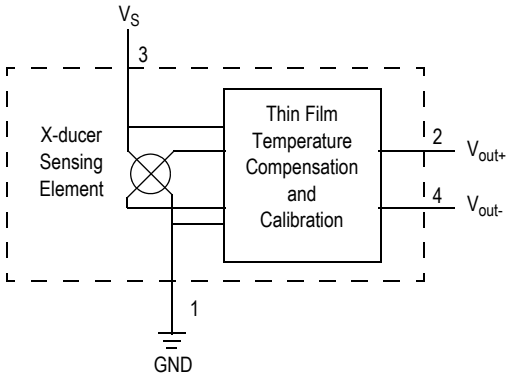

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	200	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1]	P_{OP}	0	—	50	kPa
Supply Voltage[2]	V_S	—	10	16	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span[3]	V_{FSS}	38.5	40	41.5	mV
Offset[4]	V_{off}	-1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity[5]	—	-0.6	—	0.4	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 50 kPa)	—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)	—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]	TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]	TCV_{off}	-1.0	—	1.0	mV
Input Impedance	Z_{in}	1000	—	2500	Ω
Output Impedance	Z_{out}	1400	—	3000	Ω
Response Time[6] (10% to 90%)	t_R	—	1.0	—	ms
Warm-Up	—	—	20	—	ms
Offset Stability[7]	—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the “best case” linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the “worst case” error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. The specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

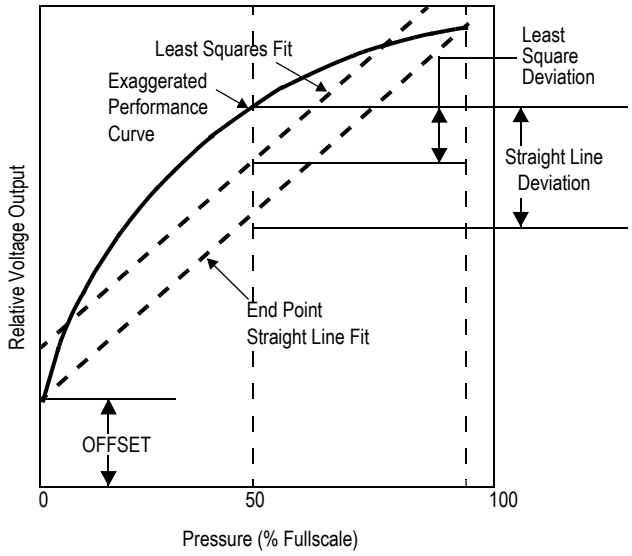

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2053 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

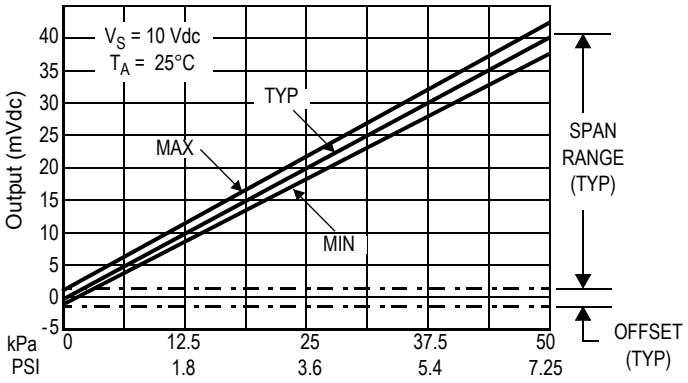

Figure 3. Output versus Pressure Differential

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100 kPa On-Chip Temperature Compensated & Calibrated Silicon Pressure Sensors

MPXM2102 SERIES

**COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 100 kPA (0 TO 14.5 psi)
40 mV FULL SCALE SPAN
(TYPICAL)**

The MPXM2102 device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output - directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

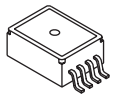
Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape & Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

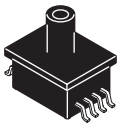
Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

MPAK PACKAGES



**MPXM2102D/A
CASE 1320-02**



**MPXM2102GS/AS
CASE 1320A-02**

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Non-ported	Gauge	1320	MPXM2102D	Rails	MPXM2102D
	Gauge	1320	MPXM2102DT1	Tape & Reel	MPXM2102D
	Absolute	1320	MPXM2102A	Rails	MPXM2102A
	Absolute	1320	MPXM2102AT1	Tape & Reel	MPXM2102A
Ported	Gauge, Axial Port	1320A	MPXM2102GS	Rails	MPXM2102G
	Gauge, Axial Port	1320A	MPXM2102GST1	Tape & Reel	MPXM2102G
	Absolute, Axial Port	1320A	MPXM2102AS	Rails	MPXM2102A
	Absolute, Axial Port	1320A	MPXM2102AST1	Tape & Reel	MPXM2102A

Pin Number			
1	Gnd	3	V_S
2	$+V_{out}$	4	$-V_{out}$

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Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

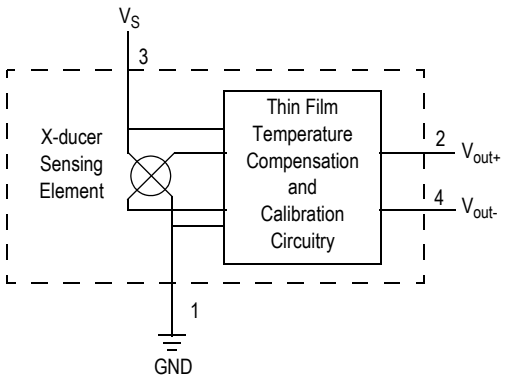

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	200	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	100	kPa
Supply Voltage[2]		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	-	mAdc
Full Scale Span[3]		V_{FSS}	38.5	40	41.5	mV
Offset[4]	MPXM2102D/G Series MPXM2102A Series	V_{off}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.4	—	mV/kPa
Linearity[5]	MPXM2102D/G Series MPXM2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]		TCV_{off}	-1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time[6] (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up		—	—	20	—	ms
Offset Stability[7]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
5. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure, using end point method, over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

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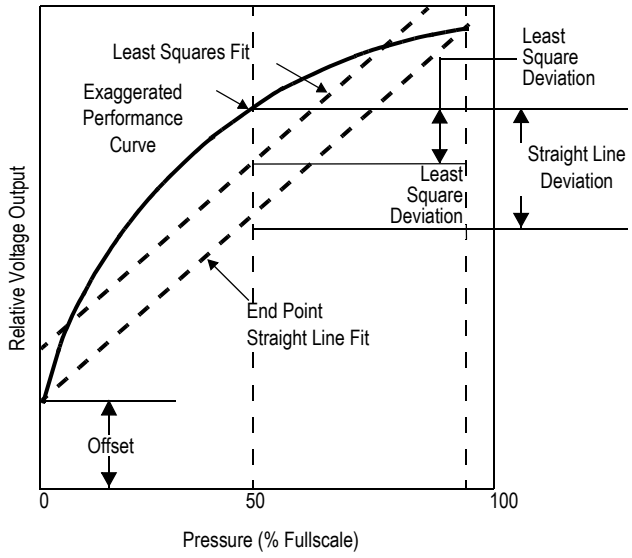

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2120 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

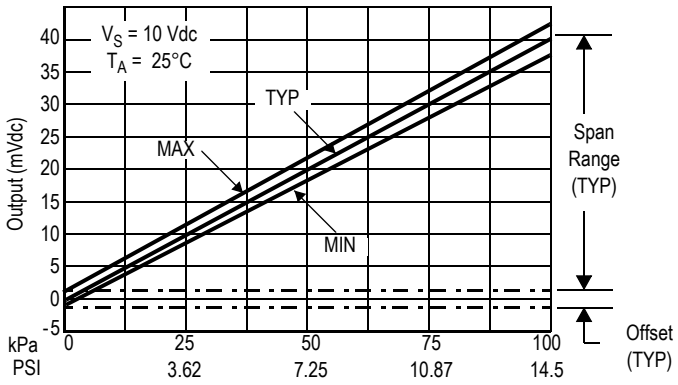

Figure 3. Output versus Pressure Differential

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200 kPa On-Chip Temperature Compensated and Calibrated Silicon Pressure Sensors

The MPXM2202 device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation.

Features

- Temperature Compensated Over 0°C to +85°C
- Available in Easy-to-Use Tape and Reel
- Ratiometric to Supply Voltage
- Gauge Ported and Non Ported Options

Typical Applications

- Pump/Motor Controllers
- Robotics
- Level Indicators
- Medical Diagnostics
- Pressure Switching
- Barometers
- Altimeters

MPXM2202 SERIES

COMPENSATED AND CALIBRATED PRESSURE SENSOR
0 TO 200 kPA (0 TO 29 psi)
40 mV FULL SCALE SPAN (TYPICAL)

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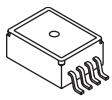
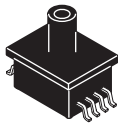


MPXM2202D/A
CASE 1320-02



MPXM2202GS/AS
CASE 1320A-02

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Non-ported	Absolute, Element Only	1320	MPXM2202D	Rails	MPXM2202D
	Absolute, Element Only	1320	MPXM2202DT1	Tape & Reel	MPXM2202D
	Absolute, Element Only	1320	MPXM2202A	Rails	MPXM2202A
	Absolute, Element Only	1320	MPXM2202AT1	Tape & Reel	MPXM2202A
Ported	Absolute, Axial Port	1320A	MPXM2202GS	Rails	MPXM2202G
	Absolute, Axial Port	1320A	MPXM2202GST1	Tape & Reel	MPXM2202G
	Absolute, Axial Port	1320A	MPXM2202AS	Rails	MPXM2202A
	Absolute, Axial Port	1320A	MPXM2202AST1	Tape & Reel	MPXM2202A

PIN NUMBER			
1	GND	3	V_S
2	$+V_{OUT}$	4	$-V_{OUT}$

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Figure 1 shows a block diagram of the internal circuitry on the stand-alone pressure sensor chip.

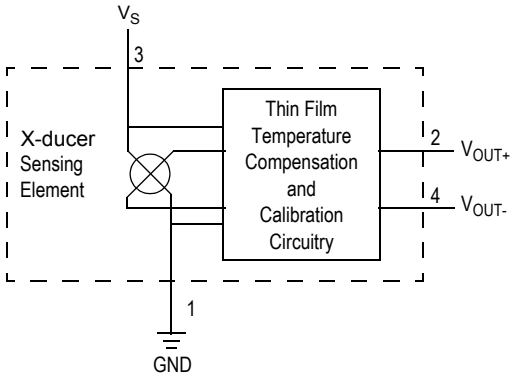

Figure 1. Temperature Compensated Pressure Sensor Schematic

VOLTAGE OUTPUT VERSUS APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the sensor is directly proportional to the differential pressure applied.

The output voltage of the differential or gauge sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side.

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40 to +125	°C
Operating Temperature	T_A	-40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 10 Vdc, T_A = 25°C.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	0	—	200	kPa
Supply Voltage[2]		V_S	—	10	16	Vdc
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span[3]		V_{FSS}	38.5	40	41.5	mV
Offset[4]	MPXM2202D/G Series MPXM2202A Series	V_{OFF}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity[5]	MPXM2202D/G Series MPXM2202A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$
Pressure Hysteresis[5] (0 to 100 kPa)		—	—	±0.1	—	$\%V_{FSS}$
Temperature Hysteresis[5] (-40°C to +125°C)		—	—	±0.5	—	$\%V_{FSS}$
Temperature Effect on Full Scale Span[5]		TCV_{FSS}	-2.0	—	2.0	$\%V_{FSS}$
Temperature Effect on Offset[5]		TCV_{OFF}	-1.0	—	1.0	mV
Input Impedance		Z_{IN}	1000	—	2500	Ω
Output Impedance		Z_{OUT}	1400	—	3000	Ω
Response Time[6] (10% to 90%)		t_R	—	1.0	—	ms
Warm-Up		—	—	20	—	ms
Offset Stability[7]		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range. Operating the device above the specified excitation range may induce additional error due to device self-heating.
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   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - TcSpan: Output deviation at full rated pressure over the temperature range of 0 to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0 to 85°C, relative to 25°C.
6. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
7. Offset stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{OUT} = V_{OFF}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

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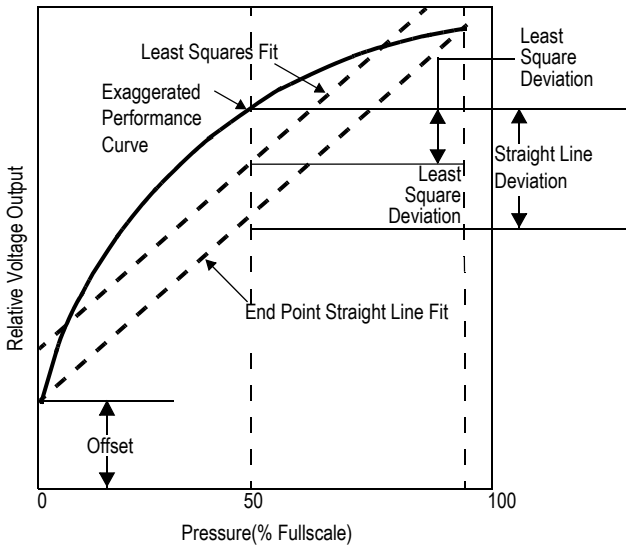

Figure 2. Linearity Specification Comparison

ON-CHIP TEMPERATURE COMPENSATION AND CALIBRATION

Figure 3 shows the minimum, maximum and typical output characteristics of the MPXM2202 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

A silicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

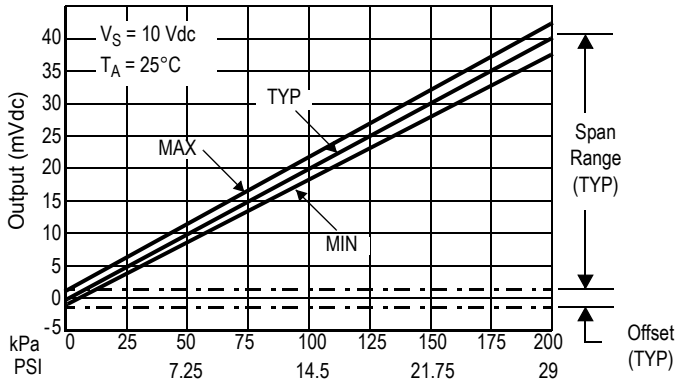

Figure 3. Output versus Pressure Differential

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV4006G

INTEGRATED PRESSURE SENSOR 0 to 6 kPa (0 to 0.87 psi) 0.2 to 4.7 V OUTPUT

The MPXV4006G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This sensor combines a highly sensitive implanted strain gauge with advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

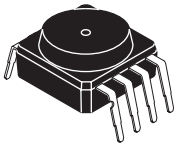
- Temperature Compensated over 10° to 60°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Available in Gauge Surface Mount (SMT) or Through-hole (DIP) Configurations
- Durable Thermoplastic (PPS) Package

MPXV4006G series pressure sensors are available in the basic element package or with pressure ports. Two packing options are offered for the 482 and 482A case configurations.

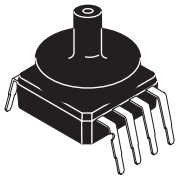
ORDERING INFORMATION

Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Marking
Basic Element	Element Only	482	MPXV4006G6U	Rails	MPXV4006G
	Element Only	482	MPXV4006G6T1	Tape & Reel	MPXV4006G
	Element Only	482B	MPXV4006G7U	Rails	MPXV4006G
Ported Element	Axial Port	482A	MPXV4006GC6U	Rails	MPXV4006G
	Axial Port	482A	MPXV4006GC6T1	Tape & Reel	MPXV4006G
	Axial Port	482C	MPXV4006GC7U	Rails	MPXV4006G
	Side Port	1369	MPXV4006GP	Trays	MPXV4006G
	Dual Port	1351	MPXV4006DP	Trays	MPXV4006G

SMALL OUTLINE PACKAGE THROUGH-HOLE

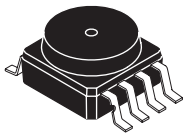


MPXV4006G7U
CASE 482B-03

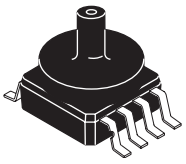


MPXV4006GC7U
CASE 482C-03

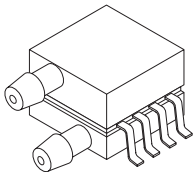
SMALL OUTLINE PACKAGE SURFACE MOUNT



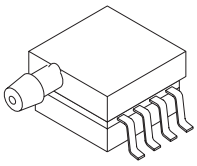
MPXV4006G6U/6T1
CASE 482-01



MPXV4006GC6U/C6T1
CASE 482A-01



MPXV4006DP
CASE 1351-01



MPXV4006GP
CASE 1369-01

PIN NUMBERS[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

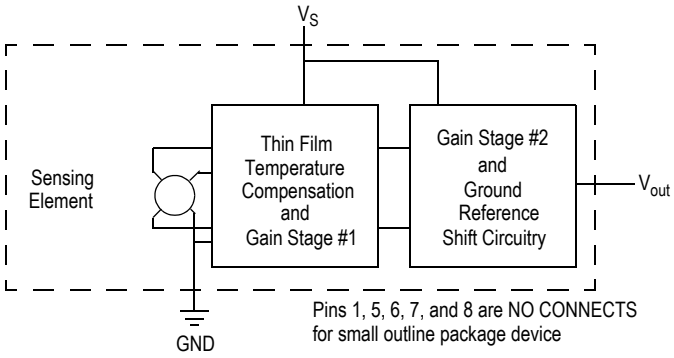


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Parametrics	Symbol	Value	Units
Maximum Pressure (P1 >P2)	P_{max}	24	kPa
Storage Temperature	T_{stg}	-30° to +100°	°C
Operating Temperature	T_A	-10° to +60°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	6.0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_S	—	—	10	mAdc
Full Scale Output(2)	(RF = 51kΩ)	V_{FSS}	—	4.6	—	V
Offset(3)(5)	(RF = 51kΩ)	V_{off}	0.100	0.225	0.430	V
Sensitivity		V/P	—	766	—	mV/kPa
Accuracy(4)(5)	(10 to 60°C)	—	—	—	±5.0	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, -30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10° to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 10° to 60°C, relative to 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPXV4006G, external mechanical stresses and mounting position can affect the zero pressure output reading. To obtain the 5% FSS accuracy, the device output must be “autozeroed" after installation. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION, AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV4006G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

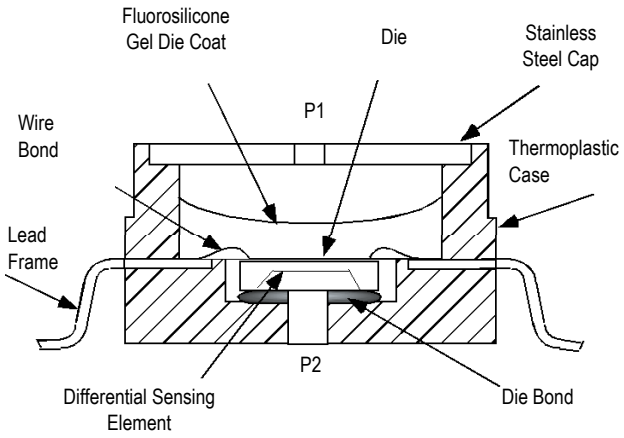

Figure 2. Cross Sectional Diagram SOP (Not to Scale)

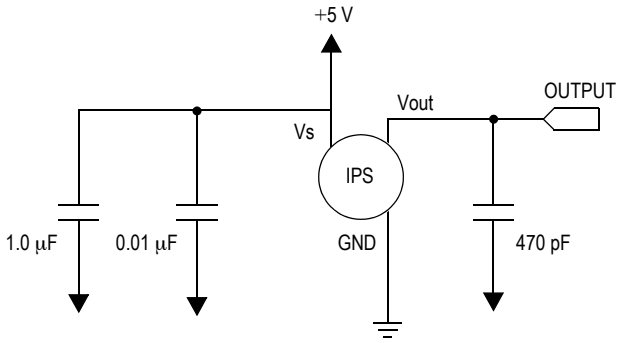

Figure 3. Recommended Power Supply Decoupling and Output Filtering Recommendations
(For additional output filtering, please refer to Application Note AN1646.)

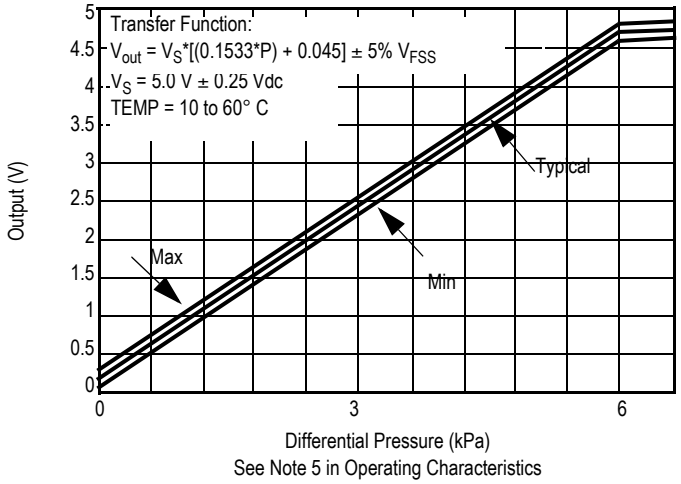

Figure 4. Output versus Pressure Differential

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Table 3. Pressure (P1)/Vacuum (P2) Side Identification Table

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV4006G6U/T1	482	Stainless Steel Cap
MPXV4006GC6U/T1	482A	Side with Port Attached
MPXV4006G7U	482B	Stainless Steel Cap
MPXV4006GC7U	482C	Side with Port Attached
MPXV4006GP	1369	Side with Port Attached
MPXV4006DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

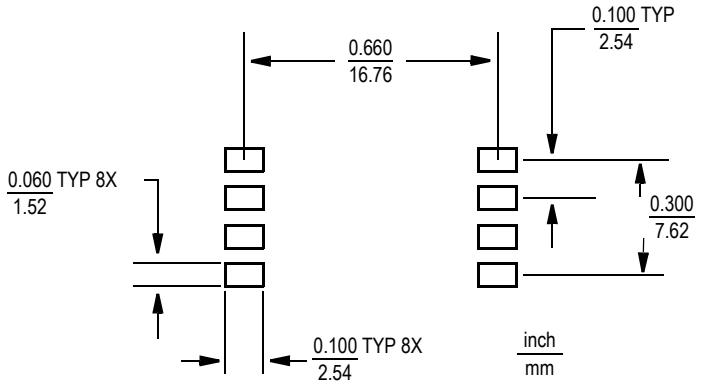

Figure 5. SOP Footprint (Case 482)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated, and Calibrated

MPXV4115V SERIES

INTEGRATED PRESSURE SENSOR –115 to 0 kPa (–16.7 to 2.2 psi) 0.2 to 4.6 V OUTPUT

The MPXV4115V series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, particularly those employing a microcontroller with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization and bipolar processing to provide an accurate, high-level analog output signal that is proportional to the applied pressure/vacuum. The small form factor and high reliability of on-chip integration make the sensor a logical and economical choice for the automotive system designer. Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

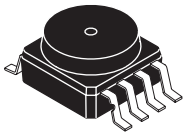
- 1.5% Maximum error over 0° to 85°C
- Temperature Compensated from –40° + 125°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

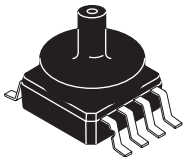
- Vacuum Pump Monitoring
- Brake Booster Monitoring

The MPXV4115V series pressure sensors are available in the basic element package or with a pressure port. Two packing options are also offered.

SMALL OUTLINE PACKAGE



MPXV4115V6U/6T1
CASE 482-01



MPXV4115VC6U
CASE 482A-01

ORDERING INFORMATION				
Device Type	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV4115V SERIES)				
Basic Elements	482	MPXV4115V6U	Rails	MPXV4115V
	482	MPXV4115V6T1	Tape & Reel	MPXV4115V
Ported Elements	482A	MPXV4115VC6U	Rails	MPXV4115V

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

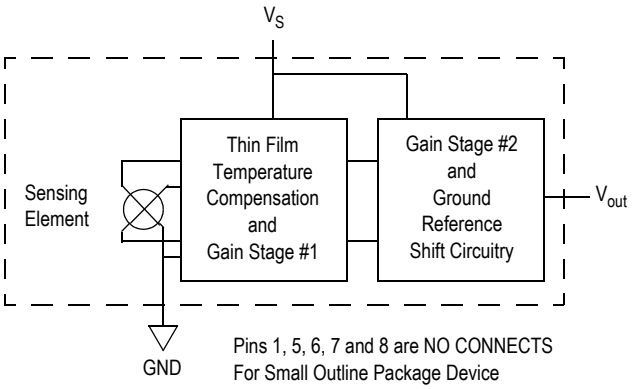


Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure	P_{max}	400	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

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Table 2. Operating Characteristics (V_S = 5 Vdc, T_A = 25°C unless otherwise noted. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range (Differential mode, Vacuum on metal cap side, Atmospheric pressure on back side)		P_{OP}	–115	—	0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Full Scale Output(2) (Pdiff = 0 kPa)2	(0 to 85°C)	V_{FSO}	4.535	4.6	4.665	Vdc
Full Scale Span(3) @ V_S = 5.0 V	(0 to 85°C)	V_{FSS}	—	4.4	—	Vdc
Accuracy(4)	(0 to 85°C)	—	—	—	1.5%	$\%V_{FSS}$
Sensitivity		V/P	—	38.26	—	mV/kPa
Response Time(5)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_o	—	0.1	—	mAdc
Warm-Up Time(6)		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	$\%V_{FSS}$

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output is defined as the output voltage at the maximum or full-rated pressure.
3. Full Scale Span is defined as the algebraic difference between the output voltage at full-rated pressure and the output voltage at the minimum-rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of errors, including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV4115V series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to differential pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 0°C to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

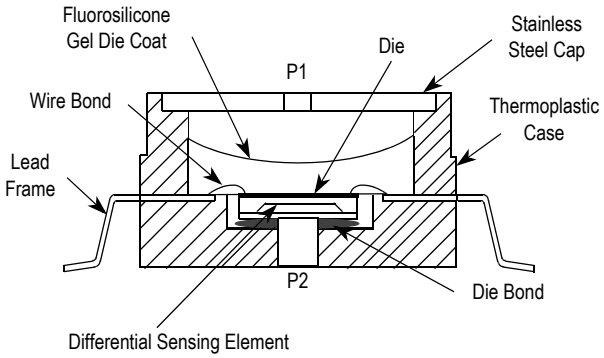

Figure 2. Cross-Sectional Diagram (not to scale)

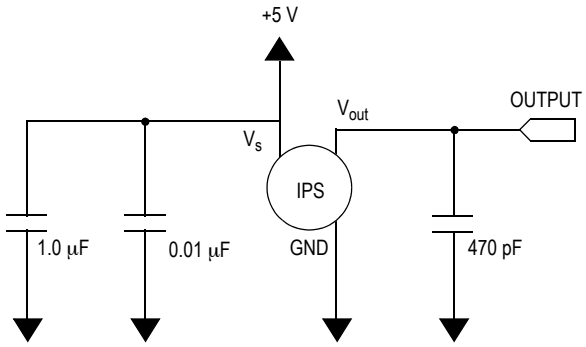

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

TRANSFER FUNCTION MPXV4115V

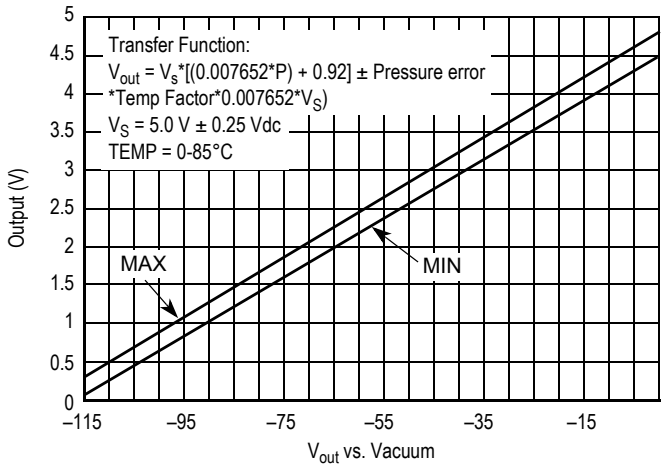

Figure 4. Applied Vacuum in kPa (below atmospheric pressure)

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MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

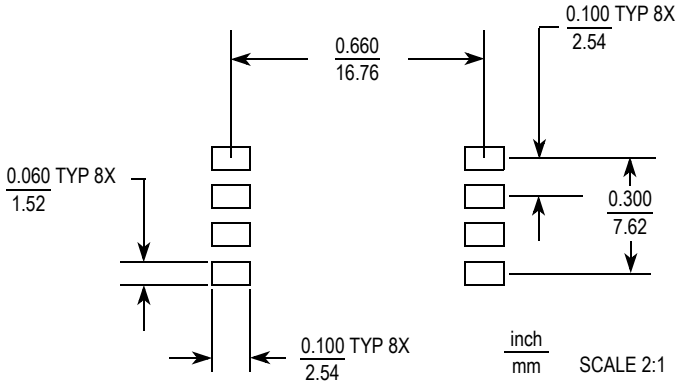

Figure 5. SOP Footprint (Case 482)

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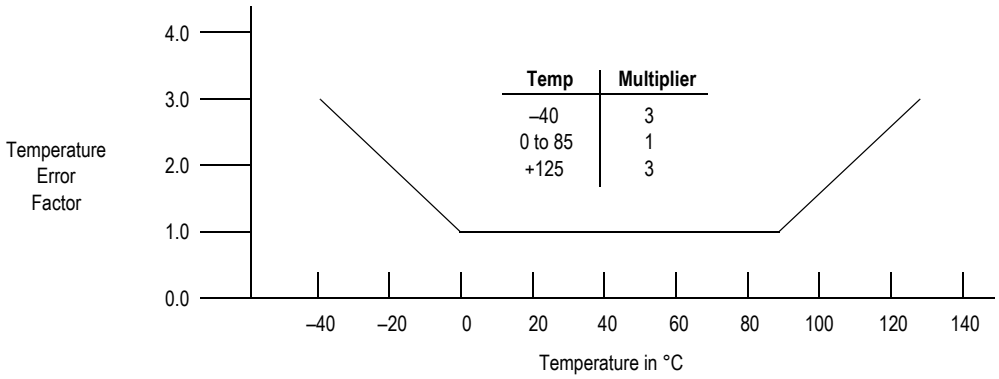
Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.007652) + 0.92)$
$\pm$ (Pressure Error x Temp. Factor x 0.007652 x V_S)
$V_S = 5\ V \pm 0.25\ Vdc$

Temperature Error Band

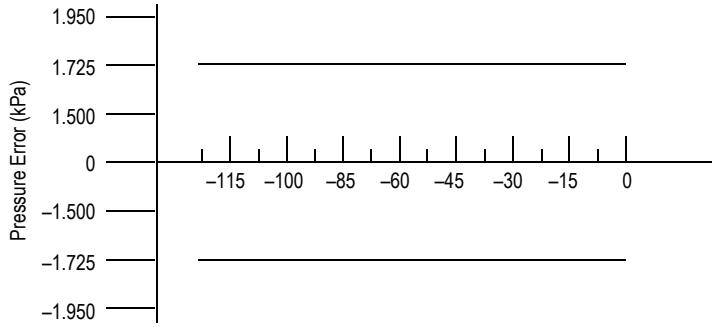
MPXV4115V Series



Temp	Multiplier
–40	3
0 to 85	1
+125	3

NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band



Pressure	Error (Max)
–115 to 0 kPa	±1.725 kPa

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV5004G SERIES

INTEGRATED PRESSURE SENSOR 0 TO 3.92 kPA (0 TO 400 mm H_2O) 1.0 TO 4.9 V OUTPUT

The MPXV5004G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This sensor combines a highly sensitive implanted strain gauge with advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

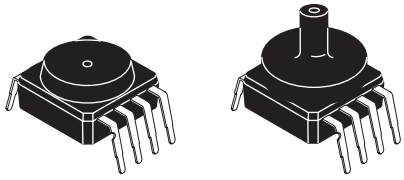
Features

- Temperature Compensated over 10° to 60°C
- Available in Gauge Surface Mount (SMT) or Through-Hole (DIP) Configurations
- Durable Thermoplastic (PPS) Package

Typical Applications

- Washing Machine Water Level
- Ideally Suited for Microprocessor or Microcontroller-Based Systems

SMALL OUTLINE PACKAGES THROUGH-HOLE



MPXV5004G7U
CASE 482B-03

MPXV5004GC7U
CASE 482C-03

ORDERING INFORMATION[1]

Device Type	Case No.	MPXV Series Order No.	Packing Options	Device Marking
Through-Hole	482B	MPXV5004G7U	Rails	MPXV5004G
	482C	MPXV5004GC7U	Rails	MPXV5004G
Surface Mount	482	MPXV5004G6U	Rails	MPXV5004G
	482	MPXV5004G6T1	Tape & Reel	MPXV5004G
	482A	MPXV5004GC6U	Rails	MPXV5004G
	482A	MPXV5004GC6T1	Tape & Reel	MPXV5004G
	1351	MPXV5004DP	Trays	MPXV5004G
	1368	MPXV5004GVP	Trays	MPXV5004G
	1369	MPXV5004GP	Trays	MPXV5004G

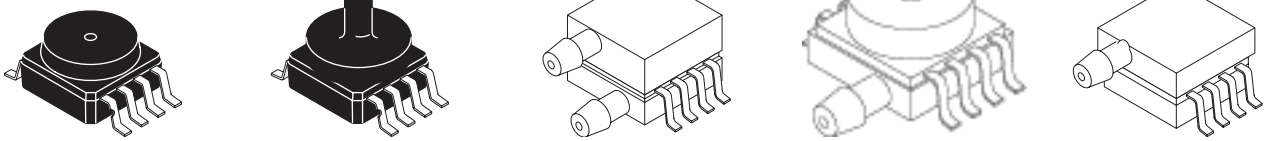
1. MPXV5004G series pressure sensors are available in the basic element package or with a pressure port. Two packing options are offered for the surface mount configuration.

PIN NUMBERS[1]

1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

SMALL OUTLINE PACKAGES SURFACE MOUNT



MPXV5004G6U
CASE 482-01

MPXV5004GC6U
CASE 482A-01

MPXV5004DP
CASE 1351-01

MPXV5004GVP
CASE 1368-01

MPXV5004GP
CASE 1369-01

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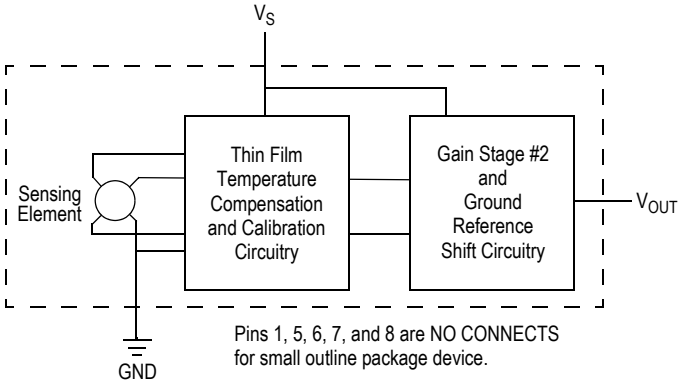

Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{MAX}	16	kPa
Storage Temperature	T_{STG}	–30 to +100	°C
Operating Temperature	T_A	0 to +85	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Units
Pressure Range		P_{OP}	0	—	3.92 400	kPa mm H_2O
Supply Voltage(1)		V_S	4.75	5.0	5.25	V_{DC}
Supply Current		I_S	—	—	10	mAdc
Span at 306 mm H_2O (3 kPa)(2)		V_{FSS}	—	3.0	—	V
Offset(3) (4)		V_{OFF}	0.75	1.0	1.25	V
Sensitivity		V/P	—	1.0 9.8	—	V/kPa mV/mm H_2O
Accuracy(4) (5)	0 to 100 mm H_2O (10 to 60°C) 100 to 400 mm H_2O (10 to 60°C)	—	— —	— —	±1.5 ±2.5	%V_{FSS} %V_{FSS}

1. Device is ratiometric within this specified excitation range.
2. Span is defined as the algebraic difference between the output voltage at specified pressure and the output voltage at the minimum rated pressure.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - Offset Stability: Output deviation, after 1000 temperature cycles, –30 to 100°C, and 1.5 million pressure cycles, with minimum rated pressure applied.
   - TcSpan: Output deviation over the temperature range of 10 to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 10 to 60°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
5. Auto Zero at Factory Installation: Due to the sensitivity of the MPXV5004G, external mechanical stresses and mounting position can affect the zero pressure output reading. Autozeroing is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations. Reference AN1636 for specific information. The specified accuracy assumes a maximum temperature change of ± 5°C between autozero and measurement.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPXV5004G series sensor operating characteristics are based on use of dry air as pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Internal reliability and qualification test for dry air, and other media, are available from the factory. Contact the factory for information regarding media tolerance in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the MPXV5004G to the A/D input of the microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum and maximum output curves are shown for operation over a temperature range of 10°C to 60°C using the decoupling circuit shown in Figure 3 The output will saturate outside of the specified pressure range.

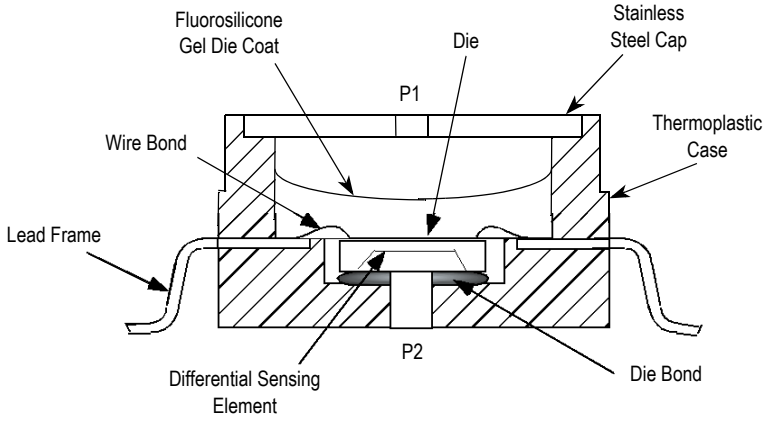

Figure 2. Cross-Sectional Diagram (Not to Scale)

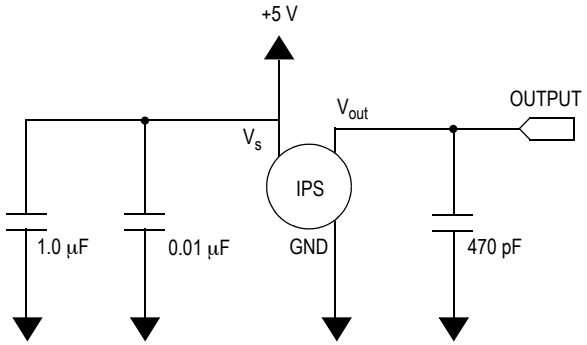

Figure 3. Recommended Power Supply Decoupling and Output Filtering.
(For additional output filtering, please refer to Application Note AN1646.)

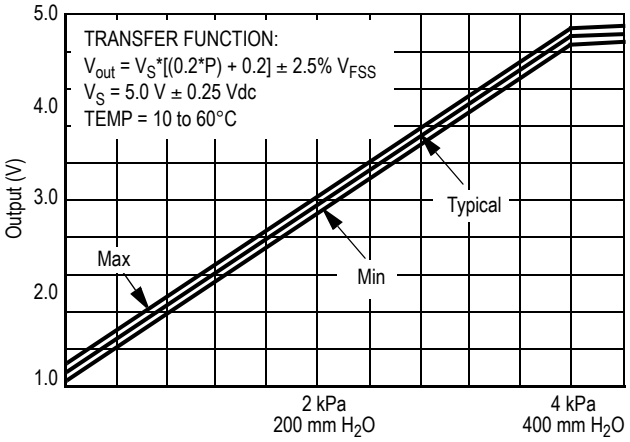

Figure 4. Output versus Pressure Differential at ±2.5% V_{FSS}
(See Note 5 in Operating Characteristics)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale Semiconductor designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing silicone gel which isolates the die from the environment. The Freescale Semiconductor pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below.

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV5004GC6U/T1	482A	Side with Port Attached
MPXV5004G6U/T1	482	Stainless Steel Cap
MPXV5004GC7U	482C	Side with Port Attached
MPXV5004G7U	482B	Stainless Steel Cap
MPXV5004GP	1369	Side with Port Attached
MPXV5004DP	1351	Side with Port Marking
MPXV5004GVP	1368	Stainless Steel Cap

INFORMATION FOR USING THE SMALL OUTLINE PACKAGE (CASE 482)

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

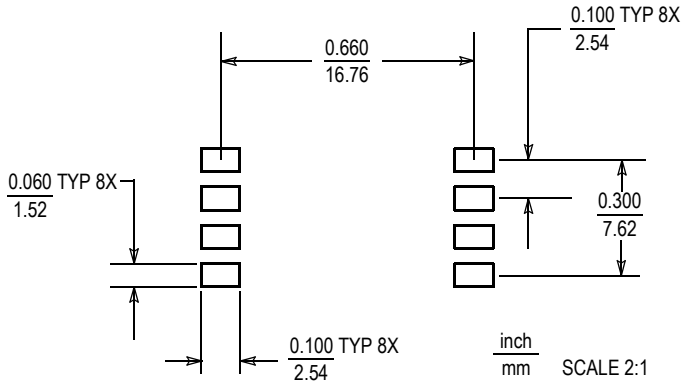

Figure 5. SOP Footprint (Case 482)

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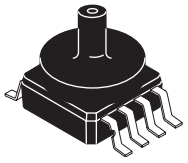
High Temperature Accuracy Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV5050VC6T1

INTEGRATED PRESSURE SENSOR
–50 to 0 kPa (–7.25 to 0 psi)
0.1 to 4.6 Volts Output

SMALL OUTLINE PACKAGE



MPXV5050VC6T1
CASE 482A-01

The MPXV5050VC6T1 sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXV5050VC6T1 piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Thermoplastic (PPS) Surface Mount Package
- Easy-to-Use Chip Carrier Option
- Ideal for Automotive and Non-Automotive Applications

Typical Applications

- Vacuum Pump Monitoring

PIN NUMBER(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

ORDERING INFORMATION					
Device Type	Options	Case No.	MPX Series Order No.	Packing Options	Device Marking
Ported Element	Vacuum, Axial Port	482A	MPXV5050VC6T1	Tape & Reel	MPXV5050VC6T1

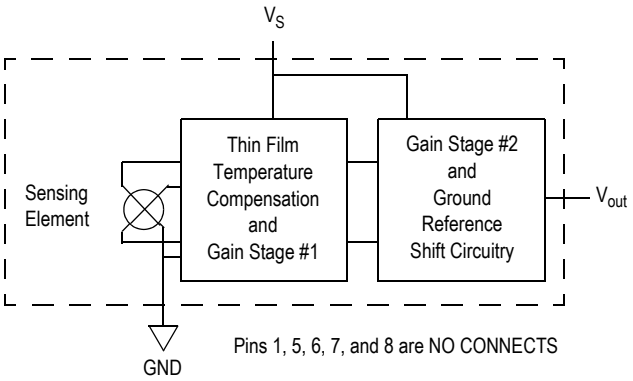


Figure 1. Fully Integrated Pressure Sensor Schematic

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Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Units
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	–50	—	0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Full Scale Output(2) @ V_S = 5.0 Volts	(0 to 85°C) (P_{diff} = 0 kPa)	V_{FSO}	4.488	4.6	4.713	Vdc
Full Scale Span(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(4)	(0 to 85°C)	—	—	—	±2.5	$\%V_{FSS}$
Sensitivity		V/P	—	90	—-	mV/kPa
Response Time(5)		t_R	—	1.0	—-	ms
Warm-Up Time(6)		—	—	20	—-	ms
Offset Stability(7)		—	—	±0.5	—-	$\%V_{FSS}$
Pressure Offset(8)	(0 to 85°C)	V_{off}	0	0.1	0.213	Vdc

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of errors, including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.
8. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.

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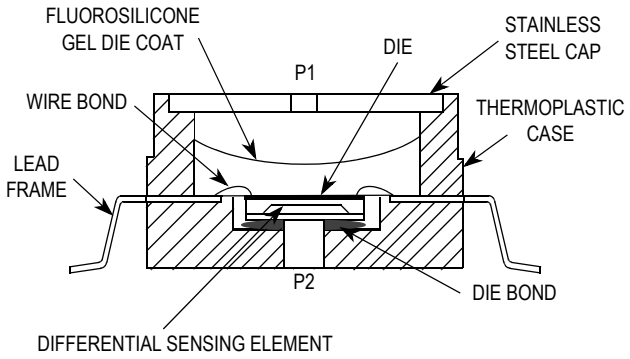

Figure 2. Cross-Sectional Diagram (not to scale)

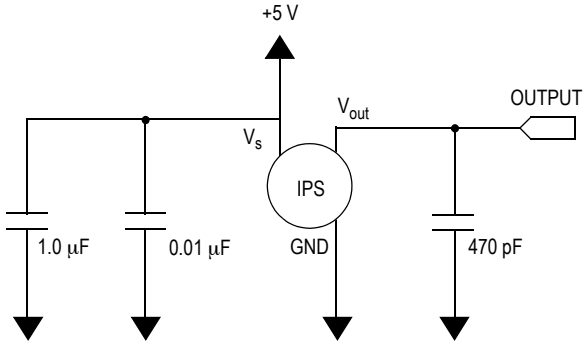

Figure 3. Typical Application Circuit (Output Source Current Operation)

TRANSFER FUNCTION MPXV5050VC6T1

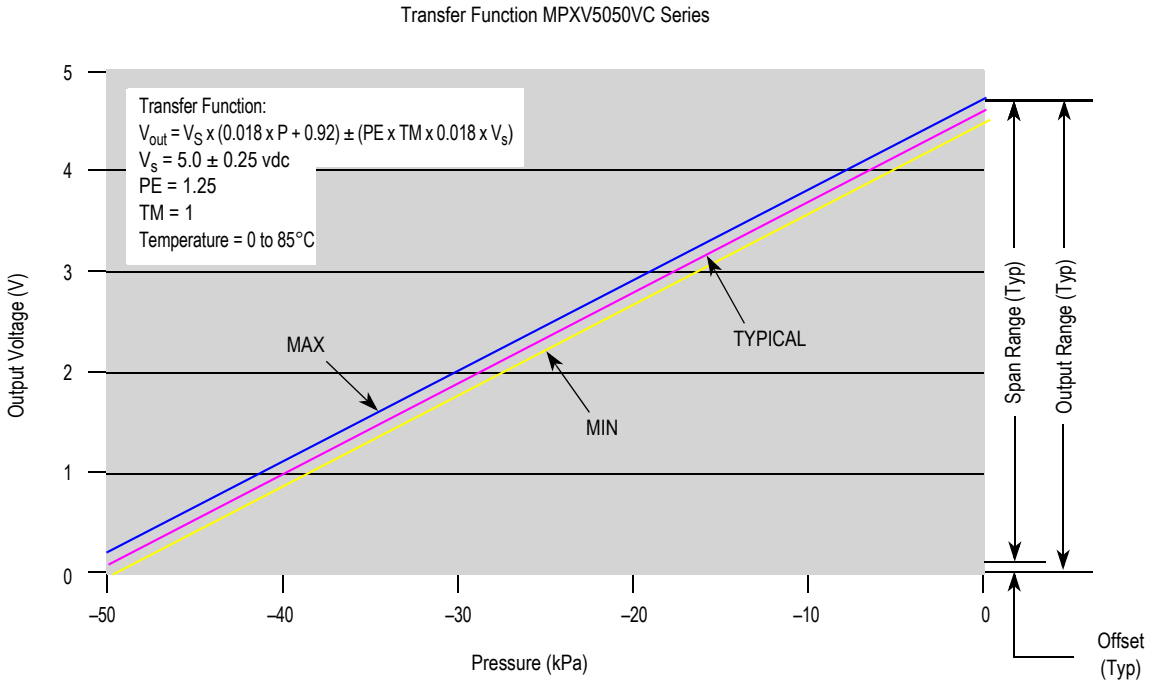

Figure 4. Output versus Absolute Pressure

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXV5050VC6T1 pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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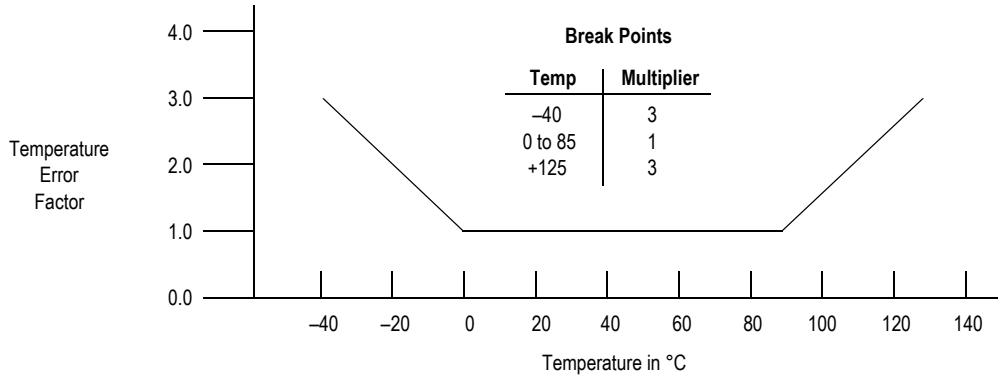
Transfer Function (MPXV5050VC6T1

Nominal Transfer Value: $V_{out} = V_S \times (0.018 \times P + 0.92)$
$\pm$ (Pressure Error x Temp Multi x $0.018 \times V_S$)
$V_S = 5.0 \pm 0.25$ V

Temperature Error Band

MPXV5050V

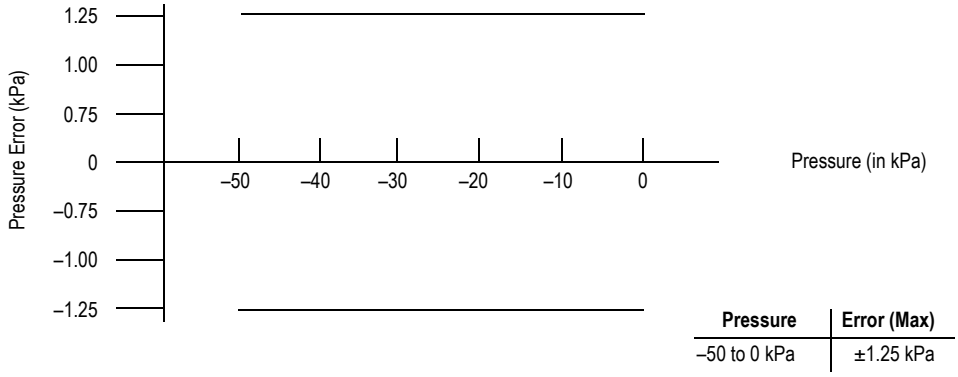


NOTE: The Temperature Multiplier is a linear response from 0°C to –40°C and from 85°C to 125°C.

Pressure Error Band

MPXV5050V

Error Limits for Pressure



Pressure	Error (Max)
–50 to 0 kPa	±1.25 kPa

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MINIMUM RECOMMENDED FOOTPRINT FOR SMALL OUTLINE PACKAGE

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

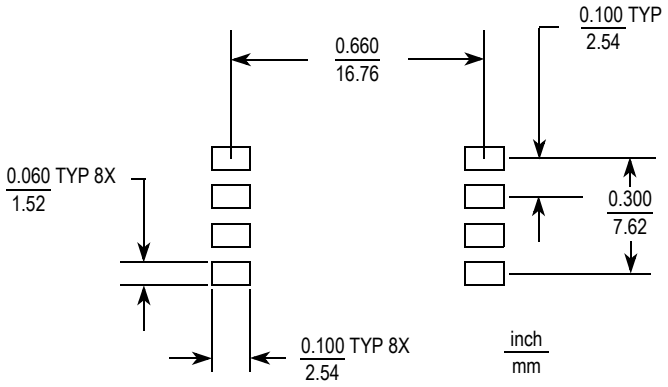

Figure 5. SOP Footprint (Case 482A)

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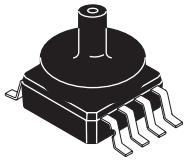
High Temperature Accuracy Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV6115VC6U

INTEGRATED PRESSURE SENSOR -115 TO 0 kPA (-16.7 TO 2.2 psi) 0.2 TO 4.6 VOLTS OUTPUT

SMALL OUTLINE PACKAGE



MPXV6115VC6U
CASE 482A-01

The MPXV6115VC6U sensor integrates on-chip, bipolar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Freescale Semiconductor, Inc. pressure sensor a logical and economical choice for the system designer.

The MPXV6115VC6U piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This sensor combines advanced micromachining techniques, thin film metallization, and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a block diagram of the internal circuitry integrated on a pressure sensor chip.

Features

- Improved Accuracy at High Temperature
- 1.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40° to +125°C
- Durable Thermoplastic (PPS) Surface Mount Package

Typical Applications

- Vacuum Pump Monitoring
- Brake Booster Monitoring

PIN NUMBER[1]			
1	N/C	5	N/C
2	V_S	6	N/C
3	GND	7	N/C
4	V_{OUT}	8	N/C

1. Pins 1, 5, 6, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is denoted by the notch in the lead.

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
Ported Element	Vacuum, Axial Port	482A	MPXV6115VC6U	Rails	MPXV6115V

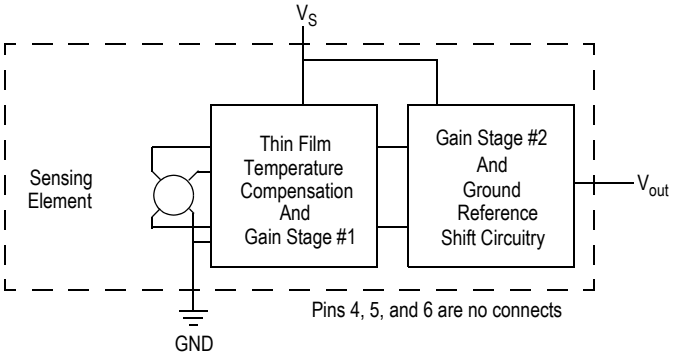


Figure 1. Fully Integrated Pressure Sensor Schematic

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Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Units
Maximum Pressure (P1 >P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	-40° to +125°	°C
Operating Temperature	T_A	-40° to +125°	°C
Output Source Current @ Full Scale Output(2)	I_o+	0.5	mAdc
Output Sink Current @ Minimum Pressure Offset(2)	I_o-	-0.5	mAdc

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.
2. Maximum Output Current is controlled by effective impedance from V_{out} to Gnd or V_{out} to V_S in the application circuit.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	-115	—	0	kPa
Supply Voltage(1)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	6.0	10	mAdc
Full Scale Output(2) @ V_S = 5.0 Volts	(0 to 85°C) (P_{diff} = 0 kPa)	V_{FSO}	4.534	4.6	4.665	Vdc
Full Scale Span(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.4	—	Vdc
Accuracy(4)	(0 to 85°C)	—	—	—	±1.5	%V_{FSS}
Sensitivity		V/P	—	38.26	—	mV/kPa
Response Time(5)		t_R	—	1.0	—	ms
Warm-Up Time(6)		—	—	20	—	ms
Offset Stability(7)		—	—	±0.5	—	%V_{FSS}

1. Device is ratiometric within this specified excitation range.
2. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
3. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
4. Accuracy is the deviation in actual output from nominal output over the entire pressure range and temperature range as a percent of span at 25°C due to all sources of error including the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
5. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
6. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the pressure has been stabilized.
7. Offset Stability is the product's output deviation when subjected to 1000 cycles of Pulsed Pressure, Temperature Cycling with Bias Test.

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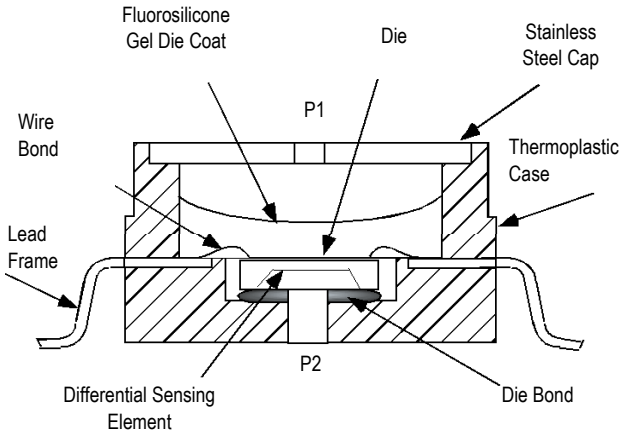

Figure 2. Cross Sectional Diagram SOP (Not to Scale)

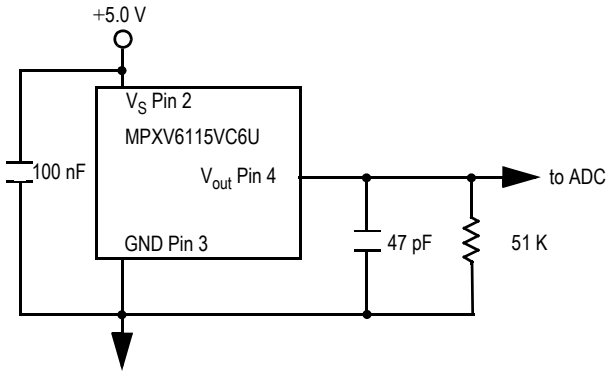

Figure 3. Typical Application Circuit (Output Source Current Operation)

Figure 2 illustrates the absolute sensing chip in the basic Small Outline chip carrier (Case 482).

Figure 3 shows a typical application circuit (output source current operation).

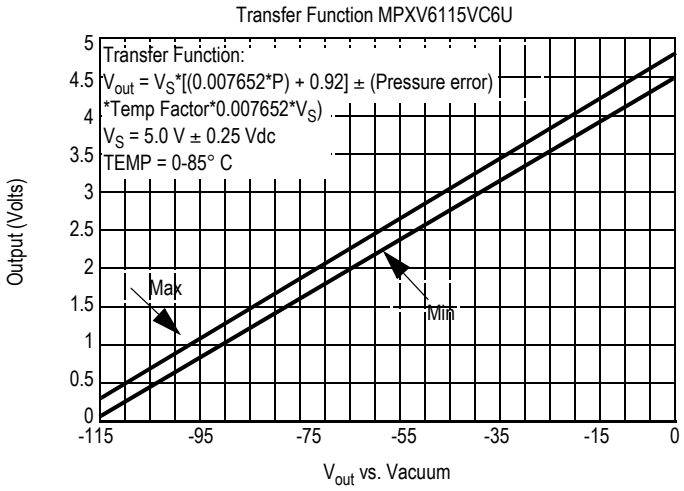

Figure 4. Output versus Absolute Pressure

Figure 4 shows the sensor output signal relative to pressure input. Typical minimum and maximum output curves are shown for operation over 0 to 85°C temperature range. The output will saturate outside of the rated pressure range.

A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPXV6115VC6U pressure sensor operating characteristics, internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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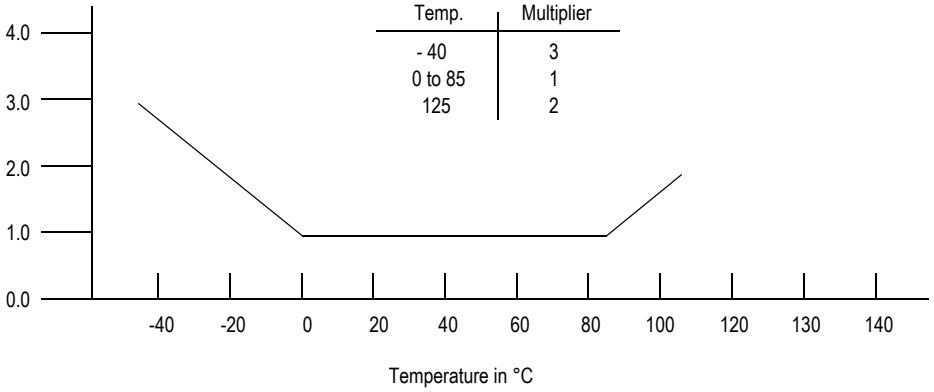
Transfer Function (MPXV6115VC6U)

Nominal Transfer Value: $V_{out} = V_S \times (0.007652 \times P + 0.92)$
$\pm$ (Pressure Error x Temp. Factor x 0.007652 x V_S)
$V_S = 5.0 \pm 0.25$ Vdc

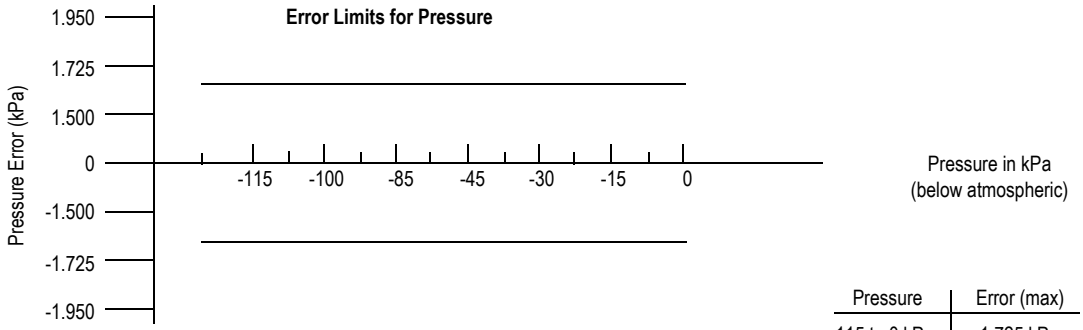
Temperature Error Band

MPXV6115VC6U



NOTE: The Temperature Multiplier is a linear response from 0° to -40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (max)
-115 to 0 kPa	± 1.725 kPa

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MINIMUM RECOMMENDED FOOTPRINT FOR SMALL OUTLINE PACKAGE

Surface mount board layout is a critical portion of the total design. The footprint for the semiconductor package must be the correct size to ensure proper solder connection interface between the board and the package. With the correct pad geometry, the packages will self-align when subjected to a solder reflow process. It is always recommended to fabricate boards with a solder mask layer to avoid bridging and/or shorting between solder pads, especially on tight tolerances and/or tight layouts.

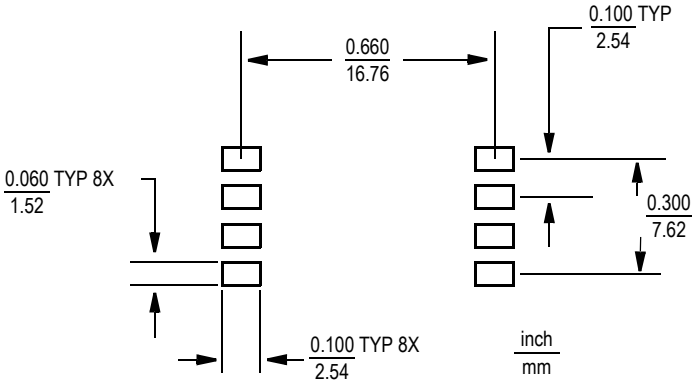

Figure 5. SOP Footprint (Case 482A)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV7002 SERIES

INTEGRATED PRESSURE SENSOR -2 to 2 kPa (-0.3 to 0.3 psi) 0.5 to 4.5 V OUTPUT

The MPXV7002 series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

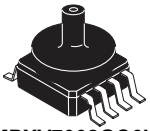
Features

- 2.5% Typical Error over +10°C to +60°C with Auto Zero
- 6.25% Maximum Error over +10°C to +60°C without Auto Zero
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over +10° to +60°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations

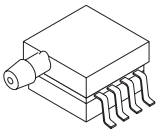
Typical Applications

- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

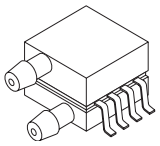
SMALL OUTLINE PACKAGE



MPXV7002GC6U
CASE 482A-01



MPXV7002GP
CASE 1369-01



MPXV7002DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV7002 SERIES)					
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV7002GC6U	Rails	MPXV7002G
	Gauge, Axial Port, SMT	482A	MPXV7002GC6T1	Tape & Reel	MPXV7002G
	Gauge, Side Port, SMT	1369	MPXV7002GP	Trays	MPXV7002G
	Differential, Dual Port, SMT	1351	MPXV7002DP	Trays	MPXV7002G
	Differential, Dual Port, SMT	1351	MPXV7002DPT1	Tape & Reel	MPXV7002G

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

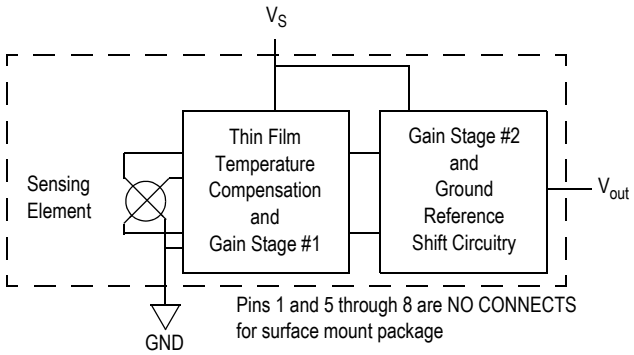


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Figure 1. Fully Integrated Pressure Sensor Schematic

Table 1. Maximum Ratings[1]

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	8.0	kPa
Storage Temperature	T_{stg}	–30 to +100	°C
Operating Temperature	T_A	10 to +60	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]		P_{OP}	–2.0	—	2.0	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	—	10	mAdc
Pressure Offset[3] @ V_S = 5.0 Volts	(10 to 60°C)	V_{off}	2.25	2.5	2.75	Vdc
Full Scale Output[4] @ V_S = 5.0 Volts	(10 to 60°C)	V_{FSO}	4.25	4.5	4.75	Vdc
Full Scale Span[5] @ V_S = 5.0 Volts	(10 to 60°C)	V_{FSS}	3.5	4.0	4.5 V	Vdc
Accuracy[6]	(10 to 60°C)	—	—	±2.5[7]	±6.25	$\%V_{FSS}$
Sensitivity		V/P	—	1.0	—	V/kPa
Response Time[8]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time[9]		—	—	20	—	ms

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 10° to 60°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 10° to 60°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Auto Zero at Factory Installation: Due to the sensitivity of the MPXV7002 Series, external mechanical stresses and mounting position can affect the zero pressure output reading. Autozero is defined as storing the zero pressure output reading and subtracting this from the device's output during normal operations. Reference AN1636 for specific information. The specified accuracy assumes a maximum temperature change of ± 5°C between autozero and measurement.
8. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
9. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A gel die coat isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPXV7002 series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 10° to 60°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

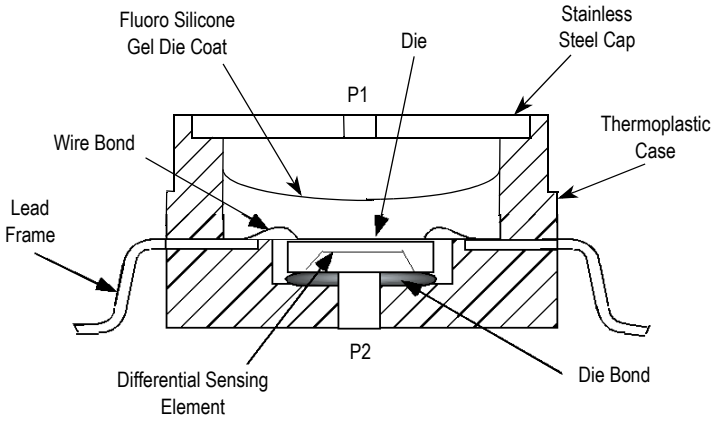

Figure 2. Cross-Sectional Diagram SOP (not to scale)

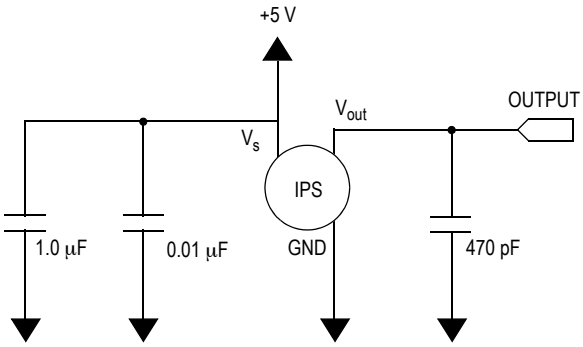

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

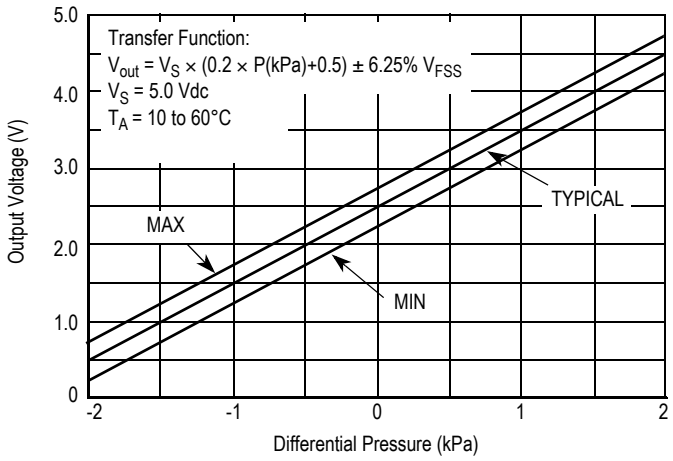

Figure 4. Output versus Pressure Differential

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing a gel die coat which protects the die from harsh media.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV7002GC6U/GC6T1	482A-01	Vertical Port Attached
MPXV7002GP	1369-01	Side with Port Attached
MPXV7002DP	1351-01	Side with Dual Port Attached

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

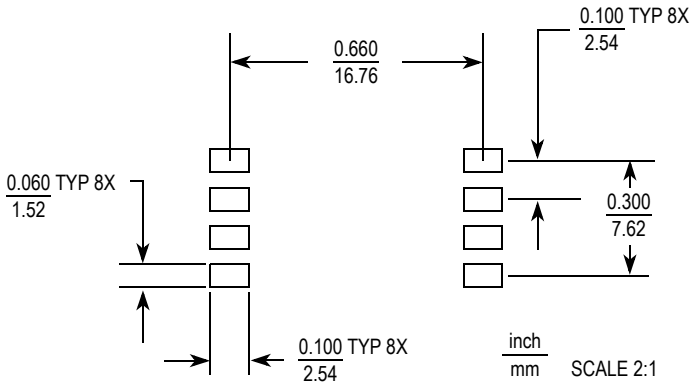

Figure 5. Small Outline Package Footprint

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV7007G SERIES

INTEGRATED PRESSURE SENSOR -7 to 7 kPa (-1 to 1 psi) 0.5 to 4.5 V OUTPUT

The MPXV7007G series piezoresistive transducers are state-of-the-art monolithic silicon pressure sensors designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

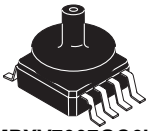
Features

- 5.0% Maximum Error over 0° to 85°C
- Ideally Suited for Microprocessor or Microcontroller-Based Systems
- Durable Epoxy Unibody and Thermoplastic (PPS) Surface Mount Package
- Temperature Compensated over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Available in Differential and Gauge Configurations
- Available in Surface Mount (SMT)

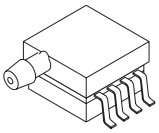
Typical Applications

- Hospital Beds
- HVAC
- Respiratory Systems
- Process Control

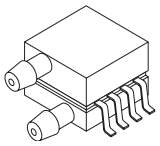
SMALL OUTLINE PACKAGE



MPXV7007GC6U
CASE 482A-01



MPXV7007GP
CASE 1369-01



MPXV7007DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV7007G SERIES)					
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV7007GC6U	Rails	MPXV7007G
	Gauge, Axial Port, SMT	482A	MPXV7007GC6T1	Tape & Reel	MPXV7007G
	Gauge, Side Port, SMT	1369	MPXV7007GP	Trays	MPXV7007G
	Gauge, Dual Port, SMT	1351	MPXV7007DP	Trays	MPXV7007G

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

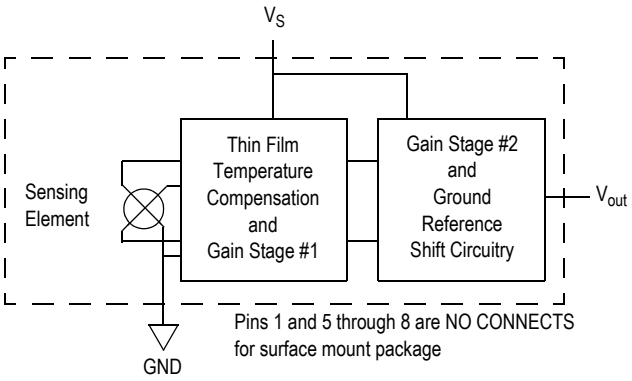


Figure 1. Fully Integrated Pressure Sensor Schematic

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Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	75	kPa
Storage Temperature	T_{stg}	–40 to +125	°C
Operating Temperature	T_A	–40 to +125	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet specification.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	-7	—	+7	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.32	0.5	0.67	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.3	4.5	4.7	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.0	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	286	—	mV/kPa
Response Time(7)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{O+}	—	0.1	—	mAdc
Warm-Up Time(8)		—	—	20	—	ms
Offset Stability(9)		—	—	±0.5	—	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure, at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum rated pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS}, at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

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ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

The performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 2 illustrates the Differential or Gauge configuration in the basic chip carrier (Case 482). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm.

The MPXV7007G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

Figure 3 shows the recommended decoupling circuit for interfacing the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

Figure 4 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

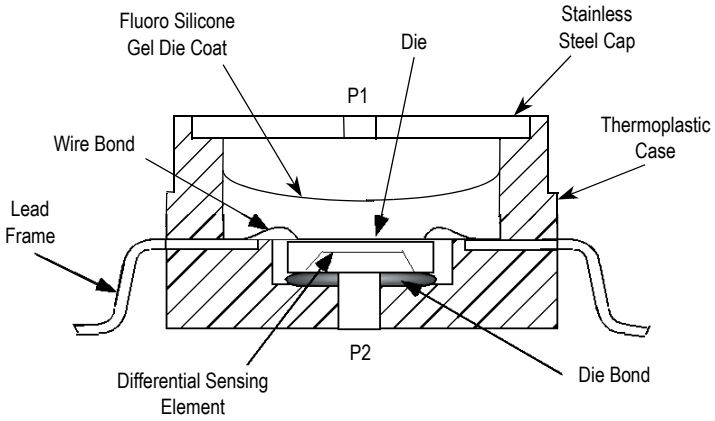

Figure 2. Cross-Sectional Diagram SOP (not to scale)

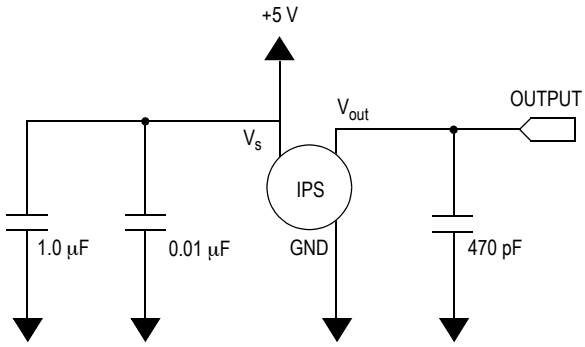

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

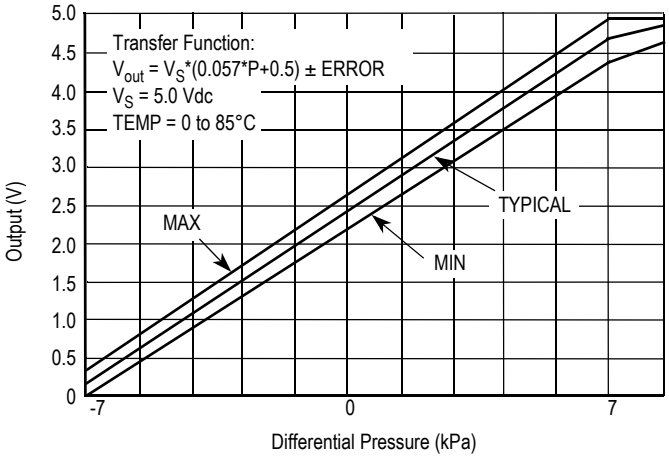

Figure 4. Output versus Pressure Differential

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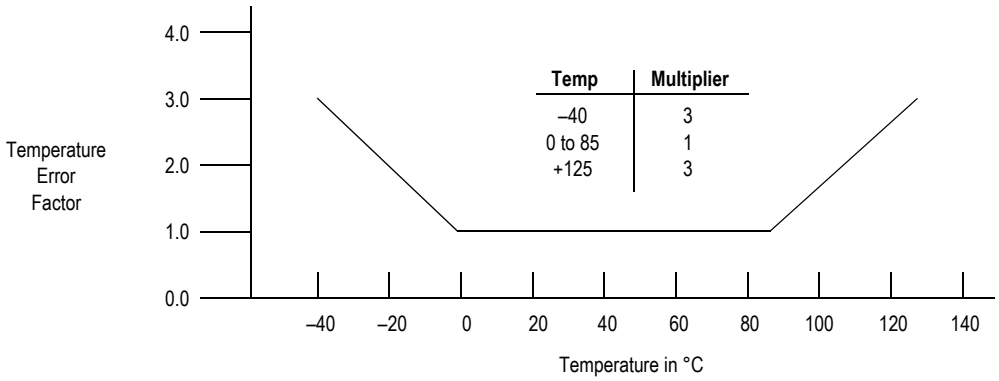
Transfer Function (MPXV7007G)

Nominal Transfer Value: $V_{out} = V_S \times (0.057 \times P + 0.5)$
$\pm$ (Pressure Error x Temp. Factor x $0.057 \times V_S$)
$V_S = 5.0\ V \pm 0.25\ Vdc$

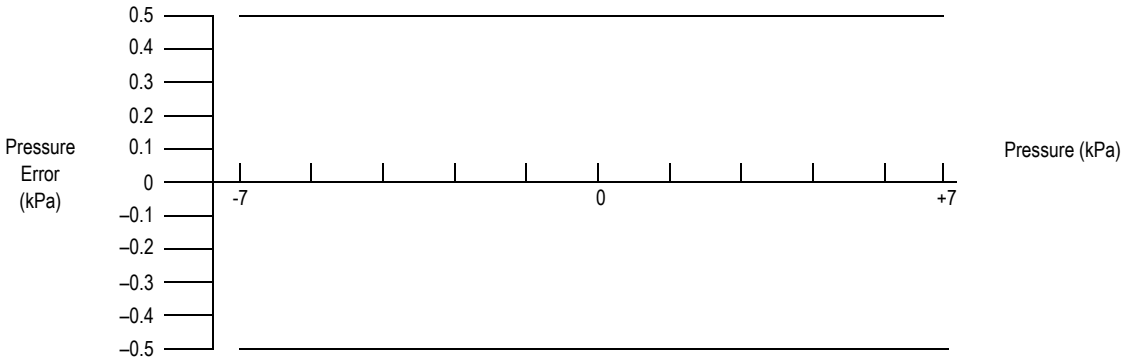
Temperature Error Band

MPXV7007G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
- 7 to 7 (kPa)	±0.5 (kPa)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPXV7007GC6U/C6T1	482A	Side with Port Attached
MPXV7007GP	1369	Side with Port Attached
MPXV7007DP	1351	Side with Part Marking

MINIMUM RECOMMENDED FOOTPRINT FOR SURFACE MOUNTED APPLICATIONS

Surface mount board layout is a critical portion of the total design. The footprint for the surface mount packages must be the correct size to ensure proper solder connection interface between the board and the package. With the correct footprint, the packages will self align when subjected to a solder reflow process. It is always recommended to design boards with a solder mask layer to avoid bridging and shorting between solder pads.

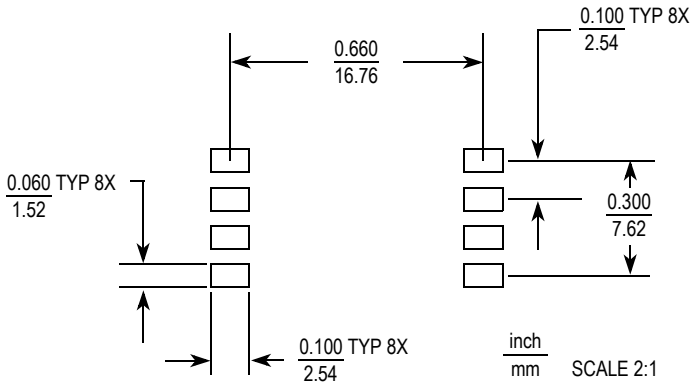

Figure 5. SOP Footprint (Case 482A)

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Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

MPXV7025G SERIES

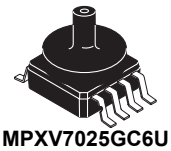
INTEGRATED PRESSURE SENSOR
-25 to 25 kPa (-3.6 to 3.6 psi)
0.2 to 4.7 V OUTPUT

The MPXV7025G series piezoresistive transducer is a state-of-the-art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin-film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

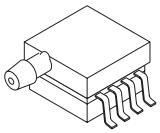
Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated Over –40° to +125°C
- Patented Silicon Shear Stress Strain Gauge
- Durable Epoxy Unibody Element
- Easy-to-Use Chip Carrier Option

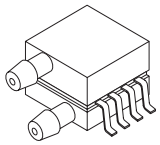
SMALL OUTLINE PACKAGE



MPXV7025GC6U
CASE 482A-01



MPXV7025GP
CASE 1369-01



MPXV7025DP
CASE 1351-01

ORDERING INFORMATION					
Device Type	**Options**	**Case No.**	**MPX Series Order No.**	**Packing Options**	**Device Marking**
SMALL OUTLINE PACKAGE (MPXV7025G SERIES)					
Ported Elements	Gauge, Axial Port, SMT	482A	MPXV7025GC6U	Rails	MPXV7025G
	Gauge, Axial Port, SMT	482A	MPXV7025GC6T1	Tape & Reel	MPXV7025G
	Gauge, Side Port, SMT	1369	MPXV7025GP	Trays	MPXV7025G
	Gauge, Dual Port, SMT	1351	MPXV7025DP	Trays	MPXV7025G

SMALL OUTLINE PACKAGE PIN NUMBERS(1)			
1	N/C	5	N/C
2	V_S	6	N/C
3	Gnd	7	N/C
4	V_{out}	8	N/C

1. Pins 1, 5, 6, 7, and 8 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

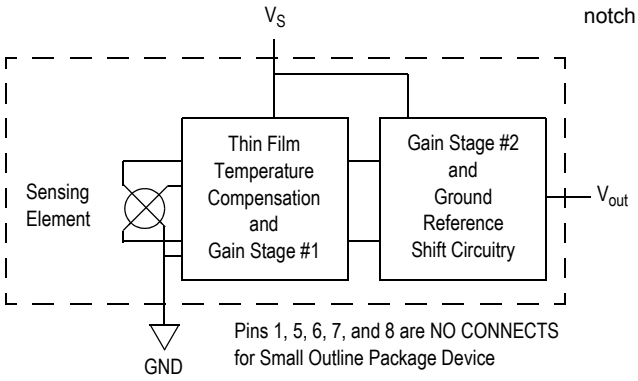


Figure 1. Fully Integrated Pressure Sensor Schematic

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Table 1. Maximum Ratings(1)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	200	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

1. Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 3 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	-25	—	25	kPa
Supply Voltage(2)		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset(3) @ V_S = 5.0 Volts	(0 to 85°C)	V_{off}	0.115	0.25	0.384	Vdc
Full Scale Output(4) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSO}	4.610	4.75	4.890	Vdc
Full Scale Span(5) @ V_S = 5.0 Volts	(0 to 85°C)	V_{FSS}	—	4.5	—	Vdc
Accuracy(6)	(0 to 85°C)	—	—	—	±5.0	$\%V_{FSS}$
Sensitivity		V/P	—	90	—-	mV/kPa
Response Time(7)		t_R	—	1.0	—-	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—-	mAdc
Warm-Up Time(8)		—	—	20	—-	ms
Offset Stability(9)		—	—	±0.5	—-	$\%V_{FSS}$

1. 1.0 kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from the minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

The MPXV7025G series pressure sensor operating characteristics, and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability. Contact the factory for information regarding media compatibility in your application.

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Figure 2 shows the sensor output signal relative to pressure input. Typical, minimum, and maximum output curves are shown for operation over a temperature range of 0° to 85°C using the decoupling circuit shown in Figure 3. The output will saturate outside of the specified pressure range.

Figure 3 shows the recommended decoupling circuit for interfacing the output of the integrated sensor to the A/D input of a microprocessor or microcontroller. Proper decoupling of the power supply is recommended.

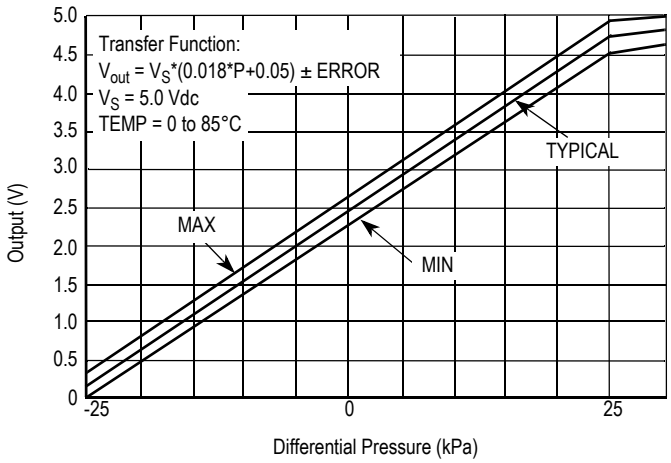

Figure 2. Output versus Pressure Differential

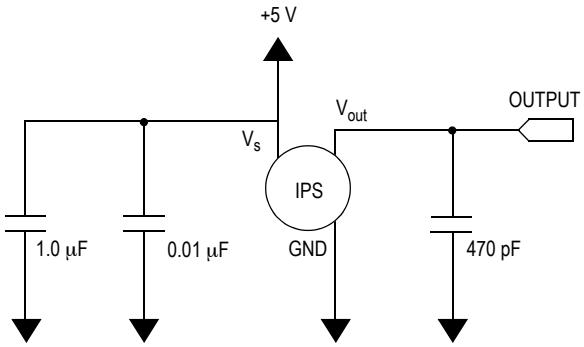

Figure 3. Recommended Power Supply Decoupling and Output Filtering
(For additional output filtering, please refer to Application Note AN1646.)

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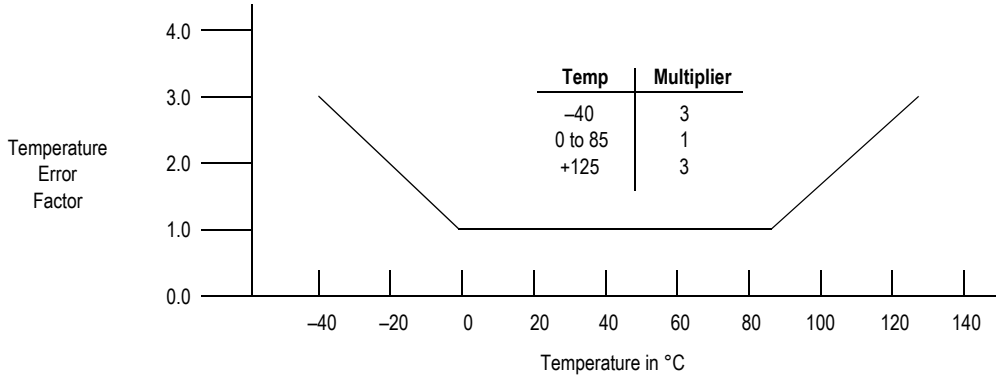
Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.018 + 0.05)$
$\pm$ (Pressure Error x Temp. Factor x 0.018 x V_S)
$V_S = 5.0\ V \pm 0.25\ Vdc$

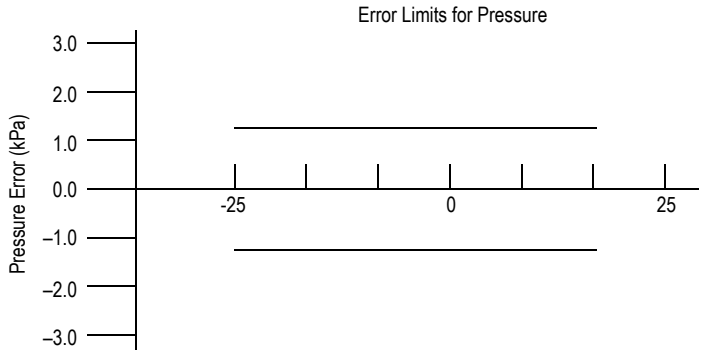
Temperature Error Band

MPXV7025G SERIES



NOTE: The Temperature Multiplier is a linear response from 0° to –40°C and from 85° to 125°C.

Pressure Error Band



Pressure	Error (Max)
-25 to 25 (kPa)	±1.25 (kPa)

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PRESSURE (P1)/VACUUM (P2) SIDE IDENTIFICATION TABLE

Freescale designates the two sides of the pressure sensor as the Pressure (P1) side and the Vacuum (P2) side. The Pressure (P1) side is the side containing fluorosilicone gel which protects the die from harsh media. The MPX pressure sensor is designed to operate with positive differential pressure applied, P1 > P2.

The Pressure (P1) side may be identified by using the table below:

Part Number	Case Type	Pressure (P1) Side Identifier
MPX7025GC6U/C6T1	482A	Gauge, Axial Port, SMT
MPXV7025GP	1369	Side with Port Attached
MPXV7025DP	1351	Side with Part Marking

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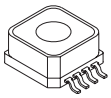
Tire Pressure Monitoring Sensor Temperature Compensated and Calibrated, Fully Integrated, Digital Output

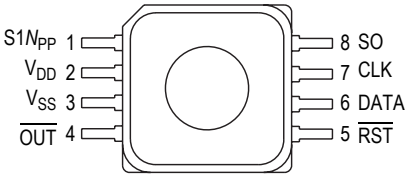
MPXY8020A
MPXY8040A

TIRE PRESSURE MONITORING SENSOR
MPXY8020A:
OPTIMIZED FOR 250 kPa – 450 kPa
MPXY8040A:
OPTIMIZED FOR 500 kPa – 900 kPa



SUPER SMALL OUTLINE PACKAGE
CASE 1352-03

PIN ASSIGNMENT



8-pin Super Small Outline Package (SSOP)

The Freescale Semiconductor MPXY8000 series sensor is an 8-pin tire monitoring sensor which is comprised of a variable capacitance pressure sensing element, a temperature sensing element, and an interface circuit (with a wake-up feature) all on a single chip. It is housed in a Super-Small Outline Package (SSOP), which includes a media protection filter. Specifically designed for the low power consumption requirements of tire pressure monitoring systems, it can combine with a Freescale Semiconductor remote keyless entry (RKE) system to facilitate a low-cost, highly integrated system.

DETAILED DESCRIPTION

The block diagram of the MPXY8000 series sensor is shown in Figure 1. The pressure sensor is a capacitive transducer constructed using surface micromachining, the temperature sensor is constructed using a diffused resistor, and the interface circuit is integrated onto the same die as the sensors using a standard silicon CMOS process.

The conditioning of the pressure signal begins with a capacitance to voltage conversion (C to V) followed by a switched capacitor amplifier. This amplifier has adjustable offset and gain trimming. The offset and gain are factory calibrated, with calibration values stored in the EEPROM trim register. This amplifier also has temperature compensation circuits for both sensitivity and offset, which also are factory adjusted using the EEPROM trim register.

The pressure is monitored by a voltage comparator, which compares the measured value against an 8-bit threshold adjusted by a serial input. By adjusting the threshold and monitoring the state of the OUT pin the external device can check whether a low-pressure threshold has been crossed, or perform up to 8-bit A/D conversions.

The temperature is measured by a diffused resistor with a positive temperature coefficient driven by a current source, thereby creating a voltage. The room temperature value of this voltage is factory calibrated using the EEPROM trim register. A two-channel multiplexer can route either the pressure or temperature signal to a sampling capacitor that is monitored by a voltage comparator with variable threshold adjust, providing a digital output for temperature.

An internal low frequency, low power 5.4 kHz oscillator with a 14-stage divider provides a periodic pulse to the OUT pin (divide by 16384 for 3 seconds). This pulse can be used to wake up an external MCU to begin an interface with the device. An additional 10-stage divider will provide a pulse every 52 minutes which can be used to reset an external MCU.

The power consumption can be controlled by several operational modes selected by external pins.

ORDERING INFORMATION	
Shipped in Rails	**Shipped in Tape & Reel**
MPXY8020A6U MPXY8040A6U	MPXY8020A6T1 MPXY8040A6T1

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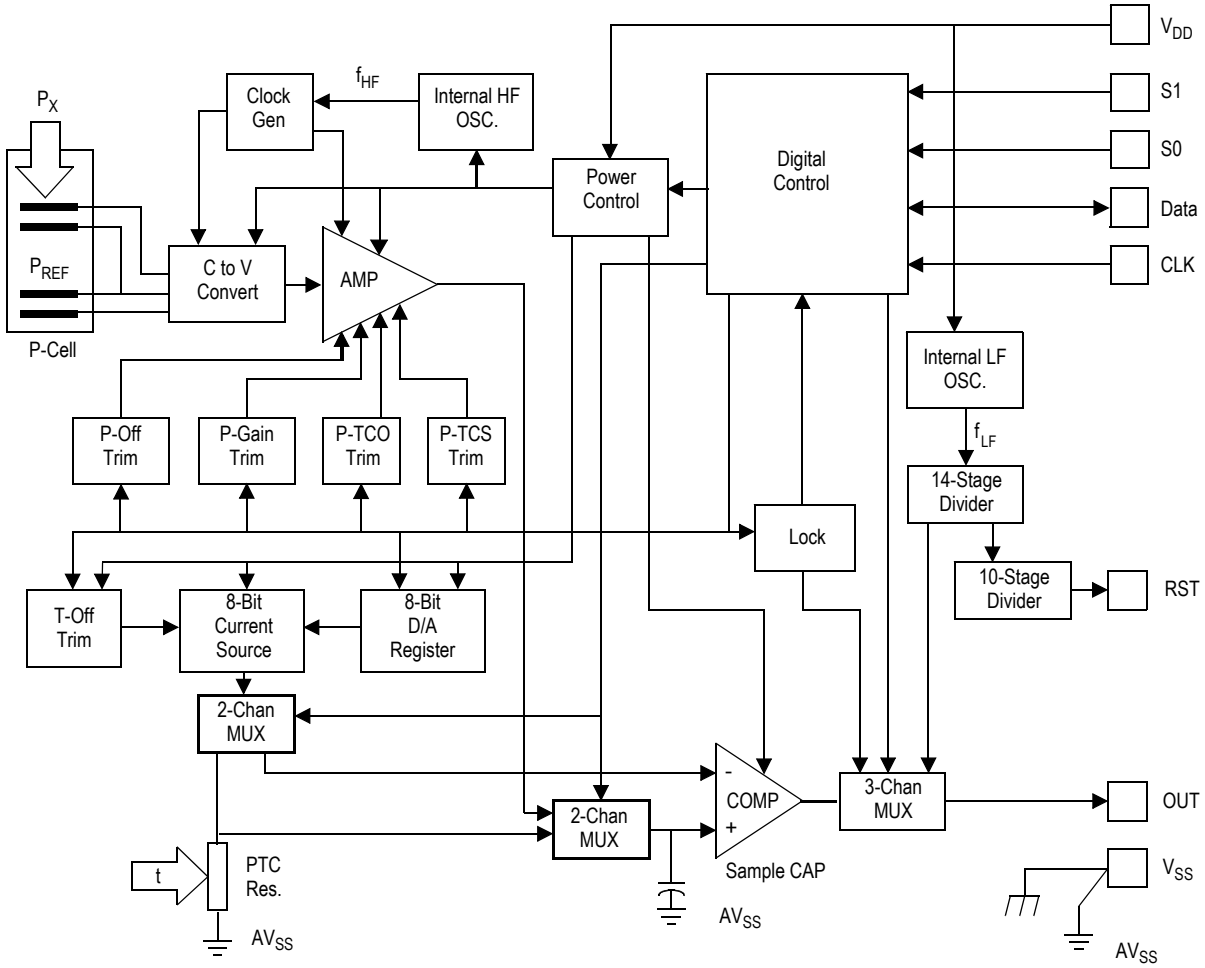

Figure 1. MPXY8000 Series Sensor Block Diagram

OPERATING MODES

The device has several operating modes dependent on the applied voltages to the S1 and S0 pins as shown in Table 1. In all the modes listed the channel multiplexers, D/A Register, LFO, and the output pulse dividers will always be powered up as long as there is a voltage source connected to the V_{DD} pin.

When only the S0 pin is at a logic one the pressure measuring circuit in the device is powered up and the pressure output signal is connected to the sample capacitor through a multiplexer. When the S0 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

When only the S1 pin is at a logic one the temperature measuring circuit in the device is powered up and the temperature output signal is connected to the sample capacitor through a multiplexer. When the S1 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

NOTE: All of the EEPROM trim bits will be powered up regardless of whether the pressure or temperature measuring circuitry is activated.

NOTE: If the voltage on the S1 pin exceeds 2.5 times the voltage on the V_{DD} pin the device will be placed into its Trim/Test Mode.

NOTE: If the V_{DD} supply source is switched off in order to reduce current consumption, it is important that all input pins be driven LOW to avoid powering up the device.

If any input pin (S1, S0, DATA, or CLK) is driven HIGH while the V_{DD} supply is switched off, the device may be powered up through an ESD protection diode. Such a case should be avoided. The effective source voltage of the device will be less than the applied voltage due to diode voltage drop. In addition, the entire source current will be drawn from the input pin.

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Table 1. Operating Modes

S1	S0	Operating Mode	Circuitry Powered				Serial Data Counter
			Pressure Measure System	Temp Measure System	A/D Output Comp.	LFO Oscill.	
0	0	Standby/Reset	OFF	OFF	OFF	ON	ACTIVE
0	1	Measure Pressure	ON	OFF	OFF	ON	RESET
1	0	Measure Temperature	OFF	ON	OFF	ON	RESET
1	1	Output Read	OFF	OFF	ON	ON	ACTIVE

PIN FUNCTIONS

The following paragraphs give a description of the general function of each pin.

V_{DD} and V_{SS} Pins

Power is supplied to the control IC through V_{DD} and V_{SS}. V_{DD} is the positive supply and V_{SS} is the digital and analog ground. The control IC operates from a single power supply. Therefore, the conductors to the power supply should be connected to the V_{DD} and V_{SS} pins and locally decoupled as shown in Figure 2.

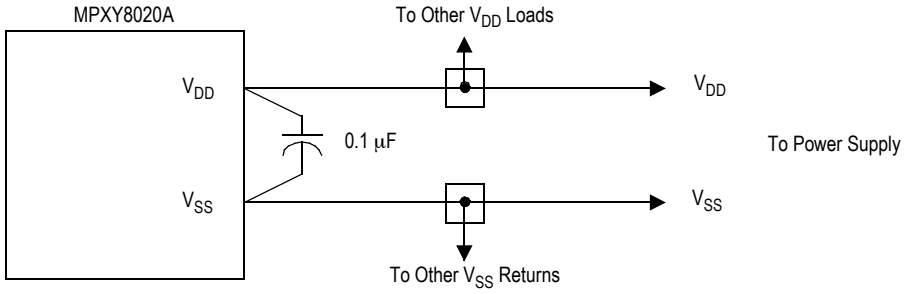

Figure 2. Recommended Power Supply Connections

OUT Pin

The OUT pin normally provides a digital signal related to the voltage applied to the voltage comparator and the threshold level shifted into an 8-bit register from an external device. When the device is placed in the standby mode the OUT pin is driven high and will be clocked low when an overflow is detected from a clock divider (divide by 16384) driven by the LFO. This allows the OUT pin to wake up an external device such as an MCU.

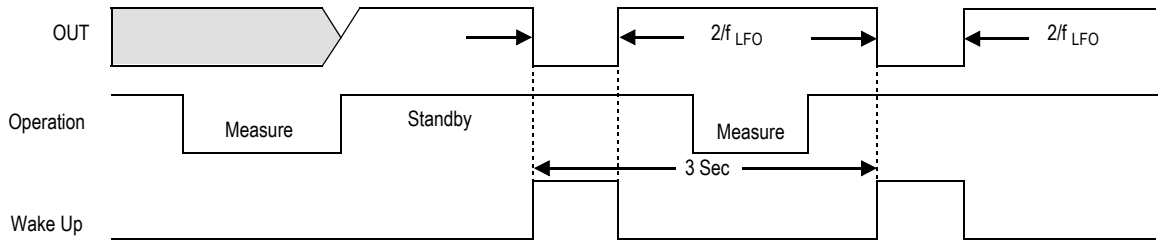

Figure 3. Pulse on OUT Pin During Standby Mode

$\overline{RST}$ Pin

The $\overline{RST}$ pin is normally driven high and will be clocked low when an overflow is detected from total clock divider (divide by 16,777,216) driven by the LFO. This allows the $\overline{RST}$ pin to reset an external device such as an MCU. This pulse will appear on the $\overline{RST}$ pin approximately every

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52 minutes regardless of the operating mode of the device. The pulse lasts for two cycles of the LFO oscillator as shown in Figure 4. Since the RST pin is clocked from the same divider string as the OUT pin, there will also be a pulse on the OUT pin when the $\overline{RST}$ pin pulses every 52 minutes.

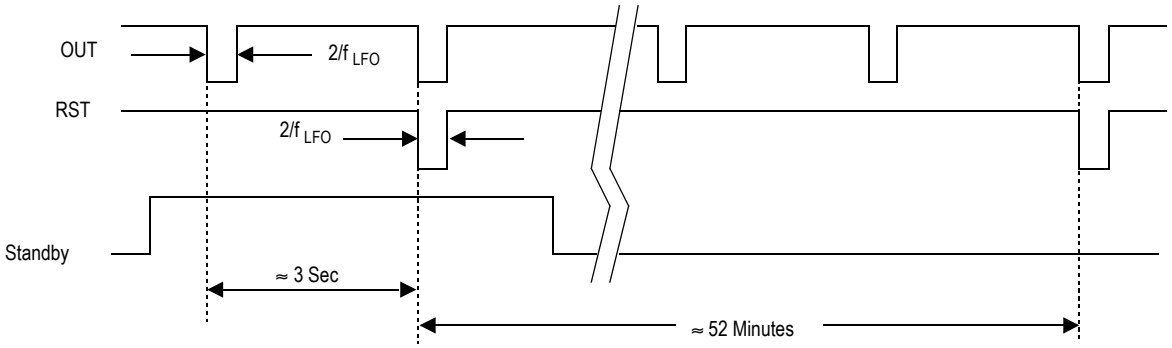

Figure 4. Pulse on $\overline{RST}$ Pin

S0 Pin

The S0 pin is used to select the mode of operation as shown in Table 1.

The S0 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The S0 pin has an internal pull-down device in order to provide a low level when the pin is left unconnected.

S1 Pin

The S1 pin is used to select the mode of operation, as shown in Table 1.

The S1 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

The S1 pin also serves the purpose of enabling factory trim and test of the device.

The higher V_{PP} programming voltage for the internal EEPROM trim register is also supplied through the S1 pin.

DATA Pin

The DATA pin is the serial data in (SDI) function for setting the threshold of the voltage comparator.

The DATA pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

CLK Pin

The CLK pin is used to provide a clock used for loading and shifting data into the DATA pin. The data on the DATA pin is clocked into a shift register on the rising edge of the CLK pin signal. The data is transferred to the D/A Register on the eighth falling edge of the CLK pin. This protocol may be handled by the SPI or SIOP serial I/O function found on some MCU devices.

The CLK pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The CLK pin has an internal pull-down device to provide a low level when the pin is left unconnected.

Output Threshold Adjust

The state of the OUT pin is driven by a voltage comparator whose output state depends on the level of the input voltage on the sample capacitor and the level of an adjustable 8-bit threshold voltage. The threshold is adjusted by shifting data bits into the D/A Register (DAR) via the DATA pin while clocking the CLK pin. The timing of this data is shown in Figure 4. Data is transferred into the serial shift register on the rising edge of the CLK pin. On the falling edge of the 8th clock the data in the serial shift register is latched into the parallel DAR register. The DAR remains powered up whenever V_{DD} is present. The serial data is clocked into the DATA pin starting with the MSB first. This sequence of threshold select bits is shown in Table 2.

Table 2. D/A Threshold Bit Assignment

Function		Bit Weight	Data Bit
Voltage Comparator Threshold Adjust (8 bits)	LSB	1	D0
		2	D1
		4	D2
		8	D3
		16	D4
		32	D5
		64	D6
	MSB	128	D7

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An analog to digital (A/D) conversion can be accomplished with eight (8) different threshold levels in a successive approximation algorithm; or the OUT pin can be set to trip at some alarm level. The voltage on the sample capacitor will maintain long enough for a single 8-bit conversion, but may need to be refreshed with a new measured reading if the read interval is longer than the specified hold time, t_{SH}.

The counter that determines the number of clock pulses into the device is reset whenever the device is placed into the Measure Pressure or Measure Temperature Modes. This provides a means to reset the data transfer count in case the clock stream is corrupted during a transmission. In these two modes the DATA and CLK pins should not be clocked to reduce noise in the captured pressure or temperature data. Any change in the DAR contents should be done during the Standby or Output Read Modes.

Both the serial bit counter and the state of the DAR are undefined following power up of the device. The serial bit counter can be reset by cycling either the SO pin or the S1/VPP pin to a high level and then back low. The DAR can then be reset to the lowest level by holding the DATA pin low while bursting the CLK pin with eight (8) clock pulses.

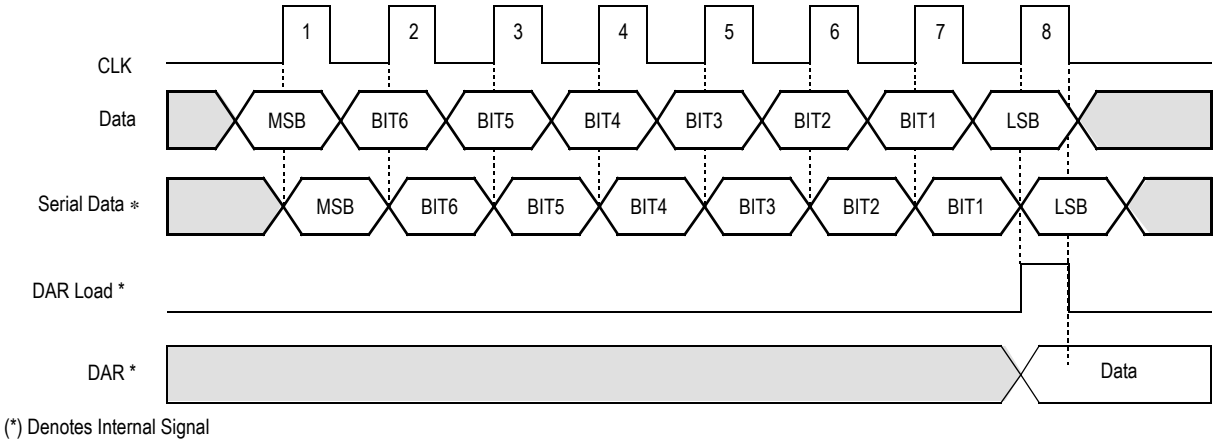

Figure 5. Serial Data Timing

Pressure Sensor Output

The pressure channel compares the output of its analog measurement circuit to the D/A reference voltage. The device is calibrated at two different nominal values depending on the calibration option.

Temperature Sensor Output

The temperature channel compares the output of a positive temperature coefficient (PTC) resistor driven by a switched current source. The current source is only active when the temperature channel is selected.

APPLICATIONS

Suggested application example is shown in Figure 6.

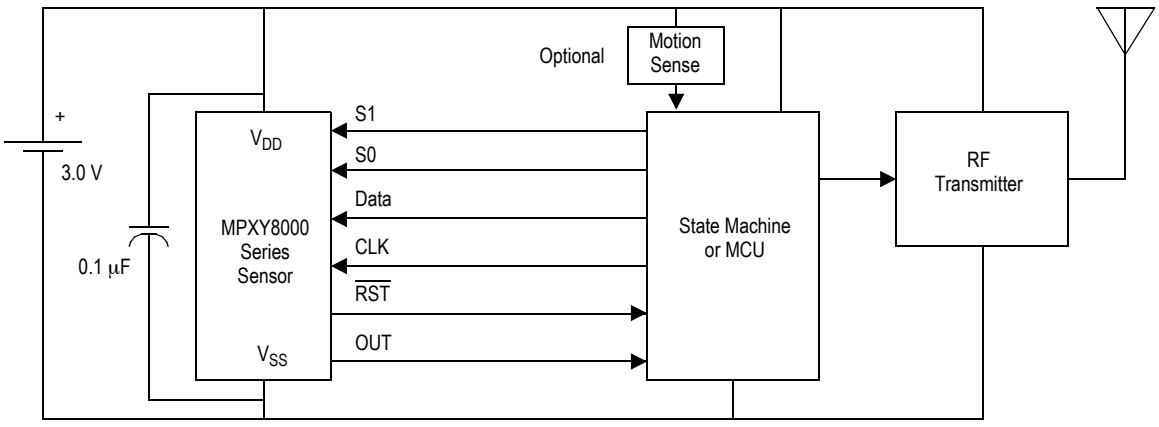

Figure 6. Application Example

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ELECTRICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it. The device contains circuitry to protect the inputs against damage from high static voltages; however, do not apply voltages higher than those shown in the table below. Keep V_{IN} and V_{OUT} within the range $V_{SS} \le (V_{IN}$ or $V_{OUT}) \le V_{DD}$.

Table 3. Maximum Ratings

Rating	Symbol	Value	Unit
Supply Voltage	V_{DD}	–0.3 to +4.0	V
Short Circuit Capability (all pins excluding V_{DD} and V_{SS}) Maximum High Voltage for 5 minutes Minimum Low Voltage for 5 minutes	 V_{SC} V_{SC}	 V_{DD} V_{SS}	 V V
Substrate Current Injection Current from any pin to V_{SS} –0.3 VDC)	 I_{SUB}	 600	 µA
Electrostatic Discharge Human Body Model (HBM) Charged Device Model (CDM) Machine Model (MM)	 V_{ESD} V_{ESD} V_{ESD}	 ±1000 ±1000 ±200	 V V V
Storage Temperature Range Standard Temperature Range	 T_{stg}	 –40 to +150	 °C

ELECTRO STATIC DISCHARGE (ESD)

WARNING: This device is sensitive to electrostatic discharge.

Extra precaution must be taken by the user to protect the chip from ESD. A charge of over 1000 volts can accumulate on the human body or associated test equipment. A charge of this magnitude can alter the performance or cause failure of the chip. When handling the pressure sensor, proper ESD precautions should be followed to avoid exposing the device to discharges which may be detrimental to its performance.

Table 4. Operating Range

These are the limits normally expected in the application which define range of operation.

Characteristic	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{DD}	2.1	3.0	3.6	V
Operating Temperature Range Standard Temperature Range	 T_A	T_L –40	 —	T_H +125	 °C
Supply Current Drain Standby Mode –40°C to +85°C +85°C to +100°C +100°C to +125°C	 I_{STBY} I_{STBY} I_{STBY}	 — — —	 0.6 0.8 1.5	 0.9 1.2 2.2	 µA µA µA
Read Mode –40°C to +125°C	 I_{READ}	 —	 400	 600	 µA
Measure Temperature Mode –40°C to +125°C	 I_{TEMP}	 —	 400	 600	 µA
Measure Pressure Mode –40°C to +10°C +10°C to +60°C +60°C to +125°C	 I_{PRESS} I_{PRESS} I_{PRESS}	 — — —	 1400 1300 1200	 1800 1700 1700	 µA µA µA

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Table 5. Electrical Characteristics

+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
Output High Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Low Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = -100 μA)	V_{OL}	—	—	0.4	V
Input High Voltage S0, S1, DATA, CLK	V_{IH}	0.7 x V_{DD}	—	—	V
Input Low Voltage S0, S1, DATA, CLK	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input Hysteresis (V_{IH} — V_{IL}) S0, S1, DATA, CLK	V_{HYS}	100	200	—	mV
Input Low Current (at V_{IL}) S0, S1, DATA, CLK	I_{IL}	–5	–25	–100	μA
Input High Current (at V_{IH}) S0, S1, DATA, CLK	I_{IH}	–5	–35	–140	μA (2)
Temperature Measurement (+2.5 V ≤ V_{DD} ≤ 3.0 V) D/A Conversion Code at –40°C D/A Conversion Code at –20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	 T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	 36 52 97 155 204 241 249	 42 57 102 163 214 252 255	 47 62 107 171 224 255 255	 counts counts counts counts counts counts counts
Temperature Measurement (+2.1 V ≤ V_{DD} ≤ 3.6 V) D/A Conversion Code at –40°C D/A Conversion Code at –20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	 T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	 36 52 97 154 203 240 249	 42 57 102 163 214 252 255	 49 64 107 172 225 255 255	 counts counts counts counts counts counts counts
Temperature Sensitivity at 25°C		—	0.80		°C/bit
Approximate Temperature Output Response	OUT = 74.75 + 0.075 x Ta + 0.0041 x Ta^2				counts

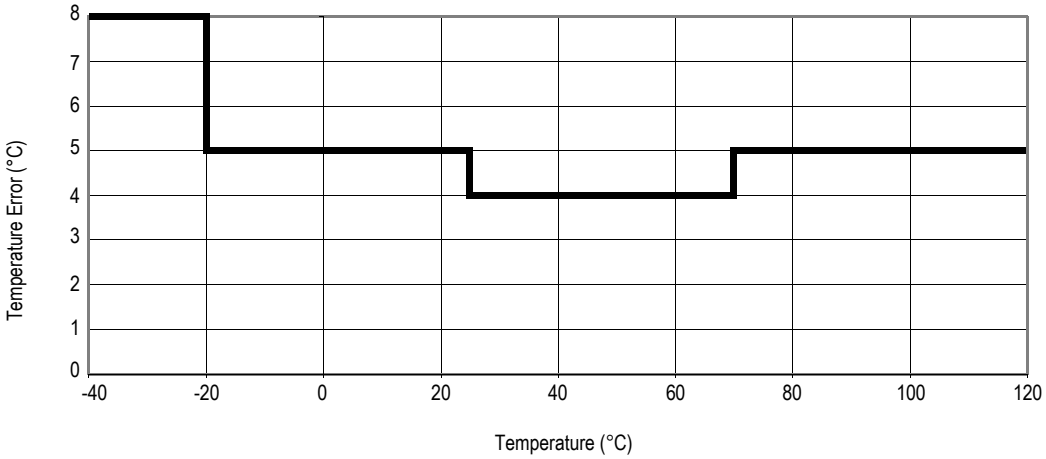

Figure 7. Temperature Error vs Temperature at V_{DD} = 3.0 V

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Table 6. Control Timing

+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
HFO Measurement Clock Frequency	f_{HF}	100	135	150	kHz
LFO Wake Up Clock Frequency Ta = –40°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +25°C, +2.1V ≤ V_{DD} ≤ +3.6 Ta = +125°C, +2.1V ≤ V_{DD} ≤ +3.6	 f_{LF} f_{LF} f_{LF}	 3300 3900 3800	 5400 5400 5300	 8000 7700 7000	 Hz Hz Hz
Wake Up Pulse Pulse Timing Pulse Width	 t_{WAKE} t_{WPW}	 — —	 16384 2	 — —	 LFO clocks LFO clocks
Reset Pulse Pulse Timing Pulse Width	 t_{RESET} t_{RPW}	 — —	 16,777,216 2	 — —	 LFO clocks LFO clocks
Minimum Setup Time (DATA edge to CLK rise)	t_{SETUP}	100	—	—	nSec
Minimum Hold Time (CLK rise to DATA change)	t_{HOLD}	100	—	—	nSec
Measurement Response Time Recommended time to hold device in measurement mode Temperature Pressure	 t_{TMEAS} t_{PMEAS}	 — —	 200 500	 — —	 µSec µSec
Read Response Time (see Figure 8) From 90% V_{DD} on S0 to OUT less than V_{OL} or greater than V_{OH}	t_{READ}	—	50	100	µSec
Sample Capacitor Discharge Time From initial full scale D/A count (255) to drop 2 counts (253)	t_{SH}	20	—	—	mSec

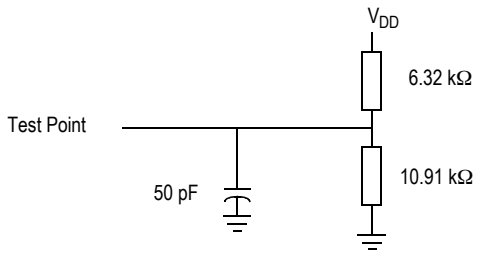

Figure 8. Control Timing Test Load for OUT and $\overline{\text{RST}}$ Pins

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SENSOR CHARACTERISTICS (MPXY8020A)

Pressure Transfer Function

kPa = 2.5 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error (±kPa): 50 kPa ≤ P < 250 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	72.5	72.5	32.5	32.5	32.5	35.0
–20	57.5	57.5	25.0	25.0	25.0	27.5
0	57.5	57.5	25.0	25.0	25.0	27.5
25	57.5	57.5	25.0	25.0	25.0	27.5
70	57.5	57.5	27.5	25.0	25.0	27.5
100	72.5	72.5	37.5	37.5	37.5	37.5
125	95.0	92.5	57.5	47.5	47.5	47.5

Pressure Error (±kPa): 250 kPa ≤ P ≤ 450 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	40.0	40.0	25.0	25.0	25.0	30.0
–20	32.5	25.0	15.0	15.0	15.0	20.0
0	30.0	25.0	10.0	10.0	10.0	15.0
25	30.0	25.0	7.5	7.5	7.5	15.0
70	35.0	25.0	10.0	7.5	7.5	15.0
100	40.0	40.0	25.0	25.0	25.0	30.0
125	62.5	60.0	35.0	35.0	35.0	35.0

Pressure Error (±kPa): 450 kPa < P ≤ 600 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	70.0	70.0	37.5	37.5	37.5	40.0
–20	55.0	55.0	25.0	25.0	25.0	35.0
0	55.0	55.0	22.5	22.5	22.5	35.0
25	55.0	55.0	22.5	22.5	22.5	35.0
70	55.0	55.0	25.0	25.0	25.0	35.0
100	70.0	70.0	32.5	32.5	32.5	40.0
125	90.0	90.0	47.5	47.5	47.5	52.5

Areas marked in grey indicate the typical operating range.

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Pressure Error

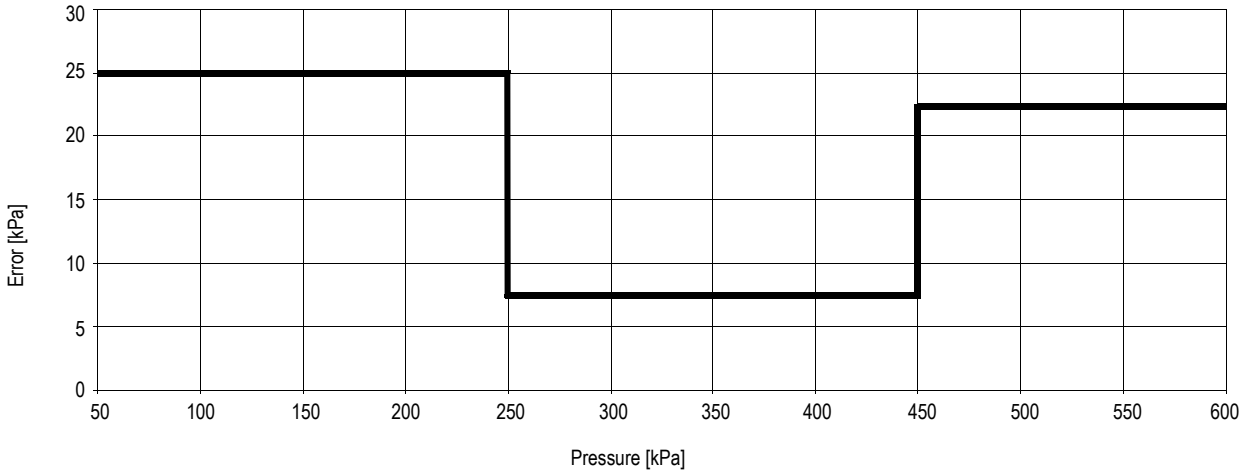

Figure 9. Pressure Error vs Pressure at T = 25°C, 2.7 V ≤ V_{DD} ≤ 3.3 V

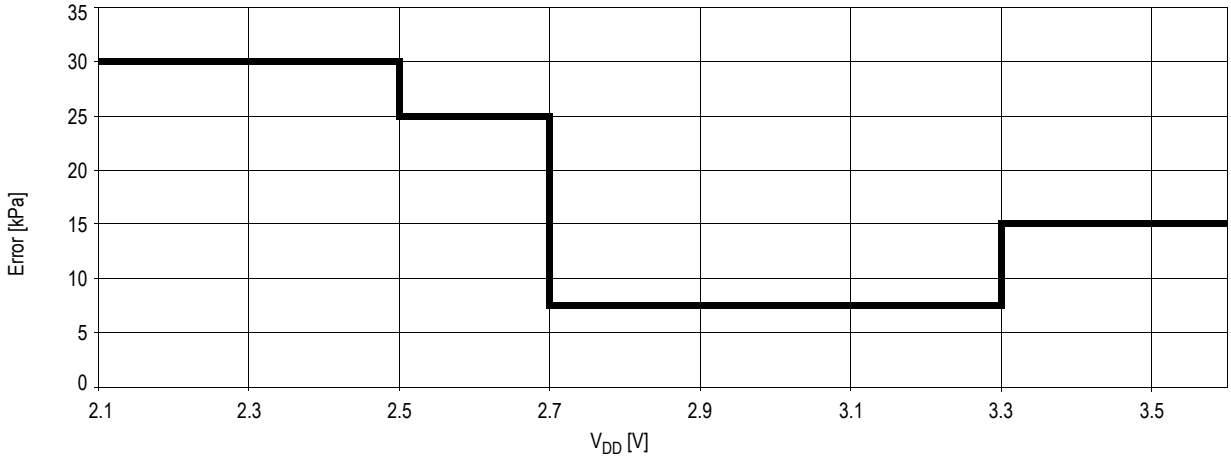

Figure 10. Pressure Error vs V_{DD} at T = 25°C, 250 kPa ≤ P ≤ 450 kPa

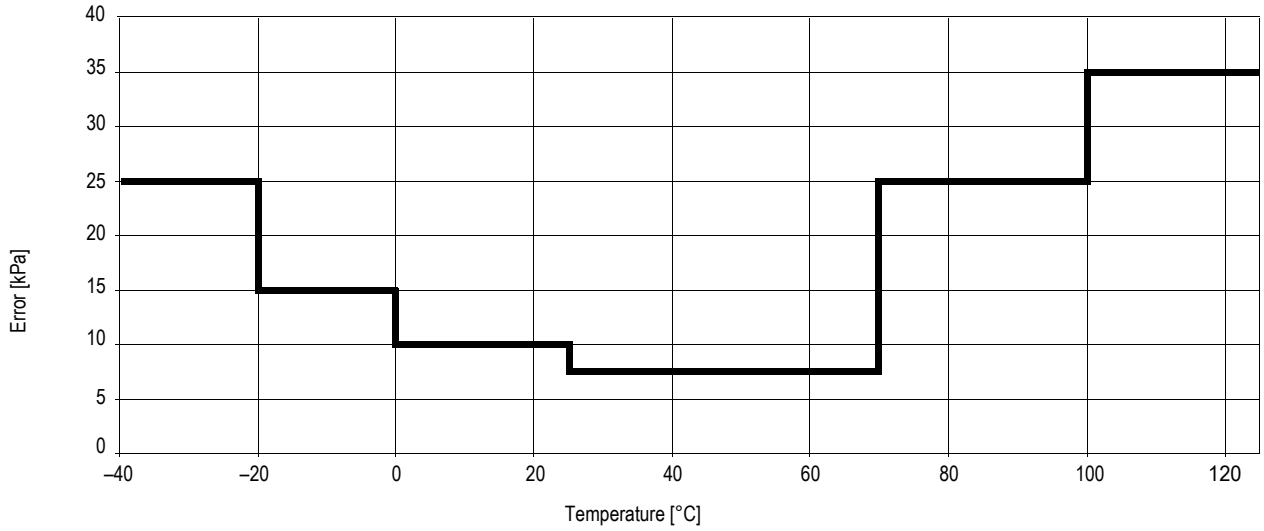

Figure 11. Pressure Error vs Temperature at V_{DD} = 3.0 V, 250 kPa ≤ P ≤ 450 kPa

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SENSOR CHARACTERISTICS (MPXY8040A)

Pressure Transfer Function

kPa = 5.0 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error [±kPa]: 50 kPa ≤ P < 500 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	80	75	70	70	70	70	75
–20	70	60	55	55	55	55	60
0	60	50	45	45	45	45	55
25	55	45	40	40	40	45	50
70	70	55	50	50	50	50	55
100	80	70	65	65	65	65	70
125	90	85	80	80	80	80	80

Pressure Error [±kPa]: 500 kPa ≤ P < 900 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	75	65	60	60	60	60	65
–20	50	35	25	25	25	40	50
0	40	30	20	20	20	25	35
25	40	30	20	20	20	25	35
70	40	30	20	20	20	25	35
100	60	45	35	35	35	45	60
125	90	85	80	80	80	80	80

Pressure Error [±kPa]: 900 kPa ≤ P < 1000 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	120	110	110	100	100	110	120
–20	100	80	80	60	60	80	100
0	90	60	60	40	40	60	90
25	90	60	60	40	40	60	90
70	90	75	75	60	60	75	90
100	90	90	90	75	75	90	90
125	130	120	120	110	110	120	130

Pressure Error [±kPa]: 1000 kPa ≤ P < 1100 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	130	120	120	100	100	120	130
–20	110	90	90	60	70	90	110
0	90	80	80	50	50	80	90
25	90	80	80	50	50	80	90
70	90	75	75	60	60	75	90
100	130	110	110	100	100	110	130
125	140	130	130	120	120	130	140

Pressure Error [±kPa]: 1100 kPa ≤ P ≤1275 kPa

T[°C] \ V_{DD}[V]	2.1	2.3	2.5	2.7	3.0	3.3	3.6
–40	150	140	140	120	120	140	150
–20	120	100	100	80	80	100	120
0	110	90	90	80	80	90	110
25	110	90	90	80	80	90	110
70	120	120	120	120	120	130	150
100	160	140	140	140	140	160	160
125	210	200	200	200	200	210	210

Areas marked in grey indicate the typical operating range.
Pressure values beyond 900 kPa are from characterization only. Pressure readings above 680 kPa are not tested in production.

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Pressure Error

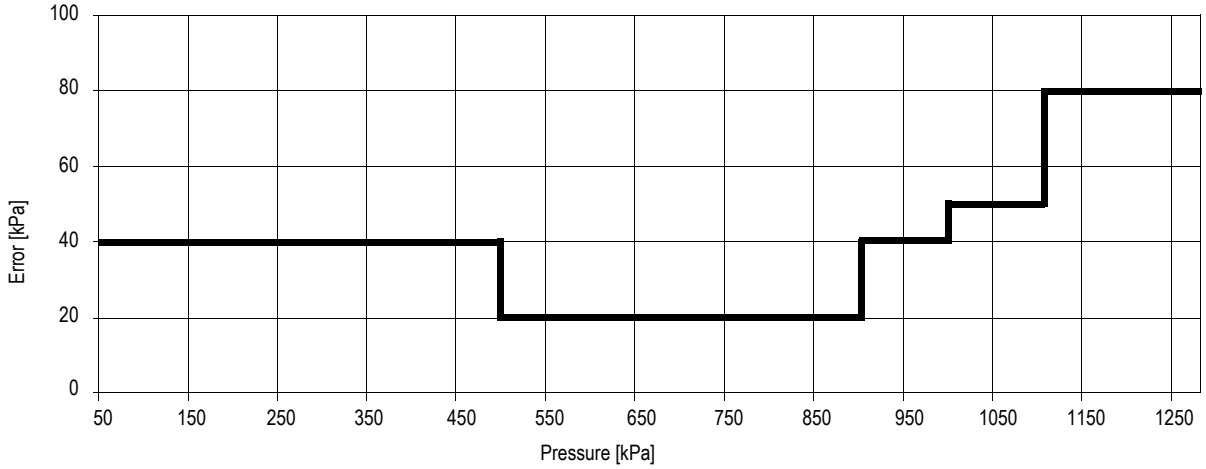

Figure 12. Pressure Error vs Pressure at T= 25°C, 2.7 V ≤ V_{DD} ≤ 3.0 V

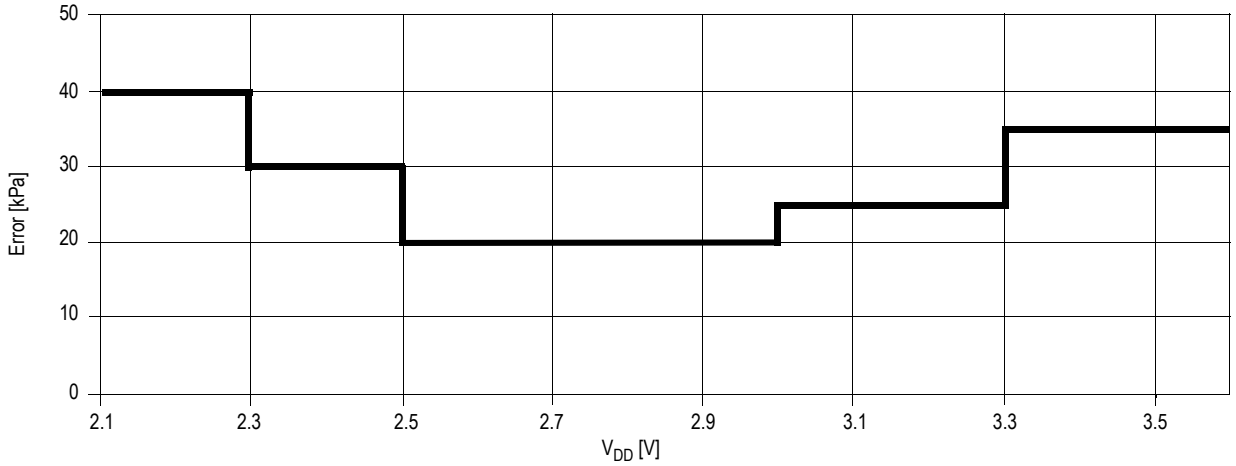

Figure 13. Pressure Error vs V_{DD} at T = 25°C, 500 kPa ≤ P ≤ 900kPa

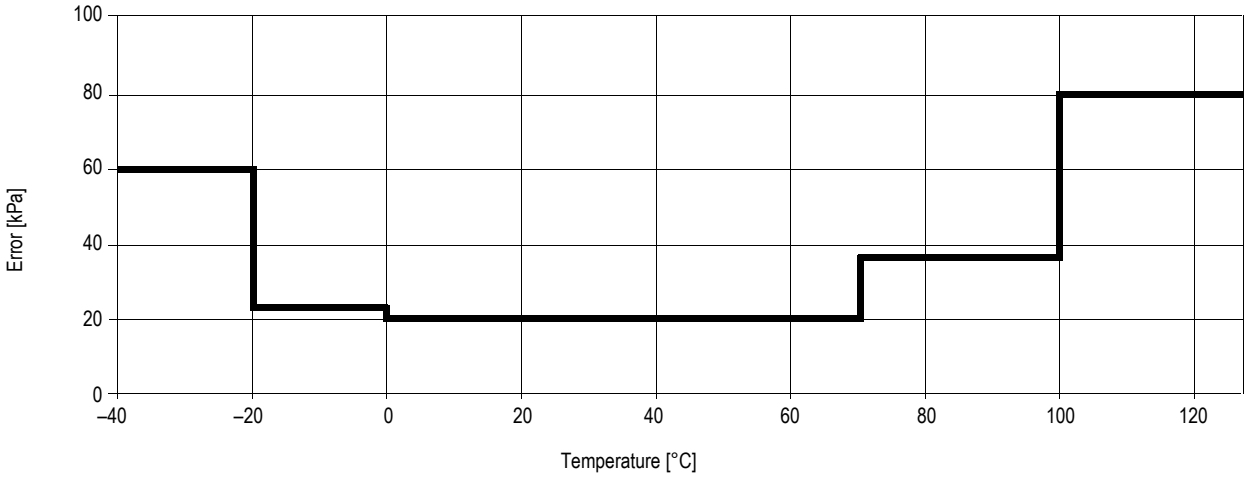

Figure 14. Pressure Error vs Temperature at V_{DD} = 3.0 V, 500 kPa ≤ P ≤ 900kPa

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MECHANICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it.

Keep V_{IN} and V_{OUT} within the range $V_{SS} \leq (V_{IN}$ or $V_{OUT}) \leq V_{DD}$.

Table 7. Maximum Ratings

Rating	Symbol	Value	Unit
Maximum Pressure(1)	p_{max}	1400	kPa(1)
Centrifugal Force Effects (3 axis) Pressure measurement change less than 1% FSS	g_{CENT}	2000	g
Unpowered Shock (three sides, 0.5 mSec duration)	g_{shock}	2000	g

1. Tested for 5 minutes at 25°C.

MEDIA COMPATIBILITY

The Daytona sensor has been designed with the tire pressure application in mind. As such, it has been tested to a variety of media typical of the tire environment. The filter provides limited, but not universal, media protection.

The customer must ensure media compatibility of the Daytona sensor in their application. In particular, it is strongly recommended that the customer design the application such that media does not come in direct contact with the sensor. Module housing design and orientation will play a role in protecting the sensor from direct media exposure. In the event that media does come in contact with the sensor it is desirable that the application minimize the duration and severity of exposure. Media may be forced through the filter by mechanical aspects of the application such as g-forces or rapid pressurization of the tire.

In addition, the customer maintains responsibility to design and carry out reliability testing verifying compatibility of the Daytona sensor with their module design and application.

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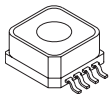
Tire Pressure Monitoring Sensor Temperature Compensated and Calibrated, Fully Integrated, Digital Output

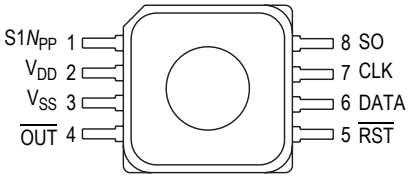
MPXY8021A

TIRE PRESSURE MONITORING SENSOR
MPXY8021A:
OPTIMIZED FOR 250 kPA – 450 kPA



SUPER SMALL OUTLINE PACKAGE
CASE 1352-03

PIN ASSIGNMENT



8-pin Super Small Outline Package (SSOP)

The Freescale Semiconductor, Inc. MPXY8021A sensor is an 8-pin tire monitoring sensor which is comprised of a variable capacitance pressure sensing element, a temperature sensing element, and an interface circuit (with a wake-up feature) all on a single chip. It is housed in a Super-Small Outline Package (SSOP), which includes a media protection filter. Specifically designed for the low power consumption requirements of tire pressure monitoring systems, it can combine with a Freescale remote keyless entry (RKE) system to facilitate a low-cost, highly integrated system.

DETAILED DESCRIPTION

The block diagram of the MPXY8021A sensor is shown in Figure 1. The pressure sensor is a capacitive transducer constructed using surface micromachining, the temperature sensor is constructed using a diffused resistor, and the interface circuit is integrated onto the same die as the sensors using a standard silicon CMOS process.

The conditioning of the pressure signal begins with a capacitance to voltage conversion (C to V) followed by a switched capacitor amplifier. This amplifier has adjustable offset and gain trimming. The offset and gain are factory calibrated, with calibration values stored in the EEPROM trim register. This amplifier also has temperature compensation circuits for both sensitivity and offset, which also are factory adjusted using the EEPROM trim register.

The pressure is monitored by a voltage comparator, which compares the measured value against an 8-bit threshold adjusted by a serial input. By adjusting the threshold and monitoring the state of the OUT pin the external device can check whether a low-pressure threshold has been crossed, or perform up to 8-bit A/D conversions.

The temperature is measured by a diffused resistor with a positive temperature coefficient driven by a current source, thereby creating a voltage. The room temperature value of this voltage is factory calibrated using the EEPROM trim register. A two-channel multiplexer can route either the pressure or temperature signal to a sampling capacitor that is monitored by a voltage comparator with variable threshold adjust, providing a digital output for temperature.

An internal low frequency, low power 5.4 kHz oscillator with a 14-stage divider provides a periodic pulse to the OUT pin (divide by 16384 for 3 seconds). This pulse can be used to wake up an external MCU to begin an interface with the device. An additional 10-stage divider will provide a pulse every 52 minutes which can be used to reset an external MCU.

The power consumption can be controlled by several operational modes selected by external pins.

ORDERING INFORMATION	
Shipped in Rails	**Shipped in Tape & Reel**
MPXY8021A6U	MPXY8021A6T1

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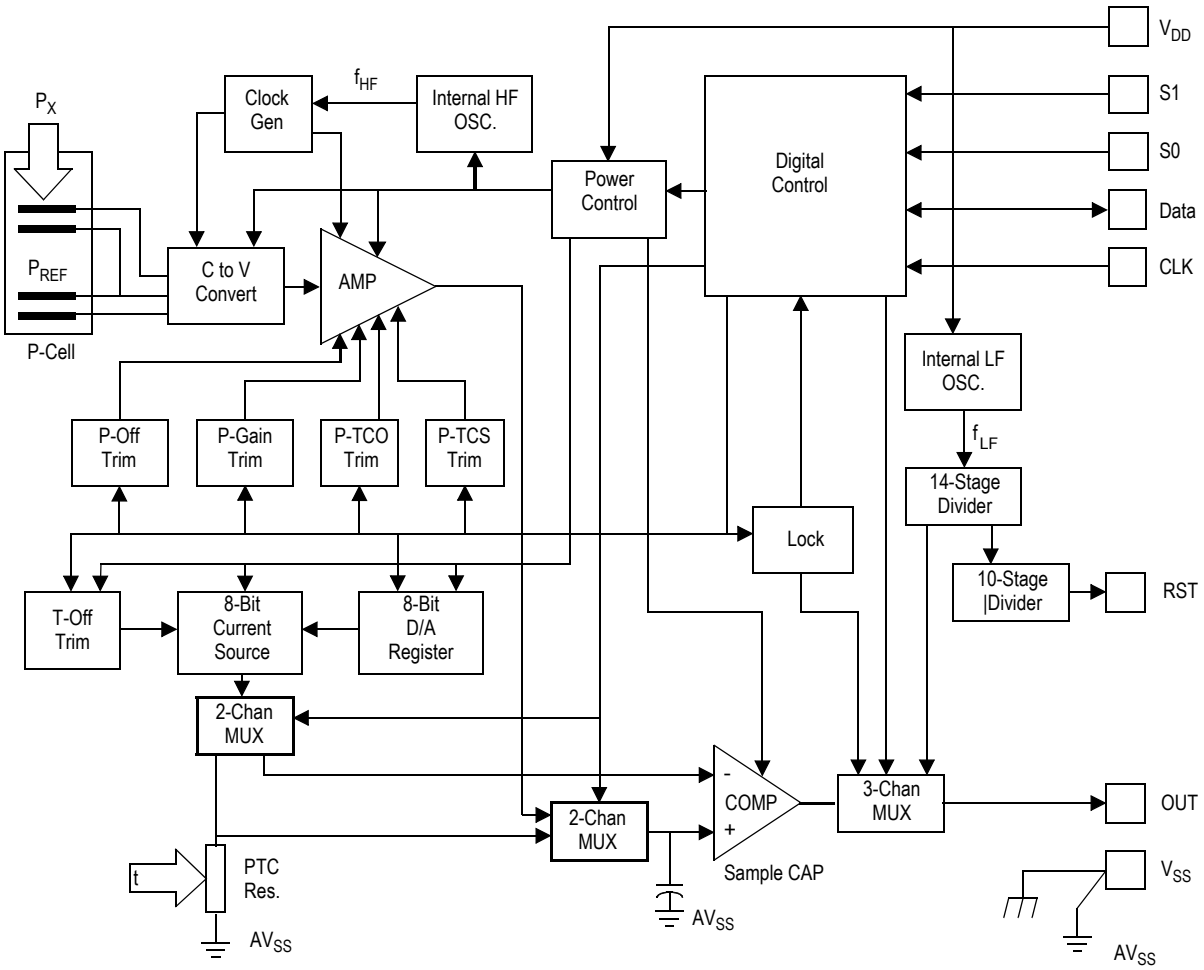

Figure 1. MPXY8021A Sensor Block Diagram

OPERATING MODES

The device has several operating modes dependent on the applied voltages to the S1 and S0 pins as shown in Table 1. In all the modes listed the channel multiplexers, D/A Register, LFO, and the output pulse dividers will always be powered up as long as there is a voltage source connected to the V_{DD} pin.

When only the S0 pin is at a logic one the pressure measuring circuit in the device is powered up and the pressure output signal is connected to the sample capacitor through a multiplexer. When the S0 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

When only the S1 pin is at a logic one the temperature measuring circuit in the device is powered up and the temperature output signal is connected to the sample capacitor through a multiplexer. When the S1 pin returns to the low state the multiplexer will first turn off to store the signal on the sample capacitor before powering down the measuring circuitry.

NOTE: All of the EEPROM trim bits will be powered up regardless of whether the pressure or temperature measuring circuitry is activated.

NOTE: If the voltage on the S1 pin exceeds 2.5 times the voltage on the V_{DD} pin the device will be placed into its Trim/Test Mode.

NOTE: If the V_{DD} supply source is switched off in order to reduce current consumption, it is important that all input pins be driven LOW to avoid powering up the device.

If any input pin (S1, S0, DATA, or CLK) is driven HIGH while the V_{DD} supply is switched off, the device may be powered up through an ESD protection diode. Such a case should be avoided. The effective source voltage of the device will be less than the applied voltage due to diode voltage drop. In addition, the entire source current will be drawn from the input pin.

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Table 1. Operating Modes

S1	S0	Operating Mode	Circuitry Powered				Serial Data Counter
			Pressure Measure System	Temp Measure System	A/D Output Comp.	LFO Oscill.	
0	0	Standby/Reset	OFF	OFF	OFF	ON	ACTIVE
0	1	Measure Pressure	ON	OFF	OFF	ON	RESET
1	0	Measure Temperature	OFF	ON	OFF	ON	RESET
1	1	Output Read	OFF	OFF	ON	ON	ACTIVE

PIN FUNCTIONS

The following paragraphs give a description of the general function of each pin.

V_{DD} and V_{SS} Pins

Power is supplied to the control IC through V_{DD} and V_{SS}. V_{DD} is the positive supply and V_{SS} is the digital and analog ground. The control IC operates from a single power supply. Therefore, the conductors to the power supply should be connected to the V_{DD} and V_{SS} pins and locally decoupled as shown in Figure 2.

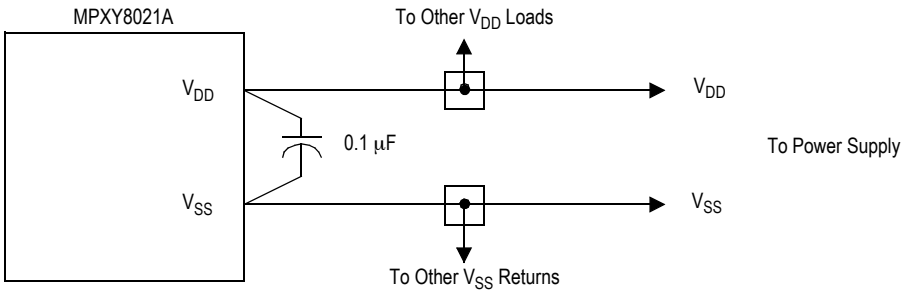

Figure 2. Recommended Power Supply Connections

OUT Pin

The OUT pin normally provides a digital signal related to the voltage applied to the voltage comparator and the threshold level shifted into an 8-bit register from an external device. When the device is placed in the standby mode the OUT pin is driven high and will be clocked low when an overflow is detected from a clock divider (divide by 16384) driven by the LFO. This allows the OUT pin to wake up an external device such as an MCU.

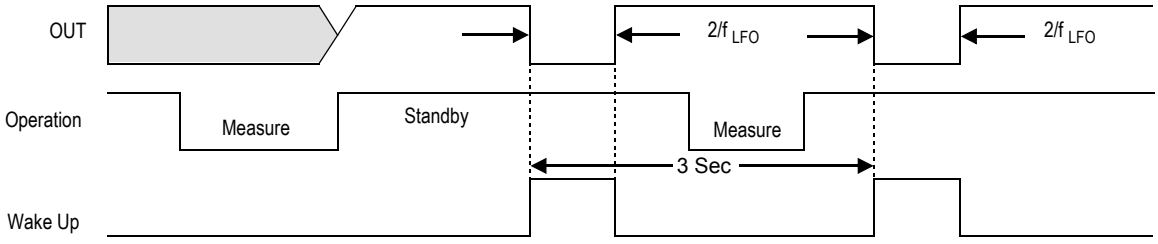

Figure 3. Pulse on OUT Pin During Standby Mode

$\overline{RST}$ Pin

The $\overline{RST}$ pin is normally driven high and will be clocked low when an overflow is detected from total clock divider (divide by 16,777,216) driven by the LFO. This allows the $\overline{RST}$ pin to reset an external device such as an MCU. This pulse will appear on the $\overline{RST}$ pin approximately every 52 minutes regardless of the operating mode of the device. The pulse lasts for two cycles of the LFO oscillator as shown in Figure 4. Since the RST pin is clocked from the same divider string as the OUT pin, there will also be a pulse on the OUT pin when the $\overline{RST}$ pin pulses every 52 minutes.

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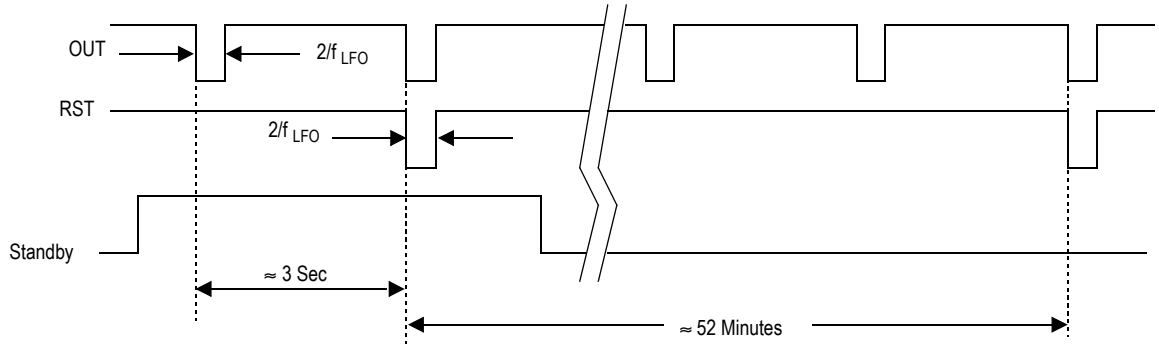

Figure 4. Pulse on $\overline{\text{RST}}$ Pin

S0 Pin

The S0 pin is used to select the mode of operation as shown in Table 1.

The S0 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The S0 pin has an internal pull-down device in order to provide a low level when the pin is left unconnected.

S1 Pin

The S1 pin is used to select the mode of operation, as shown in Table 1.

The S1 pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

The S1 pin also serves the purpose of enabling factory trim and test of the device.

The higher V_{PP} programming voltage for the internal EEPROM trim register is also supplied through the S1 pin.

DATA Pin

The DATA pin is the serial data in (SDI) function for setting the threshold of the voltage comparator.

The DATA pin contains an internal Schmitt trigger as part of its input to improve noise immunity. This pin has an internal pull-down device to provide a low level when the pin is left unconnected.

CLK Pin

The CLK pin is used to provide a clock used for loading and shifting data into the DATA pin. The data on the DATA pin is clocked into a shift register on the rising edge of the CLK pin signal. The data is transferred to the D/A Register on the eighth falling edge of the CLK pin. This protocol may be handled by the SPI or SIOP serial I/O function found on some MCU devices.

The CLK pin contains an internal Schmitt trigger as part of its input to improve noise immunity. The CLK pin has an internal pull-down device to provide a low level when the pin is left unconnected.

Output Threshold Adjust

The state of the OUT pin is driven by a voltage comparator whose output state depends on the level of the input voltage on the sample capacitor and the level of an adjustable 8-bit threshold voltage. The threshold is adjusted by shifting data bits into the D/A Register (DAR) via the DATA pin while clocking the CLK pin. The timing of this data is shown in Figure 5. Data is transferred into the serial shift register on the rising edge of the CLK pin. On the falling edge of the 8th clock the data in the serial shift register is latched into the parallel DAR register. The DAR remains powered up whenever V_{DD} is present. The serial data is clocked into the DATA pin starting with the MSB first. This sequence of threshold select bits is shown in Table 2.

Table 2. D/A Threshold Bit Assignment

Function		Bit Weight	Data Bit
Voltage Comparator Threshold Adjust (8 bits)	LSB	1	D0
		2	D1
		4	D2
		8	D3
		16	D4
		32	D5
		64	D6
	MSB	128	D7

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An analog to digital (A/D) conversion can be accomplished with eight (8) different threshold levels in a successive approximation algorithm; or the OUT pin can be set to trip at some alarm level. The voltage on the sample capacitor will maintain long enough for a single 8-bit conversion, but may need to be refreshed with a new measured reading if the read interval is longer than the specified hold time, t_{SH}.

The counter that determines the number of clock pulses into the device is reset whenever the device is placed into the Measure Pressure or Measure Temperature Modes. This provides a means to reset the data transfer count in case the clock stream is corrupted during a transmission. In these two modes the DATA and CLK pins should not be clocked to reduce noise in the captured pressure or temperature data. Any change in the DAR contents should be done during the Standby or Output Read Modes.

Both the serial bit counter and the state of the DAR are undefined following power up of the device. The serial bit counter can be reset by cycling either the SO pin or the S1/VPP pin to a high level and then back low. The DAR can then be reset to the lowest level by holding the DATA pin low while bursting the CLK pin with eight (8) clock pulses.

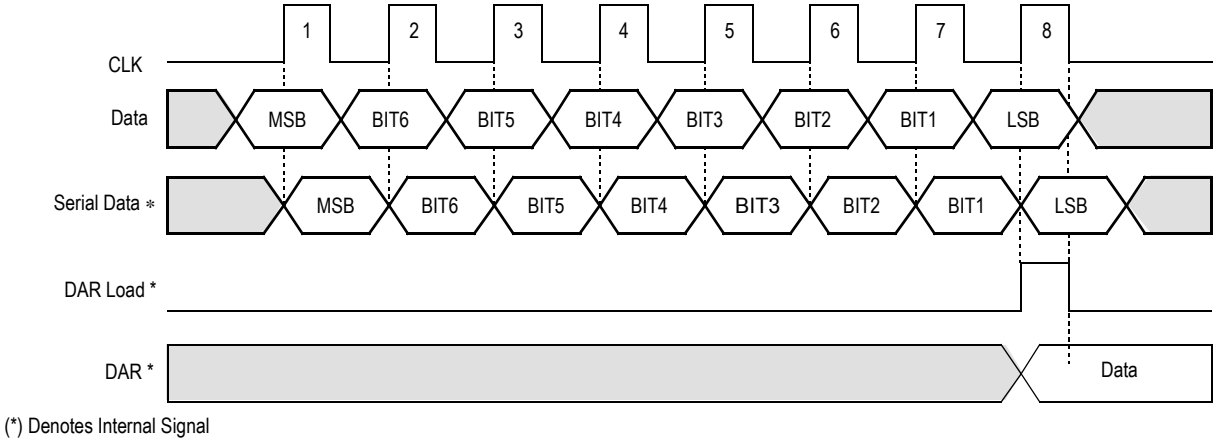

Figure 5. Serial Data Timing

Pressure Sensor Output

The pressure channel compares the output of its analog measurement circuit to the D/A reference voltage. The device is calibrated at two different nominal values depending on the calibration option.

Temperature Sensor Output

The temperature channel compares the output of a positive temperature coefficient (PTC) resistor driven by a switched current source. The current source is only active when the temperature channel is selected.

APPLICATIONS

Suggested application example is shown in Figure 6.

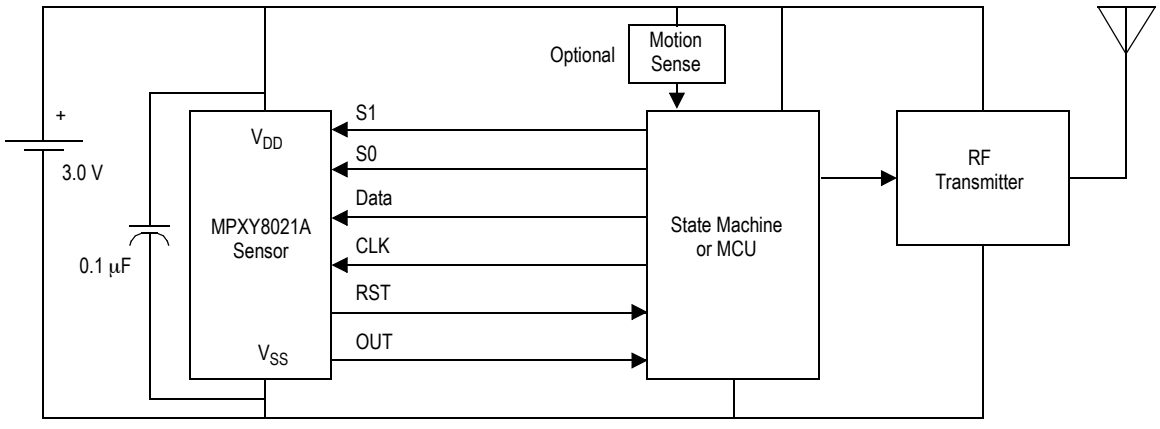

Figure 6. Application Example

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ELECTRICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it. The device contains circuitry to protect the inputs against damage from high static voltages; however, do not apply voltages higher than those shown in the table below. Keep V_{IN} and V_{OUT} within the range $V_{SS} \le (V_{IN}$ or $V_{OUT}) \le V_{DD}$.

Table 3. Maximum Ratings

Rating	Symbol	Value	Unit
Supply Voltage	V_{DD}	–0.3 to +4.0	V
Short Circuit Capability (all pins excluding V_{DD} and V_{SS}) Maximum High Voltage for 5 minutes Minimum Low Voltage for 5 minutes	 V_{SC} V_{SC}	 V_{DD} V_{SS}	 V V
Substrate Current Injection Current from any pin to V_{SS} –0.3 VDC)	I_{SUB}	600	μA
Electrostatic Discharge Human Body Model (HBM) Charged Device Model (CDM) Machine Model (MM)	 V_{ESD} V_{ESD} V_{ESD}	 ±1000 ±1000 ±200	 V V V
Storage Temperature Range Standard Temperature Range	T_{stg}	–40 to +150	°C

Table 4. Operating Range

The limits normally expected in the application which define range of operation.

Characteristic	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{DD}	2.1	3.0	3.3	V
Operating Temperature Range Standard Temperature Range	T_A	T_L –40	—	T_H +125	°C
Pressure Operating Range MPXY8021A	$P_{637.5}$	50	—	637.5	kPa
Supply Current Drain Standby Mode –40°C to +85°C +85°C to +100°C +100°C to +125°C	 I_{STBY} I_{STBY} I_{STBY}	 — — —	 0.6 0.8 1.5	 0.9 1.2 2.2	 μA μA μA
Read Mode –40°C to +125°C	I_{READ}	—	400	600	μA
Measure Temperature Mode –40°C to +125°C	I_{TEMP}	—	400	600	μA
Measure Pressure Mode –40°C to +10°C +10°C to +60°C +60°C to +125°C	 I_{PRESS} I_{PRESS} I_{PRESS}	 — — —	 1400 1300 1200	 1800 1700 1700	 μA μA μA

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Table 5. Electrical Characteristics

+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified

Characteristic	Symbol	Min	Typ	Max	Units
Output High Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = 100 μA)	V_{OH}	V_{DD} –0.8	—	—	V
Output Low Voltage DATA, OUT, $\overline{RST}$ (I_{Load} = -100 μA)	V_{OL}	—	—	0.4	V
Input High Voltage S0, S1, DATA, CLK	V_{IH}	0.7 x V_{DD}	—	—	V
Input Low Voltage S0, S1, DATA, CLK	V_{IL}	V_{SS}	—	0.3 x V_{DD}	V
Input Hysteresis (V_{IH} — V_{IL}) S0, S1, DATA, CLK	V_{HYS}	100	200	—	mV
Input Low Current (at V_{IL}) S0, S1, DATA, CLK	I_{IL}	-5	-25	-100	μA
Input High Current (at V_{IH}) S0, S1, DATA, CLK	I_{IH}	-5	-35	-140	μA (2)
Temperature Measurement (+2.1 V ≤ V_{DD} < +2.5 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	 T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	 34 52 97 154 203 240 249	 42 57 102 163 214 252 255	 51 67 107 172 225 255 255	 counts counts counts counts counts counts counts
Temperature Measurement (+2.5 V ≤ V_{DD} ≤ +3.0 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	 T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	 36 52 97 155 204 241 249	 42 57 102 163 214 252 255	 50 64 107 171 224 255 255	 counts counts counts counts counts counts counts
Temperature Measurement (+3.0 V < V_{DD} ≤ +3.6 V) D/A Conversion Code at -40°C D/A Conversion Code at -20°C D/A Conversion Code at 25°C D/A Conversion Code at 70°C D/A Conversion Code at 100°C D/A Conversion Code at 120°C D/A Conversion Code at 125°C	 T_{-40} T_{-20} T_{25} T_{70} T_{100} T_{120} T_{125}	 36 52 97 154 203 240 249	 42 57 102 163 214 252 255	 49 64 107 172 225 255 255	 counts counts counts counts counts counts counts
Temperature Sensitivity at 25°C		—	0.80		°C/bit
Approximate Temperature Output Response	OUT = 74.75 + 0.075 x Ta + 0.0041 x Ta^2				counts

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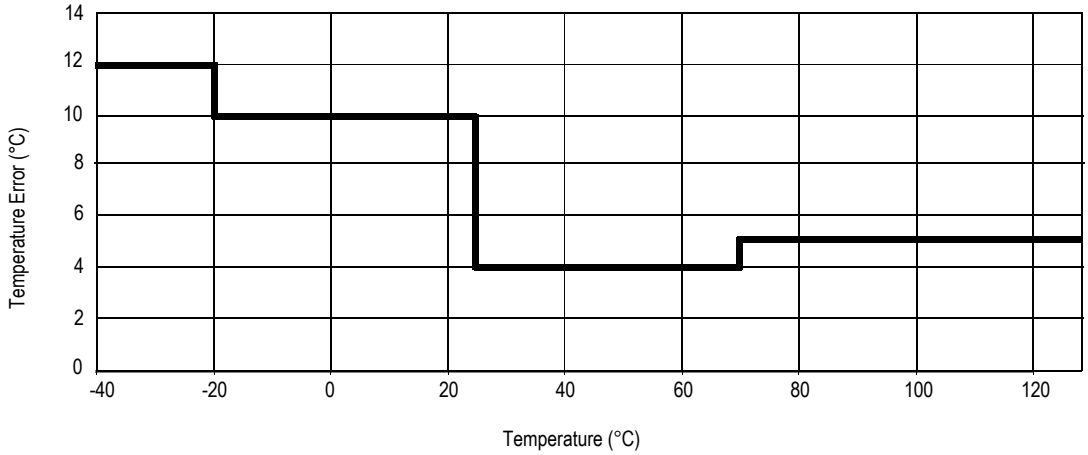

Figure 7. Temperature Error vs Temperature at V_{DD} = 3.0 V

Table 6. Control Timing

+2.1 V ≤ V_{DD} ≤ +3.6 V, T_L ≤ T_A ≤ T_H, unless otherwise specified.

Characteristic	Symbol	Min	Typ	Max	Units
HFO Measurement Clock Frequency	f_{HF}	100	135	150	kHz
LFO Wake Up Clock Frequency Ta = –40°C, +2.1 V ≤ V_{DD} ≤ +3.6 Ta = +25°C, +2.1 V ≤ V_{DD} ≤ +3.6 Ta = +125°C, +2.1 V ≤ V_{DD} ≤ +3.6	 f_{LF} f_{LF} f_{LF}	 3300 3900 3800	 5400 5400 5300	 8000 7700 7000	 Hz Hz Hz
Wake Up Pulse Pulse Timing Pulse Width	 t_{WAKE} t_{WPW}	 — —	 16384 2	 — —	 LFO clocks LFO clocks
Reset Pulse Pulse Timing Pulse Width	 t_{RESET} t_{RPW}	 — —	 16,777,216 2	 — —	 LFO clocks LFO clocks
Minimum Setup Time (DATA edge to CLK rise)	t_{SETUP}	100	—	—	nSec
Minimum Hold Time (CLK rise to DATA change)	t_{HOLD}	100	—	—	nSec
Measurement Response Time Recommended time to hold device in measurement mode Temperature Pressure	 t_{TMEAS} t_{PMEAS}	 — —	 200 500	 — —	 µSec µSec
Read Response Time (see Figure 8) From 90% V_{DD} on S0 to OUT less than V_{OL} or greater than V_{OH}	t_{READ}	—	50	100	µSec
Sample Capacitor Discharge Time From initial full scale D/A count (255) to drop 2 counts (253)	t_{SH}	20	—	—	mSec

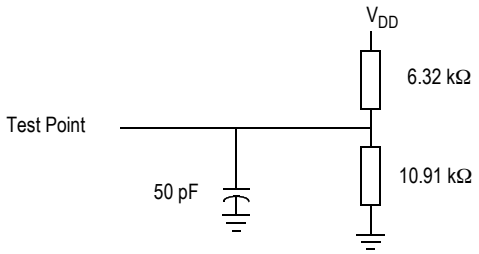

Figure 8. Control Timing Test Load for OUT and $\overline{RST}$ Pins

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PRESSURE TRANSFER FUNCTION

kPa = 2.5 x Output ± (Pressure Error)
Output = 8-bit digital pressure measurement (between 0-255)

Pressure Error (±kPa): 50 kPa ≤ P < 250 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	72.5	72.5	35.0	35.0	35.0	37.5
–20	57.5	57.5	30.0	30.0	30.0	35.0
0	57.5	57.5	25.0	25.0	25.0	27.5
25	57.5	57.5	25.0	25.0	25.0	27.5
70	57.5	57.5	27.5	25.0	25.0	27.5
100	72.5	72.5	37.5	37.5	37.5	37.5
125	95.0	92.5	57.5	47.5	47.5	47.5

Pressure Error (±kPa): 250 kPa ≤ P ≤ 450 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	40.0	40.0	30.0	30.0	30.0	35.0
–20	32.5	25.0	20.0	20.0	20.0	25.0
0	30.0	25.0	10.0	10.0	10.0	15.0
25	30.0	25.0	7.5	7.5	7.5	15.0
70	35.0	25.0	10.0	7.5	7.5	15.0
100	40.0	40.0	25.0	25.0	25.0	30.0
125	62.5	60.0	35.0	35.0	35.0	35.0

Pressure Error (±kPa): 450 kPa < P ≤ 637.5 kPa

T[°C] \ V_{DD}[V]	2.1	2.5	2.7	3.0	3.3	3.6
–40	70.0	70.0	40.0	40.0	40.0	40.0
–20	55.0	55.0	30.0	30.0	30.0	35.0
0	55.0	55.0	22.5	22.5	22.5	35.0
25	55.0	55.0	22.5	22.5	22.5	35.0
70	55.0	55.0	25.0	25.0	25.0	35.0
100	70.0	70.0	32.5	32.5	32.5	40.0
125	90.0	90.0	47.5	47.5	47.5	52.5

Areas marked in grey indicate the typical operating range.

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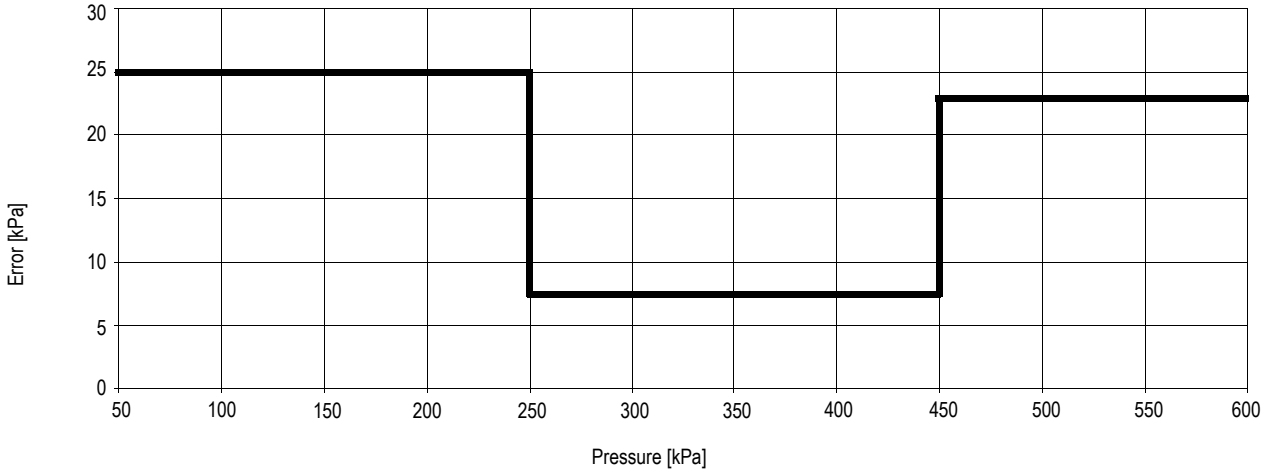

Figure 9. Pressure Error vs Pressure at T = 25°C, 2.7 V ≤ V_{DD} ≤ 3.3 V

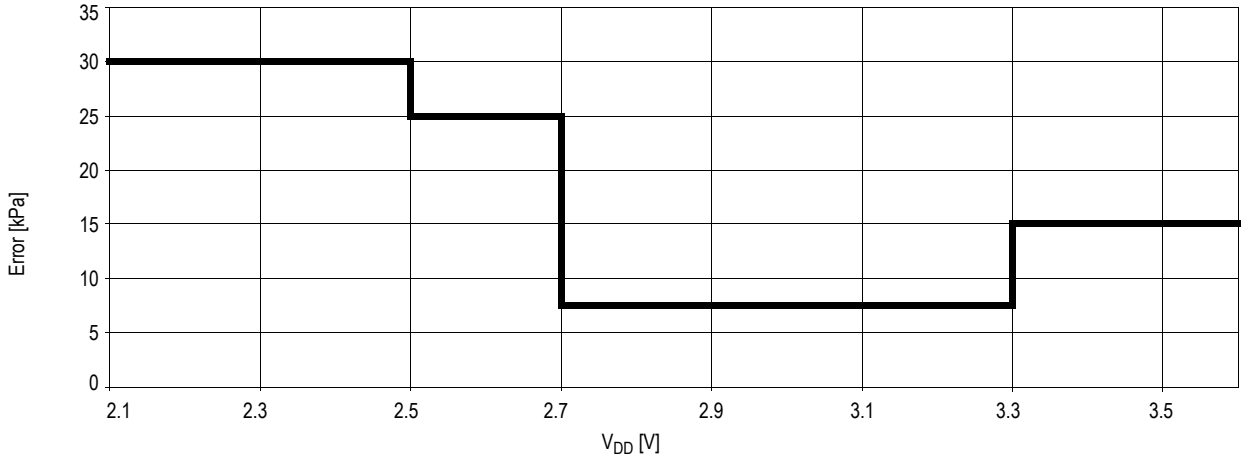

Figure 10. Pressure Error vs V_{DD} at T = 25°C, 250 kPa ≤ P ≤ 450 kPa

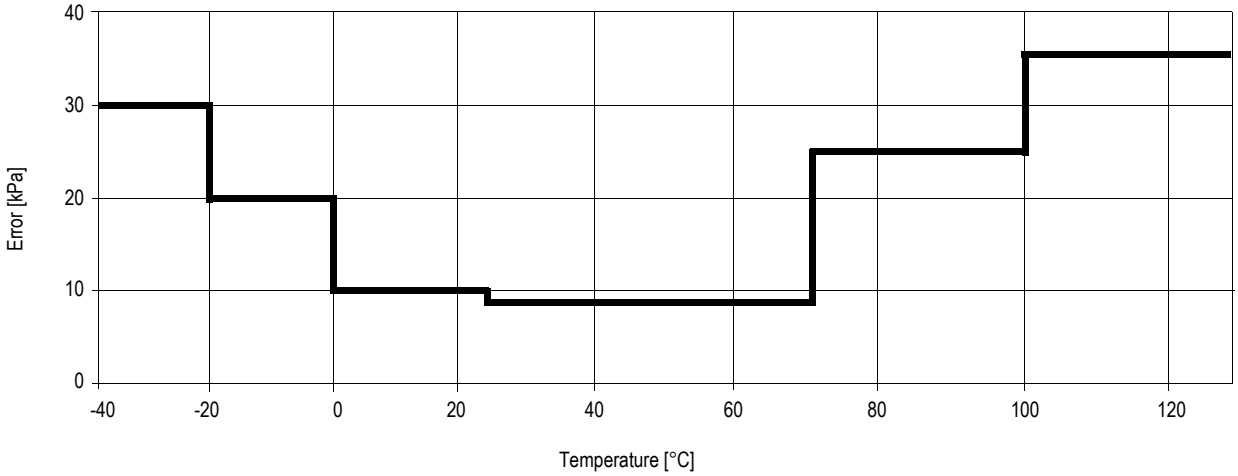

Figure 11. Pressure Error vs Temperature at V_{DD} = 3.0 V, 250 kPa ≤ P ≤ 450 kPa

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MECHANICAL SPECIFICATIONS

Maximum ratings are the extreme limits to which the device can be exposed without permanently damaging it.

Keep V_{IN} and V_{OUT} within the range $V_{SS} \le (V_{IN}$ or $V_{OUT}) \le V_{DD}$.

Table 7. Maximum Ratings

Rating	Symbol	Value	Unit
Maximum Pressure(1)	p_{max}	1400	kPa(1)
Centrifugal Force Effects (3 axis) Pressure measurement change less than 1% FSS	g_{CENT}	2000	g
Unpowered Shock (three sides, 0.5 mSec duration)	g_{shock}	2000	g

1. Tested for 5 minutes at 25°C.

MEDIA COMPATIBILITY

The Daytona sensor has been designed with the tire pressure application in mind. As such, it has been tested to a variety of media typical of the tire environment. The filter provides limited, but not universal, media protection.

The customer must ensure media compatibility of the Daytona sensor in their application. In particular, it is strongly recommended that the customer design the application such that media does not come in direct contact with the sensor. Module housing design and orientation will play a role in protecting the sensor from direct media exposure. In the event that media does come in contact with the sensor it is desirable that the application minimize the duration and severity of exposure. Media may be forced through the filter by mechanical aspects of the application such as g-forces or rapid pressurization of the tire.

In addition, the customer maintains responsibility to design and carry out reliability testing verifying compatibility of the Daytona sensor with their module design and application.

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Compensating for Nonlinearity in the MPX10 Series Pressure Transducer

by: Carl Demington
Design Engineering

INTRODUCTION

This application note describes a technique to improve the linearity of the Freescale Semiconductor, Inc. MPX10 series (i.e., MPX10, MPXV10, and MPX12 pressure sensors) pressure transducers when they are interfaced to a microprocessor system. The linearization technique allows the user to obtain both high sensitivity and good linearity in a cost effective system.

The MPX10, MPXV10 and MPX12 pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure over the pressure range of 0-10 kPa (0-75 mm Hg). These devices use a unique transverse voltage-diffused silicon strain-gauge which is sensitive to stress produced by pressure applied to a thin silicon diaphragm.

One of the primary considerations when using a pressure transducer is the linearity of the transfer function, since this parameter has a direct effect on the total accuracy of the system, and compensating for nonlinearities with peripheral circuits is extremely complicated and expensive. The purpose of this document is to outline the causes of nonlinearity, the trade-offs that can be made for increased system accuracy, and a relatively simple technique that can be utilized to maintain system performance, as well as system accuracy.

ORIGINS OF NONLINEARITY

Nonlinearity in semiconductor strain-gauges is a topic that has been the target of many experiments and much discussion. Parameters such as resistor size and orientation, surface impurity levels, oxide passivation thickness and growth temperatures, diaphragm size and thickness are all contributors to nonlinear behavior in silicon pressure transducers. The Freescale X-ducer was designed to minimize these effects. This goal was certainly accomplished in the MPX2000 series which have a maximum nonlinearity of 0.1percent FS. However, to obtain the higher sensitivity of the MPX10 series, a maximum nonlinearity of ±1percent FS has to be allowed. The primary cause of the additional nonlinearity in the MPX10 series is due to the stress induced in the diaphragm by applied pressure being no longer linear.

One of the basic assumptions in using semiconductor strain-gauges as pressure sensors is that the deflection of the diaphragm when pressure is applied is small compared to the thickness of the diaphragm. With devices that are very sensitive in the low pressure ranges, this assumption is no longer valid. The deflection of the diaphragm is a considerable percentage of the diaphragm thickness, especially in devices with higher sensitivities (thinner diaphragms). The resulting stresses do not vary linearly with applied pressure. This behavior can be reduced somewhat by increasing the area of the diaphragm and consequently thickening the diaphragm. Due to the constraint, the device is required to have high sensitivity over a fairly small pressure range, and the nonlinearity cannot be eliminated. Much care was given in the design of the MPX10 series to minimize the nonlinear behavior. However, for systems which require greater accuracy, external techniques must be used to account for this behavior.

PERFORMANCE OF AN MPX DEVICE

The output versus pressure of a typical MPX12 along with an end-point straight line is shown in Figure 1. All nonlinearity errors are referenced to the end-point straight line (see data sheet). Notice there is an appreciable deviation from the end-point straight line at midscale pressure. This shape of curve is consistent with MPX10 and MPXV10, as well as MPX12 devices, with the differences between the parts being the magnitude of the deviation from the end-point line. The major tradeoff that can be made in the total device performance is sensitivity versus linearity.

Figure 2 shows the relationship between full scale span and nonlinearity error for the MPX10 series of devices. The data shows the primary contribution to nonlinearity is nonproportional stress with pressure, while assembly and packaging stress (scatter of the data about the line) is fairly small and well controlled. It can be seen that relatively good accuracies (<0.5% FS) can be achieved at the expense of reduced sensitivity, and for high sensitivity the nonlinearity errors increase rapidly. The data shown in Figure 2 was taken at room temperature with a constant voltage excitation of 3.0 volts.

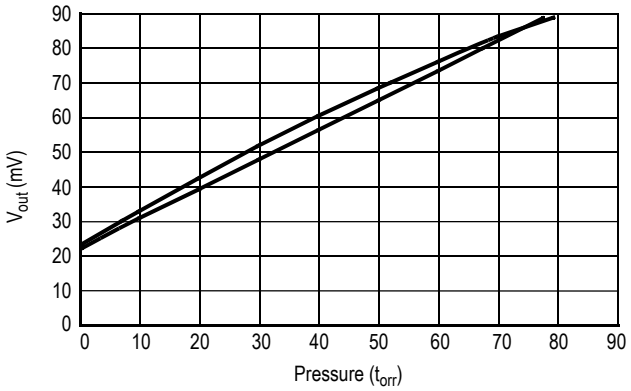

Figure 1. MPX12 Linearity Analysis Raw Data

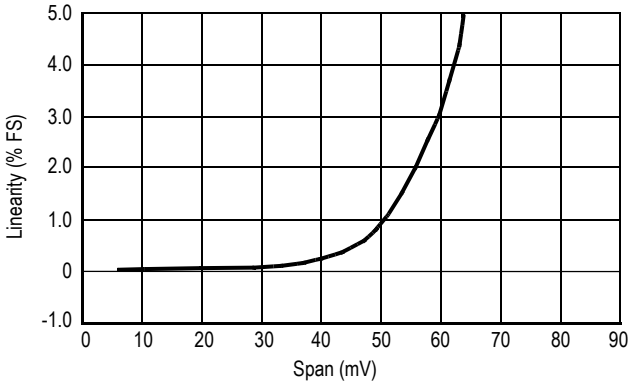

Figure 2. MPX10 Series Span versus Linearity

Compensation for Nonlinearity

The nonlinearity error shown in Figure 1 arises from the assumption that the output voltage changes with respect to pressure in the following manner:

$$V_{out} = V_{off} + sens*P \quad (1)$$

where V_{off} = output voltage at zero pressure differential
sens = sensitivity of the device
P = applied pressure

It is obvious that the true output does not follow this simple straight line equation. Therefore, if an expression could be determined with additional higher order terms that more closely described the output behavior, increased accuracies would be possible. The output expression would then become

$$V_{out} = V_{off} + (B_0 + B_1*P + B_2*P^2 + B_3*P^3 + \ldots) \quad (2)$$

where B_0, B_1, B_2, B_3, etc. are sensitivity coefficients. In order to determine the sensitivity coefficients given in equation (2) for the MPX10 series of pressure transducers, a polynomial regression analysis was performed on data taken from 139 devices with full scale spans ranging from 30 to 730 mV. It was found that second order terms are sufficient to give excellent agreement with experimental data. The calculated regression coefficients were typically 0.999999+ with the worst case being 0.99999. However, these sensitivity coefficients demonstrated a strong correlation with the full scale span of the device for which they were calculated. The correlation of B_0, B_1, and B_2 with full scale span is shown in Figure 3 through Figure 5.

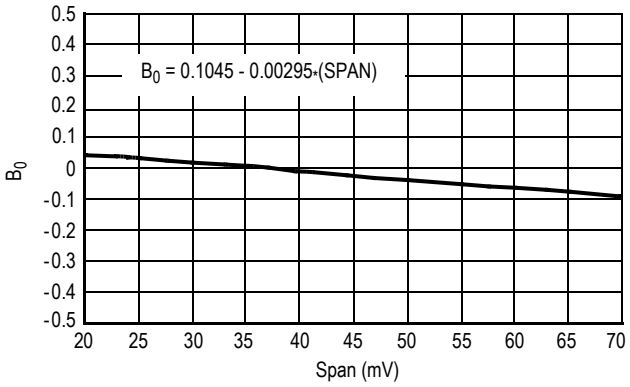

Figure 3. MPX10 Linearity Analysis — Correlation of B_0 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

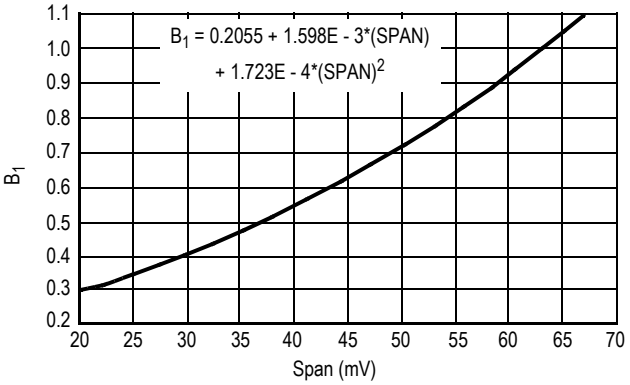

Figure 4. MPX10 Linearity Analysis — Correlation of B_1 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

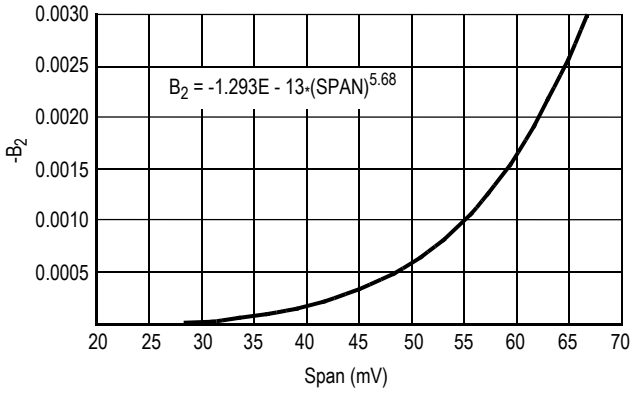

Figure 5. MPX10 Linearity Analysis — Correlation of B_2 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

In order to simplify the determination of these coefficients for the user, further regression analysis was performed so that expressions could be given for each coefficient as a function of full scale span. This would then allow the user to do a single pressure measurement, a series of calculations, and analytically arrive at the equation of the line that describes the output behavior of the transducer. Nonlinearity errors were then calculated by comparing experimental data with the values

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calculated using equation [2] and the sensitivity coefficients given by the regression analysis. The resulting errors are shown in Figure 6 through Figure 9 at various pressure points. While using this technique has been successful in reducing the errors due to nonlinearity, the considerable spread and large number of devices that showed errors >1percent indicate this technique was not as successful as desired.

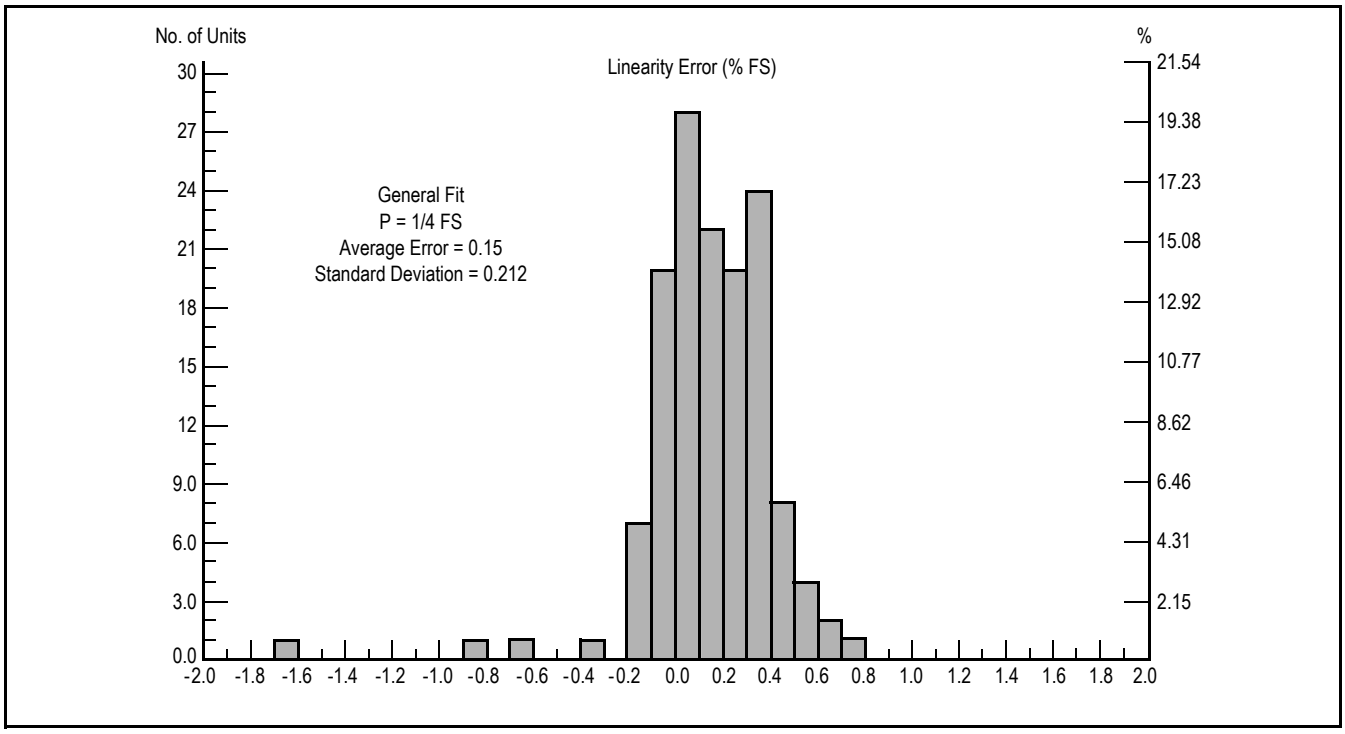

Figure 6. Linearity Error of General Fit Equation at 1/4 FS

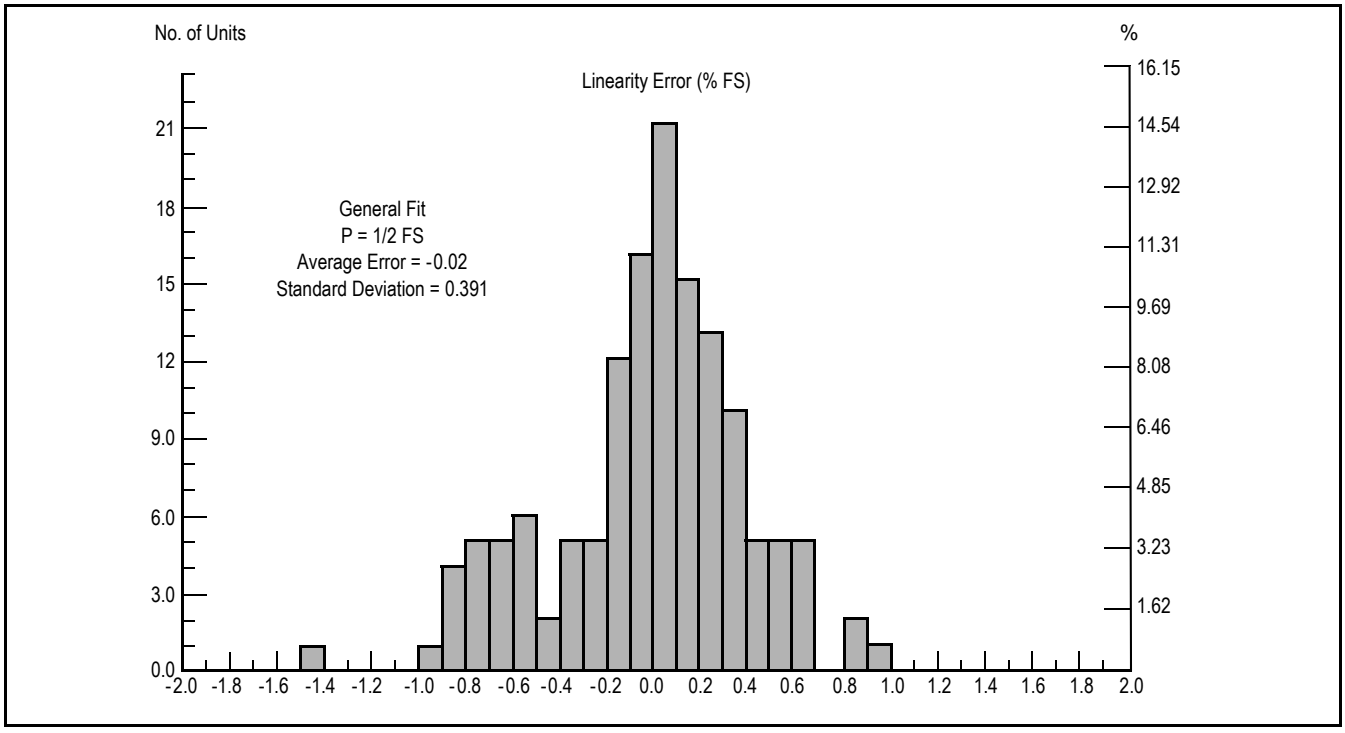

Figure 7. Linearity Error of General Fit Equation at 1/2 FS

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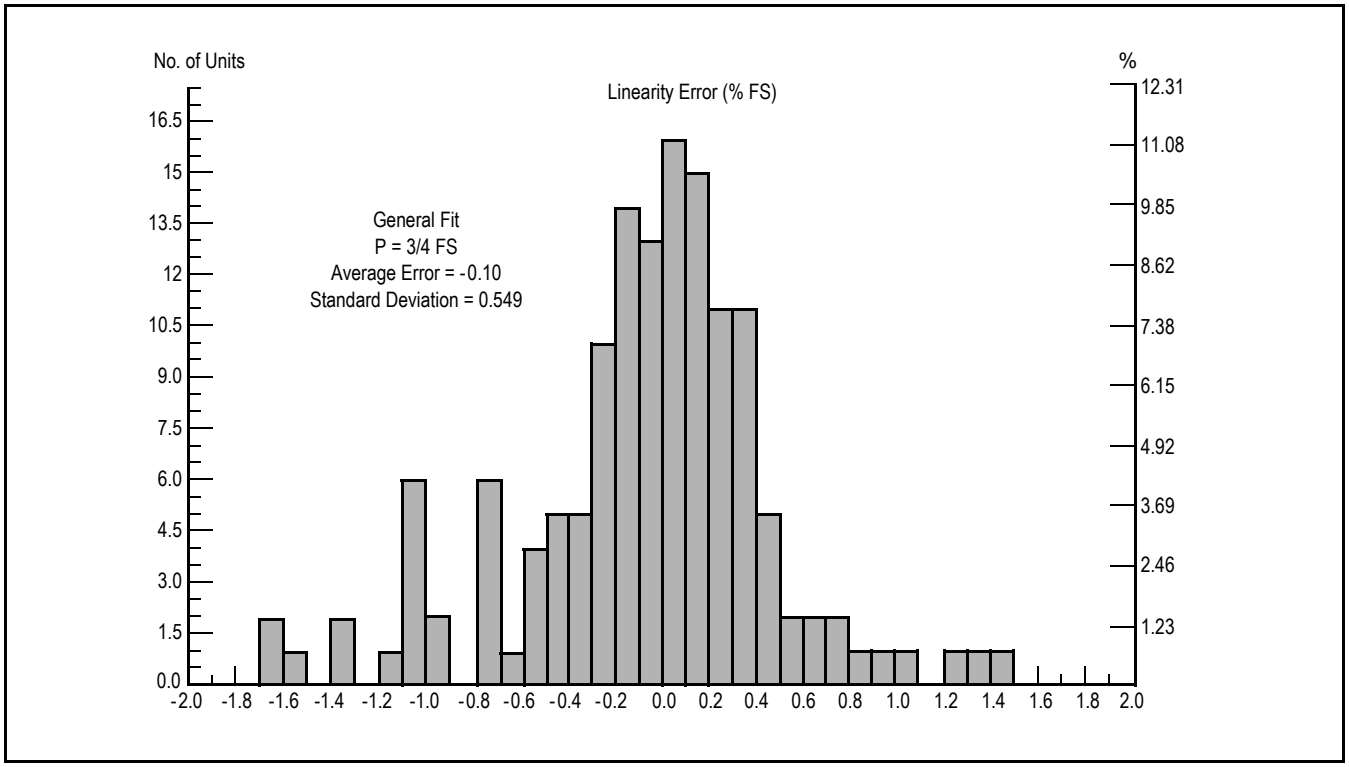

Figure 8. Linearity Error of General Fit Equation at 3/4 FS

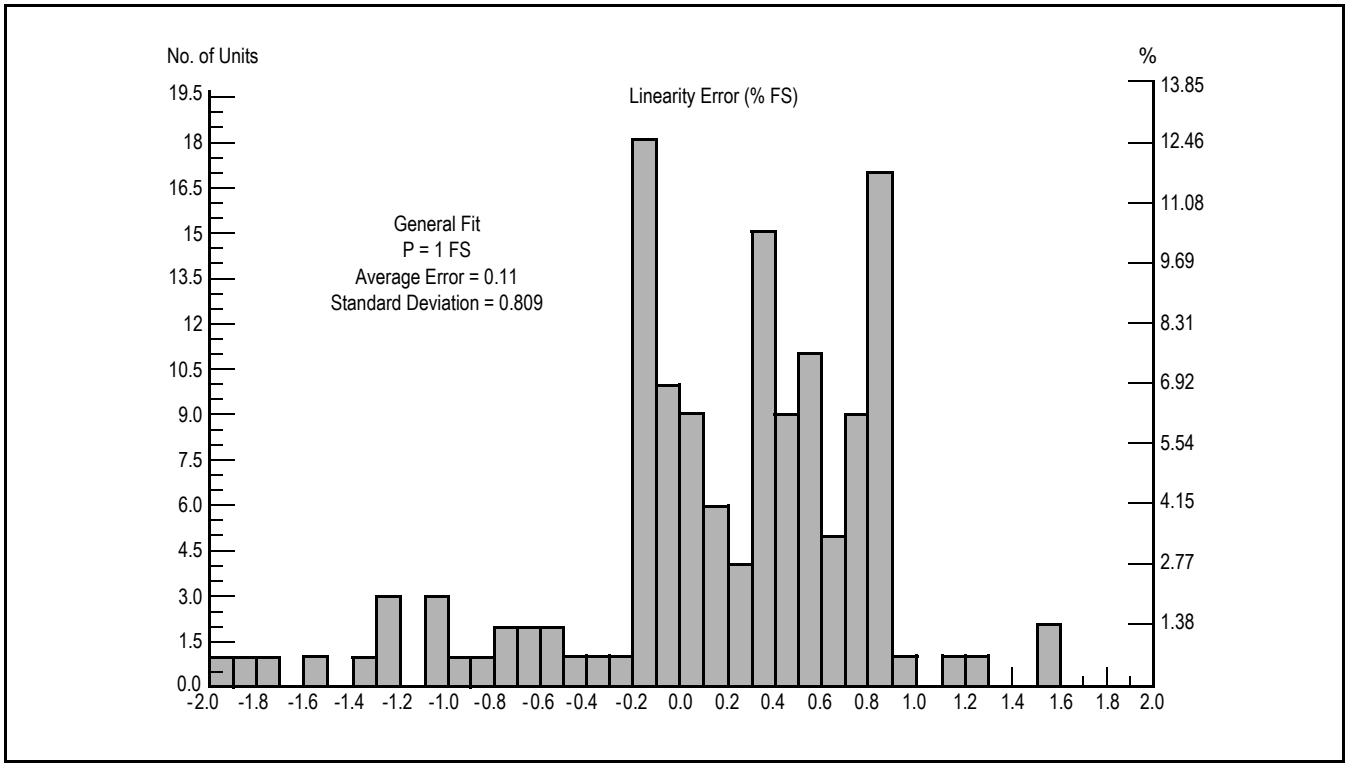

Figure 9. Linearity Error of General Fit Equation at FS

A second technique that still uses a single pressure measurement as the input was investigated. In this method, the sensitivity coefficients are calculated using a piece-wise linearization technique where the total span variation is divided into four windows of 10 mV (i.e., 30-39.99, 40-49.99, etc.) and coefficients calculated for each window. The errors that arise out of using this method are shown in Figure 10 through Figure 13. This method results in a large majority of the devices having errors <0.5%, while only one of the devices was >1%. The sensitivity coefficients that are substituted into equation [2] for the different techniques are given in Table 1. It is important to note that for either technique the only measurement that is required by the user in order to clearly determine the sensitivity coefficients is the determination of the full scale span of the particular pressure transducer.

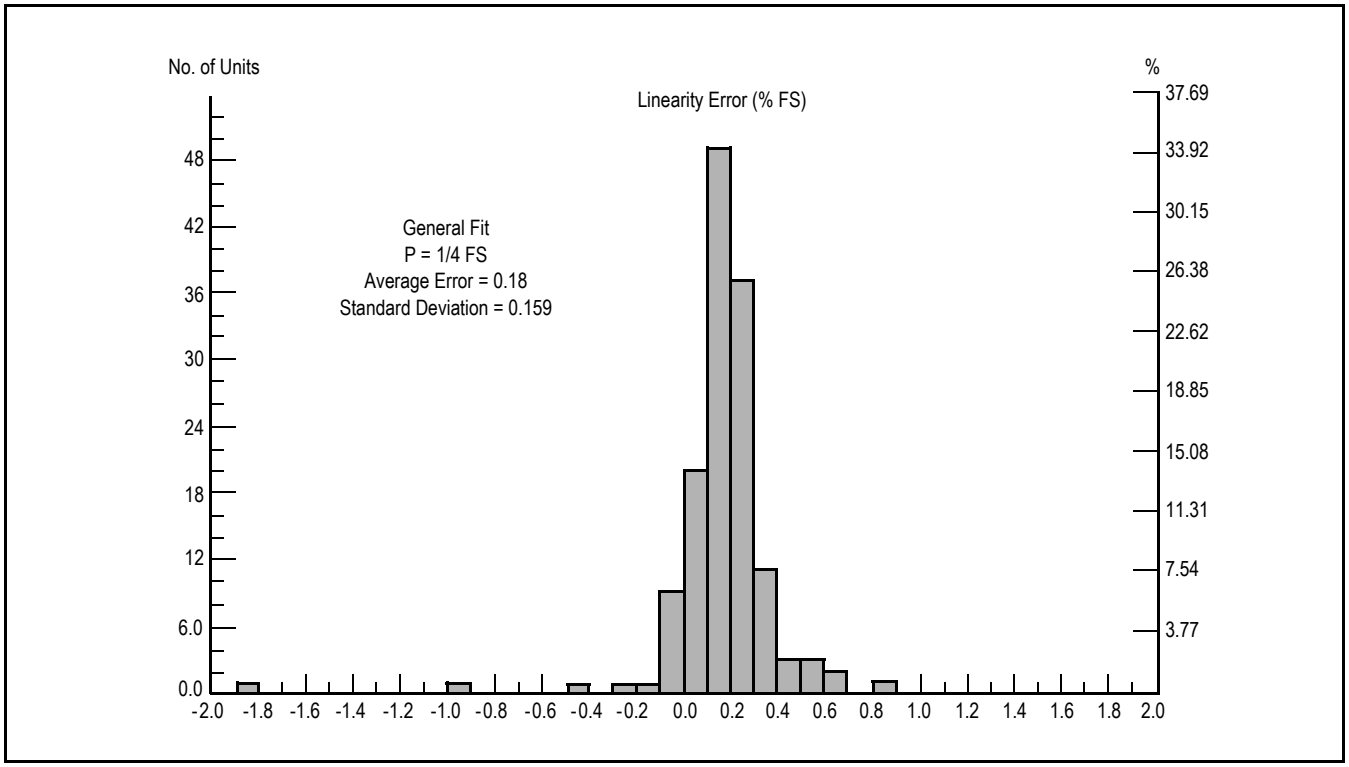

Figure 10. Linearity Error of Piece-Wise Linear Fit at 1/4 FS

Table 1. Comparison of Linearization Methods

Span Window	B_0	B_1	B_2
	General Fit		
	0.1045 + 2.95E - 3X	0.2055 + 1.598E - 3X + 1.723E - $4X^2$	1.293E - $13X^{5.681}$
	Piece-Wise Linear Fit		
30-39.99	0.08209 - 2.246E - 3X	0.02433 = 1.430E - 2X	-1.961E - 4 + 8.816E - 6X
40-49.99	0.1803 - 4.67E - 3X	-0.119 + 1.655E - 2X	-1.572E - 3 + 4.247E - 5X
50-59.99	0.1055 - 3.051E - 3X	-0.355 + 2.126E - 2X	-5.0813 - 3 + 1.116E - 4X
60-69.99	-0.288 + 3.473E - 3X	-0.361 + 2.145E - 2X	-5.928E - 3 + 1.259E - 4X

X = Full Scale Span

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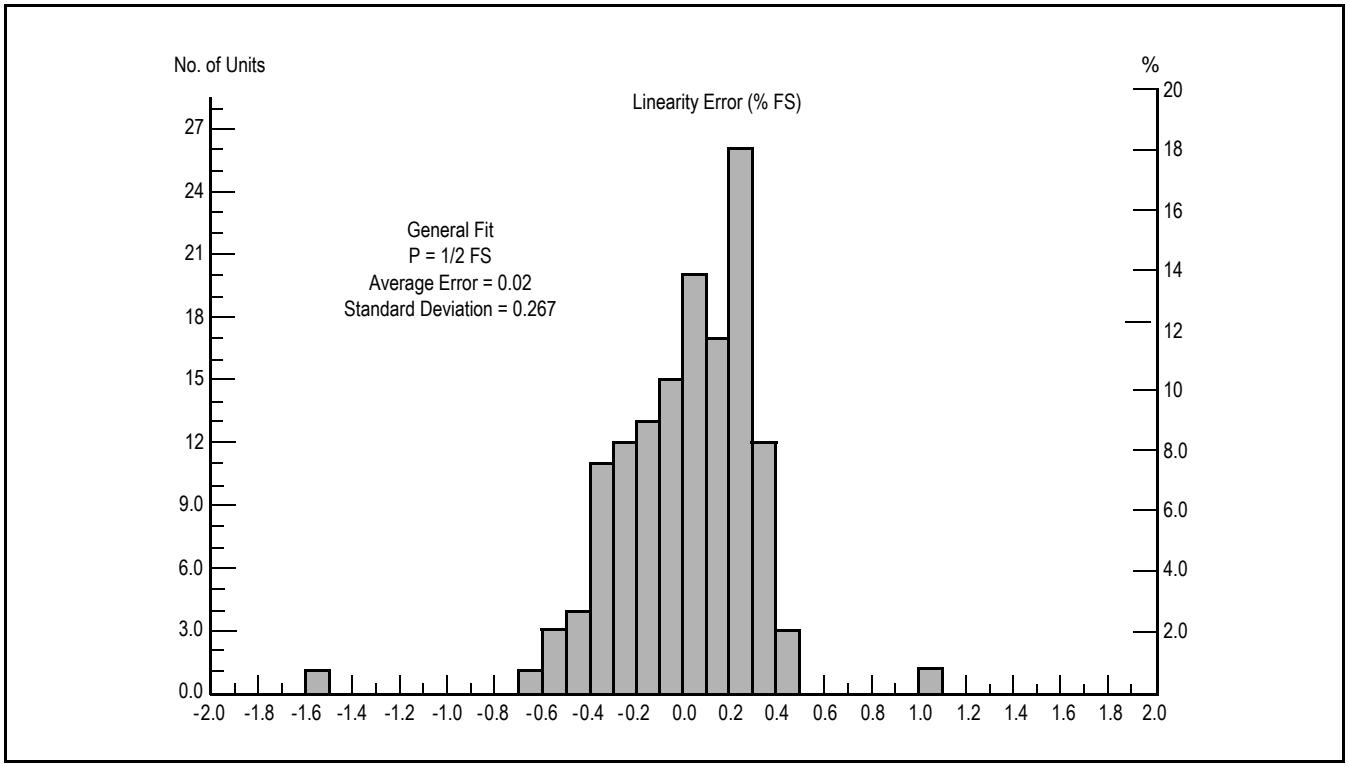

Figure 11. Linearity Error of Piece-Wise Linear Fit at 1/2 FS

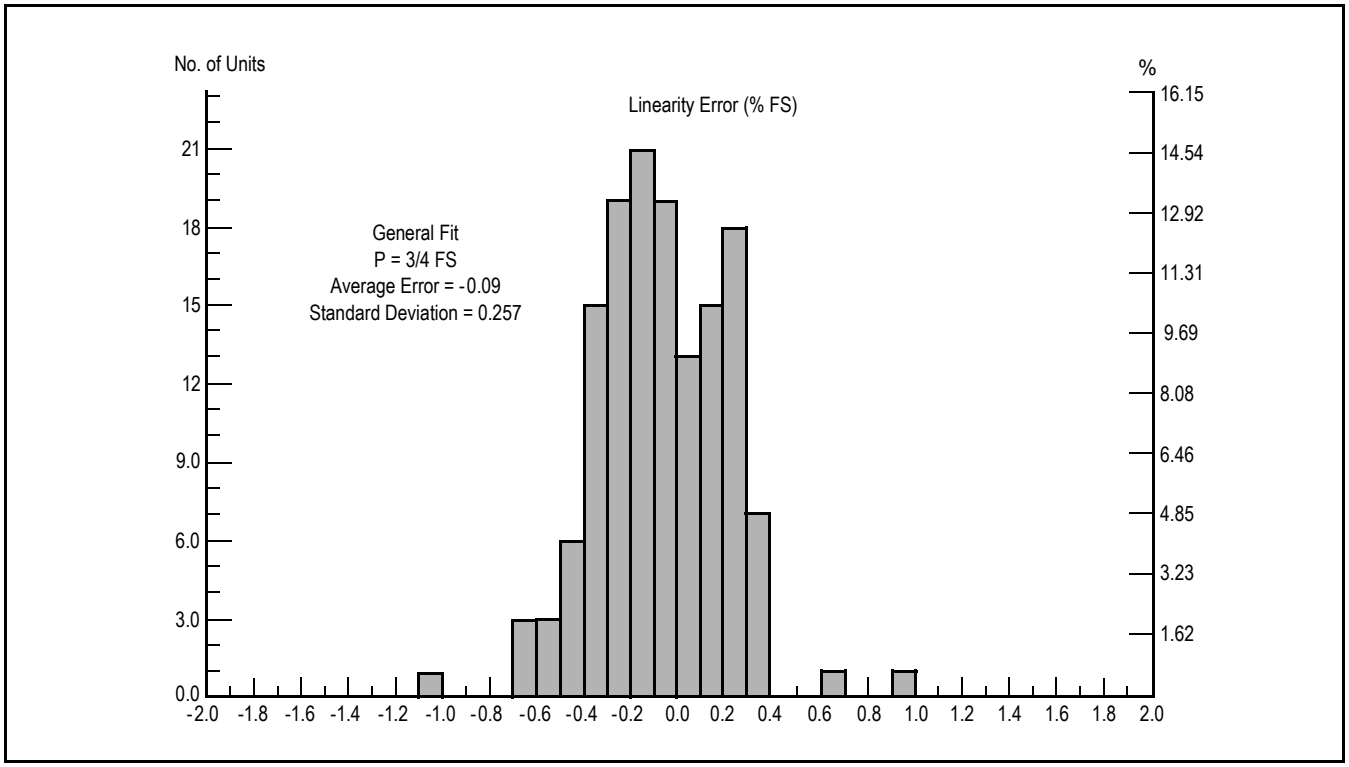

Figure 12. Linearity Error of Piece-Wise Linearity Fit at 3/4 PS

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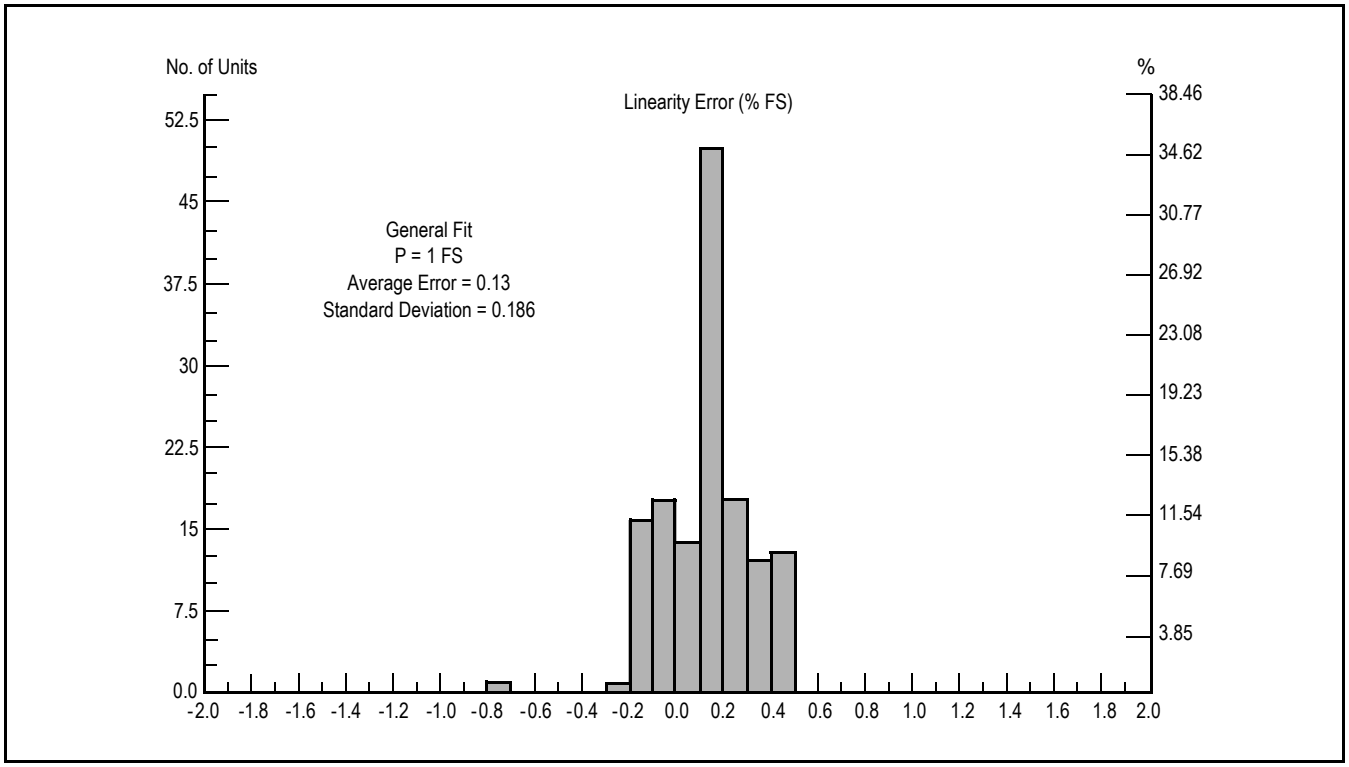

Figure 13. Linearity Error of Piece-Wise Linear Fit at FS

Once the sensitivity coefficients have been determined, a system can then be built that provides an accurate output function with pressure. The system shown in Figure 14 consists of a pressure transducer, a temperature compensation and amplification stage, an A/D converter, a microprocessor, and a display. The display block can be replaced with a control function if required. The A/D converter simply transforms the voltage signal to an input signal for the microprocessor, in which resides the look-up table of the transfer function generated from the previously determined sensitivity coefficients. The microprocessor can then drive a display or control circuit using standard techniques.

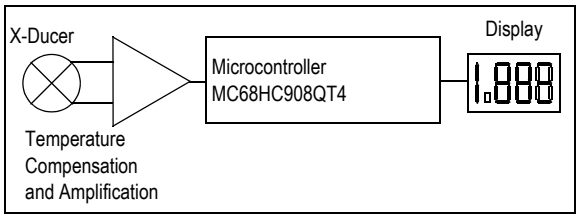

Figure 14. Linearization System Block Diagram

SUMMARY

While at first glance this technique appears to be fairly complicated, it can be a very cost effective method of building a high-accuracy, high-sensitivity pressure-monitoring system for low-pressure ranges.

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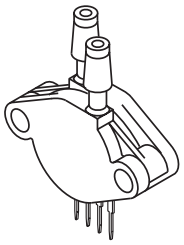
Mounting Techniques, Lead Forming, and Testing of the MPX Series Pressure Sensors

by: Randy Frank

INTRODUCTION

The Freescale Semiconductor, Inc. MPX series pressure sensors are silicon piezoresistive strain-gauges offered in a chip-carrier package (see Figure 1). The exclusive chip-carrier package was developed to realize the advantages of high-speed, automated assembly and testing. In addition to high volume availability and low cost, the chip-carrier package offers users a number of packaging options. This application note describes several mounting techniques, offers lead forming recommendations, and suggests means of testing the MPX series of pressure sensors.



Differential Port Option
Case 344C-01

Figure 1. MPX Pressure Sensor in Chip Carrier Package Shown with Port Options

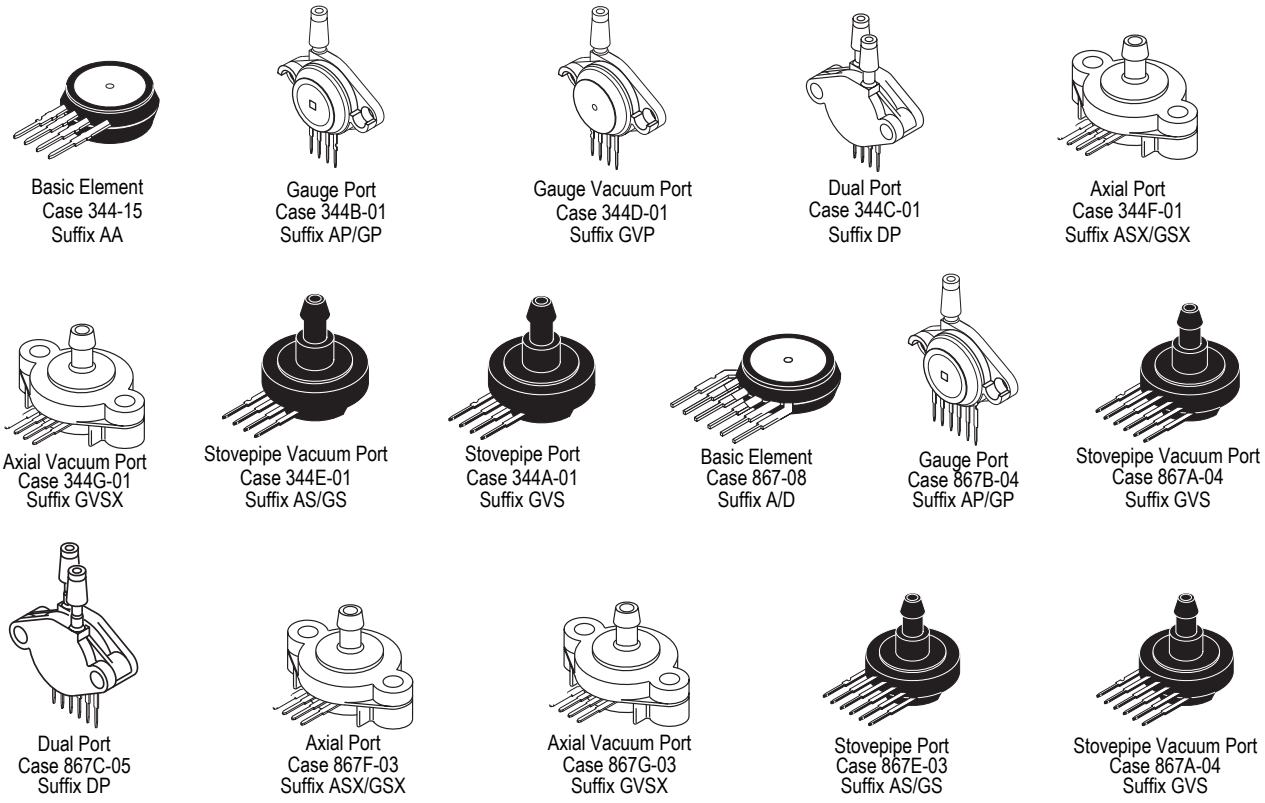


Figure 2. Chip Carrier and Available Ported Packages

PORT ADAPTERS

Available Packages

Freescale's chip-carrier package and available ports for attachment of 1/8ð I.D. hose are made from a high temperature thermoplastic that can withstand temperature extremes from -50°C to 150°C (see Figure 2). The port adapters were designed for rivet or 5/32″ screw attachment to panels, printed circuit boards, or chassis mounting.

Custom Port Adaptor Installation Techniques

The MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer-specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 3 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, 30 percent glass reinforced polyester resin plastic or Union Carbide's Udel® polysulfone (MPX2300DT1 only). Freescale recommends using Thermoset EP530 epoxy or an equivalent. The epoxy should be dispensed in a continuous bead around the case-to-port interface shoulder. Refer to Figure 4. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. The recommended cure conditions for Thermoset EP539 are 15 minutes at 150°C. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for five seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication.

TESTING MPX SERIES PRESSURE SENSORS

Pressure Connection

Testing of pressure sensing elements in the chip carrier package can be performed easily by using a clamping fixture which has an O-ring seal to attach to the beveled surface. Figure 8 shows a diagram of the fixture that Freescale uses to apply pressure or vacuum to unported elements.

When performing tests on packages with ports, a high durometer tubing is necessary to minimize leaks, especially in higher pressure range sensors. Removal of tubing must be parallel to the port since large forces can be generated to the pressure port which can break the nozzle if applied at an angle. Whether sensors are tested with or without ports, care must be exercised so that force is not applied to the back metal cap or offset errors can result.

STANDARD PORT ATTACH CONNECTION

Freescale also offers standard port options designed to accept readily available silicone, vinyl, nylon, or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Freescale's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

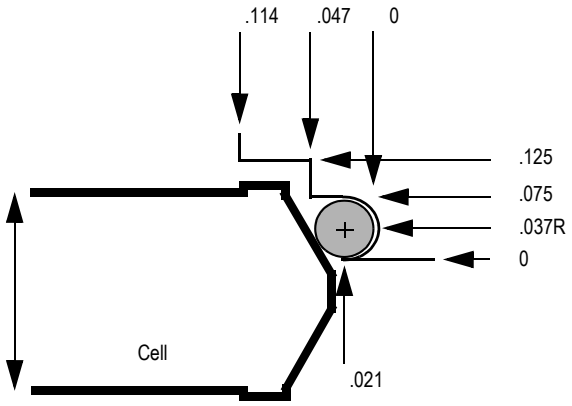


Figure 3. Examples of Sensors in Custom Housings

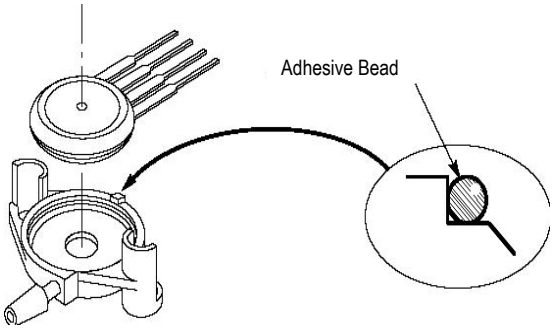


Figure 4. Case to Port Interface

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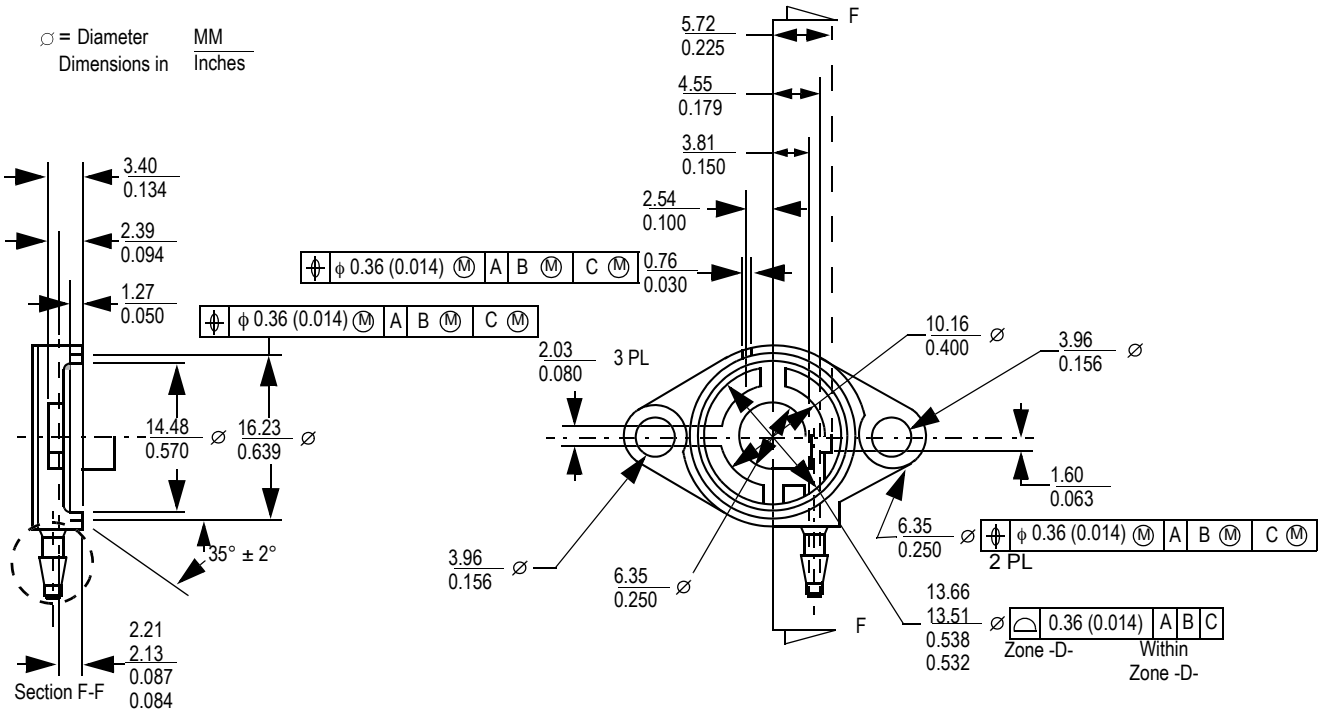
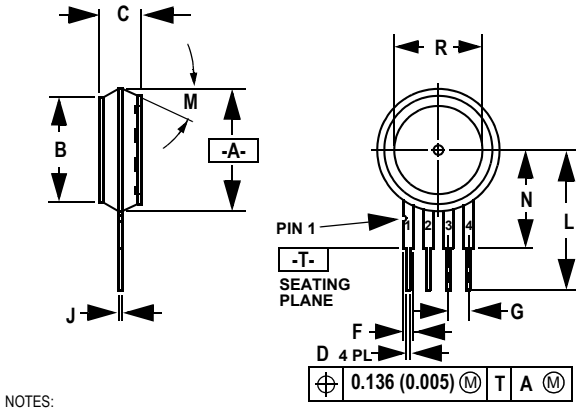


Figure 5. Port Adapter Dimensions



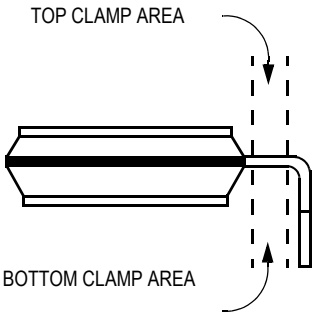
NOTES:
DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
CONTROLLING DIMENSION: INCH.
DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

STYLE 1:
PIN 1.GROUND
2.+ OUTPUT
3.+ SUPPLY
4.- OUTPUT

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30 NOM		30 NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43

Case 344-15
All seals to be made on pressure sealing surface.

Figure 6. Chip-Carrier Package



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 7. Leadforming

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Electrical Connection

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or “needlenose” pliers should never be used for leadforming unless they are specifically designed for that purpose. Refer to Figure 7 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL. The part numbers for the housing and pins are listed below.

CONCLUSION

Freescale’s MPX series pressure sensors in the chip carrier package provide the design engineer several packaging alternatives. They can easily be tested with or without pressure ports using the information provided.

CONNECTORS FOR CHIP CARRIER PACKAGES

MFG/Address/Phone	Connector	Pin
J. S. Terminal Cop. 1200 Business Center Dr. Mount Prospect, IL 60056 (800) 292-4243	4 Pin Housing: SMP-04V-BCS 6 Pin Housing: SMP-06V-BC Hand Crimper YC-12 Recommended	SHF-001T-0.8SS SHF-01T-0.8SS
Methode Electronics, Inc. Rollling Meadows, IL 60008 (312) 392-3500	1300-004 Requires Hand Crimper	1400-213 1402-213 1402-214 Reel

TERMINAL BLOCKS

Molex 2222 Wellington Court Lisle, IL 60532 (312) 969-4550	22-18-2043 22-16-2041	
Samtec P.O. Box 1147 New Albany, IN 47150 (812) 944-6733	SSW-104-02-G-S-RA SSW-104-02-G-S	

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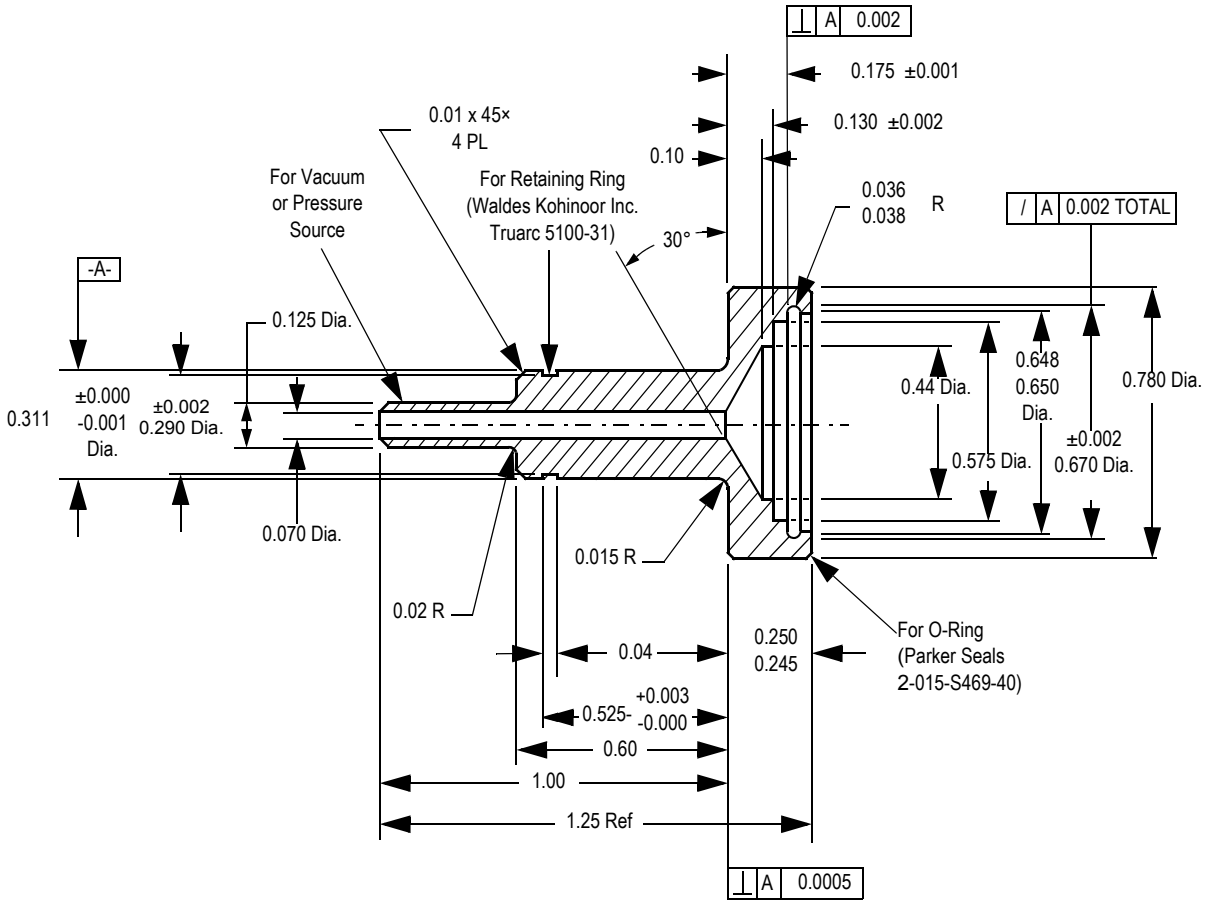

Figure 8. O-Ring Test Fixture

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Simple Design for a 4-20 mA Transmitter Interface Using a Pressure Sensor

by: Jean Claude Hamelain
Toulouse Application Lab Manager

INTRODUCTION

Pressure is a very important parameter in most industrial applications such as air conditioning, liquid level sensing and flow control.

In most cases, the sensor is located close to the measured source in a very noisy environment, far away from the receiver (recorder, computer, automatic controller, etc.)

The transmission line can be as long as a few hundred meters and is subject to electromagnetic noise when the signal is transmitted as voltage. If the signal is transmitted as a current it is easier to recover at the receiving end and is less affected by the length of the transmission line.

The purpose of this note is to describe a simple circuit which can achieve high performance, using standard pressure sensors, operational amplifiers and discrete devices.

PERFORMANCES

The following performances have been achieved using an MPXV2102DP pressure sensor and an MC33079 quad operational amplifier. The MPXV2102DP is a 100 kPa temperature compensated differential pressure sensor. The load is a 150 ohm resistor at the end of a 50 meter telephone line. The 15 volt power supply is connected at the receiver end.

Power Supply	+15 Vdc, 30 mA
Connecting Line	3 wire telephone cable
Load Resistance	150 to 400 Ohms
Temperature Range	-40 to +85°C (up to +125°C with special hardware)
Pressure Range	0 to 100 kPa
Total Maximum Error	Better than 2% full scale

Basic Circuit

The MPXV2102DP pressure sensor is a very high performance piezoresistive pressure sensor. Manufacturing technologies include standard bipolar processing techniques with state of the art metallization and on-chip laser trim for offset and temperature compensation.

This unique design, coupled with computer laser trimming, gives this device excellent performance at competitive cost for demanding applications such as automotive, industrial or healthcare.

MC33078, 79 operational amplifiers are specially designed for very low input voltage, a high output voltage swing and very good stability versus temperature changes.

First Stage

The MPXV2102 and the operational amplifier are directly powered by the 15 Vdc source. The first stage is a simple true differential amplifier made with both of the operational amplifiers in the MC33078. The potentiometer, R_G, provides adjustment for the output.

Current Generator

The voltage to current conversion is made with a unity gain differential amplifier, one of the four operational amplifiers in an MC33079. The two output connections from the first stage are connected to the input of this amplifier through R3 and R5. Good linearity is achieved by the matching between R3, R4, R5 and R6, providing a good common mode rejection. For the same reason, a good match between resistors R8 and R9 is needed.

The MC33078 or MC33079 has a limited current output; therefore, a 2N2222 general purpose transistor is connected as the actual output current source to provide a 20 mA output.

To achieve good performance with a very long transmission line it may be necessary to place some capacitors (C1, C2) between the power supply and output to prevent oscillations.

Calibration

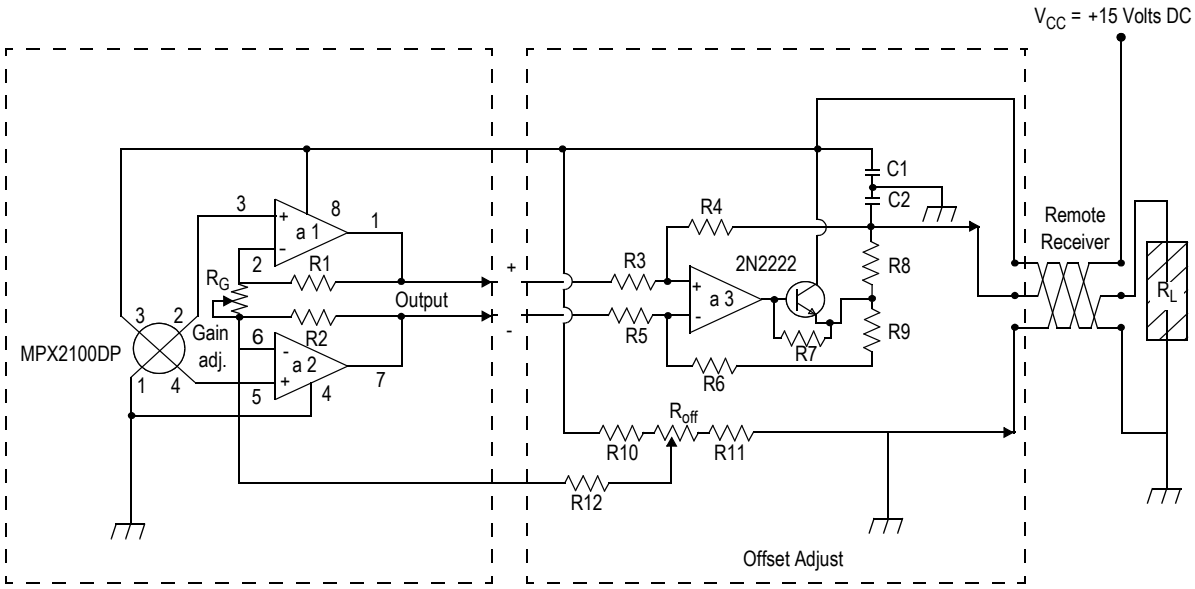
The circuit is electrically connected to the 15 Vdc power supply and to the load resistor (receiver).

The high pressure is connected to the pressure port and the low pressure (if using a differential pressure sensor), is connected to the vacuum port.

It is important to perform the calibration with the actual transmission line connected.

The circuit needs only two adjustments to achieve the 4-20mA output current.

1. With no pressure (zero differential pressure), adjust R_{off} to read exactly 4 mA on the receiver.
2. Under the full scale pressure, adjust R_G to exactly read 20 mA on the receiver. The calibration is now complete.



R_G = 47 K Pot.
R_{off} = 1 M Pot.
* R1 = R2 = 330 K
* R3 = R4 = 27 K
* R5 = R6 = 27 K
* R8 = R9 = 150
* All resistor pairs must be matched at better than 0.5%

R7 = 1 K
R10 = 110 K
R11 = 1 M
R12 = 330 K
C1 = C2 = 0.1 μF
a1, a2, a3 = 1/4 MC33079

Note A: If using SEK-1 a1, a2, a3 = 1/2 MC33078
R_G from 20 K to 47 K
R1 and R2 from 1M to 330 K

NOTE: The pressure sensor output is ratiometric to the power supply voltage. The output will change with the same ratio as voltage change.

Figure 1. Demo Kit with 4-20 mA Current Loop

The output is ratiometric to the power supply voltage. For example, if the receiver reads 18 mA at 80 kPa and 15 V power supply, the receiver should read 16.8 mA under the same pressure with 14 V power supply.

For best results it is mandatory to use a regulated power supply. If that is not possible, the circuit must be modified by inserting a 12 V regulator to provide a constant supply to the pressure sensor.

When using a MC78L12AC voltage regulator, the circuit can be used with power voltage variation from 14 to 30 volts.

The following results have been achieved using an MPX2100DP and two MC33078s. The resistors were regular carbon resistors, but pairs were matched at ±0.3% and capacitors were 0.1 μF. The load was 150 ohms and the transmission line was a two pair telephone line with the +15 Vdc power supply connected on the remote receiver side.

Note: Best performances in temperature can be achieved using metal film resistors. The two potentiometers must be chosen for high temperatures up to 125°C.

The complete circuit with pressure sensor is available under reference TZA120 and can be ordered as a regular product for evaluation.

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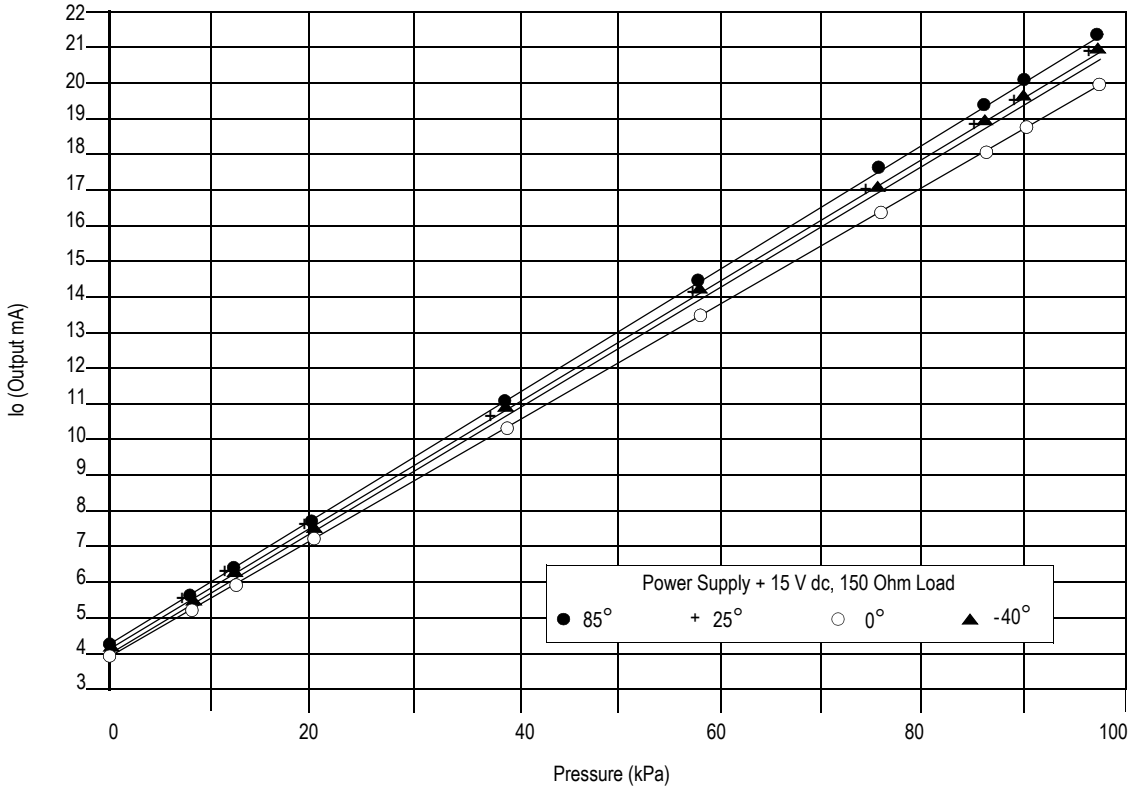

Figure 2. Output versus Pressure

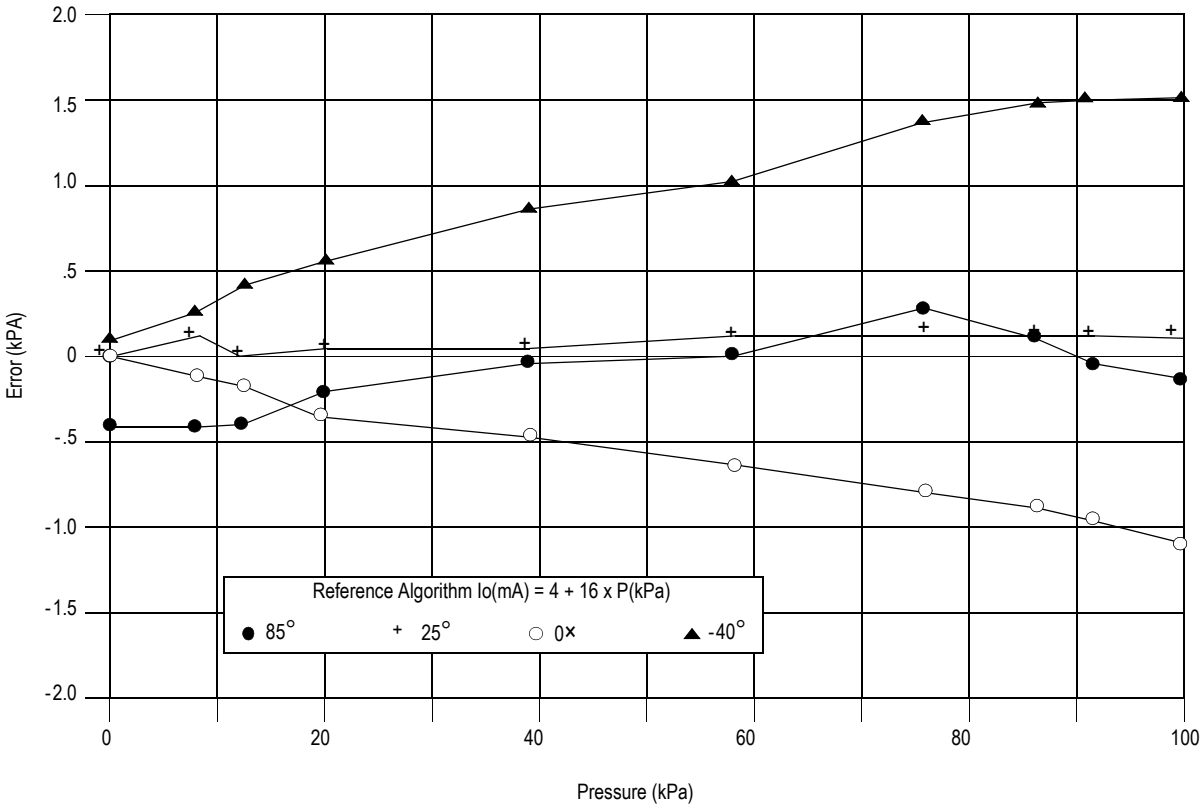

Figure 3. Absolute Error Reference to Algorithm

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Calibration-Free Pressure Sensor System

by: **Michel Burri, Senior System Engineer**
Geneva, Switzerland

INTRODUCTION

The MPX2000 series pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure. The sensors are a single monolithic silicon diaphragm with strain gauge and thin-film resistor networks on the chip. Each chip is laser trimmed for full scale output, offset, and temperature compensation.

The purpose of this document is to describe another method of measurement which should facilitate the life of the design. The MPX2000 series sensors are available both as unported elements and as ported assemblies suitable for pressure, vacuum and differential pressure measurements in the range of 10 kPa through 200 kPa.

The use of the on-chip A/D converter of the MC68HC05B6 HCMOS MCU makes possible the design of an accurate and reliable pressure measurement system.

SYSTEM ANALYSIS

The measurement system is made up of the pressure sensor, the amplifiers, and the MCU. Each element in the chain has its own device-to-device variations and temperature effects which should be analyzed separately. For instance, the 8-bit A/D converter has a quantization error of about ±0.2 percent. This error should be subtracted from the maximum error specified for the system to find the available error for the rest of elements in the chain. The MPX2000 series pressure sensors are designed to provide an output sensitivity of 4.0 mV/V excitation voltage with full-scale pressure applied or 20 mV at the excitation voltage of 5.0 V_{DC}.

An interesting property must be considered to define the configuration of the system: the ratiometric function of both the A/D converter and the pressure sensor device. The ratiometric function of these elements makes all voltage variations from the power supply rejected by the system. With this advantage, it is possible to design a chain of amplification where the signal is conditioned in a different way.

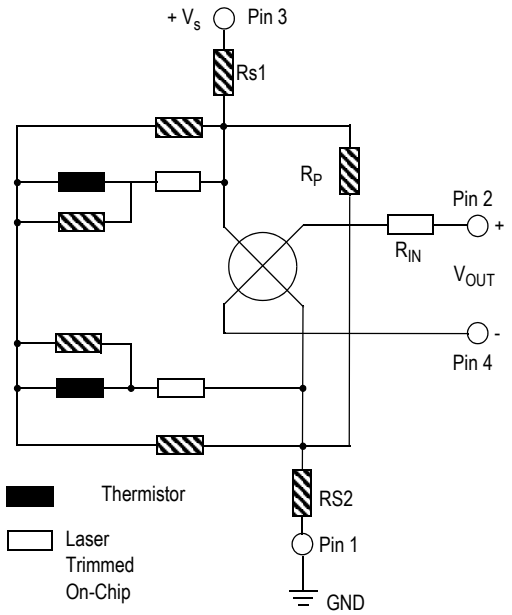

Figure 1. Seven Laser-Trimmed Resistors and Two Thermistors Calibrate the Sensor for Offset, Span, Symmetry and Temperature Compensation

The op amp configuration should have a good common-mode rejection ratio to cancel the DC component voltage of the pressure sensor element which is about half the excitation voltage value V_S. Also, the op amp configuration is important when the designer's objective is to minimize the calibration procedures which cost time and money and often don't allow the unit-to-unit replacement of devices or modules.

One other aspect is that most of the applications are not affected by inaccuracy in the region from 0 kPa to 40 kPa. Therefore, the goal is to obtain an acceptable tolerance of the system from 40 kPa through 100 kPa, thus minimizing the inherent offset voltage of the pressure sensor.

PRESSURE SENSOR CHARACTERISTICS

Figure 2 shows the differential output voltage of the MPX2100 series at +25°C. The dispersion of the output voltage determines the best tolerance that the system may

achieve without undertaking a calibration procedure, if any other elements or parameters in the chain do not introduce additional errors.

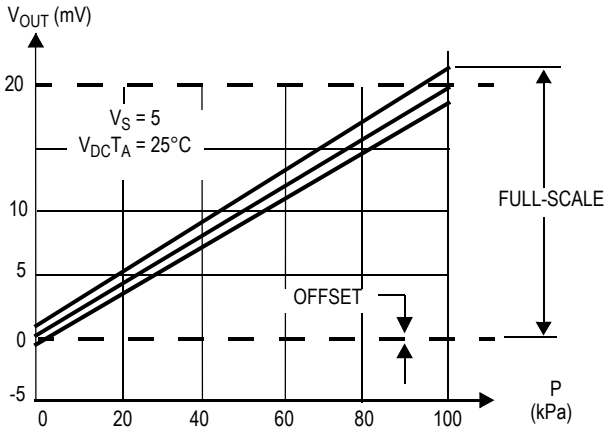

Figure 2. Spread of the Output Voltage versus the Applied Pressure at 25°C

The effects of temperature on the full scale output and offset are shown in Figure 3. It is interesting to notice that the offset variation is greater than the full scale output and both have a positive temperature coefficient respectively of +8.0 μV/degree and +5.0 μV excitation voltage. That means that the full scale variation may be compensated by modifying the gain somewhere in the chain amplifier by components arranged to produce a negative T_C of 250 PPM/°C. The dark area of Figure 3 shows the trend of the compensation which improves the full scale value over the temperature range. In the area of 40 kPa, the compensation acts in the ratio of 40/100 of the value of the offset temperature coefficient.

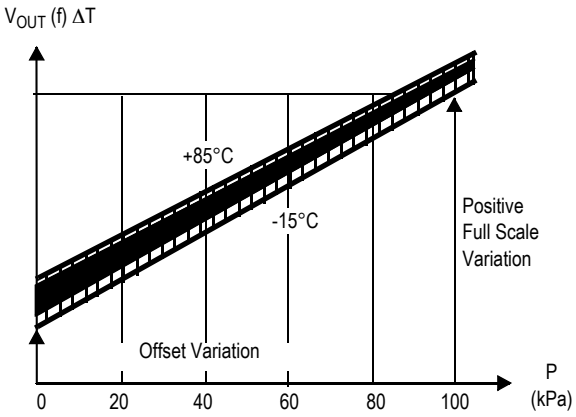

Figure 3. Output Voltage versus Temperature. The Dark Area Shows the Trend of the Compensation

OP AMP CHARACTERISTICS

For systems with only one power supply, the instrument amplifier configuration shown in Figure 4 is a good solution to monitor the output of a resistive transducer bridge.

The instrument amplifier does provide an excellent CMRR and a symmetrical buffered high input impedance at both non-inverting and inverting terminals. It minimizes the number of the external passive components used to set the gain of the amplifier. Also, it is easy to compensate the temperature variation of the Full Scale Output of the Pressure Sensor by implementing resistors "R_f" having a negative coefficient temperature of -250 PPM/°C.

The differential-mode voltage gain of the instrument amplifier is:

$$Avd = \frac{V1-V2}{Vs2-Vs4} = \left(1 + \frac{2\,R_f}{R_g}\right) \quad (1)$$

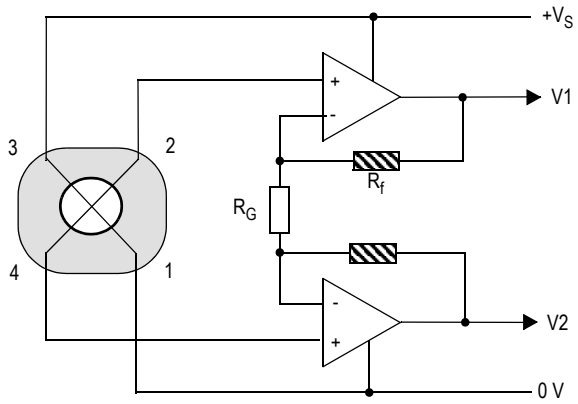

Figure 4. One Power Supply to Excite the Bridge and to Develop a Differential Output Voltage

The major source of errors introduced by the op amp is offset voltages which may be positive or negative, and the input bias current which develops a drop voltage ΔV through the feedback resistance R_f. When the op amp input is composed of PNP transistors, the whole characteristic of the transfer function is shifted below the DC component voltage value set by the Pressure Sensor as shown in Figure 5.

The gain of the instrument amplifier is calculated carefully to avoid a saturation of the output voltage, and to provide the maximum of differential output voltage available for the A/D Converter. The maximum output swing voltage of the amplifiers is also dependent on the bias current which creates a ΔV voltage on the feedback resistance R_f and on the Full Scale output voltage of the pressure sensor.

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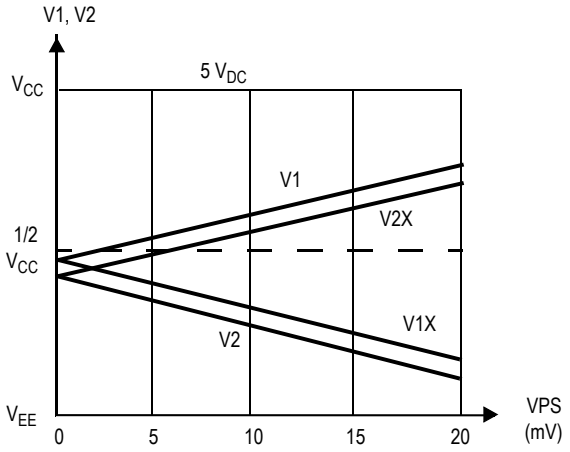

Figure 5. Instrument Amplifier Transfer Function with Spread of the Device to Device Offset Variation

Figure 5 shows the transfer function of different instrument amplifiers used in the same application. The same sort of random errors are generated by crossing the inputs of the instrument amplifier. The spread of the differential output voltage (V1-V2) and (V2x-V1x) is due to the unsigned voltage offset and its absolute value. Figure 6 and Figure 7 show the unit-to-unit variations of both the offset and the bias current of the dual op amp MC33078.

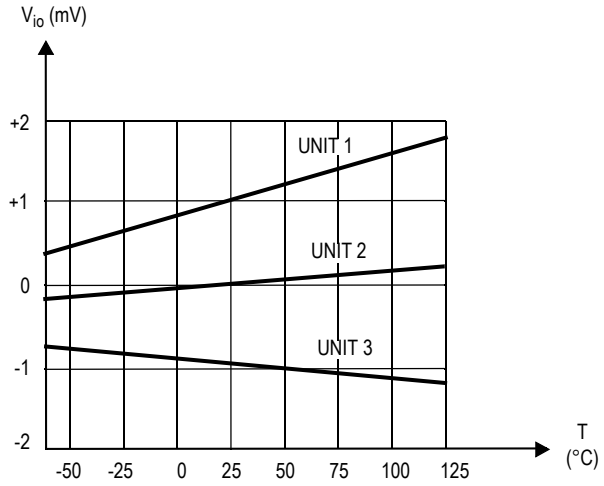

Figure 6. Input Offset Voltage versus Temperature

To realize such a system, the designer must provide a calibration procedure which is very time consuming. Some extra potentiometers must be implemented for setting both the offset and the Full Scale Output with a complex temperature compensation network circuit.

The new proposed solution will reduce or eliminate any calibration procedure.

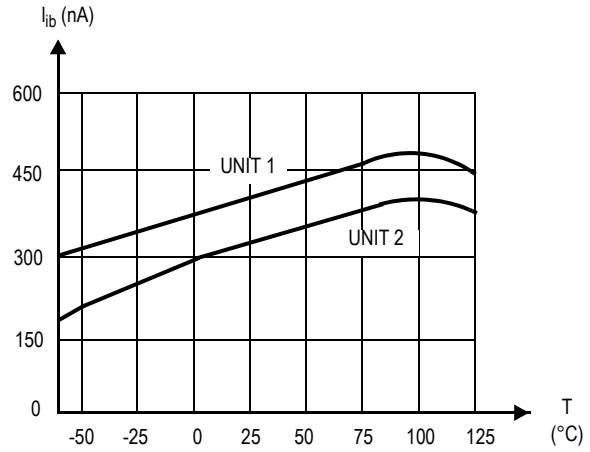

Figure 7. Input Bias Current versus Temperature

MCU CONTRIBUTION

As shown in Figure 5, crossing the instrument amplifier inputs generated their mutual differences which can be computed by the MCU.

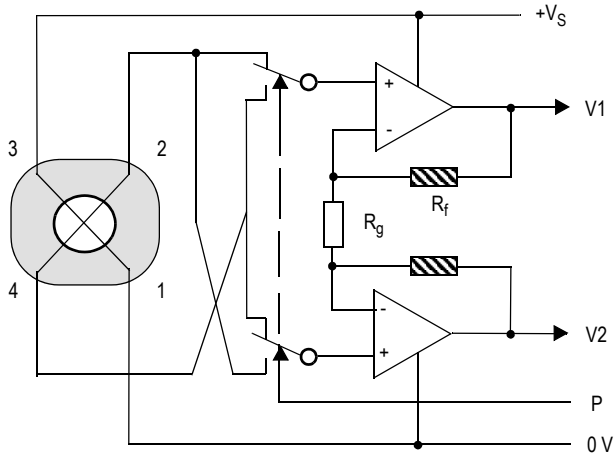

Figure 8. Crossing of the Instrument Amplifier Input Using a Port of the MCU

Figure 8 shows the analog switches on the front of the instrument amplifier and the total symmetry of the chain. The residual resistance $R_{DS(on)}$ of the switches does not introduce errors due to the high input impedance of the instrument amplifier.

With the aid of two analog switches, the MCU successively converts the output signals V1, V2.

Four conversions are necessary to compute the final result. First, two conversions of V1 and V2 are executed and stored in the registers R1, R2. Then, the analog switches are commuted in the opposite position and the two last conversions of $V2_x$ and V1x are executed and stored in the registers $R2_x$ and R1x. Then, the MCU computes the following equation:

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RESULT = (R1-R2) + (R2x-R1x) (2)

The result is twice a differential conversion. As demonstrated below, all errors from the instrument amplifier are cancelled. Other averaging techniques may be used to improve the result, but the appropriated algorithm is always determined by the maximum bandwidth of the input signal and the required accuracy of the system.

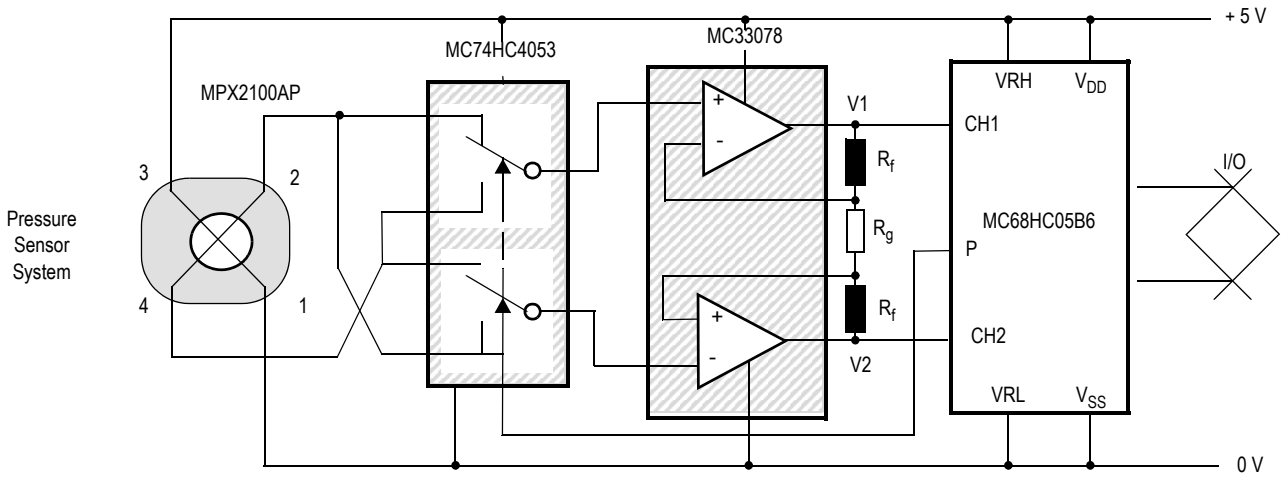

Figure 9. Two Channel Input and One Output Port Are Used by the MCU

SYSTEM CALCULATION

Sensor out 2
Vs2 = a (P) + of2

Sensor out 4
Vs4 = b (P) + of4

Amplifier out 1
V1 = Avd (Vs2 + OF1)

Amplifier out 2
V2 = Avd (Vs4 + OF2)

Inverting of the amplifier input
V1x = Avd (Vs4 + OF1) V2x = Avd (Vs2 + OF2)

Delta = V1-V2 1st differential result
= Avd * (Vs2 of OF1) - Avd * (Vs4 + OF2)

Deltax = V2x-V1x 2nd differential result
= Avd * (Vs2 + OF2) - Vdc * (Vs4 + OF1)

Adding of the two differential results

VoutV = Delta + Deltax
= Avd*Vs2 + Avd*OF2 + Avd*OF2 - Avd*OF1
+ Avd*OF1 - Avd*OF2 + Avd*OF2 - Avd*OF1
= 2 * Avd * (Vs2 -Vs4)
= 2 * Avd * [(a (P) + of2) - (b (P) + of4)]
= 2 * Avd * [V(P) + Voffset]

There is a full cancellation of the amplifier offset OF1 and OF2. The addition of the two differential results V1-V2 and V2x-V1X produce a virtual output voltage VoutV which becomes the applied input voltage to the A/D converter. The result of the conversion is expressed in the number of counts or bits by the ratiometric formula shown below:

$$count = VoutV * \frac{255}{VRH\text{-}VRL}$$

255 is the maximum number of counts provided by the A/D converter and VRH-VRL is the reference voltage of the ratiometric A/D converter which is commonly tied to the 5.0 V supply voltage of the MCU.

When the tolerance of the full scale pressure has to be in the range of ± 2.5 percent, the offset of the pressure sensor may be neglected. That means the system does not require any calibration procedure.

The equation of the system transfer is then:

count = 2 * Avd * V(P) * 51/V where:

Avd is the differential-mode gain of the instrument amplifier which is calculated using the equation (1). Then with R_f = 510 kΩ and R_g = 9.1 kΩ Avd = 113.

The maximum counts available in the MCU register at the Full Scale Pressure is:

count (Full Scale) = 2 * 113 * 0.02 V * 51/V = 230

knowing that the MPX2100AP pressure sensor provides 20 mV at 5.0 excitation voltage and 100 kPa full scale pressure.

The system resolution is 100 kPa/230 that give 0.43 kPa per count.

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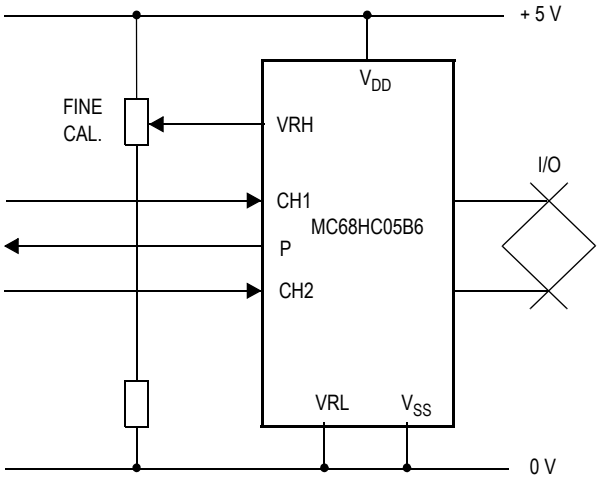

Figure 10. Full Scale Output Calibration Using the Reference Voltage VRH-VRL

When the tolerance of the system has to be in the range of ±1percent, the designer should provide only one calibration procedure which sets the Full Scale Output (counts) at 25°C 100 kPa or under the local atmospheric pressure conditions.

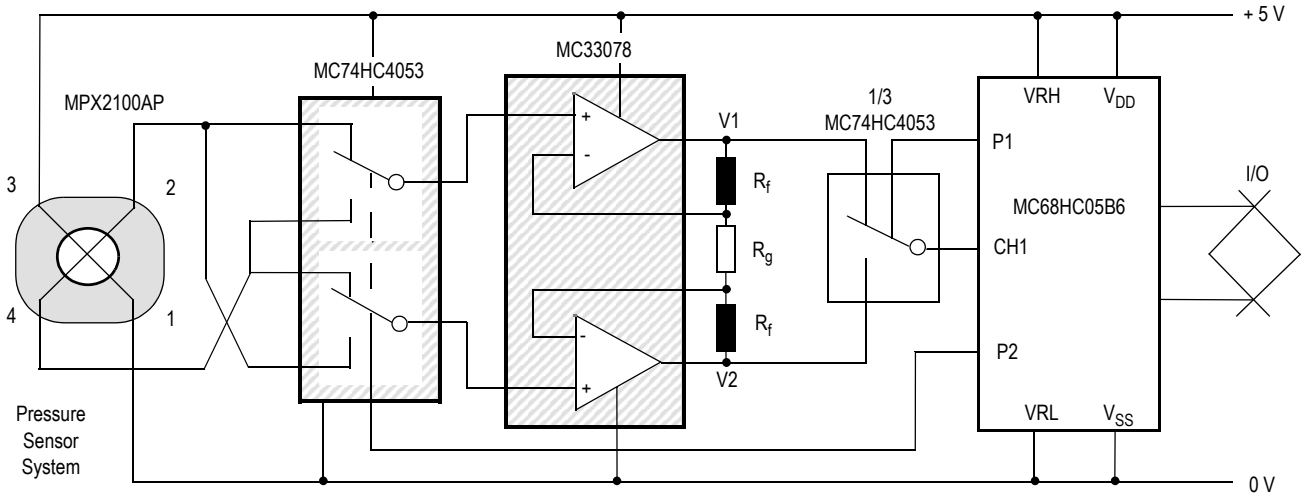

Figure 11. One Channel Input and Two Output Ports are used by the MCU

Due to the high impedance input of the A/D converter of the MC68HC05B6 MCU, another configuration may be implemented which uses only one channel input as shown in Figure 11. It is interesting to notice that practically any dual op amp may be used to do the job but a global consideration must be made to optimize the total cost of the system according to the requested specification.

When the Full Scale Pressure has to be sent with accuracy, the calibration procedure may be executed in different ways. For instance, the module may be calibrated directly using Up/Down push buttons.

The gain of the chain is set by changing the VRH voltage of the ratiometric A/D converter with the R/2R ladder network circuit which is directly driven by the ports of the MCU. (See Figure 12.)

Using a communication bus, the calibration procedure may be executed from a host computer. In both cases, the setting value is stored in the EEPROM of the MCU.

The gain may be also set using a potentiometer in place of the resistor R_f. But, this component is expensive, taking into account that it must be stable over the temperature range at long term.

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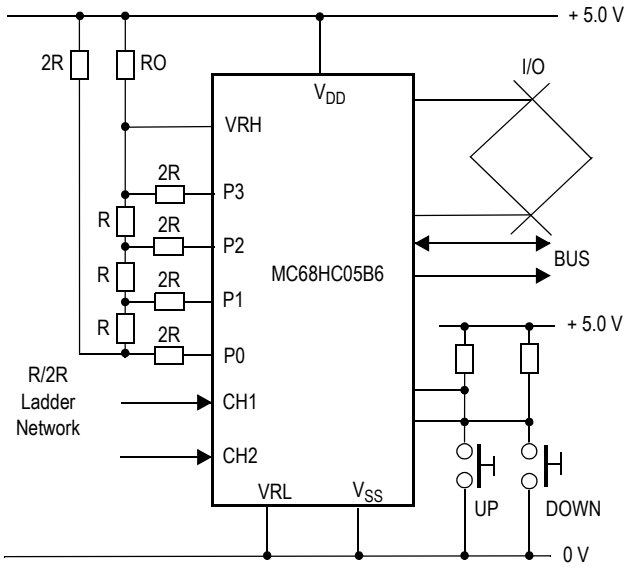

Figure 12. R/2R Ladder Network for an MCU

Table 1. Pressure Conversion Table

Unity	Pa	mbar	Torr	atm	at=kp/cm^2	mWS	psi
1 N/m2 = 1 Pascal	1	0.01	7.5 10-3	-	-	-	-
1 mbar	100	1	0.75	-	-	0.0102	0.014
1 Torr = 1 mmHg	133.32	1.333	.1	-	-	-	0.019
1 atm (1)	101325	1013.2	760	1	1.033	10.33	14.69
1 at = 1 kp/cm2(2)	98066.5	981	735.6	0.97	1	10	14.22
1 m of water	9806.65	98.1	73.56	0.097	0.1	1	1.422
1 lb/sqin = 1 psi	6894.8	68.95	51.71	0.068	-	-	1

NOTES:
1. Normal atmosphere
2. Technical atmosphere

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Analog to Digital Converter Resolution Extension Using a Pressure Sensor

PURPOSE

This paper describes a simple method to gain more than 8-bits of resolution with an 8-bit A/D. The electronic design is relatively simple and uses standard components.

Principle

Consider a requirement to measure pressure up to 200kPa. Using a pressure sensor and an amplifier, this pressure can be converted to an analog voltage output. This analog voltage can then be converted to a digital value and used by the microprocessor as shown in Figure 1.

If we assume for this circuit that 200 kPa results in a +4.5V output, the sensitivity of our system is:/

$$S = 4.5\ V/200kPa = 0.0225\ V/kPa \quad (1)$$
$$\text{or } S = 22.5\ mV/kPa$$

If an 8-bit A/D is used with 0 and 5 Volt low and high references, respectively, then the resolution would be:

$$S = 5\ V/(2^8 - 1 = 5V/255) = 0.01961\ V \quad (2)$$
$$\text{or } R_V = 19.60\ mV \text{ per bit}$$

This corresponds to a pressure resolution of:

$$R_p = 5\ V/(19.60\ mV/bit) / (22.5\ mV/kPa) = 0.871\ kPa \text{ per bit} \quad (3)$$

Assume a resolution of at least 0.1 kPa/bit is needed. This would require an A/D with at least 12 bits (2^{12} = 4096 steps).

One can artificially increase the A/D resolution as described below.

Refer to Figure 1 and assume a pressure of 124 kPa is to be measured. With this system, the input signal to the A/D should read (assuming no offset voltage error):

$$V_m(\text{measured}) = 4.5\ (Papp) \times (S) = (124\ kPa) \times (22.5\ mV/kPa) = 2790\ mV, \quad (4)$$

where Papp is the pressure applied to the sensor.

Due to the resolution of the A/D, the microprocessor receives the following conversion:

$$M = (2790\ mV) / (19.60\ mV/bit) = 142.35 = 142 \text{ (truncated to integer)} \quad (5)$$

The calculated voltage for this stored value is:

$$V_c(\text{calculated}) = (142\ count) \times (19.60mV/count) = 2783\ mV \quad (6)$$

The microprocessor will output the stored value M to the D/A. The corresponding voltage at the analog output of the D/A, for an 8-bit D/A with same references, will be 2783 mV.

The calculated pressure corresponding to this voltage would be:

$$P_c(\text{calculated}) = (2783\ mV) / (22.5\ mV/kPa) = 123.7\ kPa \quad (7)$$

Thus, the error would be:

$$E = Papp - Pc = 124\ kPa - 123.7\ kPa = 0.3\ kPa \quad (8)$$

This is greater than the 0.1 kPa resolution requirement.

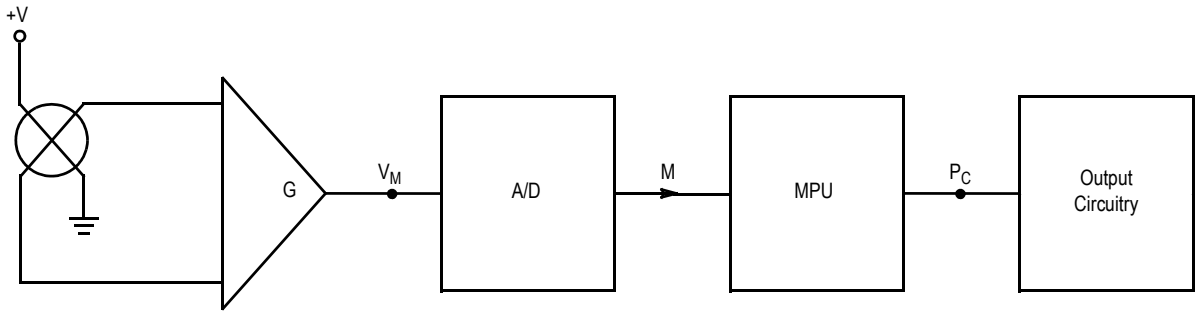

Figure 1. Figure Block Diagram

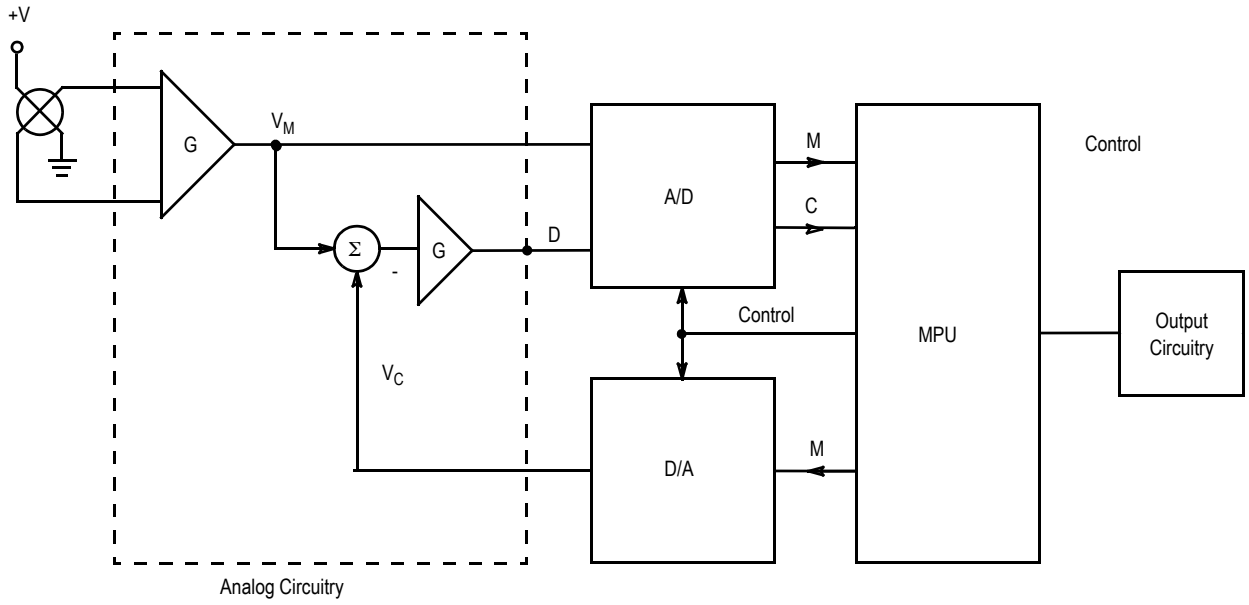

Figure 2. Expanded Block Diagram

Figure 2 shows the block diagram of a system that can be used to reduce the inaccuracies caused by the limited A/D resolution. The microprocessor would use the stored value M, as described above, to cause a D/A to output the corresponding voltage, Vc. Vc is subtracted from the measured voltage, Vm, using a differential amplifier, and the resulting voltage is amplified. Assuming a gain, G, of 10 for the amplifier, the output would be:

$$D = (Vm - Vc) \times G \quad (9)$$
$$= (2790\ mV - 2783\ mV) \times 10$$
$$= 70\ mV$$

The microprocessor will receive the following count from the A/D:

$$C = 70mV/(19.60\ mV/count) \quad (10)$$
$$= 3.6$$
$$= 3\ full\ counts$$

The microprocessor then computes the actual pressure with the following equations:

$$Expanded\ Voltage = Vc + ((C \times R)/G) \quad (11)$$
$$= 2783 + ((3 \times 19.60)/10)$$
$$= 2789\ mV,$$

NOTE: R is resolution of 8-bit d/A

$$Corresponding\ Pressure = 2789\ mV/ \quad (12)$$
$$= 22.5\ mV/kPa$$
$$= 123.9\ kPa$$

Thus the error is:

$$Pressure\ Error = Actual - Measured \quad (13)$$
$$= 124\ kPa - 123.9\ kPa$$
$$= 0.1\ kPa$$

Figure 3 and Figure 4 together provide a more detailed description of the analog portion of this system.

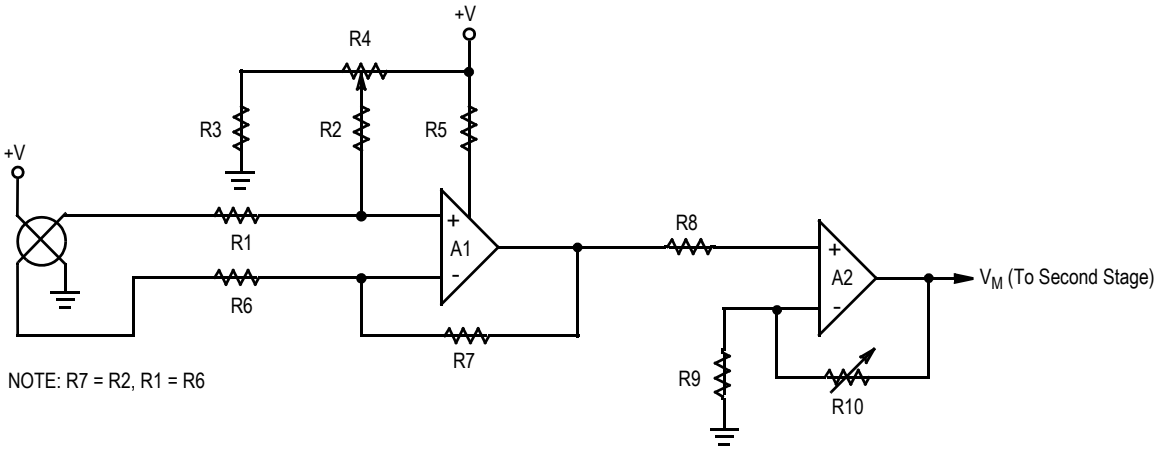

Figure 3. First Stage - Differential Amplifier, Offset Adjust and Gain Adjust

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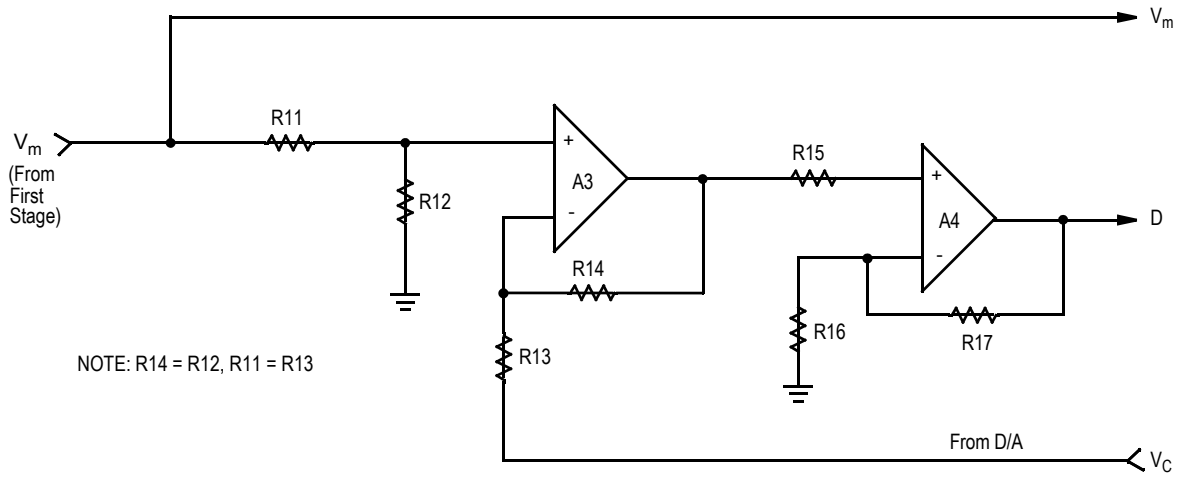

Figure 4. Second Stage - Difference Amplifier and Gains

FIRST STAGE (FIGURE 3)

The first stage consists of the pressure sensor; in this case the MPX2200 is used. This sensor typically gives a full scale span output of 40 mV at 200 kPa. The sensor output (V_S) is connected to the inputs of amplifier A1 (1/4 of the MC33079, a Quad Operational Amplifier). The gain, G1, of this amplifier is R7/R6. The sensor has a typical zero pressure offset voltage of 1 mV. Figure 3 shows offset compensation circuitry if it is needed. A1 output is fed to the non-inverting input of A2 amplifier (1/4 of a MC33079) whose gain, G2, is $1+R_{10}/R_9$. G2 should be set to yield 4.5 volts out with full-rated pressure.

THE SECOND STAGE (FIGURE 4)

The output from A2 (Vm = G1 x G2 x Vs) is connected to the non-inverting input of amplifier A3 (1/4 of a MC33079) and to the A/D where its corresponding (digital) value is stored by the microprocessor. The output of A3 is the amplified difference between Vm, and the digitized/calculated voltage Vc. Amplifier A4 (1/4 of a MC33079) provides additional gain for an amplified difference output for the desired resolution. This difference output, D, is given by:

$$D = (Vm\ V_c) \times G3$$

$$G3 = (R14/R13)\left(1 + \frac{R17}{R16}\right)$$

where G3 is the gain associated with amplifiers A3 and A4.

The theoretical resolution is limited only by the accuracy of the programmable power supply. The microprocessor used has an integrated A/D. The accuracy of this A/D is directly related to the reference voltage source stability, which can be self-calibrated by the microprocessor. $V_{expanded}$ is the system output that is the sum of the voltage due to the count and the voltage due to the difference between the count voltage and the measured voltage. This is given by the following relation:

$$V_{expanded} = V_c + D/G3$$

$$\text{therefore,}\quad PV_{expanded} = V_{expanded}/S.$$

$P_{expanded}$ is the value of pressure (in units of kPa) that results from this improved-resolution system. This value can be output to a display or used for further processing in a control system.

CONCLUSION

This circuit provides an easy way to have high resolution using inexpensive microprocessors and converters.

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A Simple 4-20 mA Pressure Transducer Evaluation Board

by: **Denise Williams**
Discrete Applications Engineering

INTRODUCTION

The two wire 4-20 mA current loop is one of the most widely utilized transmission signals for use with transducers in industrial applications. A two wire transmitter allows signal and power to be supplied on a single wire-pair. Because the information is transmitted as current, the signal is relatively immune to voltage drops from long runs and noise from motors, relays, switches and industrial equipment. The use of additional power sources is not desirable because the usefulness of this system is greatest when a signal has to be transmitted over a long distance with the sensor at a remote location. Therefore, the 4 mA minimum current in the loop is the maximum usable current to power the entire control circuitry.

Figure 1 is a block diagram of a typical 4-20 mA current loop system which illustrates a simple two chip solution to converting pressure to a 4-20 mA signal. This system is designed to be powered with a 24 Vdc supply. Pressure is converted to a differential voltage by the MPX5100 pressure sensor. The voltage signal proportional to the monitored pressure is then converted to the 4-20 mA current signal with the Burr-Brown XTR101 Precision Two-Wire Transmitter. The current signal can be monitored by a meter in series with the supply or by measuring the voltage drop across R_L. A key advantage to this system is that circuit performance is not affected by a long transmission line.

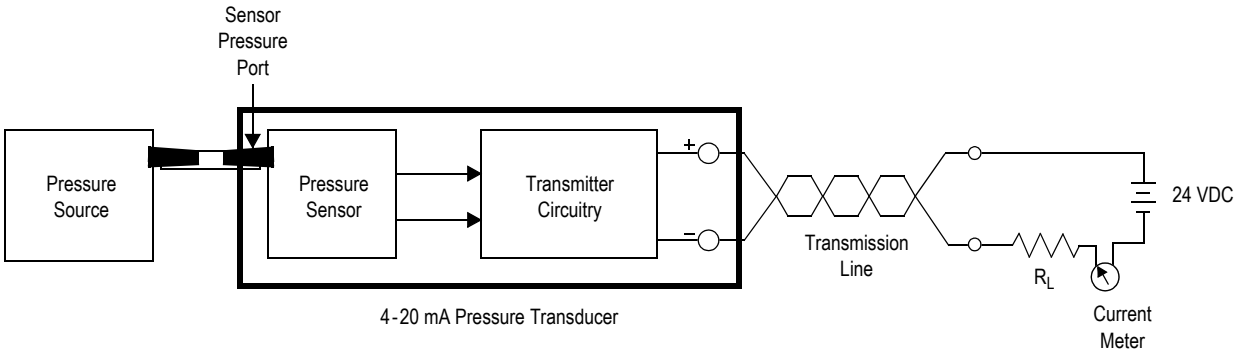

Figure 1. System Block Diagram

INPUT TERMINALS

A schematic of the 4-20 mA Pressure Transducer topology is shown in Figure 2. Connections to this topology are made at the terminals labeled (+) and (-). Because this system utilizes a current signal, the power supply, the load and any current meter must be put in series with the (+) to (-) terminals as indicated in the block diagram. The load for this type of system is typically a few hundred ohms. As described above, a typical use of a 4-20 mA current transmission signal is the transfer of information over long distances. Therefore, a long transmission line can be connected between the (+) and (-) terminals on the evaluation board and the power supply/load.

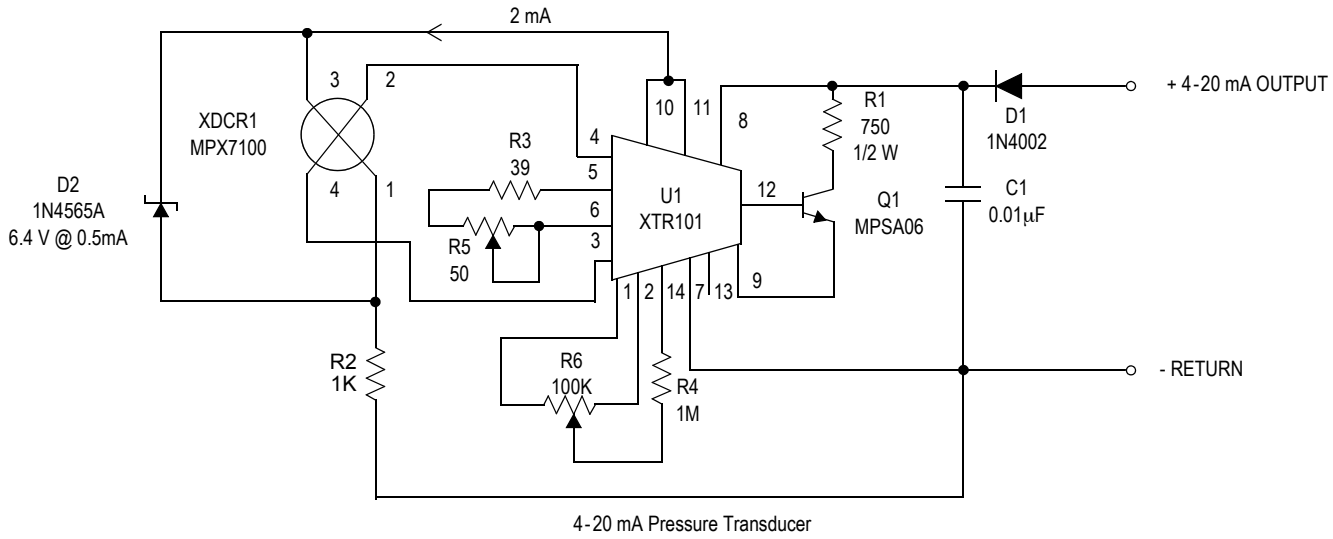

Figure 2. Schematic Diagram

PRESSURE INPUT

The device supplied on this topology is an MPX5100DP, which provides two ports. P1, the positive pressure port, is on top of the sensor and P2, the vacuum port, is on the bottom of the sensor. The system can be supplied up to 15 PSI of positive pressure to P1 or up to 15 PSI of vacuum to P2 or a differential pressure up to 15 PSI between P1 and P2. Any of these pressure applications will create the same results at the sensor output.

Circuit Description

The XTR101 current transmitter provides two one-milliamp current sources for sensor excitation when its bias voltage is between 12 V and 40 V. The MPX5100 series sensors are constant voltage devices, so a zener, D2, is placed in parallel with the sensor input terminals. Because the MPX5100 series parts have a high impedance the zener and sensor combination can be biased with just the two milliamps available from the XTR101.

The offset adjustment is composed of R4 and R6. They are used to remove the offset voltage at the differential inputs to the XTR101. R6 is set so a zero input pressure will result in the desired output of 4 mA.

R3 and R5 are used to provide the full scale current span of 16 mA. R5 is set such that a 15 PSI input pressure results in the desired output of 20 mA. Thus the current signal will span 16 mA from the zero pressure output of 4 mA to the full scale output of 20 mA. To calculate the resistor required to set the full scale output span, the input voltage span must be defined. The full scale output span of the sensor is 24.8 mV and is ΔV_{IN} to the XTR101. Burr-Brown specifies the following equation for R_{span}. The 40 and 16 mΩ values are parameters of the XTR101.

$$\begin{aligned} \text{Rspan} &= 40 / [(16\text{ mA} / \Delta\text{Vin}) - 0.016\text{ mhos}] \\ &= 64\ \Omega \end{aligned}$$

The XTR101 requires that the differential input voltage at pins 3 and 4, V2 - V1 be less than 1V and that V2 (pin 4) always be greater than V1 (pin 3). Furthermore, this differential voltage is required to have a common mode of 4-6 volts above the reference (pin 7). The sensor produces the differential output with a common mode of approximately 3.1 volts above its reference pin 1. Because the current of both 1 mA sources will go through R2, a total common mode voltage of about 5.1 volts (1 kΩ x 2 mA + 3.1 volts = 5.1 volts) is provided.

CONCLUSION

This circuit is an example of how the MPX5000 series sensors can be utilized in an industrial application. It provides a simple design alternative where remote pressure sensing is required.

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Table 1. Parts List for 4-20 mA Pressure Transducer Evaluation Board

Designator	Quantity	Description	Rating	Manufacturer	Part Number
	1 1 4 4 2 2	PC Board Input/Output Terminals 1/2″ standoffs, Nylon threaded 1/2″ screws, Nylon 5/8″ screws, Nylon 4-40 nuts, Nylon		Freescale PHX CONT	DEVB126 #1727010
C1	1	**Capacitor** 0.01 μF	50 V		
D1 D2	1 1	**Diodes** 100 V Diode 6.4 V Zener	1 A		1N4002 1N4565A
Q1	1	**Transistor** NPN Bipolar		Freescale	MPSA06
R1 R2 R3 R4	1 1 1 1	**Resistors, Fixed** 750 Ω 1 kΩ 39 Ω 1 MΩ	1/2 W		
R5 R6	1 1	**Resistors, Variable** 50 Ω, one turn 100 KΩ, one turn		Bourns Bourns	#3386P-1-500 #3386P-1-104
U1	1	**Integrated Circuit** Two wire current transmitter		Burr-Brown	XTR101
XDCR1	1	**Sensor** High Impedance	15 PSI	Freescale	MPX5100DP

NOTE: All resistors are 1/4 W with a tolerance of 5% unless otherwise noted. All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

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Integrated Sensor Simplifies Bar Graph Pressure Gauge

by: **Warren Schultz**
Discrete Applications Engineering

INTRODUCTION

Integrated semiconductor pressure sensors such as the MPX5100 greatly simplify electronic measurement of pressure. These devices translate pressure into a 0.5 to 4.5 volt output range that is designed to be directly compatible with microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with ICs such as the LM3914, making Bar Graph Pressure Gauges relatively simple. A description of a Bar Graph Pressure Sensor Evaluation Board and its design considerations are presented here.

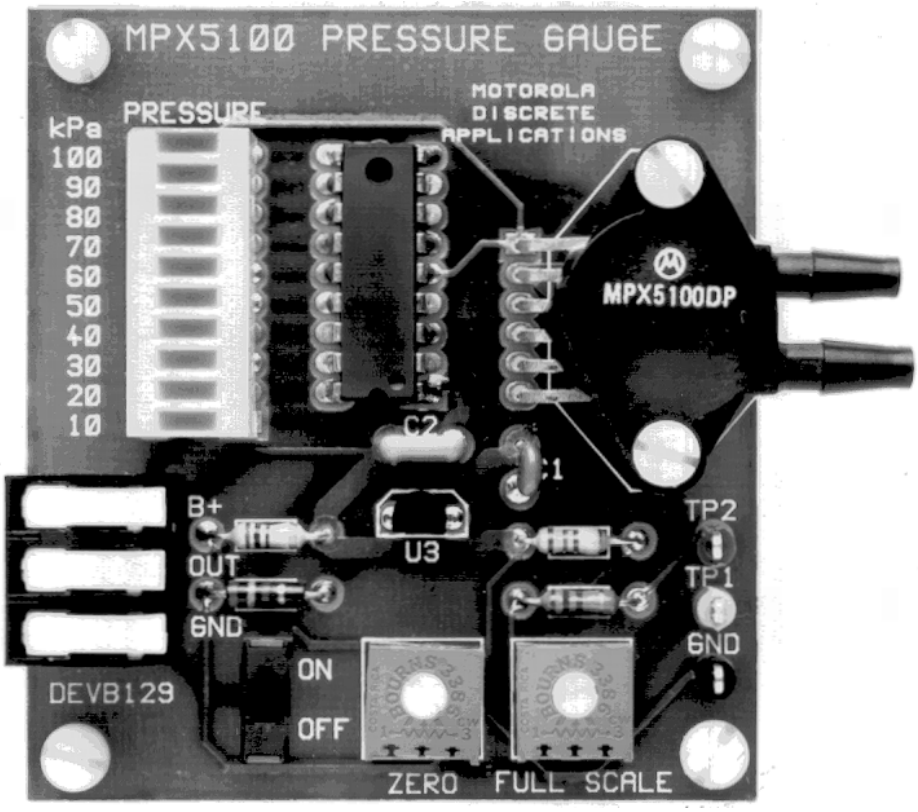

Figure 1. DEVB129 MPX5100 Bar Graph Pressure Gauge (Board No Longer Available)

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EVALUATION BOARD DESCRIPTION

A summary of the information required to use evaluation board number DEVB129 is presented as follows. A discussion of the design appears under the heading Design Considerations.

Function

The evaluation board shown in Figure 1 is designed to provide a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port is on the top side of the MPX5100 sensor, and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi)[1] of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10 kPa. If full scale pressure is adjusted for a value other than 100 kPa the bar graph may be read as a percent of full scale. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at 100 kPa. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of each other.

Electrical Characteristics

The following electrical characteristics are included to describe evaluation board operation. They are not specifications in the usual sense and are intended only as a guide to operation.

Characteristic	Symbol	Mln	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	Volts
Full Scale Pressure	PFS	—	—	100	kPa
Overpressure	PMAX	—	—	700	kPa
Analog Full Scale	VFS	—	4.5	—	Volts
Analog Zero Pressure Offset	VOFF	—	0.5	—	Volts
Analog Sensitivity	SAOUT	—	40	—	mV/kPa
Quiescent Current	ICC	—	20	—	mA
Full Scale Current	IFS	—	140	—	mA

Content

Board contents are described in the following parts list, schematic, and silk screen plot. A pin-by-pin circuit description follows in the next section.

Pin-by-Pin Description

B+

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that power dissipation in the LM3914 does not exceed 1.3 watts.

OUT

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at 100 kPa. This output is capable of sourcing 100 μA at full scale output.

GND

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board, one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1

Test point 1 is connected to the zero pressure reference voltage and can be used for zero pressure calibration. To calibrate for zero pressure, this voltage is adjusted with R6 to match the zero pressure voltage that is measured at the analog output (OUT) terminal.

TP2

Test point 2 performs a similar function at full scale. It is connected to the LM3914's reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R5 to set full scale pressure.

P1, P2

Pressure and Vacuum ports P1 & P2 protrude from the MPX5100 sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither is labeled. Either one or a differential pressure applied to both can be used to obtain full scale readings up to 100 kPa (15 psi). Maximum safe pressure is 700 kPa.

DESIGN CONSIDERATIONS

In this type of an application the design challenge is how to interface a sensor with the bar graph output. MPX5100 Sensors and LM3914 Bar Graph Display drivers fit together so cleanly that having selected these two devices the rest of the design is quite straight forward.

A block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the MPX5100's zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5 volt regulator's output voltage through R1, R4, and adjustment pot R6. The voltage

1. 100 kPa = 14.7 psi, 15 psi is used throughout the text for convenience.

generated at the wiper of R6 is then fed into R_{LO} which matches the sensor's zero pressure voltage and zeros the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R5 that are shown in Figure 2.

The MPX5100 requires 5 volt regulated power that is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R2, R5, and R3 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 85°C temperature range accuracy for both the sensor and driver IC are ±2.5%, totaling ±5%. Given a 10 segment display total accuracy is approximately ±(10 kPa +5%).

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is how easy it is to design. The interface between an MPX5100 sensor, LM3914 display driver, and bar graph output is direct and straight forward. The result is a simple circuit that is capable of measuring pressure, vacuum, or differential pressure; and will also send an analog signal to other control circuitry.

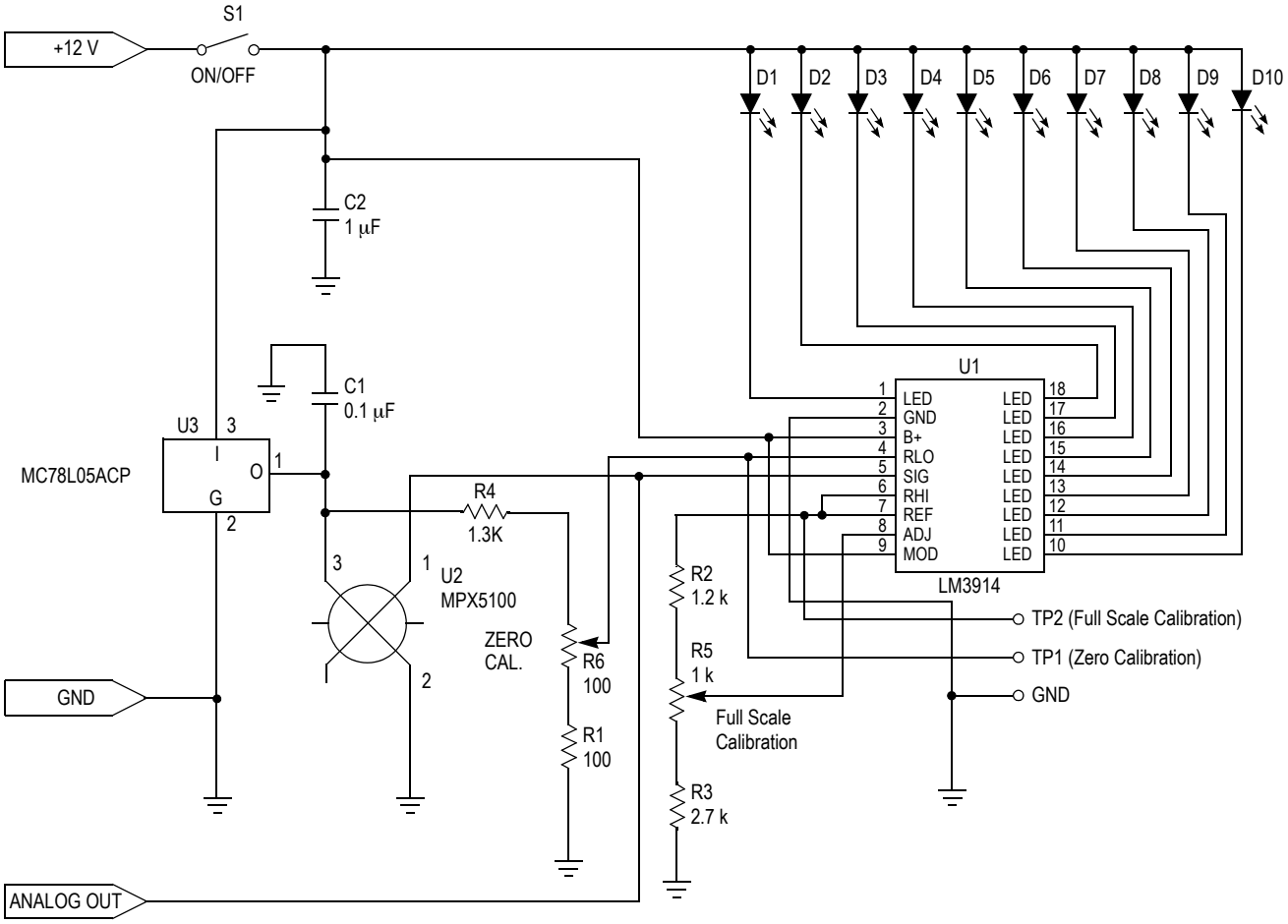

Figure 2. MPX5100 Pressure Gauge

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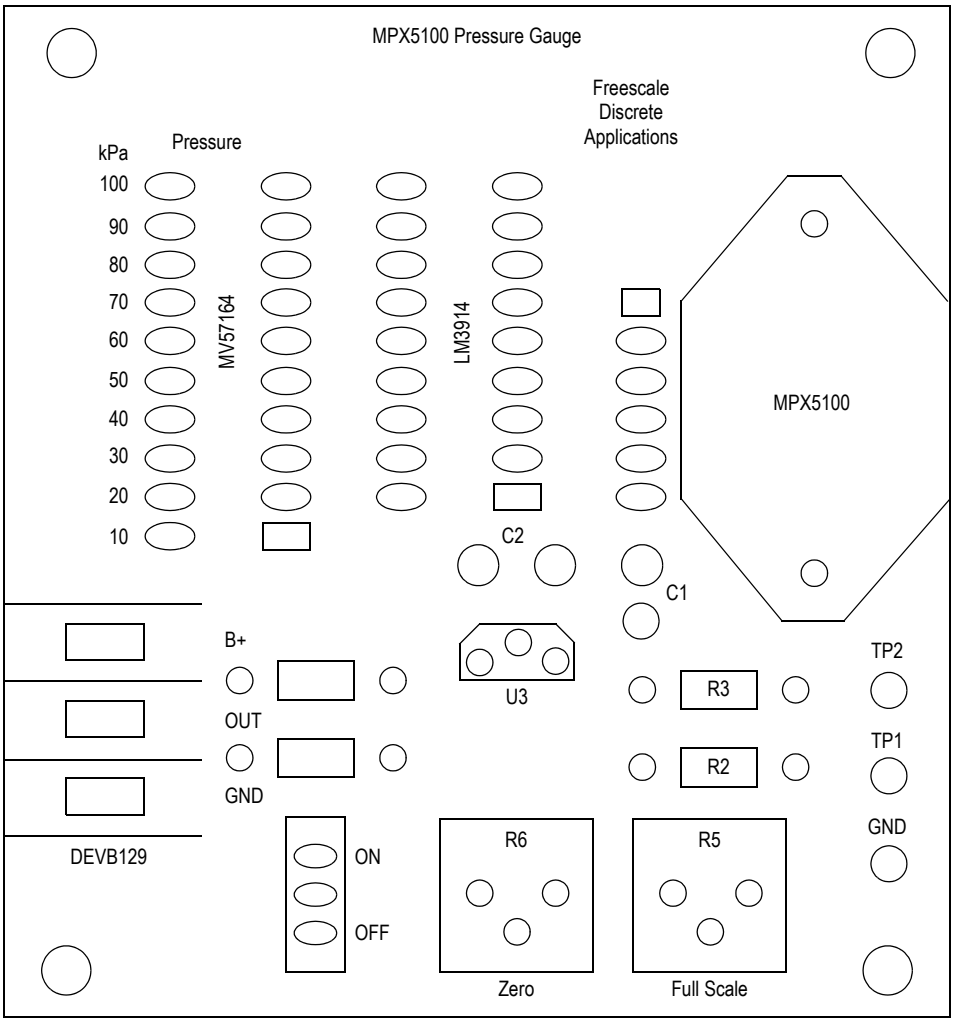

Figure 3. Silk Screen 2X

Table 1. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1 C2	1 1	Ceramic Cap Ceramic Cap	0.1 μF 1 μF		
D1-D10	1	Bar Graph LED		GI	MV57164
R1 R2 R3 R4 R5 R6	1 1 1 1 1 1	1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor Trimpot Trimpot	100 1.2K 2.7K 1.3K 1K 100	 Bourns Bourns	
S1	1	On/Off Switch		NKK	12SDP2
U1 U2 U3	1 1 1	Bar Graph IC Pressure Sensor Voltage Regulator		National Freescale Freescale	LM3914 MPX5100 MC78L05ACP
— — — —	1 3 4 4	Terminal Block Test Point Terminal Nylon Spacer 4-40 Nylon Screw	 3/8″ 1/4″	Augat Components Corp.	25V03 TP1040104

Notes: All resistors have a tolerance of 5% unless otherwise noted.
All capacitors are 50 volt ceramic capacitors with a tolerance of 10% unless otherwise noted.

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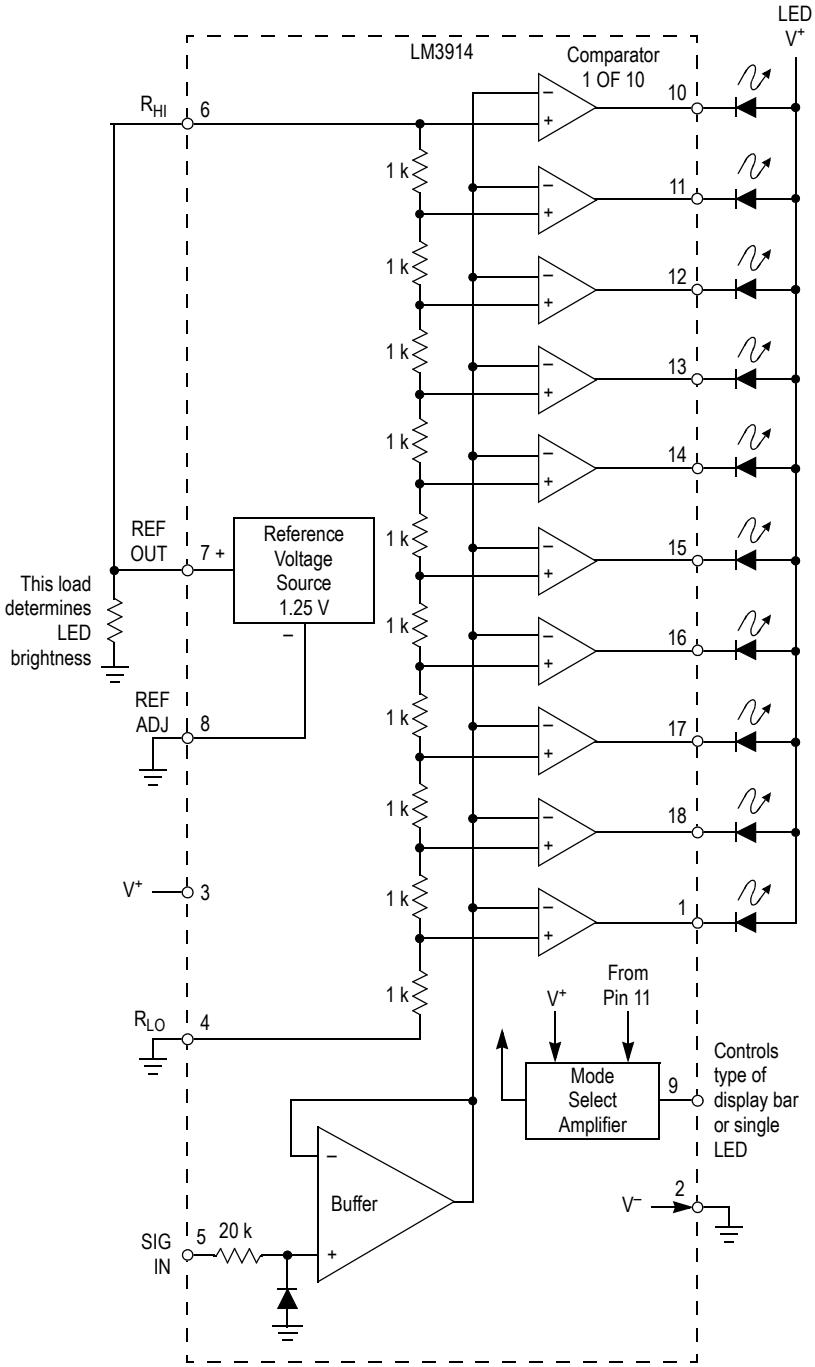

Figure 4. LM3914 Block Diagram

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An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor

by: **Bill Lucas**
Discrete Applications Engineering

INTRODUCTION

Interfacing pressure sensors to analog-to-digital converters or microprocessors with on-chip A/D converters has been a challenge that most engineers do not enjoy accepting. Recent design advances in pressure sensing technology have allowed the engineer to directly interface a pressure sensor to an A/D converter with no additional active components. This has been made possible by integrating a temperature compensated pressure sensor element and active linear circuitry on the same die. A description of an evaluation board that shows the ease of interfacing a signal conditioned pressure sensor to an A/D converter is presented here.

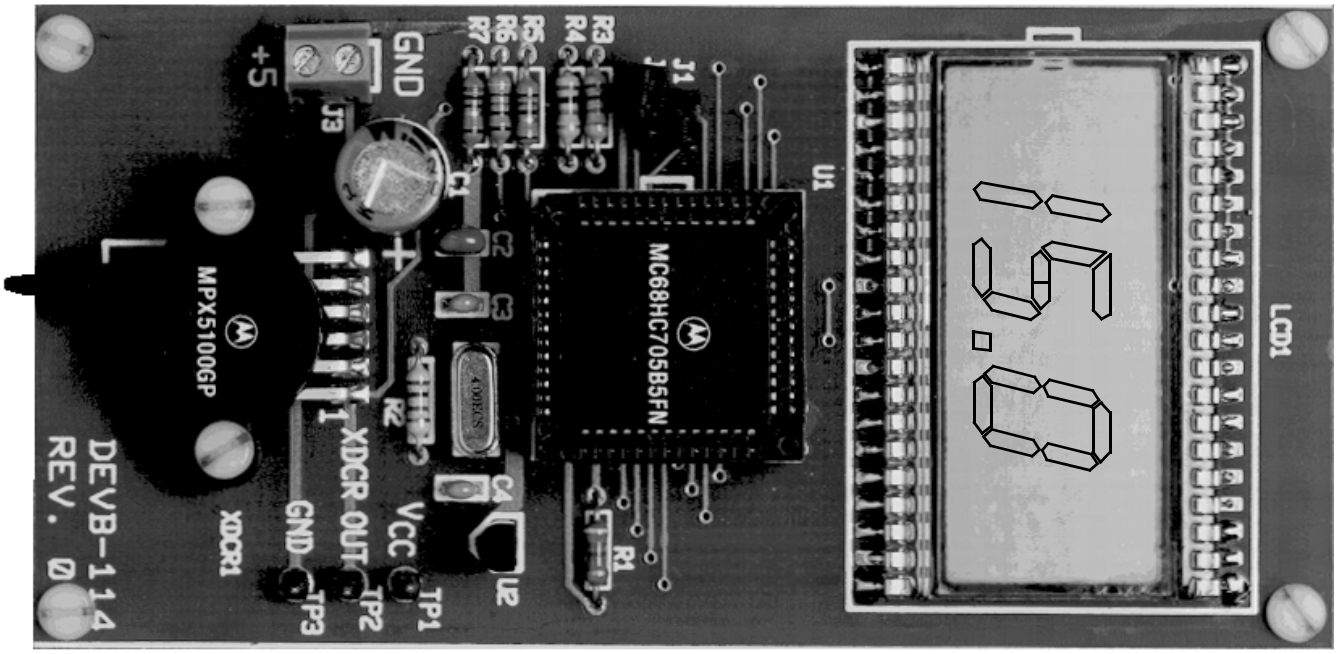

Figure 1. DEVB-114 MPX5100 Evaluation Module (Board No Longer Available)

PURPOSE

This evaluation system shown in Figure 1 demonstrates the ease of operation and interfacing of the Freescale Semiconductor, Inc. MPX5100 series pressure sensors with on-chip temperature compensation, calibration and amplification. The board may be used to evaluate the sensor's suitability for a specific application.

DESCRIPTION

The DEVB-114 evaluation board is constructed on a small printed circuit board. It is powered from a single +5 Vdc regulated power supply. The system will display the pressure applied to the MPX5100 sensor in pounds per square inch. The range is 0 PSI through 15 PSI, resolved to 0.1 PSI. No potentiometers are used in the system to adjust the span and offset. The sensor's zero offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX5100 is repeatable from unit to unit. There is a facility for a small “rubbering” of the slope constant built into the program. It is accomplished with jumpers J1 and J2, and is explained in the Operation section. The board contents are further described in the schematic, silk screen plot, and parts list that appear in Figure 2, Figure 3, and Table 1.

BASIC CIRCUIT

The evaluation board consists of three basic subsystems: an MPX5100GP pressure sensor, a four digit liquid crystal display (only three digits and a decimal are used) and a programmed microprocessor with the necessary external circuitry to support the operation of the microprocessor.

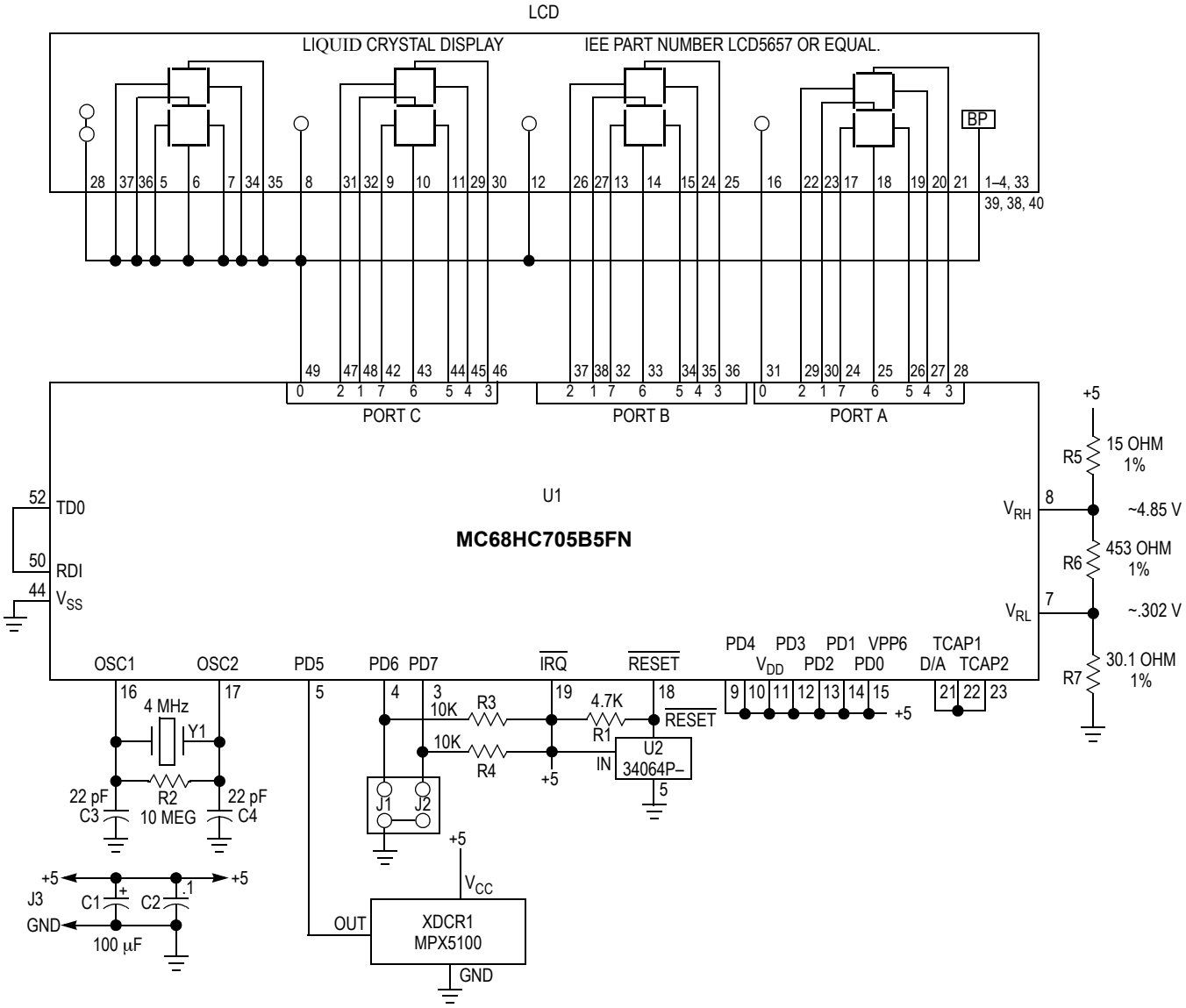

Figure 2. DEVB-114 System Schematic

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Table 1. DEVB-114 Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1	1	100 μF Electrolytic Capacitor	25 Vdc	Sprague	513D107M025BB4
C2	1	0.1 μF Ceramic Capacitor	50 Vdc	Sprague	1C105Z5U104M050B
C3, C4	2	22 pF Ceramic Capacitor	100 Vdc	Mepco/Centralab	CN15A220K
J1, J2	1	Dual Row Straight .025 Pins Arranged On .1″ Grid		Molex	10-89-1043
LCD	1	Liquid Crystal Display		AMPEREX	LTD226R-12
R1	1	4.7 k Ohm Resistor			
R2	1	10 Meg Ohm Resistor			
R3, R4	2	10 k Ohm Resistor			
R5	1	15 Ohm 1% 1/4 W Resistor			
R6	1	453 Ohm 1% 1/4 W Resistor			
R7	1	30.1 Ohm 1% 1/4 W Resistor			
XDCR1	1	Pressure Sensor		Freescale	MPX5100GP
U1	1	Microprocessor		Freescale Freescale	MC68HC705B5FN or XC68HC705B5FN
U2	1	Under Voltage Detector		Freescale	MC34064P-5
Y1	1	Crystal (Low Profile)	4.0 MHz	ECS	ECS-40-S-4
No Designator	1	52 Pin PLCC Socket		AMP	821-575-1
No Designator	2	Jumpers For J1 and J2		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			

Notes: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

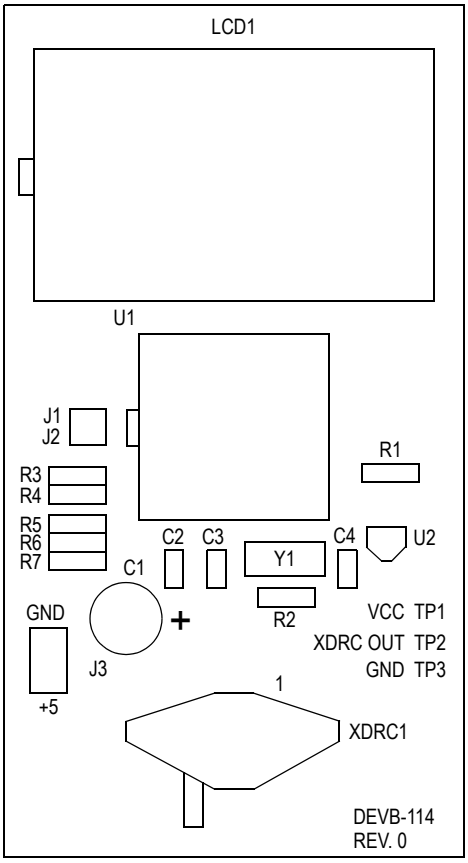

Figure 3. Silk Screen

Theory of Operation

Referring to the schematic, Figure 2, the MPX5100 pressure sensor is connected to PORT D bit 5 of the microprocessor. This port is an input to the on-chip 8 bit analog to digital converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.5 Vdc at 0 psi to 4.5 Vdc at 15 psi of applied pressure as shown in Figure 4. The input range of the A to D converter is set at approximately 0.3 Vdc to 4.85 Vdc. This compresses the range of the A to D converter around the output range of the sensor to maximize the A to D converter resolution; 0 to 255 counts is the range of the A to D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A to D converter. The resolution is defined by the following:

Analog-to-digital converter count =

$$[(V_{xdcr}-V_{RL})/(V_{RH}-V_{RL})]\cdot 255$$

The count at 0 psi = $[(.5-.302)/(4.85-.302)]\cdot 255 \approx 11$
The count at 15 psi = $[(4.5-.302)/(4.85-.302)]\cdot 255 \approx 235$
Therefore the resolution = count @ 15 psi - count @ 0 psi or the resolution is (235 - 11) = 224 counts. This translates to a system that will resolve to 0.1 psi.

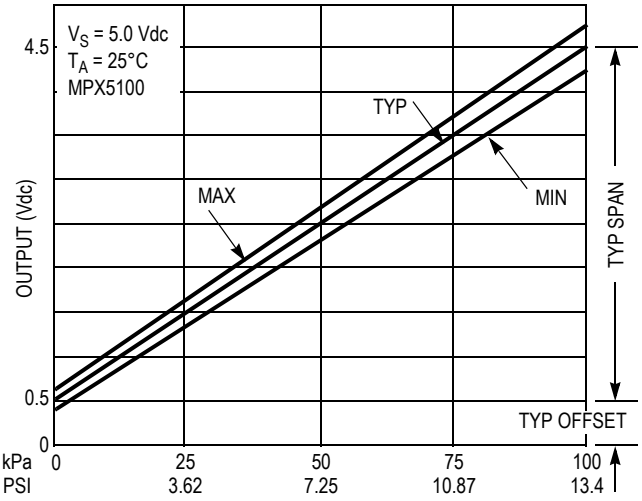

Figure 4. MPX5100 Output versus Pressure Input

The voltage divider consisting of R5 through R7 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display is directly driven from I/O ports A, B, and C on the microprocessor. The operation of a liquid crystal display requires that the data and backplane pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

The microprocessor section of the system requires certain support hardware to allow it to function. The MC34064P-5 (U2) provides an under voltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and provides a stable base for time based functions. Jumpers J1 and J2 are examined by the software and are used to “rubber” the slope constant.

OPERATION

The system must be connected to a 5 Vdc regulated power supply. Note the polarity marked on the power terminal J3. Jumpers J1 and J2 must either both be installed or both be removed for the normal slope constant to be used. The pressure port on the MPX5100 sensor must be left open to atmosphere anytime the board is powered-up. As previously stated, the sensor’s voltage offset with zero pressure applied is computed at power-up.

You will need to apply power to the system. The LCD will display CAL for approximately 5 seconds. After that time, the LCD will then start displaying pressure.

To improve upon the accuracy of the system, you can change the constant used by the program that constitutes the span of the sensor. You will need an accurate test gauge to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation (after CAL is no longer displayed), apply 15.0 PSI to the sensor. Make sure that jumpers J1 and J2 are either both installed or both removed. Referring to Table 2, you can increase the displayed value by installing J1 and removing J2. Conversely, you can decrease the displayed value by installing J2 and removing J1.

Table 2. J1/J2 Installation

J1	J2	Action
IN	IN	Use Normal Span Constant
OUT	OUT	Use Normal Span Constant
OUT	IN	Decrease Span Constant Approximately 1.5%
IN	OUT	Increase Span Constant Approximately 1.5%

SOFTWARE

The source code, compiler listing, and S-record output for the software used in this system are available on the Freescale Freeware Bulletin Board Service in the MCU directory under the filename DEVB-114.ARC. To access the bulletin board you must have a telephone line, a 300, 1200 or 2400 baud modem and a terminal or personal computer. The modem must be compatible with the Bell 212A standard. Call 1-512-891-3733 to access the Bulletin Board Service.

The software for the system consists of several modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX5100 transducer.

Figure 5 is a flowchart for the program that controls the system.

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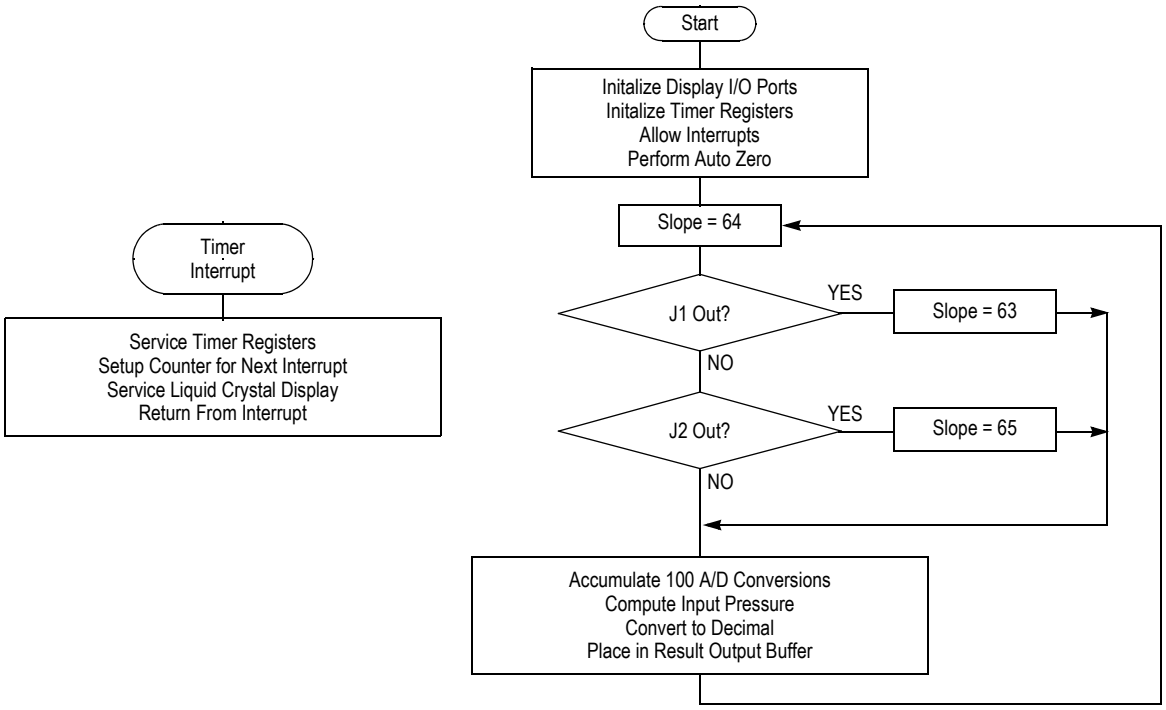

Figure 5. DEVB-114 Software Flowchart

The compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide approximately a 20 ms loop.

read_a2d() Performs one hundred reads on the analog to digital converter on multiplexer channel 5 and returns the accumulation.

fixcompare() Services the internal timer for 30 ms timer compare interrupts.

TIMERCMP() Alternates the data and backplane for the liquid crystal display.

initio() Sets up the microcomputer's I/O ports, timer, allows processor interrupts, and calls adzero().

adzero() This routine is necessary at power-up time because it delays the power supply and allows the transducer to stabilize. It then calls 'read_atod()' and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg) This routine converts the unsigned binary argument passed in 'arg' to a five digit decimal number in an array called 'digit'. It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. It is then output to the display.

display_psi() This routine is called from 'main()'. The analog to digital converter routine is called, the pressure is calculated, and the pressure applied to the sensor is displayed. The loop then repeats.

main() This is the main routine called from reset. It calls 'initio()' to set up the system's I/O. 'display_psi()' is called to compute and display the pressure applied to the sensor.

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SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
                        #pragma option v ;
                        /*

                        rev 1.1 code rewritten to use the MC68HC705B5 instead of the
                        MC68HC805B6. WLL 6/17/91

                        THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB-114 DEMONSTRATION
                        BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                BYTE CRAFT LTD.
                                                421 KING ST.
                                                WATERLOO, ONTARIO
                                                CANADA  N2J 4E4
                                                (519)888-6911

                        SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                        COMPILERS.
                                                 BILL LUCAS 8/5/90
                                                 FREESCALE, SPS            */

0800 1700               #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096               #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                        /*       Vector assignments    */
1FFE                    #pragma vector __RESET   @ 0x1ffe ;
1FFC                    #pragma vector __SWI     @ 0x1ffc ;
1FFA                    #pragma vector IRQ       @ 0x1ffa ;
1FF8                    #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                    #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                    #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                    #pragma vector SCI       @ 0x1ff2 ;

                        #pragma has STOP ;
                        #pragma has WAIT ;
                        #pragma has MUL ;

                        /*       Register assignments for the 68HC705B5 microcontroller     */
0000                    #pragma portrw porta   @ 0x00;  /*                                      */
0001                    #pragma portrw portb   @ 0x01;  /*                                      */
0002                    #pragma portrw portc   @ 0x02;  /*                                      */
0003                    #pragma portrw portd   @ 0x03;  /* in  ,-  ,SS  ,SCK  ,MOSI,MISO,TxD,RxD */
0004                    #pragma portrw ddra    @ 0x04;  /* Data direction, Port A               */
0005                    #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B               */
0006                    #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)  */
0007                    #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                    #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                    #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                    #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                    #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                    #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                    #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                    #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                    #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                    #pragma portrw scistat @ 0x10;  /* sci status reg */
```

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```
0011                          #pragma portrw scidata  @ 0x11;  /* SCI Data  */
0012                          #pragma portrw tcr      @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL       */
0013                          #pragma portrw tsr      @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0               */
0014                          #pragma portrw icaphi1  @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0015                          #pragma portrw icaplo1  @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0016                          #pragma portrw ocmphi1  @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0017                          #pragma portrw ocmplo1  @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0018                          #pragma portrw tcnthi   @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
0019                          #pragma portrw tcntlo   @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
001A                          #pragma portrw acnthi   @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001B                          #pragma portrw acntlo   @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001C                          #pragma portrw icaphi2  @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001D                          #pragma portrw icaplo2  @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001E                          #pragma portrw ocmphi2  @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/
001F                          #pragma portrw ocmplo2  @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/

                                 /* put constants and variables here...they must be global */

                              /*************************************************************************/
1EFE 74                       #pragma mor @ 0x1EFE = 0x74;/*this disables the watchdog counter and does not
                         add pull-down resistors on ports B and C */

0800 FC 30 DA 7A 36 6E E6 38 FE const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                 /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */
080A 27 10 03 E8 00 64 00 0A     const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                        unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec functio*/

0000                             registera ac;      /* processor's A register */

0055                             long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */


0059                             long slope;        /* multiplier for adc to engineering units conversion */

005B                             int adcnt;         /* a/d converter loop counter */

005C                             long xdcr_offset;  /* initial xdcr offset */

005E 0060                        unsigned long i,j; /* counter for loops */

0062                             int k;             /* misc variable */

                                 struct bothbytes
                                    {  int hi;
                                       int lo;
                                    };

                                    union isboth
                                         {  long  l;
                                         struct bothbytes b;
                                         };

0063 0002                           union isboth q;  /* used for timer set-up */
```

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```
                    /*************************************************************************/
                                                /* code starts here */
                                /*************************************************************************/
                                /* these interrupts are not used...give them a graceful return if for
                                   some reason one occurs */

1FFC 08 12                      __SWI(){}
0812 80         RTI
1FFA 08 13                      IRQ(){}
0813 80         RTI
1FF8 08 14                      TIMERCAP(){}
0814 80         RTI
1FF4 08 15                      TIMEROV(){}
0815 80         RTI
1FF2 08 16                      SCI(){}
0816 80         RTI

                                /*************************************************************************/

                                void delay(void)  /* just hang around for a while */
                                {
0817 4F        CLRA             for (i=0; i<20000; ++i);
0818 3F 57      CLR    $57
081A B7 58      STA    $58
081C B6 57      LDA    $57
081E B7 5E      STA    $5E
0820 B6 58      LDA    $58
0822 B7 5F      STA    $5F
0824 B6 5F      LDA    $5F
0826 A0 20      SUB    #$20
0828 B6 5E      LDA    $5E
082A A2 4E      SBC    #$4E
082C 24 08      BCC    $0836
082E 3C 5F      INC    $5F
0830 26 02      BNE    $0834
0832 3C 5E      INC    $5E
0834 20 EE      BRA    $0824
0836 81         RTS    }
                /*************************************************************************/

                          read_a2d(void)
                                {
                                /* read the a/d converter on channel 5 and accumulate the result
                                   in atodtemp */

0837 3F 56      CLR    $56      atodtemp=0;   /* zero for accumulation */
0839 3F 55      CLR    $55
083B 4F         CLRA                 for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
083C B7 5B      STA    $5B
083E B6 5B      LDA    $5B
0840 A8 80      EOR    #$80
0842 A1 E4      CMP    #$E4
0844 24 21      BCC    $0867
```


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```
                                {
0846 A6 25     LDA    #$25              adstat = 0x25;  /* convert on channel 5 */
0848 B7 09     STA    $09
084A 0F 09 FD  BRCLR 7,$09,$084A       while (!(adstat & 0x80));  /* wait for a/d to complete */
084D B6 08     LDA    $08              atodtemp = addata + atodtemp;
084F 3F 57     CLR    $57
0851 B7 58     STA    $58
0853 BB 56     ADD    $56
0855 B7 58     STA    $58
0857 B6 57     LDA    $57
0859 B9 55     ADC    $55
085B B7 57     STA    $57
085D B7 55     STA    $55
085F B6 58     LDA    $58
0861 B7 56     STA    $56
                                  }
0863 3C 5B     INC    $5B
0865 20 D7     BRA    $083E
0867 B6 56     LDA    $56           atodtemp = atodtemp/100;
0869 B7 58     STA    $58
086B B6 55     LDA    $55
086D B7 57     STA    $57
086F 3F 66     CLR    $66
0871 A6 64     LDA    #$64
0873 B7 67     STA    $67
0875 CD 0A 5E  JSR    $0A5E
0878 CD 0A 8F  JSR    $0A8F
087B BF 55     STX    $55
087D B7 56     STA    $56
087F 81        RTS                  return atodtemp;
                                 }

                                 /*************************************************************************/
                        void fixcompare (void) /* sets-up the timer compare for the next interrup */
                                   {
0880 B6 18     LDA    $18         q.b.hi =tcnthi;
0882 B7 63     STA    $63
0884 B6 19     LDA    $19              q.b.lo = tcntlo;
0886 B7 64     STA    $64
0888 AB 4C     ADD    #$4C             q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms.*/
088A B7 64     STA    $64
088C B6 63     LDA    $63
088E A9 1D     ADC    #$1D
0890 B7 63     STA    $63
0892 B7 16     STA    $16              ocmphi1 = q.b.hi;
0894 B6 13     LDA    $13              ac=tsr;
0896 B6 64     LDA    $64              ocmplo1 = q.b.lo;
0898 B7 17     STA    $17
089A 81        RTS                     }


                                  /*************************************************************************/
                                  void TIMERCMP (void)              /* timer service module */
1FF6 08 9B                           {
```

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```
089B 33 02    COM    $02                  portc =~ portc;       /* service the lcd */
089D 33 01    COM    $01                  portb =~ portb;
089F 33 00    COM    $00                  porta =~ porta;
08A1 AD DD    BSR    $0880                fixcompare();
08A3 80       RTI                       }

                                    /*************************************************************************/

                                    void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                          pressure offset voltage output */
                                    {

08A4 4F       CLRA                    for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
08A5 3F 57    CLR    $57
08A7 B7 58    STA    $58
08A9 B6 57    LDA    $57
08AB B7 60    STA    $60
08AD B6 58    LDA    $58
08AF B7 61    STA    $61
08B1 B6 61    LDA    $61
08B3 A0 14    SUB    #$14
08B5 B6 60    LDA    $60
08B7 A2 00    SBC    #$00
08B9 24 0B    BCC    $08C6
                                                                  power supply time to settle down */
                                     {
08BB CD 08 17 JSR    $0817             delay();
                                     }
08BE 3C 61    INC    $61
08C0 26 02    BNE    $08C4
08C2 3C 60    INC    $60
08C4 20 EB    BRA    $08B1
08C6 CD 08 37 JSR    $0837               xdcr_offset =  read_a2d();
08C9 3F 5C    CLR    $5C
08CB B7 5D    STA    $5D
08CD 81       RTS     }

                          /*************************************************************************/
                            void initio (void)     /*  setup the I/O */
                                               {
08CE A6 20    LDA    #$20                  adstat = 0x20; /* power-up the A/D */
08D0 B7 09    STA    $09
08D2 3F 02    CLR    $02                   porta = portb = portc = 0;
08D4 3F 01    CLR    $01
08D6 3F 00    CLR    $00
08D8 A6 FF    LDA    #$FF                  ddra = ddrb = ddrc = 0xff;
08DA B7 06    STA    $06
08DC B7 05    STA    $05
08DE B7 04    STA    $04
08E0 B6 13    LDA    $13                   ac=tsr;  /* dummy read */
08E2 3F 1E    CLR    $1E                   ocmphi1 = ocmphi2 = 0;
08E4 3F 16    CLR    $16
08E6 B6 1F    LDA    $1F                   ac = ocmplo2; /* clear out output compare 2 if it happens to be set */
08E8 AD 96    BSR    $0880                 fixcompare(); /* set-up for the first timer interrupt */
```

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```
08EA A6 40     LDA    #$40             tcr = 0x40;
08EC B7 12     STA    $12
08EE 9A        CLI                     CLI;  /* let the interrupts begin !  */
                                     /* write CAL to the display */
08EF A6 CC     LDA    #$CC             portc = 0xcc; /* C */
08F1 B7 02     STA    $02
08F3 A6 BE     LDA    #$BE             portb = 0xbe; /* A */
08F5 B7 01     STA    $01
08F7 A6 C4     LDA    #$C4             porta = 0xc4; /* L */
08F9 B7 00     STA    $00
08FB AD A7     BSR    $08A4            adzero();
08FD 81        RTS                    }

                                    /*************************************************************************/
                                    void cvt_bin_dec(unsigned long arg)

                                    /* First converts the argument to a five digit decimal value. The msd is in
                                    the lowest address. Then leading zero suppresses the value and writes it to
                                    the display ports.
                                       The argument value range is 0..65535 decimal. */

0069                                {
08FE BF 69     STX    $69
0900 B7 6A     STA    $6A
006B                                char i;
006C                                unsigned long l;
0902 4F        CLRA                   for ( i=0; i < 5; ++i )
0903 B7 6B     STA    $6B
0905 B6 6B     LDA    $6B
0907 A1 05     CMP    #$05
0909 24 07     BCC    $0912
                                       {
090B 97        TAX                       digit[i] = 0x0;  /* put blanks in all digit positions */
090C 6F 50     CLR    $50,X
                                       }
090E 3C 6B     INC    $6B
0910 20 F3     BRA    $0905
0912 4F        CLRA                      for ( i=0; i < 4; ++i )
0913 B7 6B     STA    $6B
0915 B6 6B     LDA    $6B
0917 A1 04     CMP    #$04
0919 24 70     BCC    $098B
                                          {
091B 97        TAX                           if ( arg  >= dectable [i] )
091C 58        LSLX
091D D6 08 0B  LDA    $080B,X
0920 B1 6A     CMP    $6A
0922 26 07     BNE    $092B
0924 D6 08 0A  LDA    $080A,X
0927 B1 69     CMP    $69
0929 27 5C     BEQ    $0987
                                             {
092B BE 6B     LDX    $6B                    l = dectable[i];
092D 58        LSLX
092E D6 08 0A  LDA    $080A,X
```

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```
0933 D6 08 0B  LDA    $080B,X
0936 B7 6D     STA    $6D
0938 B6 6A     LDA    $6A                          digit[i] = arg / l;
093A B7 58     STA    $58
093C B6 69     LDA    $69
093E B7 57     STA    $57
0940 B6 6C     LDA    $6C
0942 B7 66     STA    $66
0944 B6 6D     LDA    $6D
0946 B7 67     STA    $67
0948 CD 0A 5E  JSR    $0A5E
094B CD 0A 8F  JSR    $0A8F
094E BF 57     STX    $57
0950 B7 58     STA    $58
0952 BE 6B     LDX    $6B
0954 E7 50     STA    $50,X
0956 BE 6B     LDX    $6B                          arg = arg-(digit[i] * l);
0958 E6 50     LDA    $50,X
095A 3F 57     CLR    $57
095C B7 58     STA    $58
095E B6 6C     LDA    $6C
0960 B7 66     STA    $66
0962 B6 6D     LDA    $6D
0964 B7 67     STA    $67
0966 CD 0A 3F  JSR    $0A3F
0969 BF 57     STX    $57
096B B7 58     STA    $58
096D 33 57     COM    $57
096F 30 58     NEG    $58
0971 26 02     BNE    $0975
0973 3C 57     INC    $57
0975 B6 58     LDA    $58
0977 BB 6A     ADD    $6A
0979 B7 58     STA    $58
097B B6 57     LDA    $57
097D B9 69     ADC    $69
097F B7 57     STA    $57
0981 B7 69     STA    $69
0983 B6 58     LDA    $58
0985 B7 6A     STA    $6A
                                          }
                                       }
0987 3C 6B     INC    $6B
0989 20 8A     BRA    $0915
098B B6 6A     LDA    $6A          digit[i] = arg;
098D B7 58     STA    $58
098F B6 69     LDA    $69
0991 B7 57     STA    $57
0993 BE 6B     LDX    $6B
0995 B6 58     LDA    $58
0997 E7 50     STA    $50,X

                                  /* now zero suppress and send the lcd pattern to the display */
0999 9B        SEI             SEI;
```

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```
099A 3D 50     TST    $50          if ( digit[0] == 0 )   /* leading zero suppression */
099C 26 04     BNE    $09A2
099E 3F 02     CLR    $02            portc = 0;
09A0 20 07     BRA    $09A9            else
09A2 BE 50     LDX    $50               portc = ( lcdtab[digit[0]] );     /* 100's digit */
09A4 D6 08 00  LDA    $0800,X
09A7 B7 02     STA    $02
09A9 3D 50     TST    $50                if ( digit[0] == 0 && digit[1] == 0 )
09AB 26 08     BNE    $09B5
09AD 3D 51     TST    $51
09AF 26 04     BNE    $09B5
09B1 3F 01     CLR    $01                  portb=0;
09B3 20 07     BRA    $09BC                else
09B5 BE 51     LDX    $51                    portb = ( lcdtab[digit[1]] );      /* 10's digit */
09B7 D6 08 00  LDA    $0800,X
09BA B7 01     STA    $01
09BC BE 52     LDX    $52                    porta = ( lcdtab[digit[2]]+1 ); /* 1's digit + decimal point */
09BE D6 08 00  LDA    $0800,X
09C1 4C        INCA
09C2 B7 00     STA    $00
09C4 9A        CLI                   CLI;
09C5 CD 08 17  JSR    $0817                  delay();
09C8 81        RTS                   }

                                     /*************************************************************/

                                     void display_psi(void)
                                     /* At power-up it is assumed that the pressure port of the sensor
                                        is open to atmosphere. The code in initio() delays for the
                                        sensor and power to stabilize. One hundred A/D conversions are
                                        averaged and divided by 100. The result is called xdcr_offset.
                                        This routine calls the A/D routine which performs one hundred
                                        conversions, divides the result by 100 and returns the value.
                                        If the value returned is less than or equal to the xdcr_offset,
                                        the value of xdcr_offset is substituted. If the value returned
                                        is greater than xdcr_offset, xdcr_offset is subtracted from the
                                        returned value. That result is multiplied by a constant to yield
                                        pressure in PSI * 10 to yield a "decimal point".
                                     */
                                     {
                                      while(1)
                                        {
09C9 3F 59     CLR    $59          slope = 64;
09CB A6 40     LDA    #$40
09CD B7 5A     STA    $5A
09CF B6 03     LDA    $03               k = portd & 0xc0;  /* this lets us "rubber" the slope to closer fit
09D1 A4 C0     AND    #$C0
09D3 B7 62     STA    $62
                                                                the slope of the sensor */
09D5 A1 80     CMP    #$80               if ( k == 0x80 )    /* J2 removed, J1 installed */
09D7 26 06     BNE    $09DF
09D9 3F 59     CLR    $59                  slope = 65;
09DB A6 41     LDA    #$41
09DD B7 5A     STA    $5A
09DF B6 62     LDA    $62                    if ( k == 0x40 ) /* J1 removed, J2 installed */
```

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```
09E1 A1 40      CMP     #$40
09E3 26 06      BNE     $09EB
09E5 3F 59      CLR     $59                     slope = 63;
09E7 A6 3F      LDA     #$3F
09E9 B7 5A      STA     $5A
                                        /* else both jumpers are removed or installed... don't change the slope */
09EB CD 08 37   JSR     $0837               atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
09EE 3F 55      CLR     $55
09F0 B7 56      STA     $56
09F2 B0 5D      SUB     $5D                   if ( atodtemp <= xdcr_offset )
09F4 B7 58      STA     $58
09F6 B6 5C      LDA     $5C
09F8 A8 80      EOR     #$80
09FA B7 57      STA     $57
09FC B6 55      LDA     $55
09FE A8 80      EOR     #$80
0A00 B2 57      SBC     $57
0A02 BA 58      ORA     $58
0A04 22 08      BHI     $0A0E
0A06 B6 5C      LDA     $5C                     atodtemp = xdcr_offset;
0A08 B7 55      STA     $55
0A0A B6 5D      LDA     $5D
0A0C B7 56      STA     $56
0A0E B6 56      LDA     $56                   atodtemp -=  xdcr_offset; /* remove the offset */
0A10 B0 5D      SUB     $5D
0A12 B7 56      STA     $56
0A14 B6 55      LDA     $55
0A16 B2 5C      SBC     $5C
0A18 B7 55      STA     $55
0A1A B6 56      LDA     $56                 atodtemp *= slope; /* convert to psi */
0A1C B7 58      STA     $58
0A1E B6 55      LDA     $55
0A20 B7 57      STA     $57
0A22 B6 59      LDA     $59
0A24 B7 66      STA     $66
0A26 B6 5A      LDA     $5A
0A28 B7 67      STA     $67
0A2A CD 0A 3F   JSR     $0A3F
0A2D BF 55      STX     $55
0A2F B7 56      STA     $56
0A31 CD 08 FE   JSR     $08FE               cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0A34 20 93      BRA     $09C9             }
0A36 81         RTS                     }

                                    /*************************************************************************/

                                      main()
                                      {
0A37 CD 08 CE   JSR     $08CE          initio(); /* set-up the processor's i/o */
0A3A AD 8D      BSR     $09C9           display_psi();
0A3C 20 FE      BRA     $0A3C            while(1);   /* should never get here */
0A3E 81         RTS                     }

0A3F BE 58      LDX     $58
0A41 B6 67      LDA     $67
```

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```
0A43 42       MUL
0A44 B7 70    STA    $70
0A46 BF 71    STX    $71
0A48 BE 57    LDX    $57
0A4A B6 67    LDA    $67
0A4C 42       MUL
0A4D BB 71    ADD    $71
0A4F B7 71    STA    $71
0A51 BE 58    LDX    $58
0A53 B6 66    LDA    $66
0A55 42       MUL
0A56 BB 71    ADD    $71
0A58 B7 71    STA    $71
0A5A 97       TAX
0A5B B6 70    LDA    $70
0A5D 81       RTS

0A5E 3F 70    CLR    $70
0A60 5F       CLRX
0A61 3F 6E    CLR    $6E
0A63 3F 6F    CLR    $6F
0A65 5C       INCX
0A66 38 58    LSL    $58
0A68 39 57    ROL    $57
0A6A 39 6E    ROL    $6E
0A6C 39 6F    ROL    $6F
0A6E B6 6E    LDA    $6E
0A70 B0 67    SUB    $67
0A72 B7 6E    STA    $6E
0A74 B6 6F    LDA    $6F
0A76 B2 66    SBC    $66
0A78 B7 6F    STA    $6F
0A7A 24 0D    BCC    $0A89
0A7C B6 67    LDA    $67
0A7E BB 6E    ADD    $6E
0A80 B7 6E    STA    $6E
0A82 B6 66    LDA    $66
0A84 B9 6F    ADC    $6F
0A86 B7 6F    STA    $6F
0A88 99       SEC
0A89 59       ROLX
0A8A 39 70    ROL    $70
0A8C 24 D8    BCC    $0A66
0A8E 81       RTS
0A8F 53       COMX
0A90 9F       TXA
0A91 BE 70    LDX    $70
0A93 53       COMX
0A94 81       RTS
1FFE 0A 37
```

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```
SYMBOL TABLE

LABEL         VALUE  LABEL         VALUE  LABEL         VALUE  LABEL         VALUE

IRQ           0813 | SCI           0816 | TIMERCAP     0814 | TIMERCMP      089B
TIMEROV       0815 | __LDIV       0A5E | __LongIX     0066 | __MUL         0000
__MUL16x16    0A3F | __RDIV       0A8F | __RESET      1FFE | __STARTUP     0000
__STOP        0000 | __SWI        0812 | __WAIT       0000 | __longAC      0057
acnthi        001A | acntlo       001B | adcnt        005B | addata        0008
adstat        0009 | adzero       08A4 | arg          0069 | atodtemp      0055
b             0000 | bothbytes    0002 | cvt_bin_dec  08FE | ddra          0004
ddrb          0005 | ddrc         0006 | dectable     080A | delay         0817
digit         0050 | display_psi  09C9 | eeclk        0007 | fixcompare    0880
hi            0000 | i            005E | icaphi1      0014 | icaphi2       001C
icaplo1       0015 | icaplo2      001D | initio       08CE | isboth        0002
j             0060 | k            0062 | l            0000 | lcdtab        0800
lo            0001 | main         0A37 | misc         000C | ocmphi1       0016
ocmphi2       001E | ocmplo1      0017 | ocmplo2      001F | plma          000A
plmb          000B | porta        0000 | portb        0001 | portc         0002
portd         0003 | q            0063 | read_a2d     0837 | scibaud       000D
scicntl1      000E | scicntl2     000F | scidata      0011 | scistat       0010
slope         0059 | tcnthi       0018 | tcntlo       0019 | tcr           0012
tsr           0013 | xdcr_offset  005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0100 : ---------------- ---------------- ---------------- ----------------
0140 : ---------------- ---------------- ---------------- ----------------
0180 : ---------------- ---------------- ---------------- ----------------
01C0 : ---------------- ---------------- ---------------- --------------X-

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXX----------- ---------------- ----------------
0AC0 : ---------------- ---------------- ---------------- ----------------

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.
Errors             :    0
Warnings           :    0
```

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Compensated Sensor Bar Graph Pressure Gauge

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Discrete Applications Engineering

INTRODUCTION

Compensated semiconductor pressure sensors such as the MPX2000 family are relatively easy to interface with digital systems. With these sensors and the circuitry described herein, pressure is translated into a 0.5 to 4.5 volt output range that is directly compatible with Microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with an LM3914, making Bar Graph Pressure Gauges relatively simple.

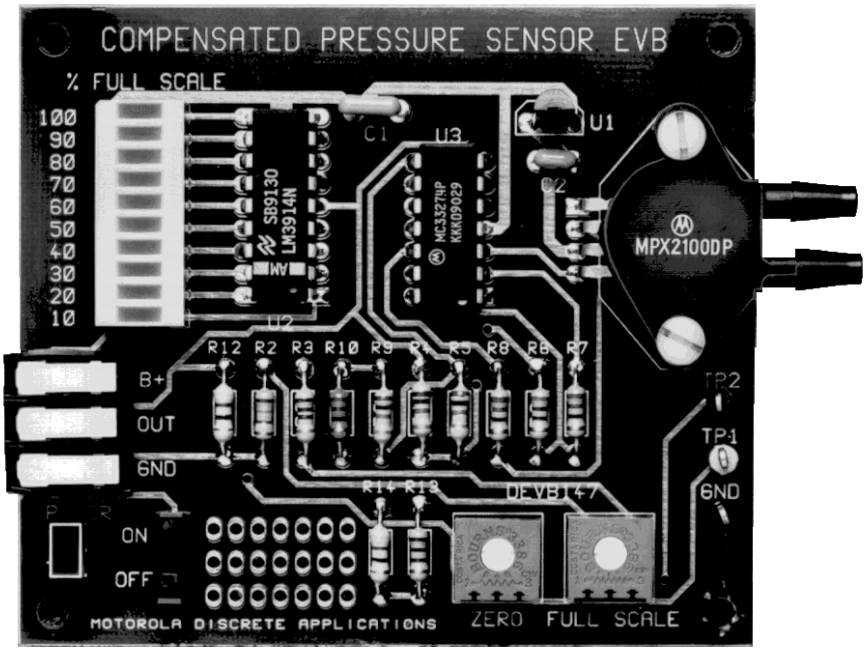

Figure 1. DEVB147 Compensated Pressure Sensor Evaluation Board (Board No Longer Available)

EVALUATION BOARD DESCRIPTION

The information required to use evaluation board number DEVB147 follows, and a discussion of the design appears in the DESIGN CONSIDERATIONS section.

Function

The evaluation board shown in Figure 1 is supplied with an MPX2100DP sensor and provides a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port, is on the top side of the sensor and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi) of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10% of full scale, or 10 kPa with the MPX2100 sensor. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at full scale. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of one another.

ELECTRICAL CHARACTERISTICS

The following electrical characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	dc Volts
Full Scale Pressure	PFS	—	—	100	kPa
Overpressure	PMAX	—	—	700	kPa
Analog Full Scale	VFS	—	4.5	—	Volts
Analog Zero Pressure Offset	VOFF	—	0.5	—	Volts
Analog Sensitivity	SAOUT	—	40	—	mV/kPa
Quiescent Current	ICC	—	40	—	mA
Full Scale Current	IFS	—	160	—	mA

Content

Board contents are described in the parts list shown in Table 1. A schematic and silk screen plot are shown in Figure 2 and Figure 6. A pin by pin circuit description follows.

Pin-by-Pin Description

B+

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that average power dissipation in the LM3914 does not exceed 1.3 watts.

OUT

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at full scale. Zero pressure voltage is adjustable and set with R11. This output is designed to be directly connected to a microcomputer A/D channel, such as one of the E ports on an MC68HC11.

GND

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1

Test point 1 is connected to the LM3914's full scale reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R1 to set full scale pressure.

TP2

Test point 2 is connected to the +5.0 volt regulator output. It can be used to verify that supply voltage is within its 4.75 to 5.25 volt tolerance.

P1, P2

Pressure and Vacuum ports P1 and P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither port is labeled. Maximum safe pressure is 700 kPa.

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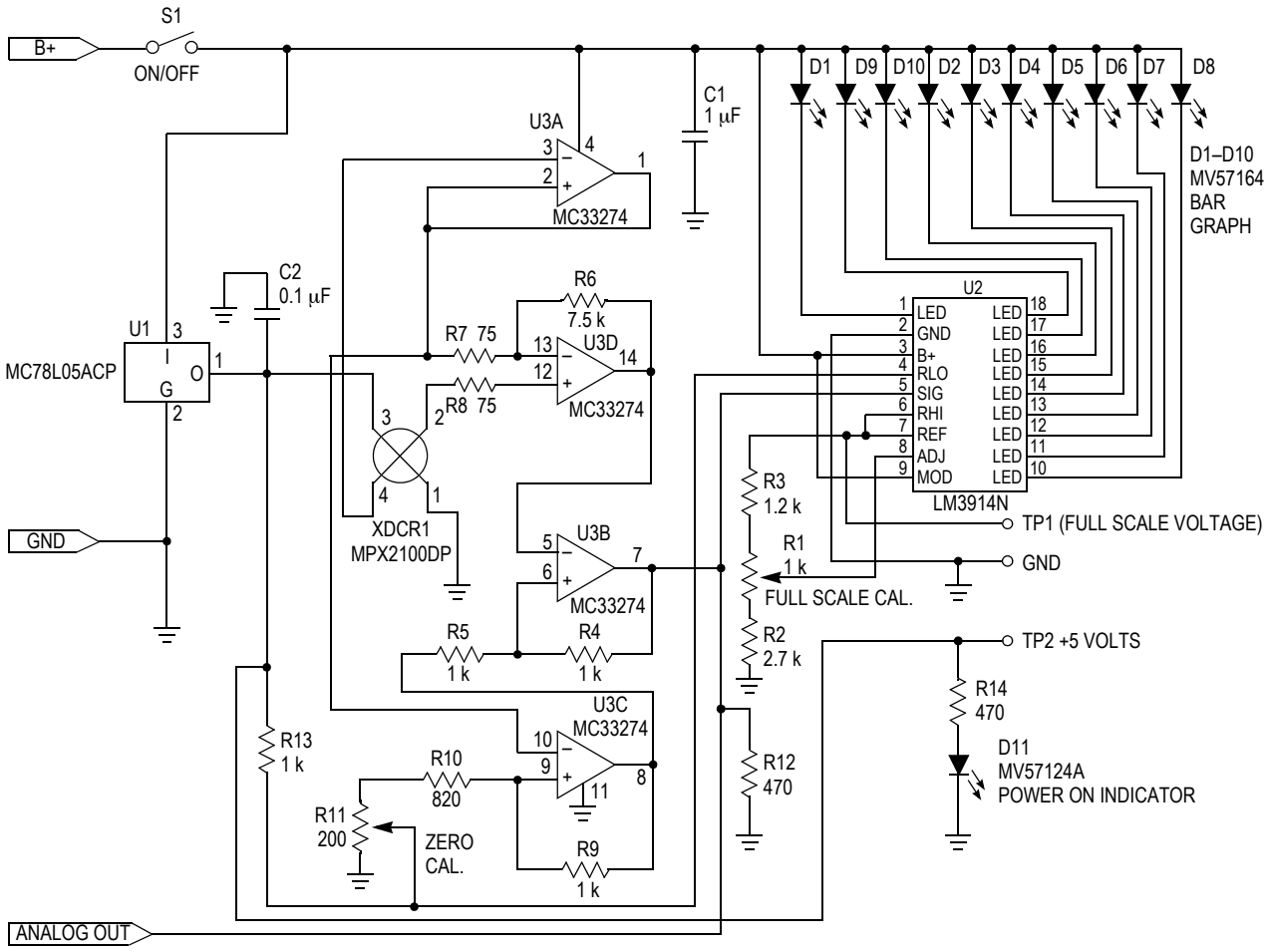

Figure 2. Compensated Pressure Sensor EVB Schematic

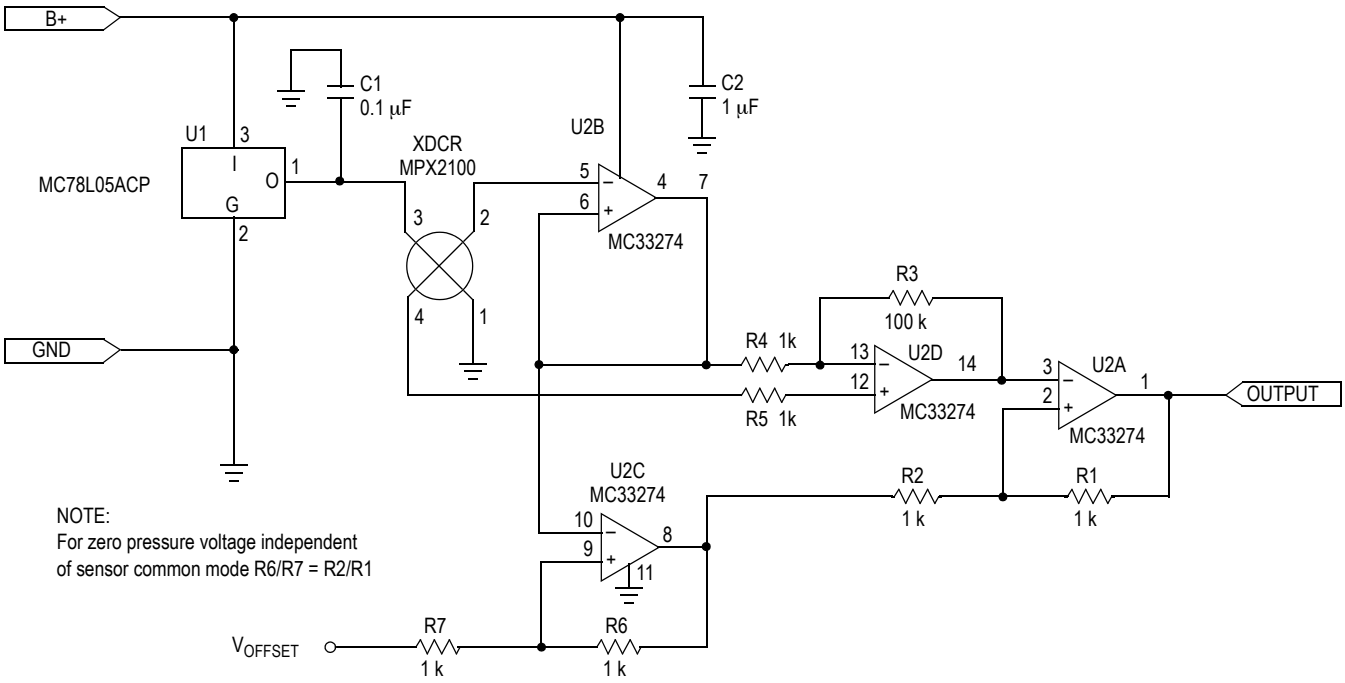

Figure 3. Compensated Sensor Interface

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DESIGN CONSIDERATIONS

In this type of application the design challenge is how to take a relatively small DC coupled differential signal and produce a ground referenced output that is suitable for driving microcomputer A/D inputs. A user friendly interface circuit that will do this job is shown in Figure 3. It uses one quad op amp and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U2D which is configured as a differential amplifier. It is isolated from the sensor's positive output by U2B. The purpose of U2B is to prevent feedback current that flows through R3 and R4 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero volts. For example with the common mode voltage at 2.5 volts, the zero pressure output voltage at pin 14 of U2D is then 2.5 volts, since any other voltage would be coupled back to pin 13 via R3 and create a nonzero bias across U2D's differential inputs. This 2.5 volt zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage (V_{OFFSET}) by U2C and U2A. To see how the level translation works, assume 0.5 volts at (V_{OFFSET}). With 2.5 volts at pin 10, pin 9 is also at 2.5 volts. This leaves 2.5 - 0.5 = 2.0 volts across R7. Since no current flows into pin 9, the same current flows through R6, producing 2.0 volts across R6 also. Adding the voltages (0.5 + 2.0 +2.0) yields 4.5 volts at pin 8. Similarly 2.5 volts at pin 3 implies 2.5 volts at pin 2, and the drop across R2 is 4.5 V - 2.5 V = 2.0 volts. Again 2.0 volts across R2 implies an equal drop across R1, and the voltage at pin 1 is 2.5 V - 2.0 V = 0.5 volts. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R6/R7 = R2/R1.

Gain is close but not exactly equal to R3/R4(R1/R2+1), which predicts 200.0 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 199.9. Cascading the gains of U2D and U2A using standard op amp gain equations does not give an exact result, because the sensor's negative going differential signal at pin 4 subtracts from the DC level that is amplified by U2A.

The resulting 0.5 V to 4.5 V output from U2A is directly compatible with microprocessor A/D inputs. Tying this output to an LM3914 for a bar graph readout is also very straight forward. The block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 volt zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5.0 volt regulator's output voltage through R13 and adjustment pot R11. The voltage generated at R11's wiper is the offset voltage identified as V_{OFFSET} in Figure 3. Its source impedance is chosen to keep the total input impedance to U3C at approximately 1K. The wiper of R11 is also fed into R_{LO} for zeroing the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R1 that are shown in Figure 2.

Five volt regulated power is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R3, R1, and R2 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 50°C temperature range combined accuracy for the sensor, interface and driver IC are +/- 10%. Given a 10 segment display total accuracy for the bar graph readout is approximately +/- (10 kPa +10%).

APPLICATION

Using the analog output to provide pressure information to a microcomputer is very straightforward. The output voltage range, which goes from 0.5 volts at zero pressure to 4.5 volts at full scale, is designed to make optimum use of microcomputer A/D inputs. A direct connection from the evaluation board analog output to an A/D input is all that is required. Using the MC68HC11 as an example, the output is connected to any of the E ports, such as port E0 as shown in Figure 5. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 volts and V_{REFL} is tied to 0.3 volts by dividing down a 5.0 volt reference with 1% resistors.

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is the ease with which it can be designed. The interface between an MPX2000 series sensor and LM3914 bar graph display driver consists of one quad op amp and a few resistors. The result is a simple and inexpensive circuit that is capable of measuring pressure, vacuum, or differential pressure with an output that is directly compatible to a microprocessor.

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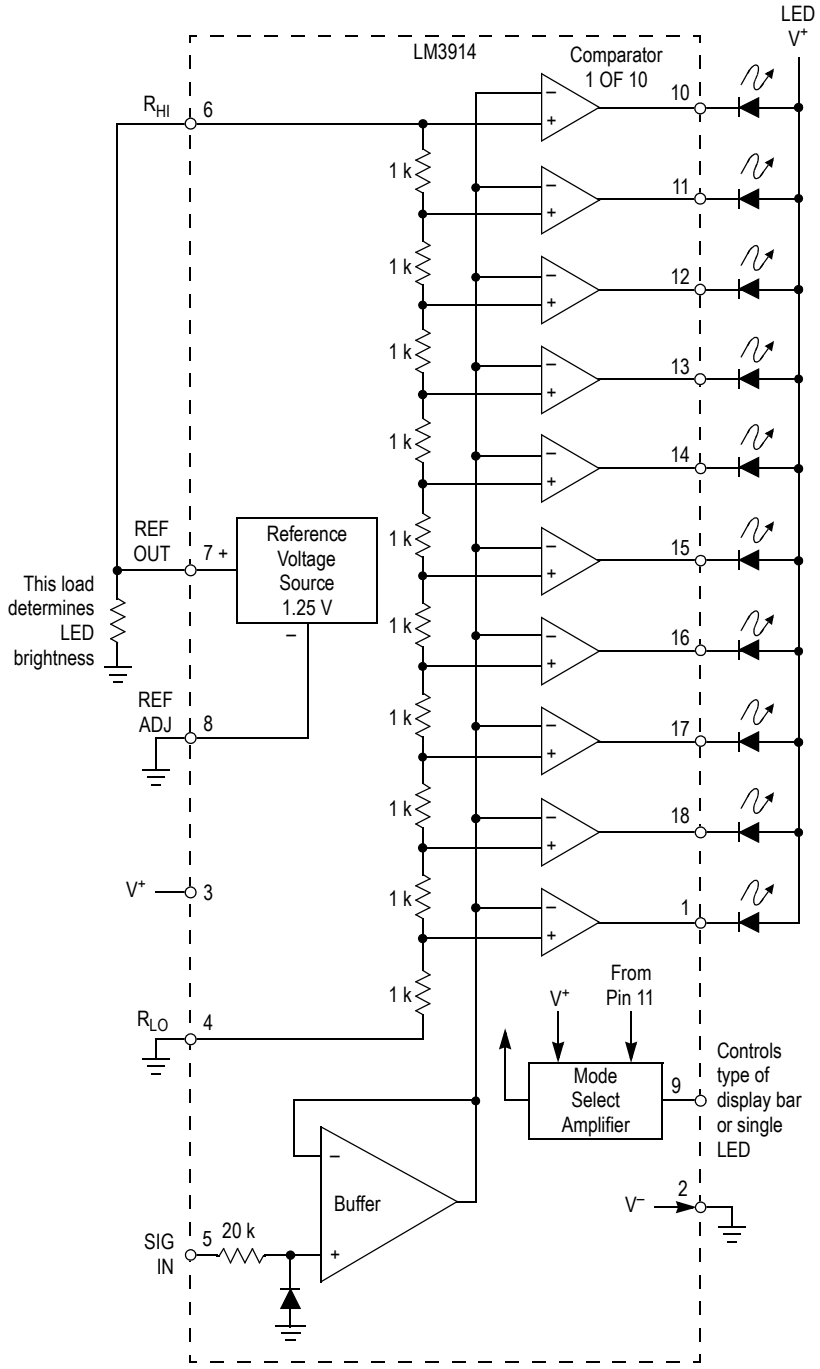

Figure 4. LM3914 Block Diagram

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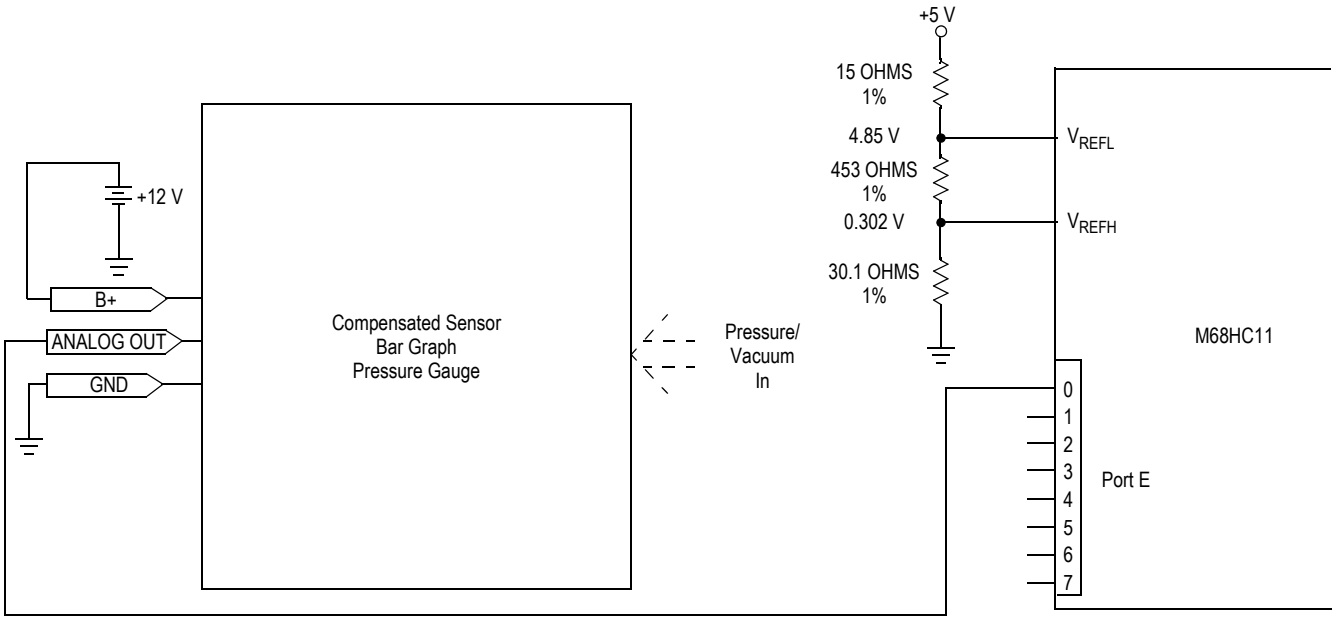

Figure 5. Application Example

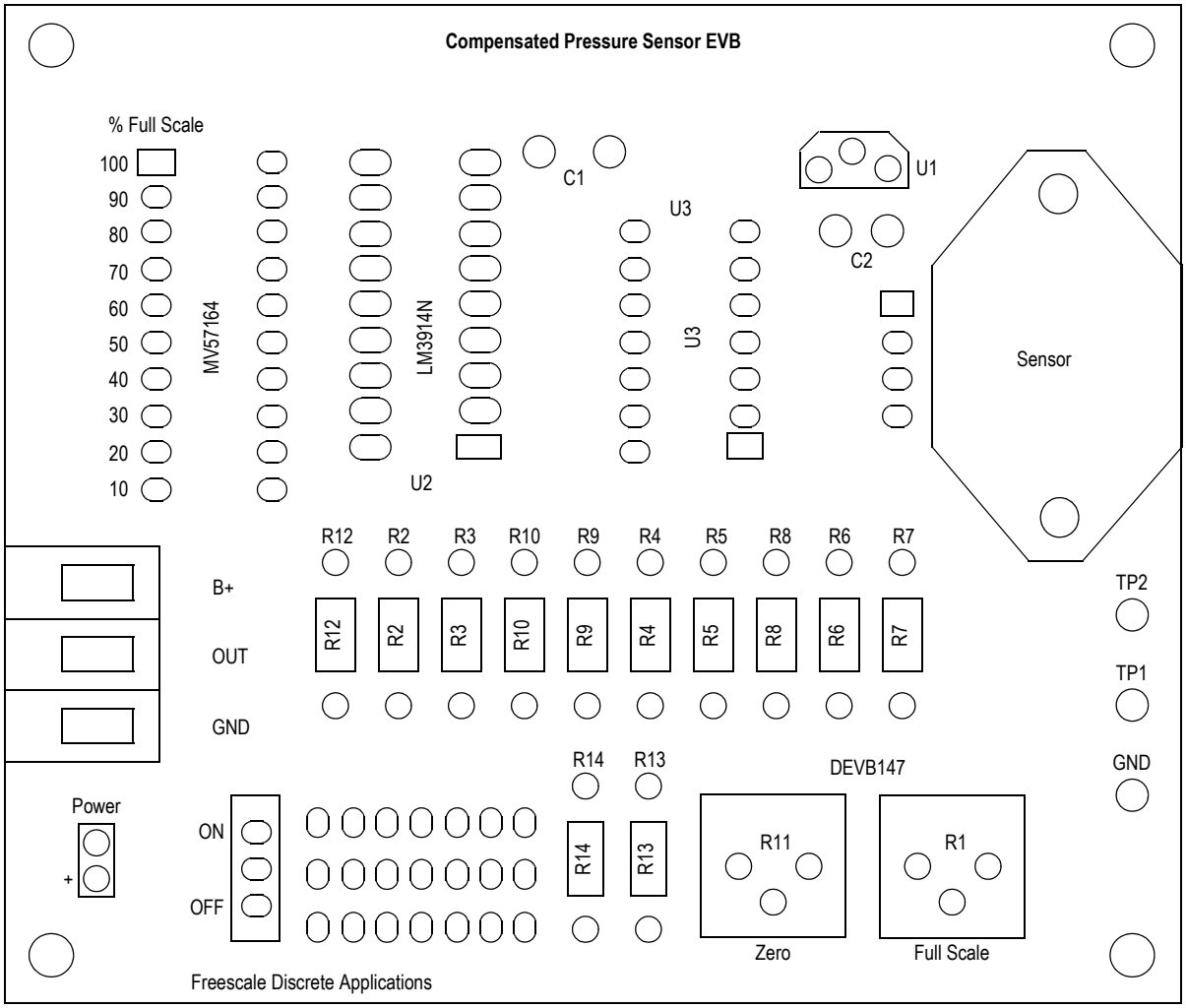

Figure 6. Silk Screen

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Table 1. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1	1	Ceramic Capacitor	1.0 μF		
C2	1	Ceramic Capacitor	0.1 μF		
D1-D10	1	Bar Graph LED		GI	MV57164
D11	1	LED		GI	MV57124A
R2	1	1/4 Watt Film Resistor	2.7K		
R3	1	1/4 Watt Film Resistor	1.2K		
R4, R5, R9, R13	4	1/4 Watt Film Resistor	1.0K		
R6	1	1/4 Watt Film Resistor	7.5K		
R7, R8	2	1/4 Watt Film Resistor	75		
R10	1	1/4 Watt Film Resistor	820		
R12, R14	2	1/4 Watt Film Resistor	470		
R1	1	Trimpot	1.0K	Bourns	3386P-1-102
R11	1	Trimpot	200	Bourns	3386P-1-201
S1	1	Switch		NKK	12SDP2
U1	1	5.0 V Regulator		Freescale	MC78L05ACP
U2	1	Bar Graph IC		National	LM3914N
U3	1	Op Amp		Freescale	MC33274P
XDCR1	1	Pressure Sensor		Freescale	MPX2100DP
—	1	Terminal Block		Augat	2SV03
—	1	Test Point Terminal (Black)		Components Corp.	TP1040100
—	1	Test Point Terminal (Red)		Components Corp.	TP1040102
—	1	Test Point Terminal (Yellow)		Components Corp.	TP1040104

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An Evaluation System Interfacing the MPX2000 Series Pressure Sensors to a Microprocessor

by: Bill Lucas
Discrete Applications Engineering

INTRODUCTION

Outputs from compensated and calibrated semiconductor pressure sensors such as the MPX2000 series devices are easily amplified and interfaced to a microprocessor. Design considerations and the description of an evaluation board using a simple analog interface connected to a microprocessor is presented here.

PURPOSE

The evaluation system shown in Figure 1 shows the ease of operating and interfacing the Freescale Semiconductor, Inc. MPX2000 series pressure sensors to a quad operational amplifier, which amplifies the sensor's output to an acceptable level for an analog-to-digital converter. The output of the op amp is connected to the A/D converter of the microprocessor and that analog value is then converted to engineering units and displayed on a liquid crystal display (LCD). This system may be used to evaluate any of the MPX2000 series pressure sensors for your specific application.

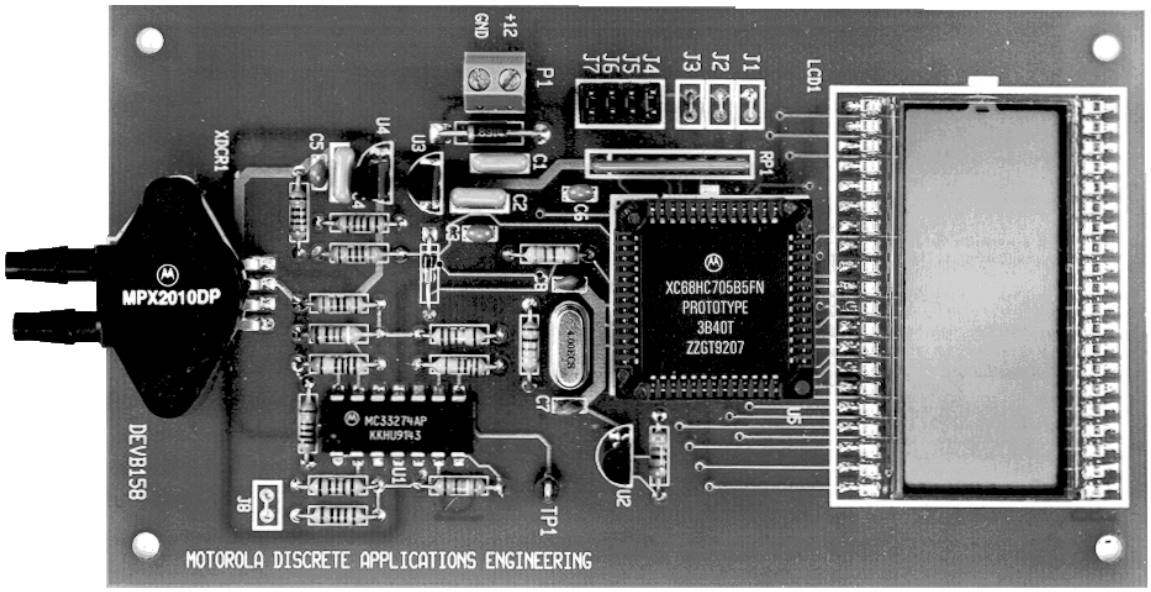

Figure 1. DEVB158 2000 Series LCD Pressure Gauge EVB (Board No Longer Available)

DESCRIPTION

The DEVB158 evaluation system is constructed on a small printed circuit board. Designed to be powered from a 12 Vdc power supply, the system will display the pressure applied to the MPX2000 series sensor in pounds per square inch (PSI) on the liquid crystal display. Table 1 shows the pressure sensors that may be used with the system and the pressure range associated with that particular sensor as well as the jumper configuration required to support that sensor. These jumpers are installed at assembly time to correspond with the supplied sensor. Should the user chose to evaluate a different sensor other than that supplied with the board, the jumpers must be changed to correspond to Table 1 for the new sensor. The displayed pressure is scaled to the full scale (PSI) range of the installed pressure sensor. No potentiometers are used in the system to adjust its span and offset. This function is performed by software.

Table 1. Missing Table Head

Sensor Type	Input Pressure PSI	Jumpers			
		J8	J3	J2	J1
MPX2010	0-1.5	IN	IN	IN	IN
MPX2050	0-7.5	OUT	IN	IN	OUT
MPX2100	0-15.0	OUT	IN	OUT	IN
MPX2200	0-30	OUT	IN	OUT	OUT

The signal conditioned sensor's zero pressure offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX2000 series pressure sensors is quite repeatable from unit to unit. There is a facility for a small adjustment of the slope constant built into the program. It is accomplished via jumpers J4 through J7, and will be explained in the OPERATION section.

Figure 2 shows the printed circuit silkscreen and Figure 3 and Figure 4show the schematic for the system.

The analog section of the system can be broken down into two subsections. These sections are the power supply and the amplification section. The power supply section consists of a diode, used to protect the system from input voltage reversal, and two fixed voltage regulators. The 5 volt regulator (U3) is used to power the microprocessor and display. The 8 volt regulator (U4) is used to power the pressure sensor, voltage references and a voltage offset source.

The microprocessor section (U5) requires minimal support hardware to function. The MC34064P-5 (U2) provides an under voltage sense function and is used to reset the microprocessor at system power-up. The 4.0 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and providing a stable base for timing functions.

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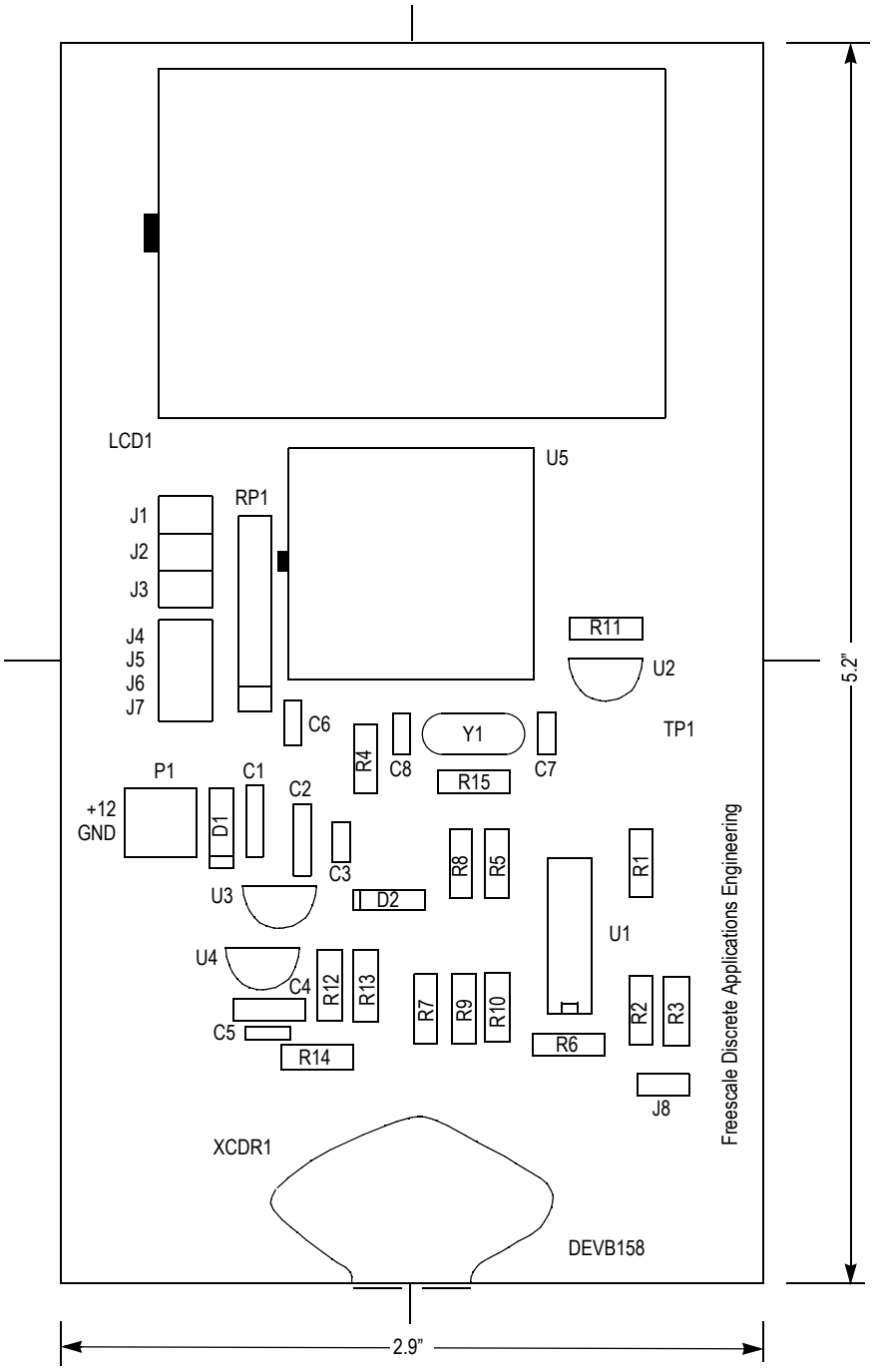

Figure 2. Printed Circuit Silkscreen

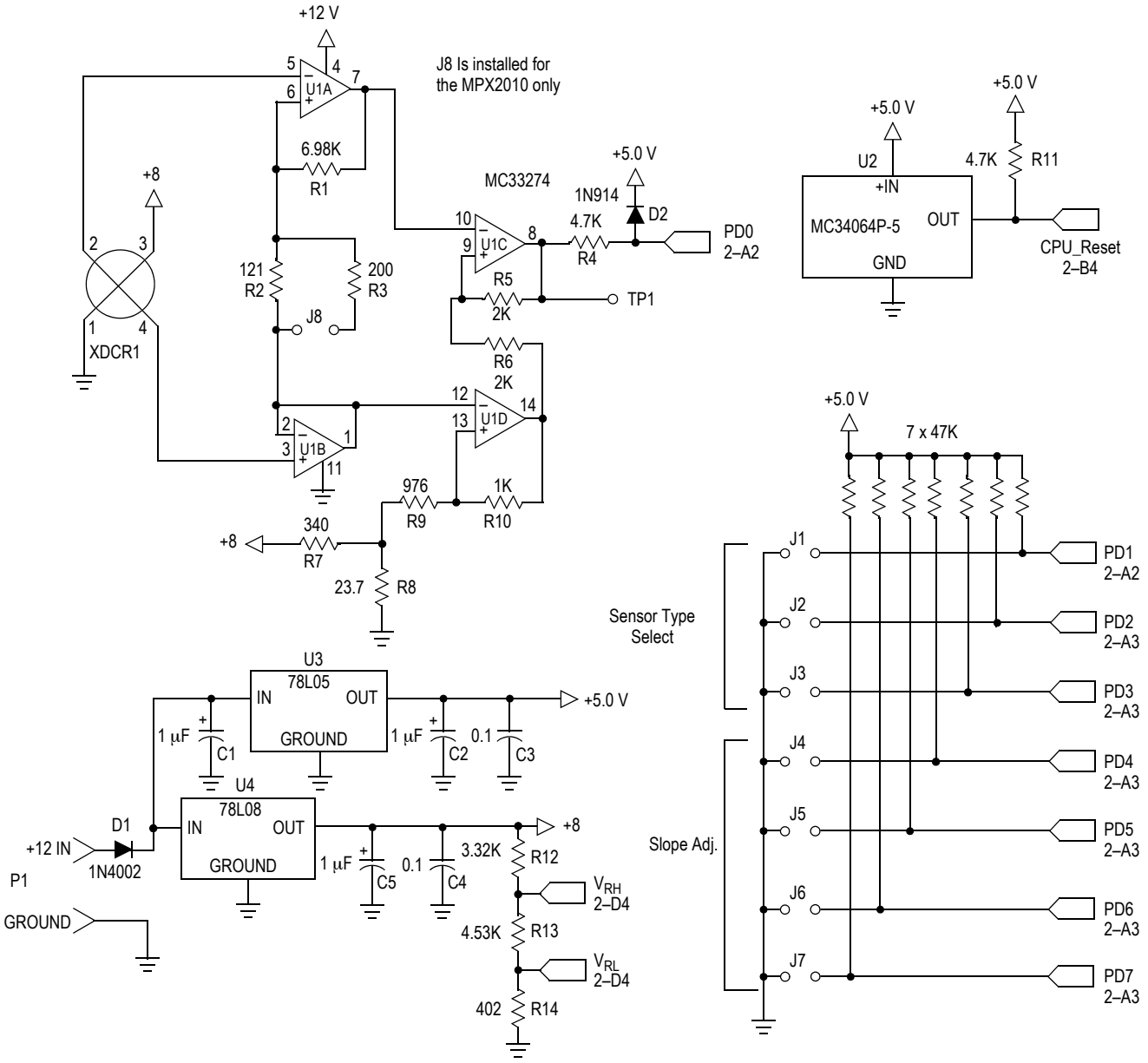

Figure 3. Schematic A

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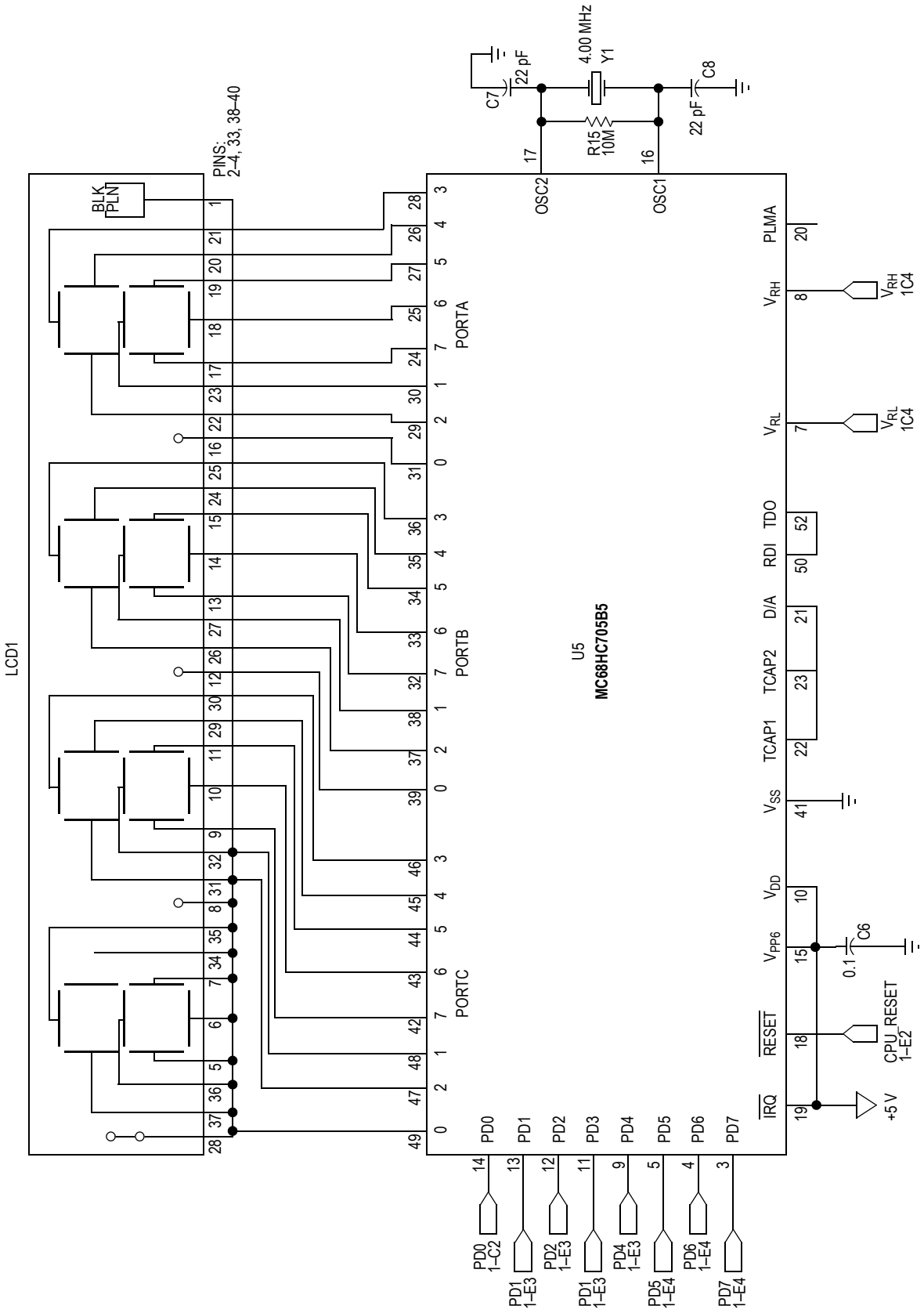

Figure 4. Schematic B

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Table 2. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C3, C4, C6	3	0.1 μF Ceramic Cap.	50 Vdc	Sprague	1C105Z5U104M050B
C1, C2, C5	3	1 μF Ceramic Cap.	50 Vdc	muRATA ERIE	RPE123Z5U105M050V
C7, C8	2	22 pF Ceramic Cap.	100 Vdc	Mepco/Centralab	CN15A220K
J1-J3, J8	3 OR 4	#22 or #24 AWG Tined Copper		As Required	
J4-J7	1	Dual Row Straight 4 Pos. Arranged On 0.1″ Grid		AMP	87227-2
LCD1	1	Liquid Crystal Display		IEE	LCD5657
P1	1	Power Connector		Phoenix Contact	MKDS 1/2-3.81
R1	1	6.98K Ohm resistor 1%			
R2	1	121 Ohm Resistor 1%			
R3	1	200 Ohm Resistor 1%			
R4, R11	2	4.7K Ohm Resistor			
R7	1	340 Ohm Resistor 1%			
R5, R6	2	2.0K Ohm Resistor 1%			
R8	1	23.7 Ohm Resistor 1%			
R9	1	976 Ohm Resistor 1%			
R10	1	1K Ohm Resistor 1%			
R12	1	3.32K Ohm Resistor 1%			
R13	1	4.53K Ohm Resistor 1%			
R14	1	402 Ohm Resistor 1%			
R15	1	10 Meg Ohm Resistor			
RP1	1	47K Ohm x 7 SIP Resistor 2%		CTS	770 Series
TP1	1	Test Point	Red	Components Corp.	TP-104-01-02
U1	1	Quad Operational Amplifier		Freescale	MC33274P
U2	1	Under Voltage Detector		Freescale	MC34064P-5
U3	1	5 Volt Fixed Voltage Regulator		Freescale	MC78L05ACP
U4	1	8 Volt Fixed Voltage Regulator		Freescale	MC78L08ACP
U5	1	Microprocessor		Freescale Freescale	MC68HC705B5FN or XC68HC705B5FN
XDCR	1	Pressure Sensor		Freescale	MPX2xxxDP
Y1	1	Crystal (Low Profile)	4.0 MHz	CTS	ATS040SLV
No Designator	1	52 Pin PLCC Socket for U5		AMP	821-575-1
No Designator	4	Jumpers For J4 thru J7		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			
No Designator	4	Self Sticking Feet		Fastex	5033-01-00-5001

Notes: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

OPERATIONAL CHARACTERISTICS

The following operational characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Max	Unit
Power Supply Voltage	+12	10.75	16	Volts
Operating Current	I_{CC}		75	mA
Full Scale Pressure	P_{fs}			
MPX2010			1.5	PSI
MPX2050			7.5	PSI
MPX2100			15	PSI
MPX2200			30	PSI

Pin-by-Pin Description

+12

Input power is supplied at the +12 terminal. The minimum operating voltage is 10.75 Vdc and the maximum operating voltage is 16 Vdc.

GND

The ground terminal is the power supply return for the system.

TP1

Test point 1 is connected to the final op amp stage. It is the voltage that is applied to the microprocessor's A/D converter.

There are two ports on the pressure sensor located at the bottom center of the printed circuit board. The pressure port is on the top left and the vacuum port is on the bottom right of the sensor.

OPERATION

Connect the system to a 12 Vdc regulated power supply. (Note the polarity marked on the power terminal P1.) Depending on the particular pressure sensor being used with the system, wire jumpers J1 through J3 and J8 must be installed at board assembly time. If at some later time it is desirable to change the type of sensor that is installed on the board, jumpers J1 through J3 and J8, must be reconfigured for the system to function properly (see Table 1). If an invalid J1 through J3 jumper combination (i.e., not listed in Table 1) is used the LCD will display “SE” to indicate that condition. These jumpers are read by the software and are used to determine which sensor is installed on the board. Wire jumper J8 is installed only when an MPX2010DP pressure sensor is used on the system. The purpose of wire jumper J8 will be explained later in the text. Jumpers J4 through J7 are read by the software to allow the user to adjust the slope constant used for the engineering units calculation (see Table 3). The pressure and vacuum ports on the sensor must be left open to atmosphere anytime the board is powered-up. This is because the zero pressure offset voltage is computed at power-up.

When you apply power to the system, the LCD will display CAL for approximately 5 seconds. After that time, pressure or vacuum may be applied to the sensor. The system will then start displaying the applied pressure in PSI.

Table 3. Slope Constants

J7	J6	J5	J4	Action
IN	IN	IN	IN	Normal Slope
IN	IN	IN	OUT	Decrease the Slope Approximately 7%
IN	IN	OUT	IN	Decrease the Slope Approximately 6%
IN	IN	OUT	OUT	Decrease the Slope Approximately 5%
IN	OUT	IN	IN	Decrease the Slope Approximately 4%
IN	OUT	IN	OUT	Decrease the Slope Approximately 3%
IN	OUT	OUT	IN	Decrease the Slope Approximately 2%
IN	OUT	OUT	OUT	Decrease the Slope Approximately 1%
OUT	IN	IN	IN	Increase the Slope Approximately 1%
OUT	IN	IN	OUT	Increase the Slope Approximately 2%
OUT	IN	OUT	IN	Increase the Slope Approximately 3%
OUT	IN	OUT	OUT	Increase the Slope Approximately 4%
OUT	OUT	IN	IN	Increase the Slope Approximately 5%
OUT	OUT	IN	OUT	Increase the Slope Approximately 6%
OUT	OUT	OUT	IN	Increase the Slope Approximately 7%
OUT	OUT	OUT	OUT	Normal Slope

To improve the accuracy of the system, you can change the constant used by the program that determines the span of the sensor and amplifier. You will need an accurate test gauge (using PSI as the reference) to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation, (after CAL is no longer displayed) apply the sensor's full scale pressure (see Table 1), to the sensor. Make sure that jumpers J4 through J7 are in the “normal” configuration (see Table 3). Referring to Table 3, you can better “calibrate” the system by changing the configuration of J4 through J7. To “calibrate” the system, compare the display reading against that of the test gauge (with J4 through J7 in the “normal slope” configuration). Change the configuration of J4 through J7 according to Table 3 to obtain the best results. The calibration jumpers may be changed while the system is powered up as they are read by the software before each display update.

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DESIGN CONSIDERATIONS

To build a system that will show how to interface an MPX2000 series pressure sensor to a microprocessor, there are two main challenges. The first is to take a small differential signal produced by the sensor and produce a ground referenced signal of sufficient amplitude to drive a microprocessor's A/D input. The second challenge is to understand the microprocessor's operation and to write software that makes the system function.

From a hardware point of view, the microprocessor portion of the system is straight forward. The microprocessor needs power, a clock source (crystal Y1, two capacitors and a resistor), and a reset signal to make it function. As for the A/D converter, external references are required to make it function. In this case, the power source for the sensor is divided to produce the voltage references for the A/D converter. Accurate results will be achieved since the output from the sensor and the A/D references are ratiometric to its power supply voltage.

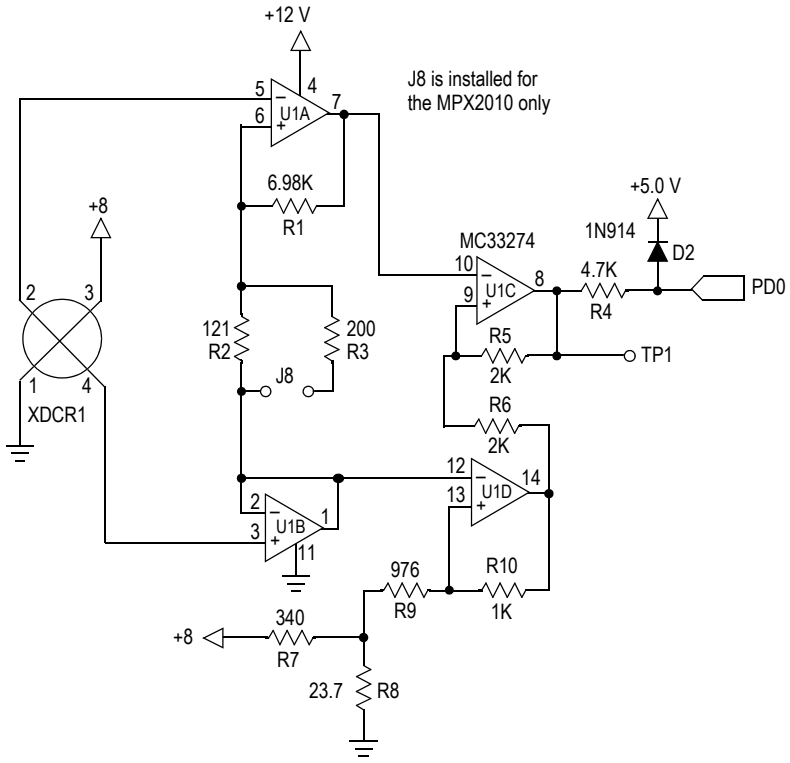

Figure 5. Analog Interface

The liquid crystal display is driven by Ports A, B and C of the microprocessor. There are enough I/O lines on these ports to provide drive for three full digits, the backplane and two decimal points. Software routines provide the AC waveform necessary to drive the display.

The analog portion of the system consists of the pressure sensor, a quad operational amplifier and the voltage references for the microprocessor's A/D converter and signal conditioning circuitry. Figure 5 shows an interface circuit that will provide a single ended signal with sufficient amplitude to drive the microprocessor's A/D input. It uses a quad operational amplifier and several resistors to amplify and level shift the sensor's output. It is necessary to level shift the output from the final amplifier into the A/D. Using single power supplied op amps, the V_{CE} saturation of the output from an op amp cannot be guaranteed to pull down to zero volts. The analog design shown here will provide a signal to the A/D converter with a span of approximately 4 volts when zero to full-scale pressure is applied to the sensor. The final amplifier's output is level shifted to approximately 0.7 volts. This will provide a signal that will swing between approximately 0.7 volts and 4.7 volts. The offset of 0.7 volts in this implementation does not have to be trimmed to an exact point. The software will sample the voltage applied to the A/D converter at initial power up time and call that value “zero”. The important thing to remember is that the span of the signal will be approximately 4 volts when zero to full scale pressure is applied to the sensor. The 4 volt swing in signal may vary slightly from sensor to sensor and can also vary due to resistor tolerances in the analog circuitry. Jumpers J4 through J7 may be placed in various configurations to compensate for these variations (see Table 3).

Referring to Figure 5, most of the amplification of the voltage from the pressure sensor is provided by U1A which is

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configured as a differential amplifier. U1B serves as a unity gain buffer in order to keep any current that flows through R2 (and R3) from being fed back into the sensor's negative output. With zero pressure applied to the sensor, the differential voltage from pin 2 to pin 4 of the sensor is zero or very close to zero volts. The common mode, or the voltage measured between pins 2 or 4 to ground, is equal to approximately one half of the voltage applied to the sensor, or 4 volts. The zero pressure output voltage at pin 7 of U1A will then be 4 volts because pin 1 of U1B is also at 4 volts, creating a zero bias between pins 5 and 6 of U1A. The four volt zero pressure output will then be level shifted to the desired zero pressure offset voltage (approximately 0.7 volts) by U1C and U1D.

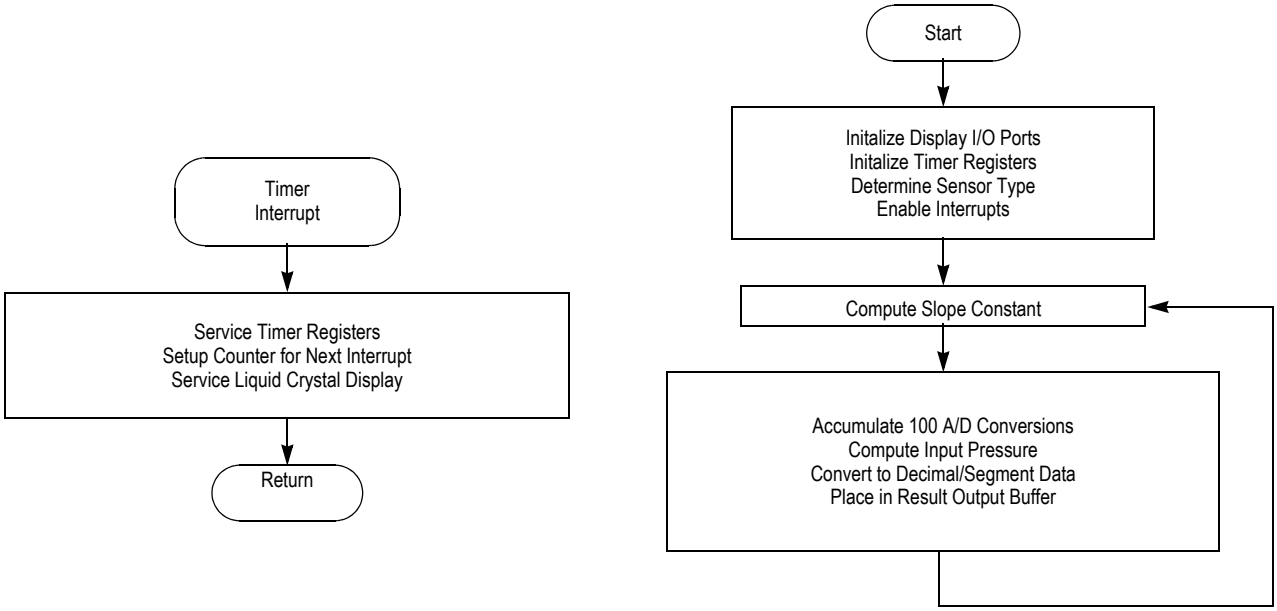

Figure 6. DEVB-158 Software Flowchart

To further explain the operation of the level shifting circuitry, refer again to Figure 5. Assuming zero pressure is applied to the sensor and the common mode voltage from the sensor is 4 volts, the voltage applied to pin 12 of U1D will be 4 volts, implying pin 13 will be at 4 volts. The gain of amplifier U1D will be (R10/(R8+R9)) +1 or a gain of 2. R7 will inject a V_{offset} (0.7 volts) into amplifier U1D, thus causing the output at U1D pin 14 to be 7.3 = (4 volts @ U1D pin 12 × 2) - 0.7 volts. The gain of U1C is also set at 2 ((R5/R6)+1). With 4 volts applied to pin 10 of U1C, its output at U1C pin 8 will be 0.7 = ((4 volts @ U1C pin 10 × 2) - 7.3 volts). For this scheme to work properly, amplifiers U1C and U1D must have a gain of 2 and the output of U1D must be shifted down by the V_{offset} provided by R7. In this system, the 0.7 volts V_{offset} was arbitrarily picked and could have been any voltage greater than the V_{sat} of the op amp being used. The system software will take in account any variations of V_{offset} as it assumes no pressure is applied to the sensor at system power up.

The gain of the analog circuit is approximately 117. With the values shown in Figure 5, the gain of 117 will provide a span of approximately 4 volts on U1C pin 8 when the pressure sensor and the 8 volt fixed voltage regulator are at their maximum output voltage tolerance. All of the sensors listed in Table 1 with the exception of the MPX2010DP output approximately 33 mV when full scale pressure is applied. When the MPX2010DP sensor is used, its full scale sensor differential output is approximately 20 mV. J8 must be installed to increase the gain of the analog circuit to still provide the 4 volts span out of U1C pin 8 with a 20 mV differential from the sensor.

Diode D2 is used to protect the microprocessor's A/D input if the output from U1C exceeds 5.6 volts. R4 is used to provide current limiting into D4 under failure or overvoltage conditions.

SOFTWARE

The source code, compiled listing, and S-record output for the software used in this system are available on the Freescale Freeware Bulletin Board Service in the MCU directory under the filename DEVB158.ARC. To access the bulletin board, you must have a telephone line, a 300, 1200 or 2400 baud modem and a personal computer. The modem must be compatible with the Bell 212A standard. Call (512) 891-3733 to access the Bulletin Board Service.

Figure 6 is a flowchart for the program that controls the system. The software for the system consists of a number of modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX2000 series pressure sensor.

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The “C” compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide a software loop delay.

read_a2d() Performs 100 reads on the A/D converter on multiplexer channel 0 and returns the accumulation.

fixcompare() Services the internal timer for 15 ms. timer compare interrupts.

TIMERCMP() Alternates the data and backplane inputs to the liquid crystal display.

initio() Sets up the microprocessor's I/O ports, timer and enables processor interrupts.

adzero() This routine is called at powerup time. It delays to let the power supply and the transducer stabilize. It then calls “read_atod()” and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg This routine converts the unsigned binary argument passed in “arg” to a five digit decimal number in an array called “digit.” It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. This is then output to the display.

display_psi() This routine is called from “main()” never to return. The A/D converter routine is called, the pressure is calculated based on the type sensor detected and the pressure applied to the sensor is displayed. The loop then repeats.

sensor_type() This routine determines the type of sensor from reading J1 to J3, setting the full scale pressure for that particular sensor in a variable for use by display_psi().

sensor_slope() This routine determines the slope constant to be used by display_psi() for engineering units output.

main() This is the main routine called from reset. It calls “initio()” to setup the system's I/O. “display_psi()” is called to compute and display the pressure applied to the sensor.

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```
                            #pragma option f0;
                            /*

                            THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB158 EVALUATION
                            BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                                BYTE CRAFT LTD.
                                                                421 KING ST.
                                                                WATERLOO, ONTARIO
                                                                CANADA  N2J 4E4
                                                                (519)888-6911

                            SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                            COMPILERS.
                                                        BILL LUCAS 2/5/92
                                                        Freescale, SPS

                            Revision history
                            rev. 1.0 initial release 3/19/92
                            rev. 1.1 added additional decimal digit to the MPX2010 sensor. Originally
                            resolved the output to .1 PSI. Modified cvt_bin_dec to output PSI resolved
                            to .01 PSI. WLL 9/25/92

                            */
0800 1700                   #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096                   #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                            /*       Vector assignments    */
1FFE                        #pragma vector __RESET   @ 0x1ffe ;
1FFC                        #pragma vector __SWI     @ 0x1ffc ;
1FFA                        #pragma vector IRQ       @ 0x1ffa ;
1FF8                        #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                        #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                        #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                        #pragma vector SCI       @ 0x1ff2 ;

                            #pragma has STOP ;
                            #pragma has WAIT ;
                            #pragma has MUL ;

                            /*       Register assignments for the 68HC705B5 microcontroller     */
0000                        #pragma portrw porta   @ 0x00;  /*                                          */
0001                        #pragma portrw portb   @ 0x01;  /*                                          */
0002                        #pragma portrw portc   @ 0x02;  /*                                          */
0003                        #pragma portrw portd   @ 0x03;  /* in  ,-    ,SS   ,SCK  ,MOSI ,MISO,TxD,RxD */
0004                        #pragma portrw ddra    @ 0x04;  /* Data direction, Port A                   */
0005                        #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B                   */
0006                        #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)      */
0007                        #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                        #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                        #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                        #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                        #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                        #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                        #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                        #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                        #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                        #pragma portrw scistat @ 0x10;  /* sci status reg */
0011                        #pragma portrw scidata   @ 0x11;  /* SCI Data  */
0012                        #pragma portrw tcr       @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL         */
0013                        #pragma portrw tsr       @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0                 */
0014                        #pragma portrw icaphi1   @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0015                        #pragma portrw icaplo1   @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0016                        #pragma portrw ocmphi1   @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0017                        #pragma portrw ocmplo1   @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0018                        #pragma portrw tcnthi    @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
0019                        #pragma portrw tcntlo    @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
001A                        #pragma portrw aregnthi    @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001B                        #pragma portrw aregntlo    @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001C                        #pragma portrw icaphi2   @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
001D                        #pragma portrw icaplo2   @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
```


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```
001E                            #pragma portrw ocmphi2   @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */
001F                            #pragma portrw ocmplo2   @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */

1EFE 74                         #pragma mor @ 0x1efe = 0x74; /* this disables the watchdog counter and does
                                                                not add pull-down resistors on ports B and C */

                                     /* put constants and variables here...they must be global */
                                  /*************************************************************************/

0800 FC 30 DA 7A 36 6E E6 38 FE   const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                  /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */

080A 27 10 03 E8 00 64 00 0A      const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                         unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec function */

0812 00 96 00 4B 00 96 00 1E 00   const long type[] = {  150,     75,      150,     30,      103   };
081B 67
                                  /*                   MPX2010  MPX2050  MPX2100  MPX2200  MPX2700
                                  The table above will cause the final results of the pressure to
                                  engineering units to display the 1.5, 7.3 and 15.0 devices with a
                                  decimal place in the tens position. The 30 and 103 psi devices will
                                  display in integer units.
                                  */

                                  const long slope_const[]={ 450,418,423,427,432,436,441,445,454,459,
081C 01 C2 01 A2 01 A7 01 AB 01                              463,468,472,477,481,450 };
0825 B0 01 B4 01 B9 01 BD 01 C6
082E 01 CB 01 CF 01 D4 01 D8 01
0837 DD 01 E1 01 C2

0000                            registera areg;    /* processor's A register */

0055                            long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */

0059                            long slope;        /* multiplier for adc to engineering units conversion */

005B                            int adcnt;         /* a/d converter loop counter */

005C                            long xdcr_offset;  /* initial xdcr offset */

005E                            long sensor_model; /*  installed sensor based on J1..J3 */
0060                            int sensor_index;  /*  determine the location of the decimal pt. */

0061 0063                       unsigned long i,j; /* counter for loops */

0065                            unsigned int k;    /* misc variable */

                                  struct bothbytes
                                     {  int hi;
                                        int lo;
                                     };

                                     union isboth
                                        {  long  l;
                                         struct bothbytes b;
                                        };

0066 0002                               union isboth q;  /* used for timer set-up */

                                  /*************************************************************************/

                                /* variables for add32  */
0068 0004                       unsigned long SUM[2];    /*     result        */
006C 0004                       unsigned long ADDEND[2]; /*     one input     */
0070 0004                       unsigned long AUGEND[2]; /*     second input  */

                                /* variables for sub32  */
0074 0004                       unsigned long MINUE[2];  /*     minuend       */
0078 0004                       unsigned long SUBTRA[2]; /*     subtrahend    */
```


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```
007C 0004                       unsigned long DIFF[2];   /*     difference    */

                                /* variables for mul32  */
0080 0004                       unsigned long MULTP[2];  /*     multiplier    */
0084 0004                       unsigned long MTEMP[2];  /*     high order 4 bytes at return */
0088 0004                       unsigned long MULCAN[2]; /*     multiplicand at input, low 4 bytes at return */

                                  /* variables for div32 */
008C 0004                       unsigned long DVDND[2];  /*     Dividend      */
0090 0004                       unsigned long DVSOR[2];  /*     Divisor       */
0094 0004                       unsigned long QUO[2];    /*     Quotient      */
0098                            unsigned int  CNT;       /*     Loop counter  */

                                                    /* The code starts here */

                                  /*************************************************************************/

                                  void add32()
                                  {
                                  #asm

                        *-------------------------------------------------------------------------*
                        * Add two 32-bit values.
                        *    Inputs:
                        *       ADDEND: ADDEND[0..3]  HIGH ORDER BYTE IS ADDEND+0
                        *       AUGEND: AUGEND[0..3]  HIGH ORDER BYTE IS AUGEND+0
                        *    Output:
                        *       SUM: SUM[0..3]  HIGH ORDER BYTE IS SUM+0
                        *-------------------------------------------------------------------------*
                        *
083C B6 6F                        LDA  ADDEND+3   low byte
083E BB 73                        ADD  AUGEND+3
0840 B7 6B                        STA  SUM+3
0842 B6 6E                        LDA  ADDEND+2   medium low byte
0844 B9 72                        ADC  AUGEND+2
0846 B7 6A                        STA  SUM+2
0848 B6 6D                        LDA  ADDEND+1   medium high byte
084A B9 71                        ADC  AUGEND+1
084C B7 69                        STA  SUM+1
084E B6 6C                        LDA  ADDEND     high byte
0850 B9 70                        ADC  AUGEND
0852 B7 68                        STA  SUM
0854 81                           RTS            done
                        *
                                    #endasm
0855 81       RTS                   }

                                    void sub32()
                                    {
                                    #asm
                        *-------------------------------------------------------------------------*
                        * Subtract two 32-bit values.
                        *    Input:
                        *       Minuend: MINUE[0..3]
                        *       Subtrahend: SUBTRA[0..3]
                        *    Output:
                        *       Difference: DIFF[1..0]
                        *-------------------------------------------------------------------------*
                        *
0856 B6 77                        LDA  MINUE+3    low byte
0858 B0 7                         SUB  SUBTRA+3
085A B7 7F                        STA  DIFF+3
085C B6 76                        LDA  MINUE+2    medium low byte
085E B2 7A                        SBC  SUBTRA+2
0860 B7 7E                        STA  DIFF+2
0862 B6 75                        LDA  MINUE+1    medium high byte
0864 B2 79                        SBC  SUBTRA+1
0866 B7 7D                        STA  DIFF+1
0868 B6 74                        LDA  MINUE      high byte
086A B2 78                        SBC  SUBTRA
086C B7 7C                        STA  DIFF
086E 81                           RTS            done
                        *
```

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```
                                #endasm
086F 81       RTS               }

                                     void mul32()
                                     {
                                     #asm
                        *-------------------------------------------------------------------------*
                        * Multiply 32-bit value by a 32-bit value
                        *
                        *
                        *    Input:
                        *       Multiplier:    MULTP[0..3]
                        *       Multiplicand:  MULCAN[0..3]
                        *    Output:
                        *       Product:       MTEMP[0..3] AND MULCAN[0..3] MTEMP[0] IS THE HIGH
                        *                          ORDER BYTE AND MULCAN[3] IS THE LOW ORDER BYTE
                        *
                        *   THIS ROUTINE DOES NOT USE THE MUL INSTRUCTION FOR THE SAKE OF USERS NOT
                        *   USING THE HC(7)05 SERIES PROCESSORS.
                        *-------------------------------------------------------------------------*
                        *
                        *
0870 AE 20                        LDX  #32        loop counter
0872 3F 84                        CLR  MTEMP      clean-up for result
0874 3F 85                        CLR  MTEMP+1    *
0876 3F 86                        CLR  MTEMP+2    *
0878 3F 87                        CLR  MTEMP+3    *
087A 36 88                        ROR  MULCAN     low but to carry, the rest one to the right
087C 36 89                        ROR  MULCAN+1   *
087E 36 8A                        ROR  MULCAN+2   *
0880 36 8B                        ROR  MULCAN+3   *
0882 24 18                MNEXT   BCC  ROTATE     if carry is set, do the add
0884 B6 87                        LDA  MTEMP+3    *
0886 BB 83                        ADD  MULTP+3    *
0888 B7 87                        STA  MTEMP+3    *
088A B6 86                        LDA  MTEMP+2    *
088C B9 82                        ADC  MULTP+2    *
088E B7 86                        STA  MTEMP+2    *
0890 B6 85                        LDA  MTEMP+1    *
0892 B9 81                        ADC  MULTP+1    *
0894 B7 85                        STA  MTEMP+1    *
0896 B6 84                        LDA  MTEMP      *
0898 B9 80                        ADC  MULTP      *
089A B7 84                        STA  MTEMP      *
089C 36 84                ROTATE  ROR  MTEMP     else: shift low bit to carry, the rest to the right
089E 36 85                        ROR  MTEMP+1    *
08A0 36 86                        ROR  MTEMP+2    *
08A2 36 87                        ROR  MTEMP+3    *
08A4 36 88                        ROR  MULCAN     *
08A6 36 89                        ROR  MULCAN+1   *
08A8 36 8A                        ROR  MULCAN+2   *
08AA 36 8B                        ROR  MULCAN+3   *
08AC 5A                           DEX            bump the counter down
08AD 26 D3                        BNE  MNEXT     done yet ?
08AF 81                           RTS            done

                                #endasm
08B0 81       RTS               }

                                  void div32()
                                  {
                                  #asm
                         *
                         *-------------------------------------------------------------------------*
                         * Divide 32 bit by 32 bit unsigned integer routine
                         *
                         *    Input:
                         *       Dividend:  DVDND [+0..+3] HIGH ORDER BYTE IS DVND+0
                         *       Divisor:   DVSOR [+0..+3] HIGH ORDER BYTE IS DVSOR+0
                         *    Output:
                         *       Quotient:  QUO [+0..+3]   HIGH ORDER BYTE IS QUO+0
                         *-------------------------------------------------------------------------*
                         *
```

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```
08B1 3F 94                      CLR  QUOzero result registers
08B3 3F 95                      CLR  QUO+1      *
08B5 3F 96                      CLR  QUO+2      *
08B7 3F 97                      CLR  QUO+3      *
08B9 A6 01                      LDA  #1         initial loop count
08BB 3D 90                      TST  DVSOR      if the high order bit is set..no need to shift DVSOR
08BD 2B 0F                      BMI  DIV153
                     *
08BF 4C                DIV151  INCA            bump the loop counter
08C0 38 93              ASL  DVSOR+3    now shift the divisor until the high order bit = 1
08C2 39 92                      ROL  DVSOR+2
08C4 39 91                      ROL  DVSOR+1    *
08C6 39 90                      ROL  DVSOR      *
08C8 2B 04              BMI  DIV153     done if high order bit = 1
08CA A1 21                      CMP  #33        have we shifted all possible bits in the DVSOR yet ?
08CC 26 F1                      BNE  DIV151     no
                     *
08CE B7 9              DIV153   STA  CNT        save the loop counter so we can do the divide
                     *
08D0 B6 8F             DIV163   LDA  DVDND+3    sub 32 bit divisor from dividend
08D2 B0 93                      SUB  DVSOR+3    *
08D4 B7 8F                      STA  DVDND+3    *
08D6 B6 8E                      LDA  DVDND+2    *
08D8 B2 92                      SBC  DVSOR+2    *
08DA B7 8E                      STA  DVDND+2    *
08DC B6 8D                      LDA  DVDND+1    *
08DE B2 91                      SBC  DVSOR+1    *
08E0 B7 8D                      STA  DVDND+1    *
08E2 B6 8C                      LDA  DVDND      *
08E4 B2 90                      SBC  DVSOR      *
08E6 B7 8C                      STA  DVDND      *
08E8 24 1B                      BCC  DIV165     carry is clear if DVSOR was larger than DVDND
                     *
08EA B6 8F                      LDA  DVDND+3    add the divisor back...was larger than the dividend
08EC BB 93                      ADD  DVSOR+3    *
08EE B7 8F                      STA  DVDND+3    *
08F0 B6 8E                      LDA  DVDND+2    *
08F2 B9 92                      ADC  DVSOR+2    *
08F4 B7 8E                      STA  DVDND+2    *
08F6 B6 8D                      LDA  DVDND+1    *
08F8 B9 91                      ADC  DVSOR+1    *
08FA B7 8D                      STA  DVDND+1    *
08FC B6 8C                      LDA  DVDND      *
08FE B9 90                      ADC  DVSOR      *
0900 B7 8C                      STA  DVDND      *
0902 98                         CLC             this will clear the respective bit in QUO due to
                     *                            the need to add DVSOR back to DVND
0903 20 01                      BRA  DIV167
0905 99                DIV165   SEC             this will set the respective bit in QUO
0906 39 97             DIV167   ROL  QUO+3      set or clear the low order bit in QUO based on above
0908 39 96                      ROL  QUO+2      *
090A 39 95                      ROL  QUO+1      *
090C 39 94                      ROL  QUO        *
090E 34 90                      LSR  DVSOR     divide the divisor by 2
0910 36 91                      ROR  DVSOR+1    *
0912 36 92                      ROR  DVSOR+2    *
0914 36 93                      ROR  DVSOR+3    *
0916 3A 98                      DEC  CNT        bump the loop counter down
0918 26 B6                      BNE  DIV163     finished yet ?
091A 81                         RTSyes
                     *


                                #endasm
091B 81        RTS              }

                                /*****************************************************************************/

                                /* These interrupts are not used...give them a graceful return for
                                   some reason one occurs */

1FFC 09 1C                      __SWI(){}
091C 80        RTI
1FFA 09 1D                      IRQ(){}
```


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```
091D 80       RTI
1FF8 09 1E                    TIMERCAP(){}
091E 80       RTI
1FF4 09 1F                    TIMEROV(){}
091F 80       RTI
1FF2 09 20                    SCI(){}
0920 80       RTI

                                /*************************************************************************/

                                void sensor_type()
                                {
0921 B6 03    LDA    $03      k = portd & 0x0e;  /* we only care about bits 1..3 */
0923 A4 0E    AND    #$0E
0925 B7 65    STA    $65
0927 34 65    LSR    $65      k = k >> 1;    /* right justify the variable */
0929 B6 65    LDA    $65       if ( k > 4 )
092B A1 04    CMP    #$04
092D 23 0C    BLS    $093B
                                   { /* we have a set-up error in wire jumpers J1 - J3 */
092F 3F 02    CLR    $02         portc = 0;     /*   */
0931 A6 6E    LDA    #$6E        portb = 0x6e;  /* S */
0933 B7 01    STA    $01
0935 A6 CE    LDA    #$CE        porta = 0xce;  /* E */
0937 B7 00    STA    $00
0939 20 FE    BRA    $0939          while(1);
                                     }
093B B6 65    LDA    $65      sensor_index = k;
093D B7 60    STA    $60
093F 97       TAX             sensor_model = type[k];
0940 58       LSLX
0941 D6 08 12 LDA    $0812,X
0944 B7 5E    STA    $5E
0946 D6 08 13 LDA    $0813,X
0949 B7 5F    STA    $5F
094B 81       RTS             }

                                /*************************************************************************/

                                void sensor_slope()
                                {
094C B6 03    LDA    $03      k=portd & 0xf0;  /* we only care about bits 4..7 */
094E A4 F0    AND    #$F0
0950 B7 65    STA    $65
0952 34 65    LSR    $65        k = k >> 4;    /* right justify the variable */
0954 34 65    LSR    $65
0956 34 65    LSR    $65
0958 34 65    LSR    $65
095A BE 65    LDX    $65      slope = slope_const[k];
095C 58       LSLX
095D D6 08 1C LDA    $081C,X
0960 B7 59    STA    $59
0962 D6 08 1D LDA    $081D,X
0965 B7 5A    STA    $5A
0967 81       RTS             }

                                /*************************************************************************/

                                void delay(void)  /* just hang around for a while */
                                {
0968 3F 62    CLR    $62      for (i=0; i<20000; ++i);
096A 3F 61    CLR    $61
096C B6 62    LDA    $62
096E A0 20    SUB    #$20
0970 B6 61    LDA    $61
0972 A2 4E    SBC    #$4E
0974 24 08    BCC    $097E
0976 3C 62    INC    $62
0978 26 0     BNE    $097C
097A 3C 61    IN     $61
097C 20 EE    BRA    $096C
097E 81       RTS             }
```


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```
                                    /*************************************************************************/

                                    read_a2d(void)
                                    {
                                    /* read the a/d converter on channel 5 and accumulate the result
                                    in atodtemp */

097F 3F 56     CLR    $56          atodtemp=0;   /* zero for accumulation */
0981 3F 55     CLR    $55
0983 3F 5B     CLR    $5B            for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
0985 B6 5B     LDA    $5B
0987 A8 80     EOR    #$80
0989 A1 E4     CMP    #$E4
098B 24 21     BCC    $09AE
                                        {
098D A6 20     LDA    #$20           adstat = 0x20;  /* convert on channel 0 */
098F B7 09      STA    $09
0991 0F 09 FD BRCLR 7,$09,$0991        while (!(adstat & 0x80));  /* wait for a/d to complete */
0994 B6 08     LDA    $08              atodtemp = addata + atodtemp;
0996 3F 57     CLR    $57
0998 B7 58     STA    $58
099A BB 56     ADD    $56
099C B7 58     STA    $58
099E B6 57     LDA    $57
09A0 B9 55     ADC    $55
09A2 B7 57     STA    $57
09A4 B7 55     STA    $55
09A6 B6 58     LDA    $58
09A8 B7 56     STA    $56
                                        }
09AA 3C 5B     INC    $5B
09AC 20 D7     BRA    $0985
09AE B6 56     LDA    $56            atodtemp = atodtemp/100;
09B0 B7 58     STA    $58
09B2 B6 55     LDA    $55
09B4 B7 57     STA    $57
09B6 3F 9A     CLR    $9A
09B8 A6 64     LDA    #$64
09BA B7 9B     STA    $9B
09BC CD 0B F1 JSR     $0BF1
09BF CD 0C 22 JSR     $0C22
09C2 BF 55     STX    $55
09C4 B7 56     STA    $56
09C6 81        RTS                  return atodtemp;
                                    }

                                    /*************************************************************************/

                                    void fixcompare (void)  /* sets-up the timer compare for the next interrupt */
                                       {
09C7 B6 18     LDA    $18            q.b.hi =tcnthi;
09C9 B7 66     STA    $66
09CB B6 19     LDA    $19              q.b.lo = tcntlo;
09CD B7 67     STA    $67
09CF AB 4C     ADD    #$4C              q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms. */
09D1 B7 67     STA    $67
09D3 B6 66     LDA    $66
09D5 A9 1D     ADC    #$1D
09D7 B7 66     STA    $66
09D9 B7 16     STA    $16              ocmphi1 = q.b.hi;
09DB B6 13     LDA    $13              areg=tsr;  /* dummy read */
09DD B6 67     LDA    $67            ocmplo1 = q.b.lo;
09DF B7 17     STA    $17
09E1 81        RTS                  }

                                    /*************************************************************************/

                                    void TIMERCMP (void)    /* timer service module */
1FF6 09 E2                          {
09E2 33 02     COM    $02              portc =~ portc;    /* service the lcd by inverting the ports */
09E4 33 01     COM    $01              portb =~ portb;
09E6 33 00     COM    $00              porta =~ porta;
```

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```
09E8 AD DD     BSR    $09C7          fixcompare();
09EA 80        RTI                   }

                                     /*************************************************************************/

                                     void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                           pressure offset voltage output */
                                     {

09EB 3F 64     CLR    $64            for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
09ED 3F 63     CLR    $63
09EF B6 64     LDA    $64
09F1 A0 14     UB     #$14
09F3 B6 63     LDA    $63
09F5 A2 00     SBC    #$00
09F7 24 0B     BCC    $0A04
                                                              power supply time to settle down */
                                     {
09F9 CD 09 68  JSR    $0968             delay();
                                     }
09FC 3C 64     INC    $64
09FE 26 02     BNE    $0A02
0A00 3C 63     INC    $63
0A02 20 EB     BRA    $09EF
0A04 CD 09 7F  JSR    $097F             xdcr_offset =  read_a2d();
0A07 3F 5C     CLR    $5C
0A09 B7 5D     STA    $5D
0A0B 81        RTS                 }

                                     /*************************************************************************/

                                     void initio (void)     /*  setup the I/O */
                                        {
0A0C A6 20     LDA    #$20              adstat = 0x20; /* power-up the A/D */
0A0E B7 09     STA    $09
0A10 3F 02     CLR    $02               porta = portb = portc = 0;
0A12 3F 01     CLR    $01
0A14 3F 00     CLR    $00
0A16 A6 FF     LDA    #$FF              ddra = ddrb = ddrc = 0xff;
0A18 B7 06     STA    $06
0A1A B7 05     STA    $05
0A1C B7 04     STA    $04
0A1E B6 13     LDA    $13               areg=tsr;  /* dummy read */
0A20 3F 1E     CLR    $1E               ocmphi1 = ocmphi2 = 0;
0A22 3F 16     CLR    $16
0A24 B6 1F     LDA    $1F               areg = ocmplo2; /* clear out output compare 2 if it happens to be set */
0A26 AD 9F     BSR    $09C7             fixcompare(); /* set-up for the first timer interrupt */
0A28 A6 40     LDA    #$40              tcr = 0x40;
0A2A B7 12     STA    $12
0A2C 9A        CLI                      CLI;  /* let the interrupts begin !  */
                                     /* write CAL to the display */
0A2D A6 CC     LDA    #$CC              portc = 0xcc; /* C */
0A2F B7 02     STA    $02
0A31 A6 BE     LDA    #$BE              portb = 0xbe; /* A */
0A33 B7 01     STA    $01
0A35 A6 C4     LDA    #$C4              porta = 0xc4; /* L */
0A37 B7 00     STA    $00
0A39 CD 09 21  JSR    $0921             sensor_type(); /* get the model of the sensor based on J1..J3 */
0A3C AD AD     BSR    $09EB             adzero();  /* auto zero */
0A3E 81        RTS                   }

                                     /*************************************************************************/

                                     void cvt_bin_dec(unsigned long arg)

                                     /* First converts the argument to a five digit decimal value. The msd is in
                                     the lowest address. Then leading zero suppress the value and write it to the
                                     display ports.
                                        The argument value is 0..65535 decimal. */

009D                               {
0A3F BF 9D     STX    $9D
0A41 B7 9E     STA    $9E
```


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```
009F                                char i;
00A0                                unsigned long l;
0A43 3F 9F     CLR    $9F            for ( i=0; i < 5; ++i )
0A45 B6 9F     LDA    $9F
0A47 A1 05     CMP    #$05
0A49 24 07     BCC    $0A52
                                        {
0A4B 97        TAX                      digit[i] = 0x0;  /* put blanks in all digit positions */
0A4C 6F 50     CL     $50,X
                                        }
0A4E 3C 9F     INC    $9F
0A50 20 F3     BRA    $0A45
0A52 3F 9F     CLR    $9F               for ( i=0; i < 4; ++i )
0A54 B6 9F     LDA    $9F
0A56 A1 04     CMP    #$04
0A58 24 7A     BCC    $0AD4
                                           {
0A5A 97        TAX                         if ( arg  >= dectable [i] )
0A5B 58        LSLX
0A5C D6 08 0B  LDA    $080B,X
0A5F B0 9E     SUB    $9E
0A61 B7 58     STA    $58
0A63 B6 9D     LDA    $9D
0A65 A8 80     EOR    #$80
0A67 B7 57     STA    $57
0A69 D6 08 0A  LDA    $080A,X
0A6C A8 80     EOR    #$80
0A6E B2 57     SBC    $57

0A70 BA 58     ORA    $58
0A72 22 5C     BHI    $0AD0
                                              {
0A74 BE 9F     LDX    $9F                      l = dectable[i];
0A76 58        LSLX
0A77 D6 08 0A  LDA    $080A,X
0A7A B7 A0     STA    $A0
0A7C D6 08 0B  LDA    $080B,X
0A7F B7 A1     STA    $A1
0A81 B6 9E     LDA    $9E                      digit[i] = arg / l;
0A83 B7 58     STA    $58
0A85 B6 9D     LDA    $9D
0A87 B7 57     STA    $57
0A89 B6 A0     LDA    $A0
0A8B B7 9A     STA    $9A
0A8D B6 A1     LDA    $A1
0A8F B7 9B     STA    $9B
0A91 CD 0B F1  JSR    $0BF1
0A94 CD 0C 22  JSR    $0C22
0A97 BF 57     STX    $57
0A99 B7 58     STA    $58
0A9B BE 9F     LDX    $9F
0A9D E7 50     STA    $50,X
0A9F BE 9F     LDX    $9F                      arg = arg-(digit[i] * l);
0AA1 E6 50     LDA    $50,X
0AA3 3F 57     CLR    $57
0AA5 B7 58     STA    $58
0AA7 B6 A0     LDA    $A0
0AA9 B7 9A     STA    $9A
0AAB B6 A1     LDA    $A1
0AAD B7 9B     STA    $9B
0AAF CD 0B D2  JSR    $0BD2
0AB2 BF 57     STX    $57
0AB4 B7 58     STA    $58
0AB6 33 57     COM    $57
0AB8 30 58     NEG    $58
0ABA 26 02     BNE    $0ABE
0ABC 3C 57     INC    $57
0ABE B6 58     LDA    $58
0AC0 BB 9E     ADD    $9E
0AC2 B7 58     STA    $58
0AC4 B6 57     LDA    $57
0AC6 B9 9D     ADC    $9D
0AC8 B7 57     STA    $57
0ACA B7 9D     STA    $9D
```

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```
0ACC B6 58     LDA    $58
0ACE B7 9E     STA    $9E
                                                }
                                              }
0AD0 3C 9F     INC    $9F
0AD2 20 80     BRA    $0A54
0AD4 B6 9E     LDA    $9E          digit[i] = arg;
0AD6 B7 58     STA    $58
0AD8 B6 9D     LDA    $9D
0ADA B7 57     STA    $57
0ADC BE 9F     LDX    $9F
0ADE B6 58     LDA    $58
0AE0 E7 50     STA    $50,X

                                    /* now zero suppress and send the lcd pattern to the display */
0AE2 9B        SEI                 SEI;
0AE3 3D 52     TST    $52          if ( digit[2] == 0 )   /* leading zero suppression */
0AE5 26 04     BNE    $0AEB
0AE7 3F 02     CLR    $02            portc = 0;
0AE9 20 07     BRA    $0AF2            else
0AEB BE 52     LDX    $52               portc = ( lcdtab[digit[2]] );     /* 100's digit */
0AED D6 08 00  LDA    $0800,X
0AF0 B7 02     STA    $02
0AF2 3D 52     TST    $52                if ( digit[2] == 0 && digit[3] == 0 )
0AF4 26 08     BNE    $0AFE
0AF6 3D 53     TST    $53
0AF8 26 04     BNE    $0AFE
0AFA 3F 01     CLR    $01                  portb=0;
0AFC 20 07     BRA    $0B05                  else
0AFE BE 53     LDX    $53                    portb = ( lcdtab[digit[3]] );    /* 10's digit */
0B00 D6 08 00  LDA    $0800,X

0B03 B7 01     STA    $01
0B05 BE 54     LDX    $54                      porta = ( lcdtab[digit[4]] );   /* 1's digit */
0B07 D6 08 00  LDA    $0800,X
0B0A B7 00     STA    $00
                                    /* place the decimal point only if the sensor is 15 psi or 7.5 psi */
0B0C B6 60     LDA    $60            if ( sensor_index < 3 )
0B0E A8 80     EOR    #$80
0B10 A1 83     CMP    #$83
0B12 24 08     BCC    $0B1C
0B14 BE 54     LDX    $54              porta = ( lcdtab[digit[4]]+1 ); /* add the decimal point to the lsd */
0B16 D6 08 00  LDA    $0800,X
0B19 4C        INCA
0B1A B7 00     STA    $00
0B1C 3D 60     TST    $60               if(sensor_index ==0) /* special case */
0B1E 26 0F     BNE    $0B2F
                                           {
0B20 BE 54     LDX    $54                 porta = ( lcdtab[digit[4]] ); /* get rid of the decimal at lsd */
0B22 D6 08 00  LDA    $0800,X
0B25 B7 00     STA    $00
0B27 BE 53     LDX    $53                 portb = ( lcdtab[digit[3]]+1 ); /* decimal point at middle digit */
0B29 D6 08 00  LDA    $0800,X
0B2C 4C        INCA
0B2D B7 01     STA    $01
                                         }
0B2F 9A        CLI                 CLI;
0B30 CD 09 68  JSR    $0968                delay();
0B33 81        RTS                 }

                                    /*****************************************************************/

                                    void display_psi(void)
                                    /*
                                      At power-up it is assumed that the pressure or vacuum port of
                                      the sensor is open to atmosphere. The code in initio() delays
                                      for the sensor and power supply to stabilize. One hundred A/D
                                      conversions are averaged. That result is called xdcr_offset.
                                      This routine calls the A/D routine which performs one hundred
                                      conversions, divides the result by 100 and returns the value.
                                      If the value returned is less than or equal to the xdcr_offset,
                                      the value of xdcr_offset is substituted. If the value returned
                                      is greater than xdcr_offset, xdcr_offset is subtracted from the
```


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```
                                    returned value.
                                  */

                                 {
                                   while(1)
                                      {
0B34 CD 09 7F  JSR    $097F          atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
0B37 3F 55     CLR    $55
0B39 B7 56     STA    $56
0B3B B0 5D     SUB    $5D              if ( atodtemp <= xdcr_offset )
0B3D B7 58     STA    $58
0B3F B6 5C     LDA    $5C
0B41 A8 80     EOR    #$80
0B43 B7 57     STA    $57
0B45 B6 55     LDA    $55
0B47 A8 80     EOR    #$80
0B49 B2 57     SBC    $57
0B4B BA 58     ORA    $58
0B4D 22 08     BHI    $0B57
0B4F B6 5C     LDA    $5C                atodtemp = xdcr_offset;
0B51 B7 55     STA    $55
0B53 B6 5D     LDA    $5D
0B55 B7 56     STA    $56
0B57 B6 56     LDA    $56              atodtemp -=  xdcr_offset; /* remove the offset */
0B59 B0 5D     SUB    $5D
0B5B B7 56     STA    $56
0B5D B6 55     LDA    $55
0B5F B2 5C     SBC    $5C
0B61 B7 55     STA    $55
0B63 CD 09 4C  JSR    $094C             sensor_slope();  /* establish the slope constant for this output */
0B66 B6 56     LDA    $56              atodtemp *= sensor_model;
0B68 B7 58     STA    $58
0B6A B6 55     LDA    $55
0B6C B7 57     STA    $57
0B6E B6 5E     LDA    $5E

0B70 B7 9A     STA    $9A
0B72 B6 5F     LDA    $5F
0B74 B7 9B     STA    $9B
0B76 CD 0B D2  JSR    $0BD2
0B79 BF 55     STX    $55
0B7B B7 56     STA    $56
0B7D 3F 89     CLR    $89               MULTP[0] = MULCAN[0] = 0;
0B7F 3F 88     CLR    $88
0B81 3F 81     CLR    $81
0B83 3F 80     CLR    $80
0B85 9F        TXA                      MULTP[1] = atodtemp;
0B86 B7 82     STA    $82
0B88 B6 56     LDA    $56
0B8A B7 83     STA    $83
0B8C B6 59     LDA    $59                MULCAN[1] = slope;
0B8E B7 8A     STA    $8A
0B90 B6 5A     LDA    $5A
0B92 B7 8B     STA    $8B
0B94 CD 08 70  JSR    $0870              mul32();   /* analog value * slope based on J1 through J3 */
0B97 3F 90     CLR    $90                DVSOR[0] = 1;   /*  now divide by 100000 */
0B99 A6 01     LDA    #$01
0B9B B7 91     STA    $91
0B9D A6 86     LDA    #$86                 DVSOR[1] = 0x86a0;
0B9F B7 92     STA    $92
0BA1 A6 A0     LDA    #$A0
0BA3 B7 93     STA    $93
0BA5 B6 88     LDA    $88                    DVDND[0] = MULCAN[0];
0BA7 B7 8C     STA    $8C
0BA9 B6 89     LDA    $89
0BAB B7 8D     STA    $8D
0BAD B6 8A     LDA    $8A                    DVDND[1] = MULCAN[1];
0BAF B7 8E     STA    $8E
0BB1 B6 8B     LDA    $8B
0BB3 B7 8F     STA    $8F
0BB5 CD 08 B1  JSR    $08B1                   div32();
0BB8 B6 96     LDA    $96                    atodtemp = QUO[1]; /* convert to psi */
0BBA B7 55     STA    $55
0BBC B6 97     LDA    $97
```

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```
0BBE B7 56     STA    $56
0BC0 BE 55     LDX    $55              cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0BC2 CD 0A 3F  JSR    $0A3F
0BC5 CC 0B 34  JMP    $0B34          }
0BC8 81        RTS                 }

                                     /*************************************************************************/

                                     void main()
                                     {
0BC9 CD 0A 0C  JSR    $0A0C        initio(); /* set-up the processor's i/o */
0BCC CD 0B 34  JSR    $0B34         display_psi();
0BCF 20 FE     BRA    $0BCF          while(1);   /* should never get back to here */
0BD1 81        RTS                 }
0BD2 BE 58     LDX    $58
0BD4 B6 9B     LDA    $9B
0BD6 42        MUL
0BD7 B7 A4     STA    $A4
0BD9 BF A5     STX    $A5
0BDB BE 57     LDX    $57
0BDD B6 9B     LDA    $9B
0BDF 42        MUL
0BE0 BB A5     ADD    $A5
0BE2 B7 A5     STA    $A5
0BE4 BE 58     LDX    $58
0BE6 B6 9A     LDA    $9A
0BE8 42        MUL
0BE9 BB A5     ADD    $A5
0BEB B7 A5     STA    $A5
0BED 97        TAX
0BEE B6 A4     LDA    $A4
0BF0 81        RTS
0BF1 3F A4     CLR    $A4
0BF3 5F        CLRX
0BF4 3F A2     CLR    $A2
0BF6 3F A3     CLR    $A3
0BF8 5C        INCX
0BF9 38 58     LSL    $58


0BFB 39 57     ROL    $57
0BFD 39 A2     ROL    $A2
0BFF 39 A3     ROL    $A3
0C01 B6 A2     LDA    $A2
0C03 B0 9B     SUB    $9B
0C05 B7 A2     STA    $A2
0C07 B6 A3     LDA    $A3
0C09 B2 9A     SBC    $9A
0C0B B7 A3     STA    $A3
0C0D 24 0D     BCC    $0C1C
0C0F B6 9B     LDA    $9B
0C11 BB A2     ADD    $A2
0C13 B7 A2     STA    $A2
0C15 B6 9A     LDA    $9A
0C17 B9 A3     ADC    $A3
0C19 B7 A3     STA    $A3
0C1B 99        SEC
0C1C 59        ROLX
0C1D 39 A4     ROL    $A4
0C1F 24 D8     BCC    $0BF9
0C21 81        RTS
0C22 53        COMX
0C23 9F        TXA
0C24 BE A4     LDX    $A4
0C26 53        COMX
0C27 81        RTS
1FFE 0B C9

SYMBOL TABLE

LABEL        VALUE  LABEL        VALUE  LABEL        VALUE  LABEL        VALUE
```

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```
ADDEND       006C | AUGEND       0070 | CNT          0098 | DIFF         007C
DIV151       08BF | DIV153       08CE | DIV163       08D0 | DIV165       0905
DIV167       0906 | DVDND        008C | DVSOR        0090 | IRQ          091D
MINUE        0074 | MNEXT        0882 | MTEMP        0084 | MULCAN       0088
MULTP        0080 | QUO          0094 | ROTATE       089C | SCI          0920
SUBTRA       0078 | SUM          0068 | TIMERCAP     091E | TIMERCMP     09E2
TIMEROV      091F | __LDIV       0BF1 | __LongIX     009A | __MAIN       0BC9
__MUL        0000 | __MUL16x16   0BD2 | __RDIV       0C22 | __RESET      1FFE
__STARTUP    0000 | __STOP       0000 | __SWI        091C | __WAIT       0000
__longAC     0057 | adcnt        005B | add32        083C | addata       0008
adstat       0009 | adzero       09EB | aregnthi     001A | aregntlo     001B
arg          009D | atodtemp     0055 | b            0000 | bothbytes    0002
cvt_bin_dec  0A3F | ddra         0004 | ddrb         0005 | ddrc         0006
dectable     080A | delay        0968 | digit        0050 | display_psi  0B34
div32        08B1 | eeclk        0007 | fixcompare   09C7 | hi           0000
i            0061 | icaphi1      0014 | icaphi2      001C | icaplo1      0015
icaplo2      001D | initio       0A0C | isboth       0002 | j            0063
k            0065 | l            0000 | lcdtab       0800 | lo           0001
main         0BC9 | misc         000C | mul32        0870 | ocmphi1      0016
ocmphi2      001E | ocmplo1      0017 | ocmplo2      001F | plma         000A
plmb         000B | porta        0000 | portb        0001 | portc        0002
portd        0003 | q            0066 | read_a2d     097F | scibaud      000D
scicntl1     000E | scicntl2     000F | scidata      0011 | scistat      0010
sensor_index 0060 | sensor_model 005E | sensor_slope 094C | sensor_type  0921
slope        0059 | slope_const  081C | sub32        0856 | tcnthi       0018
tcntlo       0019 | tcr          0012 | tsr          0013 | type         0812
xdcr_offset  005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0AC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0B00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0BC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0C00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXX-------- ----------------
0C40 : ---------------- ---------------- ---------------- ----------------
0C80 : ---------------- ---------------- ---------------- ----------------
0CC0 : ---------------- ---------------- ---------------- ----------------

1E00 : ---------------- ---------------- ---------------- ----------------
1E40 : ---------------- ---------------- ---------------- ----------------
1E80 : ---------------- ---------------- ---------------- ----------------
1EC0 : ---------------- ---------------- ---------------- --------------X-

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.

Errors             :    0
Warnings           :    0
```

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Frequency Output Conversion for MPX2000 Series Pressure Sensors

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Discrete Applications Engineering

INTRODUCTION

Typically, a semiconductor pressure transducer converts applied pressure to a “low-level” voltage signal. Current technology enables this sensor output to be temperature compensated and amplified to higher voltage levels on a single silicon integrated circuit (IC). While on-chip temperature compensation and signal conditioning certainly provide a significant amount of added value to the basic sensing device, one must also consider how this final output will be used and/or interfaced for further processing. In most sensing systems, the sensor signal will be input to additional analog circuitry, control logic, or a microcontroller unit (MCU).

MCU-based systems have become extremely cost effective. The level of intelligence which can be obtained for only a couple of dollars, or less, has made relatively simple 8-bit microcontrollers the partner of choice for semiconductor pressure transducers. In order for the sensor to communicate its pressure-dependent voltage signal to the microprocessor, the MCU must have an analog-to-digital converter (A/D) as an on-chip resource or an additional IC packaged A/D. In the latter case, the A/D must have a communications interface that is compatible with one of the MCU's communications protocols. MCU's are adept at detecting logic-level transitions that occur at input pins designated for screening such events. As an alternative to the conventional A/D sensor/MCU interface, one can measure either a period (frequency) or pulse width of an incoming square or rectangular wave signal. Common MCU timer subsystem clock frequencies permit temporal measurements with resolution of hundreds of nanoseconds. Thus, one is capable of accurately measuring the frequency output of a device that is interfaced to such a timer channel. If sensors can provide a frequency modulated signal that is linearly proportional to the applied pressure being measured, then an accurate, inexpensive (no A/D) MCU-based sensor system is a viable solution to many challenging sensing applications. Besides the inherent cost savings of such a system, this design concept offers additional benefits to remote sensing applications and sensing in electrically noisy environments.

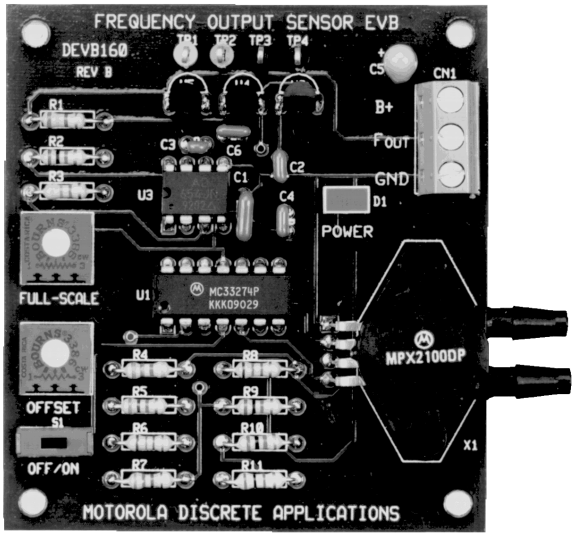

Figure 1. DEVB160 Frequency Output Sensor EVB (Board No Longer Available)

The following sections will detail the design issues involved in such a system architecture, and will provide an example circuit which has been developed as an evaluation tool for frequency output pressure sensor applications.

DESIGN CONSIDERATIONS

Signal Conditioning

The Freescale Semiconductor, Inc. MPX2000 Series sensors are temperature compensated and calibrated - i.e., offset and full-scale span are precision trimmed - pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Although the specifications in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. At the absolute maximum supply voltage specified, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to a slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level.

Many different “instrumentation-type” amplifier circuits can satisfy the signal conditioning needs of these devices. Depending on the precision and temperature performance demanded by a given application, one can design an amplifier circuit using a wide variety of operational amplifier (op amp) IC packages with external resistors of various tolerances, or a precision-trimmed integrated instrumentation amplifier IC. In any case, the usual goal is to have a single-ended supply, “rail-to-rail” output (i.e. use as much of the range from ground to the supply voltage as possible, without saturating the op amps). In addition, one may need the flexibility of performing zero-pressure offset adjust and full-scale pressure calibration. The circuitry or device used to accomplish the voltage-to-frequency conversion will determine if, how, and where calibration adjustments are needed. See Evaluation Board Circuit Description section for details.

Voltage-to-Frequency Conversion

Since most semiconductor pressure sensors provide a voltage output, one must have a means of converting this voltage signal to a frequency that is proportional to the sensor output voltage. Assuming the analog voltage output of the sensor is proportional to the applied pressure, the resultant frequency will be linearly related to the pressure being measured. There are many different timing circuits that can perform voltage-to-frequency conversion. Most of the “simple” (relatively low number of components) circuits do not provide the accuracy or the stability needed for reliably encoding a signal quantity. Fortunately, many voltage-to-frequency (V/F) converter IC's are commercially available that will satisfy this function.

Switching Time Reduction

One limitation of some V/F converters is the less than adequate switching transition times that effect the pulse or square-wave frequency signal. The required switching speed will be determined by the hardware used to detect the switching edges. The Freescale family of microcontrollers have input-capture functions that employ “Schmitt trigger-like” inputs with hysteresis on the dedicated input pins. In this case, slow rise and fall times will not cause an input capture pin to be in an indeterminate state during a transition. Thus, CMOS logic instability and significant timing errors will be prevented during slow transitions. Since the sensor's frequency output may be interfaced to other logic configurations, a designer's main concern is to comply with a worst-case timing scenario. For high-speed CMOS logic, the maximum rise and fall times are typically specified at several hundreds of nanoseconds. Thus, it is wise to speed up the switching edges at the output of the V/F converter. A single small-signal FET and a resistor are all that is required to obtain switching times below 100 ns.

APPLICATIONS

Besides eliminating the need for an A/D converter, a frequency output is conducive to applications in which the sensor output must be transmitted over long distances, or when the presence of noise in the sensor environment is likely to corrupt an otherwise healthy signal. For sensor outputs encoded as a voltage, induced noise from electromagnetic fields will contaminate the true voltage signal. A frequency signal has greater immunity to these noise sources and can be effectively filtered in proximity to the MCU input. In other words, the frequency measured at the MCU will be the frequency transmitted at the output of a sensor located remotely. Since high-frequency noise and 50-60 Hz line noise are the two most prominent sources for contamination of instrumentation signals, a frequency signal with a range in the low end of the kHz spectrum is capable of being well filtered prior to being examined at the MCU.

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Table 1. Specifications

Characteristics	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B^+	10		30	Volts
Full Scale Pressure	P_{FS}				
- MPX2010				10	kPa
- MPX2050				50	kPa
- MPX2100				100	kPa
- MPX2200				200	kPa
Full Scale Output	f_{FS}		10		kHz
Zero Pressure Offset	f_{OFF}		1		kHz
Sensitivity	S_{AOUT}		$9/P_{FS}$		kHz/kPa
Quiescent Current	I_{CC}		55		mA

EVALUATION BOARD

The following sections present an example of the signal conditioning, including frequency conversion, that was developed as an evaluation tool for Freescale's MPX2000 series pressure sensors. A summary of the information required to use evaluation board number DEVB160 is presented as follows.

Description

The evaluation board shown in Figure 1 is designed to transduce pressure, vacuum or differential pressure into a single-ended, ground referenced voltage that is then input to a voltage-to-frequency converter. It nominally provides a 1 kHz output at zero pressure and 10 kHz at full scale pressure. Zero pressure calibration is made with a trimpot that is located on the lower half of the left side of the board, while the full scale output can be calibrated via another trimpot just above the offset adjust. The board comes with an MPX2100DP sensor installed, but will accommodate any MPX2000 series sensor. One additional modification that may be required is that the gain of the circuit must be increased slightly when using an MPX2010 sensor. Specifically, the resistor R5 must be increased from 7.5 kΩ to 12 kΩ.

Circuit Description

The following pin description and circuit operation corresponds to the schematic shown in Figure 2.

Pin-by-Pin Description

B^+

Input power is supplied at the B^+ terminal of connector CN1. Minimum input voltage is 10 V and maximum is 30 V.

F_{out}

A logic-level (5 V) frequency output is supplied at the OUT terminal (CN1). The nominal signal it provides is 1 kHz at zero pressure and 10 kHz at full scale pressure. Zero pressure frequency is adjustable and set with R12. Full-scale frequency is calibrated via R13. This output is designed to be directly connected to a microcontroller timer system input-capture channel.

GND

The ground terminal on connector CN1 is intended for use as the power supply return and signal common. Test point terminal TP3 is also connected to ground, for measurement convenience.

TP1

Test point 1 is connected to the final frequency output, F_{out}.

TP2

Test point 2 is connected to the +5 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

TP3

Test point 3 is the additional ground point mentioned above in the GND description.

TP4

Test point 4 is connected to the +8 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

P1, P2

Pressure and Vacuum ports P1 and P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top (marked side of package) and vacuum port P2, if present, is on the bottom. When the board is set up with a dual ported sensor (DP suffix), pressure applied to P1, vacuum applied to P2 or a differential pressure applied between the two all produce the same output voltage per kPa of input. Neither port is labeled. Absolute maximum differential pressure is 700 kPa.

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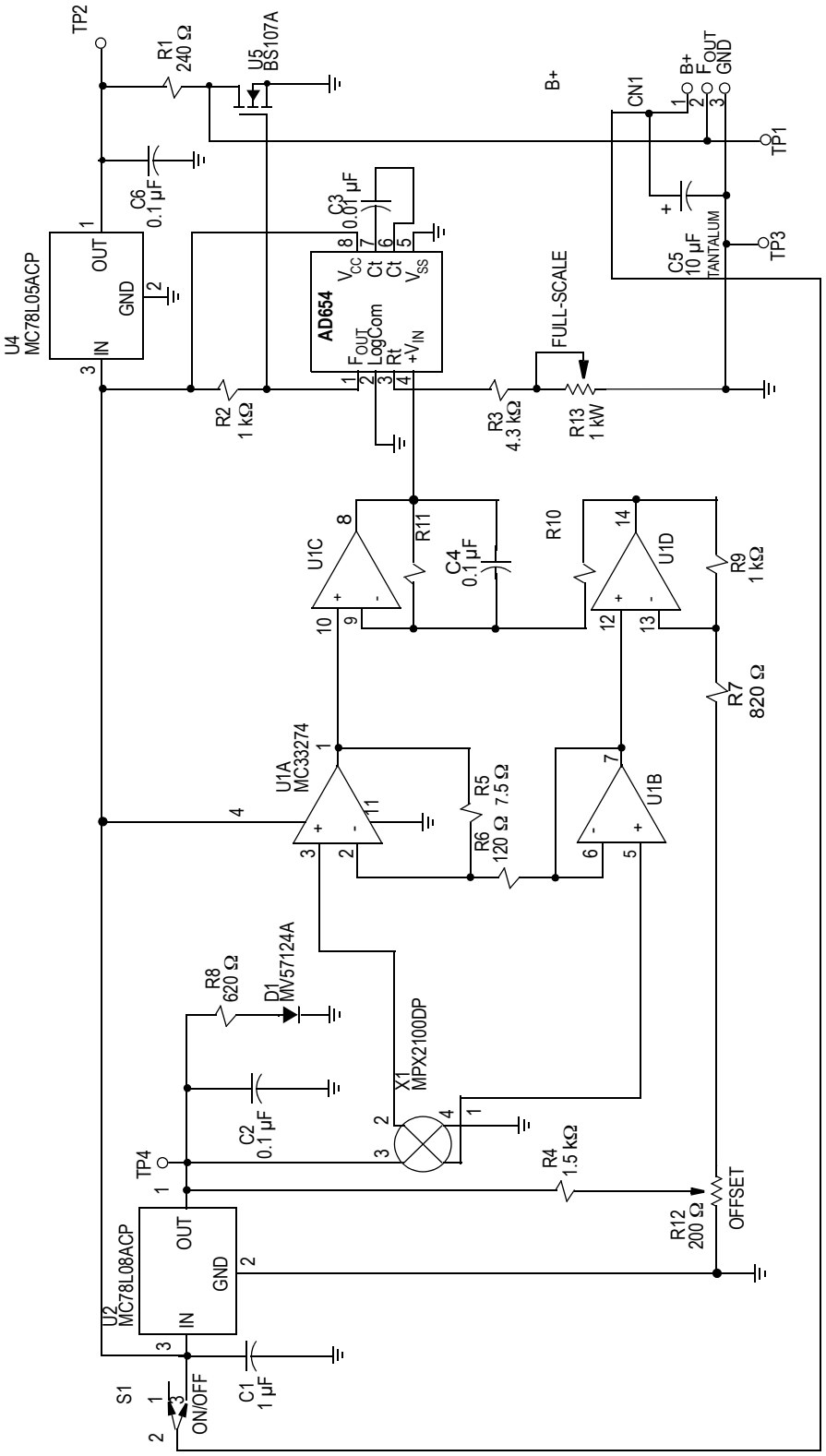

Figure 2. DEVB160 Frequency Output Sensor Evaluation Board

The following is a table of the components that are assembled on the DEVB160 Frequency Output Sensor Evaluation Board.

Table 2. Parts List

Designators	Quantity	Description	Manufacturer	Part Number
C1	1	1 μF Capacitor		
C2	1	0.1 μF Capacitor		
C3	1	0.01 μF Capacitor		
C4	1	0.1 μF Capacitor		
C5	1	10 μF Cap+		tantalum
C6	1	0.1 μF Capacitor		
CN1	1	.15LS 3 Term	PHX Contact	1727023
D1	1	RED LED	Quality Tech.	MV57124A
R1	1	240 Ω resistor		
R2, R9	2	1 kΩ resistor		
R3	1	4.3 kΩ resistor		
R4	1	1.5 kΩ resistor		
R5	1	7.5 kΩ resistor		
R6	1	120 Ω resistor		
R7	1	820 Ω resistor		
R8	1	620 Ω resistor		
R10, R11	2	2 kΩ resistor		
R12	1	200 Ω Trimpot	Bourns	3386P-1-201
R13	1	1 kΩ Trimpot	Bourns	3386P-1-102
S1	1	SPDT miniature switch	NKK	SS-12SDP2
TP1	1	YELLOW Testpoint	Control Design	TP-104-01-04
TP2	1	BLUE Testpoint	Control Design	TP-104-01-06
TP3	1	BLACK Testpoint	Control Design	TP-104-01-00
TP4	1	GREEN Testpoint	Control Design	TP-104-01-05
U1	1	Quad Op Amp	Freescale	MC33274
U2	1	8 V Regulator	Freescale	MC78L08ACP
U3	1	AD654	Analog Devices	AD654
U4	1	5 V Regulator	Freescale	MC78L05ACP
U5	1	Small-Signal FET	Freescale	BS107A
X1	1	Pressure Sensor	Freescale	MPX2100DP

NOTE: All resistors are 1/4 watt, 5% tolerance values. All capacitors are 50 V rated, ±20% tolerance values.

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Circuit Operation

The voltage signal conditioning portion of this circuit is a variation on the classic instrumentation amplifier configuration. It is capable of providing high differential gain and good common-mode rejection with very high input impedance; however, it provides a more user friendly method of performing the offset/bias point adjustment. It uses four op amps and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U1A which is configured as a differential amplifier. Unwanted current flow through the sensor is prevented by buffer U1B. At zero pressure the differential voltage from pin 2 to pin 4 on the sensor has been precision trimmed to essentially zero volts. The common-mode voltage on each of these nodes is 4 V (one-half the sensor supply voltage). The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R5 and create a non-zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage by U1C and U1D. The offset voltage is produced by R4 and adjustment trimpot R12. R7's value is such that the total source impedance into pin 13 is approximately 1 k. The gain is approximately (R5/R6)(1 + R11/R10), which is 125 for the values shown in Figure 2. A gain of 125 is selected to provide a 4 V span for 32 mV of full-scale sensor output (at a sensor supply voltage of 8 V).

The resulting 0.5 V to 4.5 V output from U1C is then converted by the V/F converter to the nominal 1-10 kHz that has been specified. The AD654 V/F converter receives the amplified sensor output at pin 8 of op amp U1C. The full-scale frequency is determined by R3, R13 and C3 according to the following formula:

$$F_{out}\ (\text{full-scale}) = \frac{V_{in}}{(10V)(R3 + R13)C3}$$

For best performance, R3 and R13 should be chosen to provide 1 mA of drive current at the full-scale voltage produced at pin 3 of the AD654 (U3). The input stage of the AD654 is an op-amp; thus, it will work to make the voltage at pin 3 of U3 equal to the voltage seen at pin 4 of U3 (pins 3 and 4 are the input terminals of the op amp). Since the amplified sensor output will be 4.5 V at full-scale pressure, R3 + R13 should be approximately equal to 4.5 kΩ to have optimal linearity performance. Once the total resistance from pin 3 of U3 to ground is set, the value of C3 will determine the full-scale frequency output of the V/F. Trimpot R13 should be sized (relative to R3 value) to provide the desired amount of full-scale frequency adjustment. The zero-pressure frequency is adjusted via the offset adjust provided for calibrating the offset voltage of the signal conditioned sensor output. For additional information on using this particular V/F converter, see the applications information provided in the Analog Devices Data Conversion Products Databook.

The frequency output has its edge transitions “sped” up by a small-signal FET inverter. This final output is directly compatible with microprocessor timer inputs, as well as any other high-speed CMOS logic. The amplifier portion of this circuit has been patented by Freescale Semiconductor, Inc. and was introduced on evaluation board DEVB150A.

Additional information pertaining to this circuit and the evaluation board DEVB150A is contained in Freescale Application Note AN1313.[1]

TEST/CALIBRATION PROCEDURE

1. Connect a +12 V supply between B+ and GND terminals on the connector CN1.
2. Connect a frequency counter or scope probe on the F_{out} terminal of CN1 or on TP1 with the test instrumentation ground clipped to TP3 or GND.
3. Turn the power switch, S1, to the on position. Power LED, D1, should be illuminated. Verify that the voltage at TP2 and TP4 (relative to GND or TP3) is 5 V and 8 V, respectively. While monitoring the frequency output by whichever means one has chosen, one should see a 50% duty cycle square wave signal.
4. Turn the wiper of the OFFSET adjust trimpot, R12, to the approximate center of the pot.
5. Apply 100 kPa to pressure port P1 of the MPX2100DP (topside port on marked side of the package) sensor, X1.
6. Adjust the FULL-SCALE trimpot, R13, until the output frequency is 10 kHz. If 10 kHz is not within the trim range of the full-scale adjustment trimpot, tweak the offset adjust trimpot to obtain 10 kHz (remember, the offset pot was at an arbitrary midrange setting as per step 4).
7. Apply zero pressure to the pressure port (i.e., both ports at ambient pressure, no differential pressure applied). Adjust OFFSET trimpot so frequency output is 1 kHz.
8. Verify that zero pressure and full-scale pressure (100 kPa) produce 1 and 10 kHz respectively, at F_{out} and/or TP1. A second iteration of adjustment on both full-scale and offset may be necessary to fine tune the 1-10 kHz range.

CONCLUSION

Transforming conventional analog voltage sensor outputs to frequency has great utility for a variety of applications. Sensing remotely and/or in noisy environments is particularly challenging for low-level (mV) voltage output sensors such as the MPX2000 Series pressure sensors. Converting the MPX2000 sensor output to frequency is relatively easy to accomplish, while providing the noise immunity required for accurate pressure sensing. The evaluation board presented is an excellent tool for either “stand-alone” evaluation of the MPX2000 Series pressure sensors or as a building block for system prototyping which can make use of DEVB160 as a “drop-in” frequency output sensor solution. The output of the DEVB160 circuit is ideally conditioned for interfacing to MCU timer inputs that can measure the sensor frequency signal.

1. Schultz, Warren (Freescale Semiconductor, Inc.), “Sensor Building Block Evaluation Board,” Freescale Application Note AN1313.

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Interfacing Semiconductor Pressure Sensors to Microcomputers

by: **Warren Schultz**
Discrete Applications Engineering

INTRODUCTION

The most popular silicon pressure sensors are piezoresistive bridges that produce a differential output voltage in response to pressure applied to a thin silicon diaphragm. Output voltage for these sensors is generally 25 to 50 mV full scale. Interface to microcomputers, therefore, generally involves gaining up the relatively small output voltage, performing a differential to single ended conversion, and scaling the analog signal into a range appropriate for analog to digital conversion. Alternately, the analog pressure signal can be converted to a frequency modulated 5 V waveform or 4-20 mA current loop, either of which is relatively immune to noise on long interconnect lines.

A variety of circuit techniques that address interface design are presented. Sensing amplifiers, analog to digital conversion, frequency modulation and 4-20 mA current loops are considered.

PRESSURE SENSOR BASICS

The essence of piezoresistive pressure sensors is the Wheatstone bridge shown in Figure 1. Bridge resistors RP1, RP2, RV1 and RV2 are arranged on a thin silicon diaphragm such that when pressure is applied RP1 and RP2 increase in value while RV1 and RV2 decrease a similar amount. Pressure on the diaphragm, therefore, unbalances the bridge and produces a differential output signal. One of the fundamental properties of this structure is that the differential output voltage is directly proportional to bias voltage B+. This characteristic implies that the accuracy of the pressure measurement depends directly on the tolerance of the bias supply. It also provides a convenient means for temperature compensation. The bridge resistors are silicon resistors that have positive temperature coefficients. Therefore, when they are placed in series with zero T_C temperature compensation resistors RC1 and RC2 the amount of voltage applied to the bridge increases with temperature. This increase in voltage produces an increase in electrical sensitivity which offsets and compensates for the negative temperature coefficient associated with piezoresistance.

Since RC1 and RC2 are approximately equal, the output voltage common mode is very nearly fixed at 1/2 B+. In a typical MPX2100 sensor, the bridge resistors are nominally 425 ohms; RC1 and RC2 are nominally 680 ohms. With these values and 10 V applied to B+, a delta R of 1.8 ohms at full scale pressure produces 40 mV of differential output voltage.

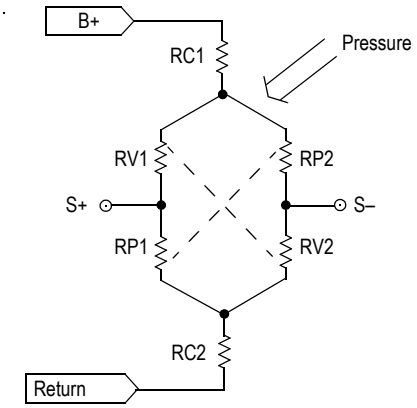

Figure 1. Sensor Equivalent Circuit

INSTRUMENTATION AMPLIFIER INTERFACES

Instrumentation amplifiers are by far the most common interface circuits that are used with pressure sensors. An example of an inexpensive instrumentation amplifier based interface circuit is shown in Figure 2. It uses an MC33274 quad operational amplifier and several resistors that are configured as a classic instrumentation amplifier with one important exception. In an instrumentation amplifier resistor R3 is normally returned to ground. Returning R3 to ground sets the output voltage for zero differential input to 0 V DC. For microcomputer interface a positive offset voltage on the order of 0.3 to 0.8 V is generally desired. Therefore, R3 is connected to pin 14 of U1D which supplies a buffered offset voltage that is derived from the wiper of R6. This voltage establishes a DC output for zero differential input. The translation is one to one. Within the tolerances of the circuit, whatever voltage appears at the wiper of R6 will also appear as the zero pressure DC offset voltage at the output.

With R10 at 240 ohms, gain is set for a nominal value of 125. This provides a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs. Over a zero to 50° C temperature range, combined accuracy for an MPX2000 series sensor and this interface is on the order of ± 10%.

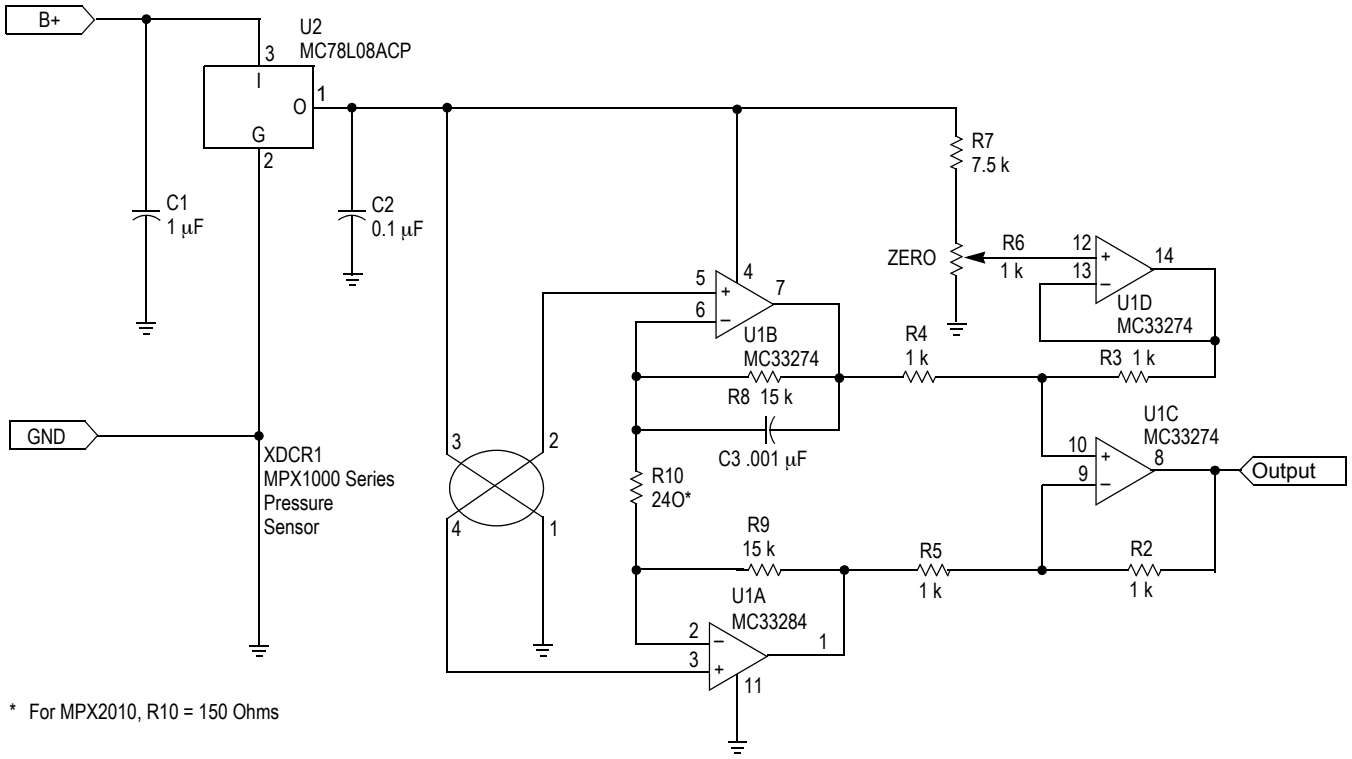

Figure 2. Instrumentation Amplifier Interface

For applications requiring greater precision a fully integrated instrument amplifier such as an LTC1100CN8 gives better results. In Figure 3 one of these amplifiers is used to provide a gain of 100, as well as differential to single ended conversion. Zero offset is provided by dividing down the precision reference to 0.5 V and buffering with U2B. This voltage is fed into the LTC1100CN8's ground pin which is equivalent to returning R3 to pin 14 of U1D in Figure 2. An additional non-inverting gain stage consisting of U2A, R1 and R2 is used to scale the sensor's full scale span to 4 V. R2 is also returned to the buffered 0.5 V to maintain the 0.5 V zero offset that was established in the instrumentation amplifier. Output voltage range is therefore 0.5 to 4.5 V.

Both of these instrumentation amplifier circuits do their intended job with a relatively straightforward tradeoff between cost and performance. The circuit of Figure 2 has the usual cumulative tolerance problem that is associated with instrumentation amplifiers that have discrete resistors, but it has a relatively low cost. The integrated instrumentation amplifier in Figure 3 solves this problem with precision trimmed film resistors and also provides superior input offset performance. Component cost, however, is significantly higher.

SENSOR SPECIFIC INTERFACE AMPLIFIER

A low cost interface designed specifically for pressure sensors improves upon the instrumentation amplifier in Figure 2. Shown in Figure 4, it uses one quad op amp and several resistors to amplify and level shift the sensor's output. Most of the amplification is done in U1A which is configured as a differential amplifier. It is isolated from the sensor's positive output by U1B. The purpose of U1B is to prevent feedback current that flows through R5 and R6 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is 0 V. For example, let's say that the common mode voltage on these pins is 4.0 V. The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R6 and create a non-zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage (V_{OFFSET}) by U1C and U1D.

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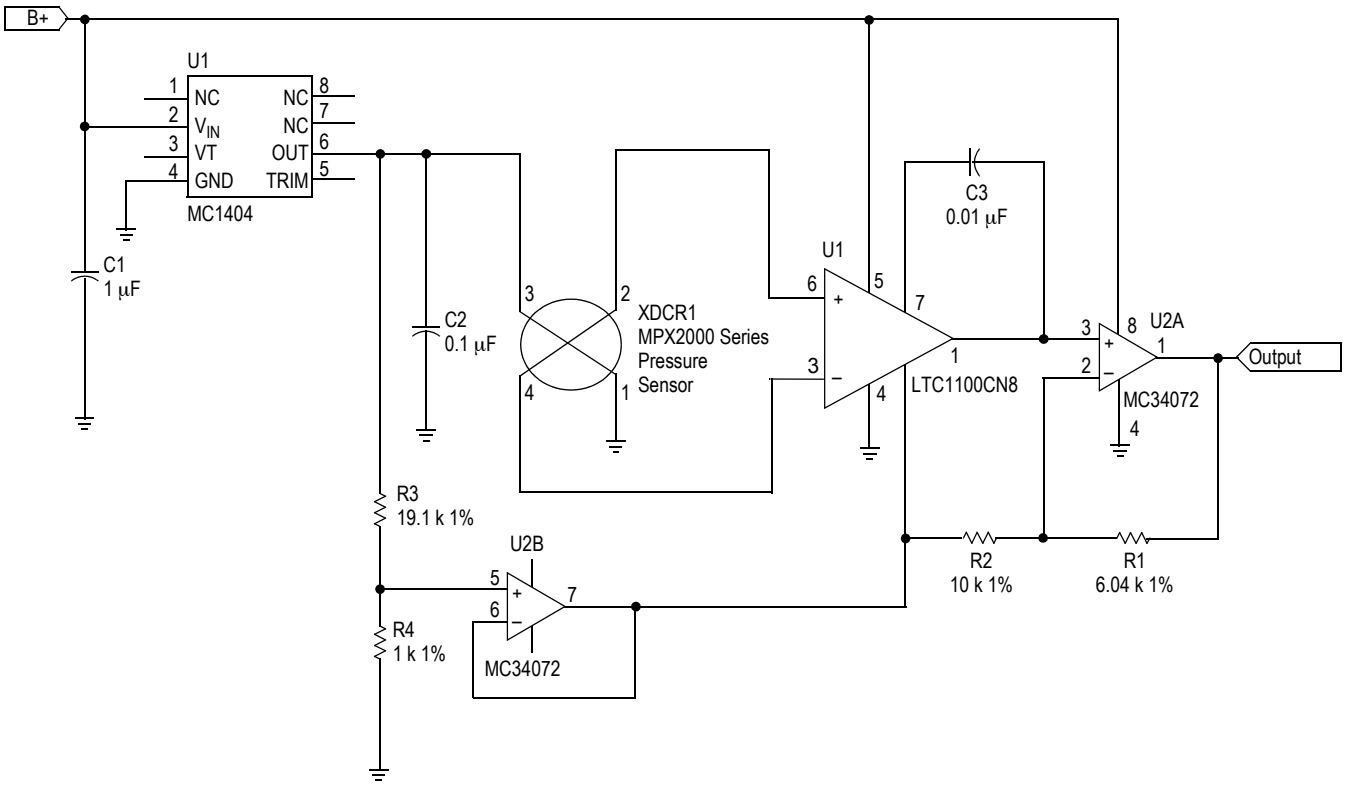
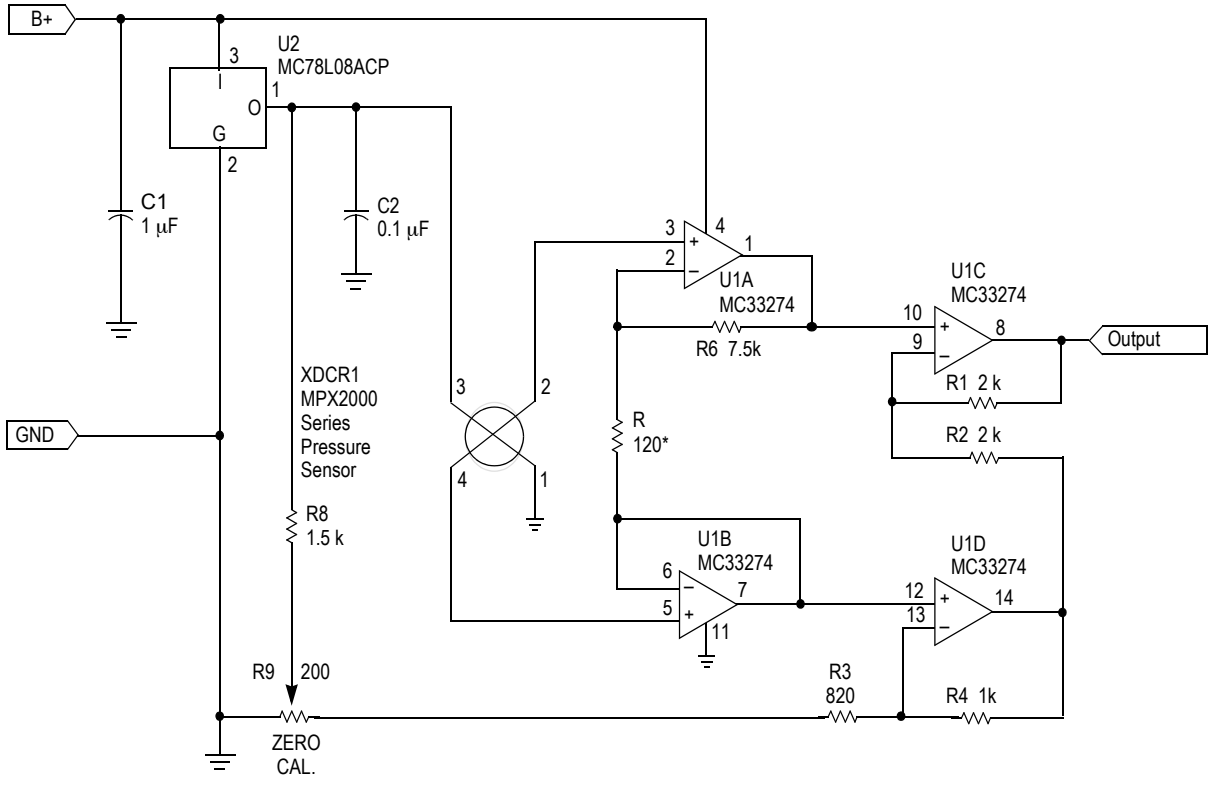


Figure 3. Precision Instrument Amplifier Interface



* NOTE: For MPX2010, R5 = 75 Ohms

Figure 4. Sensor Specific Interface Circuit

To see how the level translation works, let's look at the simplified schematic in Figure 5. Again assuming a common mode voltage of 4.0 V, the voltage applied to pin 12 of U1D is 4.0 V, implying that pin 13 is also at 4.0 V. This leaves 4.0 V - V_{OFFSET} across R3, which is 3.5 V if V_{OFFSET} is set to 0.5 V. Since no current flows into pin 13, the same current flows through both R3 and R4. With both of these resistors set to the same value, they have the same voltage drop, implying a 3.5 V drop across R4. Adding the voltages (0.5 + 3.5 + 3.5) yields 7.5 V at pin 14 of U1D. Similarly 4.0 V at pin 10 of U1C implies 4.0 V at pin 9, and the drop across R2 is 7.5 V - 4.0 V = 3.5 V. Again 3.5 V across R2 implies an equal drop across R1, and the voltage at pin 8 is 4.0 V - 3.5 V = 0.5 V. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R4/R3 = R2/R1. In Figure 4, V_{OFFSET} is produced by R8 and adjustment pot R9. R3's value is adjusted such that the total source impedance into pin 13 is approximately 1 k.

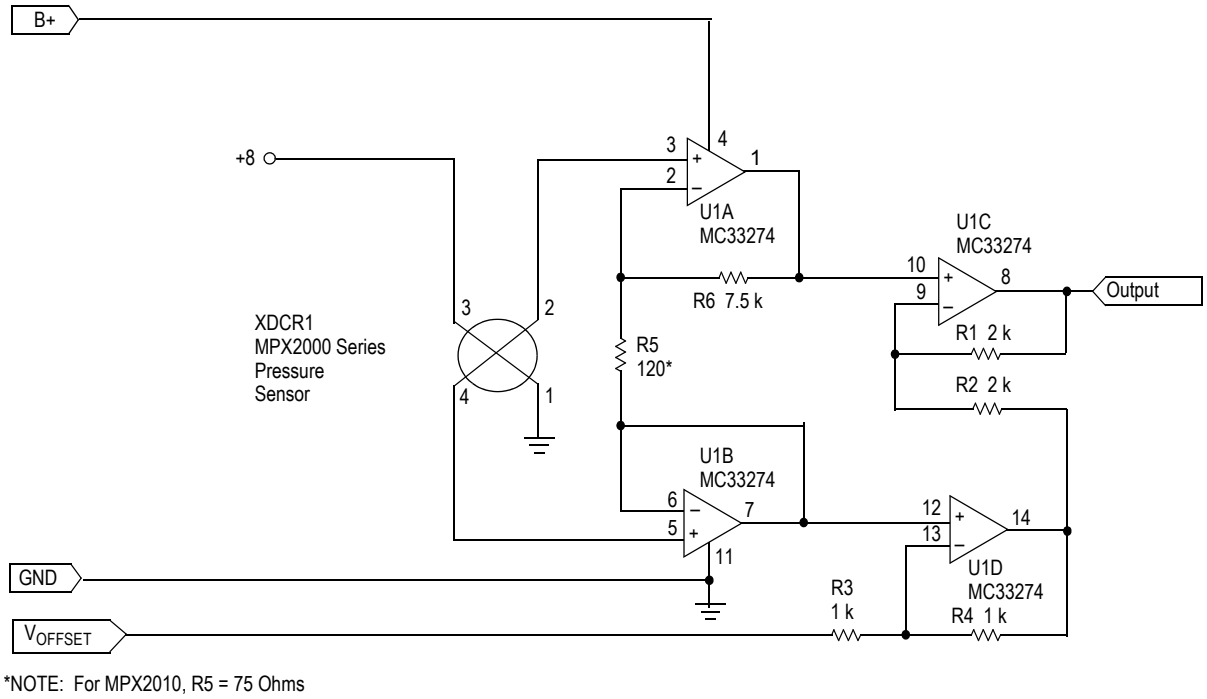


Figure 5. Simplified Sensor Specific Interface

Gain is approximately (R6/R5)(R1/R2+1), which is 125 for the values shown in Figure 4. A gain of 125 is selected to provide a 4 V span for the 32 mV of full scale sensor output that is obtained with 8 V B+.

The resulting 0.5 V to 4.5 V output from U1C is preferable to the 0.75 to 4.75 V range developed by the instrument amplifier configuration in Figure 2. It also uses fewer parts. This circuit does not have the instrument amplifier's propensity for oscillation and therefore does not require compensation capacitor C3 that is shown in Figure 2. It also requires one less resistor, which in addition to reducing component count also reduces accumulated tolerances due to resistor variations.

This circuit as well as the instrumentation amplifier interfaces in Figure 2 and Figure 3 is designed for direct connection to a microcomputer A/D input. Using the MC68HC11 as an example, the interface circuit output is connected to any of the E ports, such as port E0 as shown in Figure 6. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 V and V_{REFL} is tied to 0.30 V by dividing down a 5 V reference with 1% resistors.

SINGLE SLOPE A/D CONVERTER

The 8 bit A/D converters that are commonly available on chip in microcomputers are usually well suited to pressure sensing applications. In applications that require more than 8 bits, the circuit in Figure 7 extends resolution to 11 bits with an external analog-to-digital converter. It also provides an interface to digital systems that do not have an internal A/D function.

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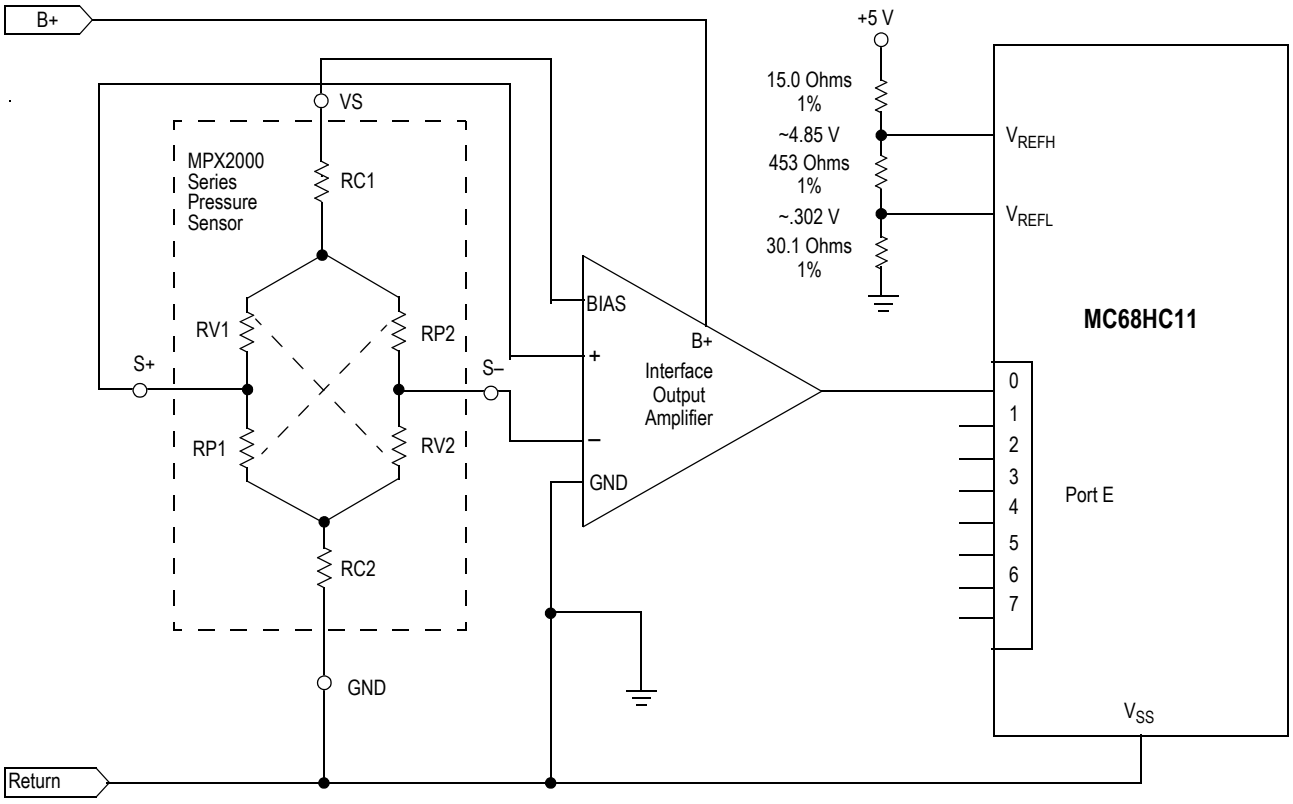

Figure 6. Application Example

Beginning with the ramp generator, a timing ramp is generated with current source U5 and capacitor C3. Initialization is provided by Q1 which sets the voltage on C3 at approximately ground. With the values shown, 470 μA flowing into 0.47 μF provide approximately a 5 msec ramp time from zero to 5 V. Assuming zero pressure on the sensor, inputs to both comparators U2A and U2B are at the same voltage. Therefore, as the ramp voltage sweeps from zero to 5 V, both PA0 and PA1 will go low at the same time when the ramp voltage exceeds the common mode voltage. The processor counts the number of clock cycles between the time that PA0 and PA1 go low, reading zero for zero pressure.

In this circuit, U4A and U4B form the front end of an instrument amplifier. They differentially amplify the sensor's output. The resulting amplified differential signal is then sampled and held in U1 and U3. The sample and hold function is performed in order to keep input data constant during the conversion process. The stabilized signals coming out of U1 and U3 feed a higher output voltage to U2A than U2B, assuming that pressure is applied to the sensor. Therefore, the ramp will trip U2B before U2A is tripped, creating a time difference between PA0 going low and PA1 going low. The processor reads the number of clock cycles between these two events. This number is then linearly scaled with software to represent the amplified output voltage, accomplishing the analog to digital conversion.

When the ramp reaches the reference voltage established by R9 and R10, comparator U2C is tripped, and a reset command is generated. To accomplish reset, Q1 is turned on with an output from PA7, and the sample and hold circuits are delatched with an output from PB1. Resolution is limited by clock frequency and ramp linearity. With the ramp generator shown in Figure 7 and a clock frequency of 2 MHz; resolution is 11 bits.

From a software point of view, the A/D conversion consists of latching the sample and hold, reading the value of the microcomputer's free running counter, turning off Q1, and waiting for the three comparator outputs to change state from logic 1 to logic 0. The analog input voltage is determined by counting, in 0.5 μsec steps, the number of clock cycles between PA0 and PA1 going low.

LONG DISTANCE INTERFACES

In applications where there is a significant distance between the sensor and microcomputer, two types of interfaces are typically used. They are frequency output and 4-20 mA loops. In the frequency output topology, pressure is converted into a zero to 5 V digital signal whose frequency varies linearly with pressure. A minimum frequency corresponds to zero pressure and above this, frequency output is determined by a Hz/unit pressure scaling factor. If minimizing the number of wires to a remote sensor is the most important design consideration, 4-20 mA current loops are the topology of choice. These loops utilize power and ground as the 4-20 mA signal line and therefore require only two wires to the sensor. In this topology 4 mA of total current drain from the sensor corresponds to zero pressure, and 20 mA to full scale.

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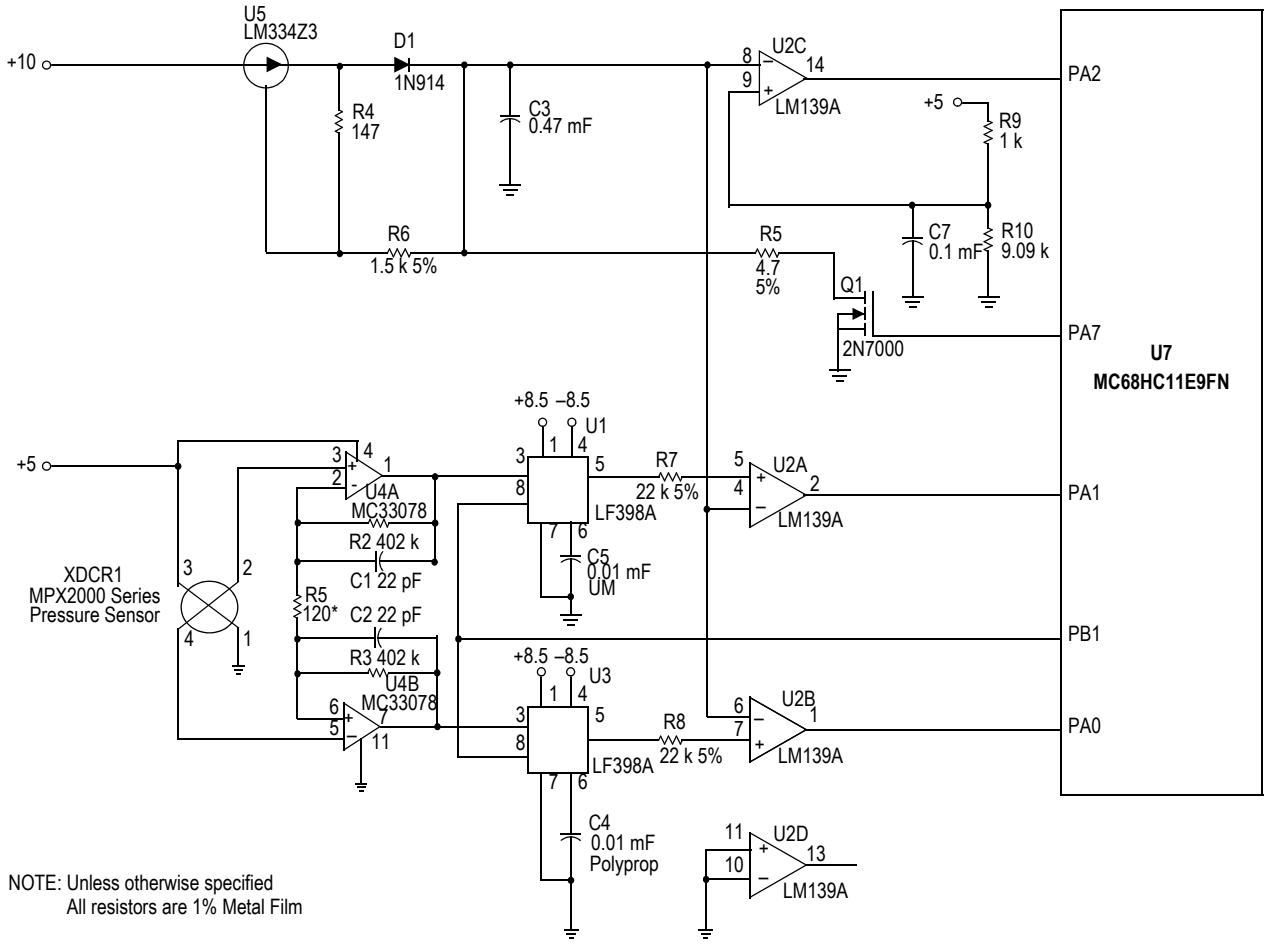

Figure 7. Single Slope A/D Converter

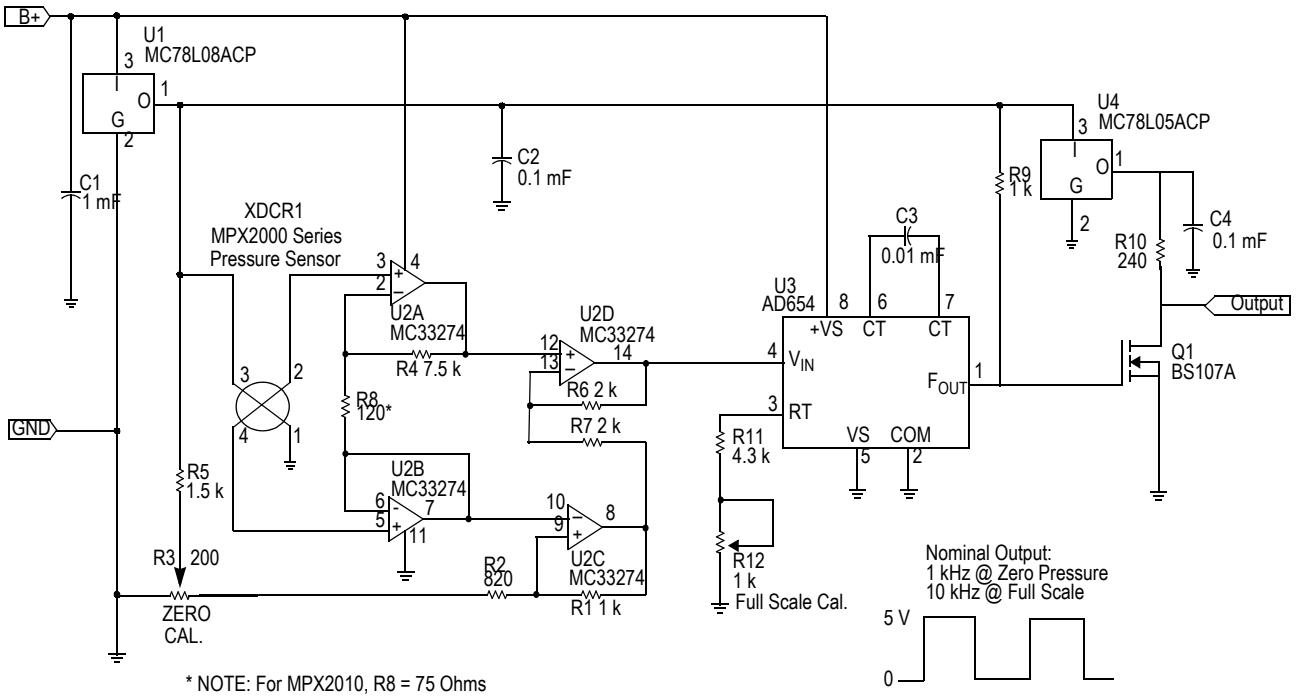

Figure 8. Frequency Output Pressure Sensor

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A relatively straightforward circuit for converting pressure to frequency is shown in Figure 9. It consists of three basic parts. The interface amplifier is the same circuit that was described in Figure 4. Its 0.5 to 4.5 V output is fed directly into an AD654 voltage-to-frequency converter. On the AD654, C3 sets nominal output frequency. Zero pressure output is calibrated to 1 kHz by adjusting the zero pressure input voltage with R3. Full scale adjustments are made with R12 which sets the full scale frequency to 10 kHz. The output of the AD654 is then fed into a buffer consisting of Q1 and R10. The buffer is used to clean up the edges and level translate the output to 5 V. Advantages of this approach are that the frequency output is easily read by a microcomputer's timer and transmission over a twisted pair line is relatively easy. Where very long distances are involved, the primary disadvantage is that 3 wires (V_{CC}, ground, and an output line) are routed to the sensor.

A 4-20 mA loop reduces the number of wires to two. Its output is embedded in the V_{CC} and ground lines as an active current source. A straightforward way to apply this technique to pressure sensing is shown in Figure 10. In this figure an MPX7000 series high impedance pressure sensor is mated to an XTR101 4-20 mA two-wire transmitter. It is set up to pull 4 mA from its power line at zero pressure and 20 mA at full scale. At the receiving end a 240 ohm resistor referenced to signal ground will provide a 0.96 to 4.8 V signal that is suitable for microcomputer A/D inputs.

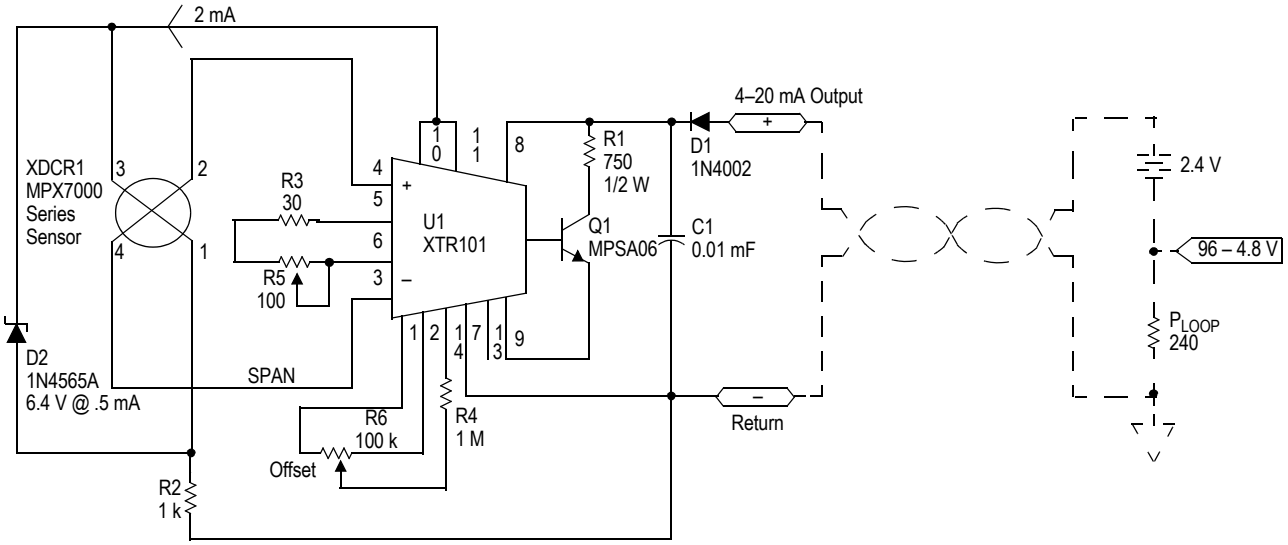

Figure 9. 4-20 mA Pressure Transducer

Bias for the sensor is provided by two 1 mA current sources (pins 10 and 11) that are tied in parallel and run into a 1N4565A 6.4 V temperature compensated zener reference. The sensor's differential output is fed directly into XTR101's inverting and non-inverting inputs. Zero pressure offset is calibrated to 4 mA with R6. Biased with 6.4 V, the sensor's full scale output is 24.8 mV. Given this input R3 + R5 nominally total 64 ohms to produce the 16 mA span required for 20 mA full scale. Calibration is set with R5.

The XTR101 requires that the differential input voltage at pins 3 and 4 has a common mode voltage between 4 and 6 V. The sensor's common mode voltage is one half its supply voltage or 3.2 V. R2 boosts this common mode voltage by 1k•2mA or 2 V, establishing a common mode voltage for the transmitter's input of 5.2 V. To allow operation over a 12 to 40 V range, dissipation is off-loaded from the IC by boosting the output with Q1 and R1. D1 is also included for protection. It prohibits reverse polarity from causing damage. Advantages of this topology include simplicity and, of course, the two wire interface.

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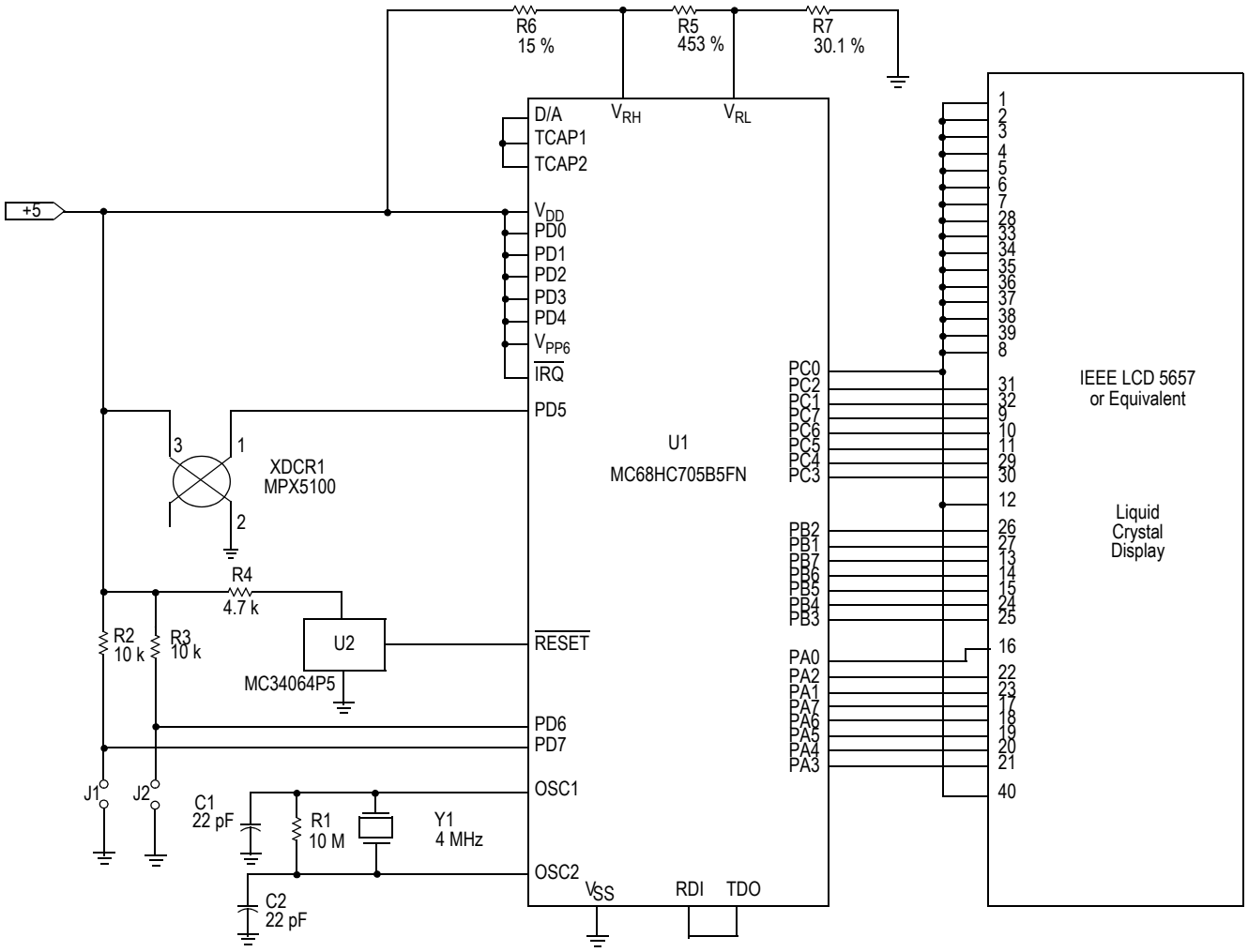

Figure 10. MPX5100 LCD Pressure Gauge

DIRECT INTERFACE WITH INTEGRATED SENSORS

The simplest interface is achieved with an integrated sensor and a microcomputer that has an on-chip A/D converter. Figure 10 shows an LCD pressure gauge that is made with an MPX5100 integrated sensor and MC68HC05 microcomputer. Although the total schematic is reasonably complicated, the interface between the sensor and the micro is a single wire. The MPX5100 has an internal amplifier that outputs a 0.5 to 4.5 V signal that inputs directly to A/D port PD5 on the HC05.

The software in this system is written such that the processor assumes zero pressure at power up, reads the sensor's output voltage, and stores this value as zero pressure offset. Full scale span is adjustable with jumpers J1 and J2. For this particular system the software is written such that with J1 out and J2 in, span is decreased by 1.5%. Similarly with J1 in and J2 out, span is increased by 1.5%. Given the ± 2.5% full scale spec on the sensor, these jumpers allow calibration to ± 1% without the use of pots.

MIX AND MATCH

The circuits that have been described so far are intended to be used as functional blocks. They may be combined in a variety of ways to meet the particular needs of an application. For example, the Frequency Output Pressure Sensor in Figure 8 uses the sensor interface circuit described in Figure 4 to provide an input to the voltage-to-frequency converter. Alternately, an MPX5100 could be directly connected to pin 4 of the AD654 or the output of Figure 3's Precision Instrumentation Amplifier Interface could by substituted in the same way. Similarly, the Pressure Gauge described in Figure 10 could be constructed with any of the interfaces that have been described.

CONCLUSION

The circuits that have been shown here are intended to make interfacing semiconductor pressure sensors to digital systems easier. They provide cost effective and relatively simple ways of interfacing sensors to microcomputers. The seven different circuits contain many tradeoffs that can be matched to the needs of individual applications. When

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considering these tradeoffs it is important to throw software into the equation. Techniques such as automatic zero pressure calibration can allow one of the inexpensive analog interfaces to provide performance that could otherwise only be obtained with a more costly precision interface.

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Applying Semiconductor Sensors to Bar Graph Pressure Gauges

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INTRODUCTION

Bar Graph displays are noted for their ability to very quickly convey a relative sense of how much of something is present. They are particularly useful in process monitoring applications where quick communication of a relative value is more important than providing specific data.

Designing bar graph pressure gauges based upon semiconductor pressure sensors is relatively straightforward. The sensors can be interfaced to bar graph display drive IC's, microcomputers and MC33161 voltage monitors. Design examples for all three types are included.

BAR GRAPH DISPLAY DRIVER

Interfacing semiconductor pressure sensors to a bar graph display IC such as an LM3914 is very similar to microcomputer interface. The same 0.5 to 4.5 V analog signal that a microcomputer's A/D converter wants to see is also quite suitable for driving an LM3914. In Figure 1, this interface is provided by dual op amp U2 and several resistors.

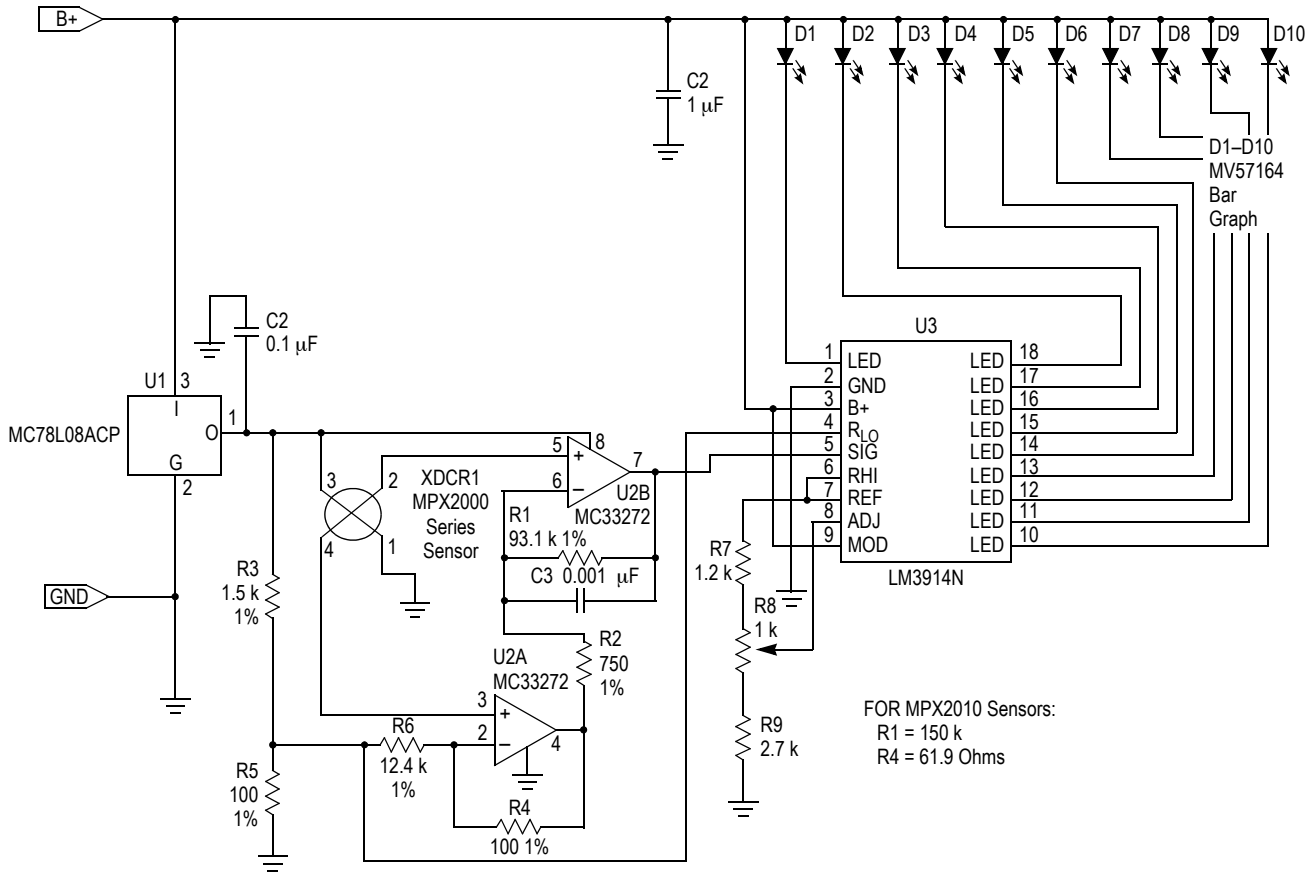

Figure 1. Compensated Sensor Bar Graph Pressure Gauge

The op amp interface amplifies and level shifts the sensor's output. To see how this amplifier works, simplify it by grounding the output of voltage divider R3, R5. If the common mode voltage at pins 2 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6. Assuming that the current in R4 is equal to the current in R6, 323 μA • 100 ohms produces a 32 mV drop across R4 which adds to the 4.0 V at pin 2. The output voltage at pin 1 of U2A is, therefore, 4.032 V. This puts 4.032 - 4.0 V across R2, producing 43 μA. The same current flowing through R1 again produces a voltage drop of 4.0 V, which sets the output at zero. Substituting a divider output greater than zero into this calculation reveals that the zero pressure output voltage is equal to the output voltage of divider R3, R5. For this DC output voltage to be independent of the sensor's common mode voltage, it is necessary to satisfy the condition that R1/R2 = R6/R4.

Gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this assume 100 mV of differential output, which puts pin 2 of U2A at 3.95 V, and pin 6 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 μA. This current flowing through R4 produces 31.9 mV, placing pin 1 of U2A at 3950 mV + 31.9 mV = 3982 mV. The voltage across R2 is then 4050 mV - 3982 mV = 68 mV, which produces a current of 91 μA that flows into R1. The output voltage is then 4.05 V + (91 μA • 93.1k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4.0 V span for 32 mV of full scale sensor output.

Setting divider R3, R5 at 0.5 V results in a 0.5 V to 4.5 V output that is easily tied to an LM3914. The block diagram that appears in Figure 2 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 V zero pressure output voltage. Returning to Figure 1, this is accomplished by using the zero pressure offset voltage that is generated at the output of divider R3, R5.

Again looking at Figure 1, full scale is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R7, R9, and adjustment pot R8.

Eight volt regulated power is supplied by an MC78L08. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R7, R8, and R9 to ground. In this design it is nominally (4.5 V/4.9 k)10 = 9.2 mA.

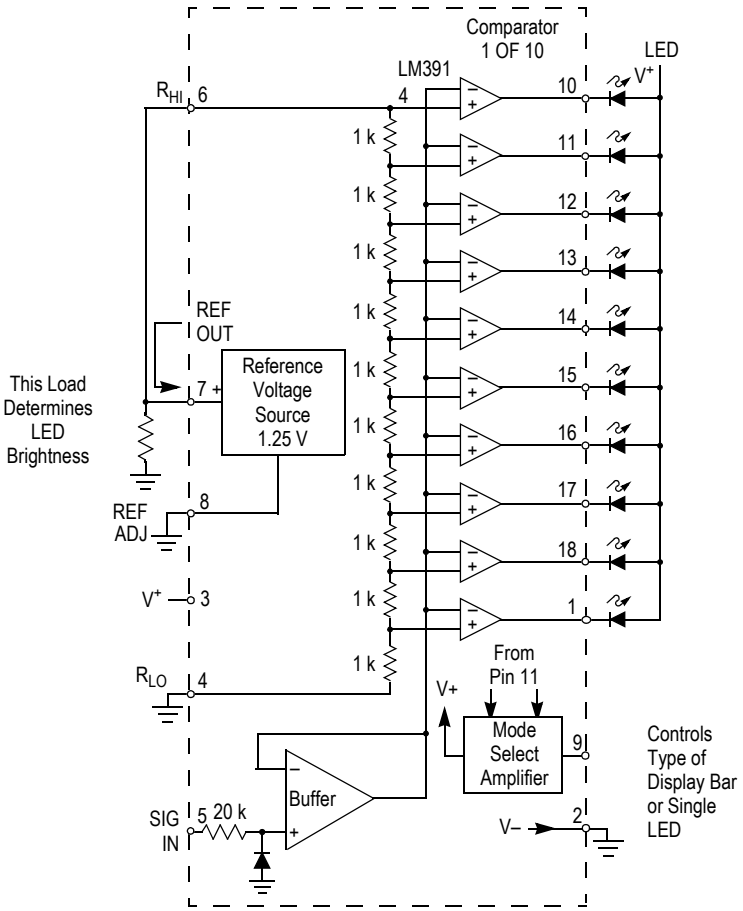

Figure 2. LM3914 Block Diagram

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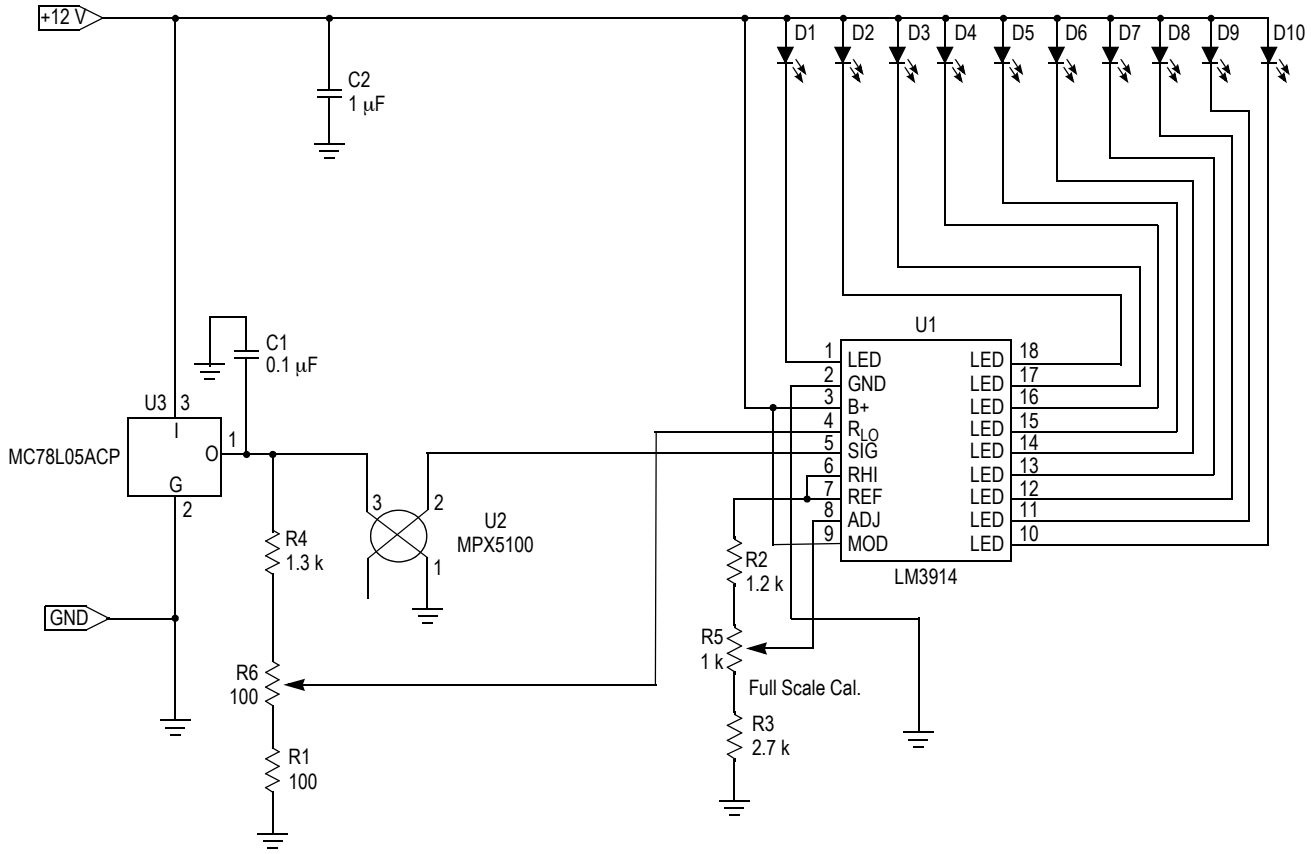

Figure 3. MPX5100 Bar Graph Pressure Gauge

Over a zero to 50°C temperature range combined accuracy for the sensor, interface, and driver IC are ±10%. Given a 10 segment display total accuracy for the bar graph readout is approximately ± (10 kPa +10%).

This circuit can be simplified by substituting an MPX5100 integrated sensor for the MPX2100 and the op amp interface. The resulting schematic is shown in Figure 3. In this case zero reference for the bar graph is provided by dividing down the 5 V regulator with R4, R1 and adjustment pot R6. The voltage at the wiper of R6 is adjusted to match the sensor's zero pressure offset voltage. It is connected to R_{LO} to zero the bar graph.

MICROCOMPUTER BAR GRAPH

Microcomputers with internal A/D converters such as an MC68HC05B5 lend themselves to easily creating bar graphs. Using the A/D converter to measure the sensor's analog output voltage and output ports to individually switch LED's makes a relatively straightforward pressure gauge. This type of design is facilitated by a new MDC4510A gated current sink. The MDC4510A takes one of the processor's logic outputs and switches 10 mA to an LED. One advantage of this approach is that it is very flexible regarding the number of segments that are used, and has the availability through software to independently adjust scaling factors for each segment. This approach is particularly useful for process monitoring in systems where a microprocessor is already in place.

Figure 4 shows a direct connection from an MPX5100 sensor to the microcomputer. Similar to the previous example, an MPX2000 series sensor with the op amp interface that is shown in Figure 1 can be substituted for the MPX5100. In this case the op amp interface's output at pin 7 ties to port PD5, and its supply needs to come from a source greater than 6.5 V.

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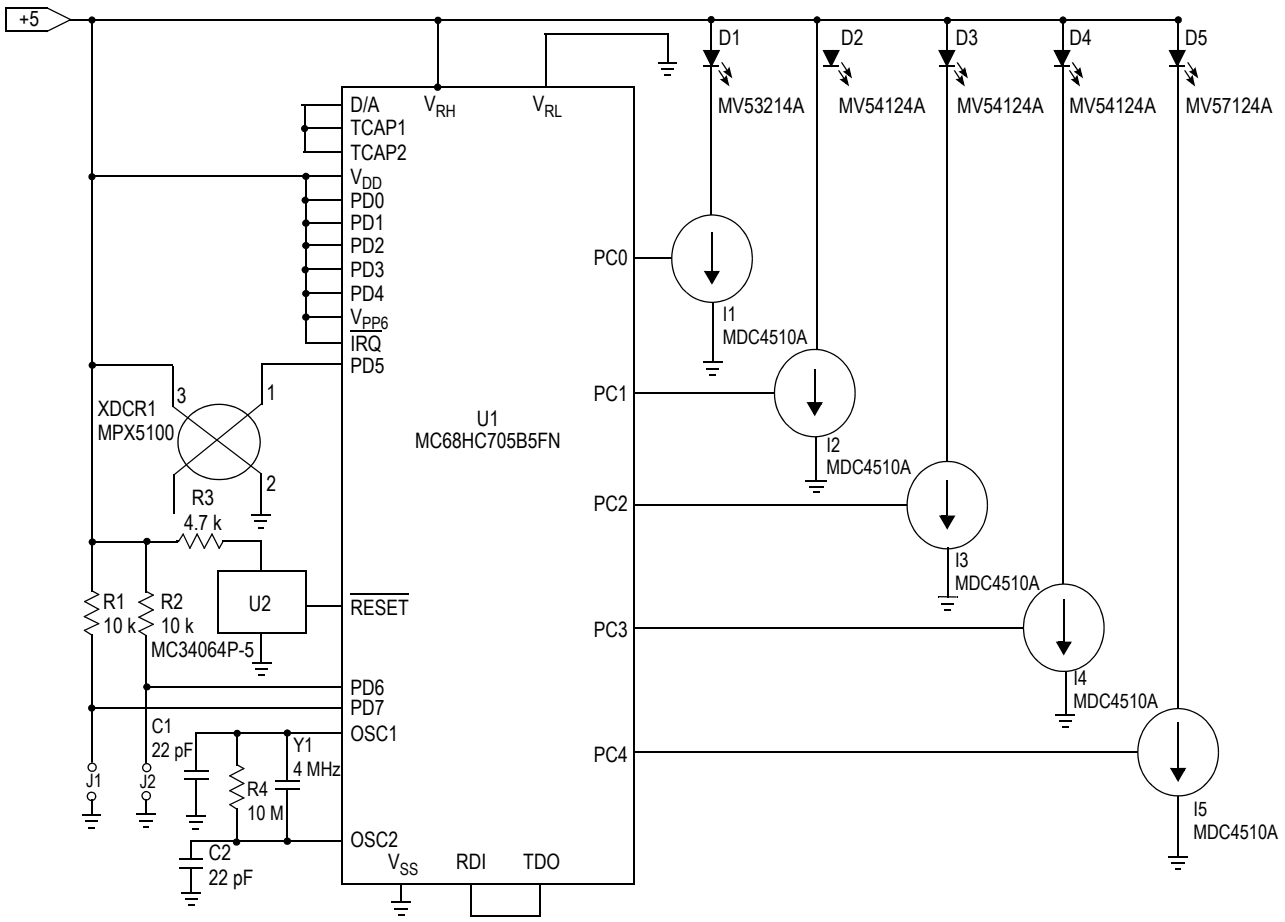

Figure 4. Microcomputer Bar Graph Pressure Gauge

PROCESS MONITOR

For applications where an inexpensive HIGH-LOW-OK process monitor is required, the circuit in Figure 5 does a good job. It uses an MC33161 Universal Voltage Monitor and the same analog interface previously described to indicate high, low or in-range pressure.

A block diagram of the MC33161 is illustrated in Figure 6. By tying pin 1 to pin 7 it is set up as a window detector. Whenever input 1 exceeds 1.27 V, two logic ones are placed at the inputs of its exclusive OR gate, turning off output 1. Therefore this output is on unless the lower threshold is exceeded. When 1.27 V is exceeded on input 2, just the opposite occurs. A single logic one appears at its exclusive OR gate, turning on output 2. These two outputs drive LED's through MDC4010A 10 mA current sources to indicate low pressure and high pressure.

Returning to Figure 5, an in-range indication is developed by turning on current source I1 whenever both the high and low outputs are off. This function is accomplished with a discrete gate made from D1, D2 and R7. Its output feeds the input of switched current source I1, turning it on with R7 when neither D1 nor D2 is forward biased.

Thresholds are set independently with R8 and R9. They sample the same 4.0 V full scale span that is used in the other examples. However, zero pressure offset is targeted for 1.3 V. This voltage was chosen to approximate the 1.27 V reference at both inputs, which avoids throwing away the sensor's analog output signal to overcome the MC33161's input threshold. In addition, R10 and R11 are selected such that at full scale output, i.e., 5.3 V on pin 7, the low side of the pots is nominally at 1.1 V. This keeps the minimum input just below the comparator thresholds of 1.27 V, and maximizes the resolution available from adjustment pots R8 and R9. When level adjustment is not desired, R8 - R11 can be replaced by a simpler string of three fixed resistors.

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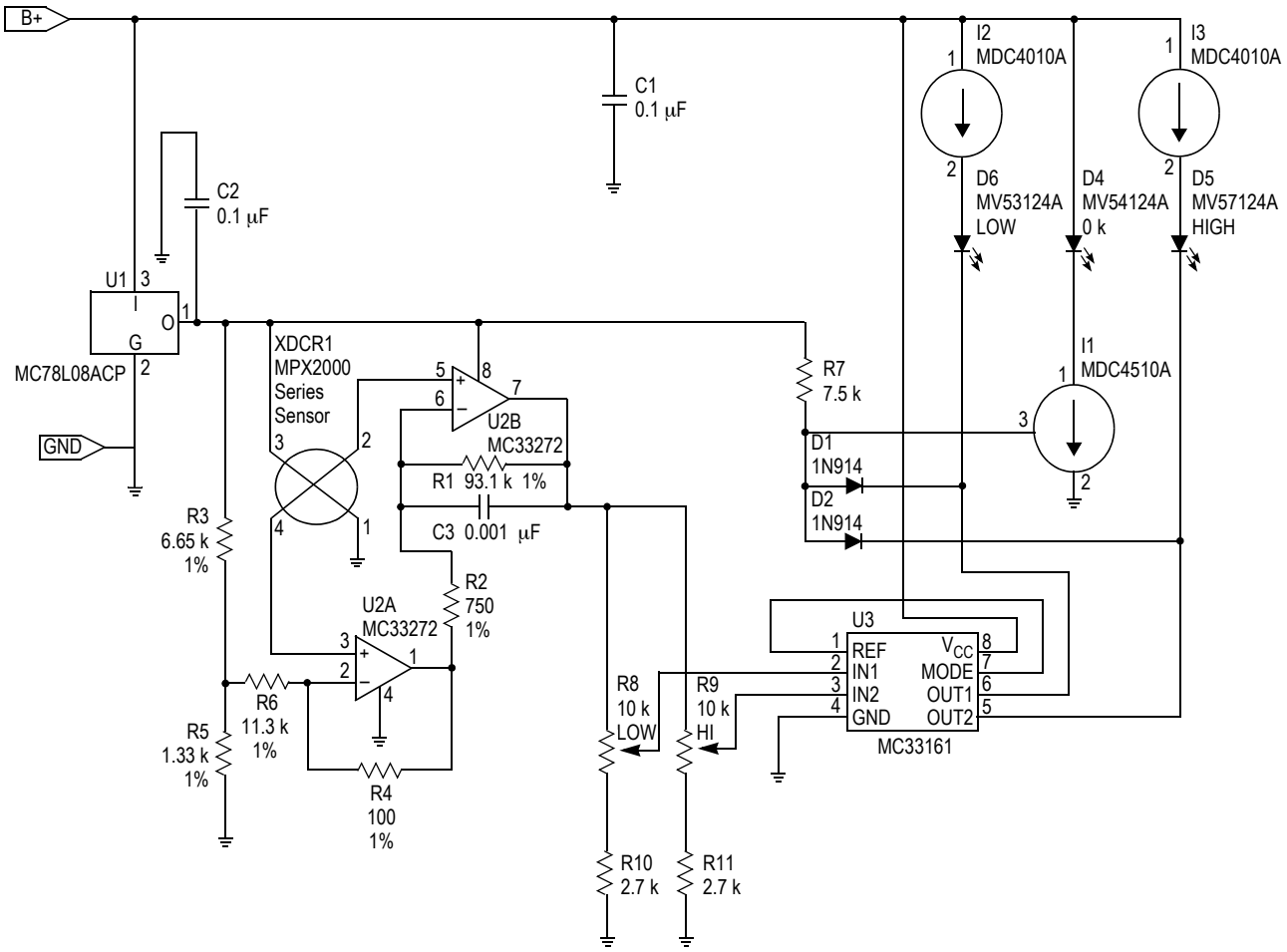

Figure 5. An Inexpensive Three-Segment Processor Monitor

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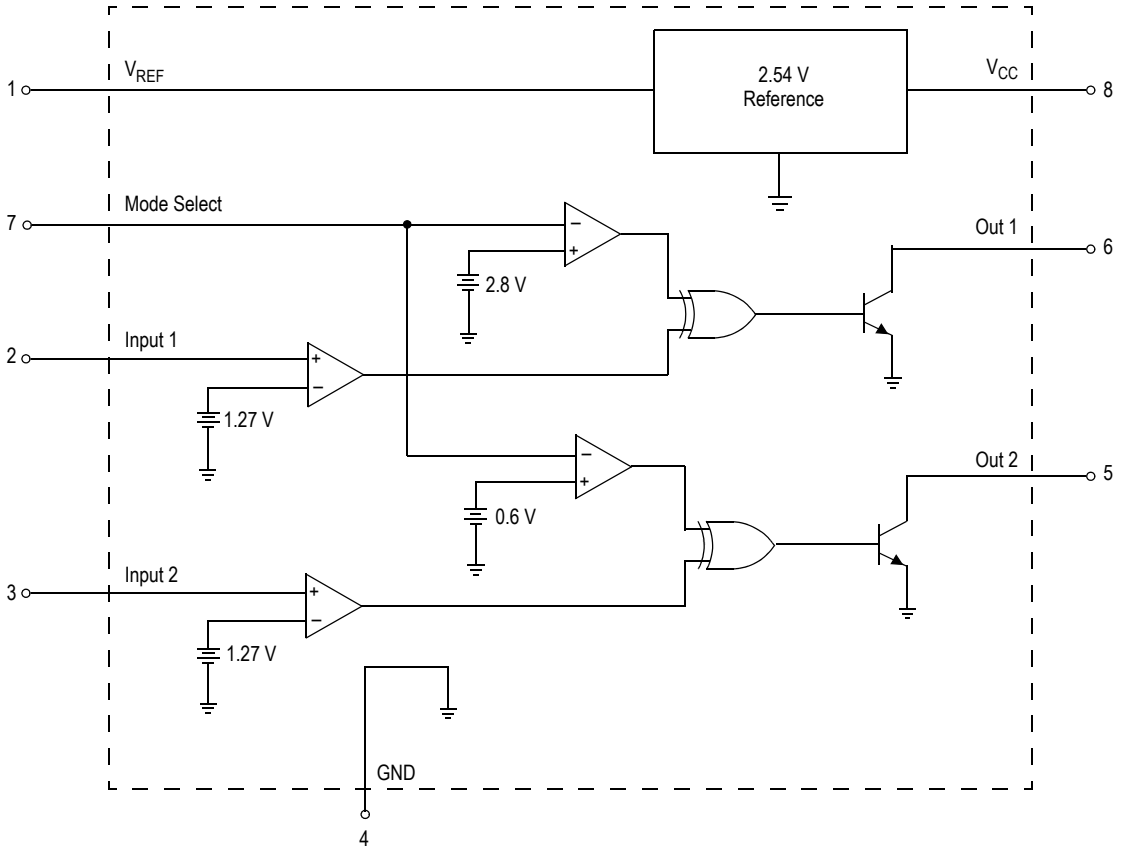

Figure 6. MC33161 Block Diagram

CONCLUSION

The circuits that have been shown here are intended to make simple, practical and cost effective bar graph pressure gauges. Their application involves a variety of trade-offs that can be matched to the needs of individual applications. In general, the most important trade-offs are the number of segments required and processor utilization. If the system in which the bar graph is used already has a microprocessor with unused A/D channels and I/O ports, tying MDC4510A current sources to the unused output ports is a very cost effective solution. On a stand-alone basis, the MC33161 based process monitor is the most cost effective where only 2 or 3 segments are required. Applications that require a larger number of segments are generally best served by one of the circuits that uses a dedicated bar graph display.

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Amplifiers for Semiconductor Pressure Sensors

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Discrete Applications Engineering

INTRODUCTION

Amplifiers for interfacing Semiconductor Pressure Sensors to electronic systems have historically been based upon classic instrumentation amplifier designs. Instrumentation amplifiers have been widely used because they are well understood standard building blocks that also work reasonably well. For the specific job of interfacing Semiconductor Pressure Sensors to today's mostly digital systems, other circuits can do a better job. This application note presents an evolution of amplifier design that begins with a classic instrumentation amplifier and ends with a simpler circuit that is better suited to sensor interface.

INTERFACE AMPLIFIER REQUIREMENTS

Design requirements for interface amplifiers are determined by the sensor's output characteristics, and the zero to 5.0 V input range that is acceptable to microcomputer A/D converters. Since the sensor's full scale output is typically tens of millivolts, the most obvious requirement is gain. Gains from 100 to 250 are generally needed, depending upon bias voltage applied to the sensor and maximum pressure to be measured. A differential to single-ended conversion is also required in order to translate the sensor's differential output into a single ended analog signal. In addition, level shifting is necessary to convert the sensor's 1/2 B^+ common mode voltage to an appropriate DC level. For microcomputer A/D inputs, generally that level is from 0.3 - 1.0V. Typical design targets are 0.5 V at zero pressure and enough gain to produce 4.5 V at full scale. The 0.5 V zero pressure offset allows for output saturation voltage in op amps operated with a single supply (V_{EE} = 0). At the other end, 4.5 V full scale keeps the output within an A/D converter's 5 V range with a comfortable margin for component tolerances. The resulting 0.5 to 4.5 V single-ended analog signal is also quite suitable for a variety of other applications such as bar graph pressure gauges and process monitors.

CLASSIC INSTRUMENTATION AMPLIFIER

A classic instrumentation amplifier is shown in Figure 1. This circuit provides the gain, level shifting and differential to single-ended conversion that are required for sensor interface. It does not, however, provide for single supply operation with a zero pressure offset voltage in the desired range.

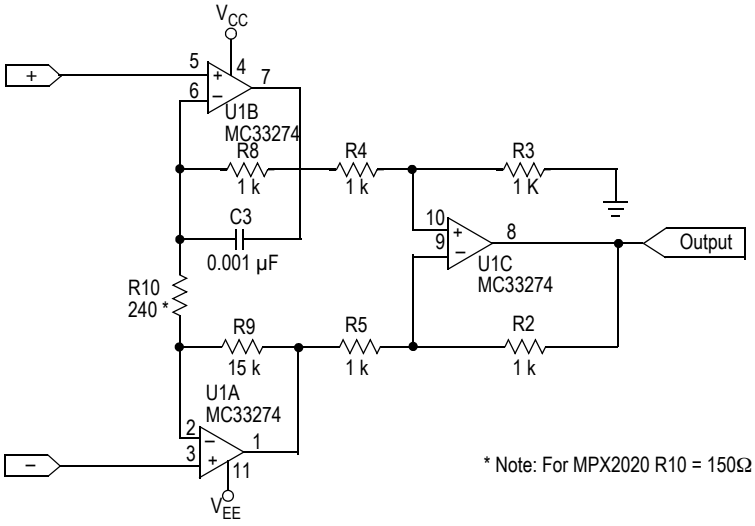

Figure 1. Classic Instrumentation Amplifier

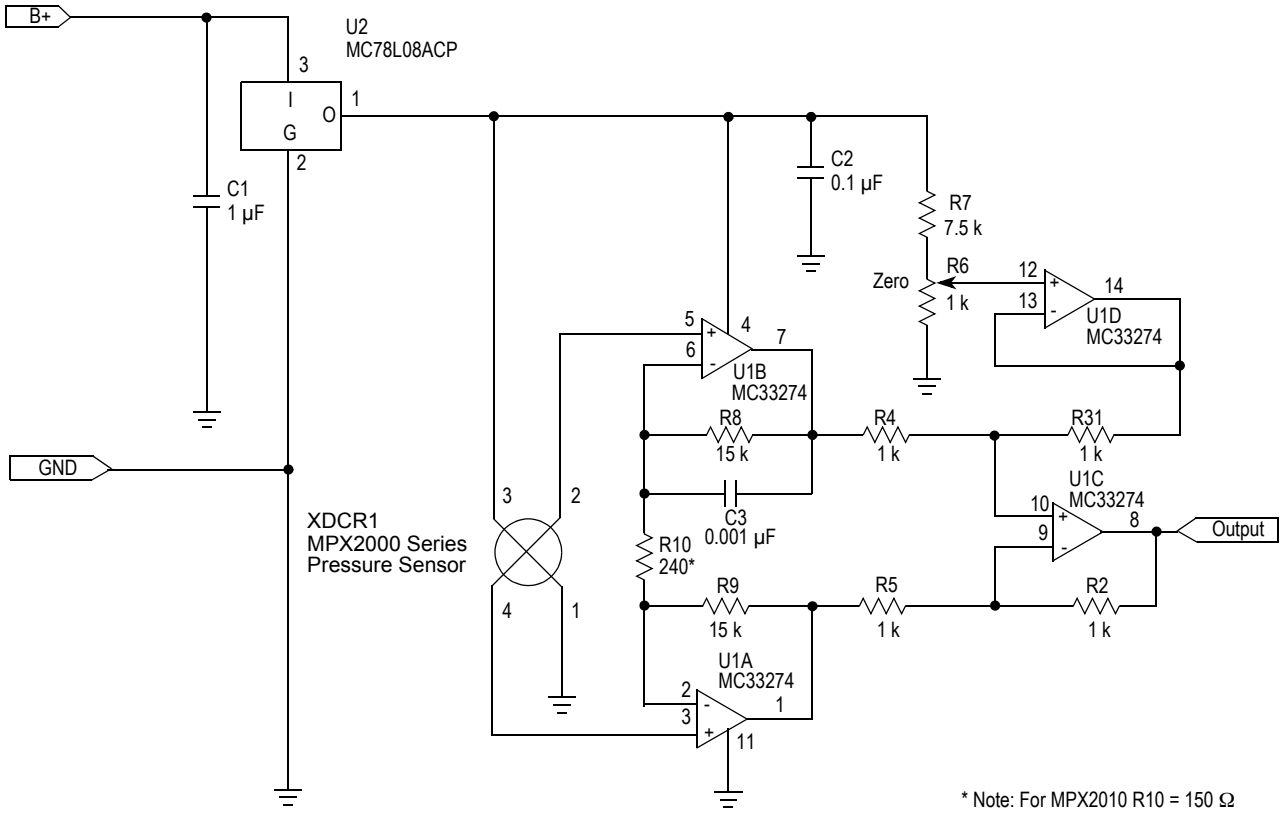

Figure 2. Instrumentation Amplifier Interface

To provide the desired DC offset, a slight modification is made in Figure 2. R3 is connected to pin 14 of U1D, which supplies a buffered offset voltage that is derived from the wiper of R6. This voltage establishes a DC output for zero differential input. The translation is one to one. Whatever voltage appears at the wiper of R6 will, within component tolerances, appear as the zero pressure DC offset voltage at the output.

With R10 at 240 Ω gain is set for a nominal value of 125, providing a 4.0 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V, results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs.

This circuit works reasonably well, but has several notable limitations when made with discrete components. First, it has a relatively large number of resistors that have to be well matched. Failure to match these resistors degrades common mode rejection and initial tolerance on zero pressure offset voltage. It also has two amplifiers in one gain loop, which makes stability more of an issue than it is in the following two alternatives. This circuit also has more of a limitation on zero pressure offset voltage than the other two. The minimum output voltage of U1D restricts the minimum zero pressure offset voltage that can be accommodated, given component tolerances. The result is a 0.75 V zero pressure offset voltage, compared to 0.5 V for each of the following two circuits.

SENSOR SPECIFIC AMPLIFIER

The limitations associated with classic instrumentation amplifiers suggest that alternate approaches to sensor interface design are worth looking at. One such approach is shown in Figure 3. It uses one quad op amp and several resistors to amplify and level shift the sensor's output.

Most of the amplification is done in U1A, which is configured as a differential amplifier. It is isolated from the sensor's minus output by U1B. The purpose of U1B is to prevent feedback current that flows through R5 and R6 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero V. For example, assume that the common mode voltage is 4.0 V. The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R6 and create a non zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage by U1C and U1D. To see how the level translation works, assume the wiper of R9 is at ground. With 4.0 V at pin 12, pin 13 is also at 4.0 V. This leaves 4.0 V across (R3 + R9), which total essentially 1.0 kΩ. Since no current flows through R4, producing approximately 4.0 V across R4, as well. Adding the voltages (4.0 + 4.0) yields 8.0 V at pin 14. Similarly, 4.0 V at pin 10 implies 4.0 V at pin 9, and the drop across R2 is 8.0 V –4.0 = 4.0 V. Again 4.0 V across R2 implies an equal drop across R1, and the voltage at pin 8 is 4.0 V – 4.0 V. In practice, the output of U1C will not go all the way to

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ground, and the voltage injected by R8 at the wiper of R9 is approximately translated into a DC offset.

Gain is approximately equal to R6/R5(R1/R2+1), which predicts 125 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 127. Cascading the gains of U1A and U1C using standard op amp gain equations does not give an exact result, because the sensor's negative going differential signal at pin 4 subtracts from the DC level that is amplified by U1C. Setting offset to 0.5 V results in an analog zero to full scale range of 0.5 to 4.5 V. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = (R3+R9)/R4.

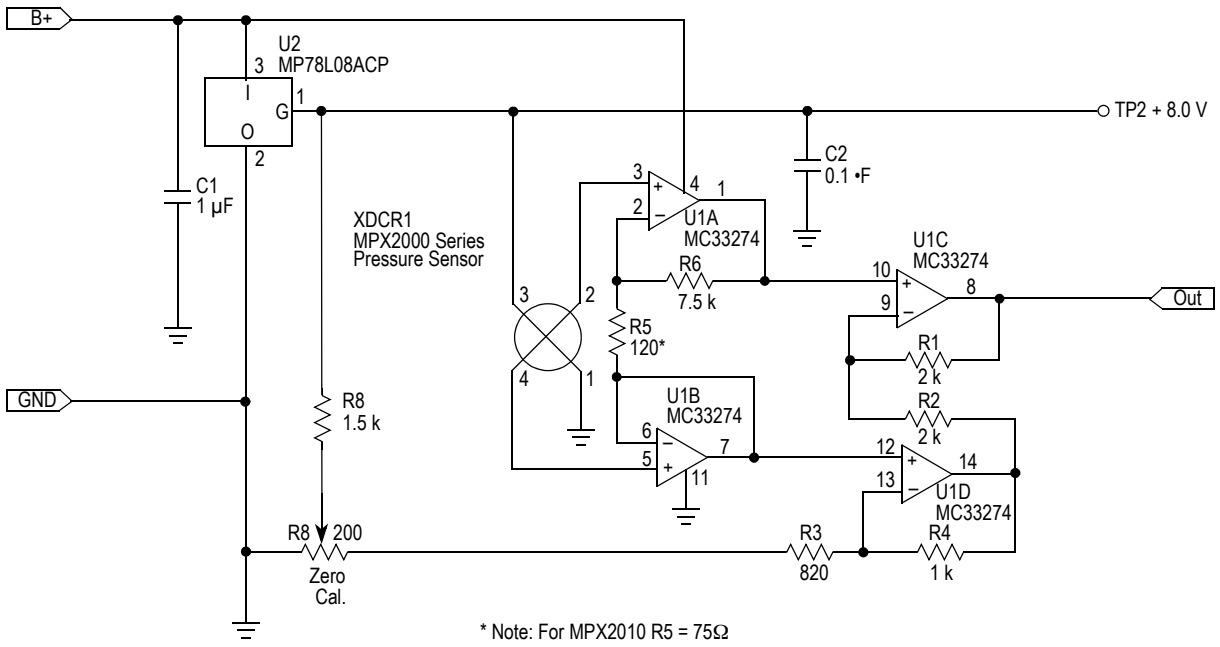

Figure 3. Sensor Specific Amplifier

This approach to interface amplifier design is an improvement over the classic instrument amplifier in that it uses fewer resistors, is inherently more stable, and provides a zero pressure output voltage that can be targeted at 0.5 V. It has the same tolerance problem from matching discrete resistors that is associated with classic instrument amplifiers.

SENSOR MINI AMP

Further improvements can be made with the circuit that is shown in Figure 4. It uses one dual op amp and several resistors to amplify and level shift the sensor's output. To see how this amplifier works, let's simplify it by grounding the output of voltage divider R3, R5 and assuming that the divider impedance is added to R6, such that R6 = 12.4 k. If the common mode voltage at pins 2 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6, producing 323 µA. Assuming that the current in R4 is equal to the current in R6, 323 µA • 100 Ω produces a 32 mV drop across R4 which adds to the 4.0 V at pin 2. The output voltage at pin 1 of U2A is, therefore, 4.032 V. This puts 4.032 - 4.0 V across R2, producing 43 µA. The same current flowing through R1 again produces a voltage drop of 4.0 V, which sets the output at zero. Substituting a divider output greater than zero into this calculation reveals that the zero pressure output voltage is equal to the output voltage of divider R3, R5. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = R6/R4, where R6 includes the divider impedance.

Gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this assume 100 mV of differential output, which puts pin 2 of U2A at 3.95 V, and pin 6 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 µA. This current flowing through R4 produces 31.9 mV, placing pin 1 of U2A at 3950 mV + 31.9 mV = 3982 mV. The voltage across R2 is then 4050 mV - 3982 mV = 68 mV, which produces a current of 91 µA that flows into R1. The output voltage is then 4.05 V + (91 µA • 93.1 k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4 V span for 32 mV of full scale sensor output. Setting divider R3, R5 at 0.5 V results in a 0.5 V to 4.5 V output that is comparable to the other two circuits.

This circuit performs the same function as the other two with significantly fewer components and lower cost. In most cases it is the optimum choice for a low cost interface amplifier.

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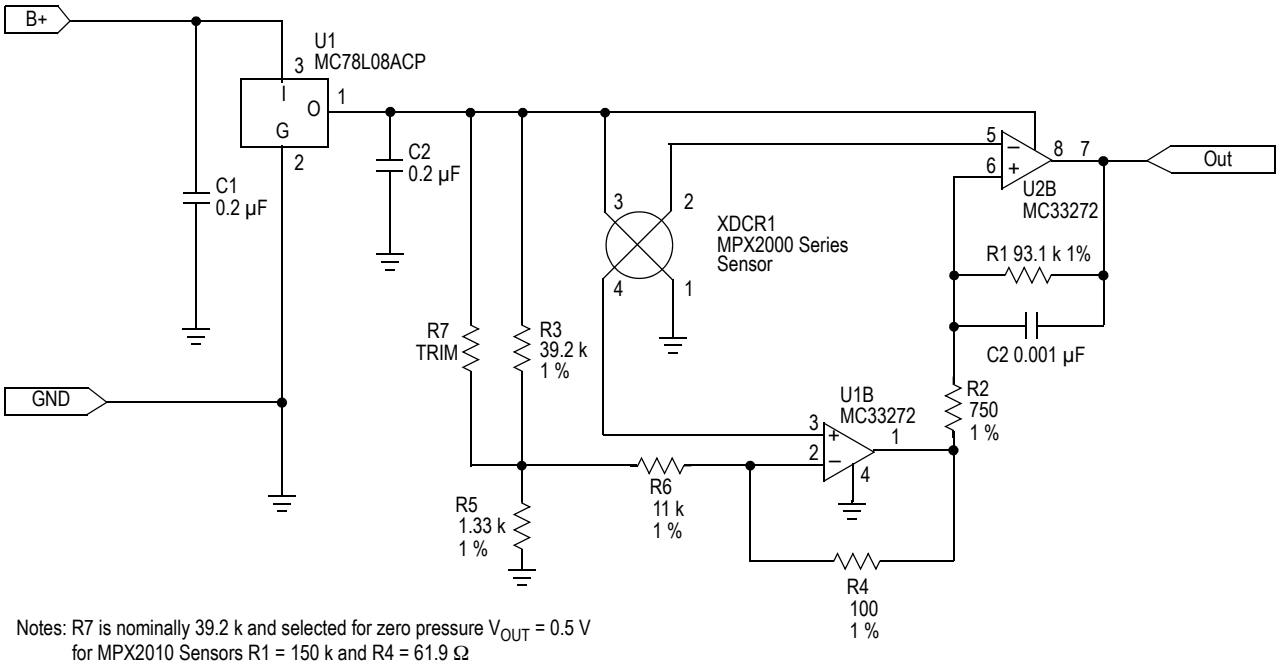

Figure 4. Sensor Mini Amp

Performance differences between the three topologies are minor. Accuracy is much more dependent upon the quality of the resistors and amplifiers that are used and less dependent on which of the three circuits are chosen. For example, input offset voltage error is essentially the same for all three circuits. To a first order approximation, it is equal to total gain times the difference in offset between the two amplifiers that are directly tied to the sensor. Errors due to resistor tolerances are somewhat dependent upon circuit topology. However, they are much more dependent upon the choice of resistors. Choosing one percent resistors rather than five percent resistors has a much larger impact on performance than the minor differences that result from circuit topology. Assuming a zero pressure offset adjustment, any of these circuits with an MPX2000 series sensor, one percent resistors and an MC33274 amplifier results in a ±5% pressure to voltage translation from 0 to 50°C. Software calibration can significantly improve these numbers and eliminate the need for analog trim.

CONCLUSION

Although the classic instrumentation amplifier is the best known and most frequently used sensor interface amplifier, it is generally not the optimal choice for inexpensive circuits made from discrete components. The circuit that is shown in Figure 4 performs the same interface function with significantly fewer components, less board space and at a lower cost. It is generally the preferred interface topology for MPX2000 series semiconductor pressure sensors.

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Barometric Pressure Measurement Using Semiconductor Pressure Sensors

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ABSTRACT

The most recent advances in silicon micromachining technology have given rise to a variety of low-cost pressure sensor applications and solutions. Certain applications had previously been hindered by the high-cost, large size, and overall reliability limitations of electromechanical pressure sensing devices. Furthermore, the integration of on-chip temperature compensation and calibration has allowed a significant improvement in the accuracy and temperature stability of the sensor output signal. This technology allows for the development of both analog and microcomputer-based systems that can accurately resolve the small pressure changes encountered in many applications. One particular application of interest is the combination of a silicon pressure sensor and a microcontroller interface in the design of a digital barometer. The focus of the following documentation is to present a low-cost, simple approach to designing a digital barometer system.

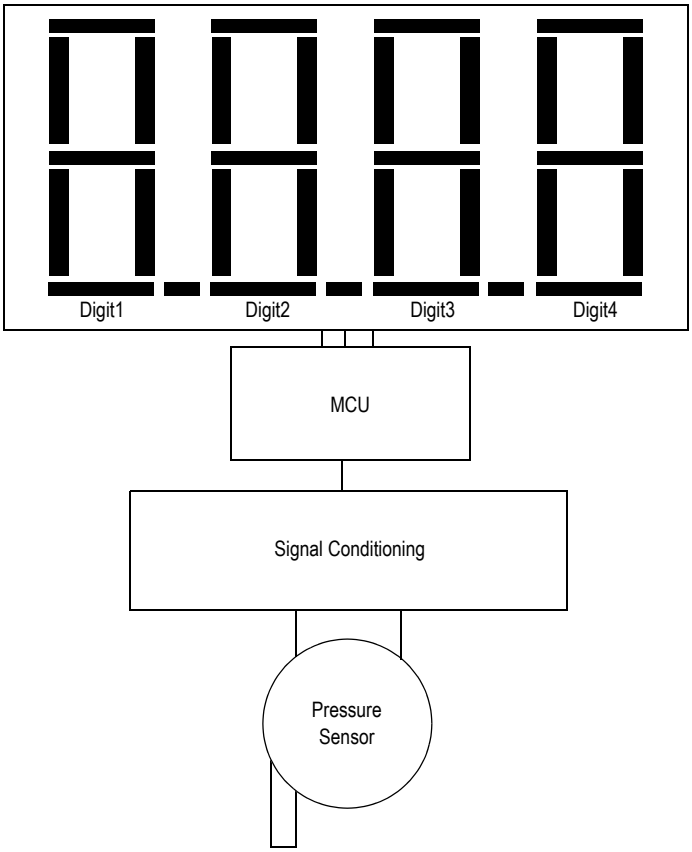

Figure 1. Barometer System

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INTRODUCTION

Figure 1 shows the overall system architecture chosen for this application. This system serves as a building block, from which more advanced systems can be developed. Enhanced accuracy, resolution, and additional features can be integrated in a more complex design.

There are some preliminary concerns regarding the measurement of barometric pressure which directly affect the design considerations for this system. Barometric pressure refers to the air pressure existing at any point within the earth's atmosphere. This pressure can be measured as an absolute pressure, (with reference to absolute vacuum) or can be referenced to some other value or scale. The meteorology and avionics industries traditionally measure the absolute pressure, and then reference it to a sea level pressure value. This complicated process is used in generating maps of weather systems. The atmospheric pressure at any altitude varies due to changing weather conditions over time. Therefore, it can be difficult to determine the significance of a particular pressure measurement without additional information. However, once the pressure at a particular location and elevation is determined, the pressure can be calculated at any other altitude. Mathematically, atmospheric pressure is exponentially related to altitude. This particular system is designed to track variations in barometric pressure once it is calibrated to a known pressure reference at a given altitude.

For simplification, the standard atmospheric pressure at sea level is assumed to be 29.9 in-Hg. “Standard” barometric pressure is measured at particular altitude at the average weather conditions for that altitude over time. The system described in this text is specified to accurately measure barometric pressure variations up to altitudes of 15,000 ft. This altitude corresponds to a standard pressure of approximately 15.0 in-Hg. As a result of changing weather conditions, the standard pressure at a given altitude can fluctuate approximately ±1 in-Hg. in either direction. Table 1 indicates standard barometric pressures at several altitudes of interest.

Table 1. Altitude versus Pressure Data

Altitude (Ft.)	Pressure (in-Hg)
0	29.92
500	29.38
1,000	28.85
6,000	23.97
10,000	20.57
15,000	16.86

SYSTEM OVERVIEW

In order to measure and display the correct barometric pressure, this system must perform several tasks. The measurement strategy is outlined below in Figure 2. First, pressure is applied to the sensor. This produces a proportional differential output voltage in the millivolt range. This signal must then be amplified and level-shifted to a single-ended, microcontroller (MCU) compatible level (0.5 – 4.5 V) by a signal conditioning circuit. The MCU will then sample the voltage at the analog-to-digital converter (A/D) channel input, convert the digital measurement value to inches of mercury, and then display the correct pressure via the LCD interface. This process is repeated continuously.

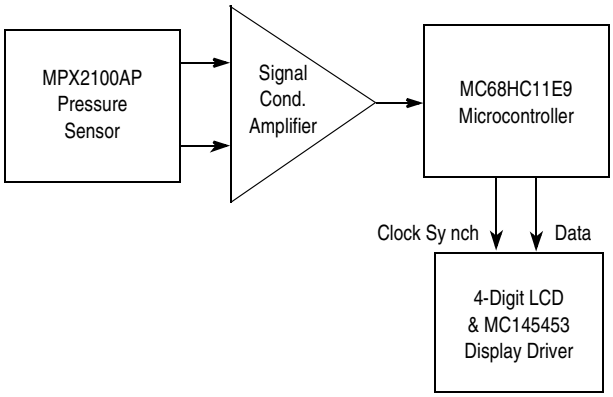

Figure 2. Barometer System Block Diagram

There are several significant performance features implemented into this system design. First, the system will digitally display barometric pressure in inches of mercury, with a resolution of approximately one-tenth of an inch of mercury. In order to allow for operation over a wide altitude range (0 – 15,000 ft.), the system is designed to display barometric pressures ranging from 30.5 in-Hg. to a minimum of 15.0 in-Hg. The display will read “lo” if the pressure measured is below 30.5 in-Hg. These pressures allow for the system to operate with the desired resolution in the range from sea-level to approximately 15,000 ft. An overview of these features is shown in Table 2.

Table 2. System Features Overview

Display Units	in-Hg
Resolution	0.1 in-Hg.
System Range	15.0 – 30.5 in-Hg.
Altitude Range	0 – 15,000 ft.

DESIGN OVERVIEW

The following sections are included to detail the system design. The overall system will be described by considering the subsystems depicted in the system block diagram, Figure 2. The design of each subsystem and its function in the overall system will be presented.

Table 3. MPX2100AP Electrical Characteristics

Characteristic	Symbol	Minimum	Typical	Max	Unit
Pressure Range	POP	0	—	100	kPa
Supply Voltage	VS	—	10	16	Vdc
Full Scale Span	VFSS	38.5	40	41.5	mV
Zero Pressure Offset	Voff	—	—	±1.0	mV
Sensitivity	S	—	0.4	—	mv/kPa
Linearity	—	—	0.05	—	%FSS
Temperature Effect on Span	—	—	0.5	—	%FSS
Temperature Effect on Offset	—	—	0.2	—	%FSS

Pressure Sensor

The first and most important subsystem is the pressure transducer. This device converts the applied pressure into a proportional, differential voltage signal. This output signal will vary linearly with pressure. Since the applied pressure in this application will approach a maximum level of 30.5 in-Hg. (100 kPa) at sea level, the sensor output must have a linear output response over this pressure range. Also, the applied pressure must be measured with respect to a known reference pressure, preferably absolute zero pressure (vacuum). The device should also produce a stable output over the entire operating temperature range.

The desired sensor for this application is a temperature compensated and calibrated, semiconductor pressure transducer, such as the MPXM2102A series sensor family. The MPX2000 series sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Furthermore, they are available in a variety of pressure configurations (gauge, differential, and absolute) and porting options. Because of the pressure ranges involved with barometric pressure measurement, this system will employ an MPXM2102AS (absolute with single port). This device will produce a linear voltage output in the pressure range of 0 to 100 kPa. The ambient pressure applied to the single port will be measured with respect to an evacuated cavity (vacuum reference). The electrical characteristics for this device are summarized in Table 3.

As indicated in Table 3, the sensor can be operated at different supply voltages. The full-scale output of the sensor, which is specified at 40 mV nominally for a supply voltage of 10 Vdc, changes linearly with supply voltage. All non-digital circuitry is operated at a regulated supply voltage of 8 Vdc. Therefore, the full-scale sensor output (also the output of the sensor at sea level) will be approximately 32 mV.

$$\left(\frac{8}{10} \times 40\ \text{mV}\right)$$

The sensor output voltage at the systems minimum range (15 in-Hg.) is approximately 16.2 mV. Thus, the sensor output over the intended range of operations is expected to vary from 32 to 16.2 mV. These values can vary slightly for each sensor as the offset voltage and full-scale span tolerances indicate.

Signal Conditioning Circuitry

In order to convert the small-signal differential output signal of the sensor to MCU compatible levels, the next subsystem includes signal conditioning circuitry. The operational amplifier circuit is designed to amplify, level-shift, and ground reference the output signal. The signal is converted to a single-ended, 0.5 – 4.5 Vdc range. The schematic for this amplifier is shown in Figure 3.

This particular circuit is based on classic instrumentation amplifier design criteria. The differential output signal of the sensor is inverted, amplified, and then level-shifted by an adjustable offset voltage (through $R_{offset1}$). The offset voltage is adjusted to produce 0.5 volts at the maximum barometric pressure (30.5 in-Hg.). The output voltage will increase for decreasing pressure. If the output exceeds 5.1 V, a zener protection diode will clamp the output. This feature is included to protect the A/D channel input of the MCU. Using the transfer function for this circuit, the offset voltage and gain can be determined to provide 0.1 in-Hg of system resolution and the desired output voltage level. The calculation of these parameters is illustrated below.

In determining the amplifier gain and range of the trimmable offset voltage, it is necessary to calculate the number of steps used in the A/D conversion process to resolve 0.1 in-Hg.

$$(30.5 - 15.0)\text{in-Hg} * 10\ \frac{\text{steps}}{\text{Hg}} = 155\ \text{steps}$$

The span voltage can now be determined. The resolution provided by an 8-bit A/D converter with low and high voltage references of zero and five volts, respectively, will detect 19.5 mV of change per step.

V_{RH} = 5 V, V_{RL} = 0 V

Sensor Output at 30.5 in-Hg = 32.44 mV
Sensor Output at 15.0 in-Hg = 16.26 mV
ΔSensor Output = ΔSO = 16.18 mV

$$\text{Gain} = \frac{3.04\ \text{V}}{\Delta\text{SO}} = 187$$

Note: 30.5 in-Hg and 15.0 in-Hg are the assumed maximum and minimum absolute pressures, respectively.

This gain is then used to determine the appropriate resistor values and offset voltage for the amplifier circuit defined by the transfer function shown below.

$$V_{out} = -\left[\frac{R_2}{R_1} + 1\right] * \Delta V + V_{off}$$

ΔV is the differential output of the sensor.

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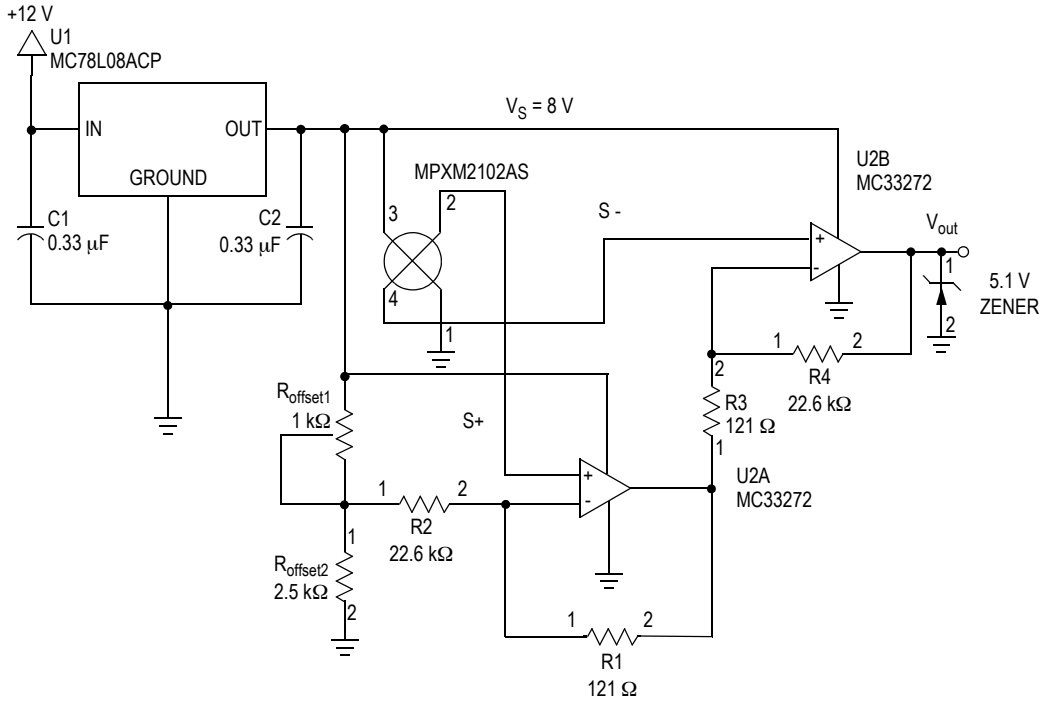

Figure 3. Signal Conditioning Circuit

The gain of 187 can be implemented with:

$R_1 \approx R_3 = 121\ \Omega$
$R_2 \approx R_4 = 22.6\ k\Omega$.

Choosing $R_{offset1}$ to be 1 kΩ and $R_{offset2}$ to be 2.5 kΩ, V_{out} is 0.5 V at the presumed maximum barometric pressure of 30.5 in-Hg. The maximum pressure output voltage can be trimmed to a value other than 0.5 V, if desired via $R_{offset1}$. In addition, the trimmable offset resistor is incorporated to provide offset calibration if significant offset drift results from large weather fluctuations.

The circuit shown in Figure 3 employs an MC33272 (low-cost, low-drift) dual operational amplifier IC. In order to control large supply voltage fluctuations, an 8 Vdc regulator, MC78L08ACP, is used. This design permits use of a battery for excitation.

Microcontroller Interface

The low cost of MCU devices has allowed for their use as a signal processing tool in many applications. The MCU used in this application, the MC68HC11, demonstrates the power of incorporating intelligence into such systems. The on-chip resources of the MC68HC11 include: an 8 channel, 8-bit A/D, a 16-bit timer, an SPI (Serial Peripheral Interface – synchronous), and SCI (Serial Communications Interface – asynchronous), and a maximum of 40 I/O lines. This device is available in several package configurations and product variations which include additional RAM, EEPROM, and/or I/O capability. The software used in this application was developed using the MC68HC11 EVB development system.

The following software algorithm outlines the steps used to perform the desired digital processing. This system will convert the voltage at the A/D input into a digital value, convert this measurement into inches of mercury, and output this data serially to an LCD display interface (through the on-board SPI). This process is outlined in greater detail below:

1. Set up and enable A/D converter and SPI interface.
2. Initialize memory locations, initialize variables.
3. Make A/D conversion, store result.
4. Convert digital value to inches of mercury.
5. Determine if conversion is in system range.

6a. Convert pressure into decimal display digits.

6b. Otherwise, display range error message.

7. Output result via SPI to LCD driver device.

The signal conditioned sensor output signal is connected to pin PE5 (Port E-A/D Input pin). The MCU communicates to the LCD display interface via the SPI protocol. A listing of the assembly language source code to implement these tasks is included in the appendix. In addition, the software can be downloaded directly from the Freescale MCU Freeware Bulletin Board (in the MCU directory). Further information is included at the beginning of the appendix.

LCD Interface

In order to digitally display the barometric pressure conversion, a serial LCD interface was developed to communicate with the MCU. This system includes an MC145453 CMOS serial interface/LCD driver, and a 4-digit,

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non-multiplexed LCD. In order for the MCU to communicate correctly with the interface, it must serially transmit six bytes for each conversion. This includes a start byte, a byte for each of the four decimal display digits, and a stop byte. For formatting purposes, decimal points and blank digits can be displayed through appropriate bit patterns. The control of display digits and data transmission is executed in the source code through subroutines BCDCONV, LOOKUP, SP12LCD, and TRANSFER. A block diagram of this interface is included below.

CONCLUSION

This digital barometer system described herein is an excellent example of a sensing system using solid state components and software to accurately measure barometric pressure. This system serves as a foundation from which more complex systems can be developed. The MPXM2102A series pressure sensors provide the calibration and temperature compensation necessary to achieve the desired accuracy and interface simplicity for barometric pressure sensing applications.

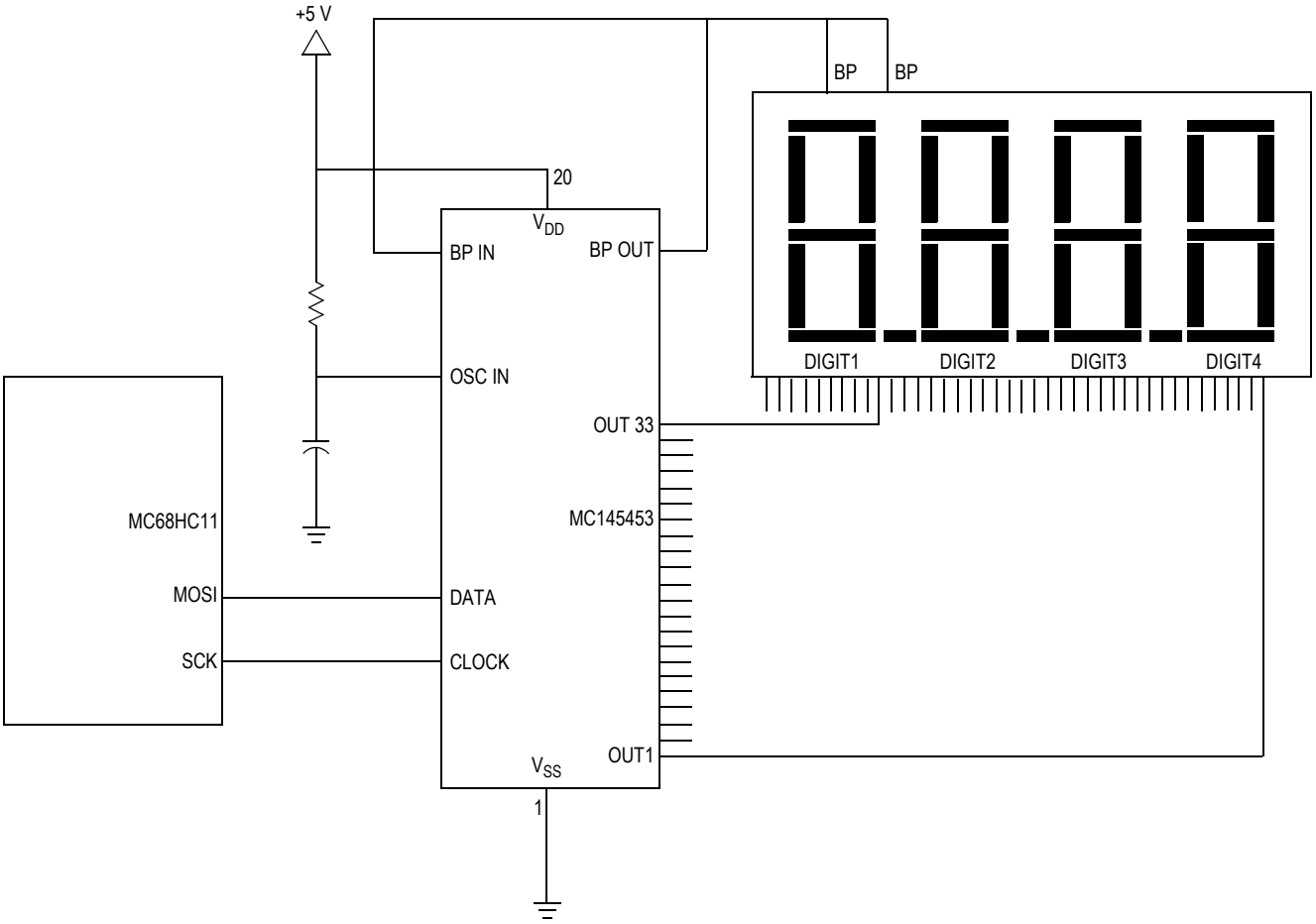

Figure 4. LCD Display Interface Diagram

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APPENDIX

MC68HC11 Barometer Software Available on:
Freescale Electronic Bulletin Board
MCU Freeware Line
8-bit, no parity, 1 stop bit
1200/300 baud
(512) 891-FREE (3733)

```
* BAROMETER APPLICATIONS PROJECT - Chris Winkler
* Developed: October 1st, 1992   - Freescale Discrete Applications
* This code will be used to implement an MC68HC11 Micro-Controller
* as a processing unit for a simple barometer system.
* The HC11 will interface with an MPX2100AP to monitor,store
* and display measured Barometric pressure via the 8-bit A/D channel
* The sensor output (32mv max) will be amplified to .5 - 2.5 V dc
* The processor will interface with a 4-digit LCD (FE202) via
* a Freescale LCD driver (MC145453) to display the pressure
* within +/- one tenth of an inch of mercury.
* The systems range is 15.0 - 30.5 in-Hg

*        A/D  & CPU Register Assignment
*        This code will use index addressing to access the
*        important control registers.  All addressing will be
*        indexed off of REGBASE, the base address for these registers.

REGBASE  EQU      $1000            * register base of control register
ADCTL             EQU      $30              * offset of A/D control register
ADR2              EQU      $32              * offset of A/D results register
ADOPT             EQU      $39              * offset for A/D option register location
PORTB             EQU      $04              * Location of PORTB used for conversion
PORTD             EQU      $08              * PORTD Data Register Index
DDRD              EQU      $09              * offset of Data Direction Reg.
SPCR              EQU      $28              * offset of SPI Control Reg.
SPSR              EQU      $29              * offset of SPI Status Reg.
SPDR              EQU      $2A              * offset of SPI Data Reg.

*        User Variables
*        The following locations are used to store important measurements
*        and calculations used in determining the altitude.  They
*        are located in the lower 256 bytes of user RAM

DIGIT1   EQU      $0001            * BCD blank digit (not used)
DIGIT2   EQU      $0002            * BCD tens digit for pressure
DIGIT3   EQU      $0003            * BCD tenths digit for pressure
DIGIT4   EQU      $0004            * BCD ones digit for pressure
COUNTER  EQU      $0005            * Variable to send 5 dummy bytes
POFFSET  EQU      $0010            * Storage Location for max pressure offset
SENSOUT  EQU      $0012            * Storage location for previous conversion
RESULT   EQU      $0014            * Storage of Pressure(in Hg) in hex format
FLAG              EQU      $0016            * Determines if measurement is within range

*        MAIN PROGRAM
*        The conversion process involves the following steps:
*
*                         1.               Set-Up SPI device-                SPI_CNFG
*                         2.               Set-Up A/D, Constants             SET_UP
*                         3.               Read A/D, store sample            ADCONV
*                         4.               Convert into in-Hg                IN_HG
*                         5.               Determine FLAG conditionIN_HG
*                                  a.      Display error                     ERROR
*                                  b.      Continue Conversion               INRANGE
*                         6.               Convert hex to BCD formatBCDCONV
*                         7.               Convert LCD display digits        LOOKUP
*                         8.               Output via SPI to LCD             SPI2LCD

*        This process is continually repeated as the loop CONVERT
*        runs unconditionally through BRA (the BRANCH ALWAYS statement)
*        Repeats to step 3 indefinitely.
                  ORG      $C000                    * DESIGNATES START OF MEMORY MAP FOR USER CODE
                  LDX      #REGBASE         * Location of base register for indirect adr
                  BSR      SPI_CNFG         * Set-up SPI Module for data X-mit to LCD
                  BSR      SET_UP           * Power-Up A/D, initialize constants
CONVERT  BSR      ADCONV           * Calls subroutine to make an A/D conversion
                  BSR      DELAY                    * Delay routine to prevent LCD flickering
```


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```
                BSR     IN_HG                   * Converts hex format to in of Hg

*       The value of FLAG passed from IN_HG is used to determine
*       If a range error has occurred.  The following logical
*       statements are used to either allow further conversion or jump
*       to a routine to display a range error message.

                LDAB    FLAG                    * Determines if an range Error has ocurred
                CMPB    #$80                    * If No Error detected (FLAG=$80) then
                BEQ     INRANGE         *   system will continue conversion process
                BSR     ERROR                   * If error occurs (FLAG<>80), branch to ERROR
                BRA     OUTPUT          * Branches to output ERROR code to display

*       No Error Detected, Conversion Process Continues

INRANGE JSR     BCDCONV         * Converts Hex Result to BCD
                JSR     LOOKUP          * Uses Look-Up Table for BCD-Decimal

OUTPUT  JSR     SPI2LCD         * Output transmission to LCD
                BRA     CONVERT         * Continually converts using Branch Always

*       Subroutine SPI_CNFG
*               Purpose is to initialize SPI for transmission
*               and clear the display before conversion.

SPI_CNFG BSET   PORTD,X #$20    * Set SPI SS Line High to prevent glitch
                LDAA    #$38                    * Initializing Data Direction for Port D
                STAA    DDRD,X          * Selecting SS, MOSI, SCK as outputs only

                LDAA    #$5D                    * Initialize SPI-Control Register
                STAA    SPCR,X          * selecting SPE,MSTR,CPOL,CPHA,CPRO

                LDAA    #$5                     * sets counter to X-mit 5 blank bytes
                STAA    COUNTER

                LDAA    SPSR,X          * Must read SPSR to clear SPIF Flag

                CLRA                            * Transmission of Blank Bytes to LCD

ERASELCD JSR    TRANSFER        * Calls subroutine to transmit
                DEC     COUNTER
                BNE     ERASELCD

                RTS

*       Subroutine SET_UP
*               Purpose is to initialize constants and to power-up A/D
*               and to initialize POFFSET used in conversion purposes.
SET_UP  LDAA    #$90                    * selects ADPU bit in OPTION register
                STAA    ADOPT,X         * Power-Up of A/D complete
                LDD     #$0131+$001A    * Initialize POFFSET
                STD     POFFSET         * POFFSET = 305 - 25 in hex
                LDAA    #$00                    * or Pmax + offset voltage (5 V)
                RTS

*       Subroutine DELAY
*               Purpose is to delay the conversion process
*               to minimize LCD flickering.

DELAY           LDA     #$FF                    * Loop for delay of display
OUTLOOP LDB     #$FF                    * Delay = clk/255*255
INLOOP  DECB
                BNE     INLOOP
                DECA
                BNE     OUTLOOP
                RTS

*       Subroutine ADCONV
*               Purpose is to read the A/D input, store the conversion into
*               SENSOUT. For conversion purposes later.
ADCONV  LDX     #REGBASE        * loads base register for indirect addressing
                LDAA    #$25
                STAA    ADCTL,X         * initializes A/D cont. register SCAN=1,MULT=0

WTCONV  BRCLR   ADCTL,X  #$80 WTCONV    * Wait for completion of conversion flag
                LDAB    ADR2,X          * Loads conversion result into Accumulator
                CLRA
                STD     SENSOUT         * Stores conversion as SENSOUT
                RTS
```


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```
*        Subroutine IN_HG
*                Purpose is to convert the measured pressure SENSOUT, into
*                units of in-Hg, represented by a hex value of 305-150
*                This represents the range 30.5 - 15.0 in-Hg
IN_HG            LDD     POFFSET          * Loads maximum offset for subtraction
                 SUBD    SENSOUT          * RESULT = POFFSET-SENSOUT in hex format
                 STD     RESULT           * Stores hex result for P, in Hg
                 CMPD    #305
                 BHI     TOHIGH

                 CMPD    #150
                 BLO     TOLOW

                 LDAB    #$80
                 STAB    FLAG
                 BRA     END_CONV

TOHIGH   LDAB    #$FF
                 STAB    FLAG
                 BRA     END_CONV

TOLOW            LDAB    #$00
                 STAB    FLAG
END_CONV RTS

*        Subroutine ERROR
*                        This subroutine sets the display digits to output
*                        an error message having detected an out of range
*                        measurement in the main program from FLAG

ERROR            LDAB    #$00                     * Initialize digits 1,4 to blanks
                 STAB    DIGIT1
                 STAB    DIGIT4

                 LDAB    FLAG                     * FLAG is used to determine
                 CMPB    #$00                     * if above or below range.
                 BNE     SET_HI           * If above range GOTO SET_HI

                 LDAB    #$0E                     * ELSE display LO on display
                 STAB    DIGIT2           * Set DIGIT2=L,DIGIT3=O
                 LDAB    #$7E
                 STAB    DIGIT3
                 BRA     END_ERR          * GOTO exit of subroutine

SET_HI   LDAB    #$37                     * Set DIGIT2=H,DIGIT3=1
                 STAB    DIGIT2
                 LDAB    #$30
                 STAB    DIGIT3

END_ERR  RTS

*        Subroutine BCDCONV
*                        Purpose is to convert ALTITUDE from hex to BCD
*                        uses standard HEX-BCD conversion scheme
*                        Divide HEX/10 store Remainder, swap Q & R, repeat
*                        process until remainder = 0.

BCDCONV  LDAA    #$00                     * Default Digits 2,3,4 to 0
                 STAA    DIGIT2
                 STAA    DIGIT3
                 STAA    DIGIT4
                 LDY     #DIGIT4          * Conversion starts with lowest digit
                 LDD     RESULT           * Load voltage to be converted
CONVLP   LDX     #$A                      * Divide hex digit by 10
                 IDIV                             * Quotient in X, Remainder in D
                 STAB    0,Y                      * stores 8 LSB's of remainder as BCD digit
                 DEY
                 CPX     #$0                      * Determines if last digit stored
                 XGDX                             * Exchanges remainder & quotient
                 BNE     CONVLP
                 LDX     #REGBASE         * Reloads BASE into main program
                 RTS

*        Subroutine LOOKUP
*                        Purpose is to implement a Look-Up conversion
*                        The BCD is used to index off of TABLE
*                        where the appropriate hex code to display
*                        that decimal digit is contained.
```


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```
*                       DIGIT4,3,2 are converted only.

LOOKUP   LDX     #DIGIT1+4               * Counter starts at 5
TABLOOP  DEX                             * Start with Digit4
                 LDY     #TABLE          * Loads table base into Y-pointer
                 LDAB    0,X                     * Loads current digit into B
                 ABY                             * Adds to base to index off TABLE
                 LDAA    0,Y                     * Stores HEX segment result in A
                 STAA    0,X
                 CPX     #DIGIT2         * Loop condition complete, DIGIT2 Converted
                 BNE     TABLOOP

                 RTS

*        Subroutine SPI2LCD
*                       Purpose is to output digits to LCD via SPI
*                       The format for this is to send a start byte,
*                       four digits, and a stop byte. This system
*                       will have 3 significant digits: blank digit
*                       and three decimal digits.

*                                                Sending LCD Start Byte

SPI2LCD  LDX     #REGBASE
                 LDAA    SPSR,X          * Reads to clear SPIF flag
                 LDAA    #$02                    * Byte, no colon, start bit
                 BSR     TRANSFER        * Transmit byte

*                                                Initializing decimal point & blank digit
                 LDAA    DIGIT3          * Sets MSB for decimal pt.
                 ORA     #$80                    * after digit 3
                 STAA    DIGIT3

                 LDAA    #$00                    * Set 1st digit as blank
                 STAA    DIGIT1

*                                                Sending four decimal digits

                 LDY     #DIGIT1         * Pointer set to send 4 bytes
DLOOP            LDAA    0,Y                     * Loads digit to be x-mitted
                 BSR     TRANSFER        * Transmit byte
                 INY                             * Branch until both bytes sent
                 CPY     #DIGIT4+1
                 BNE     DLOOP

*                                                Sending LCD Stop Byte

                 LDAA    #$00                    * end byte requires all 0's
                 BSR     TRANSFER        * Transmit byte

                 RTS

*        Subroutine TRANSFER
*                Purpose is to send data bits to SPI
*                and wait for conversion complete flag bit to be set.

TRANSFER LDX     #REGBASE
                 BCLR    PORTD,X #$20    * Assert SS Line to start X-misssion
                 STAA    SPDR,X          * Load Data into Data Reg.,X-mit
XMIT             BRCLR   SPSR,X  #$80 XMIT * Wait for flag
                 BSET    PORTD,X #$20    * DISASSERT SS Line
                 LDAB    SPSR,X          * Read to Clear SPI Flag

                 RTS

*        Location for FCB memory for look-up table
*        There are 11 possible digits: blank, 0-9

TABLE            FCB     $7E,$30,$6D,$79,$33,$5B,$5F,$70,$7F,$73,$00
                 END
```

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Liquid Level Control Using a Pressure Sensor

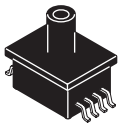
by: J.C. Hamelain
Toulouse Pressure Sensor Laboratory

INTRODUCTION

Discrete Products provide a complete solution for designing a low cost system for direct and accurate liquid level control using an ac powered pump or solenoid valve. This circuit approach which exclusively uses Freescale semiconductor parts, incorporates a piezoresistive pressure sensor with on-chip temperature compensation and a new solid-state relay with an integrated power triac, to drive directly the liquid level control equipment from the domestic 110/220V 50/60 Hz ac main power line.

PRESSURE SENSOR DESCRIPTION

The MPXM2000 Series pressure sensor integrates on-chip, laser-trimmed resistors for offset calibration and temperature compensation. The pressure sensitive element is a patented, single piezoresistive implant which replaces the four resistor Wheatstone bridge traditionally used by most pressure sensor manufacturers.



MPAK Axial Port
Case 1320A

Depending on the application and pressure range, the sensor may be chosen from the following portfolio. For this application the MPXM2010GS was selected.

Device	Pressure Range	Application Sensitivity*
MPXM2010GS	0 to 10 kPa	± 0.01 kPa (1 mm H_2O)
MPXM2053GS	0 to 50 kPa	± 0.05 kPa (5 mm H_2O)
MPXM2102GS	0 to 100 kPa	± 0.1 kPa (10 mm H_2O)
MPXM2202GS	0 to 200 kPa	± 0.2 kPa (20 mm H_2O)
* After proper gain adjustment		

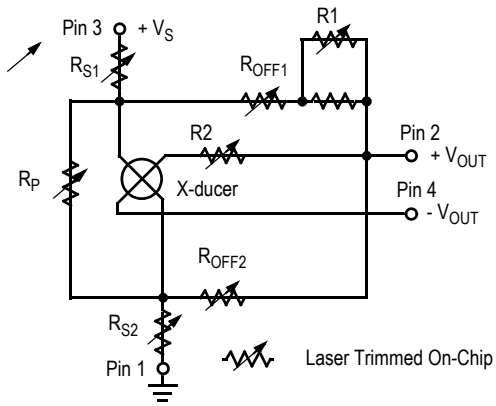
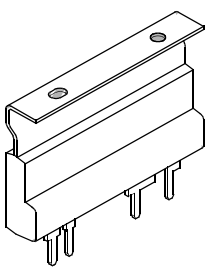


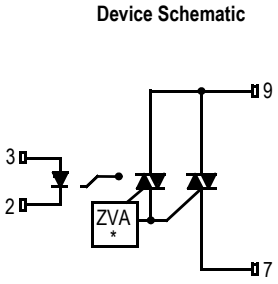
Figure 1. Pressure Sensor MPXM2000 Series

POWER ISOLATOR MOC2A60 DESCRIPTION

The MOC2A60 is a new isolator and consists of a gallium arsenide, infrared emitting diode, which is optically coupled to a zero-cross triac driver and a power triac. It is capable of driving a load of up to 2 A (rms) directly from a line voltage of 220 V (50/60 Hz).



Case 417
Plastic
Package



* Zero Voltage Activate Circuit

1, 4, 5, 6, 8. No Pin
2–LED Cathode
3–LED Anode
7–Main Terminal
9–Main Terminal

Figure 2. MOC2A60 Isolator

SIGNAL CONDITIONING

When a full range pressure is applied to the MPXM2010GS, it will provide an output of about 20 mV (at an 8 V supply). Therefore, for an application using only a few percent of the pressure range, the available signal may be as low as a few hundred microvolts. To be useful, the sensor signal must be amplified. This is achieved via a true differential amplifier (A1 and A2) as shown in Figure 4. The GAIN ADJ (500 ohm) resistor, R_G, sets the gain to about 200.

The differential output of this stage is amplified by a second stage (A3) with a variable OFFSET resistor. This stage performs a differential to single-ended output conversion and references this output to the adjustable offset voltage. This output is then compared to a voltage (V_{REF} = 4 V at TP2) at the input of the third stage (A4).

This last amplifier is used as an inverted comparator amplifier with hysteresis (Schmitt trigger) which provides a logic signal (TP3) within a preset range variation of about 10% of the input (selected by the ratio R9/(R9 + R7).

If the pressure sensor delivers a voltage to the input of the Schmitt trigger (pin 13) lower than the reference voltage (pin 12), then the output voltage (pin 14) is high and the drive current for the power stage MOC2A60 is provided. When the sensor output increases above the reference voltage, the output at pin 14 goes low and no drive current is available.

The amplifier used is an MC33179. This is a quad amplifier with large current output drive capability (more than 80 mA).

OUTPUT POWER STAGE

For safety reasons, it is important to prevent any direct contact between the ac main power line and the liquid environment or the tank. In order to maintain full isolation between the sensor circuitry and the main power, the solid-state relay is placed between the low voltage circuit (sensor and amplifier) and the ac power line used by the pump and compressor.

The output of the last stage of the MC33179 is used as a current source to drive the LED (light emitting diode). The series resistor, R8, limits the current into the LED to approximately 15 mA and guarantees an optimum drive for the power opto-triac. The LD1 (MFOE76), which is an infrared light emitting diode, is used as an indicator to detect when the load is under power.

The MOC2A60 works like a switch to turn ON or OFF the pump's power source. This device can drive up to 2 A for an ac load and is perfectly suited for the medium power motors (less than 500 watts) used in many applications. It consists of an opto-triac driving a power triac and has a zero-crossing detection to limit the power line disturbance problems when fast switching selfic loads. An RC network, placed in parallel with the output of the solid-state relay is not required, but it is good design practice for managing large voltage spikes coming from the inductive load commutation. The load itself (motor or solenoid valve) is connected in series with the solid-state relay to the main power line.

EXAMPLE OF APPLICATION: ACCURATE LIQUID LEVEL MONITORING

The purpose of the described application is to provide an electronic system which maintains a constant liquid level in a tank (within ± 5 mm H_2O). The liquid level is kept constant in the tank by an ac electric pump and a pressure sensor which provides the feedback information. The tank may be of any size. The application is not affected by the volume of the tank but only by the difference in the liquid level. Of course, the maximum level in the tank must correspond to a pressure within the operating range of the pressure sensor.

LIQUID LEVEL SENSORS

Freescale has developed a piezoresistive pressure sensor family which is very well adapted for level sensing, especially when using an air pipe sensing method. These devices may also be used with a bubbling method or equivalent.

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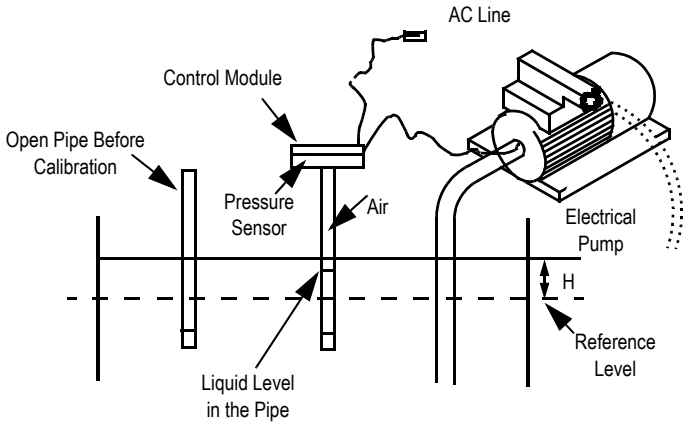

Figure 3. Liquid Level Monitoring

LEVEL SENSING THEORY

If a pipe is placed vertically, with one end dipped into a liquid and the other end opened, the level in the pipe will be exactly the same as the level in the tank. However, if the upper end of the pipe is closed off and some air volume is trapped, the pressure in the pipe will vary proportionally with the liquid level change in the tank.

For example, if we assume that the liquid is water and that the water level rises in the tank by 10 mm, then the pressure in the pipe will increase by that same value (10 mm of water).

A gauge pressure sensor has one side connected to the pipe (pressure side) and the other side open to ambient (in this case, atmospheric) pressure. The pressure difference which corresponds to the change in the tank level is measured by the pressure sensor.

PRESSURE SENSOR CHOICE

In this example, a level sensing of 10 mm of water is desired. The equivalent pressure in kilo pascals is 0.09806 kPa. In this case, Freescale's temperature compensated 0-10 kPa, MPXM2010GS is an excellent choice. The sensor output, with a pressure of 0.09806 kPa applied, will result in 2.0 mV/kPa x 0.09806 = 0.196 mV.

The sensing system is designed with an amplifier gain of about 1000. Thus, the conditioned signal voltage given by the module is 1000 x 0.196 mV = 0.196 V with 10 mm - H_2O pressure.

Table 1. Liquid Level Sensors

Method	Sensor	Advantages	Disadvantages
Liquid Weight	Magnetoresitive	Low Power, No Active Electronic	Low Resolution, Range Limited
	Magnetoresitive	Very High Resolution	Complex Electronic
	Ultrasonic	Easy to Install	Need High Power, Low Accuracy
Liquid Resistivity	No Active Electronic	No Active Electronic	Low Resolution, Liquid Dependent
String Potentionmeter	Potentionmeter	Low Power, No Active Electronic	Poor Linearity, Corrosion
Pressure	Silicon Sensors	Inexpensive, Good Resolution, Wide Range Measurements	Active Electronic, Need Power

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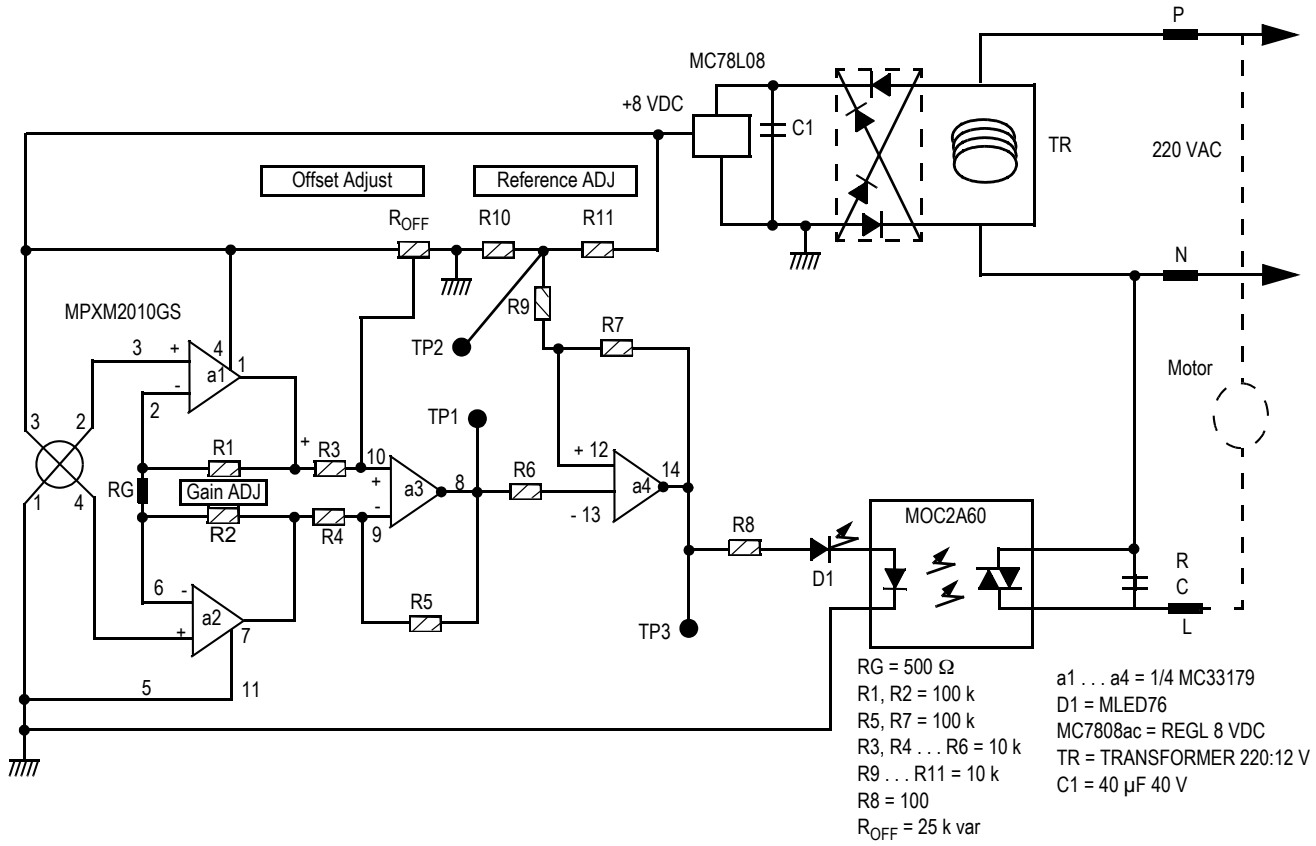
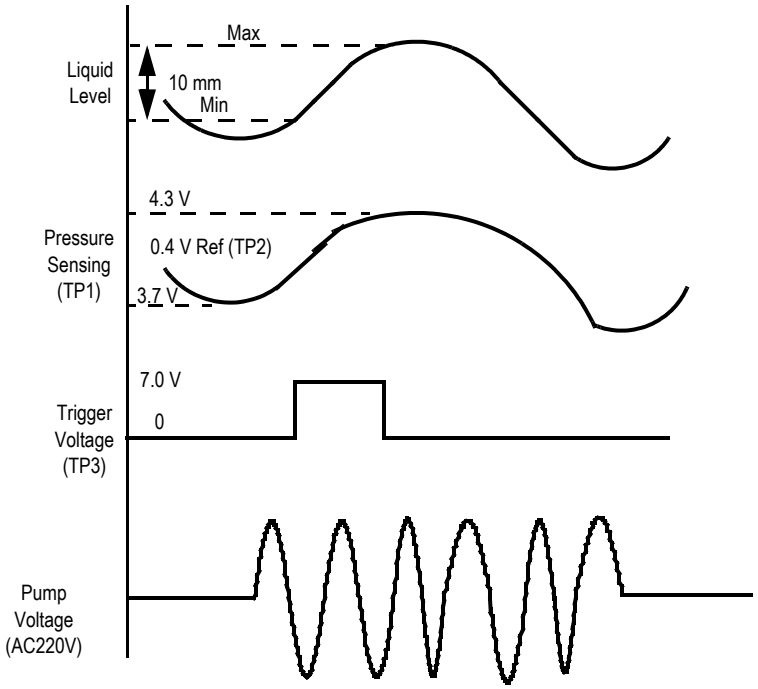


Figure 4. Electrical Circuit



Sensing for minimum level (pumping into the tank)

The sensing probe is tied to the positive pressure port of the sensor. The pump is turned on to fill the tank when the minimum level is reached.

Figure 5. Functional Diagram

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LEVEL CONTROL MODES

This application describes two ways to keep the liquid level constant in the tank; first, by pumping the water out if the liquid level rises above the reference, or second, by pumping the water in if the liquid level drops below the reference.

If pumping water out, the pump must be OFF when the liquid level is below the reference level. To turn the pump ON, the sensor signal must be decreased to drop the input to the Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the NEGATIVE pressure port (back or vacuum side) of the sensor. In the condition when the pressure increases (liquid level rises), the sensor voltage will decrease and the pump will turn ON when the sensor output crosses the referenced level. As pumping continues, the level in the tank decreases (thus the pressure on the sensor decreases) and the sensor signal increases back up to the trigger point where the pump was turned OFF.

In the case of pumping water into the tank, the pump must be OFF when the liquid level is above the reference level. To turn ON the pump, the sensor signal must be decreased to drive the input Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the POSITIVE pressure port (top side) of the sensor. In this configuration when the pressure on the sensor decreases, (liquid level drops) the sensor voltage also decreases and the pump is turned ON when the signal exceeds the reference. As pumping continues, the water level increases and when the maximum level is reached, the Schmitt trigger turns the pump OFF.

ADJUSTMENTS

The sensing tube is placed into the water at a distance below the minimum limit level anywhere in the tank. The other end of the tube is opened to atmosphere. When the tank is filled to the desired maximum (or minimum) level, the pressure sensor is connected to the tube with the desired port configuration for the application. Then the water level in the tank is the reference.

After connecting the tube to the pressure sensor, the module must be adjusted to control the water level. The output voltage at TP1 is preadjusted to about 4.0 V (half of the supply voltage). When the sensor is connected to the tube, the module output is ON (lighted) or OFF. By adjusting the offset adjust potentiometer the output is just turned into the other state: OFF, if it was ON or the reverse, ON, if it was OFF, (the change in the tank level may be simulated by moving the sensing tube up or down).

The reference point TP2 shows the ON/OFF reference voltage, and the switching point of the module is reached when the voltage at TP1 just crosses the value of the TP2 voltage. The module is designed for about 10 mm of difference level between ON and OFF (hysteresis).

CONCLUSION

This circuit design concept may be used to evaluate pressure sensors used as a liquid level switch. This basic circuit may be easily modified to provide an analog signal of the level within the controlled range. It may also be easily modified to provide tighter level control (± 2 mm H_2O) by increasing the gain of the first amplifier stage (decreasing RG resistor).

The circuit is also a useful tool to evaluate the performance of the power optocoupler MOC2A60 when driving ac loads directly.

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Pressure Switch Design with Semiconductor Pressure Sensors

by: **Eric Jacobsen and Jeff Baum**
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INTRODUCTION

The Pressure Switch concept is simple, as are the additions to conventional signal conditioning circuitry required to provide a pressure threshold (or thresholds) at which the output switches logic state. This logic-level output may be input to a microcontroller, drive an LED, control an electronic switch, etc. The user-programmed threshold (or reference voltage) determines the pressure at which the output state will switch. An additional feature of this minimal component design is an optional user-defined hysteresis setting that will eliminate multiple output transitions when the pressure sensor voltage is comparable to the threshold voltage.

This paper presents the characteristics and design criteria for each of the major subsystems of the pressure switch design: the pressure sensor, the signal conditioning (gain) stage, and the comparator output stage. Additionally, an entire section will be devoted to comparator circuit topologies which employ comparator ICs and/or operational amplifiers. A window comparator design (high and low thresholds) is also included. This section will discuss the characteristics and design criteria for each comparator circuit, while evaluating them in overall performance (i.e., switching speed, logic-level voltages, etc.).

BASIC SENSOR OPERATION

The MPX2000 Series sensors are temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Although the specifications (see Table 1) in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. For example, at the absolute maximum supply voltage rating, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to the device's slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level. For this specific design, an MPX2100 and 5.0 V supply is used to provide a maximum sensor output of 20 mV. The sensor output is then signal conditioned to obtain a four volt signal swing (span).

Table 1. MPX2100 Electrical Characteristics for V_S = 10 V, T_A = 25°C

Characteristics	Symbol	Minimum	Typical	Maximum	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	10	16	V_{DC}
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{OFF}	—	0.05	0.1	mV
Sensitivity	S	—	0.4	—	mV/kPa
Linearity	—	—	0.05	—	$\%F_{SS}$
Temperature Effect on Span	—	—	0.5	—	$\%F_{SS}$
Temperature Effect on Offset	—	—	0.2	—	$\%F_{SS}$

THE SIGNAL CONDITIONING

The amplifier circuitry, shown in Figure 1, is composed of two op-amps. This interface circuit has a much lower component count than conventional quad op amp instrumentation amplifiers. The two op amp design offers the high input impedance, low output impedance, and high gain desired for a transducer interface, while performing a differential to single-ended conversion. The gain is set by the following equation:

$$GAIN = 1 + \frac{R6}{R5}$$

where R6 = R3 and R4 = R5

For this specific design, the gain is set to 201 by setting R6=20 kΩ and R5 = 100 Ω. Using these values and setting R6=R3 and R4=R5 gives the desired gain without loading the reference voltage divider formed by R1 and R_{off}. The offset voltage is set via this voltage divider by choosing the value of R_{off}. This enables the user to adjust the offset for each application's requirements.

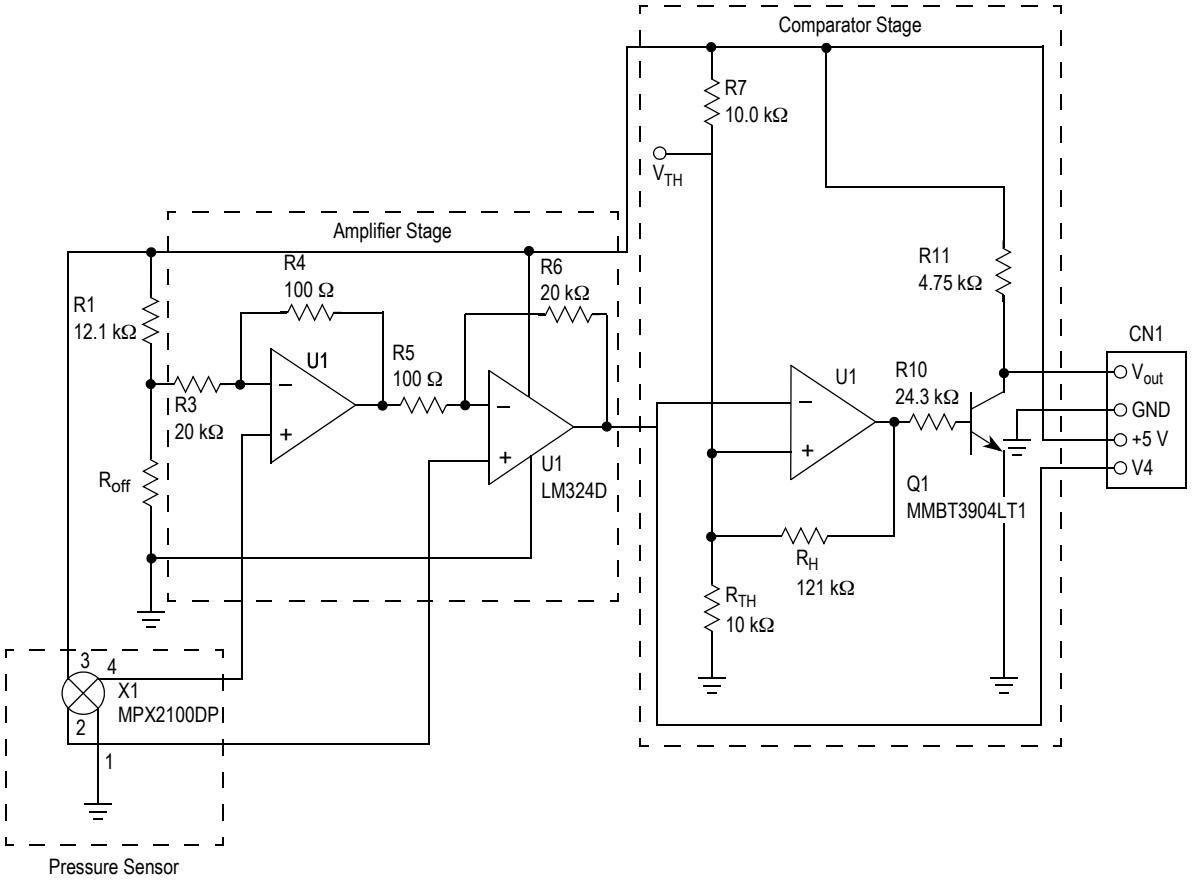

Figure 1. Pressure Switch Schematic

THE COMPARISON STAGE

The comparison stage is the “heart” of the pressure switch design. This stage converts the analog voltage output to a digital output, as dictated by the comparator's threshold. The comparison stage has a few design issues which must be addressed:

- The threshold for which the output switches must be programmable. The threshold is easily set by dividing the supply voltage with resistors R7 and R_{TH}. In Figure 1, the threshold is set at 2.5 V for R7 = R_{TH} = 10 kΩ.
- A method for providing an appropriate amount of hysteresis should be available. Hysteresis prevents multiple transitions from occurring when slow varying signal inputs oscillate about the threshold. The hysteresis can be set by applying positive feedback. The amount of hysteresis is determined by the value of the feedback resistor, R_H (refer to equations in the following section).
- It is ideal for the comparator's logic level output to swing from one supply rail to the other. In practice, this is not possible. Thus, the goal is to swing as high and low as possible for a given set of supplies. This offers the greatest

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difference between logic states and will avoid having a microcontroller read the switch level as being in an indeterminate state.

- In order to be compatible with CMOS circuitry and to avoid microcontroller timing delay errors, the comparator must switch sufficiently fast.
- By using two comparators, a window comparator may be implemented. The window comparator may be used to monitor when the applied pressure is within a set range. By adjusting the input thresholds, the window width can be customized for a given application. As with the single threshold design, positive feedback can be used to provide hysteresis for both switching points. The window comparator and the other comparator circuits will be explained in the following section.

EXAMPLE COMPARATOR CIRCUITS

Several comparator circuits were built and evaluated. Comparator stages using the LM311 comparator, LM358 Op-Amp (with and without an output transistor stage), and LM339 were examined. Each comparator was evaluated on output voltage levels (dynamic range), transition speed, and the relative component count required for the complete pressure switch design. This comparison is tabulated in Table 2.

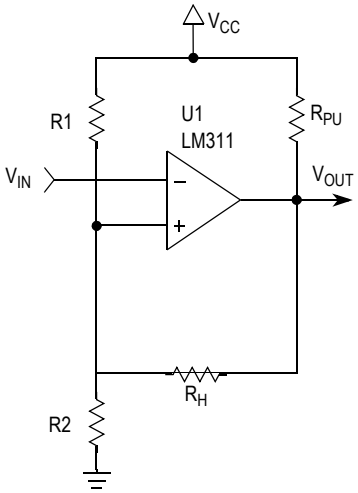

Figure 2. LM311 Comparator Circuit Schematic

LM311 USED IN A COMPARATOR CIRCUIT

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. Additionally, the LM311 is a reverse logic circuit; that is, for an input lower than the reference voltage, the output is high. Likewise, when the input voltage is higher than the reference voltage, the output is low. Figure 2 shows a schematic of the LM311 stage with threshold setting resistor divider, hysteresis resistor, and the open-collector pull-up resistor. Table 2 shows the comparator's performance. Based on its performance, this circuit can be used in many types of applications, including interface to microprocessors.

The amount of hysteresis can be calculated by the following equations:

$$V_{REF} = \frac{R2}{R1 + R2} V_{CC}$$

neglecting the effect of R_H

$$VREFH = \frac{R1R2 + R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$VREFL = \frac{R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$HYSTERESIS = V_{REF} - V_{REFL}$$

when the normal state is below V_{REF} or

$$HYSTERESIS = V_{REFH} - V_{REF}$$

when the normal state is above V_{REF}.

Table 2. Comparator Circuits Performance Characteristics

Characteristics	LM311	LM358	LM358 w/Trans.	Unit
Switching Speeds	—	—	—	—
Rise Time	1.40	5.58	2.20	µs
Fall Time	0.04	6.28	1.30	µs
Output Levels	—	—	—	—
V_{OH}	4.91	3.64	5.00	V
V_{OL}	61.1	38.0	66.0	mV
Circuit Logic Type	NEGATIVE	NEGATIVE	POSITIVE	—

The initial calculation for V_{REF} will be slightly in error due to neglecting the effect of R_H. To establish a precise value for

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V_{REF} (including R_H in the circuit), recompute R1 taking into account that V_{REF} depends on R1, R2, and R_H. It turns out that when the normal state is below V_{REF}, R_H is in parallel with R1:

$$V_{REF} = \frac{R2}{R1 \parallel R_H + R2} V_{CC}$$

(Which is identical to the equation for V_{REFH})

Alternately, when the normal state is above VREF, RH is in parallel with R2:

$$V_{REF} = \frac{R2 \parallel R_H}{R1 + R2 \parallel R_H} V_{CC}$$

(Which is identical to the equation for V_{REFL})

These two additional equations for V_{REF} can be used to calculate a more precise value for V_{REF}.

The user should be aware that V_{REF}, V_{REFH} and V_{REFL} are chosen for each application, depending on the desired switching point and hysteresis values. Also, the user must specify which range (either above or below the reference voltage) is the desired normal state (see Figure 3). Referring to Figure 3, if the normal state is below the reference voltage then V_{REFL} (V_{REFH} is only used to calculate a more precise value for V_{REF} as explained above) is below V_{REF} by the desired amount of hysteresis (use V_{REFL} to calculate R_H). Alternately, if the normal state is above the reference voltage, then V_{REFH} (V_{REFL} is only used to calculate a more precise value for V_{REF}) is above V_{REF} by the desired amount of hysteresis (use V_{REFH} to calculate R_H).

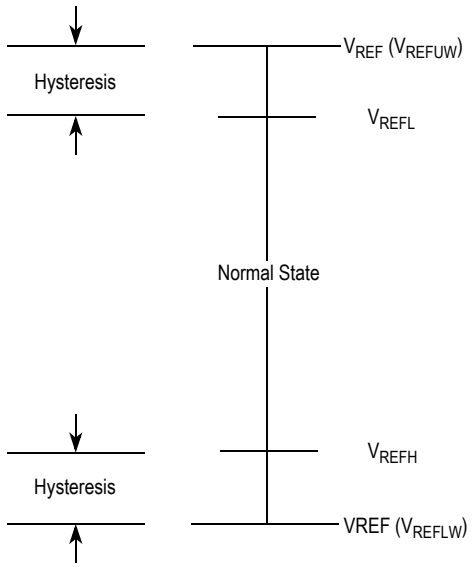

Figure 3. Setting the Reference Voltages

LM358 OP AMP USED IN A COMPARATOR CIRCUIT

Figure 4 shows the schematic for the LM358 op amp comparator stage, and Table 2 shows its performance. Since the LM358 is an operational amplifier, it does not have the fast slew-rate of a comparator IC nor the open collector output. Comparing the LM358 and the LM311 (Table 2), the LM311 is better for logic/switching applications since its output nearly extends from rail to rail and has a sufficiently high switching speed. The LM358 will perform well in applications where the switching speed and logic-state levels are not critical (LED output, etc.). The design of the LM358 comparator is accomplished by using the same equations and procedure presented for the LM311. This circuit is also reverse logic.

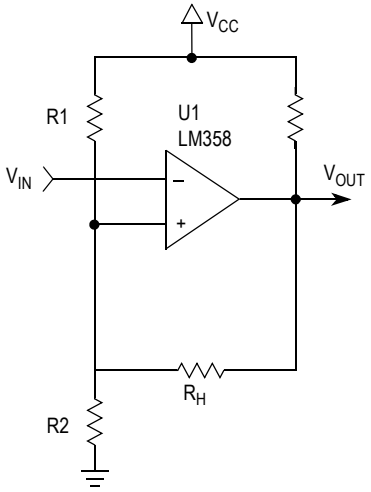

Figure 4. LM358 Comparator Circuit Schematic

LM358 OP AMP WITH A TRANSISTOR OUTPUT STAGE USED IN A COMPARATOR CIRCUIT

The LM358 with a transistor output stage is shown in Figure 5. This circuit has similar performance to the LM311 comparator: its output reaches the upper rail and its switching speed is comparable to the LM311's. This enhanced performance does, however, require an additional transistor and base resistor. Referring to Figure 1, note that this comparator topology was chosen for the pressure switch design. The LM324 is a quad op amp that has equivalent amplifier characteristics to the LM358.

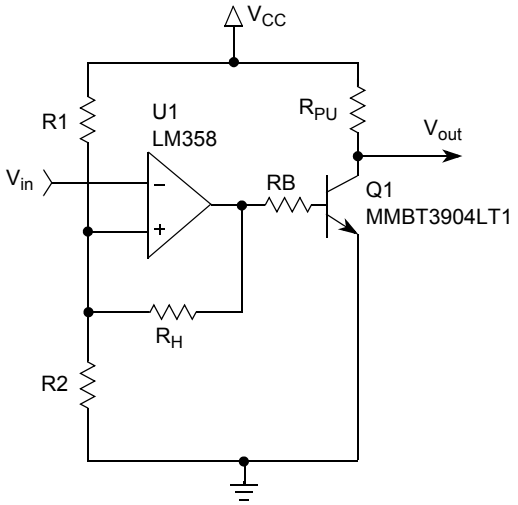

Figure 5. LM358 with a Transistor Output Stage Comparator Circuit Schematic

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Like the other two circuits, this comparator circuit can be designed with the same equations and procedure. The values for R_B and R_{PU} are chosen to give a 5:1 ratio in Q1's collector current to its base current, in order to insure that Q1 is well-saturated (V_{OUT} can pull down very close to ground when Q1 is on). Once the 5:1 ratio is chosen, the actual resistance values determine the desired switching speed for turning Q1 on and off. Also, R_{PU} limits the collector current to be within the maximum specification for the given transistor (see example values in Figure 1). Unlike the other two circuits, this circuit is positive logic due to the additional inversion created at the output transistor stage.

LM339 USED IN A WINDOW COMPARATOR CIRCUIT

Using two voltage references to detect when the input is within a certain range is another possibility for the pressure switch design. The window comparator's schematic is shown in Figure 6. The LM339 is a quad comparator IC (it has open collector outputs), and its performance will be similar to that of the LM311.

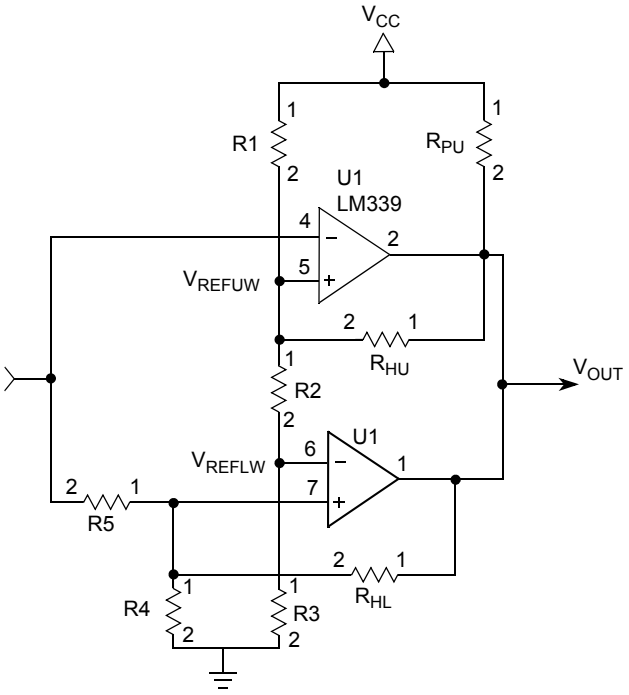

Figure 6. LM339 Window Comparator Circuit Schematic

Obtaining the correct amount of hysteresis and the input reference voltages is slightly different than with the other circuits. The following equations are used to calculate the hysteresis and reference voltages. Referring to Figure 3, V_{REFUW} is the upper window reference voltage and V_{REFLW} is the lower window reference voltage. Remember that reference voltage and threshold voltage are interchangeable terms.

For the upper window threshold:

Choose the value for V_{REFUW} and R1 (e.g., 10 kΩ). Then, by voltage division, calculate the total resistance of the combination of R2 and R3 (named R23 for identification) to obtain the desired value for V_{REFUW}, neglecting the effect of R_{HU}:

$$V_{REFUW} = \frac{R23}{R1 + R23} V_{CC}$$

The amount of hysteresis can be calculated by the following equation:

$$V_{REFUW} = \frac{R23R_{HU}}{R1R23 + R1R_{HU} + R23R_{HU}} V_{CC}$$

Notice the upper window reference voltage, V_{REFUW}, is now equal to its V_{REFL} value, since at this moment, the input voltage is above the normal state.

$$HYSTERESIS = V_{REFUW} - V_{REFL}$$

where VREFL is chosen to give the desired amount of hysteresis for the application.

The initial calculation for V_{REFUW} will be slightly in error due to neglecting the effect of R_{HU}. To establish a precise value for V_{REFUW} (including R_{HU} in the circuit), recompute R1 taking into account that V_{REFUW} depends on R2 and R3 and the parallel combination of R1 and R_{HU}. This more precise value is calculated with the following equation:

$$V_{REFUW} = \frac{R23}{R1 \parallel R_{HU} + R23} V_{CC}$$

for the lower window threshold choose the value for V_{REFLW}.

$$SetV_{REFLW} = \frac{R3}{R1 \parallel R_{HU} + R2 + R3} V_{CC}$$

where R2 + R3 = R23 from above calculation.

To calculate the hysteresis resistor:

The input to the lower comparator is one half V_{IN} (since R4 =R5) when in the normal state. When V_{REFLW} is above one half of V_{IN} (i.e., the input voltage has fallen below the window), R_{HL} parallels R4, thus loading down V_{IN}. The resulting input to the comparator can be referred to as V_{INL} (a lower input voltage). To summarize, when the input is within the window, the output is high and only R4 is connected to ground from the comparator's positive terminal. This establishes one half of V_{IN} to be compared with V_{REFLW}. When the input voltage is below V_{REFLW}, the output is low, and R_{HL} is effectively in parallel with R4. By voltage division, less of the input voltage at V_{IN} is required to make the noninverting input exceed V_{RELW}.

Therefore, the following equations are established:

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$$HYSTERESIS = V_{REFLW} - V_{INL}$$

Choose R4 = R5 to simplify the design.

$$R_{HL} = \frac{R4R5(V_{REFLW} - V_{INL} - V_{CC})}{(R4 + R5)(V_{INL} - V_{REFLW})} V_{CC}$$

NOTE:

As explained above, because the input voltage is divided in half by R4 and R5, all calculations are done relative to the one half value of V_{in}. Therefore, for a hysteresis of 200 mV (relative to V_{in}), the above equations must use one half this hysteresis value (100 mV). Also, if a V_{REFLW} value of 2.0 V is desired (relative to V_{in}), then 1.0 V for its value should be used in the above equations. The value for V_{INL} should be scaled by one half also.

The window comparator design can also be designed using operational amplifiers and the same equations as for the LM339 comparator circuit. For the best performance, however, a transistor output stage should be included in the design.

TEST/CALIBRATION PROCEDURE

1. Before testing the circuit, the user-defined values for R_{TH}, R_H and R_{off} should be calculated for the desired application.

The sensor offset voltage is set by

$$V_{OFF} = \frac{V_{OFF}}{R1 + R_{OFF}} V_{CC}$$

Then, the amplified sensor voltage corresponding to a given pressure is calculated by:

$$V_{SENSOR} = 201 \times 0.0002 \times \text{APPLIED PRESSURE} + V_{OFF},$$

where 201 is the gain, 0.0002 is in units of V/kPa and APPLIED PRESSURE is in kPa.

The threshold voltage, V_{TH}, at which the output changes state is calculated by determining V_{sensor} at the pressure that causes this change of state:

$$V_{TH} = V_{SENSOR} \text{ (@ pressure threshold)} = \frac{R_{TH}}{R7 + R_{TH}} V_{CC}$$

If hysteresis is desired, refer to the LM311 *Used in a Comparator* section to determine R_H.

2. To test this design, connect a +5 volt supply between pins 3 and 4 of the connector CN1.
3. Connect a volt meter to pins 1 and 4 of CN1 to measure the output voltage and amplified sensor voltage, respectively.
4. Connect an additional volt meter to the V_{TH} probe point to verify the threshold voltage.
5. Turn on the supply voltage.
6. With no pressure applied, check to see that V_{off} is correct by measuring the voltage at the output of the gain stage (the volt meter connected to Pin 4 of CN1). If desired, V_{off} can be fine tuned by using a potentiometer for R_{off}.
7. Check to see that the volt meter monitoring V_{TH} displays the desired voltage for the output to change states. Use a potentiometer for R_{TH} to fine tune V_{TH}, if desired.
8. Apply pressure to the sensor. Monitor the sensor's output via the volt meter connected to pin 4 of CN1. The output will switch from low to high when this pressure sensor voltage reaches or exceeds the threshold voltage.
9. If hysteresis is used, with the output high (pressure sensor voltage greater than the threshold voltage), check to see if V_{TH} has dropped by the amount of hysteresis desired.

A potentiometer can be used for R_H to fine tune the amount of hysteresis.

CONCLUSION

The pressure switch design uses a comparator to create a logic level output by comparing the pressure sensor output voltage and a user-defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications. The design presented here uses an op amp with a transistor output stage, yielding excellent logic-level outputs and output transition speeds for many applications. Finally, several other comparison stage designs, including a window comparator, are evaluated and compared for overall performance.

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Using a Pulse Width Modulated Output with Semiconductor Pressure Sensors

by: **Eric Jacobsen and Jeff Baum**
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INTRODUCTION

For remote sensing and noisy environment applications, a frequency modulated (FM) or pulse width modulated (PWM) output is more desirable than an analog voltage. FM and PWM outputs inherently have better noise immunity for these types of applications. Generally, FM outputs are more widely accepted than PWM outputs, because PWM outputs are restricted to a fixed frequency. However, obtaining a stable FM output is difficult to achieve without expensive, complex circuitry.

With either an FM or PWM output, a microcontroller can be used to detect edge transitions to translate the time-domain signal into a digital representation of the analog voltage signal. In conventional voltage-to-frequency (V/F) conversions, a voltage-controlled oscillator (VCO) may be used in conjunction with a microcontroller. This use of two time bases, one analog and one digital, can create additional inaccuracies. With either FM or PWM outputs, the microcontroller is only concerned with detecting edge transitions. If a programmable frequency, stable PWM output could be obtained with simple, inexpensive circuitry, a PWM output would be a cost-effective solution for noisy environment/remote sensing applications while incorporating the advantages of frequency outputs.

The Pulse Width Modulated Output Pressure Sensor design (Figure 1) utilizes simple, inexpensive circuitry to create an output waveform with a duty cycle that is linear to the applied pressure. Combining this circuitry with a single digital time base to create and measure the PWM signal, results in a stable, accurate output. Two additional advantages of this design are 1) an A/D converter is not required, and 2) since the PWM output calibration is controlled entirely by software, circuit-to-circuit variations due to component tolerances can be nullified.

The PWM Output Sensor system consists of a Freescale Semiconductor, Inc. MPX5000 series pressure sensor, a ramp generator (transistor switch, constant current source, and capacitor), a comparator, and an MC68HC05P9 microcontroller. These subsystems are detailed in Figure 1.

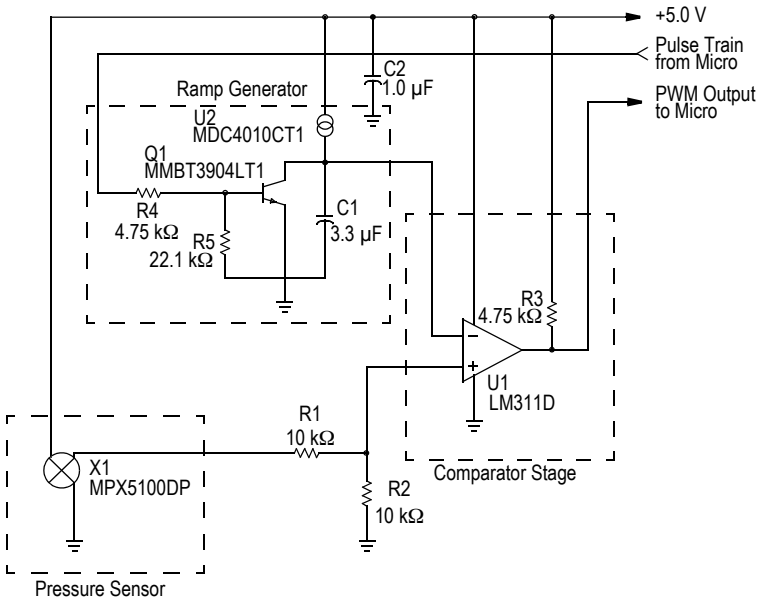

Figure 1. PWM Output Pressure Sensor Schematic

PRESSURE SENSOR

Freescale's MPX5000 series sensors are signal conditioned (amplified), temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges of 50 kPa (7.3 psi) and 100 kPa (14.7 psi). With the recommended 5.0 V supply, the MPX5000 series produces an output of 0.5 V at zero pressure to 4.5 V at full scale pressure. Referring to the schematic of the system in Figure 1, note that the output of the pressure sensor is attenuated to one-half of its value by the resistor divider comprised of resistors R1 and R2. This yields a span of 2.0 V ranging from 0.25 V to 2.25 V at the non-inverting terminal of the comparator. Table 1 shows the electrical characteristics of the MPX5100.

Table 1. MPX5100DP Electrical Characteristics

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	5.0	6.0	V_{DC}
Full Scale Span	V_{FSS}	3.9	4.0	4.1	V
Zero Pressure Offset	V_{OFF}	0.4	0.5	0.6	V
Sensitivity	S	—	40	—	mV/kPa
Linearity	—	– 0.5	—	0.5	$\%F_{SS}$
Temperature Effect on Span	—	– 1.0	—	1.0	$\%F_{SS}$
Temperature Effect on Offset	—	– 50	0.2	50	mV

THE RAMP GENERATOR

The ramp generator is shown in the schematic in Figure 1. A pulse train output from a microcontroller drives the ramp generator at the base of transistor Q1. This pulse can be accurately controlled in frequency as well as pulse duration via software (to be explained in the microcontroller section).

The ramp generator uses a constant current source to charge the capacitor. It is imperative to remember that this current source generates a stable current only when it has approximately 2.5 V or more across it. With less voltage across the current source, insufficient voltage will cause the current to fluctuate more than desired; thus, a design constraint for the ramp generator will dictate that the capacitor can be charged to only approximately 2.5 V, when using a 5.0 V supply.

The constant current charges the capacitor linearly by the following equation:

$$\Delta V = \frac{I\Delta t}{C}$$

where Δt is the capacitor's charging time and C is the capacitance.

Referring to Figure 2, when the pulse train sent by the microcontroller is low, the transistor is off, and the current source charges the capacitor linearly. When the pulse sent by the microcontroller is high, the transistor turns on into saturation, discharging the capacitor. The duration of the high part of the pulse train determines how long the capacitor discharges, and thus to what voltage it discharges. This is how the dc offset of the ramp waveform may be accurately controlled. Since the transistor saturates at approximately 60 mV, very little offset is needed to keep the capacitor from discharging completely.

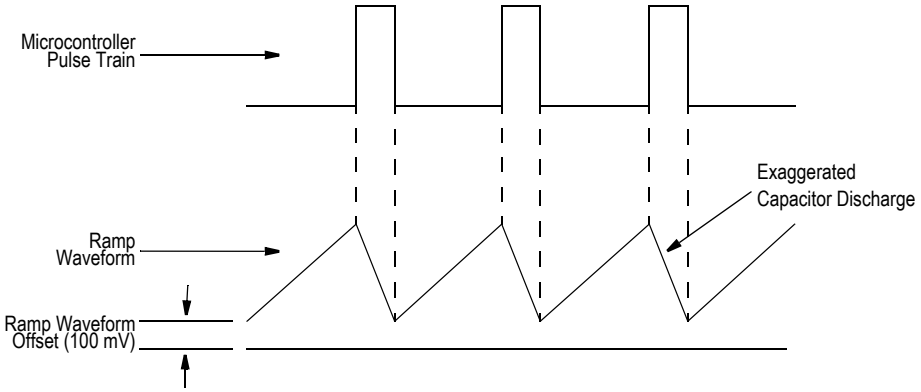

Figure 2. Ideal Ramp Waveform for the PWM Output Pressure Sensor

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The PWM output is most linear when the ramp waveform's period consists mostly of the rising voltage edge (see Figure 2). If the capacitor were allowed to completely discharge (see Figure 3), a flat line at approximately 60 mV would separate the ramps, and these “flat spots” may result in non-linearities of the resultant PWM output (after comparing it to the sensor voltage). Thus, the best ramp waveform is produced when one ramp cycle begins immediately after another, and a slight dc offset disallows the capacitor from discharging completely.

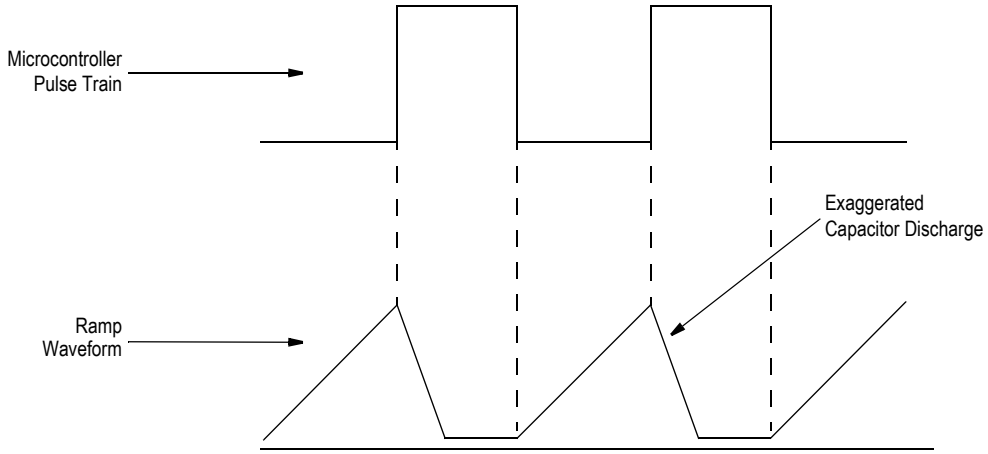

Figure 3. Non Ideal Ramp Waveform for the PWM Output Pressure Sensor

The flexibility of frequency control of the ramp waveform via the pulse train sent from the microcontroller allows a programmable-frequency PWM output. Using Equation 1 the frequency (inverse of period) can be calculated with a given capacitor so that the capacitor charges to a maximum ΔV of approximately 2.5 V (remember that the current source needs approximately 2.5 V across it to output a stable current). The importance of software control becomes evident here since the selected capacitor may have a tolerance of ±20%. By adjusting the frequency and positive width of the pulse train, the desired ramp requirements are readily obtainable; thus, nullifying the effects of component variances.

For this design, the ramp spans approximately 2.4 V from 0.1 V to 2.5 V. At this voltage span, the current source is stable and results in a linear ramp. This ramp span was used for reasons which will become clear in the next section.

In summary, complete control of the ramp is achieved by the following adjustments of the microcontroller-created pulse train:

- Increase Frequency: Span of ramp decreases.The DC offset decreases slightly.
- Decrease Frequency: Span of ramp increases. The DC offset increases slightly.
- Increase Pulse Width: The DC offset decreases. Span decreases slightly.
- Decrease Pulse Width: The DC offset increases. Span increases slightly.

THE COMPARATOR STAGE

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open-collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. As Figure 1 shows, the pressure sensor output voltage is input to the non inverting terminal of the op amp and the ramp is input to the inverting terminal. Therefore, when the pressure sensor voltage is higher than a given ramp voltage, the output is high; likewise, when the pressure sensor voltage is lower than a given ramp voltage, the output is low (refer to Figure 5). As mentioned in the Pressure Sensor section, resistors R1 and R2 of Figure 1 comprise the voltage divider that attenuates the pressure sensor's signal to a 2.0 V span ranging from 0.25 V to 2.25 V.

Since the pressure sensor voltage does not reach the ramp's minimum and maximum voltages, there will be a finite minimum and maximum pulse width for the PWM output. These minimum and maximum pulse widths are design constraints dictated by the comparator's slew rate. The system design ensures a minimum positive and negative pulse width of 20 μs to avoid nonlinearities at the high and low pressures where the positive duty cycle of the PWM output is at its extremes (refer to Figure 4). Depending on the speed of the microcontroller used in the system, the minimum required pulse width may be larger. This will be explained in the next section.

THE MICROCONTROLLER

The microcontroller for this application requires input capture and output compare timer channels. The output capture pin is programmed to output the pulse train that drives the ramp generator, and the input capture pin detects edge transitions to measure the PWM output pulse width.

Since software controls the entire system, a calibration routine may be implemented that allows an adjustment of the frequency and pulse width of the pulse train until the desired ramp waveform is obtained. Depending on the speed of the microcontroller, additional constraints on the minimum and maximum PWM output pulse widths may apply. For this

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design, the software latency incurred to create the pulse train at the output compare pin is approximately 40 μs.

Consequently, the microcontroller cannot create a pulse train with a positive pulse width of less than 40 μs. Also, the software that measures the PWM output pulse width at the input capture pin requires approximately 20 μs to execute. Referring to Figure 5, the software interrupt that manipulates the pulse train always occurs near an edge detection on the input capture pin (additional software interrupt). Therefore, the minimum PWM output pulse width that can be accurately detected is approximately 60 μs (20 μs + 40 μs). This constrains the minimum and maximum pulse widths more than the slew rate of the comparator which was discussed earlier (refer to Figure 4)

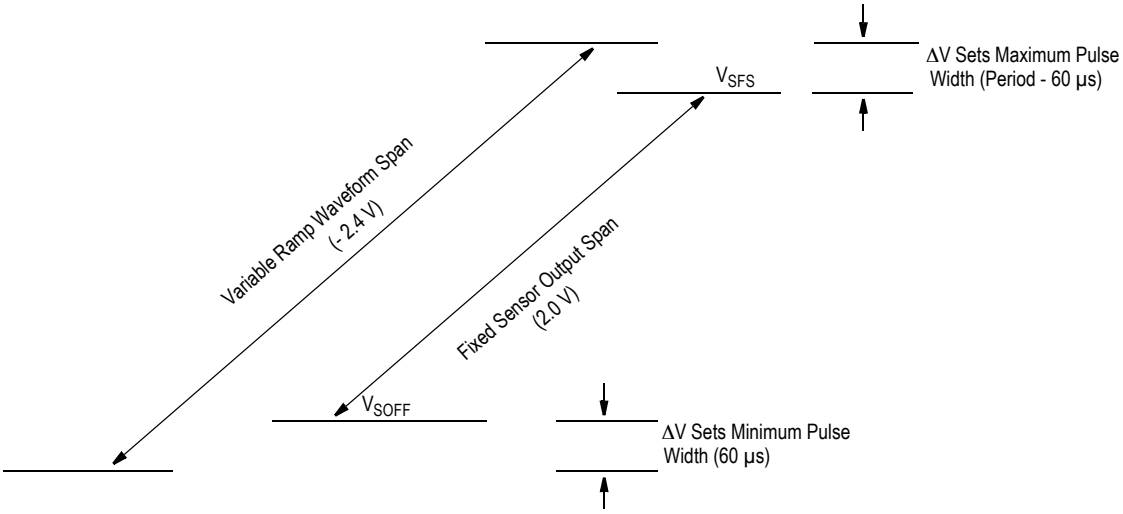

Figure 4. Desired Relationship Between the Ramp Waveform and Pressure Sensor Voltage Spans

An additional consideration is the resolution of the PWM output. The resolution is directly related to the maximum frequency of the pulse train. In our design, 512 μs are required to obtain at least 8-bit resolution. This is determined by the fact that a 4 MHz crystal yields a 2 MHz clock speed in the microcontroller. This, in turn, translates to 0.5 μs per clock tick. There are four clock cycles per timer count. This results in 2 μs per timer count. Thus, to obtain 256 timer counts (or 8-bit resolution), the difference between the zero pressure and full scale pressure PWM output pulse widths must be at least 512 μs (2 μs x 256). But since an additional 60 μs is needed at both pressure extremes of the output waveform, the total period must be at least 632 μs. This translates to a maximum frequency for the pulse train of approximately 1.6 kHz. With this frequency, voltage span of the ramp generator, and value of current charging the capacitor, the minimum capacitor value may be calculated with Equation 1.

To summarize:

The MC68HC705P9 runs off a 4 MHz crystal. The microcontroller internally divides this frequency by two to yield an internal clock speed of 2 MHz.

$$\frac{1}{2\ \text{MHz}} \Rightarrow \frac{0.5\ \mu\text{s}}{\text{clock cycle}}$$

And,

4 clock cycles = 1 timer count.

Therefore,

$$\frac{4\ \text{clock cycles}}{\text{timer count}} \times \frac{0.5\ \mu\text{s}}{\text{clock cycle}} = \frac{2\ \mu\text{s}}{\text{timer count}}$$

For 8-bit resolution,

$$\frac{2\ \mu\text{s}}{\text{timer count}} \times 256\ \text{counts} = 512\ \mu\text{s}$$

Adding a minimum of 60 μs each for the zero and full scale pressure pulse widths yields

$$512\ \mu\text{s} + 60\ \mu\text{s} + 60\ \mu\text{s} = 632\ \mu\text{s}$$

which is the required minimum pulse train period to drive the ramp generator.

Translating this to frequency, the maximum pulse train frequency is thus

$$\frac{1}{632\ \mu\text{s}} = 1.58\ \text{kHz}$$

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CALIBRATION PROCEDURE AND RESULTS

The following calibration procedure will explain how to systematically manipulate the pulse train to create a ramp that meets the necessary design constraints. The numbers used here are only for this design example. Figure 6 shows the linearity performance achieved by following this calibration procedure and setting up the ramp as indicated by Figure 4 and Figure 5.

1. Start with a pulse train that has a pulse width and frequency that creates a ramp with about 100 mV dc offset and a span smaller than required. In this example the initial pulse width is 84 μs and the initial frequency is 1.85 kHz.
2. **Decrease** the **frequency** of the pulse train until the ramp span increases to approximately 2.4 V. The ramp span of 2.4 V will ensure that the maximum pulse width at full scale pressure will be at least 60 μs less than the total period. Note, by **decreasing** the **frequency** of the pulse train, a dc offset will begin to appear. This may result in the ramp looking nonlinear at the top.
3. If the ramp begins to become nonlinear, **increase** the **pulse width** to decrease the dc offset.
4. Repeat steps 2 and 3 until the ramp spans 2.4 V and has a dc offset of approximately 100 mV. The dc offset value is not critical, but the bottom of the ramp should have a “crisp” point at which the capacitor stops discharging and begins charging. Simply make sure that the minimum pulse width at zero pressure is at least 60 μs. Refer to Figure 4 and Figure 5 to determine if the ramp is sufficient for the application.

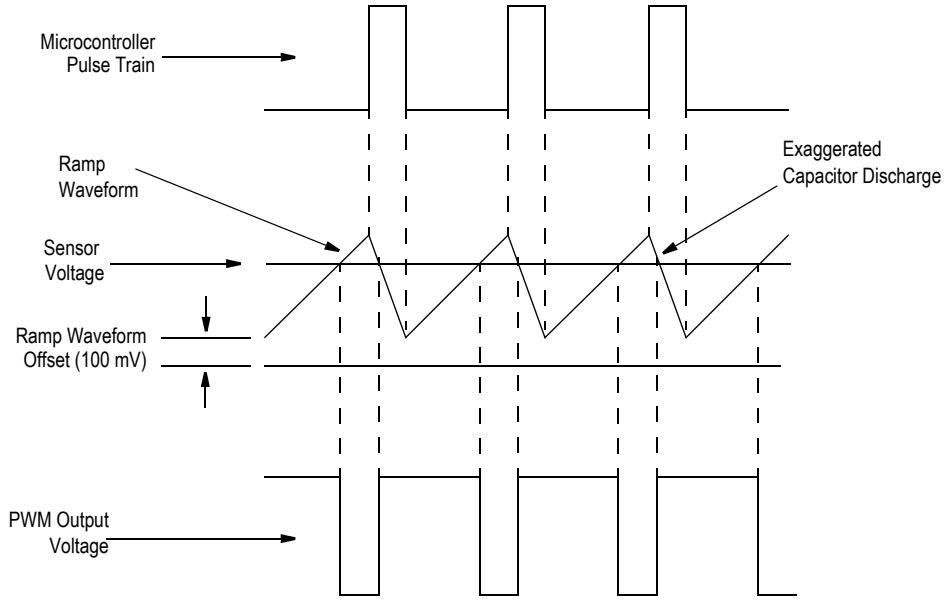

Figure 5. Relationship Between the PWM Output Pressure Sensor Voltages

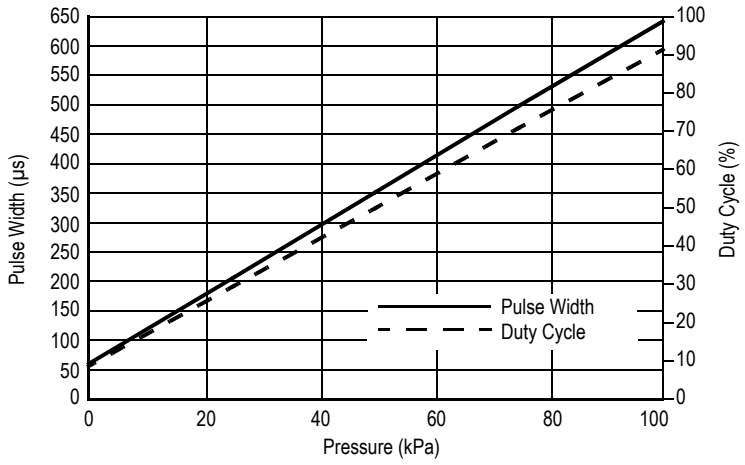

Figure 6. PWM Output Pressure Sensor Linearity Data

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CONCLUSION

The Pulse Width Modulated Output Pressure Sensor uses a ramp generator to create a linear ramp which is compared to the amplified output of the pressure sensor at the input of a comparator. The resulting output is a digital waveform with a duty cycle that is linearly proportional to the input pressure.

Although the pressure sensor output has a fixed offset and span, the ramp waveform is adjustable in frequency, dc offset, and voltage span. This flexibility enables the effect of component tolerances to be nullified and ensures that ramp span encompasses the pressure sensor output range. The ramp's span can be set to allow for the desired minimum and maximum duty cycle to guarantee a linear dynamic range.

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The ABCs of Signal-Conditioning Amplifier Design for Sensor Applications

by: **Eric Jacobsen and Jeff Baum, Sensor Applications Engineering**
Signal Products Division, Phoenix, AZ

INTRODUCTION

Although fully signal-conditioned, calibrated, and temperature compensated monolithic sensor ICs are commercially available today, there are many applications where the flexibility of designing custom signal-conditioning is of great benefit. Perhaps the need for a versatile low-level sensor output is best illustrated by considering two particular cases that frequently occur: (1) the user is in a prototyping phase of development and needs the ability to make changes rapidly to the overall transfer function of the combined sensor/amplifier subsystem, (2) the specific desired transfer function does not exist in a fully signal-conditioned, precision-trimmed sensor product (e.g., a signal-conditioned device is precision trimmed over a different pressure range than that of the application of interest). In such cases, it is obvious that there will always be a need for low-level, nonsignal-conditioned sensors. Given this need, there is also a need for sensor interface amplifier circuits that can signal condition the “raw” sensor output to a usable level. These circuits should also be user friendly, simple, and cost effective.

Today's unamplified solid-state sensors typically have an output voltage of tens of millivolts (Freescale’s basic 10 kPa pressure sensor, MPX10, has a typical full-scale output of 58 mV, when powered with a 5.0 V supply). Therefore, a gain stage is needed to obtain a signal large enough for additional processing. This additional processing may include digitization by a microcontroller's analog to digital (A/D) converter, input to a comparator, etc. Although the signal-conditioning circuits described here are applicable to low-level, differential-voltage output sensors in general, the focus of this paper will be on interfacing pressure sensors to amplifier circuits.

This paper presents a basic two operational-amplifier signal-conditioning circuit that provides the desired characteristics of an instrumentation amplifier interface:

- High input impedance
- Low output impedance
- Differential to single-ended conversion of the pressure sensor signal
- High gain capability

For this two op-amp circuit, additional modifications to the circuit allow (1) gain adjustment without compromising common mode rejection and (2) both positive and negative dc level shifts of the zero pressure offset. Varying the gain and offset is desirable since full-scale span and zero pressure offset voltages of pressure sensors will vary somewhat from unit to unit. Thus, a variable gain is desirable to fine tune the sensor's full-scale span, and a positive or negative dc level shift (offset adjustment) of the pressure sensor signal is needed to translate the pressure sensor's signal-conditioned output span to a specific level (e.g., within the high and low reference voltages of an A/D converter).

For the two op-amp gain stage, this paper will present the derivation of the transfer function and simplified transfer function for pressure sensor applications, the derivation and explanation of the gain stage with a gain adjust feature, and the derivation and explanation of the gain stage with the dc level shift modification.

Adding another amplifier stage provides an alternative method of creating a negative dc voltage level shift. This stage is cascaded with the output from the two op-amp stage (*Note:* gain of the two op-amp stage will be reduced due to additional gain provided by the second amplifier stage). For this three op-amp stage, the derivation of the transfer function, simplified transfer function, and the explanation of the negative dc level shift feature will be presented.

GENERAL NOTE ON OFFSET ADJUSTMENT

Pressure sensor interface circuits may require either a positive or a negative dc level shift to adjust the zero pressure offset voltage. As described above, if the signal-conditioned pressure sensor voltage is input to an A/D, the sensor's output dynamic range must be positioned within the high and low reference voltages of the A/D; i.e., the zero pressure offset voltage must be greater than (or equal to) the low reference voltage and the full-scale pressure voltage must be less than (or equal to) the high reference voltage (see Figure 1). Otherwise, voltages above the high reference will be digitally converted as 255 decimal (for 8-bit A/D), and voltages below the low reference will be converted as 0. This creates a nonlinearity in the analog-to-digital conversion.

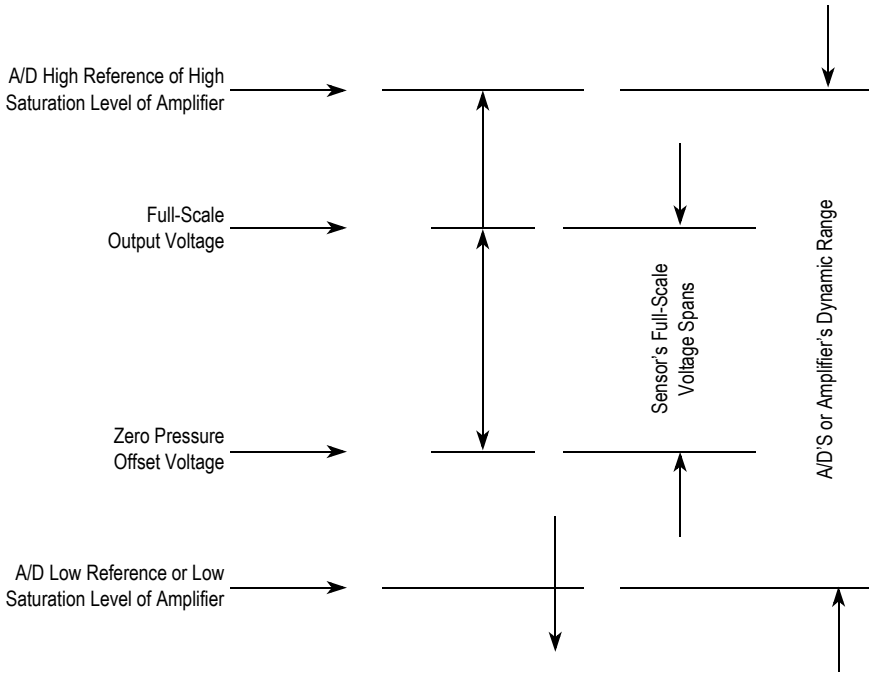

Figure 1. Positioning the Sensor's Full-Scale Span within the A/D's or Amplifier's Dynamic Range

A similar requirement that warrants the use of a dc level shift is the prevention of the pressure sensor's voltage from extending into the saturation regions of the operational amplifiers. This also would cause a nonlinearity in the sensor output measurements. For example, if an op-amp powered with a single-ended 5.0 V supply saturates near the low rail of the supply at 0.2 V, a positive dc level shift may be required to position the zero pressure offset voltage at or above 0.2 V. Likewise, if the same op-amp saturates near the high rail of the supply at 4.8 V, a negative dc level shift may be required to position the full-scale pressure voltage at or below 4.8 V. It should be obvious that if the gain of the amplifiers is too large, the span may be too large to be positioned within the 4.6 V window (regardless of ability to level shift dc offset). In such a case, the gain must be decreased to reduce the span.

THE TWO OP-AMP GAIN STAGE TRANSFER FUNCTION

The transfer function of the two op-amp signal-conditioning stage, shown in Figure 2, can be determined using nodal analysis at nodes 1 and 2. The analysis can be simplified by calculating the transfer function for each of the signals with the other two signals grounded (set to zero), and then employing superposition to realize the overall transfer function. As shown in Figure 2, V_{IN2} and V_{IN1} are the differential amplifier input signals (with $V_{IN2} > V_{IN1}$), and V_{REF} is the positive dc level adjust point. For a sensor with a small zero pressure offset and operational amplifiers powered from a single-ended supply, it may be necessary to add a positive dc level shift to keep the operational amplifiers from saturating near zero volts.

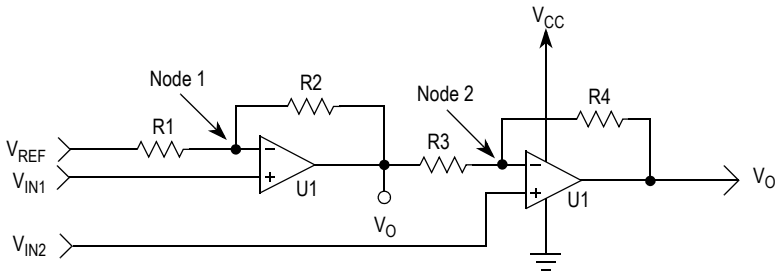

Figure 2. The Two Operational-Amplifier Gain Stage

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First, the transfer function for V_{IN1} is determined by grounding V_{REF} and V_{IN2} at Node 1:

$$\frac{V_{IN1}}{R_1} = \frac{V_{O'} - V_{IN1}}{R_2} \quad (1)$$

and at Node 2:

$$\frac{V_{O'}}{R_3} = -\frac{V_O}{R_4} \quad (2)$$

By solving Equations (1) and (2) for V_O' and equating the results, Equation (3) is established:

$$\left(\frac{R_2}{R_1} + 1\right) V_{IN1} = -\frac{R_3}{R_4} V_O \quad (3)$$

Solving for V_O yields:

$$V_{O1} = -\frac{R_4}{R_3}\left(\frac{R_2}{R_1} + 1\right) V_{IN1} \quad (4)$$

where V_{O1} represents the part of V_O that V_{IN1} contributes.

To determine the transfer function for V_{IN2}, V_{IN1}, and V_{REF} are grounded, and a similar analysis is used, yielding:

$$V_{O2} = \left(\frac{R_4}{R_3} + 1\right) V_{IN2} \quad (5)$$

where V_{O2} represents the part of V_O that V_{IN2} contributes.

Finally, to calculate the transfer function between V_O and V_{REF}, V_{IN1}, and V_{IN2} are grounded to obtain the following transfer function:

$$V_{OREF} = \frac{R_4 R_2}{R_3 R_1} V_{REF} \quad (6)$$

where V_{OREF} represents the part of V_O that V_{REF} contributes.

Using superposition for the contributions of V_{IN1}, V_{IN2}, and V_{REF} gives the overall transfer function for the signal-conditioning stage.

$$V_O = V_{O1} + V_{O2} + V_{OREF}$$

$$V_O = \left(-\frac{R_4}{R_3}\right)\left(\frac{R_2}{R_1} + 1\right) V_{IN1} + \left(\frac{R_4}{R_3} + 1\right) V_{IN2} + \frac{R_4 R_2}{R_3 R_1} V_{REF} \quad (7)$$

Equation (7) is the general transfer function for the signal-conditioning stage. However, the general form is not only cumbersome, but also if care is not taken to match certain resistance ratios, poor common mode rejection results. A simplified form of this equation that provides good common mode rejection is shown in the next section.

APPLICATION TO PRESSURE SENSOR CIRCUITS

The previous section showed the derivation of the general transfer function for the two op-amp signal-conditioning circuit. The simplified form of this transfer function, as applied to a pressure sensor application, is derived in this section.

For pressure sensors, V_{IN1} and V_{IN2} are referred to as S^- and S^+, respectively. The simplification is obtained by setting

$$\frac{R_4}{R_3} = \frac{R_1}{R_2}$$

Through this simplification, Equation (7) reduces to

$$V_O = \left(\frac{R_4}{R_3} + 1\right)(S^+ - S^-) + V_{REF} \quad (8)$$

By examining Equation (8), the differential gain of the signal-conditioning stage is:

$$G = \frac{R_4}{R_3} + 1 \quad (9)$$

Also, since the differential voltage between S^+ and S^- is the pressure sensor's actual differential output voltage (V_{SENSOR}), the following equation is obtained for V_O:

$$V_O = \left(\frac{R_4}{R_3} + 1\right) V_{SENSOR} + V_{REF} \quad (10)$$

Finally, the term V_{REF} is the positive offset voltage added to the amplified sensor output voltage. V_{REF} can only be positive when using a positive single-ended supply. This offset (dc level shift) allows the user to adjust the absolute range that the sensor voltage spans. For example, if the gain established by R_4 and R_3 creates a span of four volts and this signal swing is superimposed upon a dc level shift (offset) of 0.5 volts, then a signal range from 0.5 V to 4.5 V results.

V_{REF} is typically adjusted by a resistor divider as shown in Figure 3. A few design constraints are required when designing the resistor divider to set the voltage at V_{REF}.

- To establish a stable positive dc level shift (V_{REF}), V_{CC} should be regulated; otherwise, V_{REF} will vary as V_{CC} varies.
- When *looking* into the resistor divider from R_1, the effective resistance of the parallel combination of the resistors, R_{REF1} and R_{REF2}, should be at least an order of magnitude smaller than R_1's resistance. If the resistance of the parallel combination is not small in comparison to R_1, R_1's value will be significantly affected by the parallel combination's resistance. This effect on R_1 will consequently affect the amplifier's gain and reduce the common mode rejection.

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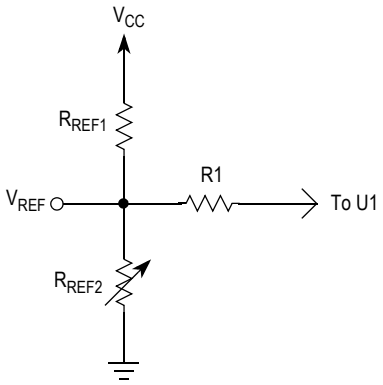

Figure 3. A Resistor Divider to Create V_{REF}

THE TWO OP-AMP GAIN STAGE WITH VARIABLE GAIN

Varying the gain of the two op-amp stage is desirable for fine-tuning the sensor's signal-conditioned output span. However, to adjust the gain in the two op-amp gain circuit in Figure 2 and to simultaneously preserve the common mode rejection, two resistors must be adjusted. To adjust the gain, it is more desirable to change one resistor. By adding an additional feedback resistor, RG, the gain can be adjusted with this one resistor while preserving the common mode rejection. Figure 4 shows the two op-amp gain stage with the added resistor, R_G.

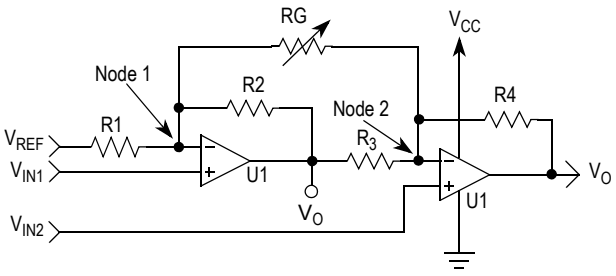

Figure 4. Two Operational-Amplifier Gain Stage with Variable Gain

As with the two op-amp gain stage, nodal analysis and superposition are used to derive the general transfer function for the variable gain stage.

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + \frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF} \quad (11)$$

This general transfer function also is quite cumbersome and is susceptible to producing poor common mode rejection without additional constraints on the resistor values. To obtain good common mode rejection, use a similar simplification as before; that is, set

$$R_1 = R_4$$

and

$$R_1 = R_4$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)V_{SENSOR} + V_{REF} \quad (12)$$

Thus, the gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \quad (13)$$

and V_{REF} is the positive dc level shift (offset).

Use the following guidelines when determining the value for RG:

- By examining the gain equation, RG's resistance should be comparable to R4's resistance. This will allow fine tuning of the gain established by R4 and R3. If RG is too large (e.g., RG approaches ∞), it will have a negligible effect on the gain. If RG is too small (e.g., RG approaches zero), the RG term will dominate the gain expression, thus prohibiting fine adjustment of the gain established via the ratio of R4 and R3.
- Use a potentiometer for RG that has a resistance range on the order of R4 (perhaps with a maximum resistance equal to the value of R4). If a fixed resistor is preferable to a potentiometer, use the potentiometer to adjust the gain, measure the potentiometer's resistance, and replace the potentiometer with the closest one percent resistor value.
- To maintain good common mode rejection while varying the gain, RG should be the only resistor that is varied. RG equally modifies both of the resistor ratios which need to be well-matched for good common mode rejection, thus preserving the common mode rejection.

THE TWO OP-AMP GAIN STAGE WITH VARIABLE GAIN AND NEGATIVE DC LEVEL SHIFT

The last two op-amp circuits both incorporate positive dc level shift capability. Recall that a positive dc level shift is required to keep the operational amplifiers from saturating near the low rail of the supply or to keep the zero pressure offset above (or equal to) the low reference voltage of an A/D. This two op-amp stage incorporates an additional resistor, R_{OFF}, to provide a negative dc level shift. A negative dc level shift is useful when the zero pressure offset voltage of the sensor is too high. In this case, the user may be required to level shift the zero pressure offset voltage down (toward zero volts). Now, for a specified amount of gain, the full-scale pressure output voltage does not saturate the amplifier at the high rail of the voltage supply, nor is it greater than the A/D's high reference voltage. Figure 5 shows the schematic for this amplifier circuit.

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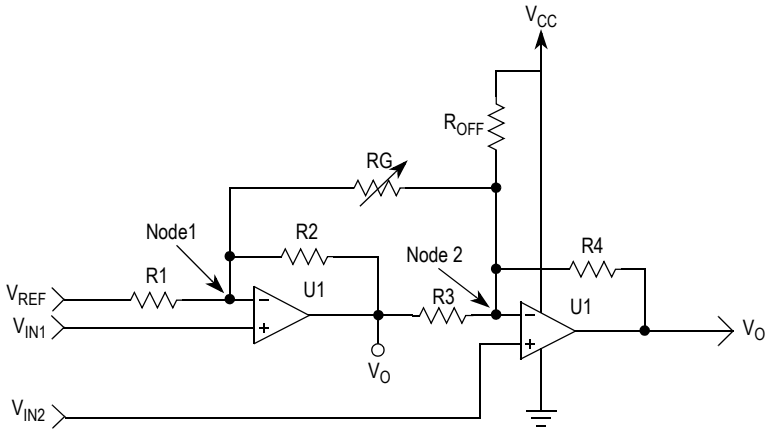

Figure 5. Two Op-Amp Signal Conditioning Stage with Variable Gain and Negative dc Level Shift Adjust

To derive the general transfer function, nodal analysis and superposition are used:

$$V_O = \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_1R_3} + \frac{R_2R_4}{R_3R_G}\right)V_{IN1} + \frac{R_2R_4}{R_1R_3}V_{REF} + \frac{R_4}{R_{OFF}}(V_{IN2} - V_{CC}) \quad (14)$$

As before, defining the sensor's differential output as V_{SENSOR}, defining V_{IN2} as S^+ for pressure sensor applications, and using the simplification that

$$R_1 = R_4$$

and

$$R_2 = R_3$$

obtains the following simplified transfer function:

$$V_O = \left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)V_{SENSOR} + V_{REF} + \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (15)$$

The gain is

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1 \quad (16)$$

To adjust the gain, refer to the guidelines presented in the section on *Two Op-Amp Gain Stage with Variable Gain*.

V_{REF} is the positive dc level shift, and the negative dc level shift is:

$$V_{-shift} = \frac{R_4}{R_{OFF}}(S^+ - V_{CC}) \quad (17)$$

The following guidelines will help design the circuitry for the negative dc voltage level shift:

- To establish a stable negative dc level shift, V_{CC} should be regulated; otherwise, the amount of negative level shift will vary as V_{CC} varies.
- R_{OFF} should be the only resistor varied to adjust the negative level shift. Varying R4 will change the gain of the two op-amp circuit and reduce the common mode rejection.
- To determine the value of R_{OFF}:
  1. Determine the amount of negative dc level shifting required (defined here as V_{-SHIFT}).
  2. R_4 already should have been determined to set the gain for the desired signal-conditioned sensor output.
  3. Although V_{-SHIFT} is dependent on S^+, S^+ changes only slightly over the entire pressure range. With Freescale's MPX10 powered at a 5.0 V supply, S^+ will have a value of approximately 2.51 V at zero pressure and will increase as high as 2.53 V at full-scale pressure. This error over the full-scale pressure span of the device is negligible when considering that many applications use an 8-bit A/D converter to segment the pressure range. Using an 8-bit A/D, the 20 mV (0.02 V) error corresponds to only 1 bit of error over the entire pressure range (1 bit / 255 bits x 100% = 0.4% error).
  4. R_{OFF} is then calculated by the following equation:

$$R_{OFF} = \frac{S^+ - V_{CC}}{V_{-shift}} R_4 \quad (18)$$

An alternative to using this equation is to use a potentiometer for R_{OFF} that has a resistance range on the order of R_4 (perhaps 1 to 5 times the value of R4). Use the potentiometer to fine tune the negative dc level shift, while monitoring the zero pressure offset output voltage, V_O. As before, if a fixed resistor is preferable, then measure the potentiometer's resistance and replace the potentiometer with the closest 1% resistor value.

Important Note: The common mode rejection of this amplifier topology will be low and perhaps unacceptable in some applications. (A SPICE model of this amplifier topology showed the common mode rejection to be 28 dB.) However,

this circuit is presented as a solution for applications where only two operational amplifiers are available and the common mode rejection is not critical when considering the required system performance. Adding a third op-amp to the circuit for the negative dc level shifting capability (as shown in the next section) is a solution that provides good common mode rejection, but at the expense of adding an additional op-amp.

THE THREE OP-AMP GAIN STAGE FOR NEGATIVE dc LEVEL SHIFTING

This circuit adds a third op-amp to the output of the two op-amp gain block (see Figure 6). This op-amp has a dual function in the overall amplifier circuit:

- Its non-inverting configuration provides gain via the ratio of R_6 and R_5.
- It has negative dc voltage level shifting capability typically created by a resistor divider at V_{-SHIFT}, as discussed in the section on Application to Pressure Sensor Circuits. Although this configuration requires a third op-amp for the negative dc level shift, it has no intrinsic error nor low common mode rejection associated with the negative level shift (as does the previous two op-amp stage). Depending on the application's accuracy requirement, this may be a more desirable configuration for providing the negative dc level shift.

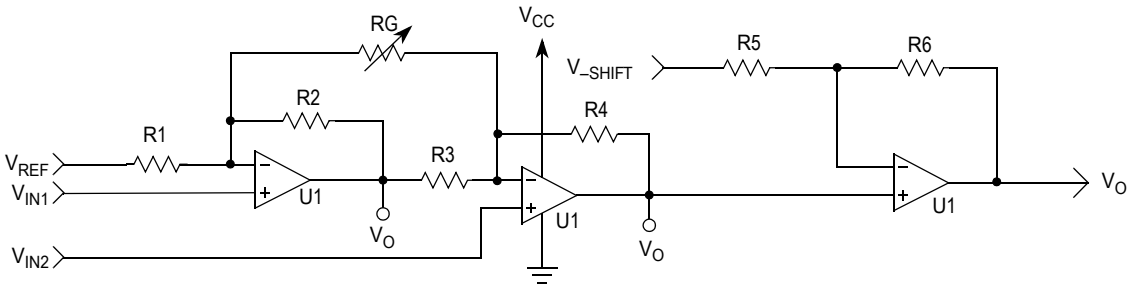

Figure 6. Three Op-Amp Gain Stage with Variable Gain and Negative DC Level Shift

The transfer function for this stage will be similar to the chosen two op-amp gain stage configuration (either the fixed gain with positive dc level shift circuit or the variable gain with positive dc level shift circuit) with additional terms for the negative level shift and gain. As an example, the variable-gain two op-amp gain circuit is used here. All of the design considerations and explanations for the variable gain two op-amp circuit apply.

The transfer function may be derived with nodal analysis and superposition.

$$V_O = \left[1 + \frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + 1\right)V_{IN2} - \left(\frac{R_4}{R_3} + \frac{R_4}{R_G} + \frac{R_2R_4}{R_3R_G} + \frac{R_2R_4}{R_1R_3}\right)V_{IN1} + \left(\frac{R_2R_4}{R_1R_3}\right)V_{REF}\right] - \frac{R_6}{R_5}V_{-shift} \quad (19)$$

First, use the same simplifications as before; that is, set

$$R_1 = R_4$$

and

$$R_2 = R_3$$

Defining the voltage differential between V_{IN2} and V_{IN1} as V_{SENSOR}, the simplified transfer function is

$$V_O = \left[1 + \frac{R_6}{R_5}\right]\left[\left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)(V_{SENSOR}) + V_{REF}\right] - \frac{R_6}{R_5}V_{-shift} \quad (20)$$

The gain is

$$G = \left[1 + \frac{R_6}{R_5}\right]\left[\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right] \quad (21)$$

V_{REF} is the positive dc level shift (offset), and V_{-SHIFT} is the negative dc level shift.

The preceding simplifications have been performed in the previous sections, but by examining Equation 20, notice that the third op-amp's gain term also amplifies the positive and negative dc voltage level shifts, V_{REF} and V_{-SHIFT}. If R_6 and R_5 are chosen to make an arbitrary contribution to the overall system gain, designing an appropriate amount of positive and negative dc level shift can be difficult. To simplify the transfer function, set $R_5 = R_6$, and the following equation for V_O results:

$$V_O = 2\left[\left(\frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1\right)(V_{SENSOR}) + V_{REF}\right] - V_{-shift} \quad (22)$$

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Now the third op-amp's contribution to the overall system gain is a factor of two. When designing the overall system gain and the positive dc level shift, use the following guidelines:

- Since the third op-amp contributes a gain of two to the overall system, design the gain that the two op-amp circuit contributes to the system to be one-half the desired system gain. The gain term for the two op-amp circuit is:

$$G = \frac{R_4}{R_3} + \frac{2R_4}{R_G} + 1$$

which is the same as presented in Equation 16.

- Similarly, since the third op-amp also amplifies V_{REF} by two (refer to Equation 22), the resistor divider that creates V_{REF} should be designed to provide one-half the desired positive dc voltage level shift needed for the final output. When designing the voltage divider for V_{REF}, use the same design constraints as were given in the section on Application to Pressure Sensor Circuits.

With the above simplification of $R_5 = R_6$, the negative dc level shift, V_{-SHIFT}, which is also created by a voltage divider, is now amplified by a factor of unity. When designing the voltage divider, use the same design constraints as were presented in the section on Application to Pressure Sensor Circuits.

CONCLUSION

The amplifier circuits discussed in this paper apply to pressure sensor applications, but the amplifier circuits can be interfaced to low-level, differential-voltage output sensors, in general. All of the circuits exhibit the desired instrumentation amplifier characteristics of high input impedance, low output impedance, high gain capability, and differential to single-ended conversion of the sensor signal. Each amplifier circuit provides positive dc level shift capability, while the last two circuit topologies presented are also able to provide a negative dc voltage level shift. This enables the user to position the sensor's dynamic output within a specified range (e.g., within the high and low references of an A/D converter). Also detailed is a method of using an additional feedback resistor to adjust easily the differential voltage gain, while not sacrificing common mode rejection. Combining the appropriate sensor device and amplifier interface circuit provides sensor users with a versatile system solution for applications in which the ideal fully single-conditioned sensor does not exist or in which such signal flexibility is warranted.

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Digital Blood Pressure Meter

by: C.S. Chua and Siew Mun Hin, Sensor Application Engineering
Singapore, A/P

INTRODUCTION

This application note describes a Digital Blood Pressure Meter concept which uses an integrated pressure sensor, analog signal-conditioning circuitry, microcontroller hardware/software and a liquid crystal display. The sensing system reads the cuff pressure (CP) and extracts the pulses for analysis and determination of systolic and diastolic pressure. This design uses a 50 kPa integrated pressure sensor (Freescale Semiconductor, Inc.P/N: MPXV5050GP) yielding a pressure range of 0 mm Hg to 300 mm Hg.

CONCEPT OF OSCILLOMETRIC METHOD

This method is employed by the majority of automated non-invasive devices. A limb and its vasculature are compressed by an encircling, inflatable compression cuff. The blood pressure reading for systolic and diastolic blood pressure values are read at the parameter identification point.

The simplified measurement principle of the oscillometric method is a measurement of the amplitude of pressure change in the cuff as the cuff is inflated from above the systolic pressure. The amplitude suddenly grows larger as the pulse breaks through the occlusion. This is very close to systolic pressure. As the cuff pressure is further reduced, the pulsation increase in amplitude, reaches a maximum and then diminishes rapidly. The index of diastolic pressure is taken where this rapid transition begins. Therefore, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are obtained by identifying the region where there is a rapid increase then decrease in the amplitude of the pulses respectively. Mean arterial pressure (MAP) is located at the point of maximum oscillation.

HARDWARE DESCRIPTION AND OPERATION

The cuff pressure is sensed by Freescale's integrated pressure X-ducer‰. The output of the sensor is split into two paths for two different purposes. One is used as the cuff pressure while the other is further processed by a circuit. Since MPXV5050GP is signal-conditioned by its internal op-amp, the cuff pressure can be directly interfaced with an analog-to-digital (A/D) converter for digitization. The other path will filter and amplify the raw CP signal to extract an amplified version of the CP oscillations, which are caused by the expansion of the subject's arm each time pressure in the arm increases during cardiac systole.

The output of the sensor consists of two signals; the oscillation signal (≈ 1 Hz) riding on the CP signal (≤ 0.04 Hz). Hence, a 2-pole high pass filter is designed to block the CP signal before the amplification of the oscillation signal. If the CP signal is not properly attenuated, the baseline of the oscillation will not be constant and the amplitude of each oscillation will not have the same reference for comparison. Figure 1 shows the oscillation signal amplifier together with the filter.

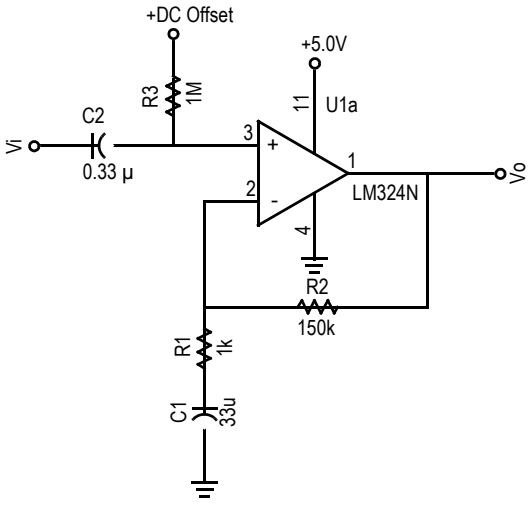

Figure 1. Oscillation Signal Amplifier

The filter consists of two RC networks which determine two cut-off frequencies. These two poles are carefully chosen to ensure that the oscillation signal is not distorted or lost. The two cut-off frequencies can be approximated by the following equations. Figure 2describes the frequency response of the filter. This plot does not include the gain of the amplifier.

$$f_{P1} = \frac{1}{2\pi R_1 C_1}$$

$$f_{P2} = \frac{1}{2\pi R_3 C_2}$$

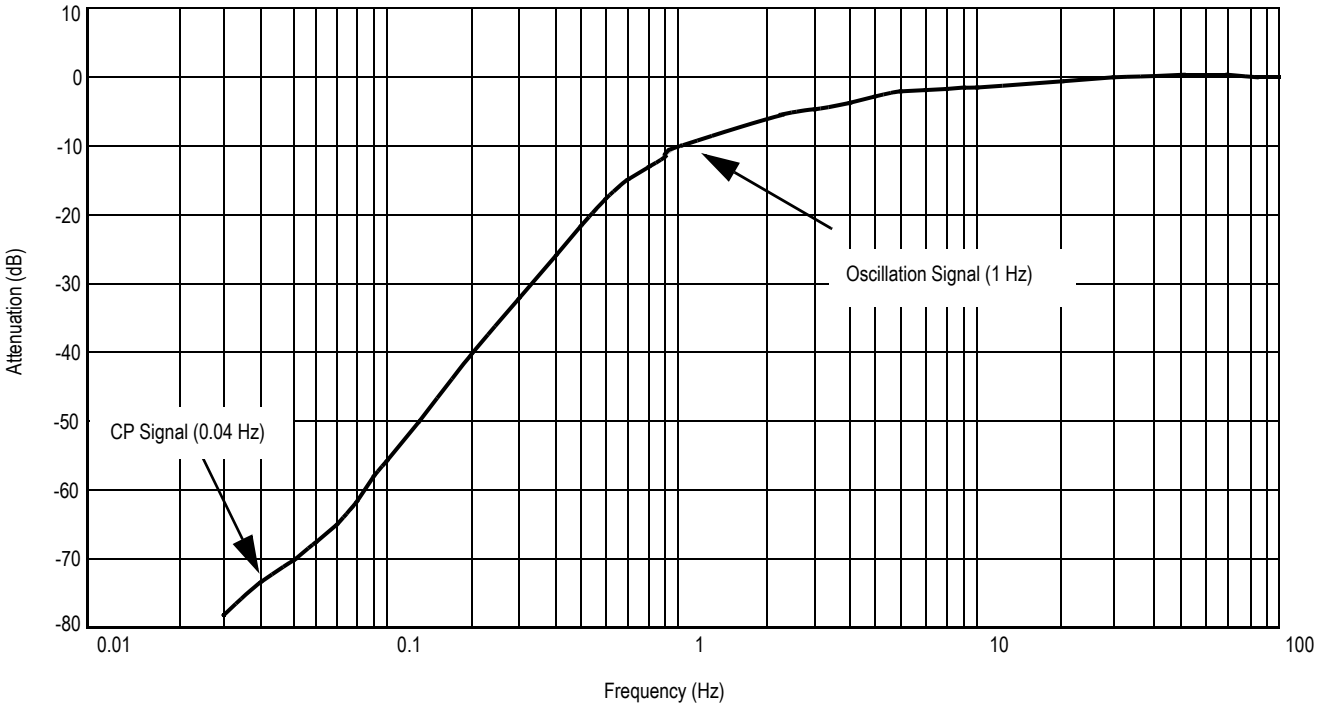

Figure 2. Filter Frequency

The oscillation signal varies from person to person. In general, it varies from less than 1 mm Hg to 3 mm Hg. From the transfer function of MPXV5050GP, this will translate to a voltage output of 12 mV to 36 mV signal. Since the filter gives an attenuation of 10 dB to the 1 Hz signal, the oscillation signal becomes 3.8 mV to 11.4 mV respectively. Experiments indicate that, the amplification factor of the amplifier is chosen to be 150 so that the amplified oscillation signal is within the output limit of the amplifier (5.0 mV to 3.5 V). Figure 3 shows the output from the pressure sensor and Figure 4 illustrates the extracted oscillation signal at the output of the amplifier.

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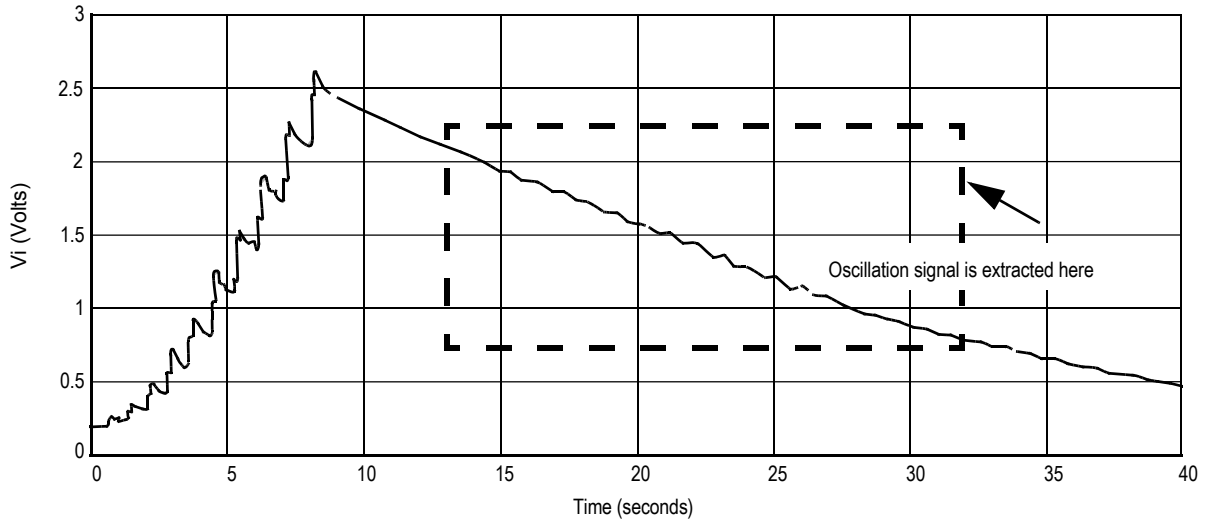

Figure 3. CP Signal at the Output of the Pressure Sensor

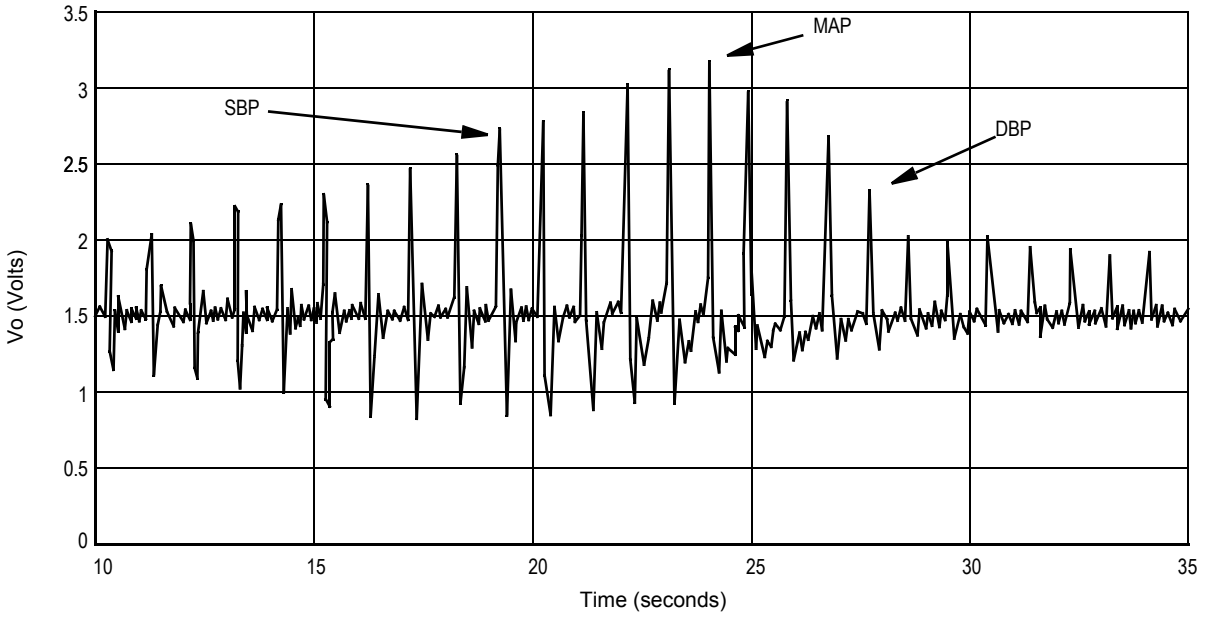

Figure 4. Extracted Oscillation Signal at the Output of Amplifier

Referring to the schematic, Figure 5, the MPX5050GP pressure sensor is connected to PORT D bit 5 and the output of the amplifier is connected to PORT D bit 6 of the microcontroller. This port is an input to the on-chip 8-bit analog-to-digital (A/D) converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.2 Vdc at 0 mm Hg to 4.7 Vdc at 375 mm Hg of applied pressure whereas the amplifier provides a signal from 0.005 V to 3.5 V. In order to maximize the resolution, separate voltage references should be provided for the A/D instead of using the 5 V supply. In this example, the input range of the A/D converter is set at approximately 0 Vdc to 3.8 Vdc. This compresses the range of the A/D converter around 0 mm Hg to 300 mm Hg to maximize the resolution; 0 to 255 counts is the range of the A/D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A/D converter. The resolution is defined by the following:

$$\text{Count} = [(V_{Xdcr} - V_{RL})/(V_{RH} - V_{RL})] \times 255$$

$$\text{The count at 0 mm Hg} = [(0.2 - 0)/(3.8 - 0)] \times 255 \approx 14$$

$$\text{The count at 300 mm Hg} = [(3.8 - 0)/(3.8 - 0)] \times 255 \approx 255$$

Therefore the resolution = 255 - 14 = 241 counts. This translates to a system that will resolve to 1.24 mm Hg.

The voltage divider consisting of R5 and R6 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common

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supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display (LCD) is directly driven from I/O ports A, B, and C on the microcontroller. The operation of a LCD requires that the data and backplane (BP) pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

Other than the LCD, there are two more I/O devices that are connected to the pulse length converter (PLM) of the microcontroller; a buzzer and a light emitting diode (LED). The buzzer, which connected to the PLMA, can produce two different frequencies; 122 Hz and 1.953 kHz tones. For instance when the microcontroller encounters certain error due to improper inflation of cuff, a low frequency tone is alarm. In those instance when the measurement is successful, a high frequency pulsation tone will be heard. Hence, different musical tone can be produced to differential each condition. In addition, the LED is used to indicate the presence of a heart beat during the measurement.

The microcontroller section of the system requires certain support hardware to allow it to function. The MC34064P-5 provides an undervoltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal provides the external portion of the oscillator function for clocking the microcontroller and provides a stable base for time based functions, for instance calculation of pulse rate.

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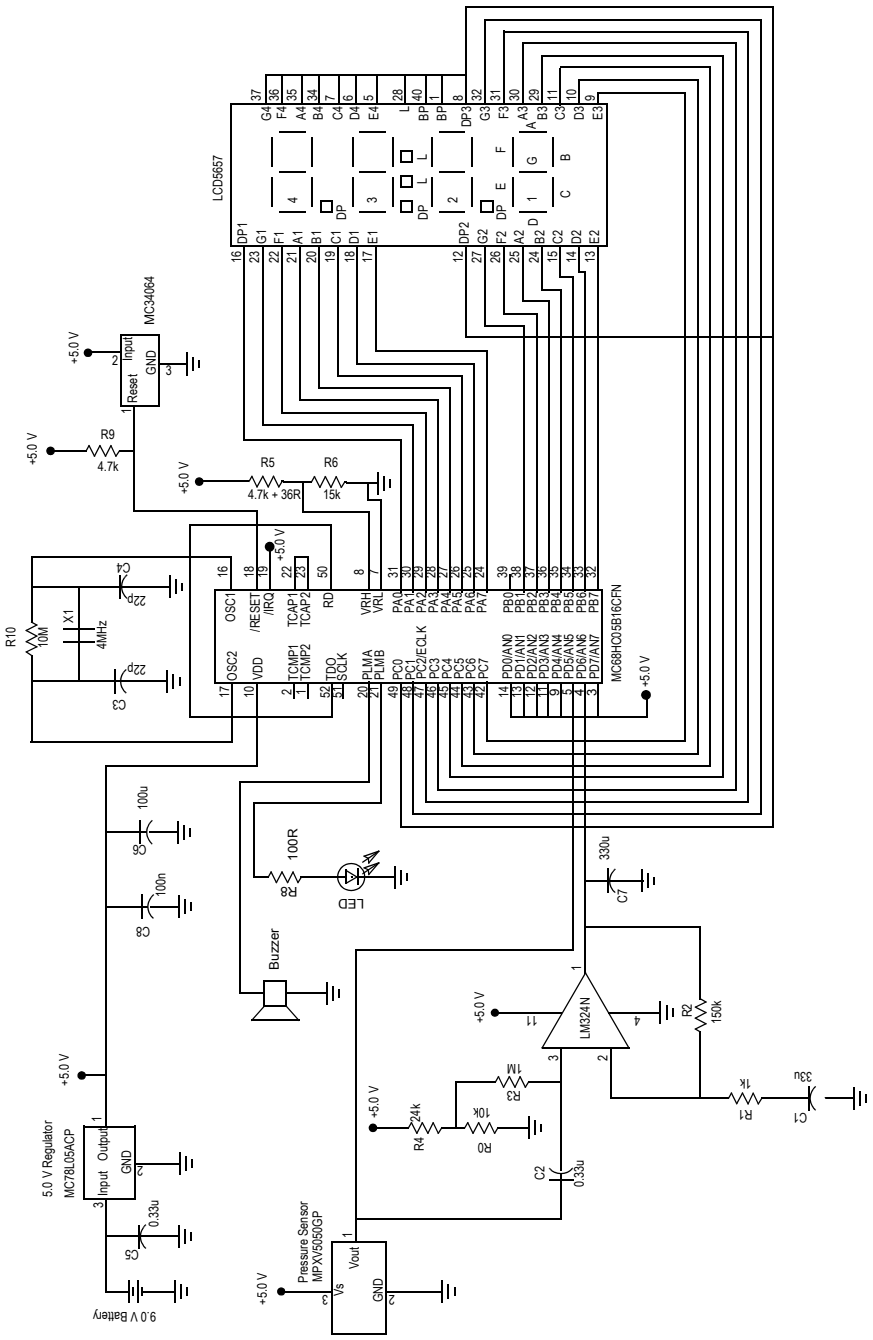

Figure 5. Blood Pressure Meter Schematic Drawing

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SOFTWARE DESCRIPTION

Upon system power-up, the user needs to manually pump the cuff pressure to approximately 160 mm Hg or 30 mm Hg above the previous SBP. During the pumping of the inflation bulb, the microcontroller ignores the signal at the output of the amplifier. When the subroutine TAKE senses a decrease in CP for a continuous duration of more than 0.75 seconds, the microcontroller will then assume that the user is no longer pumping the bulb and starts to analyze the oscillation signal. Figure 6 shows zoom-in view of a pulse.

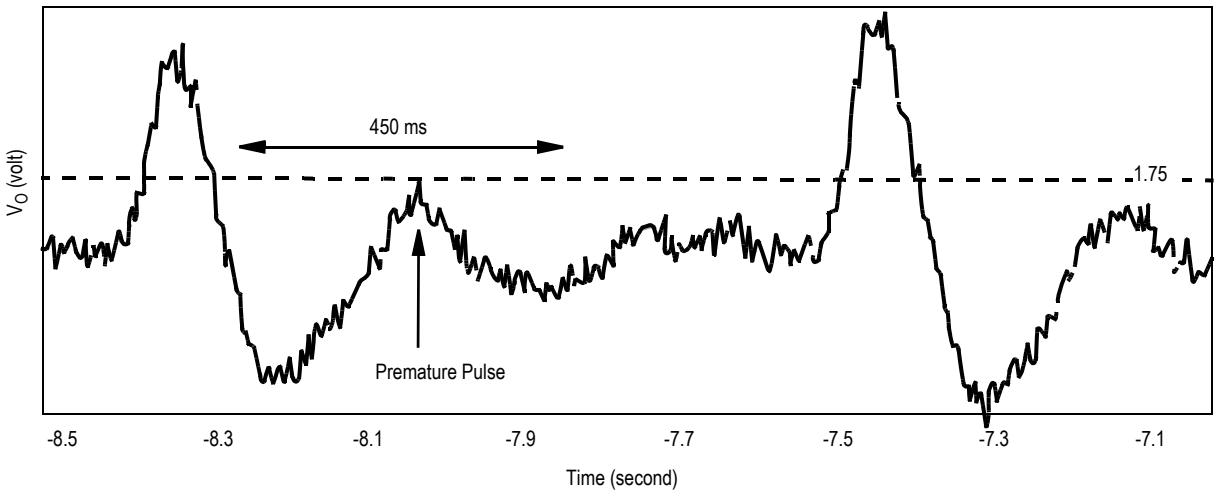

Figure 6. Zoom-In View of a Pulse

First of all, the threshold level of a valid pulse is set to be 1.75 V to eliminate noise or spike. As soon as the amplitude of a pulse is identified, the microcontroller will ignore the signal for 450 ms to prevent any false identification due to the presence of premature pulse "overshoot" due to oscillation. Hence, this algorithm can only detect pulse rate which is less than 133 beats per minute. Next, the amplitudes of all the pulses detected are stored in the RAM for further analysis. If the microcontroller senses a non-typical oscillation envelope shape, an error message (“Err”) is output to the LCD. The user will have to exhaust all the pressure in the cuff before re-pumping the CP to the next higher value. The algorithm ensures that the user exhausts all the air present in the cuff before allowing any re-pumping. Otherwise, the venous blood trapped in the distal arm may affect the next measurement. Therefore, the user has to reduce the pressure in the cuff as soon as possible in order for the arm to recover. Figure 7 on the following page is a flowchart for the program that controls the system.

SELECTION OF MICROCONTROLLER

Although the microcontroller used in this project is MC68HC05B16, a smaller ROM version microcontroller can also be used. The list below shows the requirement of microcontroller for this blood pressure meter design in this project.

- On-chip ROM space: 2 kilobytes
- On-chip RAM space: 150 bytes
- 2-channel A/D converter (min.)
- 16-bit free running counter timer
- LCD driver
- On-chip EEPROM space: 32 bytes
- Power saving Stop and Wait modes

CONCLUSION

This circuit design concept may be used to evaluate Freescale pressure sensors used in the digital blood pressure meter. This basic circuit may be easily modified to provide suitable output signal level. The software may also be easily modified to provide better analysis of the SBP and DBP of a person.

REFERENCES

Lucas, Bill (1991). “An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor,” Freescale Application Note AN1305.

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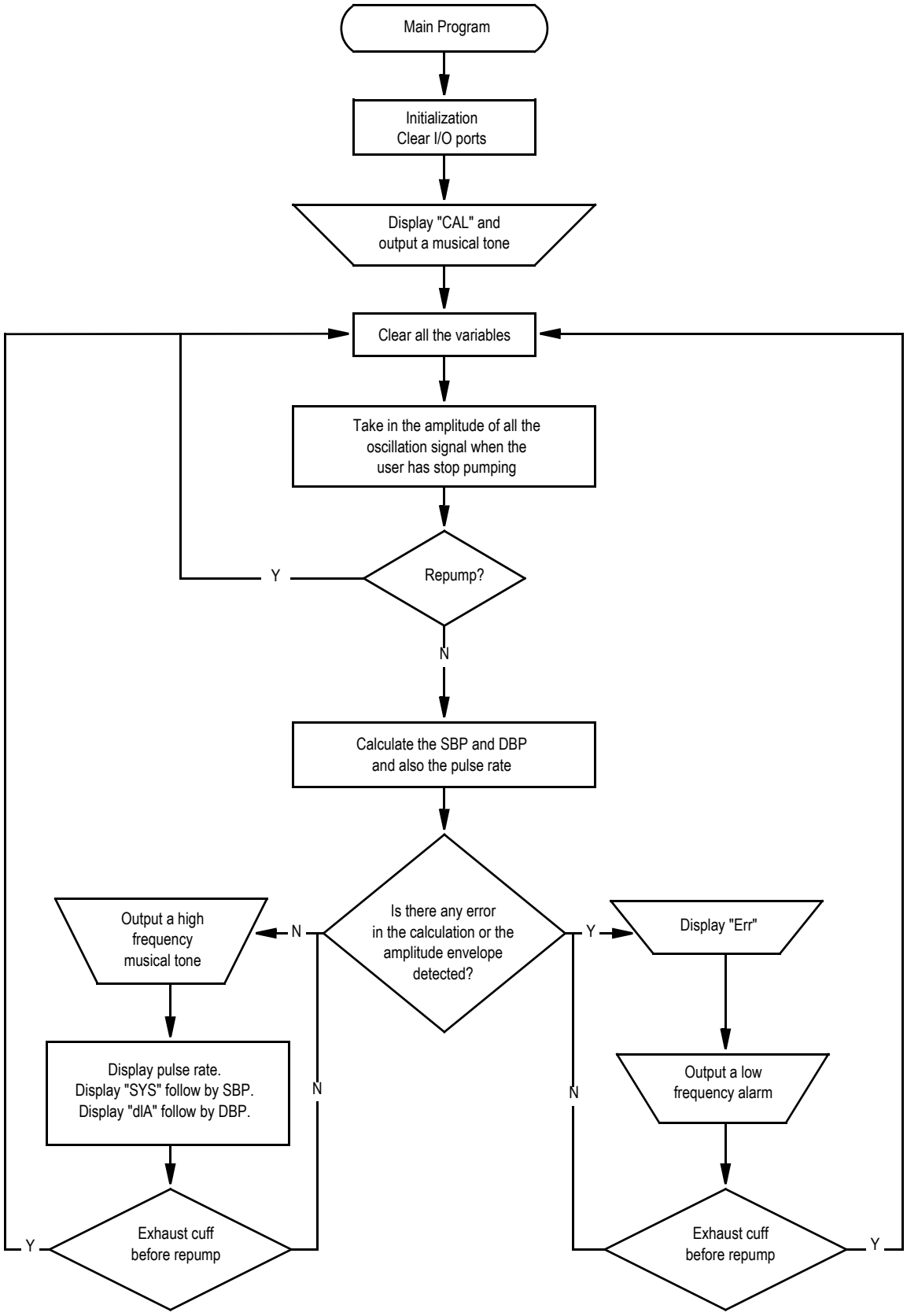

Figure 7. Main Program Flowchart

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Understanding Pressure and Pressure Measurement

by: David Heeley
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INTRODUCTION

Fluid systems, pressure and pressure measurements are extremely complex. The typical college curriculum for Mechanical Engineers includes at least two semesters in fluid mechanics. This paper will define and explain the basic concepts of fluid mechanics in terms that are easily understood while maintaining the necessary technical accuracy and level of detail.

PRESSURE AND PRESSURE MEASUREMENT

What is fluid pressure? Fluid pressure can be defined as the measure of force per-unit-area exerted by a fluid, acting perpendicularly to any surface it contacts (a fluid can be either a gas or a liquid, fluid and liquid are not synonymous). The standard SI unit for pressure measurement is the Pascal (Pa) which is equivalent to one Newton per square meter (N/m^2) or the KiloPascal (kPa) where 1 kPa = 1000 Pa. In the English system, pressure is usually expressed in pounds per square inch (psi). Pressure can be expressed in many different units including in terms of a height of a column of liquid. Table 1 lists commonly used units of pressure measurement and the conversion between the units.

Pressure measurements can be divided into three different categories: *absolute pressure, gage pressure and differential pressure*. *Absolute pressure* refers to the absolute value of the force per-unit-area exerted on a surface by a fluid. Therefore the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum. *Gage pressure* is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The U.S. standard atmospheric pressure at sea level and 59°F (20°C) is 14.696 pounds per square inch absolute (psia) or 101.325 kPa absolute (abs). When referring to pressure measurement, it is critical to specify what reference the pressure is related to. In the English system of units, measurement relating the pressure to a reference is accomplished by specifying pressure in terms of pounds per square inch absolute (psia) or pounds per square inch gage (psig). For other units of measure it is important to specify gage or absolute. The abbreviation ‘abs' refers to an absolute measurement. A gage pressure by convention is always positive. A ‘negative' gage pressure is defined as vacuum. Vacuum is the measurement of the amount by which the local atmospheric pressure exceeds the absolute pressure. A perfect vacuum is zero absolute pressure. Figure 1 shows the relationship between absolute, gage pressure and vacuum. *Differential pressure* is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. This type of pressure measurement is commonly used to measure the pressure drop in a fluid system. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference. For the English system of units this could simply be psi and for the SI system it could be kPa.

In addition to the three types of pressure measurement, there are different types of fluid systems and fluid pressures. There are two types of fluid systems; *static systems* and *dynamic systems*. As the names imply, a static system is one in which the fluid is at rest and a dynamic system is on in which the fluid is moving.

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Table 1. Conversion Table for Common Units of Pressure

	kPa	mm Hg	millibar	in H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kPa	1.000	7.50062	10.000	4.01475	0.145038
1 mm Hg	0.133322	1.000	1.33322	0.535257	0.0193368
1 millibar	0.1000	0.750062	1.000	0.401475	0.0145038
1 in H_2O	0.249081	1.86826	2.49081	1.000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.000
1 mm H_2O	0.009806	0.07355	9.8×10^{-8}	0.03937	0.0014223

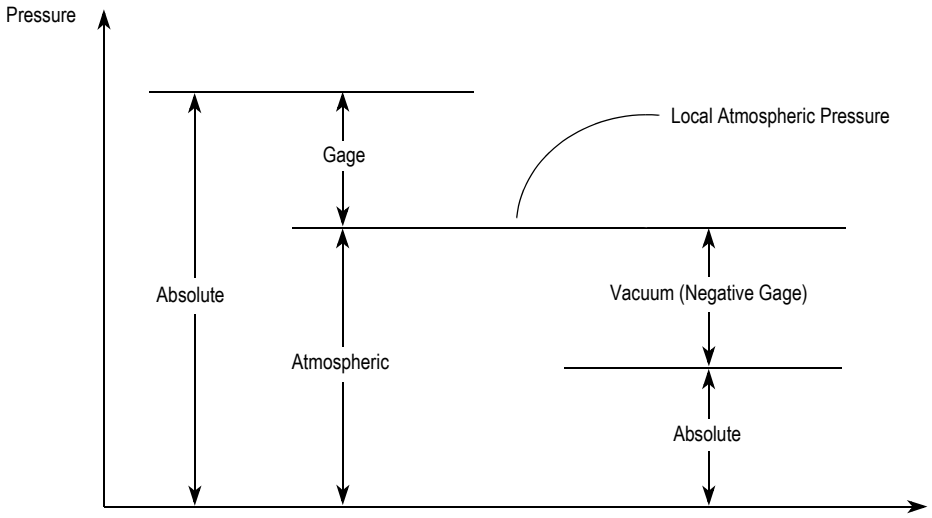

Figure 1. Pressure Term Relationships

STATIC PRESSURE SYSTEMS

The pressure measured in a static system is *static pressure*. In the pressure system shown in Figure 2 a uniform static fluid is continuously distributed with the pressure varying only with vertical distance. The pressure is the same at all points along the same horizontal plane in the fluid and is independent of the shape of the container. The pressure increases with depth in the fluid and acts equally in all directions. The increase in pressure at a deeper depth is essentially the effect of the weight of the fluid above that depth. Figure 3 shows two containers with the same fluid exposed to the same external pressure - **P**. At any equal depth within either tank the pressure will be the same. Note that the sides of the large tank are not vertical. The pressure is dependent only on depth and has nothing to do with the shape of the container. If the working fluid is a gas, the pressure increase in the fluid due to the height of the fluid is in most cases negligible since the density and therefore the weight of the fluid is much smaller than the pressure being applied to the system. However, this may not remain true if the system is large enough or the pressures low enough. One example considers how atmospheric pressure changes with altitude. At sea level the standard U.S. atmospheric pressure is 14.696 psia (101.325 kPa). At an altitude of 10,000 ft (3048 m) above sea level the standard U.S. atmospheric pressure is 10.106 psia (69.698 kPa) and at 30,000 ft (9144 m), the standard U.S. atmospheric pressure is 4.365 psia (30.101 kPa).

The pressure in a static liquid can be easily calculated if the density of the liquid is known. The absolute pressure at a depth H in a liquid is defined as:

$$P_{abs} = P + (\rho \times g \times H)$$

Where:

P_{abs} is the absolute pressure at depth H.

P is the external pressure at the top of the liquid. For most open systems this will be atmospheric pressure.

ρ is the density of the fluid.

g is the acceleration due to gravity (g = 32.174 ft/sec^2 (9.81 m/sec^2)).

H is the depth at which the pressure is desired.

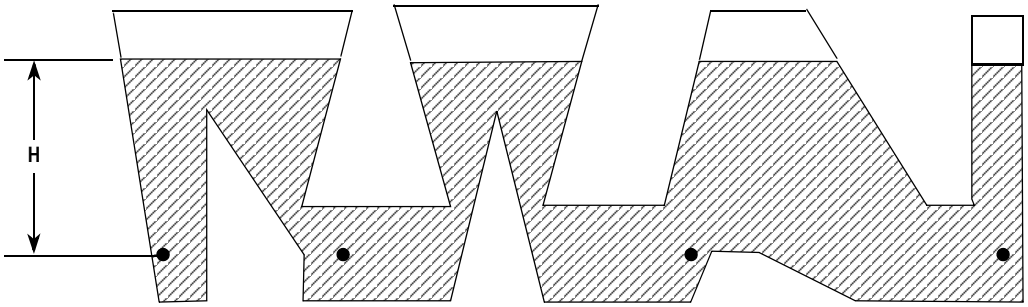

Figure 2. Continuous Fluid System

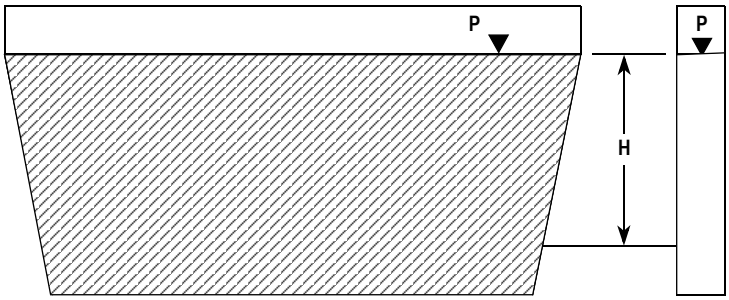

Figure 3. Pressure Measurement at a Depth in a Liquid

DYNAMIC PRESSURE SYSTEMS

Dynamic pressure systems are more complex than static systems and can be more difficult to measure. In a dynamic system, pressure typically is defined using three different terms. The first pressure we can measure is *static pressure*. This pressure is the same as the static pressure that is measured in a static system. Static pressure is independent of the fluid movement or flow. As with a static system the static pressure acts equally in all directions. The second type of pressure is what is referred to as the *dynamic pressure*. This pressure term is associated with the velocity or the flow of the fluid. The third pressure is *total pressure* and is simply the static pressure plus the dynamic pressure.

STEADY-STATE DYNAMIC SYSTEMS

Care must be taken when measuring dynamic system pressures. For a dynamic system, under steady-state conditions, accurate static pressures may be measured by tapping into the fluid stream perpendicular to the fluid flow. For a dynamic system, steady-state conditions are defined as no change in the system flow conditions: pressure, flow rate, etc. Figure 4 illustrates a dynamic system with a fluid flowing through a pipe or duct. In this example a static pressure tap is located in the duct wall at point A. The tube inserted into the flow is called a Pitot tube. The Pitot tube measures the total pressure at point B in the system. The total pressure measured at this point is referred to as the *stagnation pressure*. The stagnation pressure is the value obtained when a flowing fluid is decelerated to zero velocity in an isentropic (frictionless) process. This process converts all of the energy from the flowing fluid into a pressure that can be measured. The stagnation or total pressure is the static pressure plus the dynamic pressure. It is very difficult to accurately measure dynamic pressures. When dynamic pressure measurement is desired, the total and static pressures are measured and then subtracted to obtain the dynamic pressure. Dynamic pressures can be used to determine the fluid velocities and flow rates in dynamic systems.

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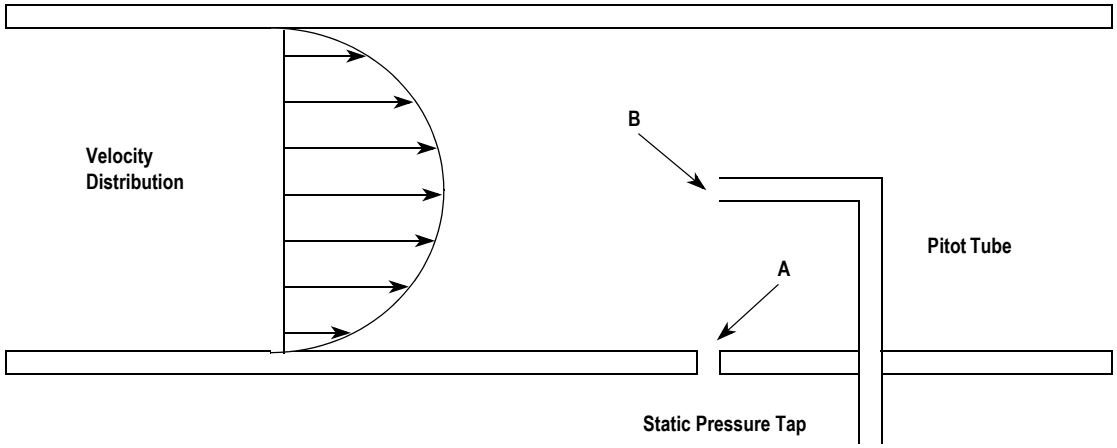
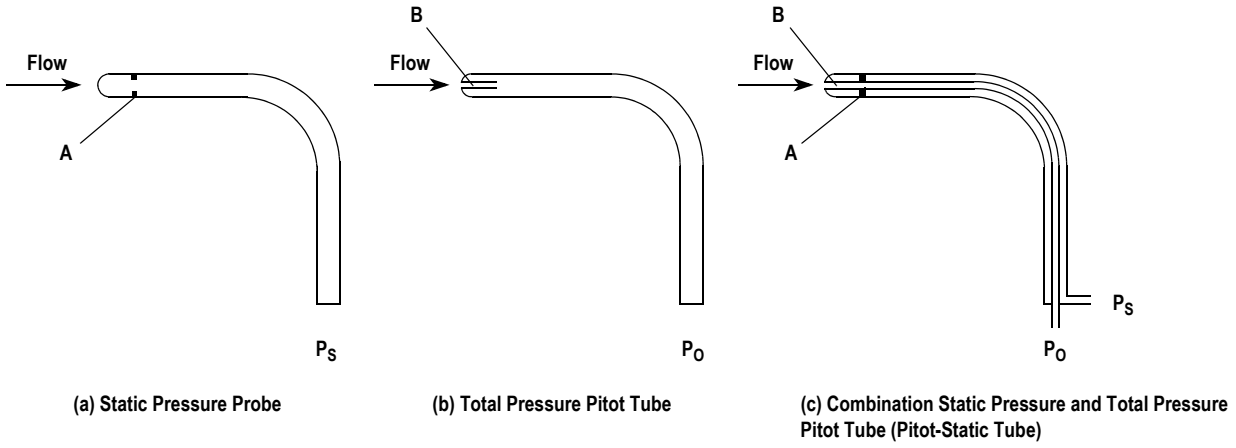


Figure 4. Static and Total Pressure Measurements Within a Dynamic Fluid System



(a) Static Pressure Probe

(b) Total Pressure Pitot Tube

(c) Combination Static Pressure and Total Pressure Pitot Tube (Pitot-Static Tube)

Figure 5. Types of Pressure Probes

When measuring dynamic system pressures, care must be taken to ensure accuracy. For static pressure measurements, the pressure tap location should be chosen so that the measurement is not influenced by the fluid flow. Typically, taps are located perpendicular to the flow field. In Figure 4, the static pressure tap at point A is in the wall of the duct and perpendicular to the flow field. In Figure 5 a and c the static taps (point A) in the pressure probes are also perpendicular to the flow field. These examples show the most common type of static pressure taps, however there are many different static pressure tap options. For total or stagnation pressure measurements, it is important that the Pitot or impact tube be aligned parallel to the flow field with the tip of the tube pointing directly into the flow. In Figure 5 b and c, the Pitot tube is aligned parallel with the flow, with the tube opening pointing directly into the flow. Although the static pressure is independent of direction, the dynamic pressure is a vector quantity which depends on both magnitude and direction for the total measured value. If the Pitot tube is misaligned with the flow, accuracy of the total pressure measurement may suffer. In addition, for accurate pressure measurements the pressure tap holes and probes must be smooth and free from any burrs or obstructions that could cause disturbances in the flow. The location of the pressure taps and probes, static and total, must also be selected carefully. Any location in the system where the flow field may be disturbed should be avoided, both upstream and downstream. These locations include any obstruction or change such as valves, elbows, flow splits, pumps, fans, etc. To increase the accuracy of pressure measurement in a dynamic system, allow at least 10 pipe / duct diameters downstream of any change or obstruction and at least two pipe / duct diameters upstream. In addition the pipe / duct diameter should be much larger than the diameter of the Pitot tube. The pipe / duct diameter should be at least 30 times the Pitot tube diameter. Flow straighteners can also be used to minimize any variations in the direction of the flow. Also, when using a Pitot tube, it is recommended that the static pressure tap be aligned in the same plane as the total pressure tap. On the Pitot-static tube, the difference in location is assumed to be negligible.

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Flow-through pipes and ducts will result in a velocity field and dynamic pressure field that are non-uniform. At the wall of any duct or pipe there exists a no-slip boundary due to friction. This means that at the wall itself the velocity of the fluid is zero. Figure 4 shows an imaginary velocity distribution in a duct. The shape of the distribution will depend on the fluid conditions, system flow and pressure. In order to accurately determine the average dynamic pressure across a duct section, a series of total pressure readings must be taken across the duct. These pressure measurements should be taken at different radii and clock positions across the cross section of a round duct or at various width and height locations for a rectangular duct. Once this characterization has been performed for the duct, a correlation can be easily made between the total pressure measurement at the center of the duct relative to the average duct total pressure. This technique is also used to determine the velocity profile within the duct.

TRANSIENT SYSTEMS

Transient systems are systems with changing conditions such as pressures, flow rates, etc. Measurements in transient systems are the most difficult to accurately obtain. If the measurement system being used to measure the pressure has a faster response time than the rate of change in the system, then the system can be treated as quasi-steady-state. That is, the measurements will be about as accurate as those taken in the steady-state system. If the measurement of the system is assumed to be a snap shot of what is happening in the system, then you want to be able to take the picture faster than the rate of change in the system or the picture will be blurred. In other words, the measurement results will not be accurate. In a pressure measurement system, there are two factors that determine the overall measurement response: (1) the response of the transducer element that senses the pressure, and (2) the response of the interface between the transducer and the pressure system such as the pressure transmitting fluid and the connecting tube, etc. For Freescale Semiconductor, Inc. pressure sensors, the second factor usually determines the overall frequency response of the pressure measurement system. The vast majority of pressure systems that require measurements today are quasi-steady-state systems where system conditions are changing relatively slowly compared to the response rate of the measurement system or the change happens instantaneously and then stabilizes.

Two transient system examples include washing machines and ventilation ducts in buildings. In a washing machine, the height of the water in the tub is measured indirectly by measuring the pressure at the bottom of the tub. As the tub fills the pressure changes. The rate at which the tub fills and the pressure changes is much slower than the response rate of the measurement system. In a ventilation duct, the pressure changes as the duct registers are opened and closed, adjusting the air movement within the building. As more registers are opened and closed, the system pressure changes. The pressure changes are virtually instantaneous. In this case, pressure changes are essentially incremental and therefore easy to measure accurately except at the instant of the change. For most industrial and building control applications, the lag in the pressure measurement system is negligible. As the control or measurement system becomes more precise, the frequency response of the measurement system must be considered.

FREESCALE PRESSURE SENSORS

This application note has covered various types of pressures that are measured and how to tap into a system to measure the desired pressures. How are the actual pressure measurements made? There are many types of pressure measurement systems ranging from simple liquid tube manometers to bourdon-tube type gages to piezo-electric silicon based transducers. Today, as electronic control and measurement systems are replacing mechanical systems, silicon-based pressure transducers and sensors are becoming the sensors of choice. Silicon micromachined sensors offer very high accuracies at very low cost and provide an interface between the mechanical world and the electrical system. Freescale carries a complete line of silicon based pressure sensors which feature a wide range of pressures with various levels of integration on a single chip. These levels of integration start with the basic uncompensated, uncalibrated pressure sensor all the way to the fully integrated, temperature compensated, calibrated and signal conditioned pressure sensors. The response time of Freescale's MPX series silicon pressure sensors is typically 1 millisecond or less. For static or dynamic systems, Freescale's pressure sensors are an excellent solution for pressure measurement systems.

CONCLUSION

Pressures and pressure measurements can be extremely complex and complicated. However, for most systems it is relatively easy to obtain accurate pressure measurements if the proper techniques are used.

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Designing a Homemade Digital Output for Analog Voltage Output Sensors

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INTRODUCTION

A digital output is more desirable than an analog output in noisy environments (e.g., automotive, washing machines) and remote sensing applications (e.g., building controls, industrial applications) because a digital signal inherently has better noise immunity compared to analog signals. Additional applications requiring a sensor with a digital output include microcontroller-based systems that have no A/D in the system or that have no A/D channels available for the sensing function. For these applications, there is no other option but a digital output to further process the signal.

Via a design example this paper shows how to easily convert an analog voltage output sensor to a digital output sensor. For the design example, each of the required circuit components is discussed in detail. While the design is applicable to analog voltage output sensors (differential or single-ended output) in general, the design example and following discussions will pertain specifically to semiconductor pressure sensors.

The digital output sensor in Figure 1 consists of the following:

- MPX2000 series pressure sensor
- A two op amp gain stage to amplify the sensor's signal
- An integrator (i.e., a low pass filter consisting of one resistor and one capacitor)
- An LM311 comparator
- An MC68HC05P9 microcontroller with which only two pins are used: the output compare timer channel (TCMP) and one general I/O pin (the input capture timer channel, TCAP, can be used in place of the general I/O pin). Since only two of the MC68HC05P9's pins are used, the remaining pins are available for other system functions.

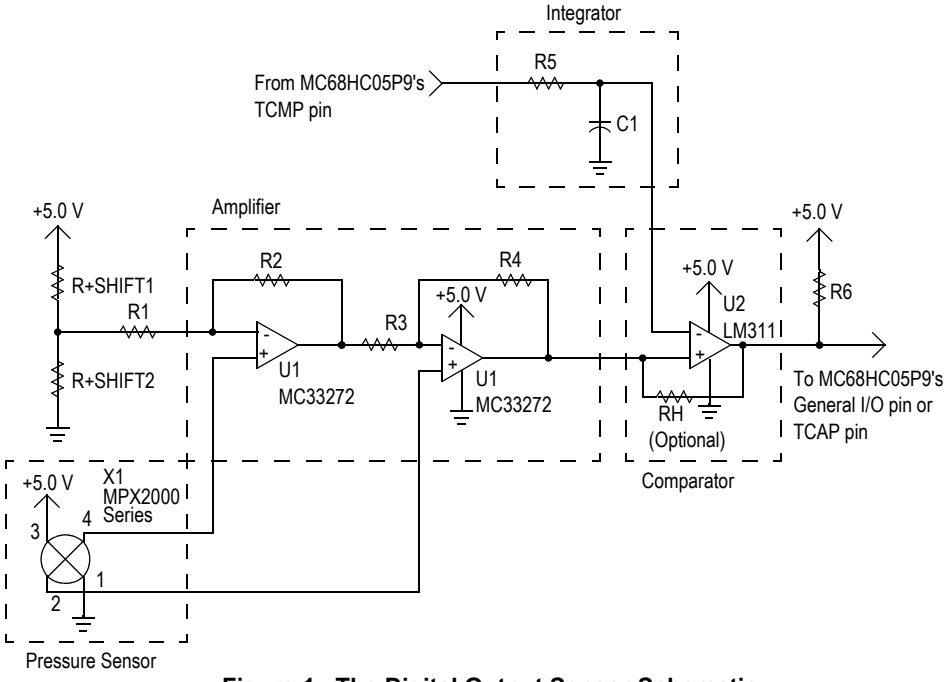

Figure 1. The Digital Output Sensor Schematic

After the discussion of the circuit components, the following system-related issues will be discussed simultaneously using the design example:

- How the system works
- Defining and designing the digital output for a desired signal resolution
- A step-by-step procedure that shows you how to digitize the signal
- A procedure to show you how to software calibrate the digital output
- Related software examples

This system, in addition to the benefits of a digital output (noise immunity, etc.), also has the following additional inherent benefits. These benefits will be addressed in more detail in the systems topics.

- The circuit topology and method of “digitizing” the sensor's analog output is very stable and accurate. The system uses the microcontroller's precise, internal, digital time base to digitize the analog signal.
- The signal resolution is user-programmable via software - i.e. the user can program whether the resolution is 8-bit, 10-bit, etc.
- The digital output is calibrated in software so that component tolerances can be nullified.
- The software required to digitize the signal requires very little CPU time and overhead.
- The required circuitry is minimal, simple, and cost-effective.

THE PRESSURE SENSOR

The Freescale Semiconductor, Inc. MPX2000 series sensors are temperature compensated and calibrated (i.e., offset and span are precision trimmed) pressure transducers. These sensors are available in full scale pressure ranges from 10 kPa (1.5 psi) to 700 kPa (100 psi). Although the specifications (see Table 1) in the data sheets apply to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. For example, at the absolute maximum supply voltage rating, 16 V, the sensor will typically produce a differential output voltage of 64 mV at the rated full scale pressure of the given sensor. One exception to this is that the span of the MPX2010 (10 kPa sensor) will be only 40 mV due to the device's slightly lower sensitivity. Since the maximum supply voltage produces the largest output signal, it is evident that even the best case scenario will require some signal conditioning to obtain a usable signal (input to an A/D, for example). For this specific design, an MPX2100 and 5.0 V supply are used, yielding a typical maximum sensor output of 20 mV (typical zero pressure offset is 0.0 mV and typical span is 20 mV). The sensor's output is then signal conditioned (amplified and level shifted) to provide a four volt span with a zero pressure offset of 0.5 V.

Table 1. MPX2100 Electrical Characteristics for V_S= 10 V, T_A = 25°C

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	10	16	V_{DC}
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{OFF}	-1.0	—	1.0	mV
Sensitivity	ΔV/ΔP	—	0.4	—	mV/kPa
Linearity	—	-0.25	—	0.25	$\%V_{FSS}$
Temperature Effect on Span	TCV_{FSS}	-1.0	—	1.0	$\%V_{FSS}$
Temperature Effect on Offset	TCV_{OFF}	-1.0	—	1.0	mV

AMPLIFIER STAGE

The amplifier circuitry, shown in Figure 1, is composed of two op amps. This interface circuit has a much lower component count than conventional quad op amp instrumentation amplifiers. The two op-amp design offers the high input impedance, low output impedance, and high gain desired for a transducer interface, while performing a differential to single-ended conversion. The amplifier incorporates level shifting capability. The amplifier has the following transfer function:

$$V_O = \left(1 + \frac{R_4}{R_3}\right) ² (V_{sensor}) + V + shift$$

where R1 = R4; R2 = R3,

the gain is $1 + \frac{R_4}{R_3}$

V_{sensor} is the sensor’s differential output ($S^+ – S^–$)

and

V+shift is the positive dc level shift voltage created by the resistor divider comprised of R+shift1 and R+shift2.

V+shift is used to position the zero pressure offset at the desired level.

Table 2 summarizes the 1% resistor values used to obtain a four-volt span with a zero pressure offset of 0.5 V (assuming the typical sensor offset and span values of 0.0 mV and 20 mV, respectively).

Table 2. Resistor Values for the MPX2100 Amplifier Design

R+shift1	R+shift2	R1	R2	R3	R4
4.99 kΩ	549 Ω	20.0 kΩ	100 Ω	100 Ω	20.0 kΩ

THE INTEGRATOR

As shown in Figure 1, the integrator consists of a single resistor and single capacitor. A programmable duty cycle

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pulse train from the microcontroller is input to the integrator. Assuming that the RC time constant of the integrator is sufficiently long compared to the pulse train's frequency, the resulting output which is input to the inverting terminal of the comparator is a dc voltage that is linearly proportional to the pulse train's duty cycle, i.e.:

DC Output Voltage = Pulse Train's Duty Cycle (%) × 5.0 V

Where the Pulse Train's Duty Cycle is multiplied by the pulse train's logic-level one voltage value which is typically the same voltage as the microcontroller's 5.0 V supply.

Table 3 shows a few examples of Pulse Train Duty Cycles and the corresponding DC Output Voltage assuming a typical pulse train logic-level one value of 5.0 V.

Table 3. Example Pulse Train Duty Cycles and the Integrator's Corresponding dc Voltage Output

Pulse Train's Duty Cycle (%)	0	25	50	75	100
DC Output Voltage (V)	0	1.25	2.5	3.75	5

To establish a stable constant dc voltage at the integrator's output, its time constant must be sufficiently long compared to the frequency of the pulse train. However, the system resolution and thus performance are directly related to the pulse train's frequency. The design of the time constant and choice of the resistor and capacitor values is discussed in *System Design: Defining and designing for a desired signal resolution.*

COMPARATOR

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open-collector output. A pull-up resistor (R6 = 5 kΩ) at the output is all that is needed to obtain a rail-to-rail output. As Figure 1 illustrates, the pressure sensor's amplified output voltage is input to the non-inverting terminal of the op-amp and the integrator's dc output voltage is input to the inverting terminal. Therefore, when the pressure sensor's output voltage is greater than the integrator's dc output voltage, the comparator's output is high (logic-level one); conversely, when the pressure sensor's output voltage is less than the integrator's dc output voltage, the comparator's output is low (logic-level zero).

An optional resistor, RH is used as positive feedback around U2 in Figure 1 to provide a small amount of hysteresis to ensure a clean logic-level transition (prevents multiple transitions (squegging)) when the comparator's inputs are similar in value. The amount of hysteresis increases as the value of RH decreases. For this design, the value of RH is not critical but should be on the order of 100 kΩ.

THE MC68HC05P9 MICROCONTROLLER

The microcontroller for this application requires an output compare timer channel and one general I/O pin. The output compare pin is programmed to output the pulse train that is input to the integrator, and the general I/O pin is configured as an input to monitor the logic-level of the comparator's output. The remainder of this paper discusses the system and software requirements.

SYSTEM DESIGN: HOW THE SYSTEM WORKS

For any analog sensor voltage output, there's a pulse train with a duty cycle that when integrated will equal the sensor's output. Therefore, by incrementing via software the pulse train's duty cycle from 0% to 100%, there's a duty cycle that when integrated will be larger than the sensor's current voltage output. When the integrated pulse train voltage becomes larger than the sensor's output voltage, the comparator's output will change from a logic-level one to a logic-level zero. This logic-level, in turn, is monitored on the general I/O pin. The pulse train's duty cycle creating the integrated voltage that caused the comparator's logic-level transition is the digital representation of the sensor's voltage. Thus every sensor analog output voltage is mapped to a specific duty cycle. This design inherently has outstanding performance (very stable and accurate) since the digital representation of the sensor signal is created by the microcontroller's digital time base. Also the pressure measurement, made via software that first increments the pulse train's duty cycle and then determines if an edge transition occurred on the general I/O pin, is straightforward and easy.

In a calibration routine (discussed below) the sensor's output at two known pressures (e.g. zero and full-scale pressure) can be mapped to two corresponding pulse train duty cycles. Since the pressure sensor's output voltage is linear with the applied pressure, and the integrator's dc output voltage is linear with the input pulse train duty cycle, then the pulse train's duty cycle that causes the logic-level transition at the comparator's output will also be linear with the applied pressure. Thus by knowing the duty cycles for two known pressures, a linear interpolation of any duty cycle gives an accurate measurement of the current pressure. The following equation is used to interpolate the pressure measurement where the pressure units are in kPa.

$$\text{Current Pressure} = \frac{\text{Current Duty Cycle} - \text{Duty Cycle @ Zero Pressure}}{\text{Duty Cycle @ Full-Scale Pressure} - \text{Duty Cycle @ Zero Pressure}} \times \text{Full-Scale Pressure in kPa}$$

For example:

At zero pressure, if the pulse train's duty cycle required to cause a logic-level transition at the comparator's output is 25% and at full-scale pressure the pulse train's duty cycle is 75%, then the current pressure that corresponds to a duty cycle of 50% (required to obtain the logic-level one to logic-level zero transition at the comparator's output) is

$$\text{Current Pressure} = \frac{50\% - 25\%}{75\% - 25\%} \times 100 \text{ kPa} = 50 \text{ kPa}$$

Until now, the pulse train has been defined in terms of duty cycle. However, in practice duty cycle is calculated from the ratio of the high time to the total period of the pulse train. Therefore, there is a high time (typically in μs) of the pulse train that causes the logic-level transition of the comparator's output. The interpolation of the current pressure can then be calculated directly from the high time of the pulse train that is programmed by the user to be generated by the microcontroller's output compare pin. The equation is similar to the one above for Current Pressure:

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$$\text{Current Pressure} = \frac{\text{Current High Time} - \text{High Time @ Zero Pressure}}{\text{High Time @ Full-Scale Pressure} - \text{High Time @ Zero Pressure}} \times \text{Full-Scale Pressure in kPa}$$

Via this equation, the digital nature of the design is revealed. The analog voltage signal has been translated into a signal in the time domain where the high time generated by the output compare pin is actually the digital time representation of the sensor's output. Since the user precisely controls the high time of the pulse train (and period) via software which is based on the accurate digital time base of the microcontroller, the digital representation of the signal is very stable and accurate. Additionally, the high accuracy of the digital representation is possible since all the user must do to digitize the signal is detect a single logic-level transition at the comparator's output.

SYSTEM DESIGN: DEFINING AND DESIGNING FOR A DESIRED SIGNAL RESOLUTION

The resolution is directly related to the period (and thus frequency) of the pulse train. In our design, the difference between the pulse train's high time at full scale pressure and the pulse train's high time and zero pressure must be 512 μs to obtain at least 8-bit resolution. This is determined by the fact that a 4.0 MHz crystal yields a 2.0 MHz clock speed in the MC68HC05P9 microcontroller. This, in turn, translates to 0.5 μs per clock tick. There are four clock cycles per timer count. This results in 2 μs per timer count. Thus, to obtain 256 timer counts (discrete high-time time intervals or 8-bit resolution), the difference between the zero pressure and full scale pressure high times must be at least 2 μs x 256 = 512 μs.

To determine the pulse train's maximum frequency (or minimum period), the sensor's analog dynamic range (span) must be known. For this design, the span is 4.0 V. Thus the 4.0 V span of the sensor must translate to 512 μs of time for 8-bit resolution. But the pulse train typically has a logic-level high value of 5.0 V, indicating that for a 100% duty cycle or a period with all high time, the integrator's output would be 5.0 V; likewise, for a duty cycle of 0% or a period with no high time, the output would be 0 V. Therefore, 512 μs accounts for only 4.0 V/5.0 V (80%) of the pulse train's total period. See Figure 2. To calculate the pulse train's total period, divide the 512 μs by 4/5 (0.8) to obtain the required minimum period for the pulse train of 640 μs. The reciprocal of this minimum period is the maximum frequency (1.56 kHz) of the pulse train to obtain at least 8-bit resolution.

To summarize:

The MC68HC05P9 runs off a 4.0 MHz crystal. The microcontroller internally divides this frequency by two to yield an internal clock speed of 2.0 MHz.

$$\frac{1}{2\text{ MHz}} = > \frac{0.5\ \mu\text{s}}{\text{Clock Cycle}}$$

and

$$4\text{ Clock Cycles} = 1\text{ Timer Count}$$

Therefore,

$$\frac{4\text{ Clock Cycles}}{\text{Timer Count}} \text{ X } \frac{0.5\ \mu\text{s}}{\text{Clock Cycle}} = \frac{2\ \mu\text{s}}{\text{Timer Count}}$$

For 8-bit resolution,

$$\frac{2\ \mu\text{s}}{\text{Timer Count}} \text{ X } 256\text{ Timer Counts} = 512\ \mu\text{s}$$

which is the required minimum time into which the sensor's 4.0 V span is translated.

To calculate the required period of the pulse train to yield the 0 to 5.0 V output (from 0% to 100% duty cycle based on the pulse train's logic-level high value of 5.0 V):

$$\text{Minimum Required Period} = \frac{512\ \mu\text{s for a 4 V Sensor Span}}{\text{4/5 of Integrator's Output}} = 640\ \mu\text{s}$$

Translating this to frequency, the maximum pulse train frequency is thus:

$$\frac{1}{640\ \mu\text{s}} = 1.55\text{ KHz}$$

The above procedure can be implemented easily for other resolution requirements (i.e. a resolution of 1%, 2%, etc.).

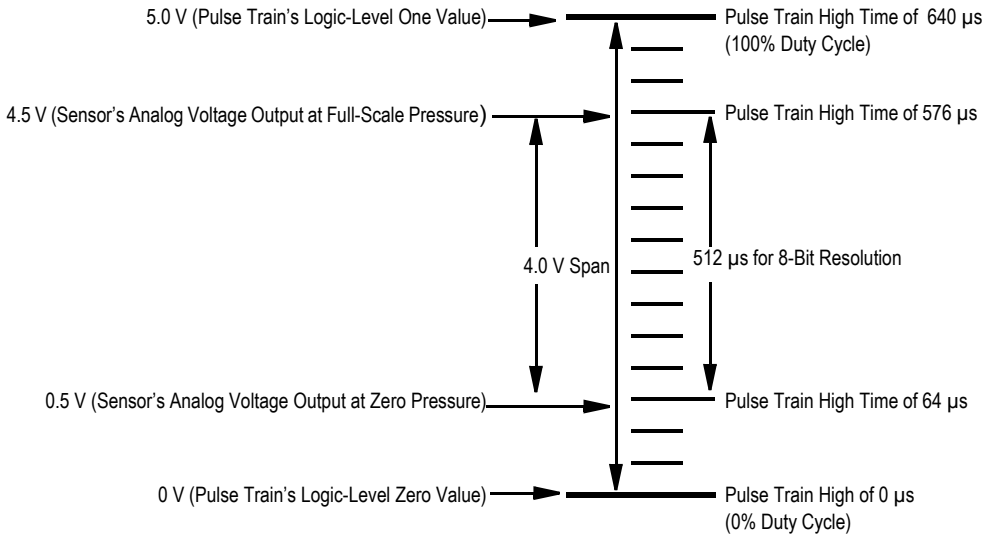

Figure 2. Designing the Pulse Train's Period for 8-Bit Resolution

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NOTE: Very small and very large high times (assuming a fixed period) are typically unattainable due to the finite amount of time it takes to generate the pulse train on the output compare pin. This amount of time will vary depending on the microcontroller's clock speed and the latency of the actual software routines implemented. Thus the sensor's analog voltage to which the integrator's dc voltage is compared must be within the possible ranges of voltages created by the integrator's input pulse train - i.e. the sensor's zero pressure offset voltage must be greater than the smallest voltage created by the integrator (corresponding to the pulse train's smallest possible high time) and the sensor's full scale output voltage must be less than the largest voltage created by the integrator (corresponding to the pulse train's largest possible high time).

After establishing the frequency of the pulse train, the RC time constant for the integrator can be determined and the resistor and capacitor value can be chosen. The RC time constant should be long compared to the period of the pulse train so that a stable dc voltage (very little ripple due to the capacitor's charging and discharging) is obtained at the output of the comparator.

Follow these steps to design the RC time constant and integrator's component values. The design example's calculations are presented simultaneously.

For the resolution desired, determine the number of volts (typically mV) that corresponds to the least significant bit (one timer count). For this design example, 8-bit resolution (256 timer counts) over the desired pressure sensor span corresponds to

$$\#\ \text{of}\ \frac{\text{mV}}{\text{timer count}} = \frac{\text{Desired Pressure Sensor Span (V)}}{\text{Number of Timer Counts}} = \frac{4.0\ \text{V}}{256\ \text{timer counts}} = \frac{15.6\ \text{mV}}{\text{timer counts}}$$

Therefore, the stability of the integrator's output voltage should be less than 15.6 mV (least significant bit). Choosing an RC time constant that allows a ripple of approximately one-fourth of the least significant bit is sufficient (approximately 3.9 mV).

The most ripple occurs at a 50% duty cycle pulse train. For this design the entire period is 640 μs. 50% duty cycle indicates a high time (and low time) of 320 μs. Furthermore, the capacitor should discharge no more than approximately 3.9 mV (defined as ΔV) over the 320 μs. The following equation is used to calculate the value for RC:

$$V(t) = V_{INITIAL} - \Delta V =$$

$$\text{Pulse Train Logic– level one value} \times \text{Duty Cycle} \times e^{\frac{t}{RC}}$$

where

$V_{INITIAL}$ = Pulse Train Logic–level one value × Duty Cycle

and

ΔV is the voltage discharge of the capacitor.

Solving for RC:

$$RC = \frac{t}{\ln\left(\frac{V(t)}{\text{Pulse Train Logic–level one value} \times \text{Duty Cycle}}\right)}$$

$$= \frac{320\ \mu\text{s}}{\ln\left(\frac{2.5\ \text{V} - 3.9\ \text{mV}}{5.0\ \text{V} \times 50\%}\right)} = 0.205\ \text{s}$$

Finally, choose the values of the resistor and capacitor. A typical resistor value is on the order of a tens of kΩ. The resistor's value can be higher (hundreds of kΩ) but care must be taken to avoid increased thermal noise.

For this design, the resistor value is chosen to be 49.9 kΩ (1% resistor). The capacitor's value is readily calculated to be

$$C = \frac{0.205\ \text{s}}{49.9\ \text{k}\Omega} = 4.1\ \mu\text{F}$$

Choose the values of the resistor and capacitor so that the actual time constant is equal to or greater than the calculated time constant.

NOTE: Be aware that temperature variations can create errors in the system (thus reducing system performance); therefore, be sure to use low temperature coefficient resistors, capacitors, etc.

SYSTEM DESIGN: STEP-BY-STEP PROCEDURE FOR PRESSURE MEASUREMENT AND CALIBRATION

To measure pressure (Note: there are other measurement algorithms that can be performed that in some cases may be more acceptable [see below, Additional notes]):

1. Start with a pulse train with the minimum high time feasible with the system's microcontroller. Pulse train should run at a frequency equal to or less than the frequency calculated above.
2. Make sure the general I/O pin's input is high (sensor's output voltage is greater than the integrator's output voltage).
3. Increment the high time of the pulse train by one timer count.
4. Check the general I/O pin to see if its input is low (sensor's output voltage has become less than the integrator's output voltage).
5. If the general I/O pin is reading a logic-level zero, store in memory the high time of the pulse train as the current pressure high time reading that created the logic-level transition in the comparator's output.
6. If the general I/O pin is reading a logic-level one, go back to step 3 and repeat.
7. Using the equation “Current Pressure = ...” shown above, calculate the current pressure (assuming the system has already been calibrated).
8. Repeat steps 1 through 7 for additional pressure measurements.

To calibrate the system:

At zero and full scale pressures, perform the above 8 step pressure measurement routine. Store the appropriate pulse train high times corresponding to zero and full scale pressure. These high times will be used to calculate the current pressure as mentioned in Step 7 above.

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SOFTWARE EXAMPLES TO GENERATE PULSE TRAIN ON OUTPUT COMPARE TIMER CHANNEL

The following software examples are written in assembly language for the MC68HC05P9 (the code is applicable to any HC05 series microcontroller with TCMP pin).

```
* GENERATES THE PULSE TRAIN ON TCMP
GEN
LDA  PERIODL                 * LOW BYTE OF THE PERIOD
SUB  HIGHTIMEL               * LOW BYTE OF THE HIGHTIME
STA  LOWTIMEL                * LOW BYTE OF THE LOWTIME
LDA  PERIODH                 * HIGH BYTE OF THE PERIOD
SBC  HIGHTIMEH               * HIGH BYTE OF THE HIGHTIME
STA  LOWTIMEH                * HIGH BYTE OF THE LOWTIME
RTS

* INCREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
INCPW
LDA  HIGHTIMEL
ADD  #$01             * INCREMENT PULSE WIDTH BY 2 µs
STA  HIGHTIMEL
LDA  HIGHTIMEH
ADC  #$0
STA  HIGHTIMEH
RTS

* DECREASE THE HIGH TIME (DUTY CYCLE) OF THE PULSE TRAIN
DECPW
LDA  HIGHTIMEL
SUB  #$01             * DECREMENT PULSE WIDTH BY 2 µs
STA  HIGHTIMEL
LDA  HIGHTIMEH
SBC  #$0
STA  HIGHTIMEH
JSR  GEN
RTS

* INCREASE THE PERIOD (DECREASE FREQUENCY) OF THE PULSE TRAIN
INCPER
LDA  PERIODL
ADD  #$05             * INCREMENT PERIOD BY 10 µs
STA  PERIODL
LDA  PERIODH
ADC  #$0              * ADJUST HIGH BYTE OF PERIOD IF CARRY
STA  PERIODH
JSR  GEN
RTS

* DECREASE THE PERIOD (INCREASE FREQUENCY) OF THE PULSE TRAIN
DECPER
LDA  PERIODL
SUB  #$05             * DECREMENT PERIOD BY 10 µs
STA  PERIODL
LDA  PERIODH
SBC  #$0              * ADJUST HIGH BYTE OF PERIOD IF BORROW
STA  PERIODH
JSR  GEN
RTS

TIMER                       * INTERRUPT SERVICE ROUTINE FOR TCMP
LDA  TSR              * CLEAR OCF FLAG IN TSR
LDA  TCMPL

BRSET 0,TCR,ADDHIGH* HIGH OR LOW PULSE TIME NEEDED?

ADDLOW
BSET 0,TCR            * ADD LOW TIME TO THE PULSE TRAIN
LDA  LOWTIMEL
ADD  TCMPL
TAX
LDA  TCMPH
ADC  LOWTIMEH
STA  TCMPH
```


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```
        STX  TCMPL
        RTI

       ADDHIGH
        BCLR 0,TCR              * ADD HIGH TIME TO THE PULSE TRAIN
        LDA  HIGHTIMEL
        ADD  TCMPL
        TAX
        LDA  TCMPH ADC          HIGHTIMEH
        STA  TCMPH
        STX  TCMPL
        RTI
```

ADDITIONAL NOTES

This type of A/D conversion method (one type of A/D conversion) inherently takes a finite period of time to digitize the signal (incrementing the pulse train's high time while polling the general I/O pin); however, for most sensor applications the physical phenomenon being measured does not change quickly (<1 ms) enough to warrant an ultra-fast A/D conversion process.

An additional advantage of this design is that the measurement process may be performed only as necessary, keeping the CPU processing time and overhead minimal.

If an input capture timer channel (TCAP) is available, it may be configured to detect the logic-level one to logic-level zero transition of the comparator's output. When the edge transition occurs, an interrupt service routine is executed that stores the pulse train's high times, calculates the current pressure, etc. This is typically more convenient and eliminates the need to poll a general I/O pin every time the pulse train's high time is incremented (interrupt subroutine is executed only when the edge transition occurs).

SUMMARY

Shown above is a minimal component design that can convert an analog sensor's output into a digital output. Each major subsystem (sensor, amplifier, integrator, comparator, and microcontroller) is explained in detail simultaneously with a design example. Next the system operation is discussed including how it works and how to design a desired system resolution. Finally a flow chart for measuring and calibrating the sensor's output is presented.

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Implementing Auto Zero for Integrated Pressure Sensors

by: **Ador Peodique**
Sensor Systems and Applications Engineering

INTRODUCTION

This application note describes how to implement an auto-zero function when using an integrated pressure sensor with a microcontroller and an analog to digital converter (MCU and an A/D). Auto-zero is a compensation technique based on sampling the offset of the sensor at reference pressure (atmospheric pressure is a zero reference for a gauge measurement) in order to correct the sensor output for long-term offset drift or variation.

Sources of offset errors are due to device to device offset variation (trim errors), mechanical stresses (mounting stresses), shifts due to temperature and aging. Performing auto-zero will greatly reduce these errors. The amount of error correction is limited by the resolution of the A/D.

In pressure sensing applications where a zero-pressure reference condition can exist, auto-zero can be implemented easily when an integrated pressure sensor is interfaced to an MCU.

EFFECTS OF OFFSET ERRORS

Figure 1 illustrates the transfer function of an integrated pressure sensor. It is expressed by the linear function:

$$V_{OUT} = V_{OFF} + [(V_{FSO} - V_{OFF})/(P_{MAX} - P_{REF})] \times P = V_{OFF} + S \times P$$

Here, V_{OUT} is the voltage output of the sensor, V_{FSO} is the full-scale output, V_{OFF} is the offset, P_{MAX} is the maximum pressure and P_{REF} is the reference pressure. Note that ($V_{FSO} \times V_{OFF}/P_{MAX} \times P_{REF}$) can be thought of as the slope of the line and V_{OFF} as they y-intercept. The slope is also referred to as the sensitivity, S, of the sensor.

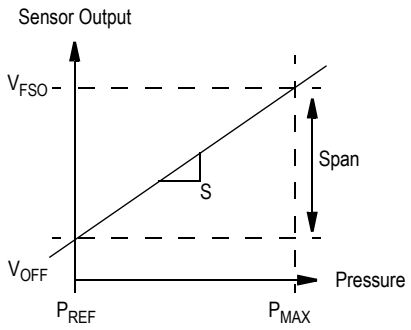

Figure 1. Definition of Span, Full-Scale Output, Offset and Sensitivity

A two-point pressure calibration can be performed to accurately determine the sensitivity and get rid of the offset calibration errors altogether. However, this can be very expensive in a high volume production due to extra time and labor involved. The system designer therefore designs a pressure sensor system by relying on the sensitivity and offset data given in the data sheet and using a linear equation to determine the pressure. Using the later, the sensed pressure is easily determined by:

$$P = (V_{OUT} - V_{OFF})/S$$

If an offset error is introduced due to device to device variation, mechanical stresses, or offset shift due to temperature (the offset has a temperature coefficient or TCO), those errors will show up as an error, DP, in the pressure reading:

$$P + \Delta P = [V_{OUT} \times (V_{OFF} + \Delta V_{OFF})]/S$$

As evident in Figure 2, offset errors, ΔV_{OFF}, have the effect of moving the intercept up and down *without* affecting the sensitivity. *We can therefore correct this error by sampling the pressure at zero reference pressure (atmosphere) and subtracting this from the sensor output.*

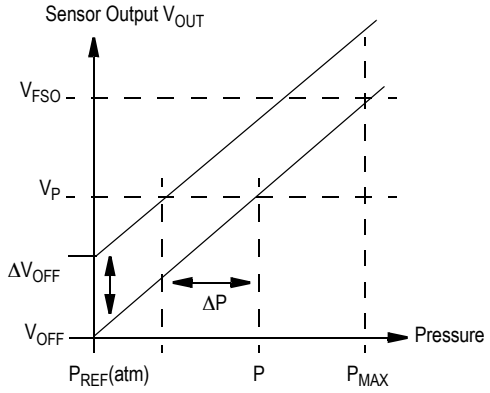

Figure 2. Effect of Offset Errors

AUTO-ZERO CONSIDERATIONS IN APPLICATIONS

There is an important consideration when implementing auto-zero. In order to use this technique, *a zero pressure reference condition must be known to exist in the system.*

There are a lot of applications that will lend themselves naturally to auto-zeroing. Typical applications are those that:

- Experience a zero-pressure condition at system start up,
- Are idle for a long time (zero pressure), take a pressure measurement then go back to idle again.

For example, in a water level measurement in a washing machine application, there is a zero pressure reference condition when the water in the tub is fully pumped out. Another application that is perfect for auto-zeroing is a beverage fill level measurement; a zero reference condition exists before the bottle is filled. HVAC air flow applications can also use auto-zeroing; before system start up, an auto-zero can be initiated. In other words, it can be used in applications where a zero pressure condition can exist in order to auto-zero the system.

An auto-zero command can be automated by the system or can be commanded manually. Each system will have a different algorithm to command an auto-zero signal. For example, using the beverage fill level measurement as an example, the system will auto zero the sensor before the bottle is filled.

IMPLEMENTATION OF AUTO-ZERO WITH A MICROCONTROLLER

Auto-zero can be implemented easily when the integrated sensor is interfaced to a microcontroller. The auto-zero algorithm is listed below:

1. Sample the sensor output when a known zero reference is applied to the sensor (atmospheric pressure is a zero reference for gauge type measurement). Store current zero pressure offset as CZPO.
2. Sample the sensor output at the current applied pressure. Call this SP.
3. Subtract the stored offset correction, CZPO, from SP. The pressure being measured is simply calculated as:

$$P_{MEAS} = (SP \times CZPO)/S$$

Note that the equation is simply a straight line equation, where S is the sensitivity of the sensor. The auto-zero algorithm is shown graphically in Figure 3.

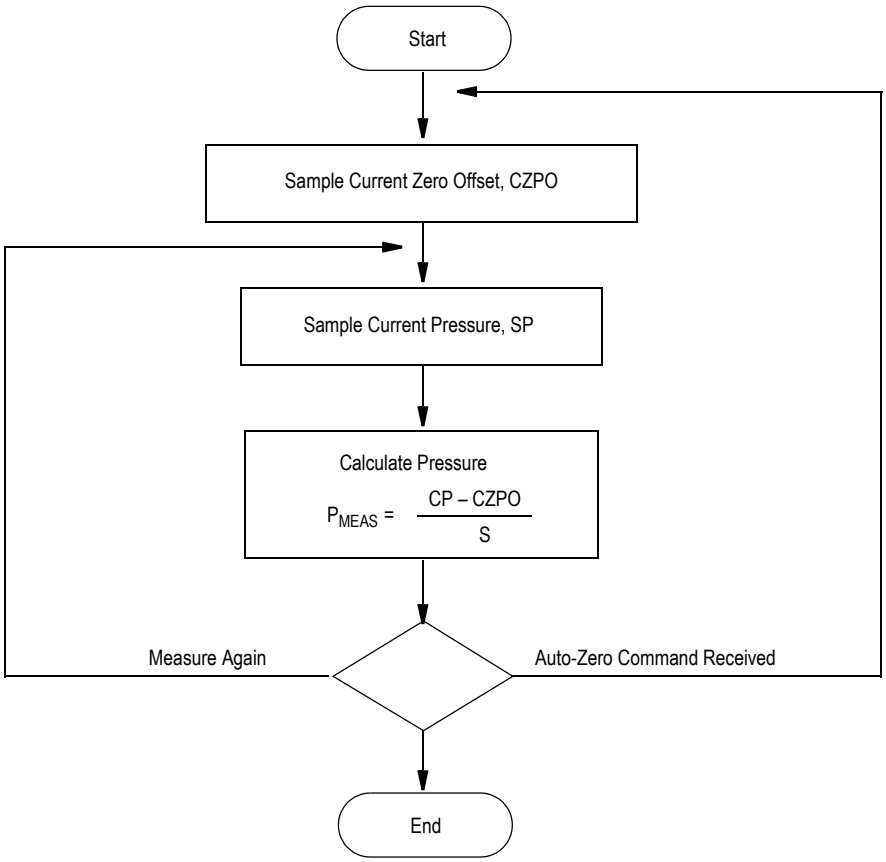

Figure 3. Flowchart of the Auto-Zero Algorithm

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IMPROVEMENT ON OFFSET ERROR

In the following calculations, we will illustrate how auto-zero will improve the offset error contribution. We will use the MPXV4006G interfaced to an 8-bit A/D as an example. When auto-zero is performed, the offset errors are reduced and the *resulting offset errors are replaced with the error (due to resolution) of the A/D.* We can categorize the offset error contributions into temperature and calibration errors.

Temperature Coefficient of Offset Error

The offset error due to temperature is due to Temperature Coefficient of Offset, or TCO. This parameter is the rate of change of the offset when the sensor is subject to temperature. It is defined as:

$$TCO = (\Delta V_{OFF}/\Delta T)$$

The MPXV4006G has a temperature coefficient of offset (normalized with the span at 25°C) of:

$$\Delta TCO = (\Delta V_{OFF}/\Delta T)/V_{FS@25°C} = 0.06\%\ FS/°C$$

As an example, if the sensor is subjected to temperature range between 10°C and 60°C, the error due to TCO is:

$$\Delta TCO = (0.06\%\ FS/C)\times(60°C - 10°C) = \pm 3.0\%\ FS$$

Offset Calibration Errors

Even though the offset is laser trimmed, offset can shift due to packaging stresses, aging and external mechanical stresses due to mounting and orientation. This results in offset calibration error. For example, the MPXV4006G data sheet shows this as:

$$V_{OFF\ MIN} = 0.100\ V,$$

$$V_{OFF\ TYPICAL} = 0.225\ V \text{ and } V_{OFF\ MAX} = 0.430V$$

We can then calculate the offset calibration error with respect to the full scale span as:

$$\Delta V_{OFF\ MIN,MAX} =$$
$$(V_{OFF\ TYPICAL} - V_{OFF\ MIN,MAX})/VFS$$

This results in the following offset calibration error,

$$\Delta V_{OFF\ MIN} = 2.7\%\ FS \text{ and}$$

$$\Delta V_{OFF\ MAX} = 4.5\%\ FS$$

A/D Error

As mentioned above, we can reduce offset errors (calibration and TCO) when we perform auto-zero. These errors are replaced with the A/D error (due to its resolution),

$$\Delta OFFSET_{AUTOZERO} = \Delta TCO + \Delta OFFSET = \Delta A/D$$

Typically, a sensor is interfaced to an 8-bit A/D. With the A/D reference tied to V_{RH} = 5.0 V and V_{RL} = 0 V, the A/D can resolve 19.6 mV/bit. For example, the MXPV4006G has a sensitivity of 7.5 mV/mm H_20, the resolution is therefore

$$A/D_{RESOLUTION} = 19.6\ mV/bit)/(7.5\ mV/mm\ H_20) = 2.6\ mm\ H_20/bit$$

Assuming ± 1 LSB error, the error due to digitization *and* the resulting offset error is,

$$\Delta A/D = \Delta OFFSET_{AUTOZERO} = 2.6\ mm\ H_20/612\ mmH_20 = \pm 0.4\%\ FS$$

It can be seen that with increasing A/D resolution, offset errors can be further reduced. For example, with a 10-bit A/D, the resulting offset error contribution is only 0.1% FS when auto-zero is performed.

If auto-zero is to be performed only once and offset correction data is stored in non-volatile memory, the TCO offset error and calibration error will not be corrected *if* the sensor later experiences a wide temperature range or later experience an offset shift. However, if auto-zero is performed *at* the operating temperature, TCO error will be compensated although subsequent offset calibration error will not be compensated. It is therefore best to auto-zero as often as possible in order to dynamically compensate the system for offset errors.

CONCLUSION

Auto-zero can be used to reduce offset errors in a sensor system. This technique can easily be implemented when an integrated pressure sensor is interfaced to an A/D and a microcontroller. With a few lines of code, the offset errors are effectively reduced; the resulting offset error reduction is limited only by the resolution of the A/D.

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Noise Considerations for Integrated Pressure Sensors

by: Ador Reodique, Sensor and Systems Applications Engineering and Warren Schultz, Field Engineering

INTRODUCTION

The Integrated Pressure Sensors (IPS) have trimmed outputs, built-in temperature compensation and an amplified single-ended output which make them compatible with Analog to Digital converters (A/D's) on low cost micro-controllers. Although 8-bit A/D's are most common, higher resolution A/D's are becoming increasingly available. With these higher resolution A/D's, the noise that is inherent to piezo-resistive bridges becomes a design consideration.

The two dominant types of noise in a piezo-resistive integrated pressure sensor are shot (white) noise and 1/f (flicker noise). Shot noise is the result of non-uniform flow of carriers across a junction and is independent of temperature. The second, 1/f, results from crystal defects and also due to wafer processing. This noise is proportional to the inverse of frequency and is more dominant at lower frequencies.

Noise can also come from external circuits. In a sensor system, power supply, grounding and PCB layout is important and needs special consideration.

The following discussion presents simple techniques for mitigating these noise signals, and achieving excellent results with high resolution A/D converters.

EFFECTS OF NOISE IN SENSOR SYSTEM

The transducer bridge produces a very small differential voltage in the millivolt range. The on-chip differential amplifier amplifies, level shifts and translates this voltage to a single-ended output of typically 0.2 volts to 4.7 volts. Although the transducer has a mechanical response of about 500 Hz, its noise output extends from 500 Hz to 1 MHz. This noise is amplified and shows up at the output as depicted in Figure 1.

There is enough noise here to affect 1 count on an 8-bit A/D, and 4 or 5 counts on a 10-bit A/D. It is therefore important to consider filtering. Filtering options are discussed as follows.

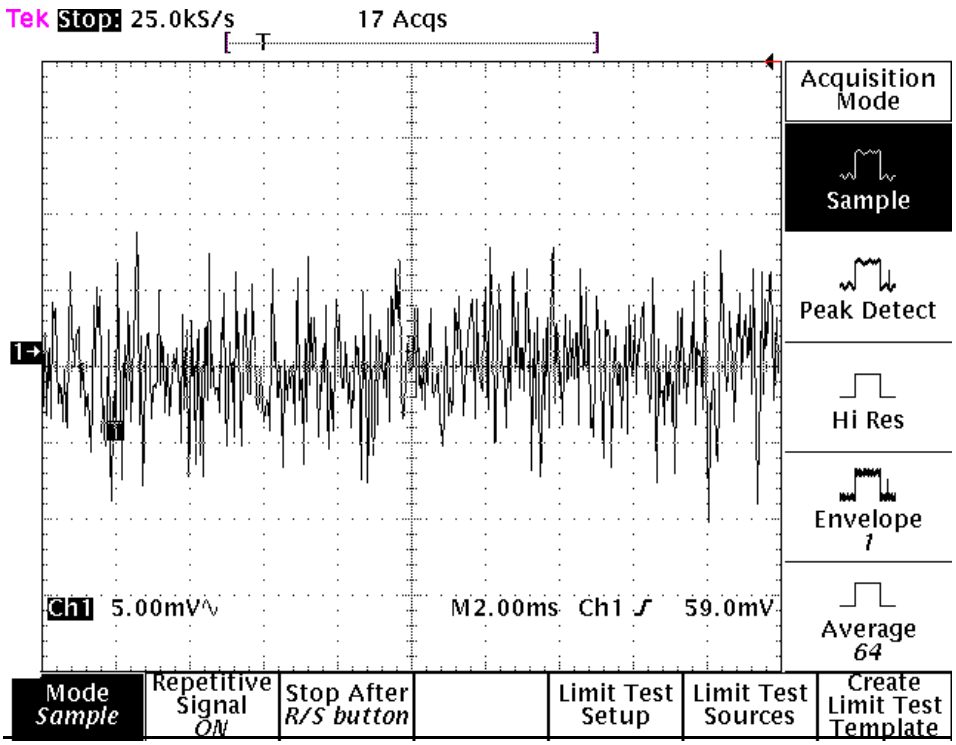

Figure 1. MPX5006 Raw Output

NOISE FILTERING TECHNIQUES AND CONSIDERATIONS

For mitigating the effects of this sensor noise, two general approaches are effective, low pass filtering with hardware, and low pass filtering with software. When filtering with hardware, a low-pass RC filter with a cutoff frequency of 650 Hz is recommended. A 750 ohm resistor and a 0.33 μF capacitor have been determined to give the best results (see Figure 2) since the 750 ohm series impedance is low enough for most A/D converters

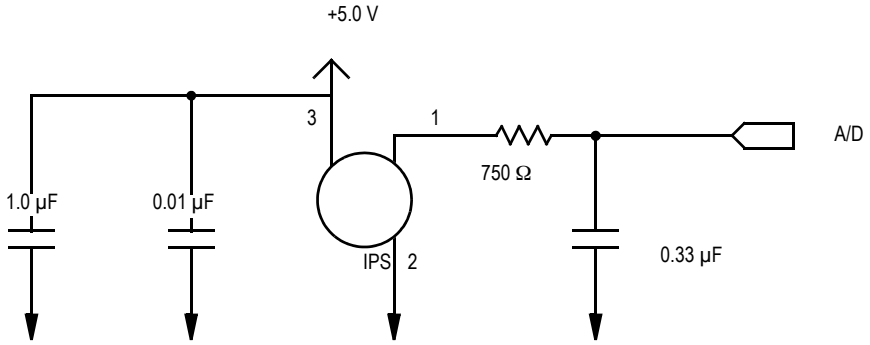

Figure 2. Integrated Pressure Sensor with RC LP Filter to Filter Out Noise

This filter has been tested with an MC68HC705P9 microcontroller which has a successive approximation A/D converter. Successive approximation A/D's are generally compatible with the DC source impedance of the filter in Figure 2. Results are shown in Figure 4.

Some A/D's will not work well with the source impedance of a single pole RC filter. Please consult your A/D converter technical data sheet if input impedance is a concern. In applications where the A/D converter is sensitive to high source impedance, a buffer should be used. The integrated pressure sensor has a rail-to-rail output swing, which dictates that a rail-to-rail operational amplifier (op amp) should be used to avoid saturating the buffer. A MC33502 rail-to-rail input and output op amp works well for this purpose (see Figure 3).

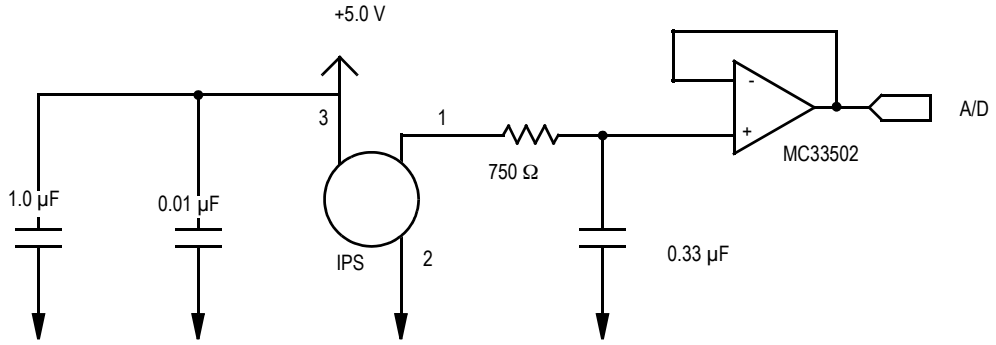

Figure 3. Use a Rail-to-Rail Buffer to Reduce Output Impedance of RC Filter

Averaging is also effective for filtering sensor noise. Averaging is a form of low pass filtering in software. A rolling average of eight to 64 samples will clean up most of the noise. A 10 sample average reduces the noise to about 2.5 mV peak to peak and a 64 sample average reduces the noise to about 1 mV peak to peak (see Figure 5 and Figure 6).

This method is simple and requires no external components. However, it does require RAM for data storage, extra computation cycles and code. In applications where the microcontroller is resource limited or pressure is changing relatively rapidly, averaging alone may not be the best solution. In these situations, a combination of RC filtering and a limited number of samples gives the best results. For example, a rolling average of four samples combined with the RC filter in Figure 2 results in a noise output on the order of 1 mV peak-to-peak.

Another important consideration is that the incremental effectiveness of averaging tends to fall off as the number of samples is increased. In other words, the signal-to-noise (S/N) ratio goes up more slowly than the number of samples. To be more precise, the S/N ratio improves as the square root of the number of samples is increased. For example, increasing the number of samples from 10 to 64, in Figure 5, and in Figure 6, reduced noise by a factor of 2.5.

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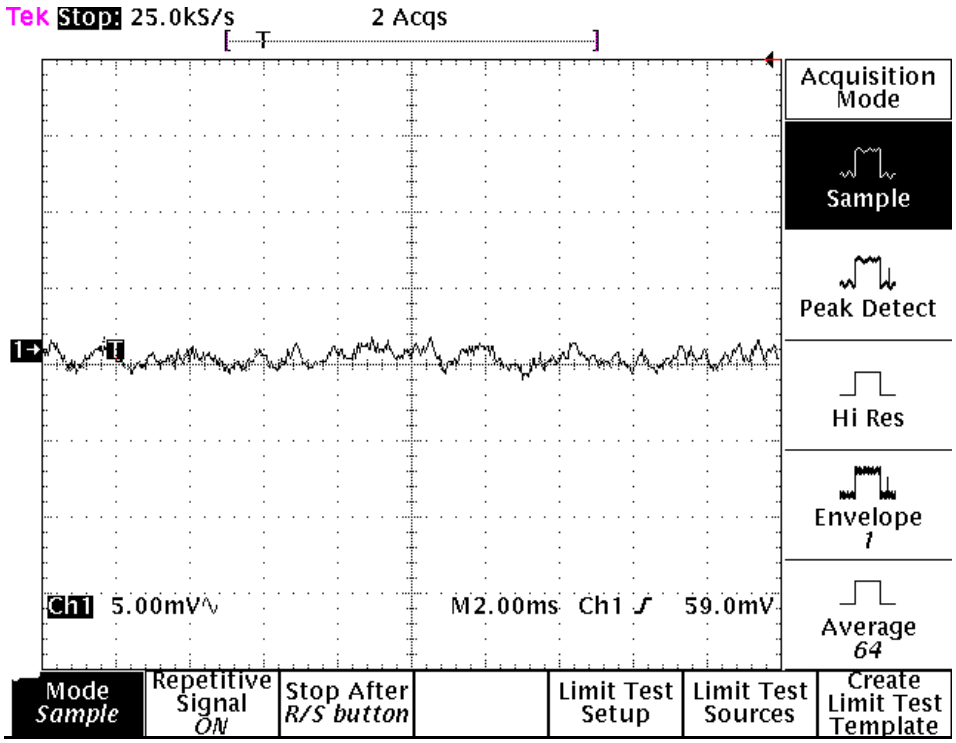

Figure 4. Output After Low Pass Filtering

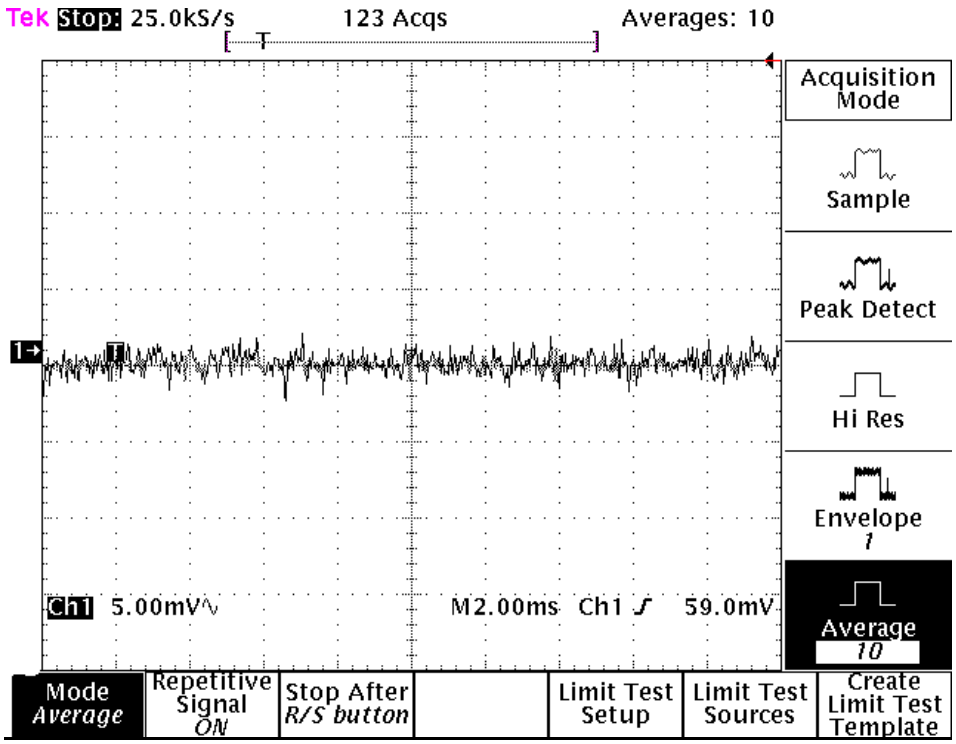

Figure 5. Output with 10 Averaged Samples

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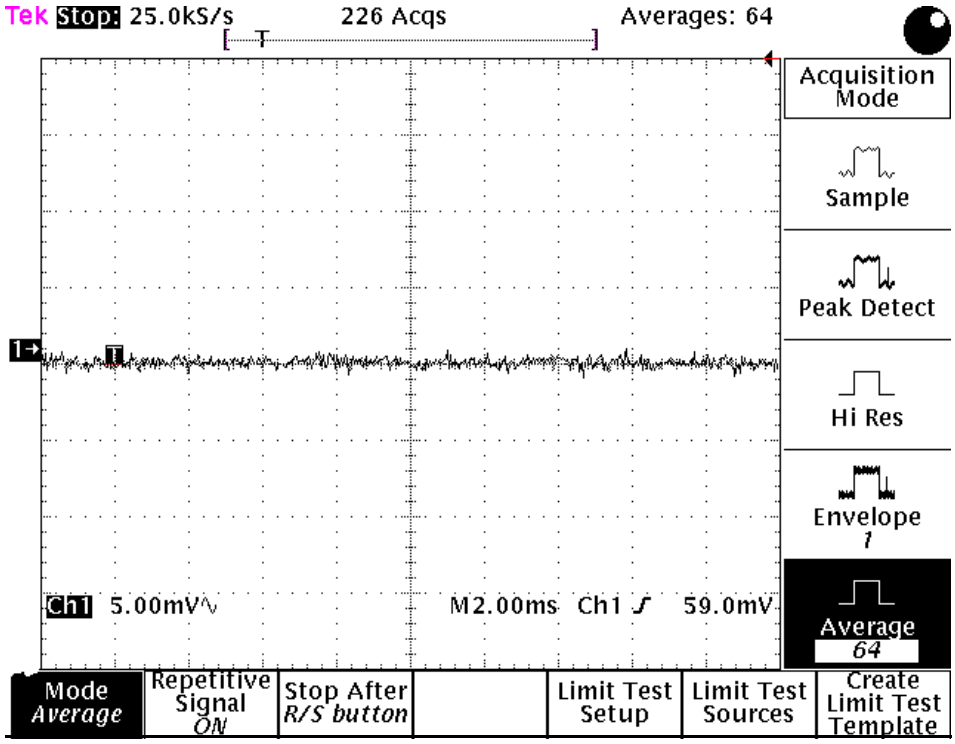

Figure 6. Output with 64 Averaged Samples

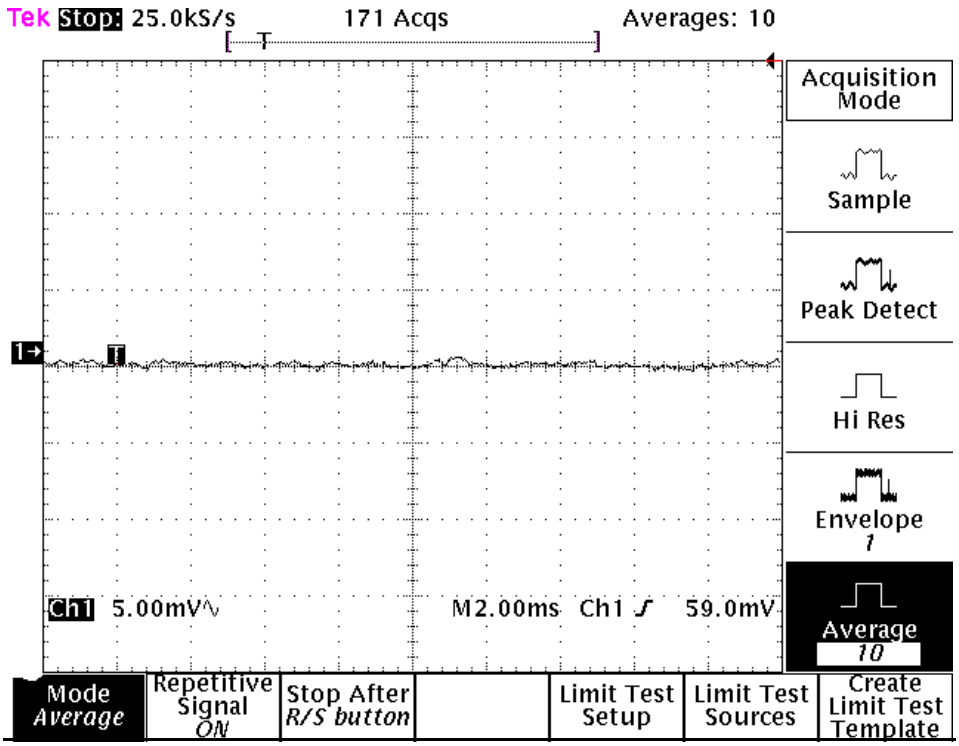

Figure 7. Filtered Sensor Output and Averaged Over 10 Samples

POWER SUPPLY

Since the sensor output is ratiometric with the supply voltage, any variation in supply voltage will also proportionally appear at the output of the sensor. The integrated pressure sensor is designed, characterized and trimmed to be powered with a 5.0 V ±5% power supply which can supply the maximum 10 mA current requirement of the sensor. Powering the integrated sensor at another voltage than specified is not recommended because the offset, temperature coefficient of offset (TCO) and temperature coefficient of span (TCS) trim will be invalidated and will affect the sensor accuracy.

From a noise point of view, adequate de-coupling is important. A 0.33 μF to 1.0 μF ceramic capacitor in parallel with a 0.01 μF ceramic capacitor works well for this purpose. Also, with respect to noise, it is preferable to use a linear regulator such as an MC78L05 rather than a relatively more noisy switching power supply 5.0 volt output. An additional consideration is that the power to the sensor and the A/D voltage reference should be tied to the same supply. Doing this takes advantage of the sensor output ratiometricity. Since the A/D resolution is also ratiometric to its reference voltage, variations in supply voltage will be canceled by the system.

LAYOUT OPTIMIZATION

In mixed analog and digital systems, layout is a critical part of the total design. Often, getting a system to work properly depends as much on layout as on the circuit design. The following discussion covers some general layout principles, digital section layout and analog section layout.

General Principles

There are several general layout principles that are important in mixed systems. They can be described as five rules.

Rule 1: Minimize loop areas.

This is a general principle that applies to both analog and digital circuits. Loops are antennas. At noise sensitive inputs, the area enclosed by an incoming signal path and its return is proportional to the amount of noise picked up by the input. At digital output ports, the amount of noise that is radiated is also proportional to loop area.

Rule 2: Cancel fields by running equal currents that flow in opposite directions as close as possible to each other.

If two equal currents flow in opposite directions, the resulting electromagnetic fields will cancel as the two currents are brought infinitely close together. In printed circuit board layout, this situation can be approximated by running signals and their returns along the same path but on different layers. Field cancellation is not perfect due to the finite physical separation, but is sufficient to warrant serious attention in critical paths. Looked at from a different perspective, this is another way of looking at Rule # 1, i.e., minimize loop areas.

Rule 3: On traces that carry high speed signals avoid 90 degree angles, including “T” connections.

If you think of high speed signals in terms of wavefronts moving down a trace, the reason for avoiding 90 degree angles is simple. To a high speed wavefront, a 90 degree angle is a discontinuity that produces unwanted reflections. From a practical point of view, 90 degree turns on a single trace are easy to avoid by using two 45 degree angles or a curve. Where two traces come together to form a “T” connection, adding some material to cut across the right angles accomplishes the same thing.

Rule 4: Connect signal circuit grounds to power grounds at only one point.

The reason for this constraint is that transient voltage drops along the power grounds can be substantial, due to high values of di/dt flowing through finite inductance. If signal processing circuit returns are connected to power ground at multiple points, then these transients will show up as return voltage differences at different points in the signal processing circuitry. Since signal processing circuitry seldom has the noise immunity to handle power ground transients, it is generally necessary to tie signal ground to power ground at only one point.

Rule 5: Use ground planes selectively.

Although ground planes are highly beneficial when used with digital circuitry, in the analog world they are better used selectively. A single ground plane on an analog board puts parasitic capacitance in places where it is not desired, such as at the inverting inputs of op amps. Ground planes also limit efforts to take advantage of field cancellation, since the return is distributed.

ANALOG LAYOUT

In analog systems, both minimizing loop areas and field cancellation are useful design techniques. Field cancellation is applicable to power and ground traces, where currents are equal and opposite. Running these two traces directly over each other provides field cancellation for unwanted noise, and minimum loop area.

Figure 8 illustrates the difference between a power supply de-coupling loop that has been routed correctly and one that has not. In this figure, the circles represent pads, the schematic symbols show the components that are connected to the pads, and the routing layers are shown as dark lines (top trace) or grey lines (bottom trace). Note, by routing the two traces one over the other, the critical loop area is minimized. In addition, it is important to keep de-coupling capacitors close to active devices such as MPX5000-series sensors and operational amplifiers. As a rule of thumb, when 50 mil ground and Vcc traces are used, it is not advisable to have more than 1 inch between a de-coupling capacitor and the active device that it is intended to be de-coupled.

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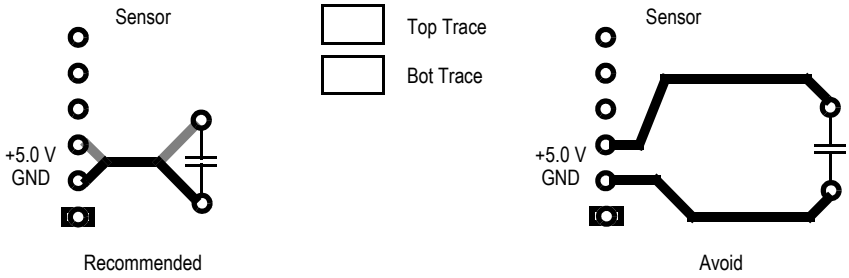

Figure 8. Minimizing Loop Areas

For similar reasons it is desirable to run sensor output signals and their return traces as close to each other as possible. Minimizing this loop area will minimize the amount of external noise that is picked up by making electrical connections to the sensor.

DIGITAL LAYOUT

The primary layout issue with digital circuits is ground partitioning. A good place to start is with the architecture that is shown in Figure 9. This architecture has several key attributes. Analog ground and digital ground are both separate and distinct from each other, and come together at only one point. For analog ground it is preferable to make the one point as close as possible to the analog to digital converter's ground reference (V_{REFL}). The power source ground connection should be as close as possible to the microcontroller's power supply return (V_{SS}). Note also that the path from V_{REFL} to V_{SS} is isolated from the rest of digital ground until it approaches V_{SS}.

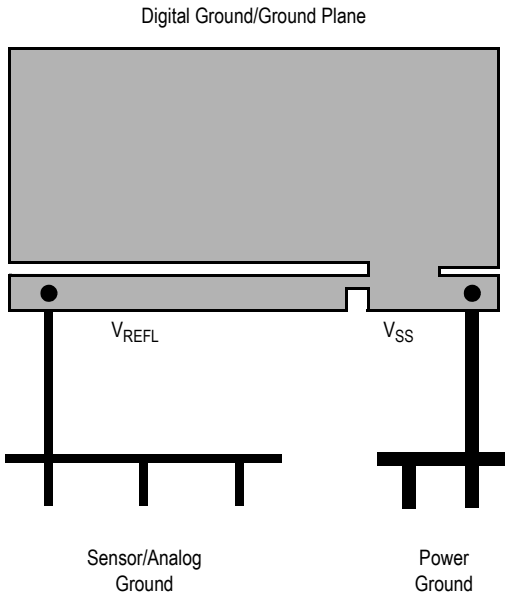

Figure 9. Ground Partitioning

In addition to grounding, the digital portion of a system benefits from attention to avoiding 90 degree angles, since there are generally a lot of high speed signals on the digital portion of the board. Routing with 45 degree angles or curves minimizes unwanted reflections, which increases noise immunity. Single traces are easy, two forty five degree angles or a curve easily accomplish a 90 degree turn. It is just as important to avoid 90 degree angles in T connections. Figure 10 illustrates correct versus incorrect routing for both cases.

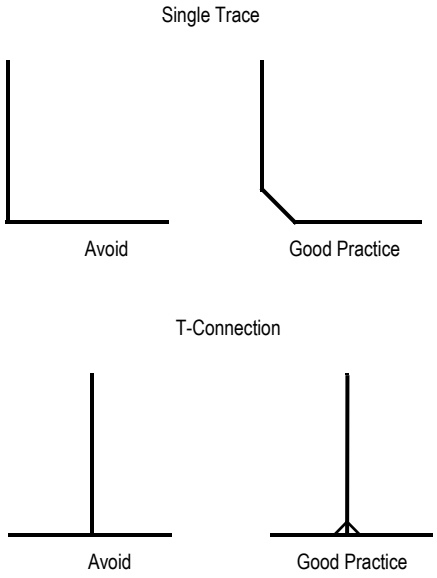

Figure 10. Degree Angles

CONCLUSION

Piezo-resistive pressure sensors produce small amounts of noise that can easily be filtered out with several methods. These methods are low pass filtering with an RC filter, averaging or a combination of both which can be implemented with minimal hardware cost.

In a mixed sensor system, noise can be further reduced by following recommended power supply, grounding and layout techniques.

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Compound Coefficient Pressure Sensor PSPICE Models

by: Warren Schultz

INTRODUCTION

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are presented here. These models use compound coefficients to improve modeling of temperature dependent behavior. The discussion begins with an overview of how the models are structured, and is followed by an explanation of compound coefficients. The emphasis is on how to use these models to estimate sensor performance. They can be found electronically on a disk included in ASB200 Sensor Development Controller kits.

MODEL STRUCTURE

Models for all three sensors series share a common structure. They are complete models set up to run as is. To obtain output voltage versus pressure, it is only necessary to run the model and display V(2,4) or V(1,0). V(2,4) gives the output voltage for Uncompensated and MPX2000 series sensors. V(1,0) applies to MPX5000 sensors. In both cases, V(2,4) and V(1,0) correspond to the pin numbers where output voltage would be, if probed on an actual part.

These models are divided into five sections to facilitate ease of use. They are:

- *Input Parameters*
- *Linear to Compound Conversion*
- *Model Coefficients*
- *Circuit*
- *Stimulus*

Each of these sections is described in the following discussion.

INPUT PARAMETERS

This section contains input parameters that describe measurable sensor characteristics. Inputs such as full scale pressure (FSP), full scale span (FSS) offset voltage (VOFFSET), and temperature coefficient of offset voltage (TCOS) are made here. Characteristics that are specific to the transducer, such as bridge impedance (RBRIDGE), temperature coefficient of bridge resistance (TCRB), and temperature coefficient of span (TCSP) are also listed here.

Parameters such as VOFFSET that set an output value for the sensor are used to calculate resistance values that produce those outputs. For example, if you input 100 mV of offset voltage and a 10 μV/degree temperature coefficient of offset voltage, the model will calculate the bridge resistance values necessary to produce 100 mV of offset voltage and a 10 μV/degree temperature coefficient.

In the MPX2000 and MPX5000 models, temperature coefficient of span (TCSP) is handled differently than the other parameters. The non-linear behavior of span over temperature is calculated from the interaction of the transducer's temperature coefficient of span (TCSP), the transducer's temperature coefficient of resistance (TCRB), and the effects of inserting fixed resistance, RTCSPAN, in series with the bridge. The result is a temperature coefficient of span that closely resembles the real thing, but is not directly controlled by the user.

LINEAR TO COMPOUND CONVERSION

The compound coefficients used in these models are from equations of the form:

$$(1)\ R(Temp) = R25(1)\ TCR)(Temp - 25)$$

where R_{25} is resistance at 25 degrees Celsius, TCR is temperature coefficient of resistance, Temp is an abbreviation for Temperature in degrees Celsius, and R(Temp) is the function resistance versus temperature.

The TCR (temperature coefficient of resistance) in equation (1) is a different number than a temperature coefficient that is stated in linear terms. The three statements in this section convert linear coefficients to the compound values that the models need. This conversion is based upon a 100 degree difference between the two points at which the linear coefficients have been measured.

MODEL COEFFICIENTS

In this section most of the calculation is performed. Values for the transducer bridge resistors are determined from pressure, temperature, offset, temperature coefficient of offset, span, temperature coefficient of span, and temperature coefficient of resistance inputs. A series of parameter statements are used, as much as is practical, to do calculations that will fit in an 80 character line without wraparounds. These calculations use PSPICE's

PARAMETER function, making the models specific to PSPICE. Parameters are described as:

- KP - Pressure constant; translates pressure into a bridge resistance multiplier
- KO - Offset constant; offset component of bridge resistance
- DT - Delta temperature; Temperature *25 degrees Celsius
- KTCO - Temperature coefficient of offset constant; translates temperature coefficient of offset into bridge resistance
- TCR - Temperature coefficient of bridge resistance; shaped by a Table that accounts for cold temperature non-linearity's
- TCR2 - Temperature coefficient of contact resistance; shaped by a Table that accounts for cold temperature non-linearity's
- TCS - Temperature coefficient of Span; shaped by a Table that accounts for cold temperature non-linearity's
- RPH - Bridge Resistance (RS1 and RS3) modified by pressure and temperature
- ROH - Offset Component of Bridge Resistors RS1 and RS3
- RPL - Bridge Resistance (RS2 and RS4) modified by pressure and temperature
- ROL - Offset Component of Bridge Resistors RS2 and RS4
- KB - Bias Constant; adjusts KP for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)
- KBT - Bias Constant; adjusts KO for bias voltage effects of span compensation network (MPX2000 and MPX5000 series sensors)
- GAIN - Instrumentation amplifier gain; differential gain (MPX5000 series)
- ROFF - Offset resistance; determines value of RS13 (MPX5000 series)

After these calculations are made, the final bridge resistance calculation is performed in the circuit section. The value for bridge resistors RS1 and RS3 is RPH + ROH. Bridge resistors RS2 and RS4 are equal to RPL-ROL.

CIRCUIT

Three circuits are used to model the three sensor families, one each for the Uncompensated series, MPX2000 series, and MPX5000 series sensors. Schematics that are derived from the circuit netlists are shown in Figure 1, Figure 2, and Figure 3. They are discussed beginning with the Uncompensated series, which is the least complex.

Uncompensated Series

The Uncompensated Series sensors (MPX10, MPX50, and MPX100) are modeled as Wheatstone bridges. In the configuration that is shown in Figure 1, resistors RS2 and RS4 decrease in value as pressure is applied. Similarly, RS1 and RS3 increase in value as pressure is applied. Resistors RS5 and RS7 are contact resistors. They represent real physical resistors that are used to make contact to the bridge. Resistors RS6 and RS8 are included to satisfy PSPICE's requirement for no floating nodes. That's it. The netlist in this model is quite simple. The hard part is calculating the values for RS1, RS2, RS3, and RS4.

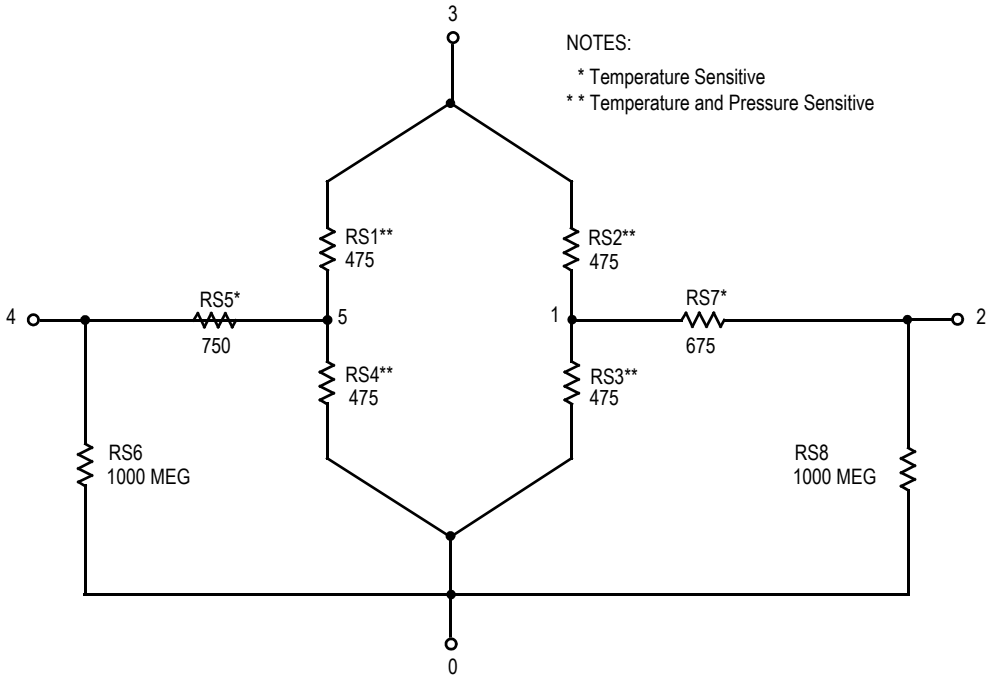

Figure 1. MPX10 and 100 PSPICE Compound Coefficient Model

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MPX2000 Series:

The MPX2000 Series sensors (MPX2010, MPX2050, MPX2100, and MPX2200) add span compensation and trim resistors to the Uncompensated model. These resistors are shown in Figure 2 as RS9, RS11, and RS10. The temperature coefficient of resistance (TCR) for the bridge resistors works against fixed resistors RS9 and RS11 to produce a bias to the bridge that increases with temperature. This increasing bias compensates for the temperature coefficient of span, which is negative.

Resistor RS12 is also added to the Uncompensated model. It represents additional impedance that is associated with the MPX2000 series sensors' offset trim network. Offset performance is modeled behaviorally. Inputs for offset (VOFFSET) and temperature coefficient of offset (TCOS) are translated into bridge resistance values that produce the specified performance. This behavioral approach was chosen in order to make it easy to plug in different values for VOFFSET and TCOS.

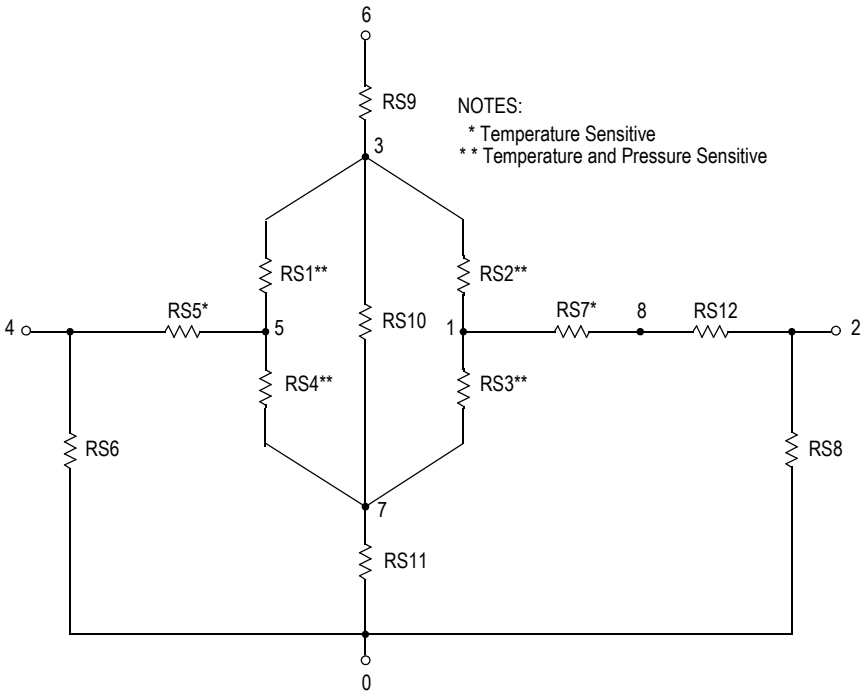

Figure 2. MPX2000 Series PSPICE Compound Coefficient Model

MPX5000 Series

The MPX5000 Series sensors (MPX5010, MPX5050, MPX5100, MPX5700, and MPX5999) add an instrumentation amplifier to the MPX2000 series model. This amplifier is shown in Figure 3. It consists of operational amplifiers ES1, ES2, ES3, and ES4. Amplifiers ES1, ES2 and ES3 are modeled as voltage controlled voltage sources with gains of 100,000. Offset voltage, input bias current effects, etc. are taken into account with the values that are used to determine offset voltage and temperature coefficient of the sensor bridge. Amplifier ES4 models saturation voltage. Its output follows the output of ES3 with saturation limits at 75 millivolts and 4.9 volts.

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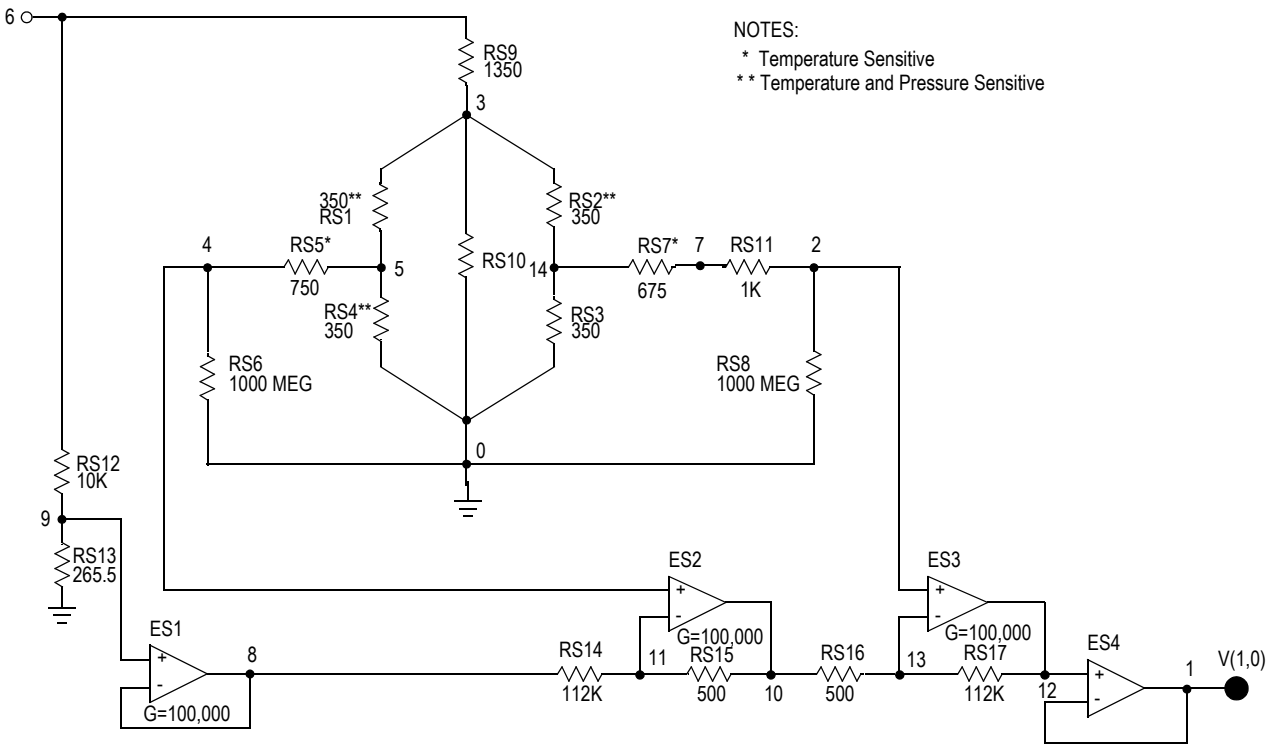

Figure 3. MPX Series PSPICE Compound Coefficient Model

STIMULUS

The last section of these models is labeled STIMULUS. Bias voltage, pressure, and temperature are applied here. Nominal bias voltage (VCC) is 3.0 volts for Uncompensated sensors, 10.0 volts for MPX2000 sensors, and 5.0 volts for MPX5000 sensors. Pressure is selected on the second line. It is effective when the asterisk (*) on line 4 is removed to command a temperature sweep. Line 3 calls for a sweep of pressure and temperature. An asterisk (*) placed in front of Line 3 allows the temperature sweep on line four to be selected.

COMPOUND COEFFICIENTS

Applying temperature coefficients to variables such as resistance is an essential part of modeling. The linear approach, that is usually used, is based upon the assumption that changes are small, and can be modeled with a linear approximation. Using temperature coefficient of resistance as (TCR) as an example, the linear expression takes the form:

(2) R(Temp) = R25(1) TCR(Temp - 25))

Provided that the TCR in equation (2) is 100 parts per million per degree Celsius or less this approach works quite well. With sensor TCR's of several thousand parts per million per degree Celsius, however, the small change assumption does not hold. To accurately model changes of this magnitude, the mathematical expression has to describe a physical process where a unit change in temperature produces a constant percentage change in resistance. For example, a 1% per degree TCR applied to a 1 K Ohm resistor should add 10 ohms to the resistor's value going from 25 to 26 degrees. At 70 degrees, where the resistor has increased to 2006 Ohms, going from 70 to 71 degrees should add 20.06 Ohms to its value. The error in the linear expression comes from that fact that it adds 10 ohms to the resistor's value at all temperatures.

A physical process whereby a unit change in temperature produces a constant percentage change in resistance is easily modeled by borrowing an expression from finance. Compound interest is a direct analog of temperature coefficients. With compound interest, a unit change in time produces a constant percentage change in the value of a financial instrument. It can be described by the expression:

(3) Future Value = Present Value (1) i)n

where i is the interest rate and n is the number of periods. Substituting R_{25} for Present Value, R(Temp) for Future Value, TCR for i, and (Temp - 25) for n yields:

(4) $R(Temp) = R_{25}(1)\ TCR)^{(Temp\ *\ 25)}$

Equation (4) works quite well, provided that TCR is constant over temperature. When modeling semiconductor resistors, it is also necessary to account for variable TCR's. At cold, the TCR for p type resistors changes with temperature. These changes are modeled using TABLE functions that have three values for TCR. Results of this modeling technique versus actual measurements and a linear model are summarized in Table 1.

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Table 1. Actual versus Modeled R(Temp)

Temp	Measured R(Temp)	Compound Model	Linear Model
*40	406	406	372
*25	418	418	395
0	445	445	434
25	474	474	474
50	509	508	513
75	545	545	552
100	585	584	592
125	627	626	632
150	671	671	671

In Table 1, 25 and 150 degree Celsius data points were used to determine both linear and compound temperature coefficients. Therefore, measured values, linear model values and compound model values all match at these two temperatures. At other temperatures, the linear model exhibits errors that are significant when modeling piezoresistive pressure sensors. The compound model, however, tracks with measured values to within 1 Ohm out of 500 Ohms.

EXAMPLES

Two examples of what the model outputs look like are shown in Figure 4 and Figure 5. Figure 4 shows a sweep of pressure versus output voltage (V_{OUT}) at 0, 25, and 85 degrees Celsius, for an MPX2010 sensor. It has the expected 0 to 25 mV output voltage, given a 0 to 10 kPa pressure input. At these three temperatures, compensation is sufficiently good that all three plots look like the same straight line.

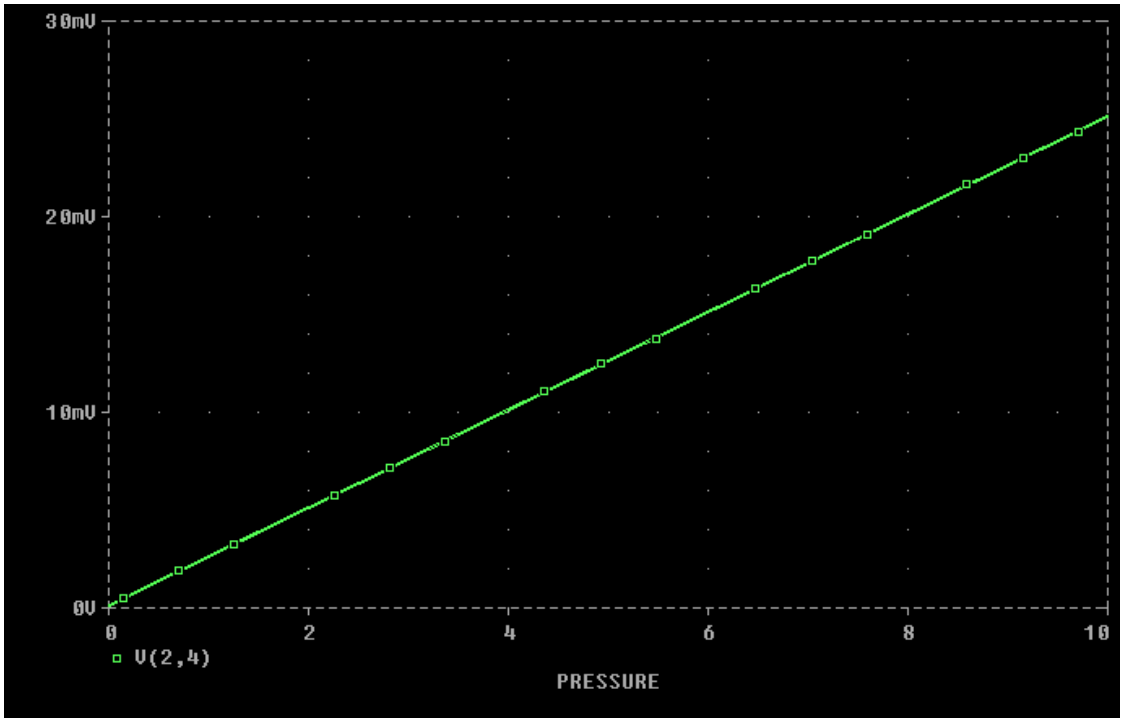

Figure 4. MPX2010 V_{OUT} versus Pressure and Temperature

To produce the plot in Figure 4, the stimulus section is set up as follows, and V(2,4) is probed.

STIMULUS

V_{CC} 6 0 DC=10; DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0; INPUT PRESSURE (kPa)
.DC PARAM PRESSURE 0_Kpa 10_Kpa 0.5_Kpa TEMP LIST 0 25 85
*.DC PARAM TEMP -40 125 5
*

This is the default configuration with which the model is shipped. To change to a sweep of zero pressure voltage versus temperature, an asterisk is placed on line 3 and removed from line 4. The stimulus section then looks as follows:

STIMULUS

VCC 6 0 DC=10; DC BIAS FROM PIN 3 TO PIN 1
.PARAM PRESSURE=0; INPUT PRESSURE (kPa)
*.DC PARAM PRESSURE 0_Kpa 10_Kpa 0.5_Kpa TEMP LIST 0 25 85
.DC PARAM TEMP -40 125 5
*

Again, V(2,4) is probed. The resulting output appears in Figure 5.

This plot shows offset versus temperature performance that is typical of MPX2000 series sensors. From –40 to +85 degrees Celsius, offset compensation is quite good. Above 85 degrees there is a hook in this curve, that is an important attribute of the sensor's performance.

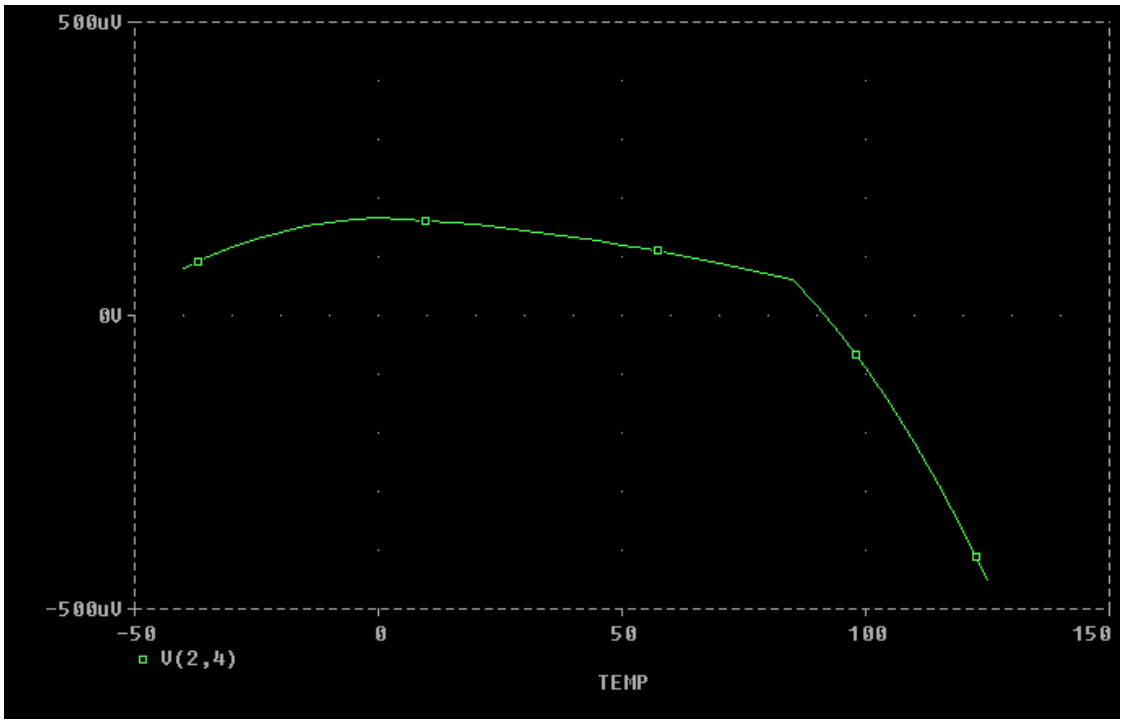

Figure 5. MPX2010 Offset versus Temperature

CONCLUSION

PSPICE models for Uncompensated, MPX2000 series, and MPX5000 series pressure sensors are available for estimating sensor performance. These models make use of the compounding concept that is used in finance to calculate compound interest. The resulting compound temperature coefficients do a better job than linear methods of modeling temperature dependent behavior. These models make extensive use of PSPICE's. PARAMETER statement, and are, therefore, specific to PSPICE. They are intended as references for determining typical sensor performance, and are structured for easy entry of alternate assumptions.

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Washing Appliance Sensor Selection

by: Ador Reodique
Sensor and Systems Applications Engineer

INTRODUCTION

North American washing machines currently in production use mechanical sensors for water level measurement function. These sensors are either purely mechanical pressure switch with discrete trip points or electromechanical pressure sensor with an on-board electronics for a frequency output.

High efficiency machines require high performance sensors (accuracy, linearity, repeatability) even at lower pressure ranges. Benchmarks indicate that these performance goals is difficult to achieve using current mechanical pressure sensors.

In Europe, where energy conservation is mandated, washing machine manufacturers have started to look at electronic solutions where accuracy, reliability, repeatability and additional functionality is to be implemented. North American and Asia Pacific manufacturers are also looking for better solutions.

From surveys of customer requirements, a typical vertical-axis machine calls for a sensor with 600 mm H_2O (24 “ H_2O ~ 6 kPa) sensor with a 5% FS accuracy spec. Certain appliances call for a lower pressure range especially in Europe where horizontal axis machines are common.

SENSOR SOLUTIONS

For the typical 600 mm H_2O, 5% FS spec, an off the shelf solution available today is the MPX10/MPX12, MXP2010 and the MPXV4006G sensor. The MPX10 (or the MPX12) is 10 kPa (40 “ H_2O) full-scale pressure range device. It is uncompensated for temperature and untrimmed offset and full-scale span. This means that the end user must temperature compensate as well as calibrate the full-scale offset and span of the device. The output of the device must be amplified using a differential amplifier (see Figure 1) so it can be interfaced to an A/D and to obtain the desired range.

Since the MPX10/MPX12 sensors must be calibrated, the implications of this device being used in high-volume production is expensive. Because the offset and full-scale output can vary from part to part, a two-point calibration is required as a minimum. A two point calibration is a time consuming procedure as well as possible modification to the production line to accommodate the calibration process. The circuitry must also accommodate for trimming, i.e., via trimpots and/or EEPROM to store the calibration data. This adds extra cost to the system.

The MPX2010 is a 10 kPa (40" H_2O), temperature compensated, offset and full-scale output calibrated device. A differential amplifier like the one shown in Figure 1 should be used to amplify its output. Unlike the MPX10 or MPX12, this device does not need a two-point calibration but auto-zeroing can improve its performance. This procedure is easily implemented using the system MCU.

The MPXV4006G is a fully integrated pressure sensor specifically designed for appliance water level sensing application. This device has an on board amplification, temperature compensation and trimmed span. An auto-zero procedure should be implemented with this device (refer to Application Note AN1636). Because expensive and time consuming calibration, temperature compensation and amplification is already implemented, this device is more suitable for high volume production. The MPXV4006G integrated sensor is guaranteed to be have an accuracy of ± 3% FS over its pressure and temperature range.

For washing machine applications where low cost and high volume productions are involved, both the MPX2010 and MPXV4006G are recommended. Both solutions can be used in current vertical axis machines where the water level in the 600 mm H_2O or 24 “ H_2O range. In the following, a comparison is made between MPX2010 and MPXV4006G in terms of system and performance considerations to help the customer make a decision.

EXPECTED ACCURACY OF THE MPX2010 SYSTEM SOLUTION

The MPX2010 compensated sensor has an off the shelf overall RMS accuracy of ± 7.2% FS over 0 to 85°C temperature range.

Auto-zeroing can improve the sensor accuracy to ± 4.42% FS. However, since this sensor does not have an integrated amplification, its amplifier section must be designed carefully in order to meet the target accuracy requirement. The MPX2010 compensated sensor has the following specifications shown on Table 1.

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Table 1. MPX2010 Specifications

Characteristic	Min	Typ	Max	Unit
Pressure Range	0		10	kPa
Supply Voltage		10	16	Vdc
Supply Current		6		mA
Full Scale Span	24	25	26	mV
Offset	*1		1	mV
Sensitivity		25		mV/kPa
Linearity	*1		1	$\%V_{FSS}$
Pressure Hysterisis		0.1		$\%V_{FSS}$
Temperature Hysterisis (*40 to 125°C)		0.5		$\%V_{FSS}$
Temperature Effect on Span	*1		1	$\%V_{FSS}$
Temperature Effect Offset (0 to 85°C)	*1		1	mV
Input Impedance	1300		2550	W
Output Impedance	1400		3000	W
Response Time (10% to 90%)		1		ms
Warm-Up		20		ms

The sensor system errors is made up of the sensor errors, amplifier errors and A/D errors. In other words,

$$\varepsilon System = \sqrt{\varepsilon Sensor^2 + \varepsilon Amplifier^2 + \varepsilon ADResolution^2} \quad (1)$$

Table 2 shows the MPX2010 with the errors converted to $\%V_{FSS}$. The expected maximum root mean squared error of the sensor is

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + TCS^2 + OffCal^2 + Tco^2 + OffStab^2} \quad (2)$$

$$= \pm 7.19\% FS.$$

With auto-zeroing, the offset calibration, temperature effect on offset and offset stability is reduced or eliminated,

$$\varepsilon Sensor = \sqrt{SpanCal^2 + Lin^2 + Phys^2 + Thys^2 + TCS^2} \quad (3)$$

$$= +/- 4.42\% FS.$$

The sensor error is calculated using the full-scale pressure range of the device, 0 to 85°C temperature and 10 V excitation.

In comparison with the MPXV4006G solution, the expected accuracy of the system (MPXV4006G + 8 bit A/D) with auto-zero is 3.1% FS.

Table 2. MPX2010 Span, Offset and Calculated Maximum RMS Error*

Span Errors (converted to $\%V_{FSS}$)	Symbol	Error Value	Note	Unit
Span Calibration	SpanCal	4		$\%V_{FSS}$
Linearity	Lin	1		$\%V_{FSS}$
Pressure Hysterisis	Phys	0.1		$\%V_{FSS}$
Temperature Hysterisis	Thys	0.5		$\%V_{FSS}$
Temperature Effect on Span	Tcs	1.5		$\%V_{FSS}$
Offset Errors (converted to $\%V_{FSS}$)				
Offset Calibration	OffCal	4		$\%V_{FSS}$
Temperature Effect on Offset	Tco	4		$\%V_{FSS}$
Offset Stability	OffStab	0.5		$\%V_{FSS}$
Calculated Maximum RMS Errors		**RMS Error**		
No Compensation*		7.19		$\%_{FS}$
With auto-zero		4.42		$\%_{FS}$

* This assumes the power supply is constant.

AMPLIFIER SELECTION AND AMPLIFIER INDUCED ERRORS

A differential amplifier is needed to convert the differential output of the MPX2010 sensor to a high level ground-referenced (single-ended). The classic three-op amp instrumentation amplifier can be used. However, it requires additional components (3 op-amps and possibly a split power supply). An instrumentation topology shown in Figure 1 requires only a single supply and only 2 op-amps and 1% resistors.

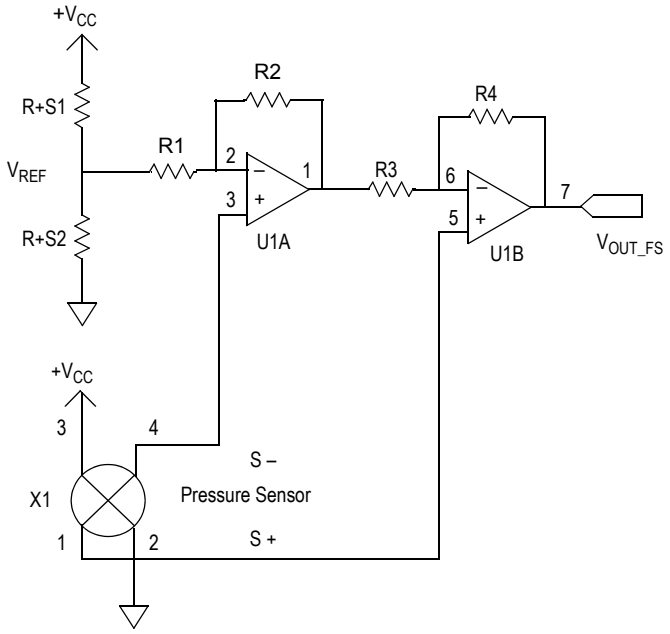

Figure 1. MPX2010 Amplifier Circuit

The circuit uses a voltage divider R+S1 and R+S2 to provide the reference (level shift), U1A and U1B are non-inverting amplifiers arranged in a differential configuration with gain resistors R1, R2, R3, and R4. Note that U1B is the main gain stage and it has the most gain. It is recommended to place a 0.015 μF capacitor in it's feedback loop (in parallel with R4) to reduce noise. The amplifier output can be characterized with the equation below:

$$\text{Gain} = \frac{R4}{R3} + 1 \qquad (4)$$

$$\text{Voffset} = \text{VREF}\left(\frac{R2 \cdot R1}{R1 \cdot R3}\right) - \text{VSCM}\left[\left(\frac{R2 \cdot R4}{R1 \cdot R3}\right)\right] - 1 \qquad (5)$$

$$\text{Vout} = (\text{S+} - \text{S-})\ \text{Gain} + \text{Voffset} \qquad (6)$$

$$\text{where (S+ - S-) = Sensor differential output + Sensor offset} \qquad (7)$$

Equation 4 is the differential gain of the amplifier and equation 5 is the resulting offset voltage of the amplifier.

The above equations assume that the amplifier is close to ideal (high A_{OL}, low input offset voltage and low input offset bias currents). Since an ideal op-amp is hard to come by, the customer should select an op-amp based on cost and performance. Below are some points to keep in mind when selecting an op-amp and designing the amplifier circuit.

Note that the ratio R2*R4/R1*R3 controls the system offset as well as the common mode error of the amplifier. Mismatches in these resistors will result in an offset and common mode error which appear as offset. It is therefore recommended to use 1% metal film resistors to reduce these errors. Also, V_{REF} source impedance should be minimized in comparison with R1 in order to reduce common mode error.

Amplifier input offset and input bias currents can induce errors. For example, an input offset (Vio) of the amplifier can become significant when the closed-loop gain of the amplifier is increased. Furthermore, there is also a temperature coefficient of the input voltage offset which contribute an additional error across temperature. If the input bias current of the amplifier is not taken into account in the design, it can also become a source of error. A technique to reduce this error is to match the impedance the source impedance of what the op-amp input pins sees.

It is important to note that high performance op-amps are more expensive. An MC33272 op-amp has a low input offset and low input bias current which is suitable for the two-op amp amplifier design. We can see that there is a tradeoff between accuracy and cost when designing a solution with the MPX2010.

When designing a system based on the MPX2010, it is important to take into account errors due to parametric variation of the sensor (i.e., offset calibration, span calibration, TcS, TcO), power supply and the inherent errors of the amplification circuit. The offset and span errors greatly determines the resolution of the system (which adds to the system error). Even though the system offset error can be

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nulled out by auto-zeroing, these errors must be accounted for when setting the system gain (refer to AN1556 for more details). This forces the total span of the system to be smaller, because we must reserve an extra headroom from the total span to account for amplifier and A/D variations (i.e., amp. sat. voltage, power supply variation, A/D quantization error, and gain errors). If these errors are not accounted for, it could, for example, result in non-linearity errors if the sensor span or offset error causes the amplified output of the sensor to reach the saturation voltage of the amplifier.

As an example, a MPX2010 sensor system is designed which has a range of 600 mm H_2O FS range with a ±5% FS RMS error. The system uses a +5.0 V ±5% linear regulated power supply, a MC33272 dual op-amp and a 1% resistors.

Table 3 shows the resulting specification and component values for the system based on MPX2010 sensor.

Table 3. MPX2010 Sensor System Values

MPX2010 Sensor Design			
Parameter	Description	Value	Units
V_{CC}	Reg Power Supply	5	V
Differential Gain	Gain	433	V/V
Vout_FS	Full Scale Span	3.02	V
V_{REF}	Offset Reference	0.66	V
Parts List			
U1A,U1B	MC33272 Op-amp		
R1	Gain Resistor	39.2K	Ω
R2	Gain Resistor	90.9	Ω
R3	Gain Resistor	909	Ω
R4	Gain Resistor	392K	Ω
R + S1	Level Shift Resistor	1K	Ω
R + S2	Level Shift Resistor	150	Ω
X1	MPX2010		

Table 4. Performance Comparison between MPX2010 and MPXV4006G Solution

Error Contribution	MPX2010 Solution Error (FS = 600 mm H_2O)		MPXV4006G Solution Error (FS = 612 mm H_2O)	
	± % FS	± mm H_2O	± % FS	± mm H_2O
Max Sensor Error	7.19	43	3.00	18
System Resolution (A/D + Amplification)	1.30	8	0.80	5
System Error (Sensor + A/D + Amplification)	7.3	44	3.10	19
System Error with Auto-Zero	4.6	28	t3	t19

Note that the error due to system resolution is higher for the MPX2010 solution (± 2 bit A/D accuracy). This is because the MPX2010 span is limited as discussed above. Also, this accuracy assumes that the amplifier does not induce significant errors. As noted MPXV4006G sensor has better overall accuracy. The system resolution is very good because of its large span (4.6 V versus 3.0 V typical).

SUMMARY

Several washing machine solutions were examined. The MPX10/12 solution can be expensive in terms of additional support circuitry and the added time and labor involved during the calibration procedure. The MPX2010 is good alternative for high volume manufacturing because is already calibrated. With this solution, however, the system amplifier design must be chosen and designed carefully in order to minimize the system error. This is a consideration when deciding to implement a high accuracy solution with the MPX2010 because the cost of the system will go up.

The MPXV4006G solution is geared towards high volume manufacturing because trimming, compensation and amplification is already on board. Besides the system simplicity and using less component, the resolution and overall accuracy of this solution is better than the MPX2010 solution. In some cases, less components can actually improve the reliability and manufacturability the system.

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Water Level Monitoring

by: **Michelle Clifford, Applications Engineer**
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INTRODUCTION

Many washing machines currently in production use a mechanical sensor for water level detection. Mechanical sensors work with discrete trip points enabling water level detection only at those points. The purpose for this reference design is to allow the user to evaluate a pressure sensor for not only water level sensing to replace a mechanical switch, but also for water flow measurement, leak detection, and other solutions for smart appliances. This system continuously monitors water level and water flow using the temperature compensated MPXM2010GS pressure sensor in the low cost MPAK package, a dual op-amp, and the MC68HC908QT4, eight-pin microcontroller.

SYSTEM DESIGN

Pressure Sensor

The pressure sensor family has three levels of integration — Uncompensated, Compensated and Integrated. For this design, the MPXM2010GS compensated pressure sensor was selected because it has both temperature compensation and calibration circuitry on the silicon, allowing a simpler, yet more robust, system circuit design. An integrated pressure sensor, such as the MPXV5004G, is also a good choice for the design eliminating the need for the amplification circuitry.

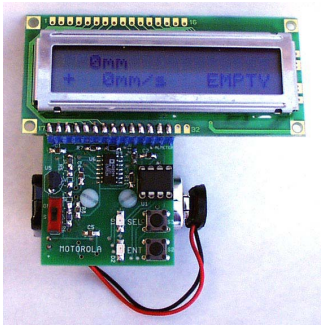

Figure 1. Water Level Reference Design Featuring a Pressure Sensor

The height of most washing machine tubs is 40 cm, therefore the water height range that this system will be measuring is between 0–40 cm. This corresponds to a pressure range of 0–4 kPa. Therefore, the MPXM2010GS was selected for this system. The sensor sensitivity is 2.5 mV/kPa, with a full-scale span of 25 mV at the supply voltage of 10 V_{DC}. The full-scale output of the sensor changes linearly with supply voltage, so a supply voltage of 5 V will return a full-scale span of 12.5 mV.

$$(V_{S\ actual} / V_{S\ spec}) * V_{OUT\ full\text{-}scale\ spec} = V_{OUT\ full\text{-}scale}$$

$$(5.0\ V / 10\ V) \times 25\ mV = 12.5\ mV$$

Since this application will only be utilizing 40 percent of the pressure range, 0–4kPa, our maximum output voltage will be 40 percent of the full-scale span.

$$V_{OUT\ FS} * (Percent_{\ FS\ Range}) = V_{OUT\ max}$$

$$12.5\ mV * 40\% = 5.0\ mV$$

The package of the pressure sensor is a ported MPAK package. This allows a tube to be connected to the sensor and the tube is connected to the bottom of the tub. This isolates the sensor from direct contact with the water. The small size and low cost are additional features making this package a perfect fit for this application.

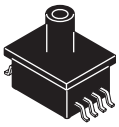

Figure 2. A Ported Pressure Sensor

Table 1. MPXM2010D OPERATING CHARACTERISTICS (V_S = 10 V_{DC}, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	10	kPa
Supply Voltage	V_S	—	10	16	Vdc
Supply Current	I_O	—	6.0	–	mAdc
Full Scale Span	V_{FSS}	24	25	26	mV
Offset	V_{off}	-1.0	—	1.0	mV
Sensitivity	DV/DP	—	2.5	—	mV/kPa
Linearity	—	-1.0	—	1.0	$\%V_{FSS}$

Amplifier Induced Errors

The sensor output needs to be amplified before being inputted directly to the microcontroller through an eight-bit A/D input pin. To determine the amplification requirements, the pressure sensor output characteristics and the 0-5 V input range for the A/D converter had to be considered.

The amplification circuit uses three op-amps to add an offset and convert the differential output of the MPXM2010GS sensor to a ground-referenced, single-ended voltage in the range of 0–5.0 V.

The pressure sensor has a possible offset of ±1 mV at the minimum rated pressure. To avoid a nonlinear response when a pressure sensor chosen for the system has a negative offset (V_{OFF}), we added a 5.0 mV offset to the positive sensor output signal. This offset will remain the same regardless of the sensor output. Any additional offset the sensor or op-amp introduces is compensated for by software routines invoked when the initial system calibration is done.

To determine the gain required for the system, the maximum output voltage from the sensor for this application had to be determined. The maximum output voltage from the sensor is approximately 12.5 mV with a 5.0 V supply since the full-scale output of the sensor changes linearly with supply voltage. This system will have a maximum pressure of 4 kPa at 40 cm of water. At a 5.0 V supply, we will have a maximum sensor output of 5 mV at 4 kPa of pressure. To amplify the maximum sensor output to 5.0 V, the following gain is needed:

Gain = (Max Output needed) / (Max Sensor Output and Initial Offset) = 5.0 V / (0.005 V + 0.005) = 500

The gain for the system was set for 500 to avoid railing from possible offsets from the pressure sensor or the op-amp.

The Voltage Outputs from the sensor are each connected to a non-inverting input of an op-amp. Each op-amp circuit has the same resistor ratio. The amplified voltage signal from the negative sensor lead is V_A. The resulting voltage is calculated as follows:

$$V_A = (1+R8/R6) * V_4$$
$$= (1+10/1000) * V_4$$
$$= (1.001) * V_4$$

The amplified voltage signal from the positive sensor lead is V_B. This amplification adds a small gain to ensure that the positive lead, V_2, is always greater than the voltage output from the negative sensor lead, V_4. This ensures the linearity of the differential voltage signal.

$$V_B = (1+R7/R5) * V_2 – (R7/R5) * V_{CC}$$
$$= (1+10/1000) * V_2 + (10/1000)*(5.0\ V)$$
$$= (1.001) * V_2 + 0.005\ V$$

The difference between the positive sensor voltage, V_B, and the negative sensor voltage, V_A is calculated and amplified with a resulting gain of 500.

$$VC = (R12/R11) * (V_B – V_A)$$
$$= (500\ K/1K) * (V_B – V_A)$$
$$= 500 * (V_B – V_A)$$

The output voltage, V_C, is connected to a voltage follower. Therefore, the resulting voltage, V_C, is passed to an A/D pin of the microcontroller.

The range of the A/D converter is 0 to 255 counts. However, the A/D Values that the system can achieve are dependent on the maximum and minimum system output values:

Count = (V_{OUT} – VRL) / (VRH – VRL) x 255

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

Count (0 mm H20) = (2.5 – 0) / (5.0 – 0) * 255 = 127

Count (40 mm H20) = (5.0 – 0) / (5.0 – 0) * 255 = 255

Total # counts = 255 – 127 = 127 counts.

The resolution of the system is determined by the mm of water represented by each A/D count. As calculated above, the system has a span of 226 counts to represent water level up to and including 40 cm. Therefore, the resolution is:

Resolution = mm of water / Total # counts

= 400mm/127 counts = 3.1 mm per A/D count

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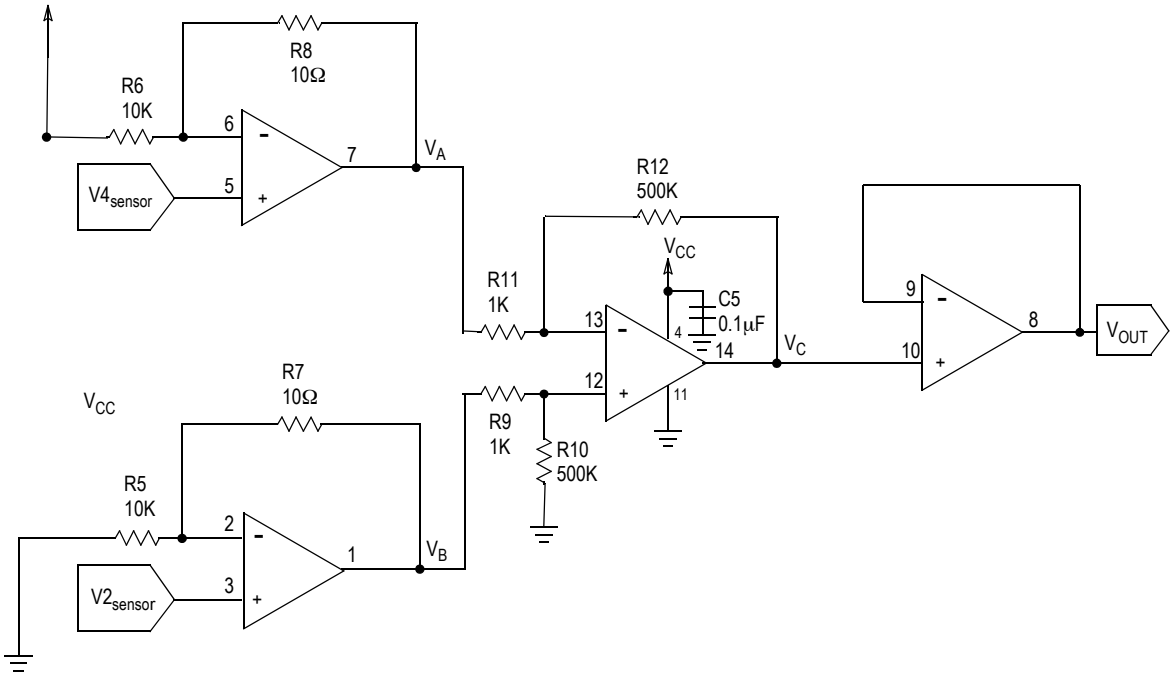

Figure 3. Amplification Scheme

Microprocessor

To provide the signal processing for pressure values, a microprocessor is needed. The MCU chosen for this application is the MC68HC908QT4. This MCU is perfect for appliance applications due to its low cost, small eight-pin package, and other on-chip resources. The MC68HC908QT4 provides: a four-channel, eight-bit A/D, a 16-bit timer, a trimmable internal timer, and in-system FLASH programming.

The central processing unit is based on the high performance M68HC08 CPU core and it can address 64 Kbytes of memory space. The MC68HC908QT4 provides 4096 bytes of user FLASH and 128 bytes of random access memory (RAM) for ease of software development and maintenance. There are five bi-directional input/output lines and one input line shared with other pin features.

The MCU is available in eight-pin as well as 16-pin packages in both PDIP and SOIC. For this application, the eight-pin PDIP was selected. The eight-pin PDIP was chosen for a small package, eventually to be designed into applications as the eight-pin SOIC. The PDIP enables the customer to reprogram the software on a programming board and retest.

Display

Depending on the quality of the display required, water level and water flow can be shown with two LEDs. If a higher quality, digital output is needed, an optional LCD interface is provided on the reference board. Using a shift register to hold display data, the LCD is driven with only three lines outputted from the microcontroller: an enable line, a data line, and a clock signal. The two LEDs are multiplexed with the data line and clock signal

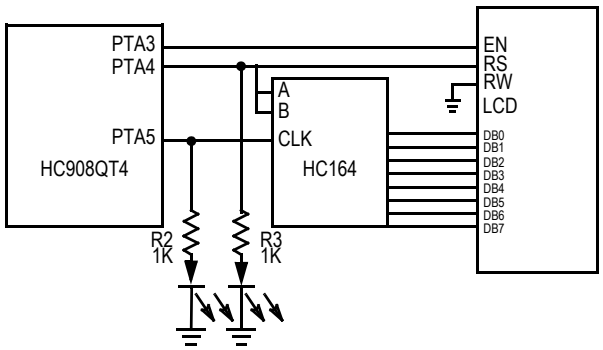

Figure 4. Multiplexed LCD Circuit

Multiplexing of the microcontroller output pins allows communication of the LCD to be accomplished with three pins instead of eight or 11 pins of I/O lines usually needed. With an eight-bit shift register, we are able to manually clock in eight bits of data. The enable line (EN) is manually accepted when eight bytes have been shifted in, telling the LCD the data on the data bus is available to execute.

The LEDs are used to show pressure output data by displaying binary values corresponding to a pressure range. Leak detection, or water-flow speed, is displayed by blinking a green LED at a speed relating to the speed of water flow. The red LED displays the direction of water flow. Turning the red LED off signifies water flowing into the tub. Turning the red LED on signifies water flowing out of the tub, or alternatively, there is a leak.

Digital values for water height, rate of water flow, and calibration values are displayed if an LCD is connected to the board

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OTHER

This system is designed to run on a 9.0 V battery. It contains a 5.0 V regulator to provide 5.0 V to the pressure sensor, microcontroller, and LCD. The battery is mounted on the back of the board using a space saving spring battery clip.

Table 2. Parts List

Ref.	Qty	Description	Value	Vendor	Part No.
U2	1	Pressure Sensor	1	Freescale	MPXM2010GS
C1	1	Vcc Cap	0.1μf	Generic	—
C2	1	Op-Amp Cap	0.1μf	Generic	—
C3	1	Shift Register Cap	0.1μf	Generic	—
D1	1	Red LED	—	Generic	—
D2	1	Green LED	—	Generic	—
S2, S3	2	Pushbuttons	—	Generic	—
U1	1	Quad Op-Amp	—	ADI	AD8544
U3	1	Voltage Regulator	5.0 V	Fairchild	LM78L05ACH
U4	1	Microcontroller	8-pin	Freescale	MC68HC908QT4
R1	1	¼ W Resistor	22 K	Generic	—
R2	1	¼ W Resistor	2.4 K	Generic	—
R3, R6	2	¼ W Resistor	1.2 M	Generic	—
R4, R5	2	¼ W Resistor	1.5 K	Generic	—
R7, R8	2	¼ W Resistor	10 K	Generic	—
R9, R10	2	¼ W Resistor	1.0 K	Generic	—
U6	1	LCD (Optional)	16 x 2	Seiko	L168200J000
U5	1	Shift Registor	—	Texas Instruments	74HC164

Smart Washer Software

This application note describes the first software version available. However, updated software versions may be available with further functionality and menu selections.

Software User Instructions

When the system is turned on or reset, the microcontroller will flash the selected LED and display the program title on the LCD for five seconds, or until the select (SEL) button is pushed. Then the menu screen is displayed. Using the select (SEL) pushbutton, it is easy to scroll through the menu options for a software program. To run the water level program, use the select button to highlight the *Water Level* option, then press the enter (ENT) pushbutton. The Water Level program will display current water level, the rate of flow, a message if the container is *Filling*, *Emptying*, *Full*, or *Empty*, and a scrolling graphical history displaying data points representing the past forty level readings.

The Water Level is displayed by retrieving the digital voltage from the internal A/D Converter. This voltage is converted to pressure in millimeters of water and then displayed on the LCD.

Calibration and Calibration Software

To calibrate the system, a two-point calibration is performed. The sensor will take a calibration point at 0 mm and at 40 mm of water. Depressing both the SEL and ENT buttons on system power-up enters the calibration mode. At this point, the calibration menu is displayed with the previously sampled offset voltage. To recalibrate the system, expose the sensor to atmospheric pressure and press the SEL button (PB1). At this point, the zero offset voltage will be sampled and saved to a location in the microcontroller memory. To obtain the second calibration point, place the end of the plastic tube from the pressure sensor to the bottom of a container holding 40 mm of water. Then press the ENT button (PB2). The voltage output will be sampled, averaged and saved to a location in memory. To exit the calibration mode, press the SEL (PB1) button.

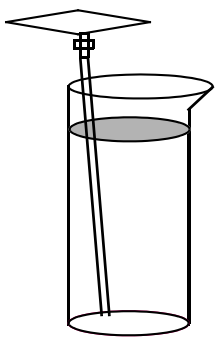

Figure 5. Water Level System Set-Up for Demonstration

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Converting Pressure to Water Level

Hydrostatic pressure being measured is the pressure at the bottom of a column of fluid caused by the weight of the fluid and the pressure of the air above the fluid. Therefore, the hydrostatic pressure depends on the air pressure, the fluid density and the height of the column of fluid.

$$P = Pa + \rho g \Delta h$$

where P = pressure

Pa = pressure

ρ = mass density of fluid

g = 9.8066 m/s^2

h = height of fluid column

To calculate the water height, we can use the measured pressure with the following equation, assuming the atmospheric pressure is already compensated for by the selection of the pressure sensor being gauge:

$$\Delta h = P \setminus \rho g$$

Software Function Descriptions

Main Function

The main function calls an initialization function *Allinit* calls a warm-up function, *Warmup,* to allow extra time for the LCD to initialize, then checks if buttons PB1 and PB2 are depressed. If they are depressed concurrently, it calls a calibration function *Calib*. If they are not both pressed, it enters the main function loop. The main loop displays the menu, moves the cursor when the PB1 is pressed and enters the function corresponding to the highlighted menu option when PB2 is depressed.

Calibration Function

The calibration function is used to obtain two calibration points. The first calibration point is taken when the head tube is not placed in water to obtain the pressure for 0 mm of water. The second calibration point is obtained when the head tube is placed at the bottom of a container with a height of 160 mm. When the calibration function starts, a message appears displaying the A/D values for the corresponding calibration points currently stored in the flash. To program new calibration points, press PB1 to take 256 A/D readings at 0 mm of water. The average is calculated and stored in a page of flash. Then the user has the option to press PB1 to exit the calibration function or obtain the second calibration point. To obtain the second calibration point, the head tube should be placed in 160 mm of water, before depressing PB2 to take 256 A/D readings. The average is taken and stored in a page of flash. Once the two readings are taken, averaged, and stored in the flash, a message displays the two A/D values stored.

Level Function

The Level function initializes the graphics characters. Once this is complete, it continues looping to obtain an average A/D reading, displaying the Water Level, the Water Flow, and a Graphical History until simultaneously depressing both PB1 and PB2 to return to the main function.

The function first clears the 40 pressure readings it updates for the Graphical History. The history then enters the loop first displaying eight special characters, each containing five data points of water level history. The function *adcbyta* is called to obtain the current averaged A/D value. The function *LfNx* is called to convert the A/D value to a water level. It is then compared to the calibration points, the maximum and minimum points, to determine if the container is full or empty. If true, then it displays the corresponding message. The current water level is compared to the previous read and displays the message *filling* if it has increased, *emptying* if it has decreased, and *steady* if it has not changed.

The water level calculation has to be converted to decimal in order to display it in the LCD. To convert the water level calculation to decimal, the value is continually divided with the remainder displayed to the screen for each decimal place. To display the Rate of Water Flow, the sign of the value is first determined. If the value is negative, the one's complement is taken, a negative sign is displayed, and then the value is continually divided to display each decimal place. If the number is positive, a plus sign.

Level Function

The Level function initializes the graphics characters. Once this is complete, it continues looping to obtain an average A/D reading, displaying the Water Level, the Water Flow, and a Graphical History until simultaneously depressing both PB1 and PB2 to return to the main function.

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The water level calculation has to be converted to decimal in order to display it in the LCD. To convert the water level calculation to decimal, the value is continually divided with the remainder displayed to the screen for each decimal place. To display the Rate of Water Flow, the sign of the value is first determined. If the value is negative, the one's complement is taken, a negative sign is displayed, and then the value is continually divided to display each decimal place. If the number is positive, a plus sign is displayed to maintain the display alignment and the value is continually divided to display each decimal place.

The most complicated part of this function is updating the graphics history display. The characters for the 16x2 LCD chosen for this reference design are 8x5 pixels by default. Therefore, each special character that is created will be able to display five water level readings. Since the height of the special character is eight pixels, each vertical pixel position will represent a water level in increments of 20 mm.

Resolution = (H1 – H0) / D

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where H1 and H2 are the maximum and minimum water levels respectively and D is the possible datapoints available per character.

Resolution = (160mm– 0mm) / 8.0 = 20 mm / data point.

The graphical history is displayed using the eight special characters. To update the graphics, all the characters have to be updated. The characters are updated by first positioning a pixel for the most recent water level reading in the first column of the first character. Then the four right columns of the first character are shifted to the right. The pixel in the last column of that character is carried to the first column of the next character. This column shifting is continued until all 40 data points have been updated in the eight special characters.

LfNx Function

The LfNx function calculates the water level from the current A/D pressure reading. The A/D Pressure value is stored in Register A before this function is called. Using the A/D value and the calibration values stored in the flash, the water level is calculated from the following function:

RBRA: = (NX –N1) * 160 / (N2 – N1),

where NX is the current A/D Value

N1 is the A/D Value at 0 mm H20

N2 is the A/D Value at 160 mm H20

To simplify the calculation, the multiplication is done first. Then the function *NdivD* is called to divide the values.

NdivD Function

The *NdivD* function performs a division by counting successive subtractions of the denominator from the numerator to determine the quotient. The denominator is subtracted from the numerator until the result is zero. If there is an overflow, the remainder from the last subtraction is the remainder of the division.

wrflash and ersflsh Functions

The *wrflash* and *ersflsh* functions are used to write to and erase values from the flash. For more information regarding flash functionality, refer to Section Four, Flash Memory from the *MC68HC908QY4/D* Databook.

ALLINIT Function

The *Allinit* function disables the COP for this version of software, sets the data direction bits, and disables the data to the LCD and turns off the LCD enable line. It also sets up the microcontroller's internal clock to half the speed of the bus clock. See Section 15, Computer Operating Properly, of the MC68908QT4 datasheet for information on utilizing the COP module to help software recover from runaway code.

WARMUP Function

The *Warmup* function alternates the blinking of the two LEDs ten times. This gives the LCD some time to warm up. Then the function *warmup* calls the LCD initialization function, *lcdinit*.

bintasc Function

The *binasc* function converts a binary value to its ascii representation.

A/D Functions

The A/D functions are used to input the amplified voltage from the pressure sensor from channel 0 of the A/D converter. The function *adcbyti* will set the A/D control register, wait for the A/D reading and load the data from the A/D data register into the accumulator. The function *adcbyta* is used to obtain an averaged A/D reading by calling *adcbyti* 256 times and returning the resulting average in the accumulator.

LCD Functions

The LCD hardware is set up for multiplexing three pins from the microcontroller using an eight-bit shift register. Channels three, four, and five are used on port A for the LCD enable (E), the LCD reset (RS), and the shift register clock bit, respectively. The clock bit is used to manually clock data from channel four into the eight-bit shift register. This is the same line as the LCD RS bit because the MSB of the data is low for a command and high for data. The RS bit prepares the LCD for instructions or data with the same bit convention. When the eight bits of data are available on the output pins of the shift register, the LCD enable (E) is toggled to receive the data.

The LCD functions consist of an initialization function *lcdinit* which is used once when the system is started and five output functions. The functions *lcdcmdo* and *lcdchro* both send a byte of data. The function *shiftA* is called by both *lcdcmdo* and *lcdchro* to manually shift eight bits of data into the shift register. The function *lcdnibo* converts the data to binary before displaying. The *lcdnibo* displays a byte of data by calling *lcdnibo* for each nibble of data. The function *lcdnibo* enables strings to be easily added to the software for display. The function accepts a comma- delimited string of data consisting of 1–2 commands for clearing the screen and positioning the cursor. It then continues to output characters from the string until the @ symbol is found, signally the end of the string.

CONCLUSION

The water level reference design uses a MPXM2010GS pressure sensor in the low cost MPAK package, the low cost, eight-pin microcontroller, and a quad op-amp to amplify the sensor output voltage. This system uses very few components, reducing the overall system cost. This allows for a solution to compete with a mechanical switch for water level detection but also offer additional applications such as monitoring water flow for leak detection, and the other applications for smart washing machines.

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SOFTWARE LISTING

```
;NitroWater 2.0  24Jan03
;--------------
;
;Water Level Reference Design
;*****************************
; - uses 908QT4 (MC68HC908QT4) and MPAK (MPXM2010GS)
;     CALIB: 2-point pressure calibration (0mm and 160mm)
;     LEVEL: displays water level, flow, and graphics
;     UNITS: allows user to select between cm and inches
;
;_____________________________________________________________
ram       equ    $0080          ;memory pointers
rom       equ    $EE00
vectors   equ    $FFDE
;_____________________________________________________________
porta     equ    $00            ;registers
ddra      equ    $04
config2   equ    $1E
config1   equ    $1F
tsc       equ    $20
tmodh     equ    $23
icgcr     equ    $36
adscr     equ    $3C
adr       equ    $3E
adiclk    equ    $3F
flcr      equ    $FE08
flbpr     equ    $FFBE
;_____________________________________________________________
          org    $FD00          ;flash variables
N1        db     $96            ;1st calibration pt. =   0mm
          org    $FD40
N2        db     $F6            ;2nd calibration pt. = 160mm
          org    $FD80
;_____________________________________________________________
          org    vectors
          dw     cold           ;ADC
          dw     cold           ;Keyboard
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;not used
          dw     cold           ;TIM Overflow
          dw     cold           ;TIM Channel 1
          dw     cold           ;TIM Channel 0
          dw     cold           ;not used
          dw     cold           ;IRQ
          dw     cold           ;SWI
          dw     cold           ;RESET ($FFFE)
;_____________________________________________________________
          org    ram
BB        ds     1              ;variables
flshadr   ds     2
flshbyt   ds     1
memSP     ds     2
mem03     ds     2
```


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```
CNT      ds    1
Lgfx     ds    1
weath    ds    1
UnitType ds    1
UnitDiv  ds    1
UnitEmpt ds    1
UnitFull ds    1
ram0     ds    1
NC       ds    1
NB       ds    1
NA       ds    1
DC       ds    1
DB       ds    1
DA       ds    1
MB       ds    1
MA       ds    1
OB       ds    1
OA       ds    1
RB       ds    1
RA       ds    1
P0C      ds    1
P0B      ds    1
P0A      ds    1
NPTR     ds    1
ramfree  ds    80          ;used both for running RAM version of wrflash & storing 40 readings
;_____________________________________________________________
;_____________________________________________________________
;_____________________________________________________________
        org   rom
cold:   rsp                ;reset SP if any issues (all interrupt vectors point here)
        jsr   ALLINIT      ;general initialization
        jsr   WARMUP       ;give LCD extra time to initialize

        brset 1,porta,nocalib
        brset 2,porta,nocalib
        jmp   CALIB        ;only do calibration if SEL & ENT at reset

nocalib: ldhx  #msg01      ;otherwise skip and show welcome messages
        jsr   lcdstro      ;"Reference Design" msg
        jsr   del1s        ;wait 1s
        ldhx  #msg01a      ;"Water Level" msg
        jsr   lcdstro
        jsr   del1s        ;wait 1s

initCM:  ldhx  #$A014      ;initialize default units to cm ($A0=cm, $3F=in)
        sthx  UnitType     ;UnitType set to $A0; UnitDiv set to $14
        ldhx  #$039E
        sthx  UnitEmpt     ;UnitEmpt set to $03; UnitFull set to $9E

MENU:   ldhx  #msg01b
        jsr   lcdstro      ;Menu msg
        clr   RA           ;menu choice=0 to begin with
        lda   #$0D
        jsr   lcdcmdo      ;blink cursor on menu choice

luke:   ldx   RA           ;get current menu choice
        clrh
        lda   menupos,x    ;and look up corresponding LCD address
        jsr   lcdcmdo      ;reposition cursor
```

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```
warm:     brclr  1,porta,PB1    ;check for SEL
          brclr  2,porta,PB2    ;or for ENT
          bclr   4,porta        ;otherwise
          bset   5,porta        ;turn on "SEL" LED
          jsr    del100ms       ;delay
          bset   4,porta        ;toggle LEDs
          bclr   5,porta        ;"ENT" now on: means choice is SEL ***or*** ENT
          jsr    del100ms       ;delay and repeat until SEL or ENT
          bra    warm

PB1:      inc    RA             ;***SEL*** toggles menu choices
          lda    RA
          cmp    #$02           ;menu choices are $00 and $01
          bne    PB1ok
          clr    RA             ;back to $00 when all others have been offered
PB1ok:    bclr   4,porta
          bclr   5,porta        ;LEDs off
          jsr    del100ms       ;wait a little bit
          brclr  1,porta,PB1ok  ;make sure they let go of SEL
          bra    luke

PB2:      bclr   4,porta        ;***ENT*** confirms menu choice
          bclr   5,porta        ;LEDs off
          lda    RA             ;get menu choice
          bne    skip00
          jmp    LEVEL          ;do ===LEVEL=== if choice=$01
skip00:   jmp    UNITS          ;do ===UNITS=== if choice=$00
;_____________________________________________________________________
;_____________________________________________________________________
CALIB:    lda    #$01
          jsr    lcdcmdo
          clr    ram0

          ldhx   #msg05         ;===CALIB=== 2-point calibration
          jsr    lcdstro        ;Calibration current values
          lda    N1             ;0mm
          jsr    lcdbyto
          lda    #'/'
          jsr    lcdchro
          lda    N2             ;160mm
          jsr    lcdbyto
          bset   4,porta
          bset   5,porta        ;LEDs on
lego1:    brclr  1,porta,lego1
lego2:    brclr  2,porta,lego2
          bclr   4,porta
          bclr   5,porta        ;LEDs off when both SEL & ENT are released
          jsr    del1s
          jsr    del1s          ;wait 2s
          ldhx   #msg05a
          jsr    lcdstro        ;show instructions
waitPB1:  brset  2,porta,no2    ;if ENT is not pressed, skip
          jmp    nocalib        ;if ENT is pressed then cancel calibration
no2:      brclr  1,porta,do1st  ;if SEL is pressed then do 1st point cal
          bra    waitPB1        ;otherwise wait for SEL or ENT
do1st:    ldhx   #msg05b        ;1st point cal: show values
          jsr    lcdstro
          clr    CNT            ;CNT will count 256 A/D readings
          clr    RB
          clr    RA             ;RB:RA will contain 16-bit add-up of those 256 values
```


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```
do256:   lda   #$C9
         jsr   lcdcmdo       ;position LCD cursor at the right spot
         lda   CNT
         deca
         jsr   lcdbyto       ;display current iteration $FF downto $00
         lda   #':'
         jsr   lcdchro
         jsr   adcbyti       ;get reading
         add   RA
         sta   RA
         lda   RB
         adc   #$00
         sta   RB            ;add into RB:RA (16 bit add)
         jsr   lcdbyto       ;show RB
         lda   RA
         jsr   lcdbyto       ;then RA
         dbnz  CNT,do256     ;and do 256x
         lsl   RA            ;get bit7 into carry
         bcc   nochg         ;if C=0 then no need to round up
         inc   RB            ;otherwise round up
nochg:   lda   RB            ;we can discard RA: average value is in RB
         ldhx  #N1           ;point to flash location
         jsr   wrflash       ;burn it in!
         ldhx  #msg05c       ;ask for 160mm
         jsr   lcdstro
waitPB2: brset 2,porta,waitPB2 ;wait for ENT
         ldhx  #msg05d       ;2nd point cal: show values
         jsr   lcdstro
         clr   CNT           ;ditto as 1st point cal
         clr   RB
         clr   RA
do256b:  lda   #$C9
         jsr   lcdcmdo
         lda   CNT
         deca
         jsr   lcdbyto
         lda   #':'
         jsr   lcdchro
         jsr   adcbyti
         add   RA
         sta   RA
         lda   RB
         adc   #$00
         sta   RB
         jsr   lcdbyto
         lda   RA
         jsr   lcdbyto
         dbnz  CNT,do256b
         lsl   RA
         bcc   nochg2
         inc   RB
nochg2:  lda   RB
         cmp   N1            ;compare N2 to N1
         bne   validcal      ;if different, we are OK
         ldhx  #msg05e       ;otherwise warn of INVALID CAL!
         jsr   lcdstro
         jsr   del1s
         jsr   del1s
         jsr   del1s         ;wait 2s
         jmp   CALIB         ;try cal again
```

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```
validcal: ldhx   #N2
        jsr    wrflash       ;burn N2 into flash
        ldhx   #msg05        ;and display new current cal values from flash
        jsr    lcdstro
        lda    N1            ;0mm value
        jsr    lcdbyto
        lda    #'/'
        jsr    lcdchro
        lda    N2            ;160mm value
        jsr    lcdbyto
        jsr    del1s
        jsr    del1s
        jmp    nocalib       ;done!
;_____________________________________________________________________
;_____________________________________________________________________
LEVEL:    lda    #$01          ;===LEVEL=== main routine: displays level, flow & graphics
        jsr    lcdcmdo       ;clear screen
        lda    #$0C
        jsr    lcdcmdo       ;cursor off

        lda    #$88          ;position cursor at LCD graphics portion
        jsr    lcdcmdo       ;(2nd half of first line)
        clra                 ;and write ascii $00 through $07
fillgfx:  jsr    lcdchro       ;which contain the graphics related to
        inca                 ;40 different readings
        cmp    #$08          ;do all 8
        bne    fillgfx

LVL:      ldhx   #ramfree      ;point to 40 pressure readings
        lda    #$28          ;count down from 40
purge:    clr    0,x           ;clear all those locations
        incx                 ;next (H cannot change: we are in page0 RAM)
        dbnza  purge
        jsr    adcbyta       ;get averaged A/D reading (i.e. NX)
        jsr    LfNx          ;convert to level and
        sta    Lgfx          ;store in "Level graphics"

LVLwarm:  bset   4,porta
        bset   5,porta       ;LEDs on during this cycle

        ldhx   #ramfree      ;point to 40 pressure readings
        mov    #$27,RA       ;count down from 39
shiftgfx: lda    1,x           ;take location+1
        sta    0,x           ;and move to location+0, i.e. shift graphics left
        incx                 ;next X (once again: we are in page 0, no need to worry about H)
        dbnz   RA,shiftgfx   ;do this 39x

        jsr    adcbyta       ;get averaged A/D reading (i.e. NX)
        jsr    LfNx          ;LX:=(NX-N1)*ConversionValue/(N2-N1)
        mov    RA,OA         ;store result in OA

        clr    RB            ;RB will contain graphic pixels (default=$00)
        cmp    UnitEmpt      ;if <UnitEmpty (preset value = empty or almost)
        bcs    Lzero         ;then "empty"  (no pixels)
        cmp    UnitFull      ;if >=UnitFull (preset value = full or almost)
        bcc    Lsat          ;then "full"   (pixel $80=bit 7)
        clrh                 ;otherwise determine one of 8 graphic values
        ldx    UnitDiv       ;UnitDiv is roughly full range/8
        div                  ;in order to give 8 values
        mov    #$01,RB       ;but now value has to be converted to pixel
```


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```
        cmp    #$01          ;if result is $01
        beq    Lzero         ;then display it directly
makeRB  lsl    RB            ;otherwise shift 1 pixel bit to the right place
        dbnza  makeRB        ;by counting down result of division
        bra    Lzero
Lsat:   mov    #$80,RB       ;if full then position highest pixel
Lzero:  lda    RB
        ldhx   #ramfree+$27  ;last of the 40
        sta    0,x           ;put it at then end of the 40 bytes (new value), all others were shifted left

        clr    weath         ;weath will contain dynamic change based also on value of RB
        lda    RB
        beq    donew         ;if RB=$00 then weath=$00: "empty"
        cmp    #$80
        bne    notfull       ;
        mov    #$01,weath    ;if $80 then weath=$01: "full"
        bra    donew
notfull mov    #$02,weath    ;prepare for "steady" if L(i)=L(i-1)
        lda    OA            ;get current level value L(i)
        cmp    Lgfx          ;compare to previous level value L(i-1)
        beq    donew
        mov    #$03,weath    ;"filling" if L(i)>L(i-1)
        bcc    donew
        mov    #$04,weath    ;"emptying" otherwise

donew:  lda    OA            ;current level L(i)
        sub    Lgfx          ;minus previous level L(i-1)
        sta    MA            ;establishes rate: L(i)-L(i-1)
        mov    RA,Lgfx       ;update L(i-1)
;-----------------------------------
golevel: lda   #$80          ;******** now let's display the level in decimal ********
        jsr    lcdcmdo       ;start on 1st character of 1st line

        lda    OA            ;get current level value
        clrh
        ldx    #$64          ;and divide by 100
        div
        bne    over100       ;if result is >0 then handle "hundreds"
        lda    #$20          ;otherwise display space (remove leading 0)
        jsr    lcdchro
        bra    lnext
over100: jsr   lcdnibo       ;display "hundreds" digit
lnext:  pshh
        pula                 ;move remainder into A
        clrh
        ldx    #$0A          ;divide by 10
        div
        jsr    lcdnibo       ;display "tens" digit
        lda    #'.'
        jsr    lcdchro       ;display decimal point
        pshh
        pula
        jsr    lcdnibo       ;and first decimal
        lda    UnitType      ;check for cm ($A0) vs. in (#3F)
        cmp    #$3F
        beq    dsplIN

dsplCM: lda    #'c'
        jsr    lcdchro
        lda    #'m'
```

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```
        jsr    lcdchro       ;display "cm" for centimeters
        bra    goflow

dsplIN:  lda    #'i'
        jsr    lcdchro
        lda    #'n'
        jsr    lcdchro       ;display "in" for inches
;--------------------------------
goflow:  lda    #$C0          ;******** now let's display the flow in decimal ********
        jsr    lcdcmdo        ;position cursor on 1st character 2nd line
        lda    MA             ;get flow
        lsla                  ;test sign of rate (in MA)
        bcc    positiv        ;if positive, then it's easy

        lda    MA             ;otherwise 1's complement of MB
        coma
        inca
        sta    MA
        cmp    #$64           ;check to see if >100
        bcs    not2lo         ;if not we are OK
        lda    #'<'           ;otherwise display that we exceeded min rate
        jsr    lcdchro        ;that LCD can display (<9.9)
        lda    #$63           ;force value to 99
        sta    MA
        bra    goconv

not2lo:  lda    #'-'
        jsr    lcdchro       ;display that minus sign
        bra    goconv

positiv: lda    MA
        cmp    #$64           ;check to see if >100
        bcs    not2hi         ;if not we are OK
        lda    #'>'           ;otherwise display that we exceeded max rate
        jsr    lcdchro        ;that LCD can display (>9.9)
        lda    #$63           ;force value to 99
        sta    MA
        bra    goconv

not2hi:  lda    #'+'
        jsr    lcdchro       ;display the plus sign (to keep alignment)

goconv:  lda    MA            ;get flow
        clrh
        ldx    #$0A           ;and divide by 10
        div
        jsr    lcdnibo        ;display "tens" digit
        lda    #'.'
        jsr    lcdchro        ;display decimal point
        pshh
        pula
        jsr    lcdnibo        ;and first decimal
        lda    UnitType       ;check for cm ($A0) vs. in (#3F)
        cmp    #$3F
        beq    dsplINf

dsplCMf: lda    #'c'
        jsr    lcdchro
        lda    #'m'
        bra    reusef
```

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```
dsplINf:  lda    #'i'
          jsr    lcdchro
          lda    #'n'
reusef:   jsr    lcdchro
          lda    #'/'
          jsr    lcdchro
          lda    #'s'
          jsr    lcdchro
;-----------------------------------
gfxupdt:  lda    #$40          ;======== Graphics Update: tough stuff ===========
          jsr    lcdcmdo       ;prepare to write 8 bytes into CGRAM starting at @ $40
ldhx#ramfree;point to 40 pressure readings (this reuses wrflash RAM)
          mov    #$08,DA       ;DA will count those 8 CGRAM addresses
cg8:      lda    0,x
  sta NC
  lda 1,x
  sta NB
  lda 2,x
  sta NA
  lda 3,x
  sta DC
  lda 4,x
staDB;readings 0-4 go into NC,NB,NA,DC,DB and will form 1 LCD special
character
          mov    #$08,RA       ;RA will count the 8 bits
fill:clrRB;start with RB=0, this will eventually contain the data for CGRAM
  rol NC
  rolRB
    rol NB
  rolRB
  rol NA
  rolRB
  rol DC
  rolRB
  rol DB
rolRB;rotate left those 5 values and use carry bits to form RB (tough part)
  lda RB
jsrlcdchro;and put it into CGRAM
dec RA              ;do this 8 times to cover all 8 bits
  bne fill
          incx
          incx
          incx
          incx
 incx ;now point to next 5 values for next CGRAM address (5 values per
 character)
          dec    DA             ;do this for all 8 CGRAM characters
          bne    cg8

ldaweath;get weather variable and decide which message to display
          cmp    #$04
          bne    try3210
          ldhx   #msg02e        ;if $04
          bra    showit
try3210:  cmp    #$03
          bne    try210
          ldhx   #msg02d        ;if $03
          bra    showit
try210:   cmp    #$02
```


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```
        bne    try10
        ldhx   #msg02c       ;if $02
        bra    showit
try10:  cmp    #$01
        bne    try0
        ldhx   #msg02b       ;if $01
        bra    showit
try0:   ldhx   #msg02a       ;otherwise this one
showit: jsr    lcdstro
        jsr    del1s         ;1s between pressure/altitude readings
        brset  1,porta,contin ;exit only if SEL
        brset  2,porta,contin ;and ENT pressed together
        jmp    MENU
contin: jmp    LVLwarm
;_____________________________________________________________________
LfNx:   sub    N1            ;*** PX=f(NX,N2,N1) ***
        ldx    UnitType      ;$A0=160 for cm, $3F=63 for in
        mul
        sta    NA
        stx    NB
        clr    NC            ;NCNBNA:=(NX-N1)* (conversion value: 160 or 63)

        lda    N2
        sub    N1
        sta    DA
        clr    DB
        clr    DC
        jsr    NdivD         ;RBRA:=(NX-N1)*(conversion value)/(N2-N1)

        lda    RA
        cmp    #$C8          ;check to see if result is negative
        bcs    noovflw       ;if <$C8 we are OK
ovflw:  clr    RA            ;otherwise force level to 0!
noovflw: lda   RA
        rts
;_____________________________________________________________________
NdivD:  clr    RA            ;RBRA:=NCNBNA/DCDBDA
        clr    RB            ;destroys NCNBNA and DCDBDA
keepatit: lda  RA
        add    #$01
        sta    RA
        lda    RB
        adc    #$00
        sta    RB            ;increment RB:RA
        lda    NA
        sub    DA
        sta    NA
        lda    NB
        sbc    DB
        sta    NB
        lda    NC
        sbc    DC
        sta    NC            ;NC:NB:NA:=NC:NB:NA-DC:DB:DA
        bcc    keepatit      ;keep counting how many times until overflow
        lda    RA
        sub    #$01
        sta    RA
        lda    RB
        sbc    #$00
        sta    RB            ;we counted once too many, so undo that
```


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```
        lsr    DC
        ror    DB
        ror    DA          ;divide DC:DB:DA by 2
        lda    NA
        add    DA
        sta    NA
        lda    NB
        adc    DB
        sta    NB
        lda    NC
        adc    DC
        sta    NC          ;and add into NC:NB:NA
        lsla
        bcs    nornd       ;if carry=1 then remainder<1/2 of dividend
        lda    RA
        add    #$01
        sta    RA
        lda    RB
        adc    #$00
        sta    RB          ;otherwise add 1 to result
nornd:  rts
;_____________________________________________________________
;_____________________________________________________________
UNITS:  brclr  2,porta,UNITS  ;let go of ENT first
        lda    #$01         ;===UNITS=== Allows user to select units: inches or cm
        jsr    lcdcmdo      ;clear screen

        ldhx   #msg03
        jsr    lcdstro      ;Unit Choice menu
        jsr    del100ms
        clr    RA           ;menu choice=0 to begin with
        lda    #$0D
        jsr    lcdcmdo      ;blink cursor on menu choice

uluke:  ldx    RA           ;get current menu choice
        clrh
        lda    menupos,x    ;and look up corresponding LCD address
        jsr    lcdcmdo      ;reposition cursor

uwarm:  brclr  1,porta,uPB1  ;check for SEL
        brclr  2,porta,uPB2  ;or for ENT
        bclr   4,porta       ;otherwise
        bset   5,porta       ;turn on "SEL" LED
        jsr    del100ms      ;delay
        bset   4,porta       ;toggle LEDs
        bclr   5,porta       ;"ENT" now on: means choice is SEL ***or*** ENT
        jsr    del100ms      ;delay and repeat until SEL or ENT
        bra    uwarm

uPB1:   inc    RA           ;***SEL*** toggles menu choices
        lda    RA
        cmp    #$02         ;menu choices are $00 and $01
        bne    uPB1ok
        clr    RA           ;back to $00 when all others have been offered
uPB1ok: bclr   4,porta
        bclr   5,porta       ;LEDs off
        jsr    del100ms      ;wait a little bit
        brclr  1,porta,uPB1ok ;make sure they let go of SEL
        bra    uluke
```

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```
uPB2:    bclr   4,porta       ;***ENT*** confirms menu choice
         bclr   5,porta       ;LEDs off
         lda    RA            ;get menu choice
         bne    SelIN

SelCM:   ldhx   #$A014        ;initialize default units to cm ($A0=cm, $3F=in)
         sthx   UnitType      ;UnitType set to $A0; UnitDiv set to $14
         ldhx   #$039E
         sthx   UnitEmpt      ;UnitEmpt set to $03; UnitFull set to $9E
         lda    #$01
         jsr    lcdcmdo       ;clear LCD
         ldhx   #msg03a
         jsr    lcdstro       ;and show choice selection to be cm
         jsr    del1s         ;wait 1s
         jmp    LEVEL         ;let's do LEVEL now...

SelIN:   ldhx   #$3F08        ;initialize default units to in ($A0=cm, $3F=in)
         sthx   UnitType      ;UnitType set to $3F; UnitDiv set to $08
         ldhx   #$033D
         sthx   UnitEmpt      ;UnitEmpt set to $03; UnitFull set to $3D
         lda    #$01
         jsr    lcdcmdo       ;clear LCD
         ldhx   #msg03b
         jsr    lcdstro       ;and show choice selection to be in
         jsr    del1s         ;wait 1s
         jmp    LEVEL         ;let's do LEVEL now...
;_____________________________________________________________________
;_____________________________________________________________________
;_____________________________________________________________________

;*********************************************************************
;*********************************************************************
;******** GENERAL Routines ***************************************
;*********************************************************************
;*********************************************************************

;-------- INITIALIZATION Routines ---------------------------------
;        ALLINIT: initializes HC08, sets I/O, resets LCD and LEDs
;        -------
ALLINIT:  bset   0,config1     ;disable COP
         mov    #$38,ddra     ;PTA0=MPAK,PTA1=SEL,PTA2=ENT,PTA3=E,PTA4=RS,PTA5=clk
         mov    #$30,adiclk   ;ADC clock /2
         bclr   3,porta       ;E=0
         bclr   4,porta       ;grn=OFF; RS=0
         bclr   5,porta       ;red=OFF; CLK=0
         rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;        WARMUP: waits half a second while it flashes LEDs, and allows LCD to get ready
;        ------
WARMUP:   bclr   4,porta
         bclr   5,porta       ;LEDs off
         lda    #$0A          ;prepare to do this 10x
tenx:     jsr    del25ms       ;delay
         bclr   4,porta
         bset   5,porta       ;alternate on/off
         jsr    del25ms
         bset   4,porta
         bclr   5,porta       ;and off/on
         dbnza  tenx          ;10 times so the LCD can get ready (slow startup)
         jsr    lcdinit       ;now initialize it
```


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```
        bclr   4,porta
        bclr   5,porta       ;LEDs off
        rts
;-------- WRITE TO EEPROM Routines ---------------------------------
;       wrflash: burns A into flash at location pointed by H:X
;       -------
wrflash:  sthx   flshadr       ;this is the address in the flash
        sta    flshbyt       ;and the byte we want to put there
        tsx
        sthx   memSP         ;store SP in memSP, so it can be temporarily used as a 2nd index register
        ldhx   #ramfree+1    ;SP now points to RAM (remember to add 1 to the address!!!, HC08 quirk)
        txs                ;SP changed (careful not to push or call subroutines)
        ldhx   #ersflsh      ;H:X points to beginning of flash programming code
doall:    lda    0,x          ;get 1st byte from flash
        sta    0,sp         ;copy it into RAM
        aix    #$0001        ;HX:=HX+1
        ais    #$0001        ;SP:=SP+1
        cphx   #lastbyt      ;and continue until we reach the last byte
        bne    doall
        ldhx   memSP         ;once done, restore the SP
        txs
        jsr    ramfree       ;and run the subroutine from RAM, you cannot write the flash while
        rts                ;running a code in it, so the RAM has to take over for that piece
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;*************** THE FOLLOWING CODE WILL BE COPIED INTO AND WILL RUN FROM RAM ******
ersflsh:  lda    #$02          ;textbook way to erase flash
        sta    flcr
        lda    flbpr
        clra
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$0A
        sta    flcr
        bsr    delayf
        lda    #$08
        sta    flcr
        bsr    delayf
        clra
        sta    flcr
        bsr    delayf
pgmflsh:  lda    #$01          ;textbook way to program flash
        sta    flcr
        lda    flbpr
        clra
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$09
        sta    flcr
        bsr    delayf
        lda    flshbyt
        ldhx   flshadr
        sta    0,x
        bsr    delayf
        lda    #$08
        sta    flcr
        bsr    delayf
        clra
        sta    flcr
```

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```
        bsr    delayf
        rts
delayf:   ldhx   #$0005        ;wait 5x20us
        mov    #$36,tsc       ;stop TIM & / 64
        sthx   tmodh          ;count H:X x 20us
        bclr   5,tsc          ;start clock
delayfls: brclr  7,tsc,delayfls
        rts                   ;this RTS will move from RAM back into EEPROM
lastbyt:  nop
;*************** END OF CODE THAT WILL BE COPIED INTO AND WILL RUN FROM RAM ******
;-------- DELAY Routines ----------------------------------------
;       del1s: generates a 1s delay
;       -----
del1s:    pshh
        pshx
        ldhx   #$C350         ;1 second delay=$C350=50000 x 20us
        bra    delmain
;-----------------------------------
;       del100ms: generates a 100ms delay
;       --------
del100ms: pshh
        pshx
        ldhx   #$1388
        bra    delmain
;-----------------------------------
;       del50ms: generates a 50ms delay
;       -------
del50ms:  pshh
        pshx
        ldhx   #$09C4
        bra    delmain
;-----------------------------------
;       del25ms: generates a 25ms delay
;       -------
del25ms:  pshh
        pshx
        ldhx   #$04E2
        bra    delmain
;-----------------------------------
;       del5ms: generates a 5ms delay
;       ------
del5ms:   pshh
        pshx
        ldhx   #$00FA
        bra    delmain
;-----------------------------------
;       del1ms: generates a 1ms delay
;       ------
del1ms:   pshh
        pshx
        ldhx   #$0032
        bra    delmain
;-----------------------------------
;       del100us: generates a 100us delay
;       -----
del100us: pshh
        pshx
        ldhx   #$0005
        bra    delmain
;-----------------------------------
```


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```
;       delmain: main delay routine; generates delay equal to H:X x 20us
;       -------
delmain:  mov    #$36,tsc       ;stop TIM & / 64
        sthx   tmodh          ;count H:X x 20us
        bclr   5,tsc          ;start clock
delwait:  brclr  7,tsc,delwait  ;wait for end of countdown
        pulx
        pulh
        rts                   ;this RTS serves for all delay routines!
;-------- A/D Routines ----------------------------------------------
;       adcbyti: gets single A/D reading from PTA0 and returns it in A
;       -------
adcbyti:  mov    #$00,adscr     ;ADC set to PTA0
        brclr  7,adscr,*      ;wait for ADC reading
        lda    adr            ;result in adr
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       adcbyta: gets averaged A/D reading from PTA0 and returns it in A
;       -------
adcbyta:  clr    CNT            ;average 256 readings
        clr    RB             ;will be addint them up
        clr    RA             ;in RB:RA
do256a:   bsr    adcbyti
        add    RA
        sta    RA
        lda    RB
        adc    #$00
        sta    RB             ;16-bit add into RB:RA
        dbnz   CNT,do256a     ;do all 256
        lsl    RA             ;if RA<$80
        bcc    nochga         ;then RB result is correctly rounded
        inc    RB             ;otherwise round off to next value
nochga:   lda    RB
        rts
;-------- LCD Routines ---------------------------------------------
;       lcdinit: initializes LCD
;       -------
lcdinit:  lda    #$3C           ;set 8-bit interface, 1/16 duty, 5x10 dots
        bsr    lcdcmdo
        lda    #$0C           ;display on, cursor off, blink off
        bsr    lcdcmdo
        lda    #$06           ;increment cursor position, no display shift
        bsr    lcdcmdo
        lda    #$01           ;clear display
        bsr    lcdcmdo
        rts
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       lcdcmdo: sends a command to LCD
;       -------
lcdcmdo:  bsr    shiftA
        bclr   4,porta        ;RS=0 for command
        bset   3,porta
        bclr   3,porta        ;toggle E
        bsr    del5ms         ;some commands require 2ms for LCD to execute
        rts                   ;so let's play it safe
;- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
;       lcdchro: sends a character (data) to LCD
;       -------
lcdchro:  bsr    shiftA
        bset   4,porta        ;RS=1 for data
```

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```
        bset   3,porta
        bclr   3,porta       ;toggle E
        bsr    del100us      ;data only requires 40us for LCD to execute
        rts
;-----------------------------------
;       shiftA: shifts A into shift register and provides 8-bits to LCD
;       ------
shiftA:   psha
        mov    #$08,BB       ;will be shifting 8 bits
all8:     lsla               ;get bit
        bcc    shift0        ;if bit=0 then shift a 0
shift1:   bset   4,porta      ;otherwise shift a 1
        bra    shift
shift0:   bclr   4,porta      ;bit 4 is data to shift register
shift:    bclr   5,porta      ;bit 5 is shift register clock
        bset   5,porta
        bclr   5,porta       ;toggle CLK
        dbnz   BB,all8       ;do all 8 bits
        pula
        rts
;-----------------------------------
;       lcdnibo: displays 1 character (0-9,A-F) based on low-nibble value in A
;       -------
lcdnibo:  psha               ;convert 4 bits from binary to ascii
        add    #$30          ;add $30 (0-9 offset)
        cmp    #$39          ;is it a number (0-9) ?
        bls    d0to9b        ;if so skip
        add    #$07          ;else add $07 = total of $37 (A-F offset)
d0to9b:   bsr    lcdchro
        pula
        rts
;-----------------------------------
;       lcdbyto: displays 2 characters based on hex value in A
;       -------
lcdbyto:  psha
        psha                 ;remember A (for low nibble)
        lsra                ;shift right 4 times
        lsra
        lsra
        lsra
        bsr    lcdnibo       ;high nibble
        pula
        and    #$0F
        bsr    lcdnibo       ;low nibble
        pula
        rts
;-----------------------------------
;       lcdstro: displays message ending in '@', but also sends commands to LCD
;       -------
lcdstro:  psha
        lda    0,x
lcon:     cmp    #$80          ;if ASCII >=$80
        bhs    iscmd
        cmp    #$1F          ;or <=$1F then
        bls    iscmd         ;assume it is a command to LCD
isdta:    bsr    lcdchro       ;otherwise it is data to LCD
reuse1:   aix    #$0001        ;next character
        lda    0,x           ;indexed by x
        cmp    #$40          ;continue until
        bne    lcon          ;character = '@'
```


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```
        pula                ;we are done
        bclr   4,porta      ;so
        bclr   5,porta      ;turn off LEDs
        rts
iscmd:   bsr    lcdcmdo
        bra    reuse1
;-------- ROM DATA: contains all LCD messages ----------------------
msg01    db     $01,$80,'*MPAK & 908QT4* '
        db       $C0,'Reference Design','@'
msg01a   db     $01,$80,'Water Level &   '
        db       $C0,'Flow       v2.0','@'
msg01b   db     $01,$80,'1:Level/Flow    '
        db       $C0,'2:Set Units     ','@'
msg05    db     $01,$80,'* Calibration! *'
        db       $C0,'Curr lo/hi:','@'
msg05a   db     $01,$80,'1st point:   0mm'
        db       $C0,'SEL:cal ENT:quit','@'
msg05b   db     $01,$80,'Calibrating...  '
        db       $C0,'    0mm: ','@'
msg05c   db     $01,$80,'2nd point: 160mm'
        db       $C0,'ENT:continue    ','@'
msg05d   db     $01,$80,'Calibrating...  '
        db       $C0,'  160mm: ','@'
msg05e   db     $01,$80,'INVALID         '
        db       $C0,'CALIBRATION!    ','@'
msg02a   db       $C8,'   EMPTY','@'
msg02b   db       $C8,'    FULL','@'
msg02c   db       $C8,'  steady','@'
msg02d   db       $C8,' H20  in','@'
msg02e   db       $C8,' H20 out','@'
msg03    db    $01,$80,'1: unit=cm H20 '
        db       $C0,'2: unit=in H20 ','@'
msg03a   db       $80,'Unit is now: cm','@'
msg03b   db       $80,'Unit is now: in','@'
menupos  db    $80,$C0

        end
```

REFERENCES

Baum, Jeff, “Frequency Output Conversion for MPX2000 Series Pressure Sensors,” Application Note AN1316/D.

Hamelain, JC, “Liquid Level Control Using a Pressure Sensor,” Application Note AN1516/D.

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Altimeter and Barometer System

by: Michelle Clifford and Fernando Gonzalez
Sensor Products Division, Tempe, AZ

INTRODUCTION

With smaller packages and lower costs, pressure sensors can be designed into more consumer applications. This document describes a reference design for a digital barometer and altimeter using the MPXM2102A pressure sensor in the low cost MPAK package, a quad op-amp, and the MC68HC908QT4 microcontroller. This system continuously monitors the barometric pressure and compares it to previous pressure readings to update altitude and weather predictions. This reference design enables the user to evaluate a Freescale Semiconductor, Inc. pressure sensor for barometer, personal weather station and altimeter applications. This reference design also allows customers to evaluate barometer pressure readings obtainable from the MPXM2102A sensor for watches or GPS systems with this feature. In addition, many systems require barometric pressure data to correct system response errors. This application note describes the reliability and accuracy that our sensors can provide in this system.

SYSTEM DESIGN

Pressure Sensor

The barometer/altimeter system requires a pressure sensor that has a pressure range of 64 kPa to 105 kPa. Freescale Semiconductor, Inc. has a broad portfolio of silicon piezo-resistive pressure sensors. They provide a very accurate and linear voltage output directly proportional to the applied pressure. By evaluating the application design and cost, the right pressure sensor can be selected from our portfolio.

Figure 1. Pressure Sensor

There are three types of pressure measurements: gauge, absolute, and differential. Since this reference design measures changes in ambient pressure, we need a known pressure reference. Therefore, an absolute pressure sensor was selected. Freescale offers three levels of integration: uncompensated, compensated, and integrated. Since there can be large temperature changes from one elevation to another the sensor for this reference design needs to be offset calibrated and temperature compensated. Therefore a compensated sensor was selected requiring external amplification circuitry. However, integrated solutions such as the MPXM5100A, can also be considered, thereby eliminating the need for the external amplification circuitry.

Knowing the range of pressure, the type of pressure measurement, and the level of integration required for this application, the MPXM2102A sensor was selected. The sensor has both temperature compensation and calibration circuitry on the silicon and is capable of producing a linear output voltage in the range of 0 to 100 kPa, but can be pushed further up to 105 kPa with linear results. The characteristics of this sensor are described in greater detail in Table 2. A 5-volt supply was used throughout the circuit to power the components. Since the MPXM2102A is ratio metric, meaning the output voltage changes linearly with the supply voltage, the sensor will have a full scale span of 20 mV instead of the specified 40 mV at a 10 V supply. The calculation of the full scale span is shown below:

$$(V_{S\ actual}/V_{S\ spec}) \times V_{OUT\ full\text{-}scale\ spec} = V_{OUT\ full\text{-}scale}$$

$$(5.0\ V/\ 10\ V) \times 40\ mV = 20\ mV$$

One of the most important decisions for a pressure application is the packaging. Freescale has a large offering of pressure packaging options. To minimize the space of a final application, the MPAK package was selected. A non-ported MPAK is the ideal pressure sensor package for hand held GPS units or altimeter watches due to its small size. However, a ported MPAK package can also be selected, allowing a tube to be attached to the port for testing and demonstration purposes.

Figure 2. MPXM2102A Case 1320A-02

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Table 1. MPXM2102A Operating Characteristics

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range		P_{OP}	0	—	100	kPa
Supply Voltage		V_S	—	10	15	Vdc
Supply Current		I_O	—	6.0	—	mAdc
Full Scale Span		V_{FSS}	38.5	40	41.5	mV
Offset		V_{off}	-1.0 -2.0	— —	1.0 2.0	mV
Sensitivity	MPX2102D Series MPX2102A Series	$\Delta V/\Delta P$	—	0.4	—	MV/kPa
Linearity	MPX2102D Series MPX2102A Series	— —	-0.6 -1.0	— —	0.4 1.0	$\%V_{FSS}$

Amplifier Selection and Amplifier Induced Errors

The main goal of the signal conditioning circuit is to convert the MPX2102A differential output to a single-ended, ground-referenced output. The differential output is extremely small for the MCU to process so a conditioning circuit also needs to provide amplification.

This reference design has a barometric pressure range of 64 kPa to 105 kPa. The output of the sensor is ratiometric to the supply voltage and the supply voltage is 5.0 V, the FSS, Sensitivity, and Offset are 5.0 V/10 V, or half, of the specified values at a 10 V supply. Using these calculated sensitivity and offset ranges, the lowest and highest possible values were calculated.

V_{OUT} = (Applied Pressure * Sensitivity) ± Offset

V_{OUT} at 64 kPa = 64 kPa * 0.2 mV/kPa — 1 mV = 11.32 mV

V_{OUT} at 105 kPa = 105 kPa * 0.2 mV/kPa + 1 mV = 21.0 mV

These values were found to be 11.32 mV to 22.79 mV differential output from the sensor.

Two-Stage Design

This two-stage design level shifts the differential output voltage of the sensor by subtracting an offset voltage from each of the sensor outputs, then uses a differential amplification as shown in Figure 2.

After the first stage of amplification, the output of op-amp A is:

$V_A = (1+R8/R6) \times V_4 - (R8/R6) \times V_S$(1)

$= (1+10/4.42k) \times V_4 - (10/4.42k) \times 5.0$ V

$= (1+10/4.42k) \times V_4 - 11.3$ mV

and the output of op-amp B is:

$V_B = (1+R7 / R5) \times V_2 - (R7 / R5) \times V_S$(2)

$= (1+10/4.42\ k) \times V_2 - (10/4.42\ k) \times 0$ V

$= (1+10/4.42\ k) \times V_2 - 0$

The second stage of amplification connects these two outputs to a common differential amplifier (op-amp C) also shown in Figure 3. With some algebraic manipulation, the output voltage (V_{OUT}) of the entire amplification circuit is

$V_C = (R12/R11) \times [(1+R8/R6) \times (V_2 - V_4) - (R8/R6) \times V_S]$(3)

$= (412K/1\ k) \times [(1+10/4.42\ K) \times (V_2 - V_4) - (10/4.42\ K) * 5\ V]$

$= (412) \times [(1.002) \times (V_2 - V_4) - 11.3\ mV]$

$= 412 \times (V_2 - V_4) - 11.3$ mV

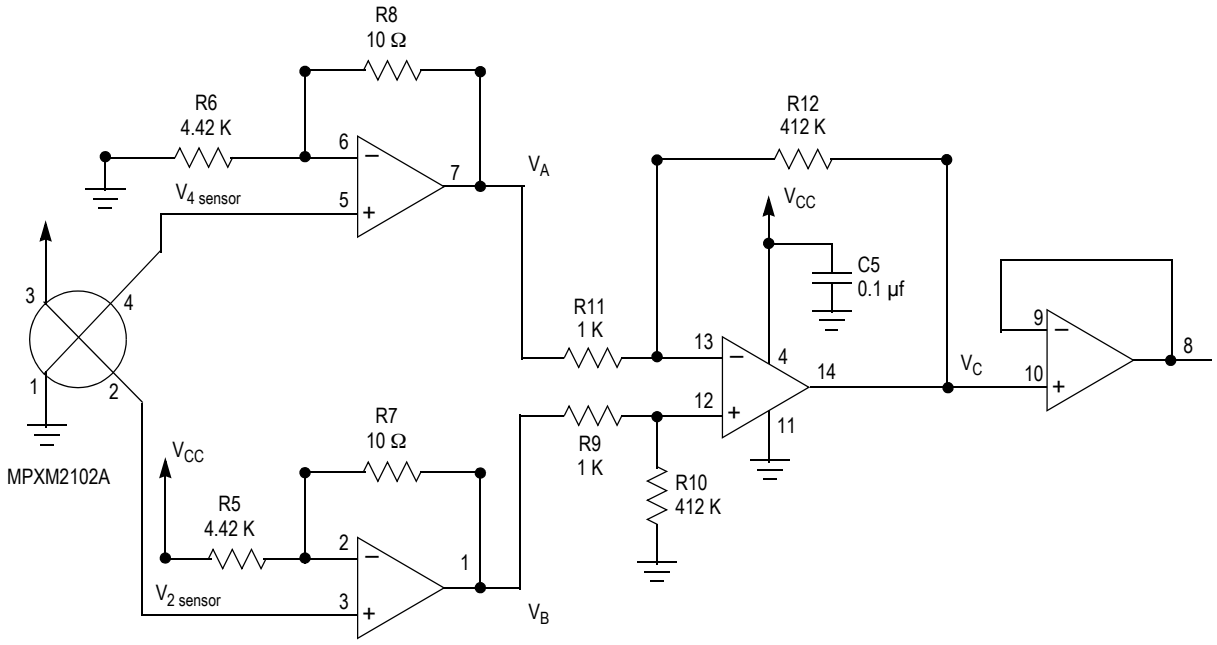

Figure 3. Amplification Scheme

The range of the A/D converter is 0 to 255 counts. However, the A/D values that the system can achieve are dependent on the maximum and minimum system output values:

Count = $(V_{OUT} – V_{RL}) / (V_{RH} – V_{RL})$ x 255(4)

where V_{Xdcr} = Transducer Output Voltage

V_{RH} = Maximum A/D voltage

V_{LH} = Minimum A/D voltage

Count (64 kPa) = (0.03 – 0.0) / (5.0 – 0.0) x 255 = 2

Count (105 kPa) = (4.85 – 0.0) / (5.0 – 0.0) x 255 = 247

Total # counts = 247 – 2 = 245 counts.

The resolution of the system is determined by the barometric pressure represented by each A/D count. As calculated above, the system has a span of 247 counts to represent a pressure from 64 kPa to 105 kPa. Therefore, the resolution is:

Resolution = (System Pressure Range) /
Total # counts (5)

= (105 kPa — 64 kPa)/245 counts

= 0.17 kPa per A/D count

Microprocessor

To provide the signal processing for pressure values, a microprocessor is needed. The MCU chosen for this application is the MC68HC908QT4. This MCU is perfect for appliance applications due to its low cost, small eight-pin package, and other on-chip resources. The MC68HC908QT4 provide: a four-channel, eight-bit A/D, a 16-bit timer, a trimmable internal timer, and in-system FLASH programming.

The central processing unit is based on the high performance M68HC08 CPU core and it can address 64 Kbytes of memory space. The MC68HC908QT4 provides 4096 bytes of user FLASH and 128 bytes of random access memory (RAM) for ease of software development and maintenance. There are five bi-directional input/output lines and one input line that are shared with other pin features.

The MCU is available in eight-pin as well as 16-pin packages in both PDIP and SOIC. For this application, the eight-pin PDIP was selected. The eight-pin PDIP was chosen for a small package, eventually to be designed into applications as the eight-pin SOIC. If added circuitry for programming the microcontroller is added, a cyclone could be used to program an SOIC on the PCB. If your design requires software updates, consult the MC68HC908QT4 handbook for adding this option.

IMPROVEMENTS

The resolution of this design is limited by the eight-bit A/D converter on the microcontroller. Theoretically, the accuracy achieved by this device should produce an output when altitude change differs by about 41.54 feet (ΔZ). This occurs at approximately 1000 feet below sea level. Due to the logarithmic relationship between pressure and elevation, the accuracy of the results decreases as the device is elevated. At 12,000 feet above sea level, the device should recognize a change of about 65.53 feet (ΔZ) as shown in Table 3. A 10-bit, 12-bit or even a 16-bit A/D converter could be implemented in order to increase the resolution of this reference design.

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Table 2. Microcontroller Accuracy Comparisons

Z (ft)	P (kPa)	V (mV)	Amp scheme	Vamp (mV)	Vamp – 1 bit	P0	Px	ΔZ (m)	ΔZ (ft)	Micro
-1000	105	20.265	(Vx–12.8)*650	4852.3	4832.6	20.265	20.235	12.66	41.54	8 bits
12000	64.259	12.852		33.8	14.2	12.852	12.822	19.97	65.53	8 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4847.4	20.265	20.257	3.15	10.35	10 bits
12000	64.259	12.852		33.8	28.9	12.852	12.844	4.97	16.32	10 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4851	20.265	20.263	0.79	2.59	12 bits
12000	64.259	12.852		33.8	32.6	12.852	12.85	1.24	4.08	12 bits
-1000	105	20.265	(Vx–12.8)*650	4852.3	4852.2	20.265	20.265	0.05	0.16	16 bits
12000	64.259	12.852		33.8	33.7	12.852	12.852	0.08	0.25	16 bits

Table 2 shows the theoretical maximum resolution that this reference design can achieve. However, factors such as noise within the circuit, sensitivity of the sensor, and voltage offsets in the amplification scheme should be taken into consideration. Accommodating for these factors in the software can filter out some of these factors.

Further testing is required to determine the accuracy of the reference design without the limiting A/D converter.

DISPLAY

The display of the barometric pressure, barometric pressure history, current calculated altitude, and a simple weather prediction is displayed on a 16x2 LCD.

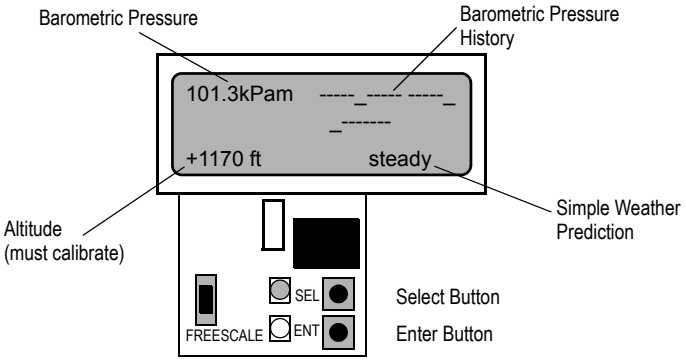

Figure 4. Barometric Display

Due to the limited number of bi-directional data pins on the microcontroller, a system was designed to serially buffer the display data. Using a shift register to hold display data, the LCD is driven with only three lines of output from the microcontroller: an enable line, a data line, and a clock signal while the two LEDs are multiplexed with the data line and clock signal.

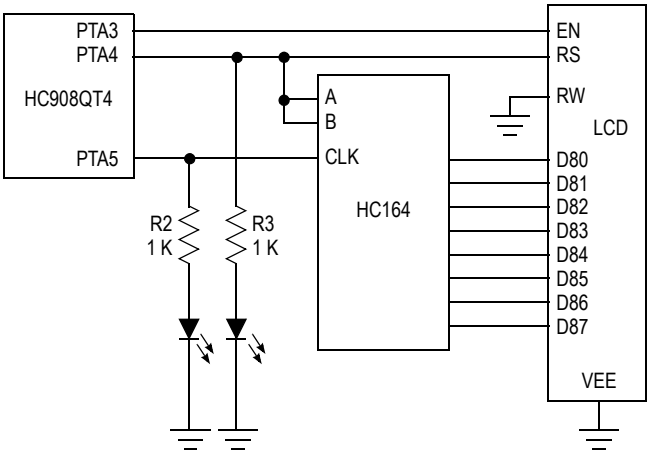

Figure 5. Multiplexed LCD Circuit

Multiplexing of the microcontroller output pins allows communication of the LCD to be accomplished with three pins instead of eight or 11 I/O pins usually required. With an eight-bit shift register, we are able to manually clock in eight bits of data. The enable line, EN, is manually enabled when eight bytes have been shifted in, telling the LCD the data on the data bus is available to execute. The LCD will only be written to and the contrast can be held at a constant brightness, allowing the read/write and the VEE bits to be held low, also minimizing additional I/O lines.

Table 3. Parts List

Ref	Qty.	Description	Value	Vendor	Part No.
U3	1	Pressure Sensor	1.0	Freescale	MPXM2102A
C1	1	V_{CC} Cap	0.1 μF	Generic	
C2	1	Op-Amp Cap	0.1 μF	Generic	
C3	1	Shift Register Cap	0.1 μF	Generic	
D1	1	Red LED	—	Generic	
D2	1	Green LED	—	Generic	
S2, S3	1	Push buttons	—	Generic	
U1	1	Microcontroller	8-Pin	Freescale	MC68HC908QT4
U2	1	16x2 B&W LCD	16x2	Seiko	L168200J000
U4	1	Shift Register	—	Texas	74HC164
U5	1	Voltage Regulator	5.0 V	Fairchild	LM78L05ACH
U6	1	Quad Op-Amp	—	ADI	AD8544
R1, R4	1	1/4 W Resistor	10 K	Generic	
R2, R3	2	1/4 W Resistor	1.0 K	Generic	
R5, R6	2	1/4 W Resistor	3.65 K	Generic	
R7, R8	2	1/4 W Resistor	10 K	Generic	
R9, R11	2	1/4 W Resistor	1.0 K	Generic	
R10, R12	2	1/4 W Resistor	200 K	Generic	

OTHER

This system is designed to run on a 9.0 V battery. It contains a 5.0 V Regulator to provide a 5.0 V supply to the pressure sensor, microcontroller, and LCD. The battery is mounted on the back of the board using a space saving spring battery clip.

ALTIMETER/BAROMETER SOFTWARE

This application note describes the software version that was available during publication. However updated software versions may be available with further functionality and menu selections. Check our website update for updates to Sensor Products Reference designs.

Software User Instructions

When the system is turned on or reset, the microcontroller will flash the select LED and display the program title on the LCD for five seconds or until the select (SEL) button is pushed. Then the menu screen is displayed. Using the select (SEL) push button, the user can scroll through the menu options for a software program. To run the altimeter program, use the (SEL) select button to high-light the “Alti/Barometer” option, then press the enter (ENT) push button. The Altimeter program will display current barometric pressure reading, the calculated altitude in feet, a message displaying a simple weather prediction such as “sunny”, “rainy”, “steady” without a pressure change, and “history” before enough history is collected to make a prediction. In the top right corner of the display, a scrolling graphical history displays data points representing the past forty pressure readings.

Calibration and Calibration Software

There are two forms of calibration for this system. The first calibration is used for the barometer part of the system. This calibration was already done before you received the reference design and only needs to be done once per system. To calibrate the barometer module, a two-point calibration is performed using a highly accurate pressure generator. The system takes a calibration point at 64 kPa and another at 105 kPa. Holding down both the SEL and ENT buttons on system power-up will put the system into calibration mode. At this point, the calibration menu will be displayed with the previously sampled offset voltage. To recalibrate the system, apply a pressure of 64 kPa and press the SEL button (PB1). This A/D value is then saved to a location in the microcontroller memory. To obtain the second calibration point, using the accurate pressure generator apply a pressure of 105 kPa directly to the sensor. Then press the ENT button (PB2). This signal is similarly sampled, averaged and saved to

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a location in FLASH. To exit the calibration mode, press the SEL (PB1) button.

The second calibration is done for the altimeter. The Altimeter requires a one-point calibration where a known altitude is entered with a known pressure. This ensures that changes in atmospheric pressure are due to increases or decreases in altitude and not changes in barometric pressure. By returning to the main menu, and selecting the “Set Elevation”, the user can select an elevation by pressing the SEL button to cycle through the Elevation options from 0 to 12000 feet in 100-foot increments. Once the selection has been made the elevation is flashed into the microcontroller and the user is brought to the Altimeter/Barometer function. Calibration is required for each use of the altimeter module.

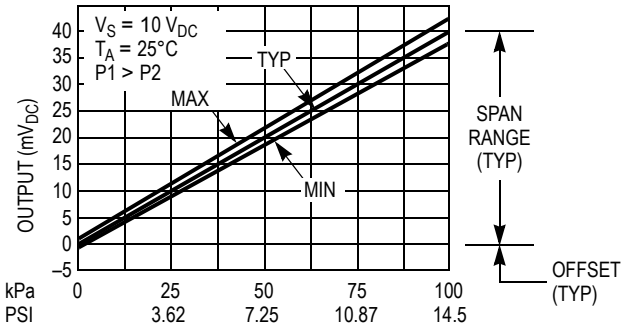

Figure 6. Analog Output to Pressure

CONVERTING ANALOG OUTPUT TO PRESSURE

Freescale pressure sensors have an extremely linear analog voltage output that is proportional to the pressure input. Since the sensor output is linear, the pressure can be calculated by using the equation of a line, y = mx + b, where y is the output voltage, the slope, m, is the Sensitivity, and the y intercept, b, is the Offset:

V_{OUT} = Sensitivity x Pressure + Offset

With algebraic manipulation, pressure can be determined by:

Pressure = (V_{OUT} – Offset)/Sensitivity

Below is an example of determining the pressure from the analog output of 9.5 mV using the Sensitivity and Offset of the MPX2102a sensor specified in the datasheet:

Pressure = (V_{OUT} – Offset)/Sensitivity

= (9.5 mV – 0.5 mV) / 0.1 mV/kPa

= (9.0)/0.1 mV/kPa

= 90 kPa

where 0.5 mV is the typical offset for the MPX2102 and 0.1 mV/kPa is the sensitivity with a 5.0 V supply

This system uses additional amplifiers and an A/D converter that all add additional offset and gain errors; however, the translation function was corrected with the two-point calibration. The known pressure values that are used for calibration are the maximum and minimum pressures for the system, 105 kPa and 64 kPa respectively. The A/D values for these known pressures are saved in the flash memory of the microcontroller.

ATD = (Po – P_{64kPa})/(P_{105kPa} - P_{64kPa}) x 255

By algebraic manipulation, the following equation is reached to find the barometric pressure:

Po = (ATD/255) x (P_{105kPa} - P_{64kPa}) + P_{64kPa}

Converting Pressure to Altitude

The method of determining altitude for this reference design is measuring the changes in barometric pressure. The relationship of pressure vs. altitude is not linear. As pressure decreases, altitude increases, but the higher the altitude gets the less pressure changes. The equation that was used for this reference design is:

P = (P0) e^[-(g/(RT)) x (Z — Z0),

where P = pressure at an unknown altitude,

P0 = pressure at a known altitude,

e = a constant,

g = gravitational constant 9.8 (m/s^2),

R = dry air constant 287 J/(kg x K),

T = temperature at unknown elevation in Kelvin,

Z = unknown altitude in meters,

and Z0 = known altitude also in meters.

This equation originates from the hydrostatic equation:

dP = -ρgdZ

in conjunction with the ideal gas law:

P = ρRT

After some algebraic manipulation, plugging in constant values and converting meters to feet, the following equation was generated:

Z = Z0 — 27,887 in (P/P0),

where Z = unknown altitude in feet,

Z0 = known altitude also in feet,

P = known pressure at unknown altitude,

and P0 = known pressure at known altitude.

For this system to calculate an altitude, Z, at a known pressure P, the user must enter a known pressure, P0, and its corresponding altitude, Z0. To accommodate for changes in barometric conditions, the known pressure and altitude data must be re-entered during each use to ensure accuracy.

Simple Weather Prediction

Atmospheric pressure at the Earth’s surface is one of the measurements used to make weather predictions. Air in a high-pressure area compresses and warms as it descends. The warming air inhibits the formation of clouds. Therefore, the sky is normally sunny in high-pressure areas with a small chance of haze or fog. However, in an area of low atmospheric pressure, the air rises and cools. With enough humidity in the

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air, the rising air will cool, the air will condense forming clouds and precipitation in the form of rain or snow.

This reference design saves the current pressure reading and compares it to past pressure measurements. It determines if there was a pressure drop or a pressure increase. Using this information, it makes a simple weather prediction by sending a message of ‘sunny’ for a pressure increase, ‘rainy for a pressure drop, and ‘steady’ for no significant change in pressure.[1]

CONCLUSION

The Altimeter is one of many applications for the MPXM2102AS pressure sensor. This reference design can be used as a reference for developing more integrated barometer applications such as hand-held weather stations, altimeter features for camera or GPS systems, as well as barometric pressure monitoring systems for industrial systems. The MPXM2102AS is an excellent pressure sensor for this application since it is calibrated and temperature compensated. By having these features available on-chip, there is a large savings in PCB real estate in addition to savings in cost for external components

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Table 4. Elevation Pressure and Temperature Changes

Altitude Above Sea Level		Temperature		Barometer	Atmospheric Pressure	
Feet	Meters	F	C	mm * Hg	psi	kPa
-1000	-305	63	17	787.9	15.23	105.0
-500	-153	61	16	773.9	14.96	103.1
0	0	59	15	760.0	14.69	101.33
500	153	57	14	746.3	14.43	99.49
1000	305	55	13	733.0	14.16	97.63
1500	458	54	12	719.6	13.91	95.91
2000	610	52	11	706.6	13.66	94.19
2500	763	50	10	693.9	13.41	92.46
3000	915	48	9	681.2	13.17	90.81
3500	1068	47	8	668.8	12.93	89.15
4000	1220	45	7	656.3	12.69	87.49
4500	1373	43	6	644.4	12.46	85.91
5000	1526	41	5	632.5	12.23	84.33
6000	1831	38	3	609.3	11.78	81.22
7000	2136	34	1	586.7	11.34	78.19
9000	2441	31	-1	564.6	10.91	75.22
9000	2746	27	-3	543.3	10.5	72.40
10,000	3050	23	-5	522.7	10.1	69.64
15,000	4577	6	-14	429.0	8.29	57.16

1. This information was found from the USA Today Weather Book from USAToday.com.

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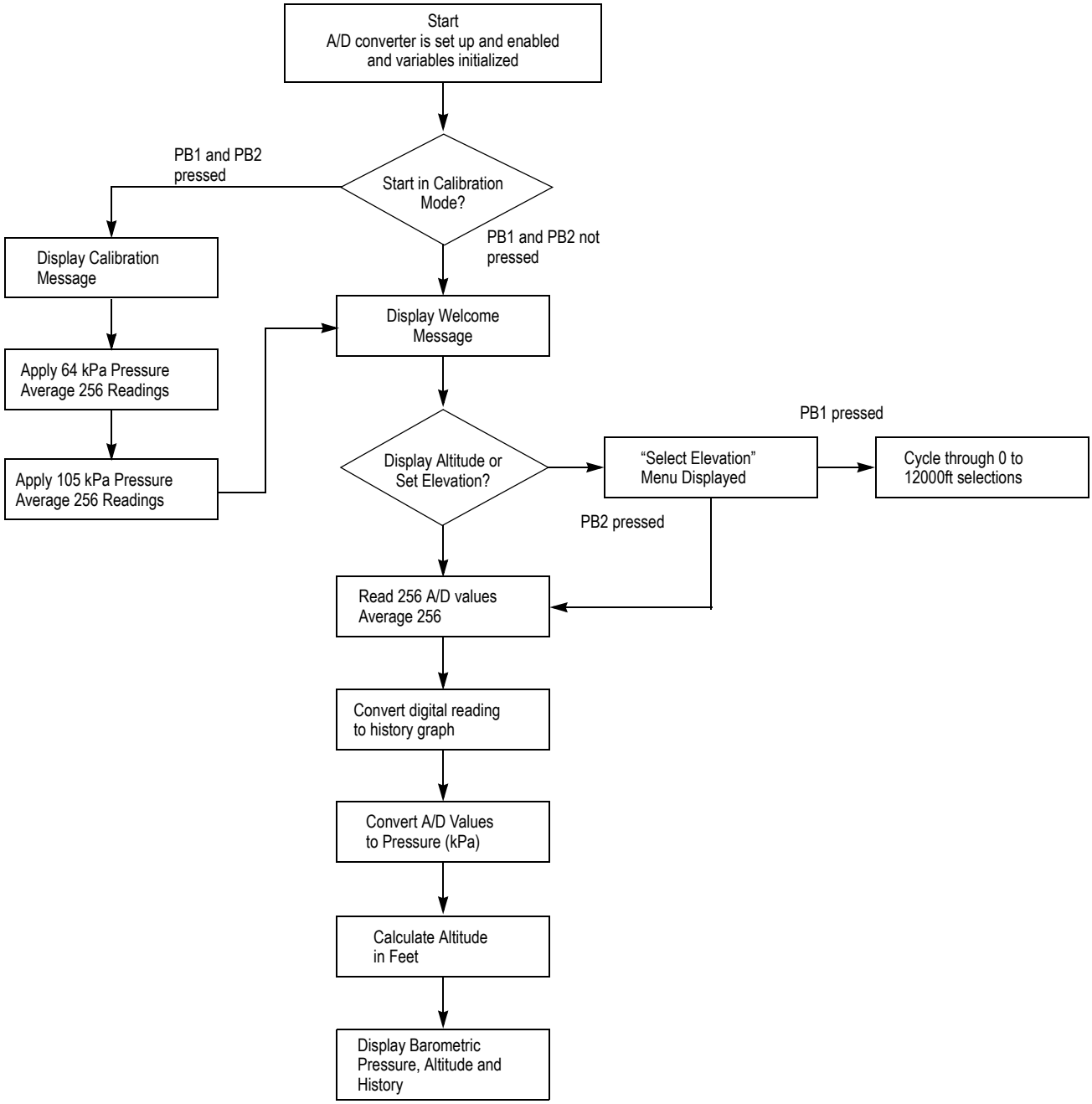

Figure 7. Altimeter/Barometer Software Flow Diagram

REFERENCES

Williams, Jack. (2001). Understanding Air Pressure. *The Weather Book*, 5, 117–123. Retrieved April 4, 2003, from http://www.usatoday.com/weather/wfront.htm

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Handling Freescale Pressure Sensors

by: William McDonald

INTRODUCTION

Smaller package outlines and higher board densities require the need for automated placement of components. These components are supplied in embossed carrier tape on plastic reels to meet the increased demand and facilitate ease of handling. This application note is intended to provide general information and understanding for handling Freescale's surface mount pressure sensors. Equipment details are not provided in this document and it is recommended that end users contact suppliers of equipment for specific applications.

METHODS OF HANDLING

Components can be picked from the carrier tape using either the vacuum assist or the mechanical type pick up heads. A vacuum assist nozzle type is most common due to its lower cost of maintenance and ease of operation. The recommended vacuum nozzle configuration should be designed to make contact with the device directly on the metal cover and avoid vacuum port location directly over the vent hole in the metal cover of the device. To provide a more secure hold on the device, contact with the plastic ridge around the perimeter of the metal cover should be avoided to prevent loss of vacuum pressure. Multiple vacuum ports within the nozzle may be required to effectively handle the device and prevent shifting during movement to placement position.

Figure 1 shows two styles of multiple port vacuum nozzles for the MPXH series device as an example. Figure 2 represents the nozzle location on the device.

Vacuum pressure required to adequately support the component should be approximately 25 in Hg (85kPa). This level is typical of in-house vacuum supply.

Pick up nozzles are available in various sizes and configurations to suit a variety of component geometries. To select the nozzle best suited for the specific application, it is recommended that the customer consult their pick and place equipment supplier to determine the correct nozzle. In some cases it may be necessary to fabricate a special nozzle depending on the equipment and speed of operation.

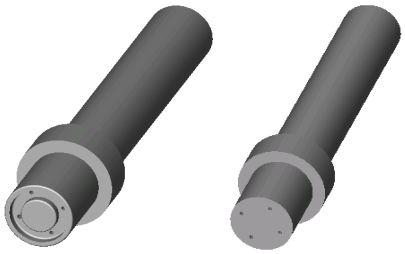

Figure 1. MPXH Series Multiple Port Vacuum Nozzles

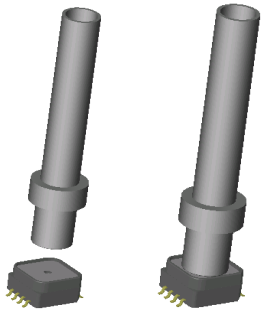

Figure 2. Nozzle Location

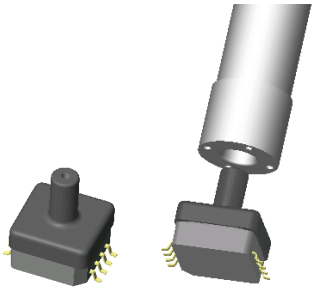

Figure 3. SSOP Axial Style Port

AVAILABLE PACKAGES

Freescale offers several small outline surface mount device families. These are MPXA, MPXH, MPXM, and MPXY series of devices.

These devices are also available in axial ported versions to allow pressure to be interfaced to a device via a hose connection.

Pick up nozzles for these packages should be configured to apply vacuum only to the flat surface of a port base. An access clearance in the nozzle for a port shank is necessary to properly handle these device configurations. See Figure 3.

SOP

SSOP

MPAK

SOIC16

Figure 2. Available Packages

Table 1. Tape and Reel Information

	Case	423A	1317	1317A	1320	1320A	482	482A	1369
Carrier Tape		**Chip Pak**	**SSOP**	**SSOP Ported**	**M-Pak**	**M-Pak Ported**	**SOP**	**SOP Ported**	**SOP Side Port**
Tape Width	W	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	24.0+/-0.3	32+/-0.3	32+/-0.3	32+/-0.3
Pocket Width	A_o	8.5+/-0.2	7.7+/-0.1	8.8+/-0.1	6.8+/-0.1	7.2+/-0.1	11.3+/-0.1	12.0+/-0.2	12.6+/-0.2
Length	B_o	14.2+/-0.2	10.7+/-0.1	11.8+/-0.1	12.6+/-0.1	13.2+/-0.1	18.9+/-0.1	18.8+/-0.2	18.8+/-0.2
Depth	K_o	4.7+/-0.1	5.0+/-0.1	10.8+/-0.1	4.6+/-0.1	10.5+/-0.1	6.4+/-0.1	13.8+/-0.1	9.2+/-0.2
Sprocket Hole Pitch	P_o	4.0 +/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1	4.0+/-0.1
Sprocket Hole Diagram	D_o	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.55+/-0.05	1.5+/-0.05	1.5+/-0.1	1.5+/-0.1
Edge to Hole	E_1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1	1.75+/-0.1
Hole to Edge	E_2	22.2 min	22.2 min	22.2 min	22.2 min	22.2 min	N/A	N/A	N/A
Distance between Holes	S_o	N/A	N/A	N/A	N/A	N/A	28.4+/-0.1	28.4+/-0.1	28.4+/-0.1
Pocket Pitch	P_1	12.0+/-0.1	12.0+/-0.1	16.0+/-0.1	12.0+/-0.1	16.0+/-0.1	16.0+/-0.1	20.0+/-0.1	24.0+/-.01
Pocket Position	P_2	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1
	F	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	11.5+/-0.1	14.2+/-0.1	14.2+/-0.1	14.2+/-0.1
Tape Thickness	T	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.40+/-0.05	0.30+/-0.05	0.35+/-0.05	0.40+/-0.05
Distance Pocket to Edge	S_1	0.6 min.	0.6 min	0.6 min	0.6 min	0.6 min	N/A	N/A	N/A
Pocket Hole Diagram	D_1	N/A	1.5+/-0.1	1.5+/-0.1	1.5+/-0.1	1.5+/-0.1	2.0+/-0.1	2.0+/-0.1	2.0+/-0.1
Cover Tape									
Thickness	T_1	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01	0.052 +/-0.01
Width	W_4	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	21.1+/-0.1	25.5+/-0.1	25.5+/-0.1
Reel									
Width at Hub	W_1	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	23.7 - 25.2	31.7 - 33.2	31.7 - 33.2
Width at outer flange	W_3	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	23.7 - 28.0	31.7 - 36.0	31.7 - 36.0
Overall Width	W_2	30.4 max.	30.4 max.	30.4 max.	30.4 max.	30.4 max.	30.4 max.	38.4 max.	38.4 max
Hub Diagram	N	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	100+/-2.50	178+/-2.50	178+/-2.50
Arbor Hole Diagram	C	13.0+ 0.5/-0.2	13.0+ 0.5/-0.2	13.0+ 0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2	13.0 +0.5/-0.2
Slot of Arbor Hole	B	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50	1.50/2.50
Reel Diagram	A	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76	330+/-0.76
DEVICE QTY/REEL	MPQ	1000	1000	300	1000	400	600	100	200

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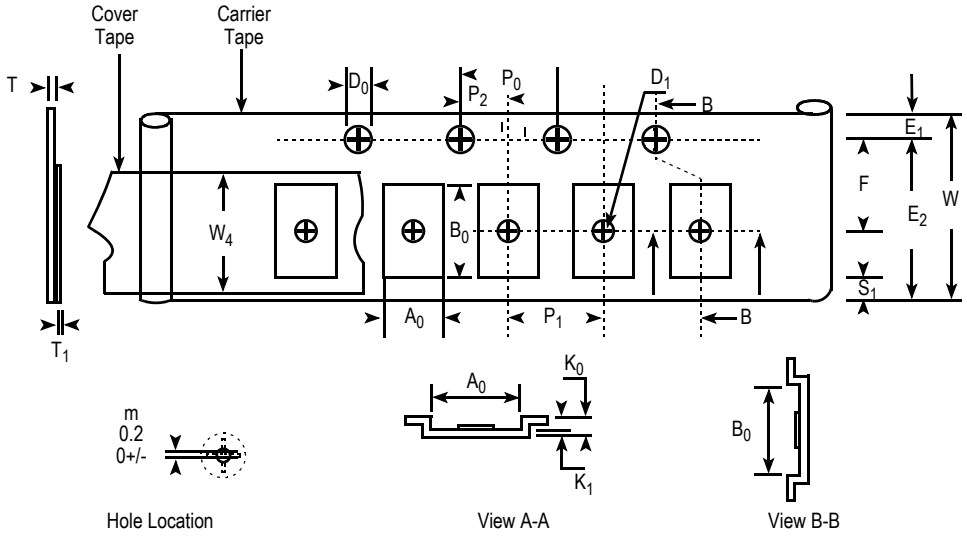

Figure 3. Carrier Tape

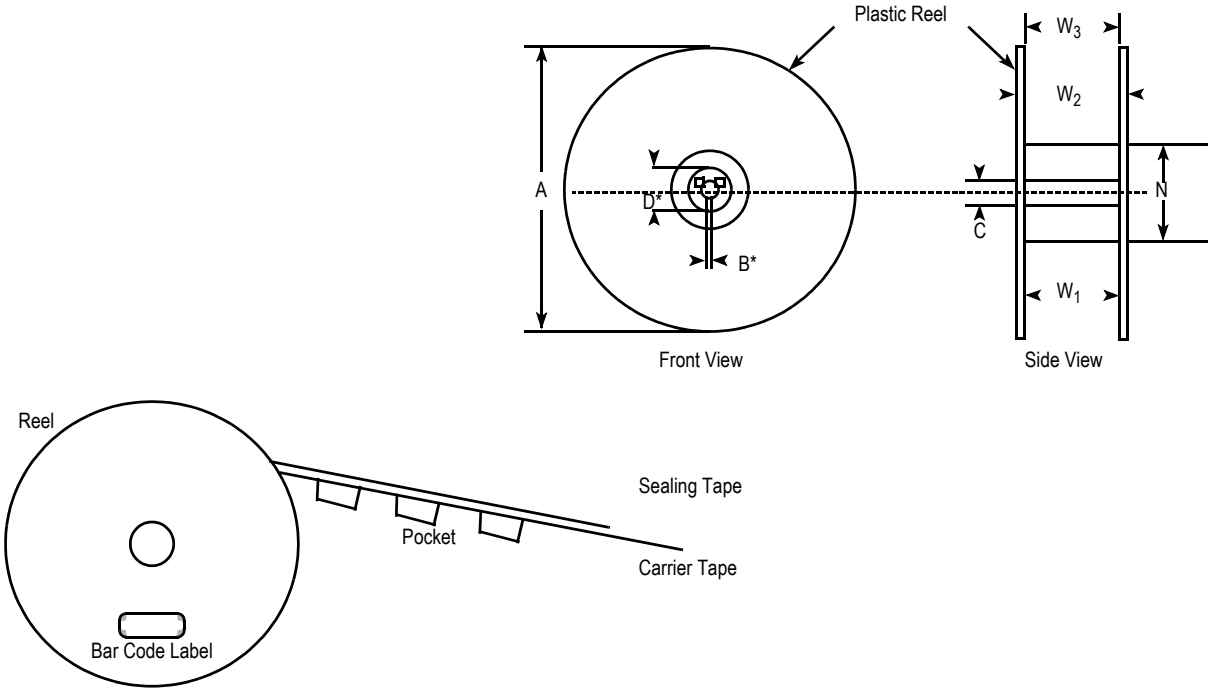

Figure 4. Reel

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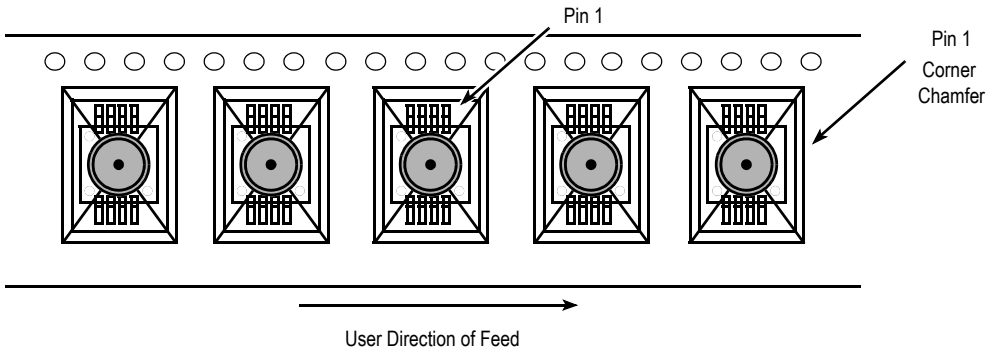

Figure 5. Orientation of Small Outline Package Sensor Device

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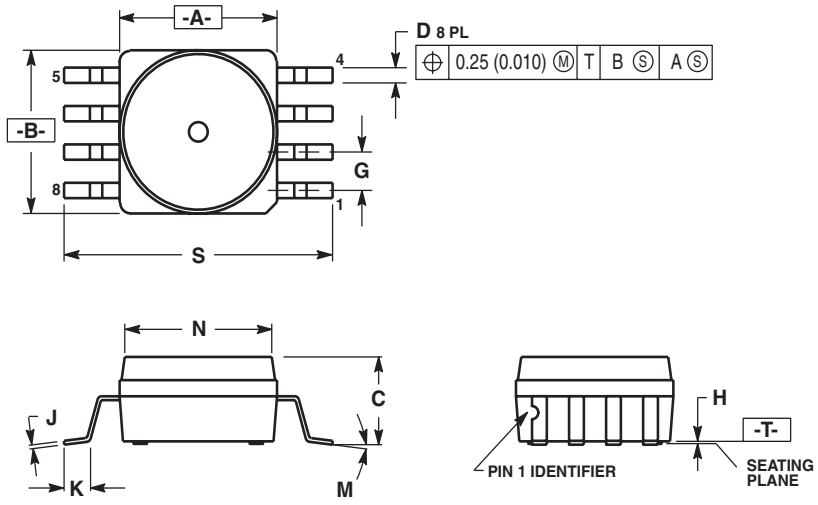
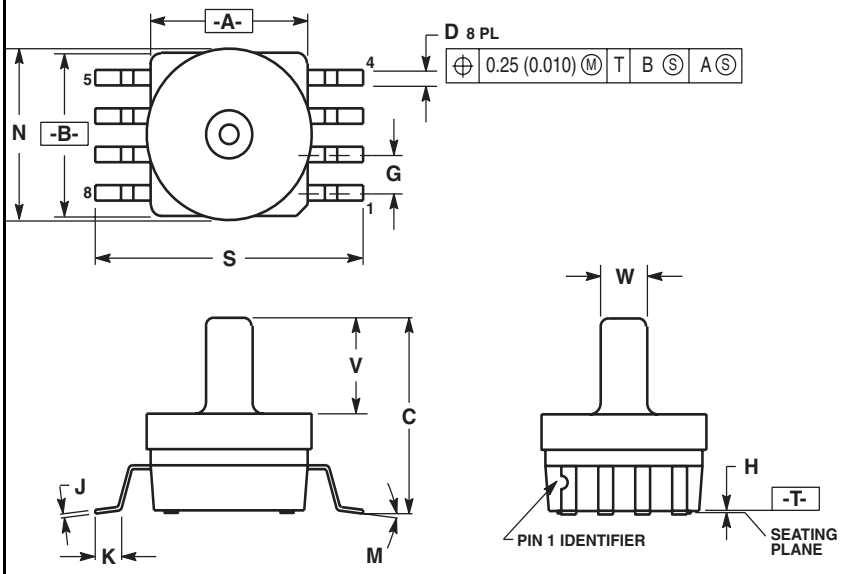
PACKAGE DIMENSIONS



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.212	0.230	5.38	5.84
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.405	0.415	10.29	10.54
S	0.709	0.725	18.01	18.41

SOP PACKAGE
CASE 482-01
ISSUE O



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	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.444	0.448	11.28	11.38
S	0.709	0.725	18.01	18.41
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

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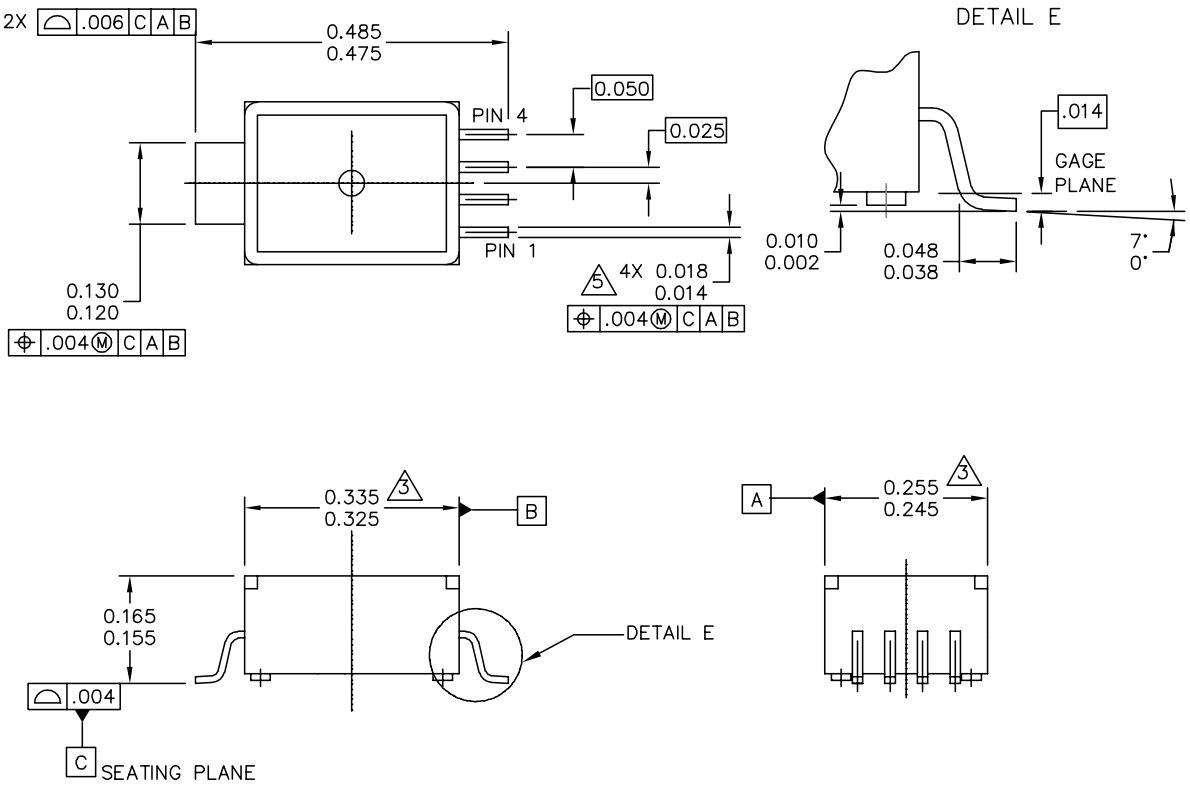

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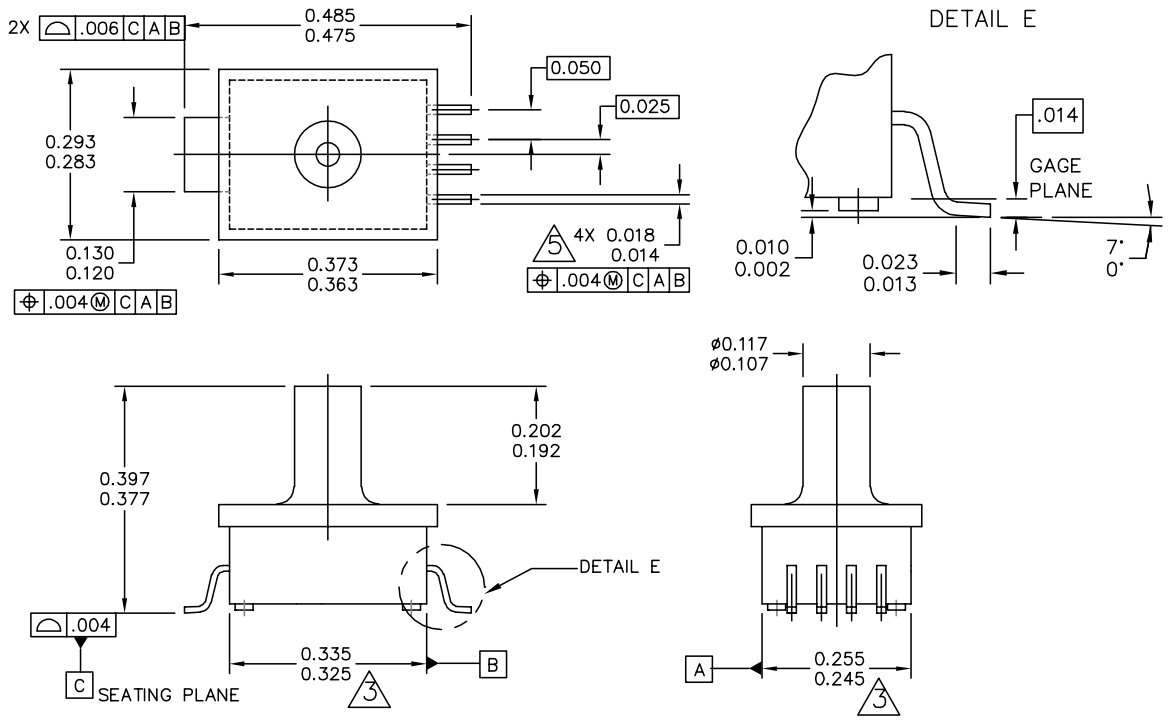

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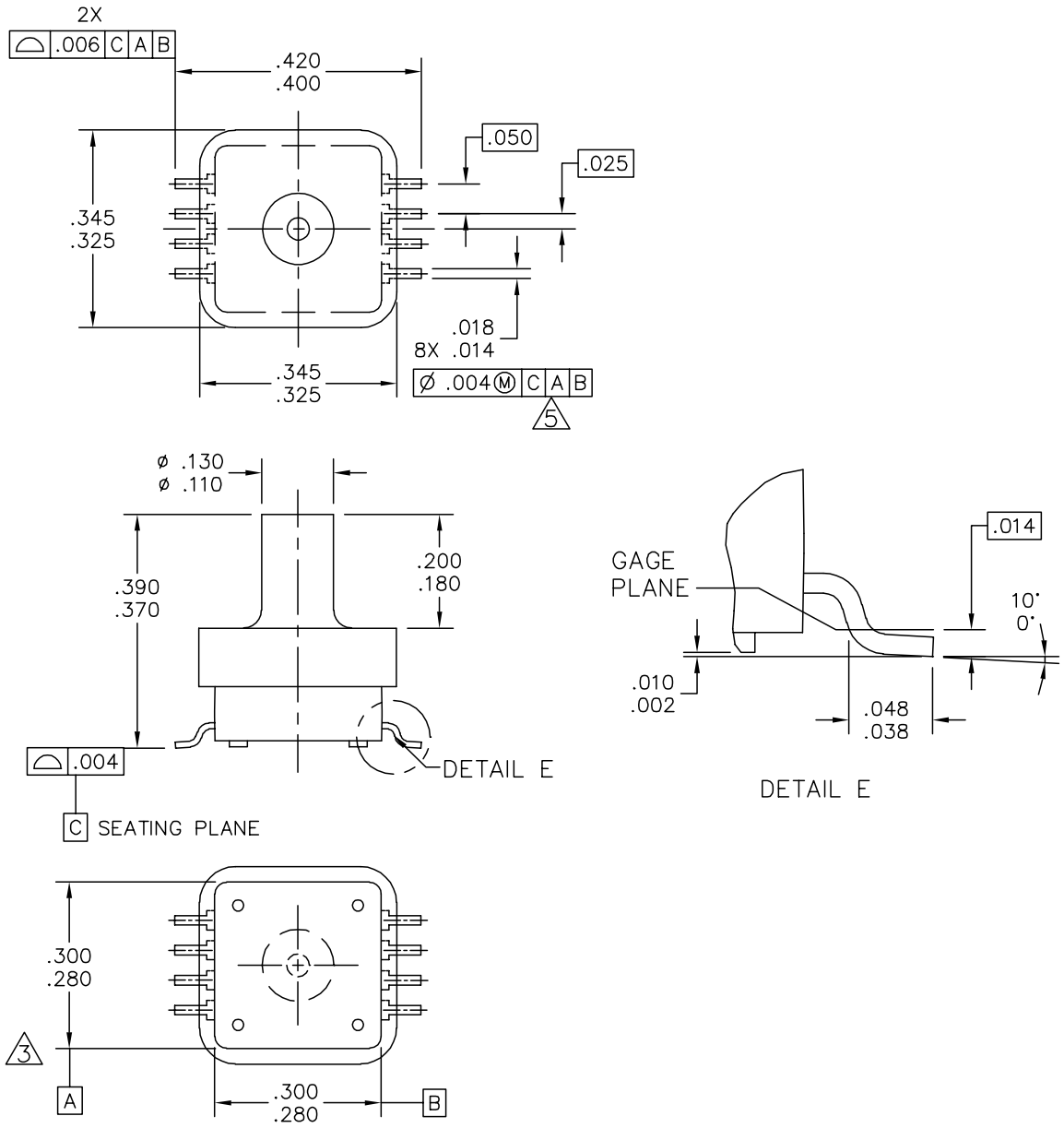

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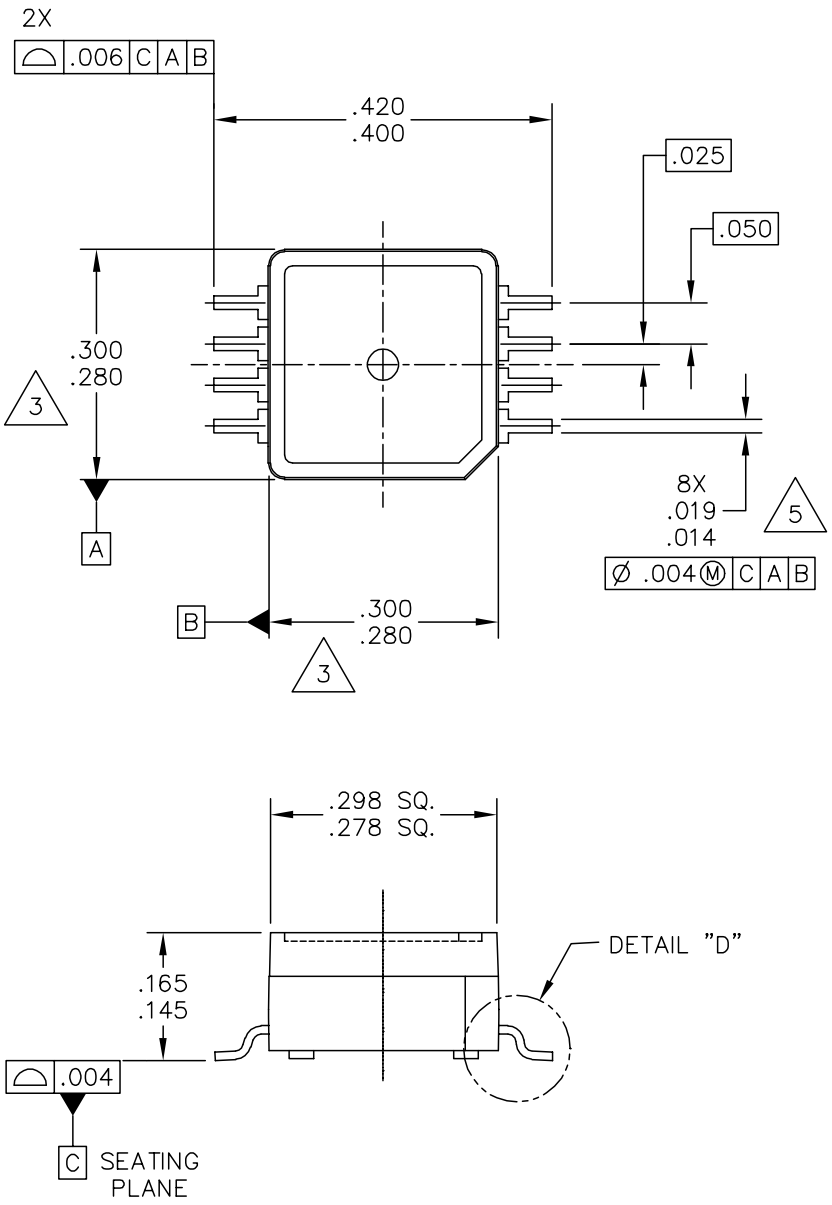

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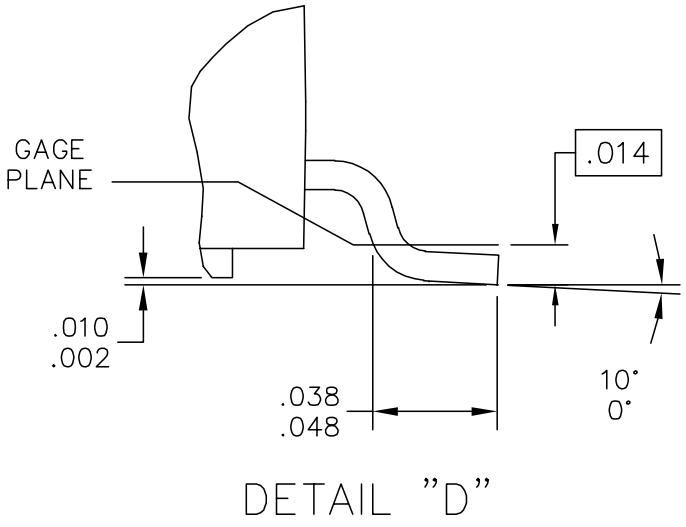

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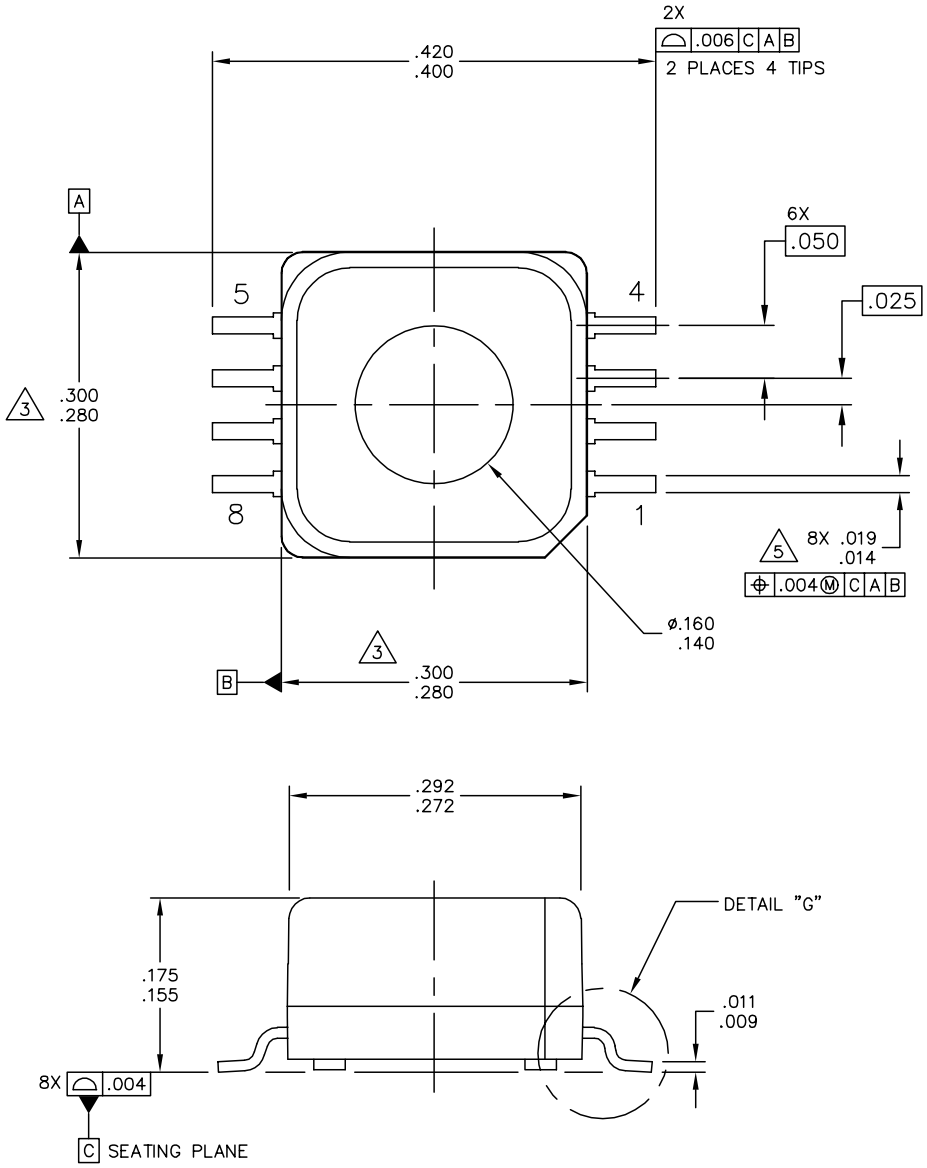

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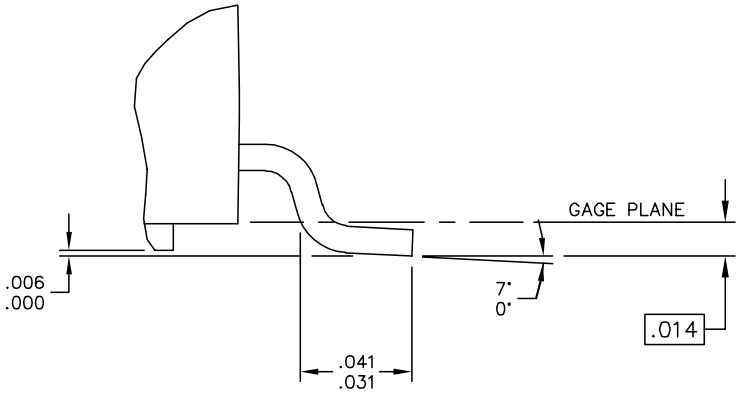

DETAIL "G"

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TITLE: 8 LEAD TPMP GULL WING FORM	DOCUMENT NO: 98ASA99256D	REV: C
	CASE NUMBER: 1352–03	24 JUL 2005
	STANDARD: NON–JEDEC	

SSOP PACKAGE
CASE 1352-03
ISSUE C

PACKAGE DIMENSIONS

NOTES:

1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FALSH AND PRPTRUSIONS SHALL NOT EXCEED .006 PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAX.

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASA99256D	REV: C
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SSOP PACKAGE
CASE 1352-03
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MPXY80XX Application Mounting

by: **Michael Agic**
Freescale Semiconductor, Inc.
Sensor Products

SYNOPSIS

Tire pressure has long been known to be a significant factor in the driving experience and vehicle performance. Keeping the recommended level of pressure, as specified by tire and/or car manufacturers, is a very important part of the overall vehicle maintenance affecting the vehicle's suspension, steering, braking systems, and tire wear among others.

Following popular concerns regarding tire pressure security and in response to a mandate in the Transportation Recall Enhancement, Accountability, and Documentation (TREAD) Act of 2000, the National Traffic Highway Safety Administration (NHTSA) issued a ruling mandating installation of Tire Pressure Monitoring Systems (TPMS) that warn drivers when a tire is significantly under-inflated. This new Federal Motor Safety Standard mandates that vehicle manufacturers and TPMS suppliers, over time, equip all light vehicles with such systems. For the newest timeline and for more information on TPMS requirements, please refer to http://www.nhtsa.dot.gov/.

Within its extensive portfolio of pressure sensors, Freescale Semiconductor, Inc. offers highly integrated solutions for tire pressure monitoring systems – the MPXY80xx family.

This application note deals with considerations pertaining to the mounting of the MPXY80xx family sensors in the end user's applications.

MPXY80XX FAMILY

Freescale's MPXY80xx tire pressure monitoring sensor is a capacitive pressure sensing element, a temperature-sensing element, and an interface circuit with a wake-up feature, all on a single chip. The die is housed in Freescale's Super Small Outline Package (SSOP). The SSOP's size and enhanced media protection make it the perfect package solution for the TPMS.

Tire pressure monitoring systems operate in potentially corrosive environments that could lead to device failures if no protection is implemented. For that reason, the MPXY80xx family sensors use a media filter as the protection method. The filter allows pressure equalization on both sides of the filter. This, in turn, subjects the sensor's silicon diaphragm to the true tire pressure.

Despite these precautions, the tire's rapid and wide temperature variation, in concert with high humidity levels, present a major challenge in terms of pressure sensor operability.

Figure 1. MPXY80XX Sensor Package

MODULE MOUNTING CONSIDERATIONS

MPXY80xx sensors are designed to be mounted inside the tire either in valve stems or on the rim.

On-rim module installation typically requires that the module's case, containing the sensor and the rest of the system components, is mounted on the rim inside the tire as depicted in Figure 2.

Valve-stem installation typically involves mounting the combination of the valve stem and module casing on the outside rim as depicted in Figure 3.

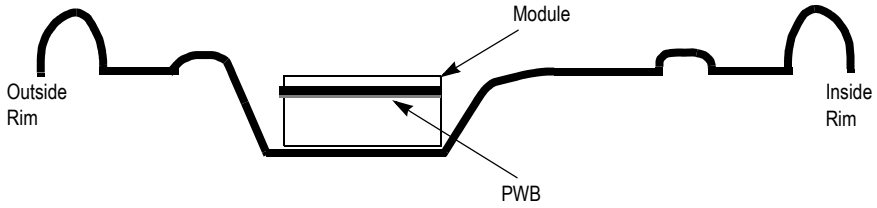

Figure 2. In-Rim Mounting Conceptual Depiction

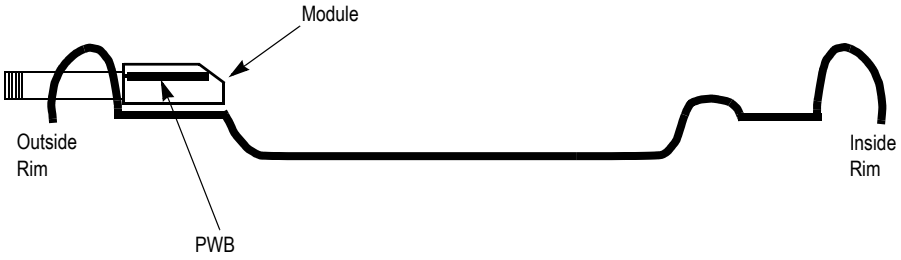

Figure 3. Valve-Stem Conceptual Depiction

SENSOR MOUNTING CONSIDERATIONS

Moisture Related Considerations

The MPXY80xx family integrated filter provides media and humidity protection needed for demanding automotive environments. The devices have been successfully qualified to a stringent list of qualification tests based on the Automotive Electronics Council (AEC) – Q100 requirements. These tests include accelerated humidity testing, long-term pressure and temperature cycling, as well as exposure to chemicals commonly found in Tire Pressure Monitoring applications. The integrated filter's ability to provide sensors with sufficient humidity and media protection, while not causing any false electrical signals from the devices due to acceleration forces in system applications, demonstrates the capabilities of this innovative packaging solution.

In order to maximize the media protection benefits from the integrated filter, the sensor's position needs to be carefully considered. Position of the MPXY80xx sensor in its final application is an important design decision since, in the extreme case where liquid would accumulate inside the tire and settle on top of the sensor package, the media filter may become obstructed (see Figure 4).

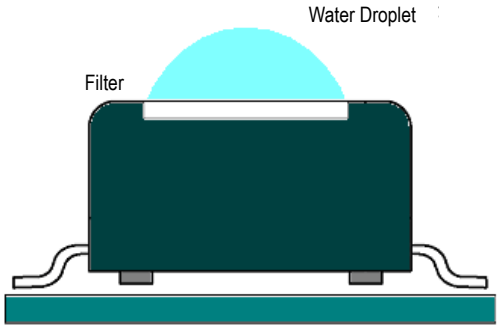

Figure 4. Filter Blockage

In addition to liquid possibly obstructing pressure transmission, liquid can be forced through the filter if it is present on the filter's exterior surface at a time when the device sees rapid pressurization such as when a tire is first installed on a rim.

In order to minimize the likelihood of liquid impacting the device's performance, it is suggested that the media filter on MPXY80xx family sensors faces outward and away from the wheel axis as depicted in Figure 5. This position of the sensor will take advantage of the strong radial forces experienced by the tire allowing for removal of water captured on top of, or inside, the package.

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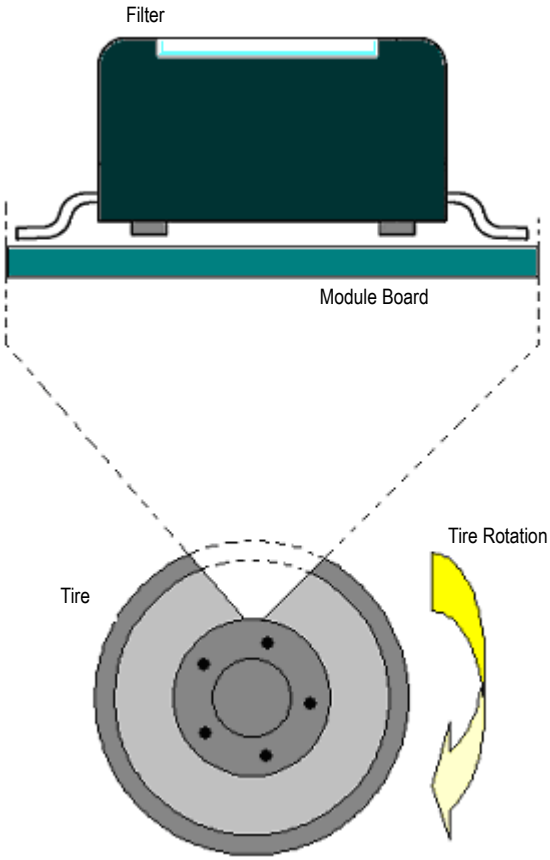

Figure 5. Filter Orientation

Vibration Related Considerations

During normal driving conditions, tire pressure monitoring systems are subjected to high levels of vibrations and strong dynamic forces as shown in an example of the P215/50R16 tire (refer to Figure 6). To ensure that the MPXY80xx family of sensors can withstand these harsh conditions, they are tested to acceleration and shock forces of up to 2000g.

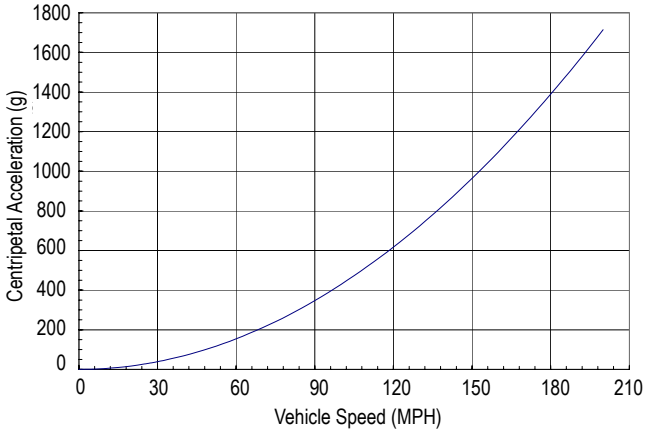

Figure 6. Centripetal Acceleration On a Rim Mounted Pressure Sensor for a P215/50R16 Tire

Due to these dynamic forces caused by the road conditions, the package leads may oscillate with the varying frequency. In order to prevent the board-level vibration failure caused by the driving dynamics, appropriate steps need to be taken when mounting the MPXY80xx family sensors to the system board. Quality automotive-grade components and assembly need to be used in order to prevent such failures. In addition to electrically protecting the MPXY80xx sensor's pins, potting and/or conformal coating techniques may help with the vibration failures and are commonly used as the final step in manufacturing the tire pressure monitoring systems.

SUMMARY

There are several important mounting considerations for the MPXY80xx family of sensors. In-tire environment demands that the sensor faces away from the wheel axis; this position takes advantage of the radial forces which will help remove any possible accumulated liquid off the integrated filter. The sensor position within the tire needs to be chosen such that the sensor is not immersed in the liquid for prolonged periods of time.

Dynamic forces induced by the driving conditions require that the board housing the MPXY80xx family of sensors is made with quality, automotive-grade materials. A non-conductive, potting material needs to be applied in order to protect electrically active parts on the system board from creation of unintended, electrically conductive paths.

ACKNOWLEDGMENTS

I would like to acknowledge the expert advice, and inputs given to me by Dave Monk, PhD., the design manager from Freescale Semiconductor, Inc., Sensor Products Division (SPD). I would also like to acknowledge inputs, and review contributed to creation of this application note by Carl Lopez, the new product development manager from Freescale Semiconductor, Inc., Sensor Products Division (SPD).

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Soldering Recommendations for Pressure Sensor Devices

by: Bill McDonald

INTRODUCTION

Pressure sensor devices require the internal cavity containing the silicon transducer to be exposed to ambient in order for the device to function. Exposed cavity packages require special considerations during board assembly to prevent damage to the device during soldering and subsequent cleaning operations.

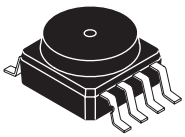


Figure 1. Basic Element

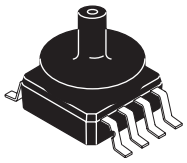


Figure 2. Port Adapter

SURFACE MOUNT COMPONENTS

Components can be mounted using solder paste stencil, screen printed or dispensed onto the PCB pads prior to placement of the component. The volume of solder paste applied to the PCB is normally sufficient to secure the component during transport to the subsequent reflow soldering process. Use of adhesives to secure component is not recommended, but where necessary can be applied providing the vent at the underside of the package does not become blocked. This is applicable only to a gauge pressure sensor device. Absolute pressure sensor devices do not have a backside vent so vent blocking is not an issue.

Solder pastes are available in variety of metal compositions, particle size and flux types. The solder paste consists of metals and flux required for a reliable connection between the component lead and the PCB pad. Flux aids the removal of oxides that may be present on PCB pads and prevents further oxidation from occurring during the solder process.

The use of a No-Clean (NC) flux is recommended for exposed cavity components. Using pressure spray or other methods of cleaning is not recommended. If cleaning of the pcb is performed Water Soluble (WS) flux can be used, but it is recommended the component cavity to be protected by adhesive Kapton tape, vinyl cap or other means prior to the cleaning process to prevent contamination and foreign materials from being introduced into device cavity as result of cleaning processes. Refer to this link for info.

http://www.stockcap.com/products.asp

Ultrasonic cleaning is not recommended as the frequencies can damage wire bond interconnections.

Reflow soldering is typically used for surface mount components and accomplished by convection heat from the sides of the reflow furnace utilizing air circulation to produce uniform temperature across the PCB. Hot spots and shielding of the smaller components by adjacent larger components can be minimized thus achieving more reliable solder connection.

THROUGH-HOLE (DIP) STYLE COMPONENTS

Dual in-line and other styles of through-hole components packages are typically wave soldered where the leads protrude through the circuit board and exposed to a flux bath then immersed into molten solder as the board is passed over a solder wave to create the solder connection. In this application the top board surface and component body are not directly exposed to high temperatures.

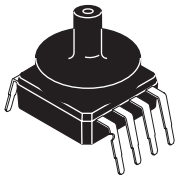
SOLDERING PRECAUTIONS

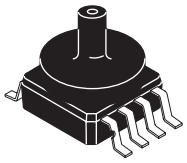
Wave solder does not typically expose component to excessive temperature, but there may be cases where components are subjected to secondary reflow cycle during double side board assembly.

Vapor phase soldering process is not recommended for open cavity devices. There is a potential for liquid to ingress into the cavity or possibility of condensation to form in cavity of the device.

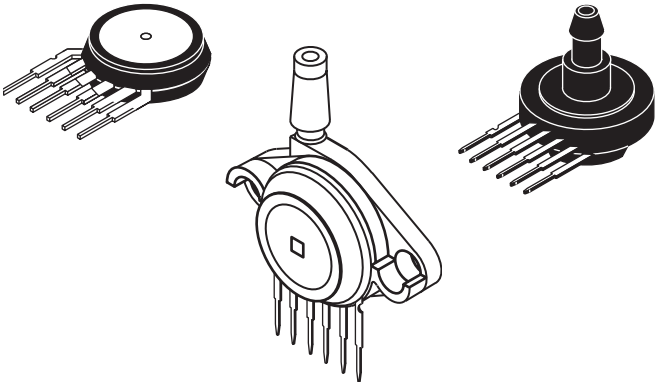
IR reflow is not recommended due to potential damage to plastic features as result of radiation heat transfer.

MPXA, MPXH, MPXM and MPXV series pressure sensors with port adapters should not be exposed to temperatures greater than 245°C. Suffix designations for these devices are; C, AP, DP and GSX.





MPX series pressure sensors with port adapters should not be exposed to temperatures greater than 220°C. The suffix designations for these devices are; AP, GP, DP, AS, GS,ASX or GSX.



Refer to the following table for listing of device types and recommended maximum temperature exposure. The reflow temperature profile for surface mount devices must be in accordance with JEDEC STD. 020. Refer to following link for specific profile details.

http://www.jedec.org/download/search/jstd020c.pdf

Devices provided with a mounting bracket for special applications are to be excluded.

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REWORK OF SOLDERED COMPONENTS

Rework is not recommended, but should it be necessary, maximum temperature exposure for devices should not exceed the limits shown in Table 1 with minimized duration.

Table 1. Pressure Sensors

Device Number	Suffix Designation	Package	Maximum Temperature °C
MPX	A,D	BASIC ELEMENT	245
	AP	PORT ADAPTER	220
	GP	PORT ADAPTER	220
	DP	PORT ADAPTER	220
	AS	PORT ADAPTER	220
	GS	PORT ADAPTER	220
	ASX	PORT ADAPTER	220
	GSX	PORT ADAPTER	220
MPXA	A	BASIC ELEMENT	245
	C	PORT ADAPTER	245
	GSX	PORT ADAPTER	245
MPXV	G	BASIC ELEMENT	245
	C	PORT ADAPTER	245
	DP	PORT ADAPTER	245
	GP	PORT ADAPTER	245
	GVP	PORT ADAPTER	245
	GSX	PORT ADAPTER	245
MPXH	A	BASIC ELEMENT	250
	C	PORT ADAPTER	250
MPXM	A,D	BASIC ELEMENT	250
	AS,GS	PORT ADAPTER	250

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New Small Amplified Automotive Vacuum Sensors

A Single Chip Sensor Solution for Brake Booster Monitoring

by: Marc Osajda
Automotive Sensors Marketing, Sensor Products Division
Semiconductors S.A., Toulouse France

BRAKING SYSTEM

Different types of braking principles can be found in vehicles depending on whether the brake system is only activated by muscular energy or power assisted (partially or completely).

Muscular activated brakes are mostly found on motorcycles and very light vehicles. The driver's effort on the hand lever or pedal is directly transmitted via a hydraulic link to the brake pads.

Power assisted brakes are found on most passenger cars and some light vehicle trucks. In this case, the driver's effort is amplified by a *brake booster* to increase the force applied to the brake pedal.

BRAKE BOOSTER OPERATION PRINCIPLE

The vacuum brake booster is a system using the differential between atmospheric pressure and a lower pressure source (vacuum) to assist the braking operation. The brake booster is located between the brake pedal and the master cylinder. Figure 1 shows a simplified schematic of a vacuum brake booster.

When no brake pressure is applied on the push rod (brake pedal side), the air intake valve is closed and the vacuum valve open. Thus, both the vacuum and working chambers are at the same pressure, typically around -70 kPa (70 kPa below atmospheric pressure). Vacuum is generated by either the engine intake manifold or by an auxiliary vacuum pump.

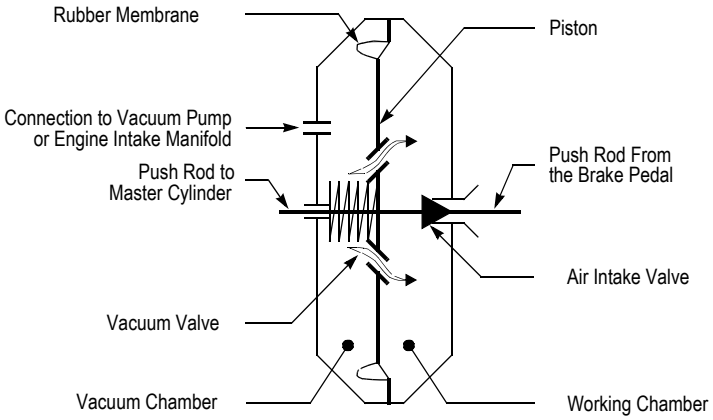

Figure 1. Brake Booster Simplified Schematic

Once the brake pedal is activated (force Fp), the vacuum valve is closed and the air intake valve is open proportionally to the displacement of the push rod (Figure 2). The working chamber is progressively open to atmospheric pressure, which creates a differential between the vacuum chamber and the working chamber. This differential pressure applied to the surface (S) of the piston results in a force *Fb = (Pw - Pv) x S*.

The forces Fb + Fp are then applied to the brake pads through the master cylinder and hydraulic links.

When the brake pedal is released, the spring moves the piston back, closing the air intake valve and opening the vacuum valve to rebalance the pressure between the two chambers.

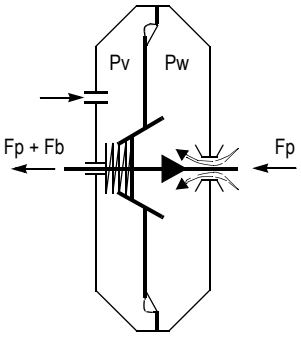

Figure 2. Braking Phase

VACUUM GENERATION

On most passenger cars, vacuum is generated by the engine itself. When the engine throttle valve is closed, the displacement of the pistons produces vacuum in the intake manifold. Thanks to a tube or hose connected between the engine intake manifold and the brake booster, vacuum can be applied to the chambers. A backslash valve inserted between the intake manifold and the booster maintains the vacuum in the booster when the engine throttle valve is open.

This principle has some limitations, however. For example, it can be only used on engines that have the ability to generate enough vacuum. On diesel engines, which have no throttle valve, it is necessary to use an auxiliary pump to generate vacuum. This will also be the case on the Gasoline Direct Injection (GDI) engine, where in some driving conditions (idle, lean burn) the electrically assisted throttle valve will be maintained slightly open. In this situation, the vacuum available on the intake manifold is not sufficient to provide an efficient braking.

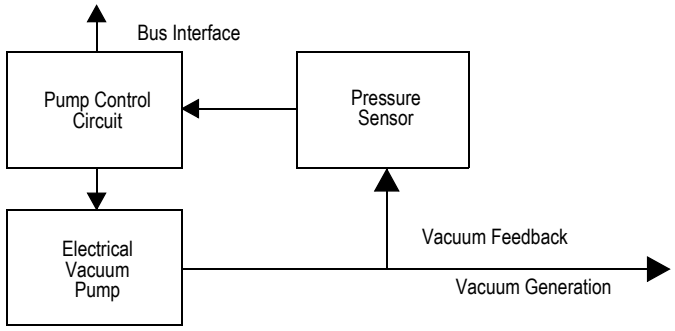

Figure 3. Vacuum Pump Monitoring

Therefore, it is necessary and desirable to use an electrical pump that will generate the vacuum for the brake booster. The use of an auxiliary electrical pump (Figure 3) provides several advantages over the “intake manifold” vacuum.

- Vacuum generation is no longer related to the engine running condition. Vacuum is only generated and controlled by the pump thanks to a vacuum pressure sensor that provides an accurate reading to the pump electrical control circuit.
- The electrical pump can be switched on and off based on the required vacuum. To compensate atmospheric pressure variation in order to maintain a constant booster effect, the pump also can be switched on independently from the atmospheric pressure. Various algorithms for driving the pump can be implemented depending on the required braking conditions.
- Pressure variations during braking can be measured, and the pump can be activated to generated additional vacuum if required to increase the braking force.
- Leakage can be detected by the pressure sensors and the pump can be switched on to compensate them. The driver can be informed of any type of failure thanks to the bus interface. Vacuum level, and thus available braking force can be communicated through the bus to other braking systems such as, for example, ABS or ESP.

Freescale Semiconductor, Inc., a worldwide leader in automotive semiconductors, has introduced a new integrate pressure sensor dedicated to vacuum measurements in applications such as brake booster monitoring. The single-chip vacuum sensor may be placed directly onto the pump electronic control unit or integrated as component within the brake booster, thus providing flexibility, system integration and reduced system cost.

FREESCALE’S NEW MPXV6115VC6U VACUUM SENSOR

PIEZORESISTIVE/AMPLIFIED SENSORS

Freescale's pressure sensors are based on a piezoresistive technology that consists of a silicon micromachined diaphragm and a diffused piezoresistive strain gauge. When vacuum or pressure is applied on the die, the diaphragm is deformed and stressed. The resulting constraints create a variation of resistance in the piezoresistive strain gauge. In order to read this variation, an excitation current passes through the gauge, and a voltage proportional to the applied pressure and excitation current appears between the voltage taps. To get an accurate pressure reading, such a sensing element needs usually to be calibrated, temperature compensated and amplified.

In order to solve the inherent limitation of the basic sensing element, Freescale produces an entire family of calibrated, thermally compensated and amplified pressure sensors (see Figure 4) called Integrated Pressure Sensors (IPS).

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The IPS is a state of the art, monolithic, amplified and signal-conditioned silicon pressure sensor. The sensor combines advanced micromachining techniques, thin film memorization and bipolar semiconductor processing to provide an accurate, high-level analog output that is proportional to the applied pressure. IPS sensors can be directly connected to an A/D converter.

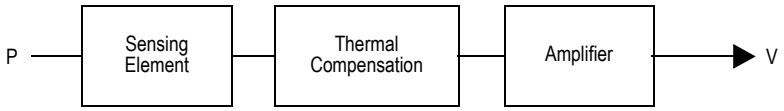

Figure 4. Integrated Pressure Sensor Block Diagram

PRESSURE MEASUREMENT CONVENTION

Pressure measurements can be divided into three different categories: absolute, gage and differential pressure.

Absolute pressure refers to the absolute value of the force per unit area exerted on a surface by a fluid. Therefore, the absolute pressure is the difference between the pressure at a given point in a fluid and the absolute zero of pressure or a perfect vacuum.

Gage pressure is the measurement of the difference between the absolute pressure and the local atmospheric pressure. Local atmospheric pressure can vary depending on ambient temperature, altitude and local weather conditions. The standard atmospheric pressure at sea level and 20°C is 101.325 kPa absolute. When referring to pressure measurement, it is critical to specify what reference the pressure is related to: gage or absolute. A gage pressure by convention is always positive. A 'negative' gage pressure is defined as vacuum. Figure 5 shows the relationship between absolute, gage pressure and vacuum.

Differential pressure is simply the measurement of one unknown pressure with reference to another unknown pressure. The pressure measured is the difference between the two unknown pressures. Since a differential pressure is a measure of one pressure referenced to another, it is not necessary to specify a pressure reference.

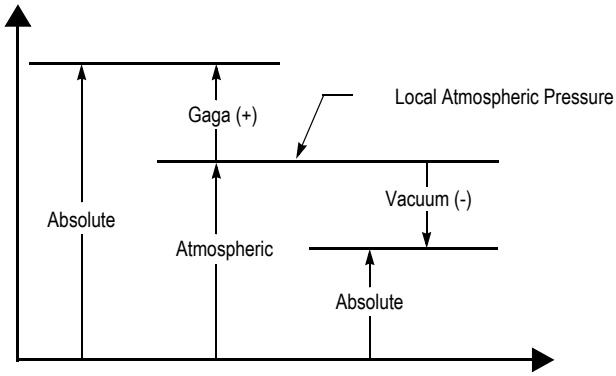

Figure 5. Pressure Convention

TRANSFER FUNCTION

The behavior of an IPS is defined by a linear transfer function. This transfer function applies to all Freescale's Integrated Pressure Sensors whatever the pressure range and type of sensing element (absolute or differential).

$$V_{out} = V_S \times (P \times K1 + K2)$$
$$\pm (PE \times TM \times V_S \times K1)$$

- V_{out}: Sensor output voltage
- P: Applied pressure in kPa
- Vs: Sensor supply voltage in V
- K1: Sensitivity constant in V/V/kPa
- K2: Offset Constant inV/V
- PE: Pressure error in kPa
- TM: Temperature multiplier

The constants, K1, K2, PE & TM are specific to each device, temperature and pressure encountered in the application.

The variables P and Vs are dependent on the user application but must remain within the operating specification of the device.

THE MPXV6115VC6U INTEGRATED PRESSURE SENSOR

The MPXV6115VC6U gauge vacuum sensor, designed to measure pressure below the atmospheric pressure, is suitable for automotive application such as vacuum pump or brake booster monitoring. The MXPV4115V is also ideal for non-automotive applications where vacuum control is required.

The MPXV6115VC6U has the following basic characteristics (Note: Detailed characteristics of Freescale's pressure sensors can be found on http://www.freescale.com/semiconductors).

MPXV6115VC6U CHARACTERISTICS

$$V_{out} = V_S \times (P \times 0.007652 + 0.92)$$
$$\pm (PE \times TM \times V_S \times 0.007652)$$

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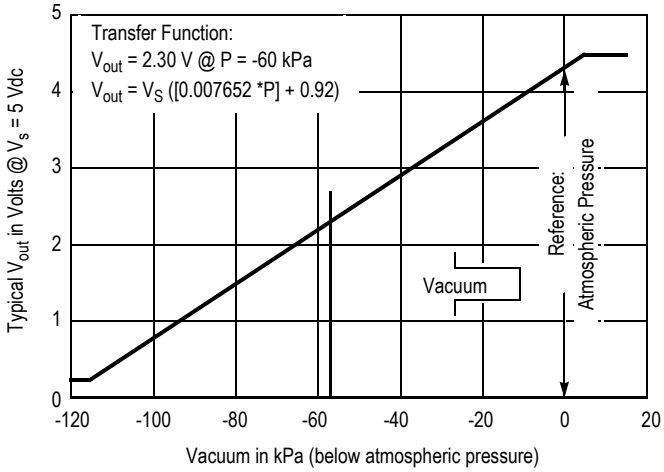

Figure 6. MPXV6115VC6U Transfer Function

- P is the applied vacuum to the sensor pressure port. Pressures below atmospheric pressure have a negative sign. For example, 50 kPa below atmospheric is P = -50 in the transfer function. For pressure higher than the atmospheric pressure, the device will electrically saturate. The sensor is designed to measure vacuum from 0 kPa (Atmospheric pressure applied to the sensor pressure port) down to -115kPa.

  Since the MPXV6115VC6U is using the atmospheric pressure as reference, -115 kPa can only be reached if the atmospheric pressure is higher or equal than 115 kPa. The device will electrically saturate for vacuum below -115 kPa.
- PE = 1.725 kPa (1.5% of full scale span) over the entire pressure range
- TM = 1 between 0 and +85°C, 3 at -40°C and +125°C. TM is a linear response from -40°C to 0°C and from 85°C to 125°C.

The real intent for the pressure-sensor user is to know the measured pressure. In this case it is preferable to express the transfer function as:

$$P = (V_{out}/V_S - 0.92)\ 0.007652 \pm (PE \times TM)$$

As an example, if Vout = 2.30 V for a 5 Vdc power supply and at 25°C ambient temperature, the measured vacuum is

P = -60.1 kPa ± 1.725 kPa.

SENSOR PACKAGING

The packaging of a pressure sensor die is critical to achieve optimal performances of the final product. The package must isolate the pressure sensor die from unwanted external stress which can cause undesired drift of the electrical signal while being robust enough to support the pressure applied to the device without cracks, leaks or mechanical failures. It must be media compatible for the same reasons.

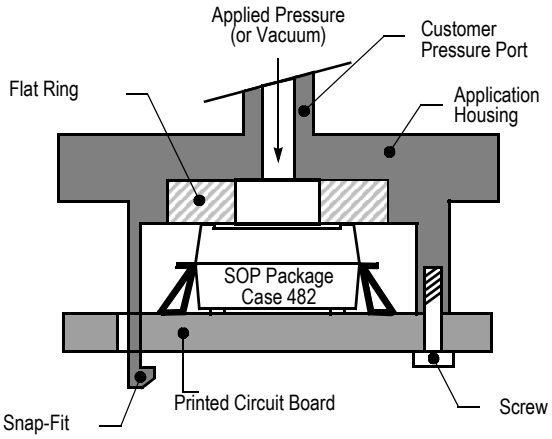

Figure 7. Mounting Suggestion

The new small pressure sensor package from Freescale addresses those requirements and lets designers mount a pressure sensor directly on a printed circuit board, thus providing great flexibility for space saving design. Figure 7 shows a typical assembly using a small outline package (SOP) Case 482-01.

The sensor can be mounted on the printed circuit board by an automatic pick and place machine as with every other surface mount component. Sealing is done by using a silicone flat ring inserted in the application housing. The printed circuit board must be maintained against the flat ring either by a snap fit, or by a screws as shown.

The new small outline package (SOP) is fabricated using poly-phenyl sulfide (PPS), a robust material, which can withstand high temperatures and is highly resistant to chemicals. Consequently, the package is ideal for harsh environment such as automotive, industrial or medical systems.

The small outline package is suitable for any of Freescale's sensor chips from the basic uncompensated sensor to the fully integrated sensing solution that include amplifiers and other circuitry all on one chip.

Freescale's sensors using this package are available in both tubes and tape and reel configuration for high productivity on your assembly line.

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Low-Pressure Sensing Using MPX2010 Series Pressure Sensors

by: **Memo Romero and Raul Figueroa**
Sensor Products Division
Systems and Applications Engineering

INTRODUCTION

This application note presents a design for a low pressure evaluation board using the Freescale Semiconductor, Inc. MPX2010 series pressure sensors. By providing large gain amplification and allowing for package flexibility, this board is intended to serve as a design-in tool for customers seeking to quickly evaluate this family of pressure sensors.

The MPX2010 family of pressure sensors appeals to customers needing to measure small gauge, vacuum, or differential pressures at a low cost. However, different applications present design-in challenges for these sensors. For very low pressure sensing, large signal amplification is required, with gains substantially larger than what is provided in Freescale's current integrated pressure sensor portfolio. In terms of packaging, customers often need more mechanical flexibility such as smaller size, dual porting or both. In many cases, customers often lack the engineering resources, time or expertise to evaluate the sensor. The low-pressure evaluation board, shown in Figure 1, facilitates the design-in-process by providing large signal gain and by providing for different package designs in a relatively small footprint.

CIRCUIT DESCRIPTION

For adequate and stable signal gain and output flexibility, a two-stage differential op-amp circuit with analog or switch output is utilized, as shown in Figure 2. The four op-amps are packaged in a single 14 pin quad package. There are several features to note about the circuitry.

The first gain stage is accomplished by feeding both pressure sensor outputs (VS- & VS+) into the non-inverting inputs of operational amplifiers. These op-amps are used in the standard non-inverting feedback configuration. With the condition that Resistors R2=R3, and R1=R4 (as closely as possible), this configuration results in a gain of G1= R4/R3+1.

The default gain is 101, but there are provisions for easily changing this value. The signal V (op-amp Pin 7) is then calculated as:

$$V_1 = G1*(VS+ - VS-) + Voffset. \quad \ldots . \text{Equation (1)}$$

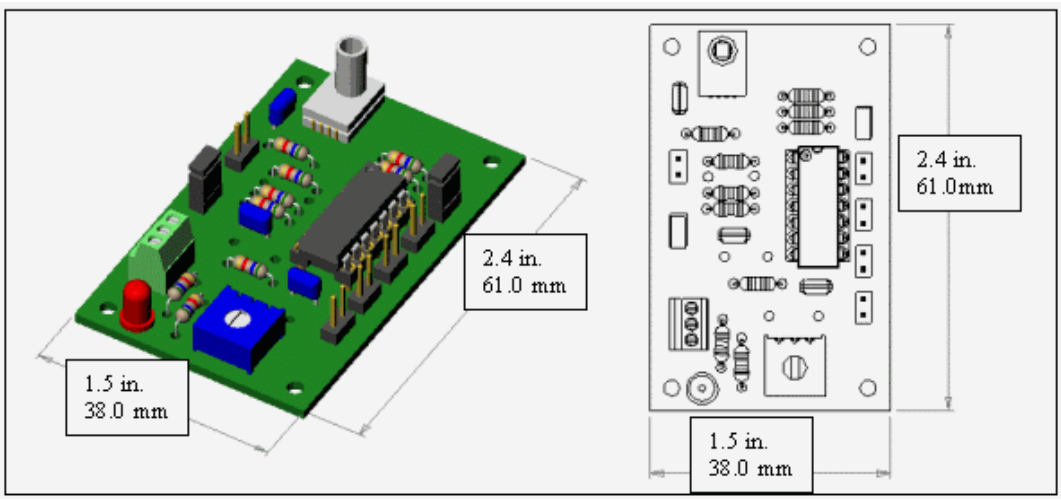

Figure 1. Low Pressure Evaluation Board

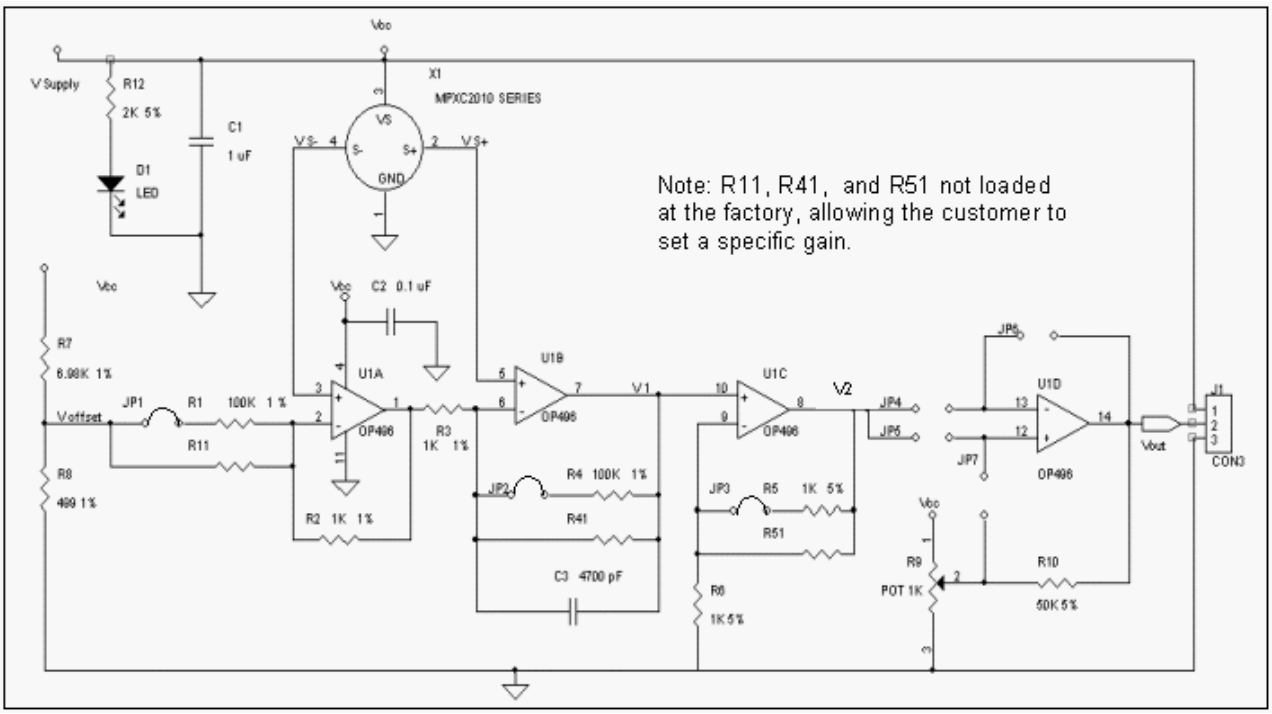

Figure 2. Circuit Schematic

Voffset is the reference voltage for the first op-amp and is pre-set with a voltage divider from the supply voltage. This value is set to be 6.7 percent of the supply voltage. It is important to keep this value relatively small simply because it too is amplified by the second gain stage. It is also desirable to have resistors R7 and R8 sufficiently large to reduce power consumption.

The second gain stage takes the signal from the first gain stage, V, and feeds it into the non-inverting input of a single op-amp. This op-amp is also configured with standard non-inverting feedback, resulting in a gain of G2=R5/R6+1. The default value is set to 2, but can easily be changed.

The signal produced at the output of the second stage amplifier, V (op-amp pin 8) is the fully amplified signal. This is calculated as

$$V_2 = G2 * V_1. \quad \text{. . . .Equation (2)}$$

From this point, there are two possible output types available. One is a simple follower circuit, as shown in Figure 3, in which the circuit output, Vout (op-amp pin 14), is essentially a buffered V signal. This analog output option is available for applications in which the real time nature of the pressure signal needs to be measured. This option is selected by connecting jumpers J5 and J6. J4 and J7 are not connected for analog output.

The second output choice, a switch output as shown in Figure 4, is accomplished by setting jumpers J4 and J7, and leaving J5 and J6 unconnected. This is appropriate for applications in which a switching function is desired. In this case, the fourth op-amp is configured as a comparator, which will invert V_2, high or low, depending on whether V_2 is larger or smaller than the preset reference signal, set by trim-pot R9. This signal can be used to simulate a real world threshold.

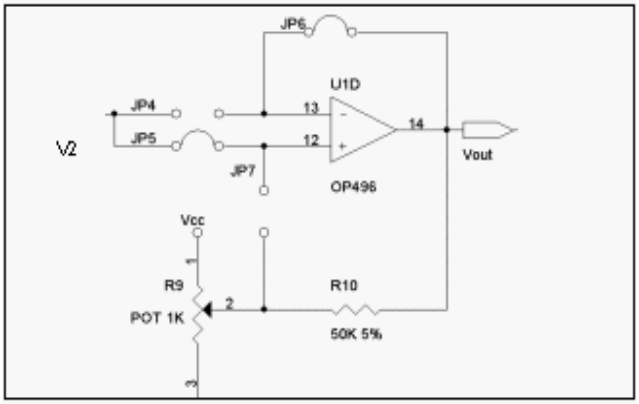

Figure 3. Analog Output Jumper Settings

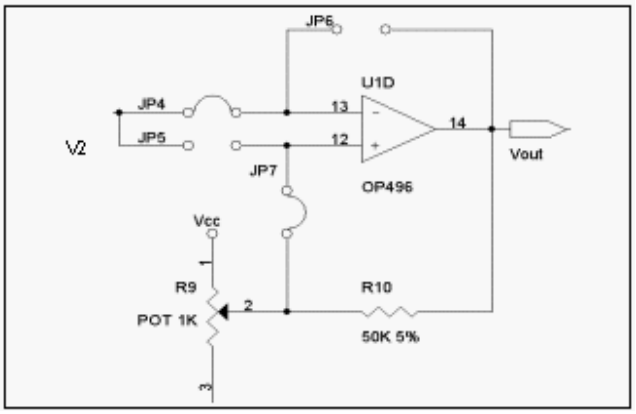

Figure 4. Switch Output Jumper Settings

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Table 1 shows the jumper settings for both analog and switches outputs.

Table 1. Output Jumper Settings

Output	JP4	JP5	JP6	JP7
Analog	Out	In	In	Out
Switch	In	Out	Out	In

For the switch output option, it is desirable to apply some hysteresis on the output signal to make it relatively immune to potential noise that may be present in the voltage signal as it reaches and passes the threshold value. This is accomplished with feedback resistor R10. From basic op-amp theory, it can be shown that the amount of hysteresis is computed as follows:

$$V_H = Vout *[1-(10 / (R10 + R\ pot\text{-}eff))]$$

Where:

- VH is the output voltage attenuation, due to hysteresis, in volts
- Vout is the output voltage (railed hi or low)
- R10 is the feedback resistor, = 50K
- Rpot-eff is the effective potentiometer resistance

V_H may vary depending on the particular value of the potentiometer.

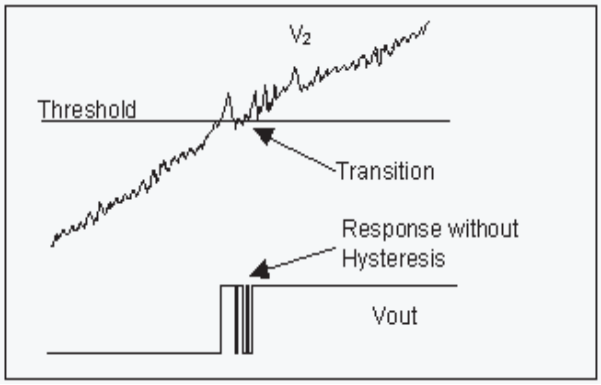

Figure 5. Output Transition without Hysteresis

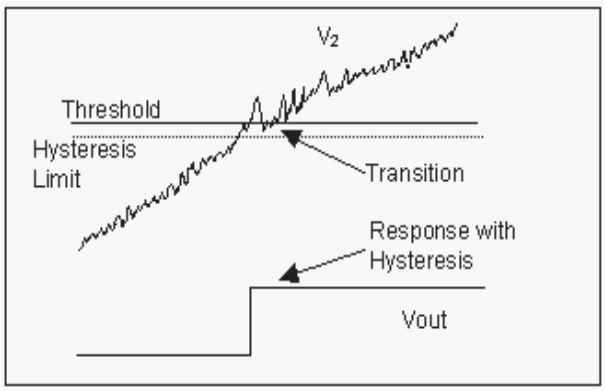

Figure 6. Output Transition with Hysteresis

To take an example, suppose that the supply voltage, Vs is 5 volts, and the threshold is set to 60 percent of Vs, or 3 volts. This corresponds to one leg of the 1K potentiometer set to 0.4K while the other is set to 0.6K. Thus the effective pot resistance is 0.4K // 0.6K = 0.24K.

Therefore,

$$V_H = 5V* [1- (50K/(50K + 0.24K))] = 24\ mV.$$

Under these conditions, V signals passing through the threshold will not cause Vout to oscillate between Vs and Ground as long as noise and signal variations in V are less than 24mV during the transition. Figure 5 illustrates the benefit of having a hysteresis feedback resistor.

GAIN CUSTOMIZATION

The low-pressure evaluation board comes with default gains for both G1 and G2. G1 is factory set at 101, while G2 is set to 1. Jumpers JP1, JP2 and JP3 physically connect the resistors that produce these default gains. Three resistor sockets (R11, R41 and R51) are provided in parallel with R1, R4 and R5, respectively. By removing jumpers JP1, JP2 and JP3, and soldering different resistor values in the appropriate sockets, different gain values can be achieved. The limit on the largest overall gain that can be used is determined by op-amp saturation. Thus if gain values are chosen such that the output would be larger than the supply voltage, then the op-amp would saturate, and the pressure would not be accurately reflected. Table 2 outlines the jumper settings for customizing the gain.

Table 2. Resistor and Jumper Settings for Gain Customization

Gain		Resistors			Jumpers			Remarks
G1	*G2*	*R11*	*R41*	*R51*	*JP1*	*JP2*	*JP3*	
101	2	no load	no load	no load	In	In	In	Default
User Set	2	load	load	no load	Out	Out	In	R11=R41
101	User Set	no load	no load	load	In	In	Out	
User Set	User Set	load	load	load	Out	Out	Out	R11=R41

DESIGN CONSIDERATIONS

Since the evaluation board is primarily intended for low-pressure gage and differential applications, large gain values can be utilized for pressures less than 1.0 kPa. For example if G1 is set to 101, and G2 set to 6, then the total gain is 606.

Inherent in the MPX2010 family of pressure sensors is a zero-pressure offset voltage, which can be up to 1 mV. This offset is amplified by the circuit and appears as a DC offset at Vout with no pressure applied. The op-amp also has a voltage offset specification, though for the recommended op-amp this value is small and does not contribute significantly to the Vout offset.

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For example, if the evaluation board is being used under the following conditions:

Vs = 3V
G1 = 101
G2 = 6

MPX2010 zero pressure offset = 0.3mV

At this supply voltage, VOFFSET can be calculated to be 6.7% x 3V = 0.2V. The voltage V, due simply to the zero pressure sensor offset voltage of 0.3mV, can be calculated from equation (1):

$V_1 = 0.3mV * 101 + 0.2V = 0.23V$

The voltage after the second gain stage comes from equation (2),

$V_2 = 6 \times 0.23V = 1.38$ V.

Therefore, before any pressure is applied to the sensor, a 1.38V DC signal will appear at V. Since the supply voltage is 3V, the available signal for actual pressure is 1.62 V. With a total gain of G1 x G2 = 606, the largest raw pressure signal that can be accurately measured would be 1.62V/606 = 2.67 mV. For the MPX2010 family operating at Vs = 3V, this corresponds to roughly 3.5 kPa.

The board lends itself well to system integration via an A/D converter and microprocessor. For particular applications, general knowledge of the expected pressure signal can aid in choosing the proper customized gain. This will avoid op-amp saturation and will also ensure that the full-scale output signal is suitable for A/D conversion. To take another example, suppose that a particular application has the following constraints:

Supply Voltage, Vs = 5.0 V,
(thus VOFFSET = 6.7% x 5 = 0.335 V)
Sensor zero-pressure offset voltage, V_{ZP} = 0.3mV
Expected Pressure range = 0-2 kPa,
(corresponds to $\Delta V_{SENSOR-MAX}$ = 2.5mV @ 5V)
Desired maximum output range, ΔV_{2MAX} = 2V
(assume VMIN = 2V, V_{2MAX} = 4V for reasonable A/D resolution)
By manipulating equations (1) and (2) it can be shown that,
$\Delta V_{2MAX} = G_T \times \Delta V_{SENSOR-MAX}$

where GT is the total gain, equal to G1G2.

Thus GT = 2V/2.5mV = 800

To find G1 and G2, evaluate V_{2MIN} at the zero pressure condition.

$V_{2MIN} = G2\ V_{1MIN}$,
But $V_{1MIN} = G1\ V_{ZP} + V_{OFFSET}$
Thus $V_{2MIN} = G_T\ V_{ZP} + G2\ V_{OFFSET}$
Solving for G2, $G2 = (V_{2MIN} - G_T\ V_{ZP})/\ V_{OFFSET}$
numerically, G2 = (2V - (800x.0003V))/.335V
G2 = 5.2, and G1 = GT /G2 = 152

BOARD LAYOUT & CONTENT

The low-pressure evaluation board has been designed using standard components. The only item that requires careful selection is the operation amplifier IC. Because the selected gain may be relatively high as in the previous example, it is essential that this device have a low offset voltage. A device with a typical voltage offset of 35 mV has been selected. Even with a gain of 1500, this will result in a 52mV offset. Table 3 is a parts list for the board layout shown in Figure 1.

Table 3. Parts List

Ref.	Qty.	Description	Value	Vendor	Part No.
X1	1	Pressure Sensor	10 Kpa	Freescale	MPX2010 MPXC2011
C1	1	Vcc Cap	1 uF	Generic	
C2	1	Op-Amp Cap	0.1 uF	Generic	
C3	1	2nd stage cap	4700 pF	Generic	
D1	1	LED		Generic	
for U1	1	Op-Amp socket		Generic	
U1	1	Op-Amp		Analog Devices	OP496GP
R1, R4	2	1/4 W Resistor	100K	Generic	
R2,R3, R5,R6	4	1/4 W Resistor	1K	Generic	
R7	1	1/4 W Resistor	6.8K	Generic	
R8	1	1/4 W Resistor	510	Generic	
R9	1	Potentiometer	1K	Bourns	3386P-102
R10	1	1/4 W Resistor	51K	Generic	
R11	1	1/4 W Resistor	custom	Generic	
R12	1	1/4 W Resistor	2K	Generic	
R41	1	1/4 W Resistor	custom	Generic	
R51	1	1/4 W Resistor	custom	Generic	
JP1 - JP7	7	Jumper		Generic	
J1	1	3 Pos Connector		Phoenix	MKDS1

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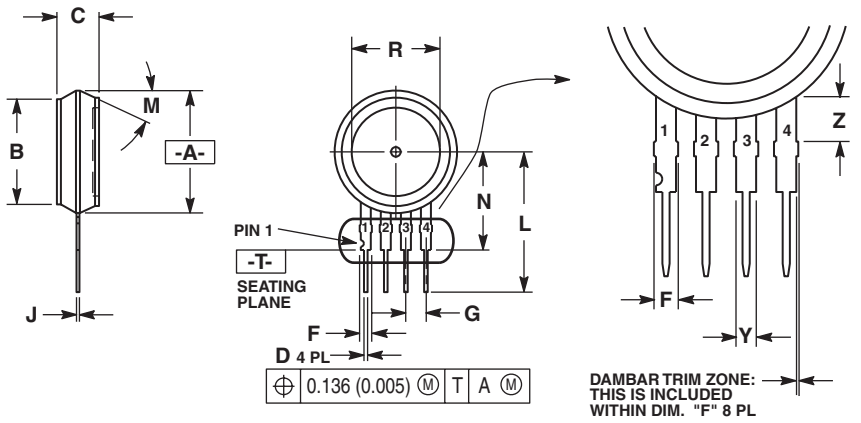
Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

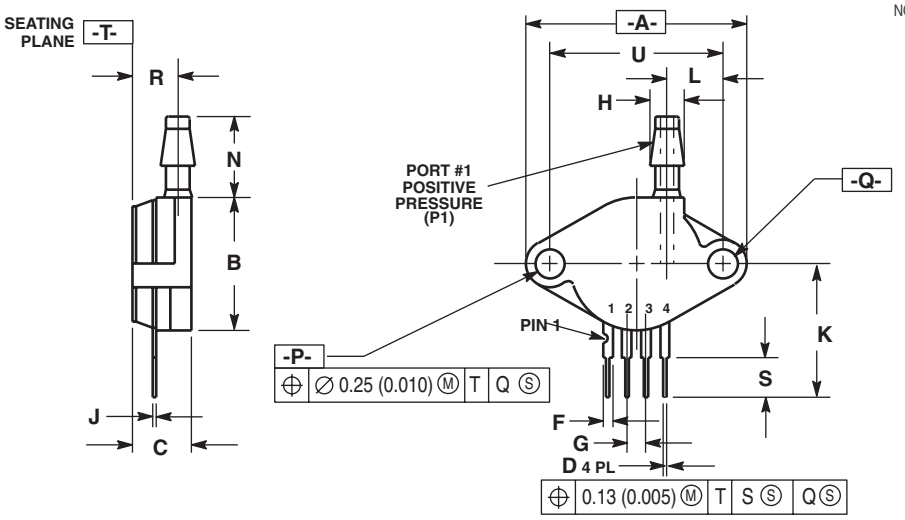
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
Y	0.048	0.052	1.22	1.32
Z	0.106	0.118	2.68	3.00

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

STYLE 2:
PIN 1. V_{CC}
2. - SUPPLY
3. + SUPPLY
4. GROUND

STYLE 3:
PIN 1. GND
2. -VOUT
3. VS
4. +VOUT

CASE 344-15
ISSUE AA
SMALL OUTLINE PACKAGE



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344B-01
ISSUE B
SMALL OUTLINE PACKAGE

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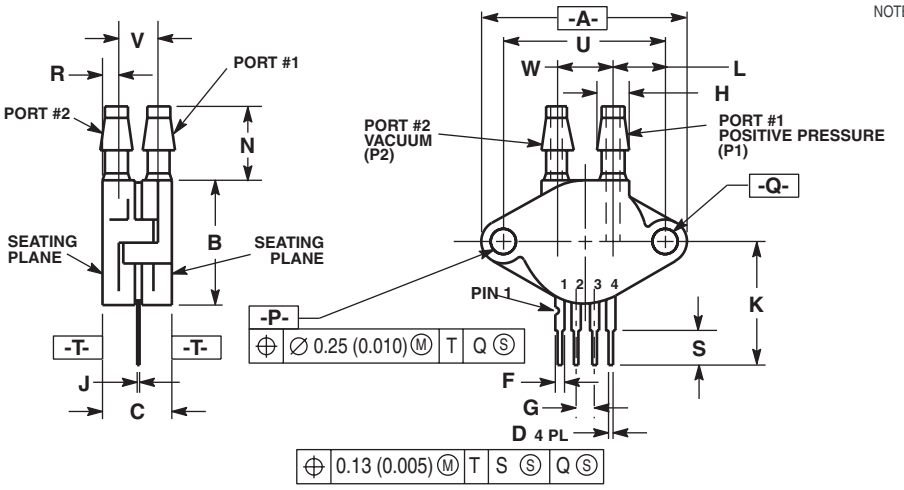
Package Dimensions



NOTES:
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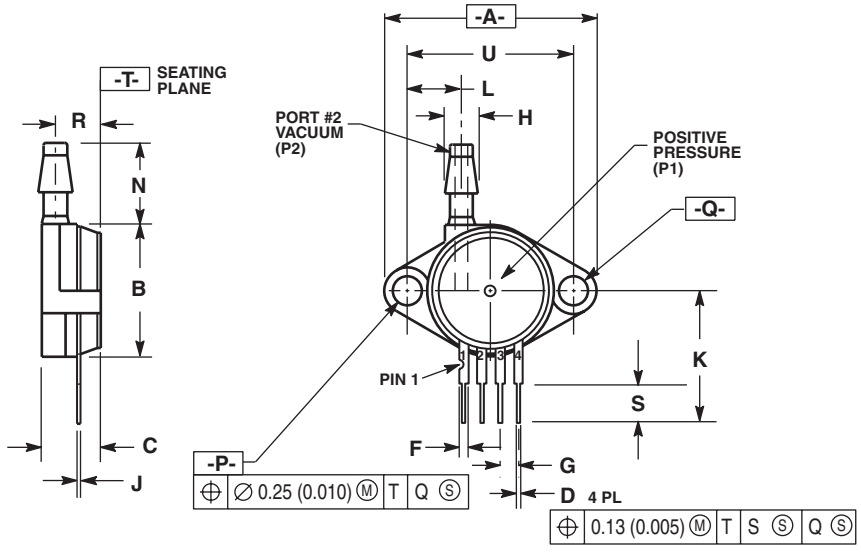
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.248	0.278	6.30	7.06
W	0.310	0.330	7.87	8.38

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344C-01
ISSUE B
SMALL OUTLINE PACKAGE



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1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.305	0.325	7.75	8.26
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.93
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.158	3.89	4.04
R	0.230	0.250	5.84	6.35
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344D-01
ISSUE B
SMALL OUTLINE PACKAGE

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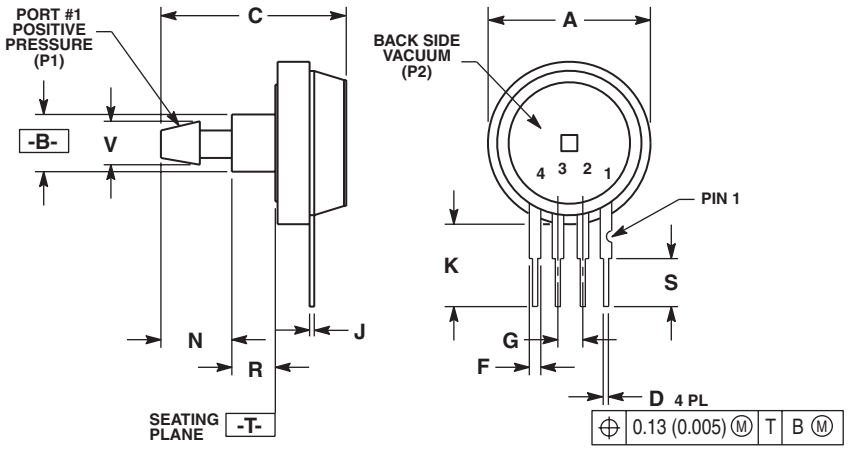
Package Dimensions

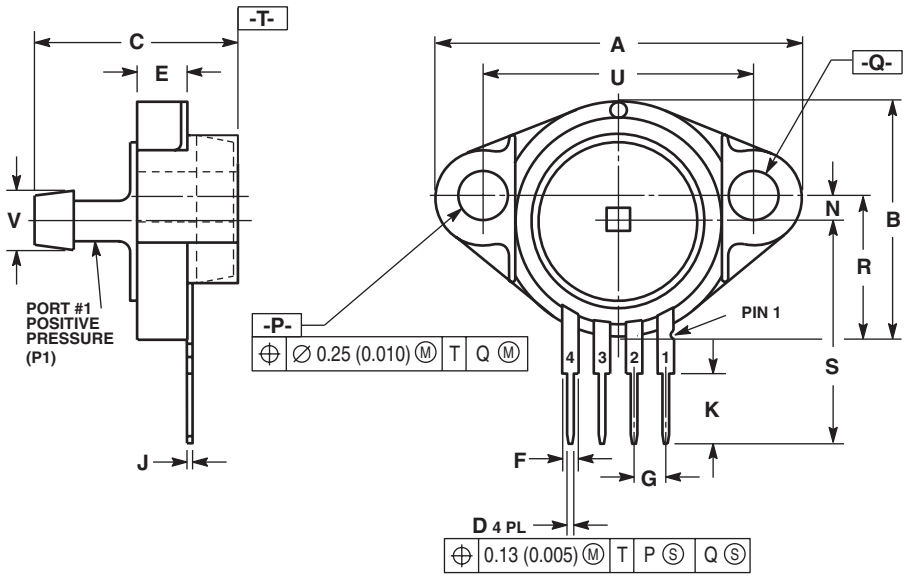


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.016	0.020	0.41	0.51
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
R	0.178	0.186	4.52	4.72
S	0.220	0.240	5.59	6.10
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 344E-01
ISSUE B
SMALL OUTLINE PACKAGE



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.016	0.020	0.41	0.51
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.92

STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (-) OUT

CASE 344F-01
ISSUE B
SMALL OUTLINE PACKAGE

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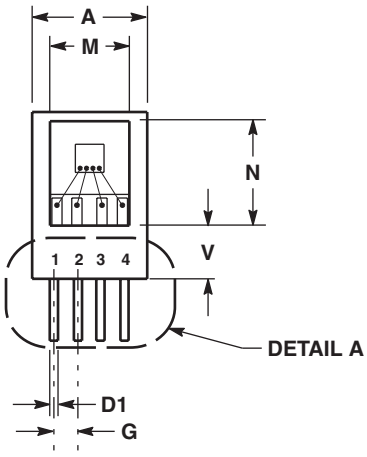
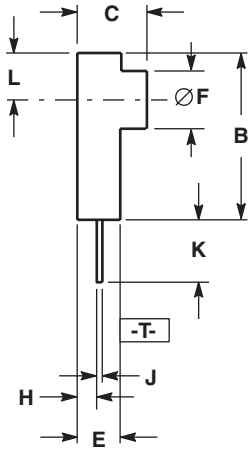
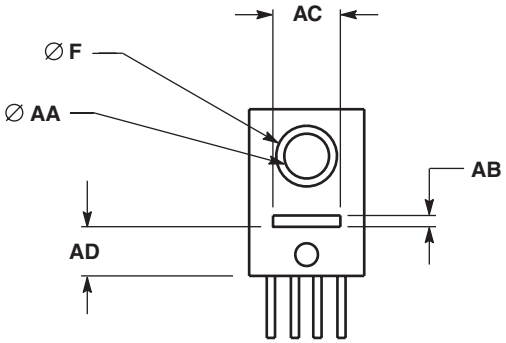
Package Dimensions



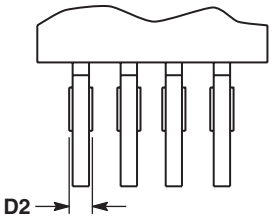
FRONT VIEW



END VIEW



BACK VIEW



DETAIL A

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.240	0.260	6.10	6.60
B	0.350	0.370	8.89	9.40
C	0.140	0.150	3.56	3.81
D1	0.012	0.020	0.30	0.51
D2	0.014	0.022	0.36	0.56
E	0.088	0.102	2.24	2.59
F	0.123	0.128	3.12	3.25
G	0.045	0.055	1.14	1.40
H	0.037	0.047	0.94	1.19
J	0.007	0.011	0.18	0.28
K	0.120	0.140	3.05	3.56
L	0.095	0.105	2.41	2.67
M	0.165	0.175	4.19	4.45
N	0.223	0.239	5.66	6.07
V	0.105	0.115	2.67	2.92
AA	0.095	0.107	2.41	2.72
AB	0.015	0.035	0.38	0.89
AC	0.120	0.175	3.05	4.45
AD	0.100	0.115	2.54	2.92

STYLE 1:
PIN 1. V_{CC}
2. +OUT
3. -OUT
4. GROUND

CASE 423A-03
ISSUE C
CHIP PAK PACKAGE

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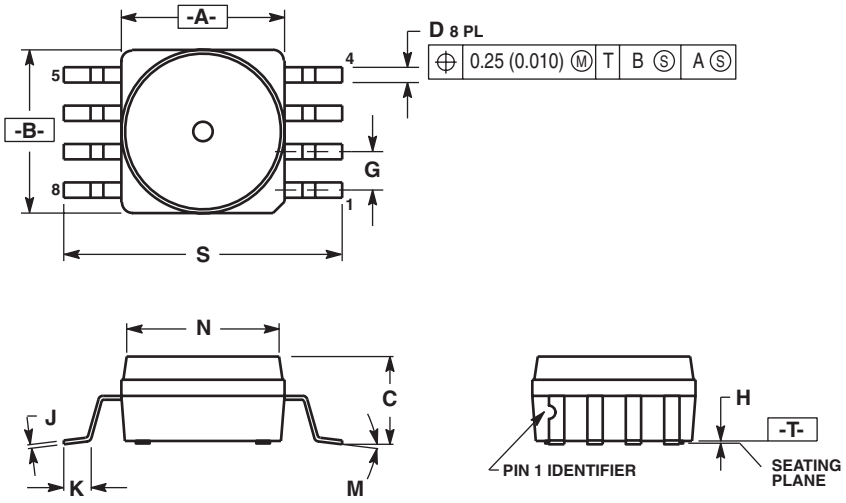
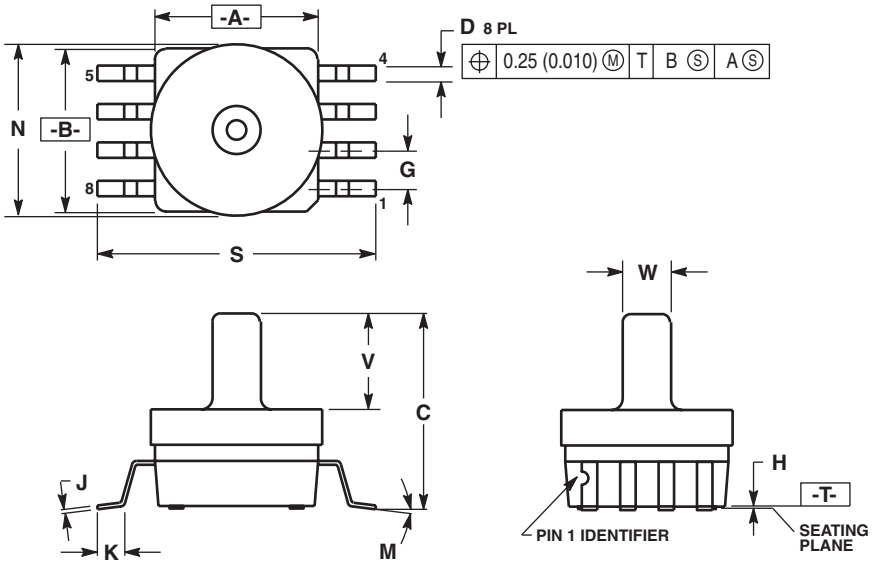
Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.212	0.230	5.38	5.84
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.405	0.415	10.29	10.54
S	0.709	0.725	18.01	18.41

CASE 482-01
ISSUE O
SMALL OUTLINE PACKAGE

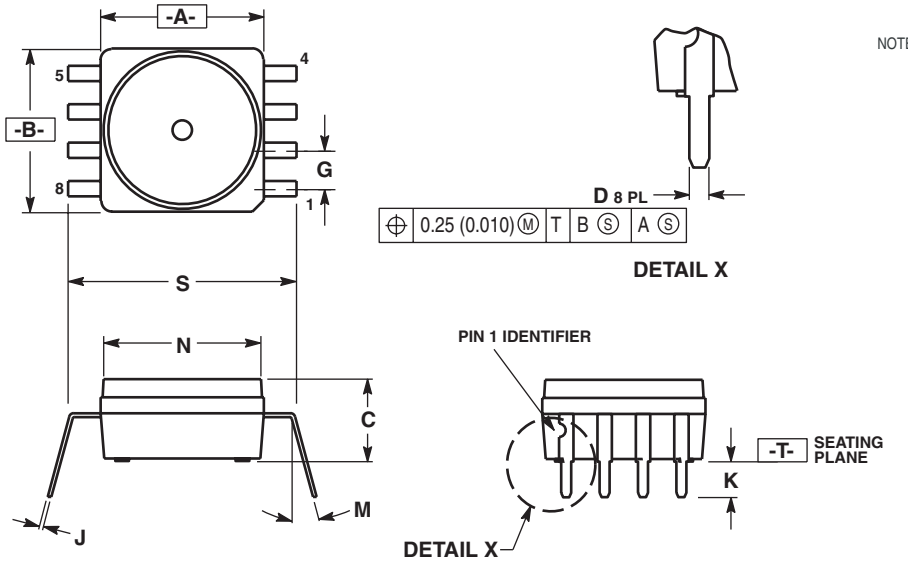


NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5˚ TYPICAL DRAFT.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.038	0.042	0.96	1.07
G	0.100 BSC		2.54 BSC	
H	0.002	0.010	0.05	0.25
J	0.009	0.011	0.23	0.28
K	0.061	0.071	1.55	1.80
M	0˚	7˚	0˚	7˚
N	0.444	0.448	11.28	11.38
S	0.709	0.725	18.01	18.41
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482A-01
ISSUE A
SMALL OUTLINE PACKAGE

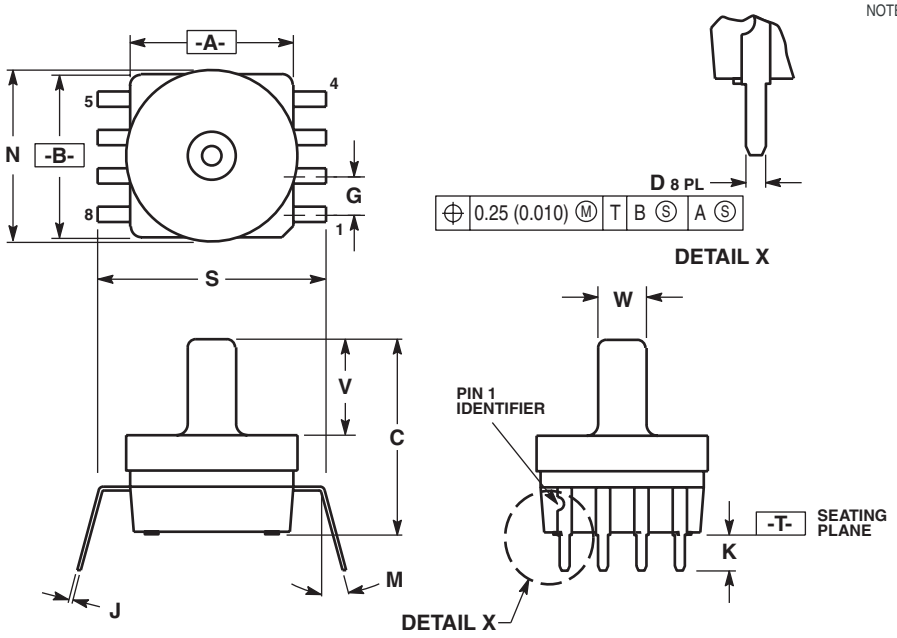
Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.210	0.220	5.33	5.59
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0°	15°	0°	15°
N	0.405	0.415	10.29	10.54
S	0.540	0.560	13.72	14.22

CASE 482B-03
ISSUE B
SMALL OUTLINE PACKAGE



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION A AND B DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15 (0.006).
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION S TO CENTER OF LEAD WHEN FORMED PARALLEL.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.415	0.425	10.54	10.79
B	0.415	0.425	10.54	10.79
C	0.500	0.520	12.70	13.21
D	0.026	0.034	0.66	0.864
G	0.100 BSC		2.54 BSC	
J	0.009	0.011	0.23	0.28
K	0.100	0.120	2.54	3.05
M	0°	15°	0°	15°
N	0.444	0.448	11.28	11.38
S	0.540	0.560	13.72	14.22
V	0.245	0.255	6.22	6.48
W	0.115	0.125	2.92	3.17

CASE 482C-03
ISSUE B
SMALL OUTLINE PACKAGE

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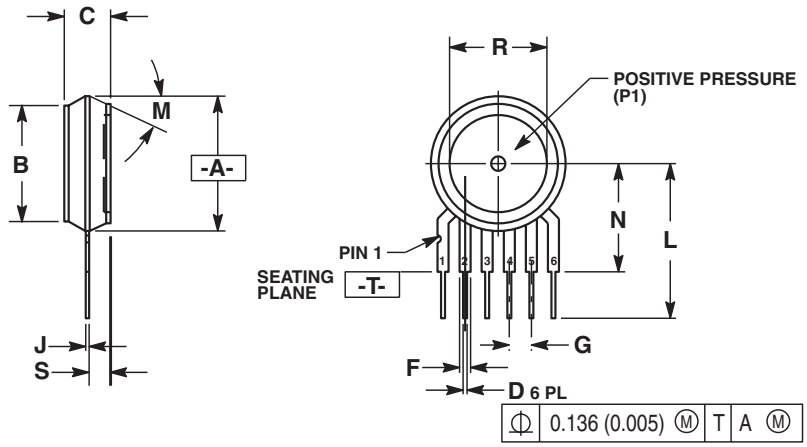
Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSION -A- IS INCLUSIVE OF THE MOLD STOP RING. MOLD STOP RING NOT TO EXCEED 16.00 (0.630).

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.595	0.630	15.11	16.00
B	0.514	0.534	13.06	13.56
C	0.200	0.220	5.08	5.59
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.695	0.725	17.65	18.42
M	30° NOM		30° NOM	
N	0.475	0.495	12.07	12.57
R	0.430	0.450	10.92	11.43
S	0.090	0.105	2.29	2.66

STYLE 1:
PIN 1. VOUT
2. GROUND
3. VCC
4. V1
5. V2
6. VEX

STYLE 2:
PIN 1. OPEN
2. GROUND
3. -VOUT
4. VSUPPLY
5. +VOUT
6. OPEN

STYLE 3:
PIN 1. OPEN
2. GROUND
3. +VOUT
4. +VSUPPLY
5. -VOUT
6. OPEN

CASE 867-08
ISSUE N
UNIBODY PACKAGE

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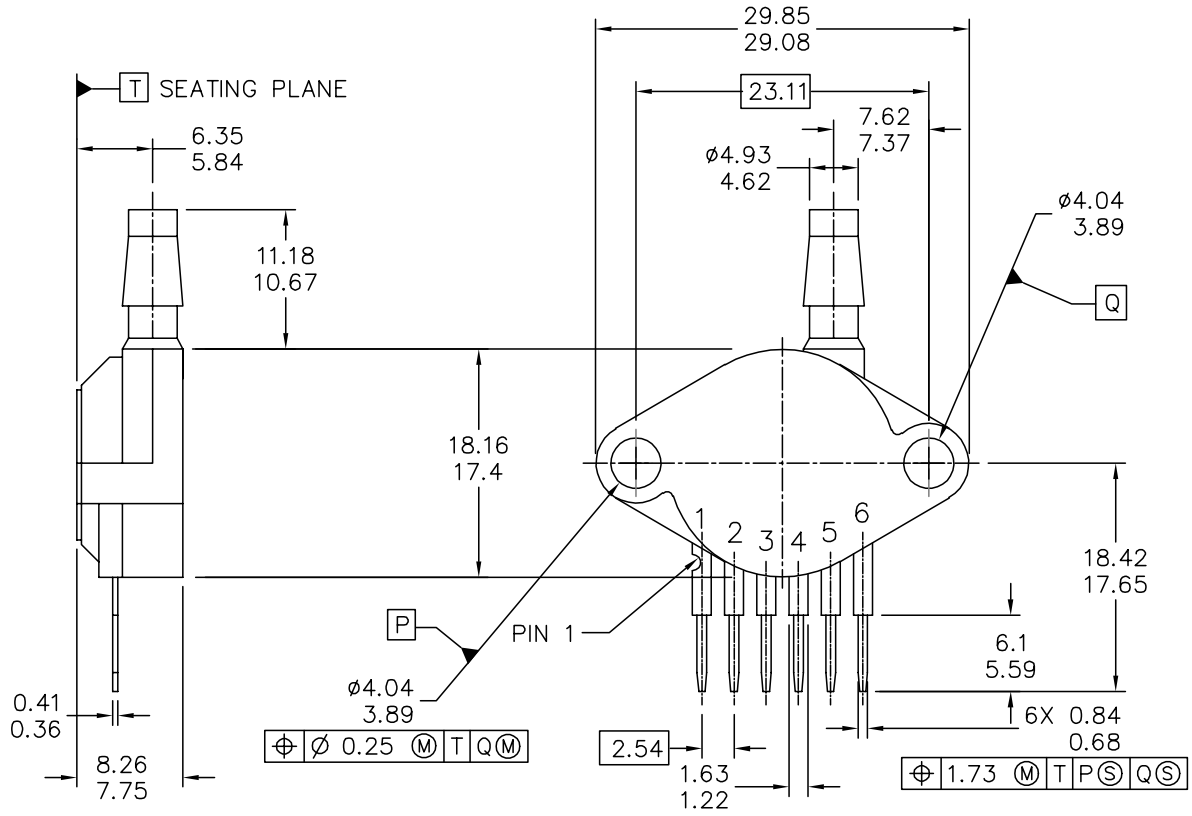
Package Dimensions



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TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B	DOCUMENT NO: 98ASB42796B	REV: G
	CASE NUMBER: 867B-04	28 JUL 2005
	STANDARD: NON-JEDEC	

CASE 867B-04
ISSUE G
UNIBODY PACKAGE

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NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. 867B–01 THRU –3 OBSOLETE, NEW STANDARD 867B–04.

STYLE 1:

PIN 1: V OUT
2: GROUND
3: VCC
4: V1
5: V2
6: V EX

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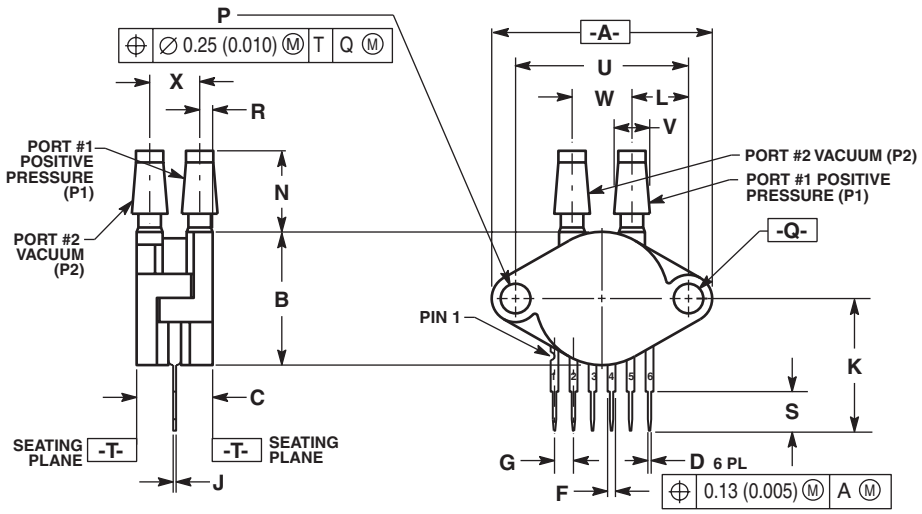
TITLE: SENSOR, 6 LEAD UNIBODY CELL, AP & GP 01ASB09087B	DOCUMENT NO: 98ASB42796B	REV: G
	CASE NUMBER: 867B–04	28 JUL 2005
	STANDARD: NON–JEDEC	

CASE 867B-04
ISSUE G
UNIBODY PACKAGE

Package Dimensions

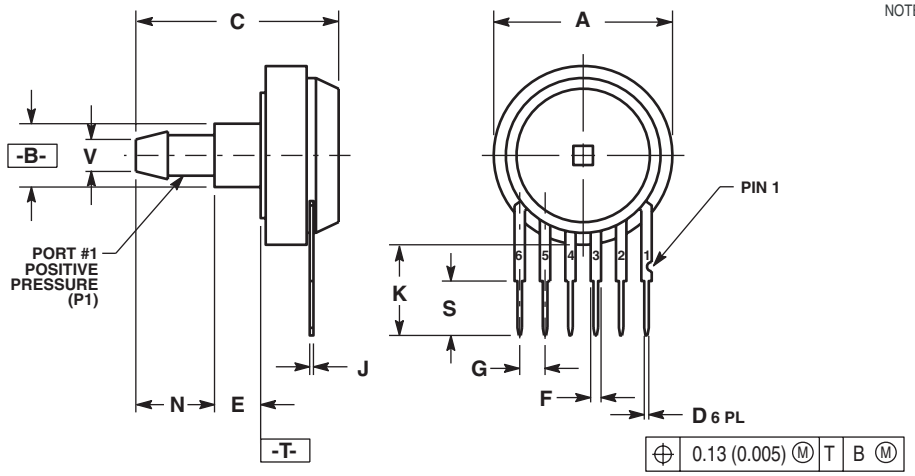


NOTES:
1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M, 1994.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.145	1.175	29.08	29.85
B	0.685	0.715	17.40	18.16
C	0.405	0.435	10.29	11.05
D	0.027	0.033	0.68	0.84
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.695	0.725	17.65	18.42
L	0.290	0.300	7.37	7.62
N	0.420	0.440	10.67	11.18
P	0.153	0.159	3.89	4.04
Q	0.153	0.159	3.89	4.04
R	0.063	0.083	1.60	2.11
S	0.220	0.240	5.59	6.10
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93
W	0.310	0.330	7.87	8.38
X	0.248	0.278	6.30	7.06

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867C-05
ISSUE F
UNIBODY PACKAGE



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.245	0.255	6.22	6.48
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.69	0.84
E	0.178	0.186	4.52	4.72
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.345	0.375	8.76	9.53
N	0.300	0.310	7.62	7.87
S	0.220	0.240	5.59	6.10
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867E-03
ISSUE D
UNIBODY PACKAGE

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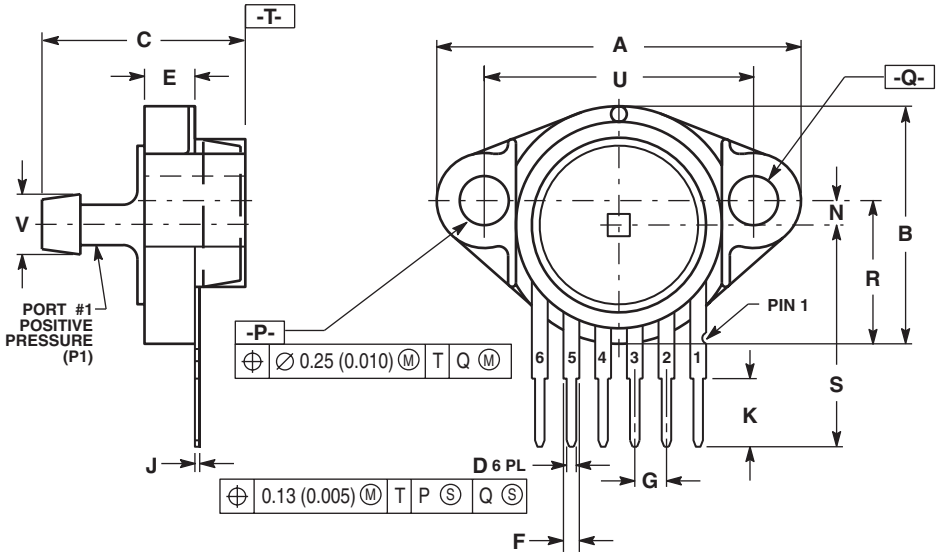
Package Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.080	1.120	27.43	28.45
B	0.740	0.760	18.80	19.30
C	0.630	0.650	16.00	16.51
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.064	1.22	1.63
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.440	0.460	11.18	11.68
S	0.695	0.725	17.65	18.42
U	0.840	0.860	21.34	21.84
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867F-03
ISSUE D
UNIBODY PACKAGE

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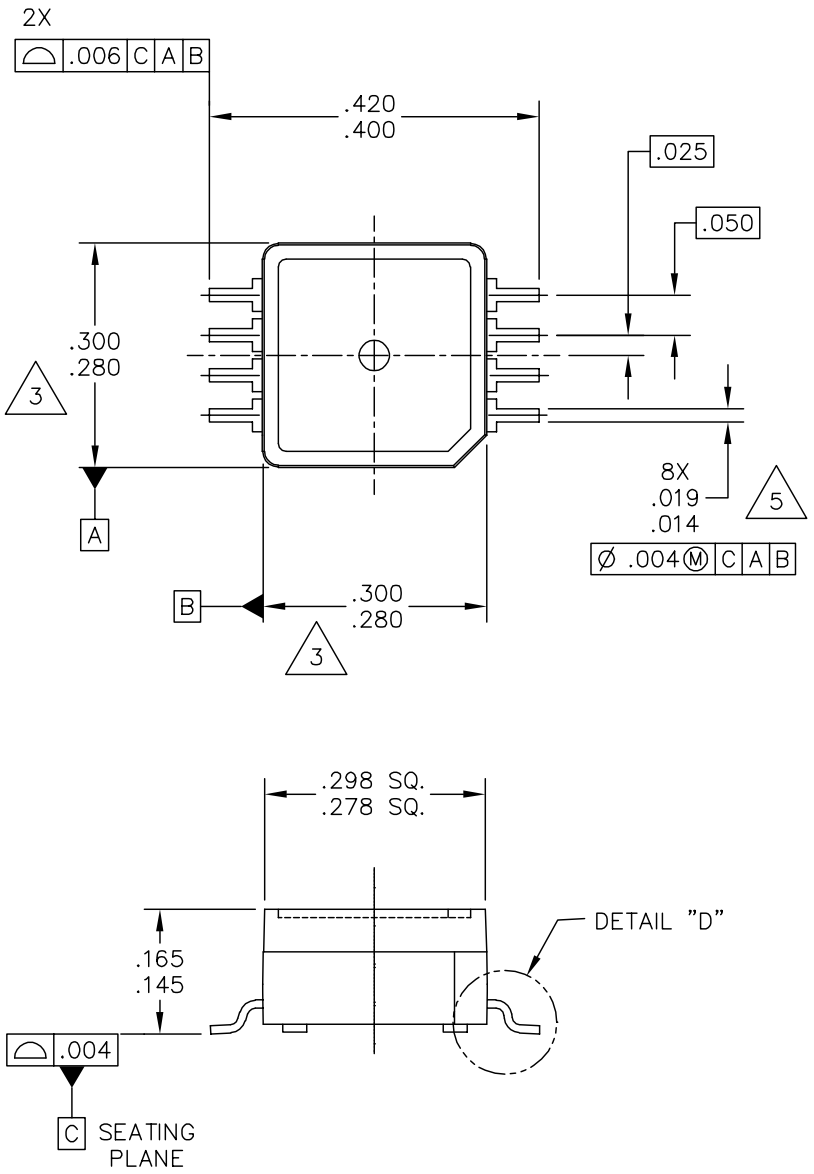
Package Dimensions



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TITLE: 8 LEAD SSOP	DOCUMENT NO: 98ARH99066A	REV: F
	CASE NUMBER: 1317–04	24 MAY 2005
	STANDARD: NON–JEDEC	

PAGE 1 OF 3

CASE 1317-04
ISSUE F
SUPER SMALL OUTLINE PACKAGE

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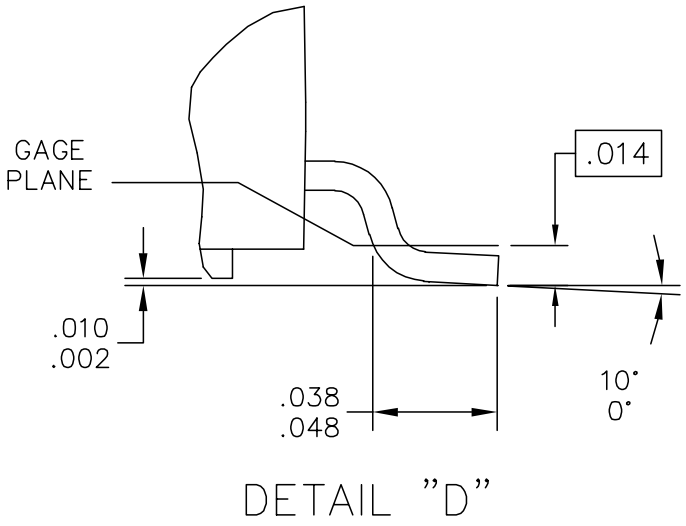
Package Dimensions



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TITLE: 8 LEAD SSOP	DOCUMENT NO: 98ARH99066A	REV: F
	CASE NUMBER: 1317–04	24 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1317-04
ISSUE F
SUPER SMALL OUTLINE PACKAGE

Package Dimensions

NOTES:

1. ALL DIMENSIONS IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
   MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006 INCHES PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION.
   ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 INCHES MAXIMUM.

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ARH99066A	REV: F
8 LEAD SSOP	CASE NUMBER: 1317–04	24 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1317-04
ISSUE F
SUPER SMALL OUTLINE PACKAGE

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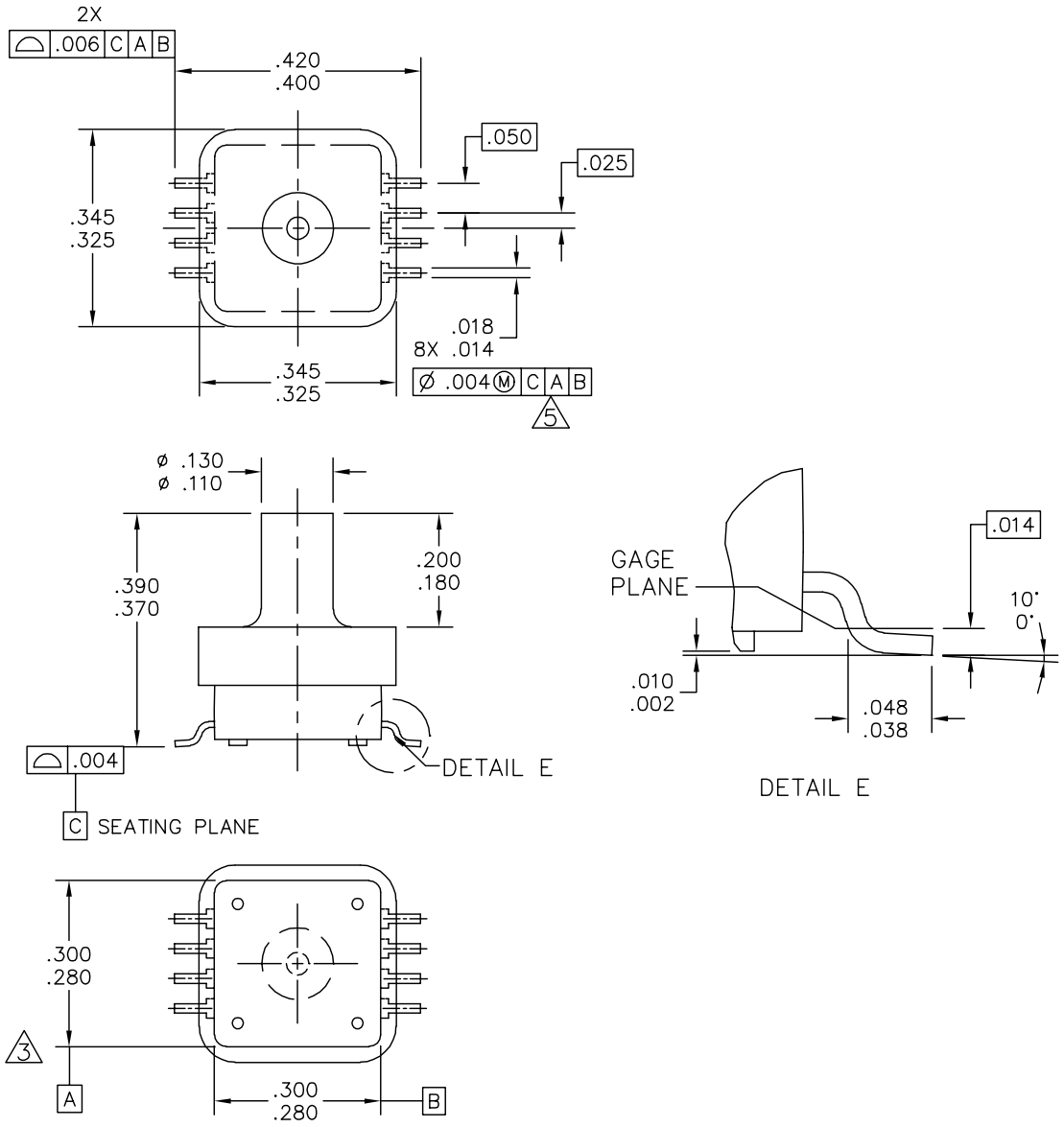
Package Dimensions



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TITLE: 8 LD, PORTED SSOP	DOCUMENT NO: 98ARH99089A	REV: C
	CASE NUMBER: 1317A-03	24 MAY 2005
	STANDARD: NON-JEDEC	

CASE 1317A-03
ISSUE C
SUPER SMALL OUTLINE PACKAGE

Archived Archived Archived Archived Archived Archived Archived

Package Dimensions

NOTES:

1. ALL DIMENSIONS IN INCHES.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
   MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006 INCHES PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION.
   ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 INCHES MAXIMUM.

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TITLE: 8 LD, PORTED SSOP	DOCUMENT NO: 98ARH99089A	REV: C
	CASE NUMBER: 1317A-03	24 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1317A-03
ISSUE C
SUPER SMALL OUTLINE PACKAGE

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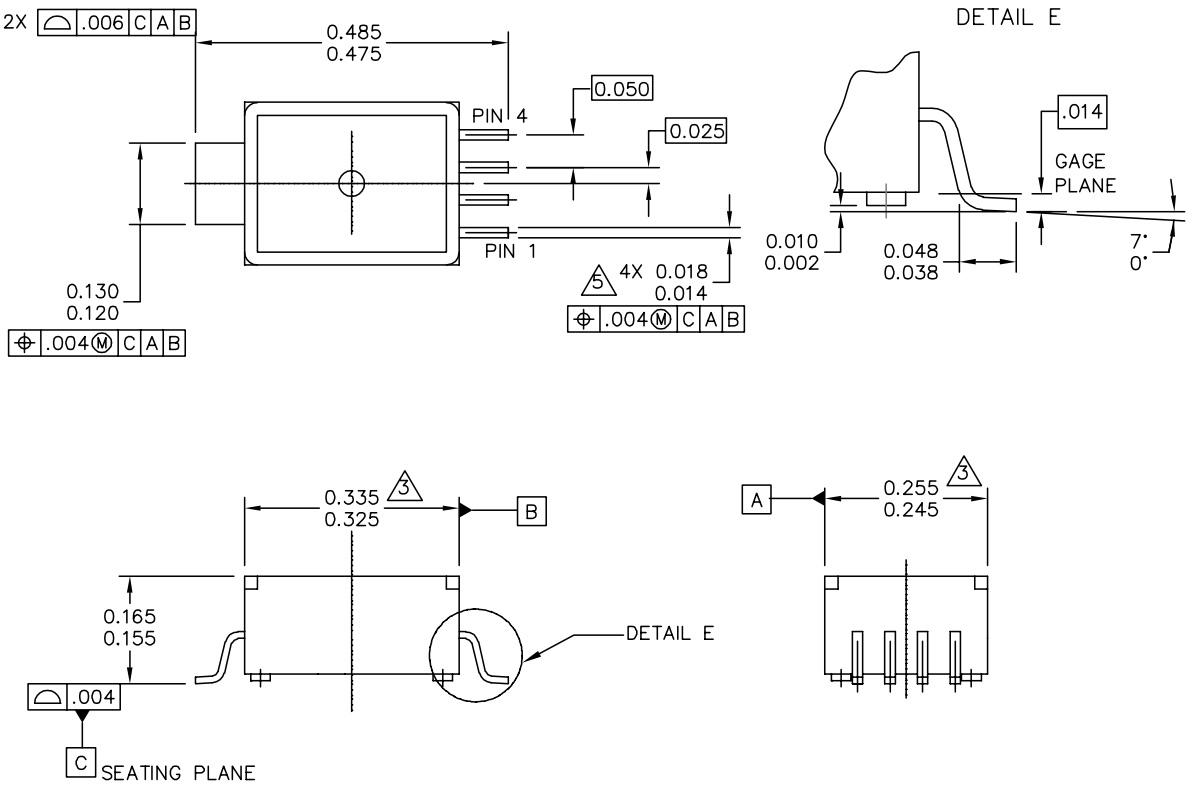
Package Dimensions



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TITLE: 5 LD M–PAC	DOCUMENT NO: 98ARH99088A	REV: B
	CASE NUMBER: 1320-02	22 JUL 2005
	STANDARD: NON-JEDEC	

PAGE 1 OF 2

CASE 1320-02
ISSUE B
MPAK PACKAGE

Archived Archived Archived Archived Archived Archived Archived

Package Dimensions

NOTES:

1. DIMENSIONS ARE IN INCHES.

2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.

3. DIMENSION DOES NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.

4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.

5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

PIN 1: GND
PIN 2: +Vout
PIN 3: Vs
PIN 4: –Vout

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TITLE: 5 LD M–PAC	DOCUMENT NO: 98ARH99088A	REV: B
	CASE NUMBER: 1320–02	22 JUL 2005
	STANDARD: NON–JEDEC	

CASE 1320-02
ISSUE B
MPAK PACKAGE

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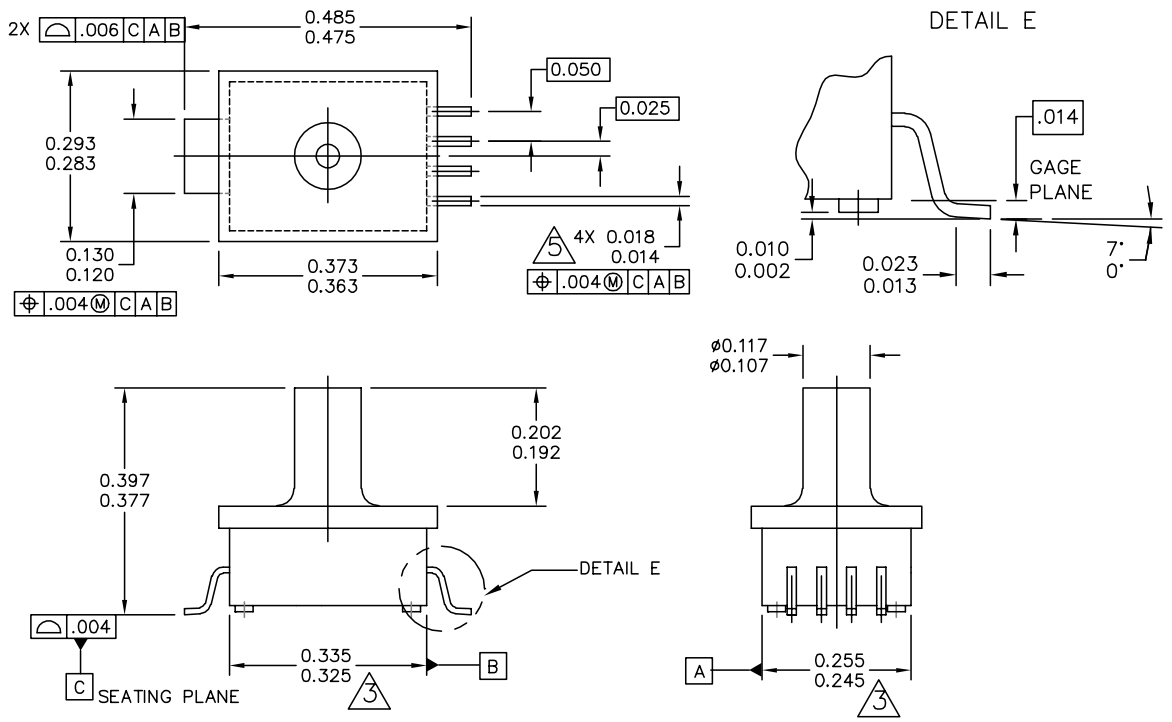
Package Dimensions



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TITLE: 5 LD M–PAC, PORTED	DOCUMENT NO: 98ARH99087A	REV: A
	CASE NUMBER: 1320A–02	22 JUL 2005
	STANDARD: NON–JEDEC	

PAGE 1 OF 2

CASE 1320A-02
ISSUE A
MPAK PACKAGE

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NOTES:

1. DIMENSIONS ARE IN INCHES.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS DOES NOT INCLUDE MOLD FLASH OR PROTRUSION. MOLD FLASH OR PROTRUSION SHALL NOT EXCEED .006" PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5" MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

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TITLE: 5 LD M–PAC, PORTED	DOCUMENT NO: 98ARH99087A	REV: A
	CASE NUMBER: 1320A–02	22 JUL 2005
	STANDARD: NON–JEDEC	

CASE 1320A-02
ISSUE A
MPAK PACKAGE

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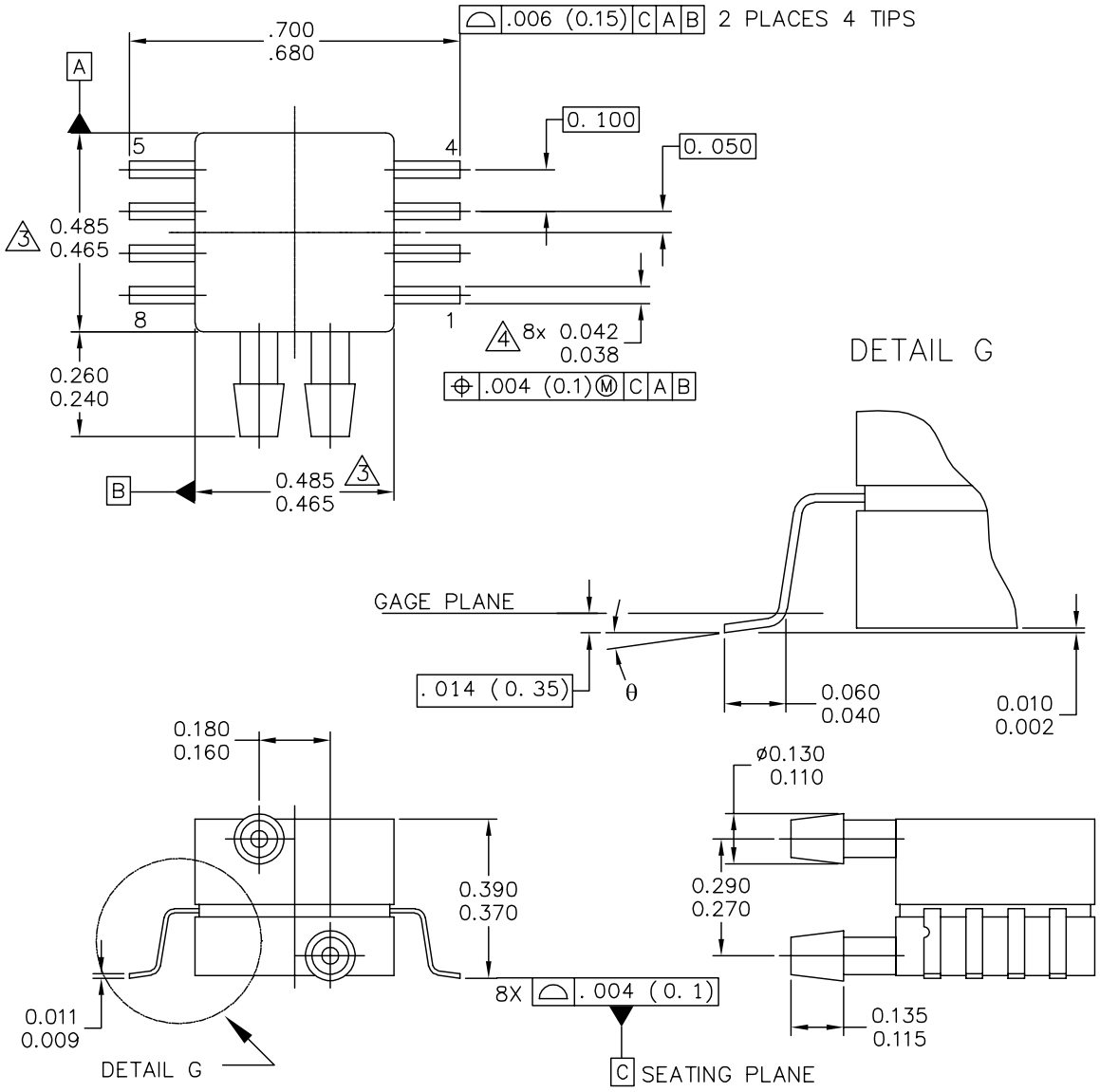
Package Dimensions



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TITLE: 8 LD SNSR, DUAL PORT	DOCUMENT NO: 98ASA99255D	REV: A
	CASE NUMBER: 1351-01	27 JUL 2005
	STANDARD: NON-JEDEC	

CASE1351-01
ISSUE A
SMALL OUTLINE PACKAGE

NOTES:

1. CONTROLLING DIMENSION: INCH

2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.

3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PPROTRUSIONS.
MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED .006 PER SIDE.

4. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR
PROTRUSION SHALL BE .008 MAXIMUM.

STYLE 1:	STYLE 2:
PIN 1: GND	PIN 1: N/C
PIN 2: +Vout	PIN 2: Vs
PIN 3: Vs	PIN 3: GND
PIN 4: –Vout	PIN 4: Vout
PIN 5: N/C	PIN 5: N/C
PIN 6: N/C	PIN 6: N/C
PIN 7: N/C	PIN 7: N/C
PIN 8: N/C	PIN 8: N/C

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASA99255D	REV: A
8 LD SNSR, DUAL PORT	CASE NUMBER: 1351–01	27 JUL 2005
	STANDARD: NON–JEDEC	

CASE1351-01
ISSUE A
SMALL OUTLINE PACKAGE

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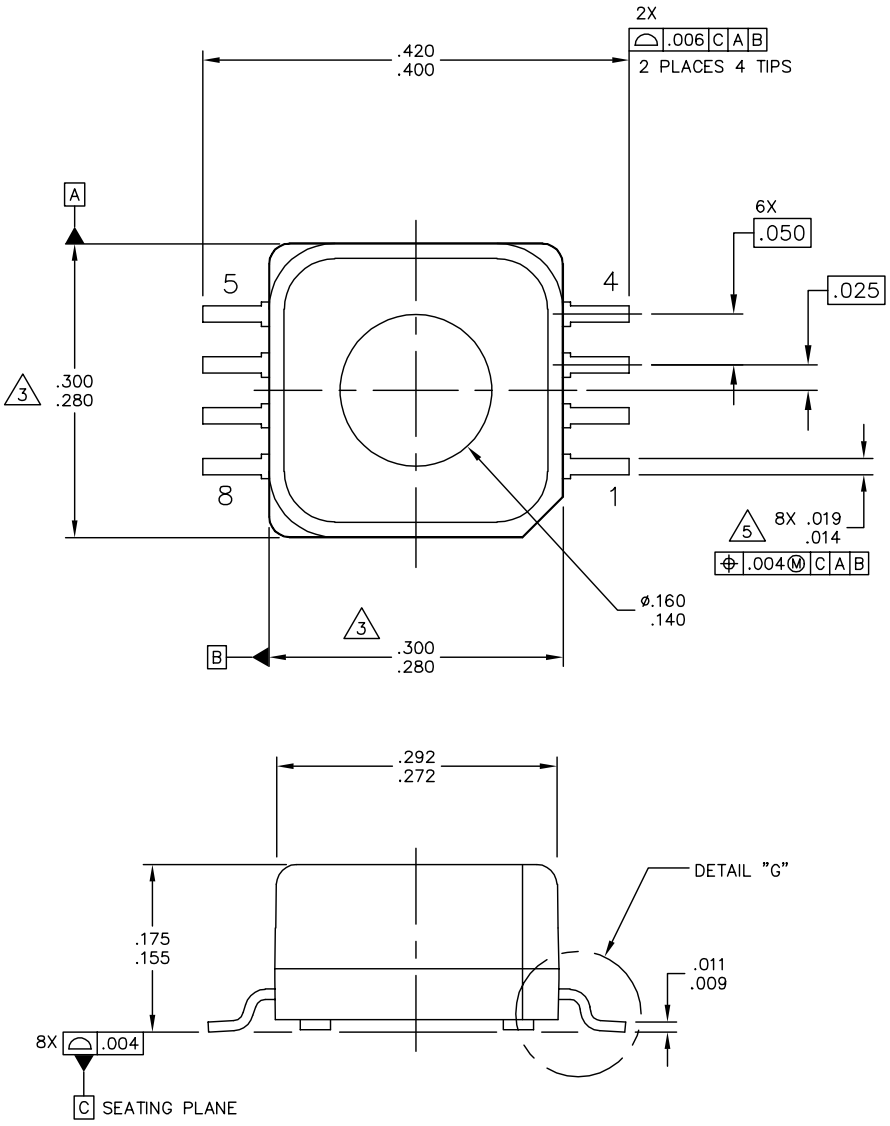
Package Dimensions



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TITLE: 8 LEAD TPMP GULL WING FORM	DOCUMENT NO: 98ASA99256D	REV: C
	CASE NUMBER: 1352-03	24 JUL 2005
	STANDARD: NON-JEDEC	

CASE 1352-03
ISSUE C
SUPER SMALL OUTLINE PACKAGE

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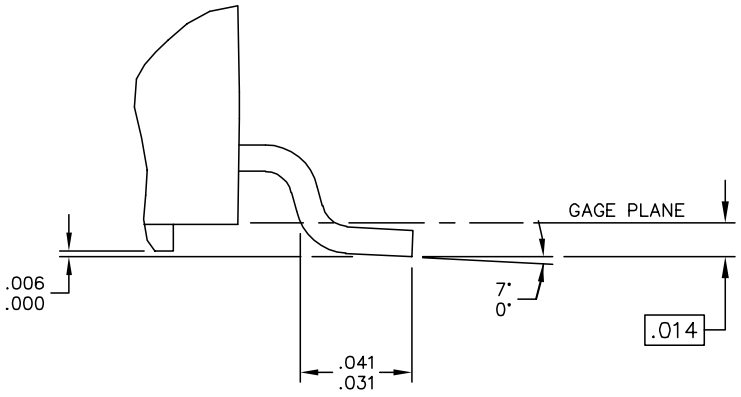
Package Dimensions



DETAIL "G"

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TITLE: 8 LEAD TPMP GULL WING FORM	DOCUMENT NO: 98ASA99256D	REV: C
	CASE NUMBER: 1352–03	24 JUL 2005
	STANDARD: NON–JEDEC	

CASE 1352-03
ISSUE C
SUPER SMALL OUTLINE PACKAGE

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Package Dimensions

NOTES:

1. CONTROLLING DIMENSION: INCH.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.
3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FALSH AND PRPTRUSIONS SHALL NOT EXCEED .006 PER SIDE.
4. ALL VERTICAL SURFACES TO BE 5° MAXIMUM.
5. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAX.

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TITLE: 8 LEAD TPMP GULL WING FORM	DOCUMENT NO: 98ASA99256D	REV: C
	CASE NUMBER: 1352–03	24 JUL 2005
	STANDARD: NON–JEDEC	

CASE 1352-03
ISSUE C
SUPER SMALL OUTLINE PACKAGE

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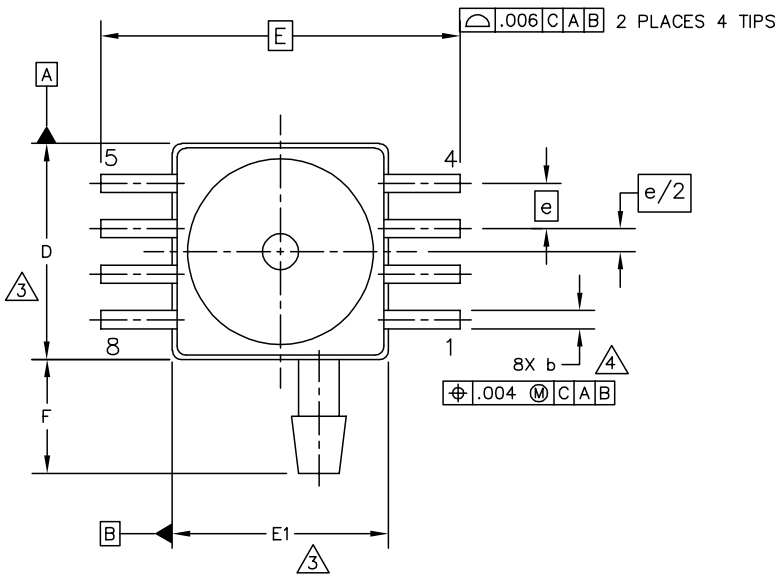
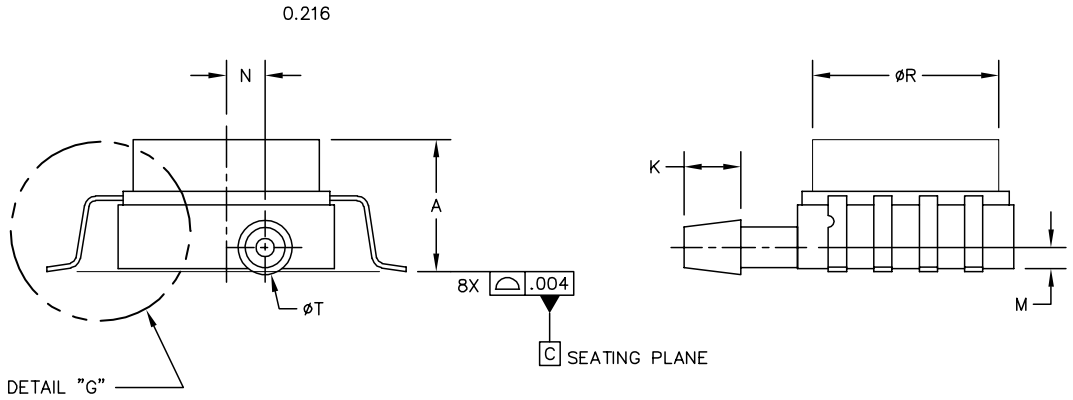
Package Dimensions





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TITLE: 8 LD SOP, GVP	DOCUMENT NO: 98ASA99302D	REV: B
	CASE NUMBER: 1368-01	23 MAY 2005
	STANDARD: NON-JEDEC	

PAGE 1 OF 3

CASE 1368-01
ISSUE B
SMALL OUTLINE PACKAGE

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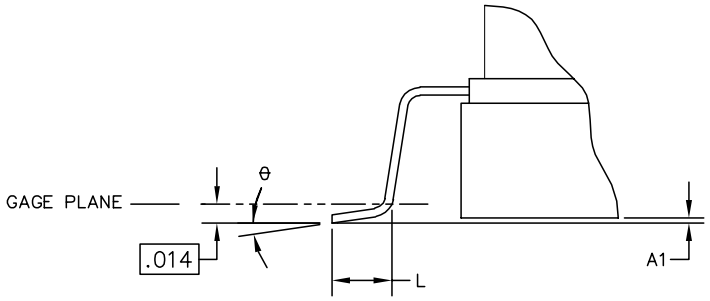
Package Dimensions



DETAIL "G"

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TITLE: 8 LD SOP, GVP	DOCUMENT NO: 98ASA99302D	REV: B
	CASE NUMBER: 1368–01	23 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1368-01
ISSUE B
SMALL OUTLINE PACKAGE

Archived Archived Archived Archived Archived Archived Archived

Package Dimensions

NOTES:

1. CONTROLLING DIMENSION: INCH

2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.

3. THIS DIMENSIONS DOES NOT INCLUDE MOLD FLASH OR PPROTRUSIONS. MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED .006 PER SIDE.

4. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL BE .008 MAXIMUM.

STYLE 1:
PIN 1: GND
PIN 2: +Vout
PIN 3: Vs
PIN 4: –Vout
PIN 5: N/C
PIN 6: N/C
PIN 7: N/C
PIN 8: N/C

STYLE 2:
PIN 1: N/C
PIN 2: Vs
PIN 3: GND
PIN 4: Vout
PIN 5: N/C
PIN 6: N/C
PIN 7: N/C
PIN 8: N/C

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	.280	.300	7.11	7.62	R	.405	.415	10.28	10.54
A1	.002	.010	0.05	0.25	θ	0°	7°	0°	7°
b	.038	.042	0.96	1.07	–	---	---	---	---
D	.465	.485	11.81	12.32	–	---	---	---	---
E	.690 BSC		17.52 BSC		–	---	---	---	---
E1	.465	.485	11.85	12.32	–	---	---	---	---
e	.100 BSC		2.54 BSC		–	---	---	---	---
F	.240	.260	6.10	6.60	–	---	---	---	---
K	.115	.135	2.92	3.43	–	---	---	---	---
L	.040	.060	1.02	1.52	–	---	---	---	---
M	.035	.055	1.90	2.41	–	---	---	---	---
N	.075	.095	0.89	1.39	–	---	---	---	---
P	.009	.011	0.23	0.28	–	---	---	---	---
T	.110	.130	2.79	3.30	–	---	---	---	---

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASA99302D	REV: B
8 LD SOP, GVP	CASE NUMBER: 1368–01	23 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1368-01
ISSUE B
SMALL OUTLINE PACKAGE

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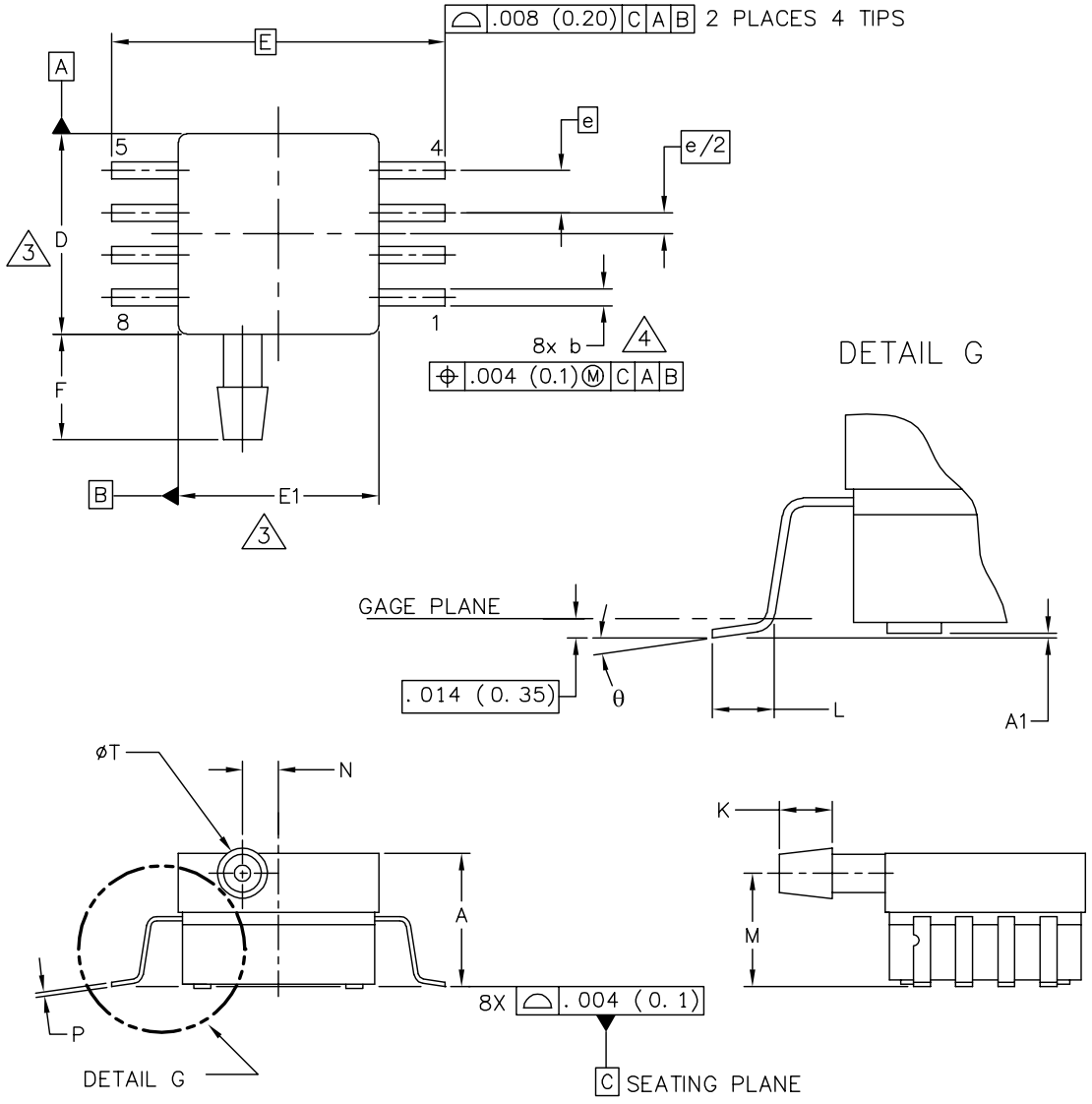
Package Dimensions



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TITLE: 8 LD SOP, SIDE PORT	DOCUMENT NO: 98ASA99303D	REV: B
	CASE NUMBER: 1369-01	24 MAY 2005
	STANDARD: NON-JEDEC	

CASE 1369-01
ISSUE B
SMALL OUTLINE PACKAGE

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Package Dimensions

NOTES:
1. CONTROLLING DIMENSION: INCH

2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M–1994.

3. DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PPROTRUSIONS.
MOLD FLASH AND PROTRUSIONS SHALL NOT EXCEED .006 (0.152) PER SIDE.

4. DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR
PROTRUSION SHALL BE .008 (0.203) MAXIMUM.

DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX	DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	.300	.330	7.11	7.62	θ	0°	7°	0°	7°
A1	.002	.010	0.05	0.25	–	---	---	---	---
b	.038	.042	0.96	1.07	–	---	---	---	---
D	.465	.485	11.81	12.32	–	---	---	---	---
E	.717 BSC		18.21 BSC		–	---	---	---	---
E1	.465	.485	11.81	12.32	–	---	---	---	---
e	.100 BSC		2.54 BSC		–	---	---	---	---
F	.245	.255	6.22	6.47	–	---	---	---	---
K	.120	.130	3.05	3.30	–	---	---	---	---
L	.061	.071	1.55	1.80	–	---	---	---	---
M	.270	.290	6.86	7.36	–	---	---	---	---
N	.080	.090	2.03	2.28	–	---	---	---	---
P	.009	.011	0.23	0.28	–	---	---	---	---
T	.115	.125	2.92	3.17	–	---	---	---	---

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MECHANICAL OUTLINE | PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASA99303D	REV: B
8 LD SOP, SIDE PORT	CASE NUMBER: 1369–01	24 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1369-01
ISSUE B
SMALL OUTLINE PACKAGE

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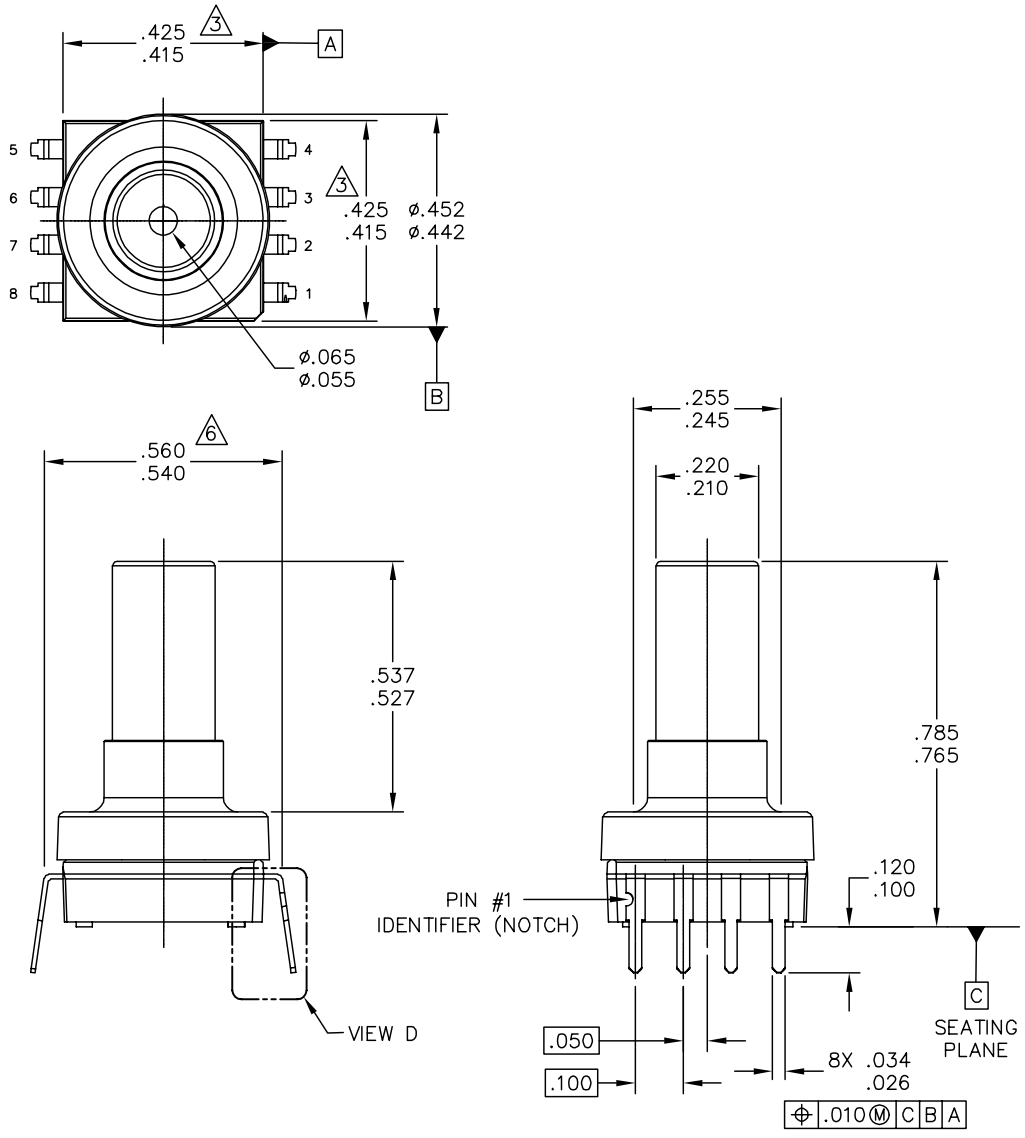
Package Dimensions



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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D	REV: C
	CASE NUMBER: 1560-02	26 MAY 2005
	STANDARD: NON-JEDEC	

CASE 1560-02
ISSUE C
SMALL OUTLINE PACKAGE

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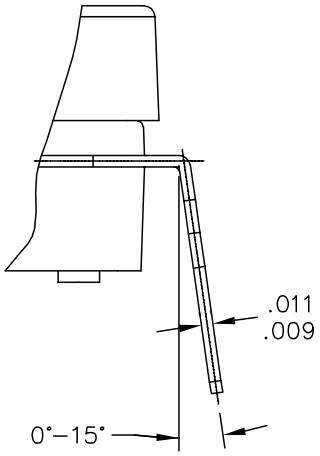
Package Dimensions



VIEW D

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D	REV: C
	CASE NUMBER: 1560–02	26 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1560-02
ISSUE C
SMALL OUTLINE PACKAGE

Archived Archived Archived Archived Archived Archived Archived

Package Dimensions

NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M – 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION IS .006.
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION TO CENTER OF LEAD WHEN FORMED PARALLEL.

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10611D	REV: C
	CASE NUMBER: 1560–02	26 MAY 2005
	STANDARD: NON–JEDEC	

CASE 1560-02
ISSUE C
SMALL OUTLINE PACKAGE

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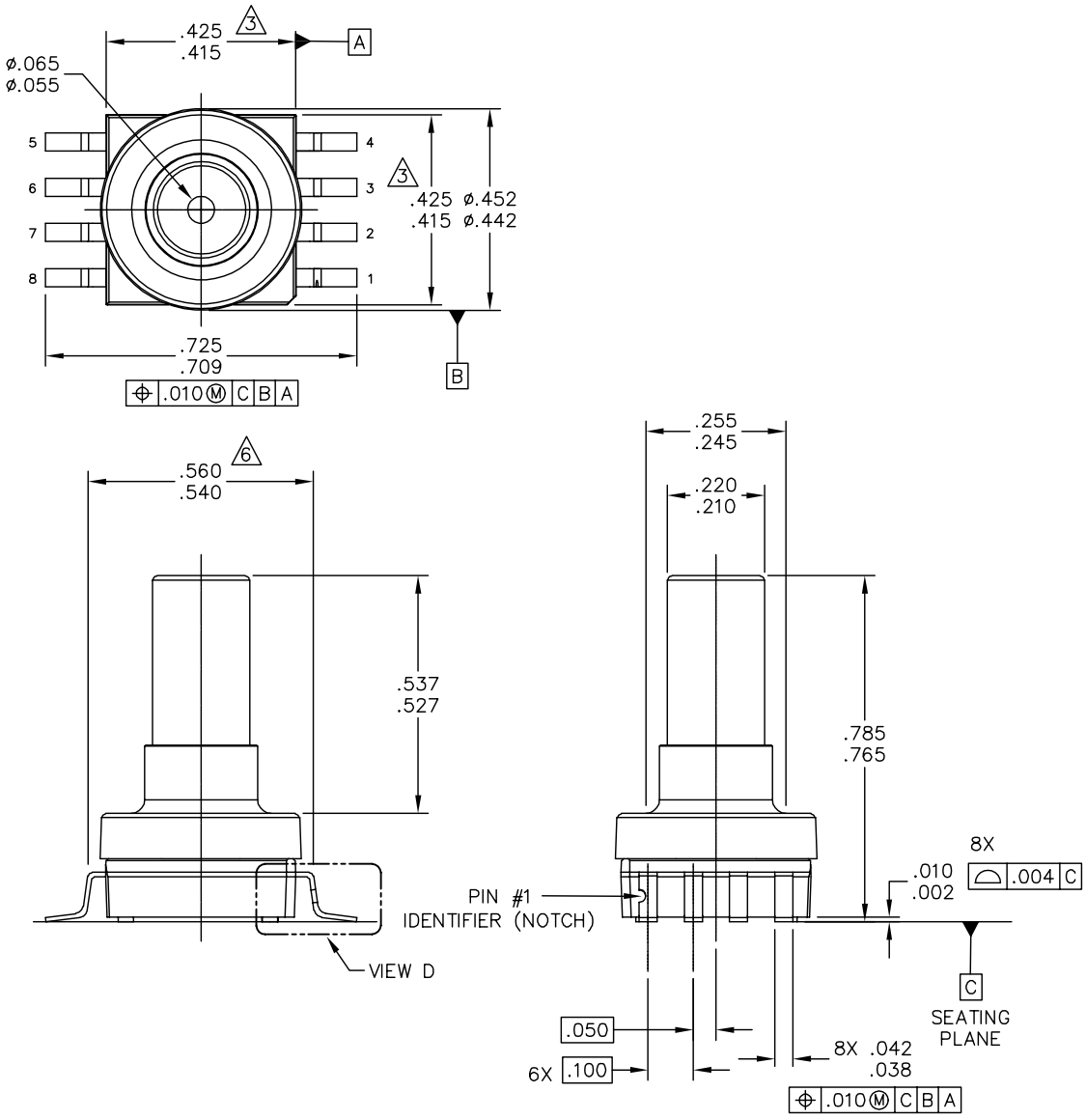
Package Dimensions



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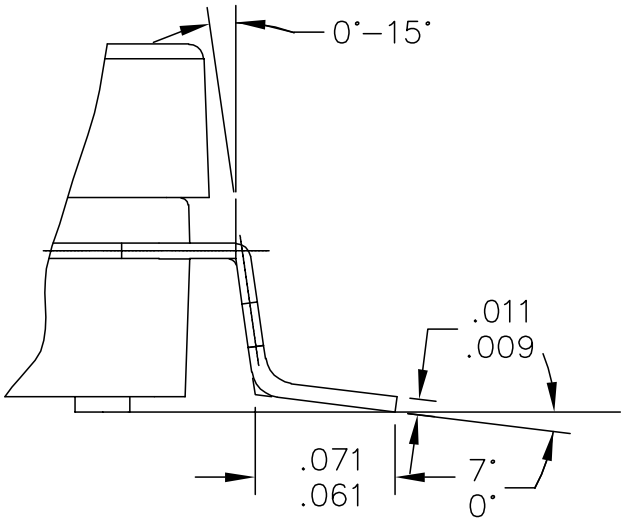
TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D	REV: A
	CASE NUMBER: 1735–01	16 AUG 2005
	STANDARD: NON–JEDEC	

CASE 1735-01
ISSUE A
SMALL OUTLINE PACKAGE



VIEW D

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D	REV: A
	CASE NUMBER: 1735–01	18 AUG 2005
	STANDARD: NON–JEDEC	

CASE 1735-01
ISSUE A
SMALL OUTLINE PACKAGE

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Package Dimensions

NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M – 1994.
2. CONTROLLING DIMENSION: INCH.
3. DIMENSIONS DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION IS .006.
5. ALL VERTICAL SURFACES 5° TYPICAL DRAFT.
6. DIMENSION TO CENTER OF LEAD WHEN FORMED PARALLEL.

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TITLE: SO, 8 I/O, .420 X .420 PKG, .100 IN PITCH	DOCUMENT NO: 98ASA10686D	REV: A
	CASE NUMBER: 1735–01	18 AUG 2005
	STANDARD: NON–JEDEC	

CASE 1735-01
ISSUE A
SMALL OUTLINE PACKAGE

Reference Tables

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FLOW EQUIVALENTS

1 Cu. Ft./Hr.		1 Cu. Ft./Min.		1 CC/Min.		1 CC/Hr.	
0.0166	Cu. Ft./Min	60	Cu. Ft./Min	60	CC/Hr.	0.0167	CC/Min.
0.4719	LPM	28.316	LPM	0.000035	Cu. Ft./Min	0.0000005	Cu. Ft./Min
28.316	LPH	1699	LPH	0.0021	Cu. Ft./Hr.	0.00003	Cu. Ft./Hr.
471.947	CC/Min.	28317	CC/Min.	0.001	LPM	0.000017	LPM
28317	CC/Hr.	1,699,011	CC/Hr.	0.06	LPH	0.001	LPH
0.1247	Gal/Min.	7.481	Gal/Min.	0.00026	Gal/Min.	0.000004	Gal/Min.
7.481	Gal/Hr.	448.831	Gal/Hr.	0.0159	Gal/Hr.	0.00026	Gal/Hr.
1 LPM		**1 LPH**		**1 Gal/Min.**		**1 Gal/Hr.**	
60	LPH	0.0166	LPH	60	Gal/Hr.	0.0167	Gal/Min.
0.035	Cu. Ft./Min.	0.00059	Cu. Ft./Min.	0.1337	Cu. Ft./Min.	0.002	Cu. Ft./Min.
2.1189	Cu. Ft./Hr.	0.035	Cu. Ft./Hr.	8.021	Cu. Ft./Hr.	0.1337	Cu. Ft./Hr.
1000	CC/Min.	16.667	CC/Min.	3.785	LPM	0.063	LPM
60,002	CC/Hr.	1000	CC/Hr.	227.118	LPH	3.785	LPH
0.264	Gal/Min.	0.004	Gal/Min.	3,785.412	CC/Min.	63.069	CC/Min.
15.851	Gal/Hr.	0.264	Gal/Hr.	227,125	CC/Hr.	3785	CC/Hr.

Airspeed

Knots	Inches of Mercury
60	0.1727
80	0.3075
100	0.4814
110	0.5832
120	0.6950
130	0.8168
140	0.9488
150	1.0910
175	1.4918
200	1.9589
225	2.4943
250	3.1002
275	3.7792
300	4.5343
325	5.3687
350	6.2859
375	7.2900

Knots	Inches of Mercury
400	8.3850
425	9.5758
450	10.8675
475	12.2654
500	13.7756
525	15.4045
550	17.1590
575	19.0465
600	21.0749
650	25.5893
700	30.7642
750	36.5662
800	42.9378
850	49.8423
900	57.2554
1,000	73.5454

Altitude (Feet)	Equivalent Pressure (Inches of Mercury)
-1,000	31.0185
-900	30.9073
0	29.9213
500	29.3846
1,000	28.8557
1,500	28.3345
2,000	27.8210
3,000	26.8167
4,000	25.8418
6,000	23.9782
8,000	22.2250
10,000	20.5770
12,000	19.0294

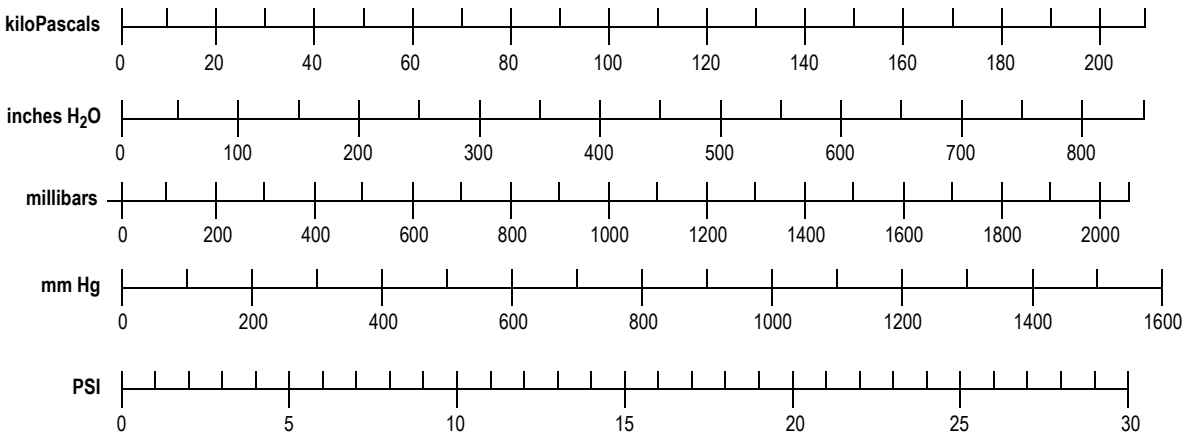
Altitude (Feet)	Equivalent Pressure (Inches of Mercury)
14,000	17.5774
16,000	16.2164
18,000	14.9421
20,000	13.7501
22,000	12.6363
25,000	11.1035
30,000	8.88544
35,000	7.04062
40,000	5.53802
45,000	4.35488
49,900	3.44112 (EST)
50,000	3.42466

Reference Tables (continued)

CONVERSION TABLE FOR COMMON UNITS OF PRESSURE

	kiloPascals	mm Hg	millibars	inches H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038
1 mm Hg	0.133322	1.00000	1.33322	0.535257	0.0193368
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038
1 inch H_2O	0.249081	1.86826	2.49081	1.00000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038
1 cm H_2O	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223

QUICK CONVERSION CHART FOR COMMON UNITS OF PRESSURE



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Mounting and Handling Suggestions for the Unibody Pressure Sensor Package

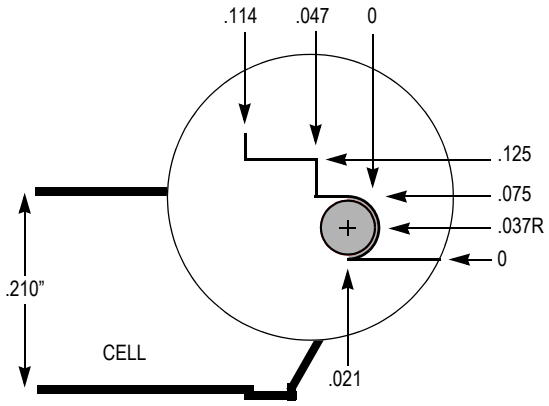


Figure 1. O-Ring to Sensor Cell Interface Dimensions

CUSTOM PORT ADAPTOR INSTALLATION TECHNIQUES

The Freescale Semiconductor MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 1 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, reinforced polyester resin plastic polysulfone (MPX2040D only). The epoxy should be dispensed in a continuous bead around the cell-to-port interface shoulder. Refer to Figure 2. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for 5 seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication. Be sure device is thoroughly dried after this test.

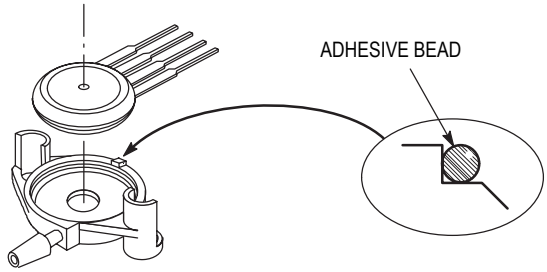


Figure 2. Glueing of Sensor Cell

STANDARD PORT ATTACH CONNECTION

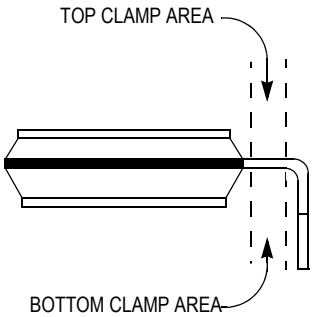
Freescale Semiconductor also offers standard port options designed to accept readily available silicone, vinyl, nylon or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Dimensions of the ports may be found in the case outline drawings. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Freescale Semiconductor's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

ELECTRICAL CONNECTION

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or “needlenose” pliers should never be used for leadforming unless they are specifically designed for that purpose. Industrial leadform tooling is available from various companies including *Janesville Tool & Manufacturing* (608-868-4925). Refer to Figure 3 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL.

The part numbers for the housing and pins are:

- 4 Pin Housing: SMP-04V-BC
- 6 Pin Housing: SMP-06V-BC
- Pin: SHF-01T-0.8SS
- The crimp tool part number is: YC12.



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 3. Leadforming

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Standard Warranty Clause

Seller warrants that its products sold hereunder will at the time of shipment be free from defects in material and workmanship, and will conform to Seller's approved specifications. If products are not as warranted, Seller shall, at its option and as Buyer's exclusive remedy, either refund the purchase price, or repair, or replace the product, provided proof of purchase and written notice of nonconformance are received within the applicable periods noted below and provided said nonconforming products are, with Seller's written authorization, returned in protected shipping containers FOB Seller's plant within thirty (30) days after expiration of the warranty period unless otherwise specified herein. If product does not conform to this warranty, Seller will pay for the reasonable cost of transporting the goods to and from Seller's plant. This warranty shall not apply to any products Seller determines have been, by Buyer or otherwise, subjected to improper testing, or have been the subject of mishandling or misuse.

THIS WARRANTY EXTENDS TO BUYER ONLY AND MAY BE INVOKED BY BUYER ONLY FOR ITS CUSTOMERS. SELLER WILL NOT ACCEPT WARRANTY RETURNS DIRECTLY FROM BUYER'S CUSTOMERS OR USERS OF BUYER'S PRODUCTS. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES WHETHER EXPRESS, IMPLIED OR STATUTORY INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

Seller's warranty shall not be enlarged, and no obligation or liability shall arise out of Seller's rendering of technical advice and/or assistance.

A Time periods, products, exceptions and other restrictions applicable to the above warranty are:

1 Unless otherwise stated herein, products are warranted for a period of one (1) year from date of shipment.

2 Device Chips/Wafers. Seller warrants that device chips or wafers have, at shipment, been subjected to electrical test/probe and visual inspection. Warranty shall apply to products returned to Seller within ninety (90) days from date of shipment. This warranty shall not apply to any chips or wafers improperly removed from their original shipping container and/or subjected to testing or operational procedures not approved by Seller in writing.

B Development products and Licensed Programs are licensed on an “AS IS” basis. IN NO EVENT SHALL SELLER BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.

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Glossary of Terms

Absolute Pressure Sensor	A sensor which measures input pressure in relation to a zero pressure (a total vacuum on one side of the diaphragm) reference.
Analog Output	An electrical output from a sensor that changes proportionately with any change in input pressure.
Accuracy — also see Pressure Error	A comparison of the actual output signal of a device to the true value of the input pressure. The various errors (such as linearity, hysteresis, repeatability and temperature shift) attributing to the accuracy of a device are usually expressed as a percent of full scale output (FSO).
Altimetric Pressure Transducer	A barometric pressure transducer used to determine altitude from the pressure-altitude profile.
Barometric Pressure Transducer	An absolute pressure sensor that measures the local ambient atmospheric pressure.
Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
Calibration	A process of modifying sensor output to improve output accuracy.
Chip	A die (unpackaged semiconductor device) cut from a silicon wafer, incorporating semiconductor circuit elements such as resistors, diodes, transistors, and/or capacitors
Compensation	Added circuitry or materials designed to counteract known sources of error.
Diaphragm	The membrane of material that remains after etching a cavity into the silicon sensing chip. Changes in input pressure cause the diaphragm to deflect.
Differential Pressure Sensor	A sensor which is designed to accept simultaneously two independent pressure sources. The output is proportional to the pressure difference between the two sources.
Diffusion	A thermochemical process whereby controlled impurities are introduced into the silicon to define the piezoresistor. Compared to ion implantation, it has two major disadvantages: 1) the maximum impurity concentration occurs at the surface of the silicon rendering it subject to surface contamination, and making it nearly impossible to produce buried piezoresistors; 2) control over impurity concentrations and levels is about one thousand times poorer than obtained with ion implantation.
Drift	An undesired change in output over a period of time, with constant input pressure applied.
End Point Straight Line Fit	Freescale Semiconductor's method of defining linearity. The maximum deviation of any data point on a sensor output curve from a straight line drawn between the end data points on that output curve.
Error	The algebraic difference between the indicated value and the true value of the input pressure. Usually expressed in percent of full scale span, sometimes expressed in percent of the sensor output reading.
Error Band	The band of maximum deviations of the output values from a specified reference line or curve due to those causes attributable to the sensor. Usually expressed as “± % of full scale output.” The error band should be specified as applicable over at least two calibration cycles, so as to include repeatability, and verified accordingly.
Excitation Voltage (Current) — see Supply Voltage (Current)	The external electrical voltage and/or current applied to a sensor for its proper operation (often referred to as the supply circuit or voltage). Freescale Semiconductor specifies constant voltage operation only.
Full Scale Output	The output at full scale pressure at a specified supply voltage. This signal is the sum of the offset signal plus the full scale span.
Full Scale Span	The change in output over the operating pressure range at a specified supply voltage. The SPAN of a device is the output voltage variation given between zero differential pressure and any given pressure. FULL SCALE SPAN is the output variation between zero differential pressure and when the maximum recommended operating pressure is applied.
Hysteresis — also see Pressure Hysteresis and Temperature Hysteresis	HYSTERESIS refers to a transducer's ability to reproduce the same output for the same input, regardless of whether the input is increasing or decreasing. PRESSURE HYSTERESIS is measured at a constant temperature while TEMPERATURE HYSTERESIS is measured at a constant pressure in the operating pressure range.
Input Impedance (Resistance)	The impedance (resistance) measured between the positive and negative (ground) input terminals at a specified frequency with the output terminals open. For Freescale Semiconductor X-ducer, this is a resistance measurement only.

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Glossary of Terms (Continued)

Ion Implantation	A process whereby impurity ions are accelerated to a specific energy level and impinged upon the silicon wafer. The energy level determines the depth to which the impurity ions penetrate the silicon. Impingement time determines the impurity concentration. Thus, it is possible to independently control these parameters, and buried piezoresistors are easily produced. Ion implantation is increasingly used throughout the semiconductor industry to provide a variety of products with improved performance over those produced by diffusion.
Laser Trimming (Automated)	A method for adjusting the value of thin film resistors using a computer-controlled laser system.
Leakage Rate	The rate at which a fluid is permitted or determined to leak through a seal. The type of fluid, the differential pressure across the seal, the direction of leakage, and the location of the seal must be specified.
Linearity Error	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
Load Impedance	The impedance presented to the output terminals of a sensor by the associated external circuitry.
Null	The condition when the pressure on each side of the sensing diaphragm is equal.
Null Offset	The electrical output present, when the pressure sensor is at null.
Null Temperature Shift	The change in null output value due to a change in temperature.
Null Output	See ZERO PRESSURE OFFSET
Offset	See ZERO PRESSURE OFFSET
Operating Pressure Range	The range of pressures between minimum and maximum pressures at which the output will meet the specified operating characteristics.
Operating Temperature Range	The range of temperature between minimum and maximum temperature at which the output will meet the specified operating characteristics.
Output Impedance	The impedance measured between the positive and negative (ground) output terminals at a specified frequency with the input open.
Overpressure	The maximum specified pressure which may be applied to the sensing element of a sensor without causing a permanent change in the output characteristics.
Piezoresistance	A resistive element that changes resistance relative to the applied stress it experiences (e.g., strain gauge).
Pressure Error	The maximum difference between the true pressure and the pressure inferred from the output for any pressure in the operating pressure range.
Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
Pressure Range — also see Operating Pressure Range	The pressure limits over which the pressure sensor is calibrated or specified.
Pressure Sensor	A device that converts an input pressure into an electrical output.
Proof Pressure	See OVERPRESSURE
Ratiometric	Ratiometricity refers to the ability of the transducer to maintain a constant sensitivity, at a constant pressure, over a range of supply voltage values.
Ratiometric (Ratiometricity Error)	At a given supply voltage, sensor output is a proportion of that supply voltage. Ratiometricity error is the change in this proportion resulting from any change to the supply voltage. Usually expressed as a percent of full scale output.
Range	See OPERATING PRESSURE RANGE
Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
Resolution	The maximum change in pressure required to give a specified change in the output.
Response Time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
Room Conditions	Ambient environmental conditions under which sensors most commonly operate.
Sensing Element	That part of a sensor which responds directly to changes in input pressure.

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Glossary of Terms (Continued)

Sensitivity	The change in output per unit change in pressure for a specified supply voltage or current.
Sensitivity Shift	A change in sensitivity resulting from an environmental change such as temperature.
Stability	The maximum difference in the output at any pressure in the operating pressure range when this pressure is applied consecutively under the same conditions and from the same direction.
Storage Temperature Range	The range of temperature between minimum and maximum which can be applied without causing the sensor to fail to meet the specified operating characteristics.
Strain Gauge	A sensing device providing a change in electrical resistance proportional to the level of applied stress.
Supply Voltage (Current)	The voltage (current) applied to the positive and negative (ground) input terminals.
Temperature Coefficient of Full Scale Span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature.
Temperature Coefficient of Resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature.
Temperature Error	The maximum change in output at any pressure in the operating pressure range when the temperature is changed over a specified temperature range.
Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
Thermal Offset Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thermal Span Shift	See TEMPERATURE COEFFICIENT OF FULL SCALE SPAN
Thermal Zero Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thin Film	A technology using vacuum deposition of conductors and dielectric materials onto a substrate (frequently silicon) to form an electrical circuit.
Vacuum	A perfect vacuum is the absence of gaseous fluid.
Zero Pressure Offset	The output at zero pressure (absolute or differential, depending on the device type) for a specified supply voltage or current.

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Symbols, Terms and Definitions

The following are the most commonly used letter symbols, terms and definitions associated with solid state silicon pressure sensors.

P_{burst}	Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
I_o	Supply Current	The current drawn by the sensor from the voltage source.
I_{o+}	Output Source Current	The current sourcing capability of the pressure sensor.
kPa	Kilopascals	Unit of pressure. 1 kPa = 0.145038 PSI.
—	Linearity	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
mm Hg	Millimeters of Mercury	Unit of pressure. 1 mmHg = 0.0193368 PSI.
P_{max}	Overpressure	The maximum specified pressure which may be applied to the sensing element without causing a permanent change in the output characteristics.
P_{OP}	Operating Pressure Range	The range of pressures between minimum and maximum temperature at which the output will meet the specified operating characteristics.
—	Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
PSI	Pounds per Square Inch	Unit of pressure. 1 PSI = 6.89473 kPa.
—	Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
R_o	Input Resistance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open.
T_A	Operating Temperature	The temperature range over which the device may safely operate.
TCR	Temperature Coefficient of Resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature (typically +25°C).
TCV_{FSS}	Temperature Coefficient of Full Scale Span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature (typically +25°C).
TCV_{off}	Temperature Coefficient of Offset	The percent change in offset per unit change in temperature relative to the offset at a specified temperature (typically +25°C).
T_{stg}	Storage Temperature	The temperature range at which the device, without any power applied, may be stored.
t_R	Response Time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
—	Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
V_{FSS}	Full Scale Span Voltage	The change in output over the operating pressure range at a specified supply voltage.
V_{off}	Offset Voltage	The output with zero differential pressure applied for a specified supply voltage or current.
V_S	Supply Voltage DC	The dc excitation voltage applied to the sensor. For precise circuit operation, a regulated supply should be used.
V_{Smax}	Maximum Supply Voltage	The maximum supply voltage that may be applied to a circuit or connected to the sensor.
Z_{in}	Input Impedance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open. For Freescale Semiconductor X-ducer, this is a resistance measurement only.
Z_{out}	Output Impedance	The resistance measured between the positive and negative output terminals at a specified frequency with the input terminals open.
$\Delta V/\Delta P$	Sensitivity	The change in output per unit change in pressure for a specified supply voltage.

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Section Four

Electric Field Sensor Overview

Freescale's electric field (E-field) sensor is intended for applications where non-contact sensing of objects is desired. It contains circuitry necessary to generate a low level electric field and measure the field loading caused by objects moved into the field. The sensor is intended for use in detecting objects in an electric field associated with an electrode. When connected to external electrodes, an electric field is created. The IC generates a low frequency sine wave. The frequency is adjustable by using an external resistor and is optimized for 125 kHz. The sine wave has very low harmonic content to avoid the generation of harmonic interference. The internal generator produces a nominal 5.0 V peak-to-peak output which is passed through an internal resistor of about 22 kOhm. The sensor contains support circuits for an MCU to allow the construction of a 2 chip E-field system.

Freescale's electric field sensor is economical and can be used for touch panel applications, liquid sensing and proximity detection.

Electric Field Sensor Products

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Data Sheets 4-3
AN1985 4-33
RDTOUCHEFRM 4-55
SITOUCHEFUG 4-100
Package Dimensions 4-107

Mini Selector Guide

E-Field Sensing

Product	Description	Main Characteristics	No. of Channels	5 V Reg. Current Limit (mA)	Max Voltage (V)	Operating Temp Range (°C)	Communications	Packaging	Status
MC33794DWBR2	Electric Field Imaging Device	120 kHz generator, shield driver, 9 electrodes + 2 V_{REF} outputs, 5 V regulator, MCU support	11	75	40	-40 – 85	ISO-9141	54-pin SOICW	EVB Available
MC33941EGR2	Electric Field Imaging Device	Selectable from 60 kHz to 240 kHz generator, shield driver, 7 electrodes, 5 V regulator	7	75	40	0 – 110	N/A	24-pin SOICW	EVB Available
MC34940EGR2	Electric Field Imaging Device	Selectable from 60 kHz to 240 kHz generator, shield driver, 7 electrodes	7	N/A	40	0 – 90	N/A	24-pin SOICW	EVB Available

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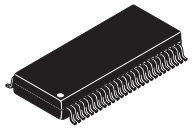
Document Number: MC33794
Rev 9

RoHS

Electric Field Imaging Device

MC33794

ELECTRIC FIELD IMAGING DEVICE



EK SUFFIX
54-LEAD SOICW-EP
CASE 1390-02

The MC33794 is intended for applications where noncontact sensing of objects is desired. When connected to external electrodes, an electric field is created.,The MC33794 is intended for use in detecting objects in this electric field. The IC generates a low-frequency sine wave. The frequency is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference.

The MC33794 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

Features

- Supports up to 9 Electrodes and 2 References or Electrodes
- Shield Driver for Driving Remote Electrodes Through Coaxial Cables
- +5.0 V Regulator to Power External Circuit
- ISO-9141 Physical Layer Interface
- Lamp Driver Output
- Watchdog and Power-ON Reset Timer
- Critical Internal Nodes Scaled and Selectable for Measurement
- High-Purity Sine Wave Generator Tunable with External Resistor

Typical Applications

- Occupant Detection Systems
- Appliance Control Panels and Touch Sensors
- Linear and Rotational Sliders
- Spill Over Flow Sensing Measurement
- Refrigeration Frost Sensing
- Industrial Control and Safety Systems Security
- Proximity Detection for Wake-Up Features
- Touch Screens
- Garage Door Safety Sensing
- Liquid Level Sensing

ORDERING INFORMATION			
Device Name	**Temperature Range (T_A)**	**Package Drawing**	**Package**
MC33794EK/R2	-40°C to 85°C	1390-02	54 SOICW-EP

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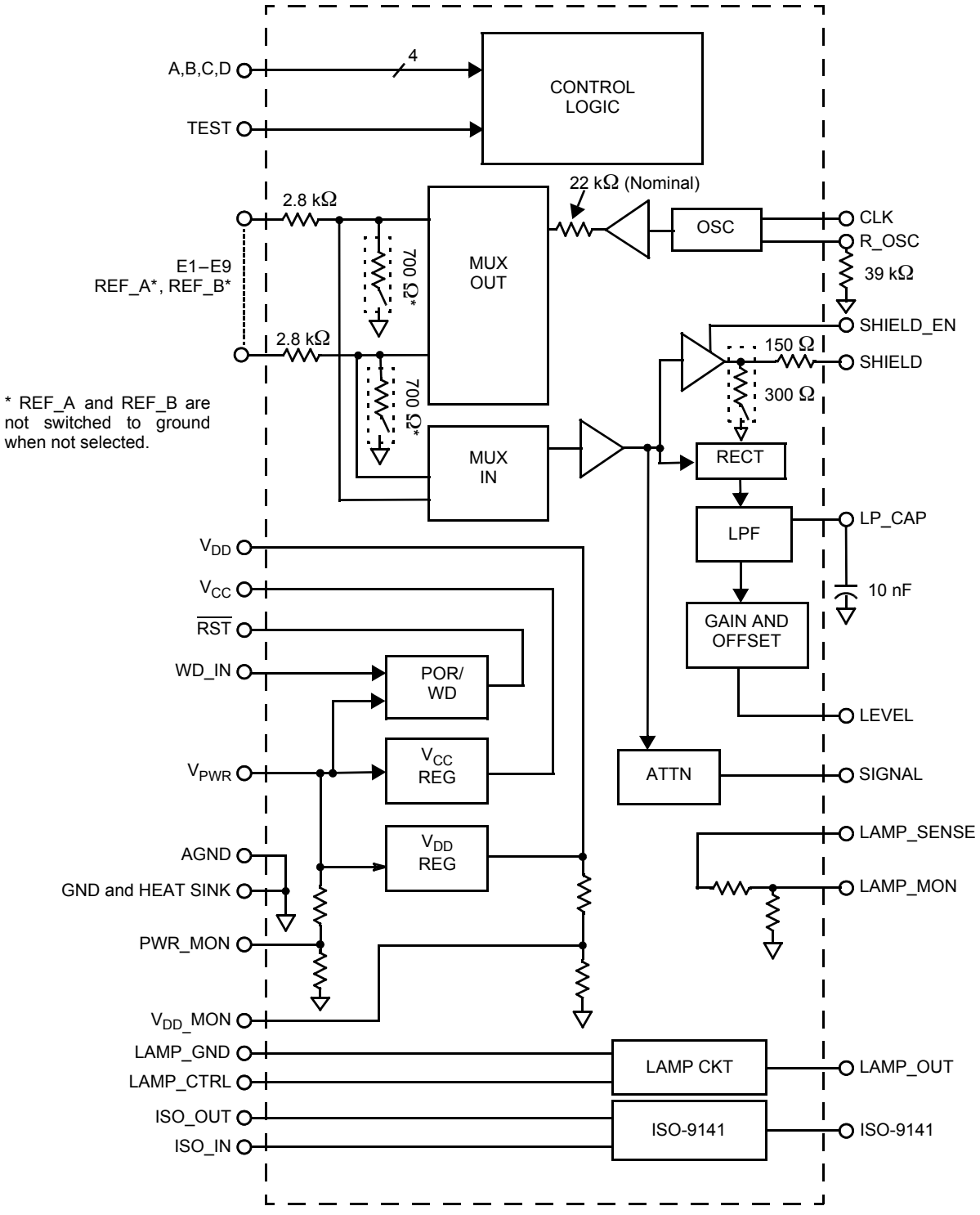
INTERNAL BLOCK DIAGRAM



(Note: All Resistor Values are Nominal)

Figure 1. Simplified Functional Block Diagram

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SOICW-EP TERMINAL CONNECTIONS

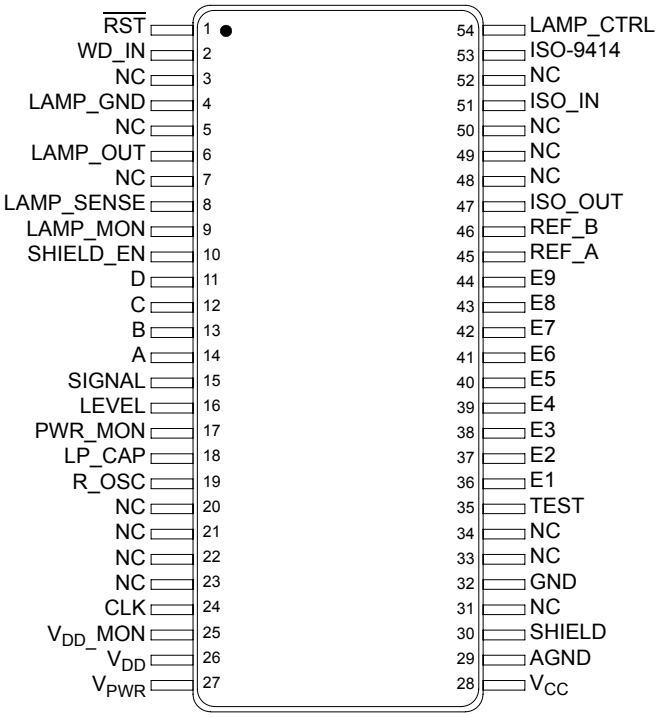

Figure 2. SOICW-EP Terminal Connections

Table 1. SOICW-EP TERMINAL FUNCTION DESCRIPTION

Terminal	Terminal Name	Formal Name	Definition
1	$\overline{\text{RST}}$	Reset	This output is intended to generate the reset function of a typical MCU. It has a delay for Power-ON Reset, level detectors to force a reset when V_{CC} REG is out-of-range high or low, and a watchdog timer that will force a reset if WD_IN is not asserted at regular intervals. Timing is derived from the oscillator and will change with changes in the resistor attached to R_OSC.
2	WD_IN	Watchdog In	This terminal must be asserted and deserted at regular interval in order to prevent $\overline{\text{RST}}$ from being asserted. By having the MCU program perform this operation more often the allowed time, a check that the MCU is running and executing its program is assured. If this doesn't occur, the MCU will be reset. If the watchdog function is not desired, this terminal may be connected to CLK to prevent a reset from being issued.
3, 5, 7, 20–23, 31, 33, 34, 48–50, 52	NC	No connect	These terminals may be used at some future date and should be left open.
4	LAMP_GND	Lamp Ground	This is the ground for the current from the lamp. The current into LAMP_OUT flows out through this terminal.
6	LAMP_OUT	Lamp Driver	This is an active low output capable of sinking current of a typical indicator lamp. One end of the lamp should be connected to a positive supply (for example, battery voltage) and the other side to this terminal. The current is limited to prevent damage to the IC in the case of a short or surge during lamp turn-on or burn-out.

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Table 1. SOICW-EP TERMINAL FUNCTION DESCRIPTION (continued)

Terminal	Terminal Name	Formal Name	Definition
8	LAMP_SENSE	Lamp Sense	This terminal is normally connected to the LAMP_OUT terminal. The voltage at this terminal is reduced and sent to LAMP_MON so the voltage at the lamp terminal is brought into the range of the analog-to-digital converter (ADC) in the MCU.
9	LAMP_MON	Lamp Monitor	This terminal is connected through a voltage divider to the LAMP_SENSE terminal. The voltage divider scales the voltage at this terminal so that battery voltage present when the lamp is off is scaled to the range of the MCU ADC. With the lamp off, this terminal will be very close to battery voltage if the lamp is not burned out and the terminal is not shorted to ground. This is useful as a lamp check.
10	SHIELD_EN	Shield Driver	This terminal is used to enable the shield signal. The shield is disabled when SHIELD_EN is a logic low (ground)
11–14	A, B, C, D	Selector Inputs	These input terminals control which electrode or reference is active. Selection values are shown in Table 5, Electrode Selection, page 12. These are logic level inputs.
15	SIGNAL	Undetected Signal	This is the undetected signal being applied to the detector. It has a DC level with the low radio frequency signal superimposed on it. Care must be taken to minimize DC loading of this signal. A shift of DC will change the center point of the signal and adversely affect the detection of the signal.
16	LEVEL	Detected Level	This is the detected, amplified, and offset representation of the signal voltage on the selected electrode. Filtering of the rectified signal is performed by a capacitor attached to LP_CAP.
17	PWR_MON	Power Monitor	This is connected through a voltage divider to V_{PWR}. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
18	LP_CAP	Low-Pass Filter Capacitor	A capacitor on this terminal forms a low pass filter with the internal series resistance from the detector to this terminal. This terminal can be used to determine the detected level before amplification or offset is applied. A 10 nF capacitor connected to this terminal will smooth the rectified signal. More capacitance will increase the response time.
19	R_OSC	Oscillator Resistor	A resistor from this terminal to circuit ground determines the operating frequency of the oscillator. The MC33794 is optimized for operation around 120 kHz.
24	CLK	Clock	This terminal provides a square wave output at the same frequency as the internal oscillator. The edges of the square wave coincide with the peaks (positive and negative) of the sine wave.
25	V_{DD}_MON	V_{DD} Monitor	This is connected through an internal voltage divider to V_{DD} REG. It allows reduction of the voltage so it will fall within the range of the ADC on the MCU.
26	V_{DD}	V_{DD} Capacitor	A capacitor is connected to this terminal to filter the internal analog regulated supply. This supply is derived from V_{PWR} through internal V_{DD} REG.
27	V_{PWR}	Positive Power Supply	12 V power applied to this terminal will be converted to the regulated voltages needed to operate the part. It is also converted to 5.0 V (internal V_{CC} REG) and 8.5 V (internal V_{DD} REG) to power the MCU and external devices.
28	V_{CC}	5.0 V Regulator Output	This output terminal requires a 47 μF capacitor and internal V_{CC} REG provides a regulated 5.0 V for the MCU and for internal needs of the MC33794.
29	AGND	Analog Ground	This terminal is connected to the ground return of the analog circuitry. This ground should be kept free of transient electrical noise like that from logic switching. Its path to the electrical current return point should be kept separate from the return for GND.
30	SHIELD	Shield Driver	This terminal connects to cable shields to cancel cable capacitance.

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Table 1. SOICW-EP TERMINAL FUNCTION DESCRIPTION (continued)

Terminal	Terminal Name	Formal Name	Definition
32	GND	Ground	This terminal and metal backing is the IC power return and thermal radiator/ conductor.
35	TEST	Test Mode Control	This terminal is normally connected to circuit ground. There are special operating modes associated with this terminal when it is not at ground.
36–44	E1–E9	Electrode Connections	These are the electrode terminals. They are connected either directly or through coaxial cables to the electrodes for measurements. When not selected, these outputs are grounded through the internal resistance.
45, 46	REF_A, REF_B (E10, E11)	Reference Connections (Or as additional electrodes)	These terminals can be individually selected to measure a known capacitance value. Unlike E1-E9, these two inputs are not grounded when not selected.
47	ISO_OUT	ISO-9141 Output	This terminal translates ISO-9141 receive levels to 5.0 V logic levels for the MCU.
51	ISO_IN	ISO-9141 Input	This terminal accepts data from the MCU to be sent over the ISO-9141 communications interface. It translates the 5.0 V logic levels from the MCU to transmit levels on the ISO-9141 bus.
53	ISO-9141	ISO-9141 Bus	This terminal connects to the ISO-9141 bus. It provides the drive and detects signaling on the bus and translates it from the bus level to logic levels for the MCU.
54	LAMP_CTRL	Lamp Control	This signal is used to control the lamp driver. A high logic level turns on the lamp.

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MAXIMUM RATINGS

Table 2. Maximum Ratings

All voltages are with respect to ground unless otherwise noted. Exceeding these ratings may cause a malfunction or permanent damage to the device.

Rating	Symbol	Value	Unit
Peak VPWR Voltage	V_{PWRPK}	40	V
Double Battery 1 Minute Maximum T_A = 30°C	V_{DBLBAT}	26.5	V
ESD Voltage Human Body Model (1) Machine Model (2)	 V_{ESD1} V_{ESD2}	 ±2000 ±200	V
Storage Temperature	T_{STG}	-55 to 150	°C
Operating Ambient Temperature	T_A	-40 to 85	°C
Operating Junction Temperature	T_J	-40 to 150	°C
Thermal Resistance Junction-to-Ambient (3) Junction-to-Case (4) Junction-to-Board (5)	 $R_{\theta JA}$ $R_{\theta JC}$ $R_{\theta JB}$	 41 0.2 3.0	°C/W
Lead Soldering Temperature (for 10 Seconds)	T_{SOLDER}	260	°C

Notes

1. ESD1 performed in accordance with the Human Body Model (C_{ZAP} = 100 pF, R_{ZAP} = 1500 Ω).
2. ESD2 performed in accordance with the Machine Model (C_{ZAP} = 200 pF, R_{ZAP} = 0 Ω).
3. Junction temperature is a function of on-chip power dissipation, package thermal resistance, mounting site (board) temperature, ambient temperature, air flow, power dissipation of other components on the board, and board thermal resistance. In accordance with SEMI G38-87 and JEDEC JESD51-2 with the single layer board horizontal.
4. Indicates the average thermal resistance between the die and the case top surface as measured by the cold plate method (MILSPEC 883 Method 1012.1) with the cold plate temperature used for the case temperature.
5. Thermal resistance between the die and the printed circuit board per JEDEC JESD51-8. Board temperature is measured on the top surface of the board near the package.

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STATIC ELECTRICAL CHARACTERISTICS

Table 3. Static Electrical Characteristics

Characteristics noted under conditions 9.0 V ≤ VPWR ≤ 18 V, -40°C ≤ T_A ≤ 85°C unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under normal conditions unless otherwise noted. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
Voltage Regulators					
5.0 V Regulator Voltage 7.0 V ≤ V_{PWR} ≤ 18 V, 1.0 mA ≤ I_L ≤ 75 mA, C_{FILT} = 47 µF	V_{CC}	4.75	5.0	5.25	V
Analog Regulator Voltage 9.0 V ≤ V_{PWR} ≤ 18 V, C_{FILT} = 47 µF	V_{ANALOG}	8.075	8.5	8.925	V
Out-of-Range Voltage Detector (Terminal name V_{CC})					
5.0 V Low Voltage Detector	V_{LV5}	4.0	4.52	4.72	V
5.0 V High Voltage Detector	V_{HV5}	5.26	5.55	5.83	V
5.0 V Out-of-Range Voltage Detector Hysteresis	V_{HYS5}	–	0.05	–	V
ISO-9141 Communications Interface					
Input Low Level (6)	VIF_{INLO}	0.30	0.33	–	V/V
Input High Level (6)	VIF_{INHI}	–	0.53	0.7	V/V
Input Hysteresis (6)	VIF_{INHYS}	–	0.2	–	V/V
Output Low (6)	VIF_{OLO}	–	–	0.2	V/V
Output High (6)	VIF_{OHI}	0.8	–	–	V/V
Output Breakdown I_{OUT} = 20 mA	VIF_Z	40	–	–	V
Output Resistance I_{OUT} = 40 mA	RIF_{ON}	–	58	–	Ω
Current Limit Sinking Current with V_{OUT} < 0.3 $V_{PWR\ IN}$	IIF_{LIM}	60	90	120	mA
Output Propagation Delay Out to ISO-9141, C_{LOAD} = 20 pF	TIF_{DLY}	–	–	8.0	µs
ISO In					
Logic Output Low I_{SINK} = 1.0 mA	VIF_{OLO}	–	–	1.0	V
Logic Output Pull-Up Current V_{OUT} = 0 V	IIF_{PU}	100	–	–	µA
Input to Output Propagation Delay ISO-9141 to ISO_IN, R_L = 10 kΩ, C_L = 470 pF, 7.0 V ≤ VPWR ≤ 18 V	TIF_{DLY}	–	–	5.4	µs

Notes

6. Ratio to V_{PWR}

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Table 3. Static Electrical Characteristics (continued)

Characteristics noted under conditions 9.0 V ≤ VPWR ≤ 18 V, -40°C ≤ T_A ≤ 85°C unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under normal conditions unless otherwise noted. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
Electrode Signals					
Total Variance Between Electrode Measurements (7) All C_{LOAD} = 15 pF	ELV_{VAR}	–	–	3.0	%
Electrode Maximum Harmonic Level Below Fundamental (8) 5.0 pF ≤ C_{LOAD} ≤ 100 pF	EL_{HARM}	–	-20	–	dB
Electrode Transmit Output Range 5.0 pF ≤ C_{LOAD} ≤ 100 pF	EL_{TXV}	1.0	–	8.0	V
Receive Input Voltage Range	RX_V	0	–	9.0	V
Grounding Switch on Voltage I_{SW} = 1.0 mA	SW_{VON}	–	–	5.0	V
Shield Driver					
Shield Driver Output Level 0 pF ≤ C_{LOAD} ≤ 500 pF	SD_{TXV}	1.0	–	8.0	V
Shield Driver Input Range	SD_{IN}	0	–	9.0	V
Grounding Switch on Voltage (9)	SW_{VON}	–	–	1.5	V
Logic I/O					
CMOS Logic Input Low Threshold	V_{THL}	0.3	–	–	V_{CC}
Logic Input High Threshold	V_{THH}	–	–	0.7	V_{CC}
Voltage Hysteresis	V_{HYS}	–	0.06	–	V_{CC}
Input Current V_{IN} = V_{CC} V_{IN} = 0 V	I_{IN}	10 -5.0	– –	50 5.0	μA
Signal Detector					
Detector Output Resistance	DET_{RO}	–	50	–	kΩ
LP_CAP to LEVEL Gain	A_{REC}	3.6	4.0	4.4	A_V
LP_CAP to LEVEL Offset	V_{RECOFF}	-3.3	-3.0	-2.7	V

Notes
7. Verified by design. Not tested in production.
8. Verified by design and characterization. Not tested in production.
9. Current into grounded terminal under test = 1.0 mA.

Table 3. Static Electrical Characteristics (continued)

Characteristics noted under conditions 9.0 V ≤ VPWR ≤ 18 V, -40°C ≤ T_A ≤ 85°C unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under normal conditions unless otherwise noted. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
Lamp Driver					
On Resistance I_{IN} = 400 mA	RLD_{DSON}	–	1.75	3.5	Ω
Current Limit V_{OUT} = 1.0 V	ILD_{LIM}	0.7	–	1.7	A
On-Voltage I_{OUT} = 400 mA	VLD_{ON}	–	–	1.4	V
Breakdown Voltage I_{OUT} = 100 μA, Lamp Off	VLD_Z	40	–	–	V
Voltage Monitors					
LAMP_MON to LAMP_SENSE Ratio	LMP_{MON}	0.1950	0.20524	0.2155	V/V
PWR_MON to V_{PWR} Ratio	PWR_{MON}	0.2200	0.2444	0.2688	V/V
V_{DD}_MON to V_{DD} Ratio	V_{DD_MON}	0.45	0.5	0.55	V/V
Supply					
Quiescent supply current (11) V_{PWR} = 14 V(10)	I_{pwr}	–	7.0	–	mA

Notes

10. Verified by design and characterization. Not tested in production.
11. No external devices connected to internal voltage regulators.

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DYNAMIC ELECTRICAL CHARACTERISTICS

Table 4. Dynamic Electrical Characteristics

Characteristics noted under conditions 9.0 V ≤ VPWR ≤ 18 V, -40°C ≤ T_A ≤ 85°C unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under normal conditions unless otherwise noted. Voltages are relative to GND unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
OSC					
OSC Frequency Stability (12), (13)	f_{STAB}	–	–	10	%
OSC Center Frequency R_OSC = 39 kΩ	f_{OSC}	– 	120 	– 	kHz
Harmonic Content (12) 2nd through 4th Harmonic Level 5th and Higher	$OSCH_{ARM}$	 – –	 – –	 -20 -60	dB
Shield Driver					
Shield Driver Maximum Harmonic level below Fundamental (12) 10 pF ≤ C_{LOAD} ≤ 500 pF	SD_{HARM}	–	-20	–	dB
Shield Driver Gain Bandwidth Product (12) Measured at 120 kHz	SD_{GBW}	–	4.5	–	MHz
POR					
POR Time-Out Period	t_{PER}	9.0	–	50	ms
Watchdog					
Watchdog Time-Out Period	t_{WDPER}	50	68	250	ms
Watchdog Reset Hold Time	t_{WDHLD}	9.0	–	50	ms
Lamp Driver					
Short Circuit to Battery Survival Time	t_{SCB}	3.0	–	–	ms

Notes
12. Verified by design and characterization. Not tested in production.
13. Does not include errors in external reference parts.

ELECTRODE SELECTION

Table 5. Electrode Selection

TERMINAL/SIGNAL	D	C	B	A
Source (internal)	0	0	0	0
E1	0	0	0	1
E2	0	0	1	0
E3	0	0	1	1
E4	0	1	0	0
E5	0	1	0	1
E6	0	1	1	0
E7	0	1	1	1

Table 5. Electrode Selection (continued)

TERMINAL/SIGNAL	D	C	B	A
E8	1	0	0	0
E9	1	0	0	1
REF_A	1	0	1	0
REF_B	1	0	1	1
Internal OSC	1	1	0	0
Internal OSC after 22 kΩ	1	1	0	1
Internal Ground	1	1	1	0
Reserved	1	1	1	1

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FUNCTIONAL DESCRIPTION

INTRODUCTION

The MC33794 is intended for use in detecting objects using an electric field. The IC generates a low radio frequency sine wave. The frequency is set by an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce potential interference at higher harmonically related frequencies. The internal generator produces a nominal 5.0 V peak-to-peak output that is passed through an internal resistor of about 22 kΩ. An internal multiplexer routes the signal to one of 11 terminals under control of the ABCD input terminals. A receiver multiplexer simultaneously connected to the selected electrode routes its signal to a detector, which converts the sine wave to a DC level. This DC level is filtered by an external capacitor and is multiplied and offset to increase sensitivity. All of the unselected electrode outputs are grounded by the device. The current flowing between the selected electrode and the other grounded electrodes plus other grounded objects around the electrode causes a voltage drop across the internal resistance. Objects brought into or out of the electric field change the current and resulting voltage at the IC terminal, which in turn reduces the voltage at LP_CAP and LEVEL.

A shield driver is included to minimize the effect of capacitance caused by using coaxial cables to connect to remote electrodes. By driving the coax shield with this signal, the shield voltage follows that of the center conductor, significantly reducing the effective capacitance of the coax and maintaining sensitivity to the capacitance at the electrode.

The MC33794 is made to work with and support a microcontroller. It provides two voltage regulators, a Power-ON-reset/out-of-range voltage detector, watchdog circuit, lamp driver and sense circuit, and a physical layer ISO-9141 communications interface.

BLOCK DIAGRAM COMPONENTS

Refer to Figure 1, MC33794 Internal Block Diagram, page 4, for a graphic representation of the block diagram information in this section.

OSC

This section generates a high purity sine wave. The center frequency is controlled by a resistor attached to R_OSC. The normal operating frequency is around 120 kHz. A square wave version of the frequency output is available at CLK. Timing for the Power-ON Reset and watchdog (POR/WD) circuit are derived from this oscillator's frequency.

MUX OUT

This circuit directs the output of the sine wave to one of nine possible electrode outputs or two reference terminals. All unused terminals are automatically grounded (except the two reference terminals). The selected output is controlled by the ABCD inputs.

ELECTRODES E1-E9

These are the electrode terminals. They are connected either directly or through coaxial cables to the electrodes for measurements. Every electrode has a 2.8K (± 20%) resistor in series with the external pad and the internal electronics. Only one of these electrodes can be selected at a time for capacitance measurement. All of the other unselected electrodes are switched to ground by an internal switch that has an internal on-resistance of approximately 700 Ω. The signal at the selected electrode terminal is routed to the shield driver amplifier by an internal switch. All of the coaxial cable shields should be isolated from ground and connected SHIELD.

REF_A & REF_B ELECTRODES

These terminals can be individually selected like E1 through E9. Unlike E1 through E9, these terminals are not grounded when not selected. Both terminals have a 2.8K (± 20%) resistor in series with the external pad and the internal electronics. The purpose of these terminals is to allow known capacitors to be measured. By using capacitors at the low and high end of the expected range, absolute values for the capacitance on the electrodes can be computed. These terminals can be used for electrodes E10 and E11 with the only difference is that these two electrodes will not be grounded when not selected.

SHIELD DRIVE

This circuit provides a buffered version of the returned AC signal from the electrode. Since it nearly has the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals thereby cancelling out any electric field. In effect, the shield drives and isolates the electrode signal from external virtual grounds. A common application is to connect the Shield Drive to the shield of a coax cable used to connect an electrode to the corresponding electrode terminal. Another typical use is to drive a ground plane that is used behind an array of touch sensor electrodes in order to cancel out any virtual grounds that could attenuate the AC signal.

MUX IN

This circuit connects the selected electrode, reference, or one of two internal nodes to an amplifier/detector. The selection is controlled by the ABCD inputs and follows the driven electrode/reference when one is selected.

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RECT

The rectifier circuit detects the level from MUX IN by offsetting the midpoint of the sine wave to zero volts and inverting the waveform when it is below the midpoint. It is important to avoid DC loading of the signal, which would cause a shift in the midpoint voltage of the signal.

LPF

The rectified sine wave is filtered by a low pass function formed by an internal resistance and an external capacitance attached to LP_CAP. The nominal value of the internal resistance is 50 kΩ. The value of the external capacitor is selected to provide filtering of noise while still allowing the desired settling time for the detector output. A 10 nF capacitor would allow 99% settling in less than 5.0 ms. In practice, it is recommended you wait at least 1.5 ms after selecting an electrode before reading LEVEL.

GAIN AND OFFSET

This circuit multiplies the detected and filtered signal by a gain and offsets the result by a DC level. This results in an output range that covers 1.0 V to 4.0 V for capacitive loading of the field in the range of 10 pF to 100 pF. This allows higher sensitivity for a digital-to-analog converter with a 0 V-to-5.0 V input range.

ATTN

This circuit passes the undetected signal to SIGNAL for external use.

SHIELD_EN

A logic low on this input disables the shield drive. The purpose of doing this is to be able to detect that the shield signal is not working or the connection to the coax shields is broken. If either of these conditions exists, there will be little or no change in the capacitance measured when the SHIELD_EN is changed. If the SHIELD output is working and properly connected, the capacitance of the coax will not be cancelled when this terminal is asserted and the measured capacitance will appear to change by approximately the capacitance between the center conductor and the shield in the coax.

LAMP CKT

This section controls the operation of the LAMP_OUT terminal. When LAMP_CTRL is asserted, LAMP_OUT is pulled to LAMP_GND. If one side of an indicator lamp or LED (with appropriate current setting resistor) is connected to a positive voltage source and the other is connected to LAMP_OUT, and LAMP_GND is connected to ground, the lamp will light. This circuit provides current limiting to prevent damage to itself in the case of a shorted lamp or during a high-surge condition typical of an incandescent lamp burnout.

LAMP_GND should always be connected to ground even if the lamp circuit is not used.

ISO-9141

This circuit connects to an ISO-9141 bus to allow remote communications. ISO_IN is data from the bus to the MCU and ISO_OUT is data to drive onto the bus from the MCU.

POR/WD

This circuit is a combined Power-ON Reset and watchdog timer. The $\overline{RST}$ output is held low until a certain amount of time after the V_{CC} REG output (V_{CC}) has remained above a minimum operating threshold. If V_{CC} falls below the level at any time, $\overline{RST}$ is pulled low again and held until the required time after V_{CC} has returned high. An over voltage circuit is also included, which will force a reset if V_{CC} rises above a maximum voltage. The watchdog function also can force $\overline{RST}$ low if too long an interval is allowed to pass between positive transitions on WD_IN.

INTERNAL V_{CC} REGULATOR

This circuit converts an unregulated voltage from VIN to a regulated 5.0 V source, which is used internally and available for other components requiring a regulated voltage source.

INTERNAL V_{DD} REGULATOR

This is a regulator for analog devices that require more than 5.0 V. This is used by the device and some current is available to operate op-amps and other devices. By having this higher voltage available, some applications can avoid the need for a rail-to-rail output amplifier and still achieve the 0 V-to-5.0 V output for a digital-to-analog converter input. V_{DD_MON} is a divided output from internal V_{DD} REG, which allows a 0.0 V-to-5.0 V ADC to measure V_{DD}. Normal value for V_{DD} is 8.5 Volts.

CONTROL LOGIC

This contains the logic that decodes and controls the MUXes and some of the test modes

APPLICATION INFORMATION

The MC33794 is intended to be used where an object's size and proximity are to be determined. This is done by placing electrodes in the area where the object will be. The proximity of an object to an electrode can be determined by the increase in effective capacitance as the object gets closer to the electrode and modifies the electric field between the electrode and surrounding electrically common objects. The shape and size of an object can be determined by using multiple electrodes over an area and observing the capacitance change on each of the electrodes. Those that don't change have nothing near them, and those that do change have part of the object near them.

A “capacitor” can be formed between the driving electrode and the object, each forming a “plate” that holds the electric charge. Capacitance is directly proportional to the area of the electrode plates. Doubling the area doubles the capacitance. Capacitance is also directly proportional to the *dielectric constant* of the material between the plates. Air typically has a dielectric constant of 1 (unity) whereas water can have a dielectic constant of 80 (which means the capacitance is roughly 80 times larger). Plastics and glass that are commonly used in touch panel applications have dielectric constants greater than unity. A third consideration is that capacitance is *inversely proportional* to the distance between the plates. Doubling the distance between the two plates will reduce capacitance by four. This property can be exploited in cases where small distances need to be measured.

From the above, it can be seen that increased detection sensitivity is a function of the plate size, the dielectric constant of the material between the plates, and the distance between them.

The voltage measured at LEVEL is an inverse function of the capacitance between the electrode being measured and the surrounding electrodes and other objects in the electric field surrounding the electrode. Increasing capacitance results in decreasing voltage. The value of series resistance (22 kΩ) was chosen to provide a nearly linear relationship at 120 kHz over a range of 10 pF to 100 pF.

The measured value may change with any change in frequency, series resistance, driving voltage, the dielectric constant of the capacitor, or detector sensitivity. These can change with temperature and time. There are several ways to compensate for these changes. One method uses the REF_A and REF_B capacitors. Another method may use long term averages to set a baseline value.

Using REF_A and REF_B, a typical measurement algorithm would start by measuring the voltage for two known value capacitors (attached to REF_A and REF_B). The value of these capacitors would be chosen to be near the minimum and maximum values of capacitance expected to be seen at the electrodes. These reference voltages and the known capacitance values are then used with the electrode measurement voltage to determine the capacitance seen by the electrode. This method can be used to detect short- and long-term changes due to objects in the electric field and significantly reduce the effect of temperature-and time-induced changes.

Another approach is to run long term averaging of the electrode values. Long term, in this case, may mean several seconds. These long term averages are then used as a set point so that short term changes in the field intensity can be reliably determined. This is typically the method used for touch panel applications.

The MC33794 does not contain an ADC. It is intended to be used with an MCU that contains one. Offset and gain have been added to the MC33794 to maximize the sensitivity over the range of 0 pF to 100 pF. An 8-bit ADC can resolve around 0.4 pF of change and a 10-bit converter around 0.1 pF. Higher resolution results in more distant detection of smaller objects. Due to the relatively slow data access requirements (approximately 2 ms per electrode), digital over-sampling techniques can be used to extend the resolution of 8- or 10-bit converters by 2 or 3 bits.

DC loading on the electrodes should be avoided. A typical situation where this might occur is if moisture gets in direct contact between electrodes, or between an electrode and ground or shield drive. The signal is generated with a DC offset that is more than half the peak-to-peak level. This keeps the signal positive above ground at all times. The detector uses this voltage level as the midpoint for detection. All signals below this level are inverted and added to all signals above this level. Loading of the DC level will cause some of the positive half of the signal to be inverted and added and will change the measurement.

If it is not possible to assure that the electrodes will always have a high DC resistance to ground source, a series capacitor of about 10 nF should be connected between the IC electrode terminals and the electrodes. This capacitor will block DC bias voltages to the detector. Note that it is also advisable to add a DC blocking capacitor in series with the Shield Driver output as well.

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EXAMPLE APPLICATION DIAGRAM

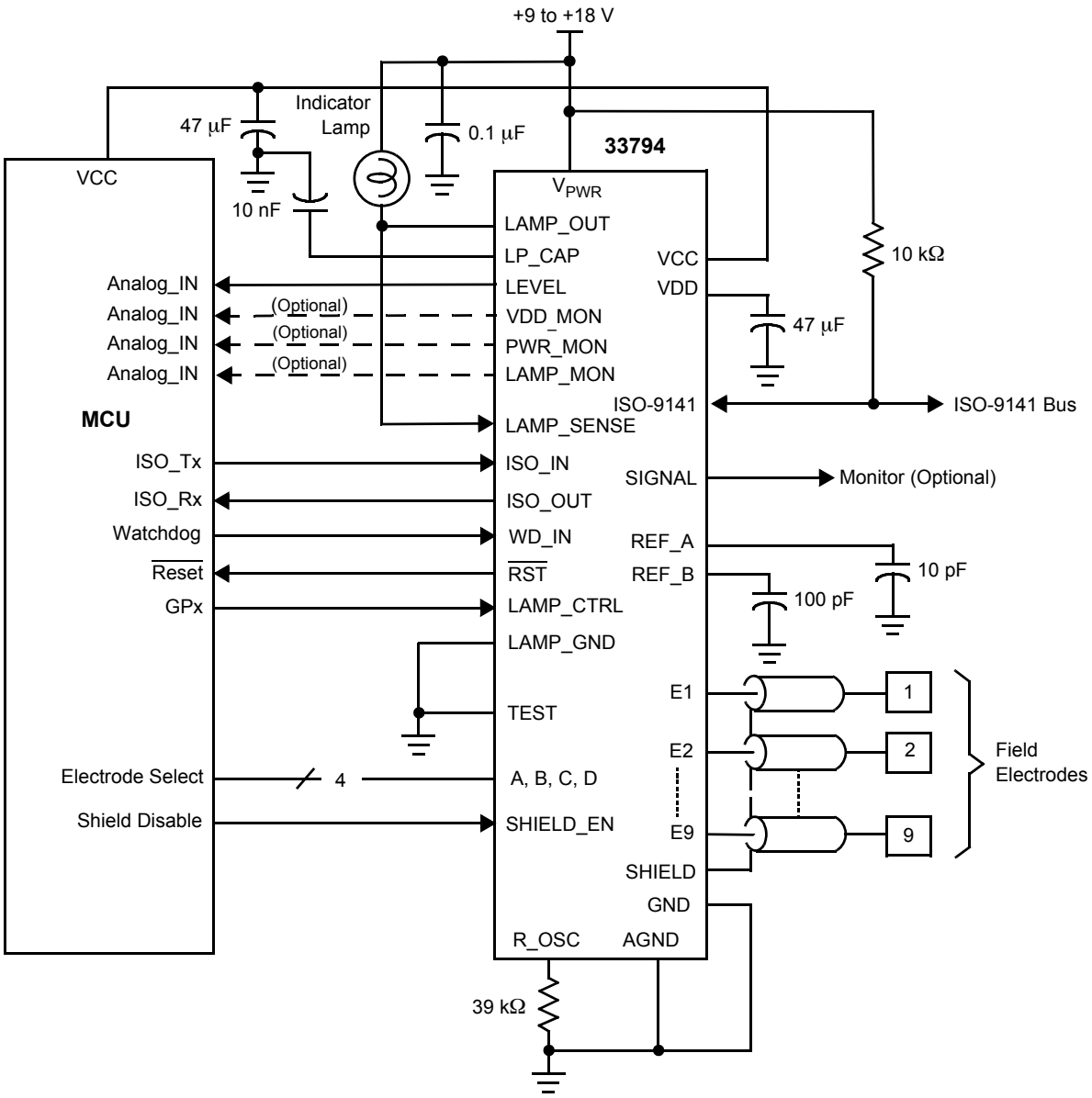

Figure 3. Example Application Diagram

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Document Number: MC33941
Rev. 3, 11/2006

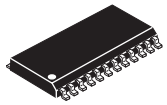
RoHS

Electric Field Imaging Device

MC33941

The MC33941 is intended for cost-sensitive applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created. The MC33941 detects objects in this electric field. The IC generates a low-frequency sine wave, which is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference. The MC33941 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

ELECTRONIC FIELD IMAGING DEVICE



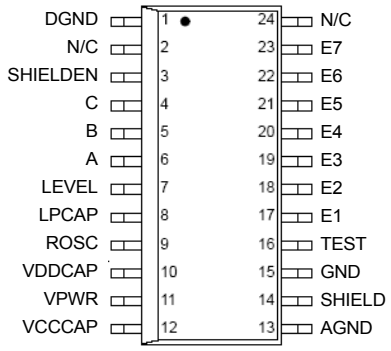
EG SUFFIX (Pb-FREE)
24-TERMINAL SOICW
CASE 751E-04

Features

- Supports up to 7 Electrodes
- Shield Driver for Driving Remote Electrodes Through Coaxial
- High-Purity Sine Wave Generator Tunable with External Resistor
- Response Time Tunable with External Capacitor
- +5V Regulator to Power External Circuit
- Can support up to 28 touch pad sensors (2 way multiplexing)
- Extended Temperature Range 0 to 110°C
- Pb-Free and RoHS compliant

Typical Applications

- Appliance Control Panels and Touch Sensors
- Linear and Rotational Sliders
- Spill Over Flow Sensing Measurement
- Refrigeration Frost Sensing
- Industrial Control and Safety Systems Security
- Proximity Detection for Wake-Up Features
- Touch Screens
- Garage Door Safety Sensing
- PC Peripherals
- Patient Monitoring
- Point of Sale Terminals
- Size Detection
- Liquid Level Sensing



Pin Connections

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Drawing**	**Package**
MC33941EG/R2	0 to 110°C	98ASB42564B	SOICW-24

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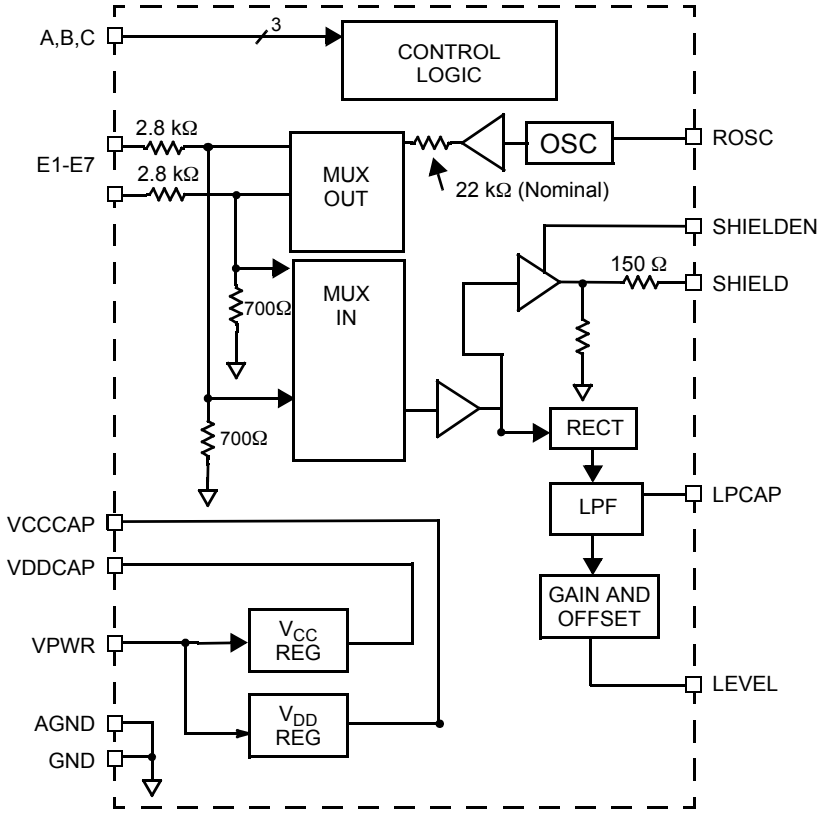

Figure 1 Simplified Functional Block Diagram

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Table 1. Maximum Ratings

All voltages are with respect to ground unless otherwise noted. Exceeding these ratings may cause a malfunction or permanent damage to the device.

Rating	Symbol	Value	Unit
ELECTRICAL RATINGS			
Peak V_{PWR} Voltage	V_{PWRPK}	40	V
Double Battery 1 Minute Maximum T_A = 30°C	V_{DBLBAT}	 26.5	V
ESD Voltage Human Body Model (C_{ZAP} = 100 pF, R_{ZAP} = 1500 W) Machine Model (C_{ZAP} = 200 pF, R_{ZAP} = 0 W) Charge Device Model (CDM), Robotic (C_{ZAP} = 4.0pF)	V_{ESD}	 ±2000 ±200 ±1200	V
THERMAL RATINGS			
Storage Temperature	T_{STG}	-55 to 150	°C
Operating Ambient Temperature	T_A	-0 to 110	°C
Operating Junction Temperature	T_J	-0 to 150	°C
Thermal Resistance Junction-to-Ambient (1) Junction-to-Case (2) Junction-to-Board (3)	 $R_{\theta JA}$ $R_{\theta JC}$ $R_{\theta JB}$	 41 0.2 3.0	°C/W
Soldering Temperature (4)			

Notes

1. Junction temperature is a function of on-chip power dissipation, package thermal resistance, mounting site (board) temperature, ambient temperature, air flow, power dissipation of other components on the board, and board thermal resistance. In accordance with SEMI G38-87 and JEDEC JESD51-2 with the single layer board horizontal.
2. Indicates the average thermal resistance between the die and the case top surface as measured by the cold plate method (MILSPEC 883 Method 1012.1) with the cold plate temperature used for the case temperature.
3. Thermal resistance between the die and the printed circuit board per JEDEC JESD51-8. Board temperature is measured on the top surface of the board near the package.
4. Terminal soldering temperature limit is for 10 seconds maximum duration. The device is not designed for immersion soldering. Exceeding these limits may cause malfunction or permanent damage to the device.

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Table 2. Static Electrical Characteristics

Characteristics noted under conditions 5.5 V ≤ V_{SUP} ≤ 18 V, 0°C ≤ T_A ≤ 110°C, GND = 0 V unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under nominal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
SUPPLY (V_{PWR})					
Supply Voltage	V_{PWR}	9.0	12	18	V
I_{DD} (V_{PWR} = 14V) (Quiescent supply current measured over temperature. Assumes that no external devices connected to internal voltage regulators)	I_{DD}	6.0	7.0	8.0	mA
VOLTAGE REGULATOR					
5V Regulator Voltage 7.0 V ≤ VPWR ≤ 18 V, 1.0 mA ≤ I_L ≤ 75 mA, CFILT = 47 μF	VCCCAP	4.75	5	5.25	V
ELECTRODE SIGNALS (E1–E7)					
Total Variance Between Electrode Measurements [5] All C_{LOAD} = 15 pF	ELV_{VAR}	–	–	3.0	%
Electrode Maximum Harmonic Level Below Fundamental [5] 5.0 pF ≤ C_{LOAD} ≤ 150 pF	EL_{HARM}	–	-20	–	dB
Electrode Transmit Output Range 5.0 pF ≤ C_{LOAD} ≤ 150 pF	EL_{TXV}	1.0	–	8.0	V
Receive Input Voltage Range	RX_V	0	–	9.0	V
Grounding Switch on Voltage[6] I_{SW} = 1.0 mA	SW_{VON}	–	–	5.0	V
LOGIC I/O (C, B, A)					
CMOS Logic Input Low Threshold	V_{THL}	0.3	–	–	V_{CC}
Logic Input High Threshold	V_{THH}	–	–	0.7	V_{CC}
Voltage Hysteresis	V_{HYS}	–	0.06	–	V_{CC}
Input Current V_{IN} = V_{CC} V_{IN} = 0 V	I_{IN}	10 -5.0	– –	50 5.0	μA
SIGNAL DETECTOR (LPCAP)					
Detector Output Resistance	DET_{RO}	–	50	–	kΩ
LPCAP to LEVEL Gain	A_{REC}	3.6	4.0	4.4	A_V
LPCAP to LEVEL Offset	V_{RECOFF}	-3.3	-3.0	-2.7	V

Notes

5. Verified by design and characterization. Not tested in production.
6. Current into grounded terminal under test = 1.0 mA.

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Table 3. Dynamic Electrical Characteristics [7]

Characteristics noted under conditions 5.5 V ≤ V_{SUP} ≤ 18 V, 0°C ≤ T_A ≤ 110°C, GND = 0 V unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under nominal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
OSC (ROSC)					
OSC Frequency Stability	f_{STAB}	–	–	10	%
OSC Center Frequency ROSC = 39 kΩ ROSC = 20 kΩ ROSC = 82 kΩ	f_{OSC}	 – – –	 120 240 60	 – – –	kHz
Harmonic Content 2nd through 4th Harmonic Level 5th and Higher	$OSCH_{ARM}$	 – –	 – –	 -20 -60	dB
SHIELD DRIVER (SHIELD)					
Shield Driver Maximum Harmonic level below Fundamental 10 pF ≤ C_{LOAD} ≤ 500 pF	SD_{HARM}	 –	 -20	 –	dB
Shield Driver Gain Bandwidth Product Measured at 120 kHz	SD_{GBW}	 –	 4.5	 –	MHz

Notes

7. All parameters are guaranteed by design.

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PRINCIPLE OF OPERATION

The 33941 generates a low radio frequency sine wave with nominal 5.0 V peak-to-peak amplitude. The frequency is set by an external resistor and is optimized for 120 kHz. An internal multiplexer routes the signal to one of the 7 terminals under control of the ABC input terminals. A receiver multiplexer simultaneously connected to the selected electrode and routes its signal to a detector, which converts the sine wave to a DC level. The DC level is filtered by an external capacitor, is multiplied and offset to increase sensitivity. All electrode outputs are grounded internally by the device when not selected.

The amplitude and phase of the sinusoidal wave at the electrode are affected by objects in proximity. A “capacitor” is formed between the driving electrode and the object, each forming a “plate” that holds the electric charge. The voltage measured is an inverse function of the capacitance between the electrode being measured, the surrounding electrodes, and other objects in the electric field surrounding the electrode. Increasing capacitance results in decreasing voltage. The value of the series resistor (22kohm) was chosen to provide a near linear relationship at 120 kHz over a range of 10pF to 70pF.

While exploring applications using the E-Field chip, it is always useful to approach the problem using the capacitor model.

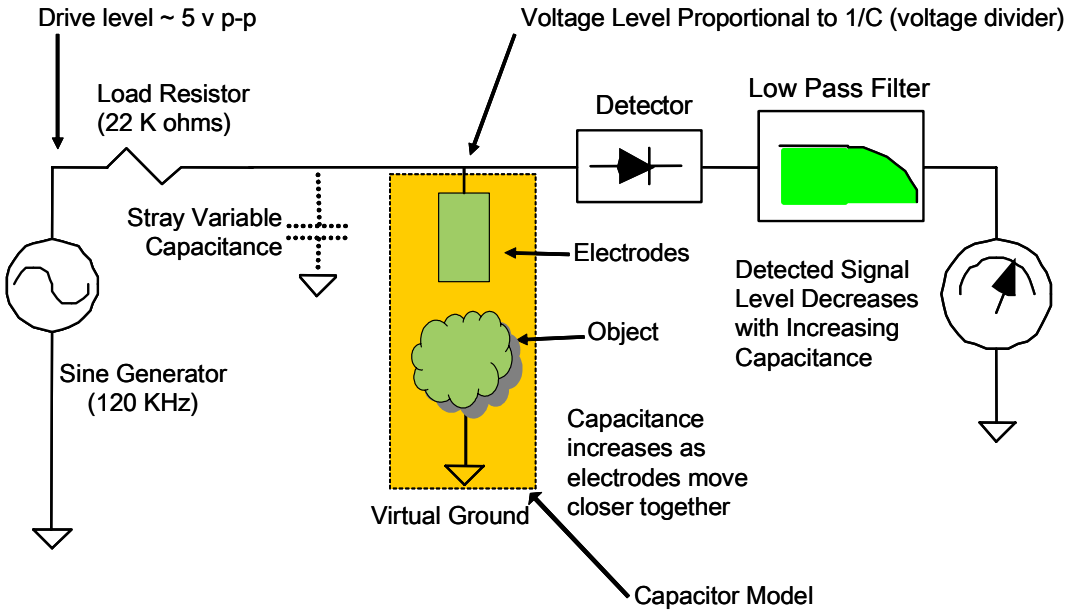


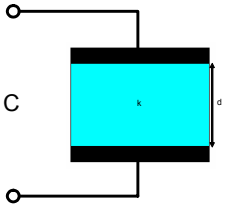
Figure 2 . Conceptual Block Diagram

CAPACITOR MODEL

The capacitance measured by the E-Field IC is:

- Proportional to the area of the electrode
- Proportional to the dielectric constant of the material between the electrodes
- Inversely proportional to the distance between the objects

$$C = \frac{k\varepsilon_0 A}{d}$$



C=The Capacitance in Farads (F)
A=The area of the plates in square meters (m2)
d=The distance between the plates in meters (m)
k=The dielectric constant of the material separating the plates
0=Is the permittivity of free space (8.85 x 10-12 F/m)

Figure 3. Capacitor Model

Table 4 Dielectric Constants of Various Materials

Dielectric Material	Thickness (mil)	*k*
Acrylic	84.5	2.4-4.5
Glass	74.5	7.5
Nylon Plastic	68	3.0-5.0
Polyester Film	10	3.2
Flexible Vinyl Film	9	2.8-4.5
Air	-	1
Water	-	80
Ice	-	3.2
Automotive Oil	-	2.1

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SHIELD DRIVER

A shield driver is included to minimize the electrode signal along wires. This circuit provides a buffered version of the returned AC signal from the electrode. Since it has nearly the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals, thereby canceling out any electric field. In effect, the shield drive isolates the electrode signal from external virtual grounds. A common application is to connect the Shield Driver to the shield of a coax cable used to connect an electrode to the corresponding electrode terminal. Another typical use is to drive a ground plane that is used behind an array of touch sensor electrodes in order to cancel out any virtual grounds that could attenuate the AC signal.

TUNABLE FREQUENCY

The 33941 offers 3 operating frequencies. In addition to the default frequency of 120 kHz, the 33941 has also been characterized to work in two other frequencies (240 kHz and 60 kHz) for applications with specific needs. These frequencies are tunable by attaching a 20k and 82k resistor at ROSC respectively. If a wider capacitance range is needed, simply change the ROSC resistor value to 82k to have the signal generator operate at 60 kHz which will extend the capacitance range to 150pF as seen on Figure 4. The figure also shows that one can achieve higher sensitivity at lower capacitances by setting the ROSC resistor value to 20k. All resistor values listed above are for 5% tolerance resistors.

ADJUSTABLE RESPONSE TIME

The rectified sine wave is filtered by a Low Pass Filter formed by and internal resistor and an external capacitor attached to LP_CAP. The value of the external capacitor is selected to allow the designer to optimize the balance between noise and settling time. A typical value for the external capacitor is 10nF and in practice it will have a response time of 1.5ms. If faster response time is required a 1nF capacitor can be used and it will have response times < 200uS. Please note that reducing the LP_CAP capacitor value increases noise accordingly.

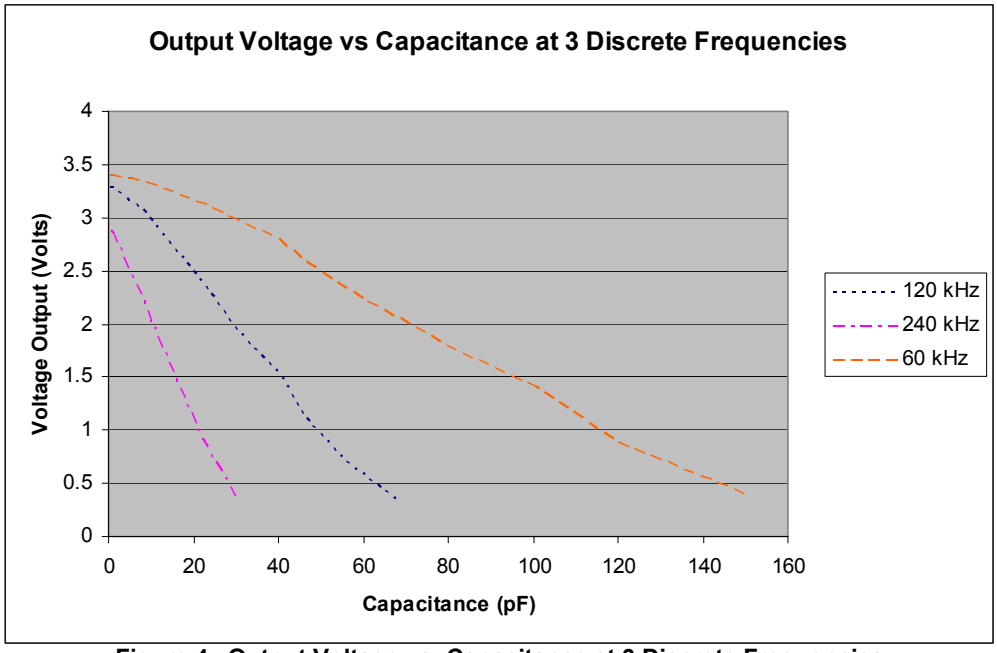

Figure 4 . Output Voltage vs. Capacitance at 3 Discrete Frequencies

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PIN DESCRIPTIONS

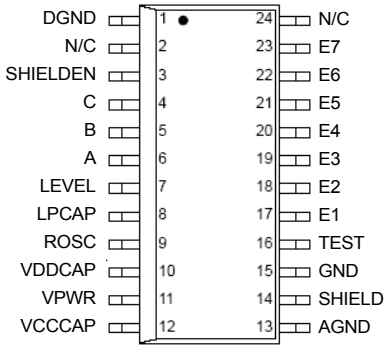

Figure 5. Pin Descriptions

Table 5. Electrode Selection

Terminal/SIGNAL	C	B	A
No electrodes selected	0	0	0
E1	0	0	1
E2	0	1	0
E3	0	1	1
E4	1	0	0
E5	1	0	1
E6	1	1	0
E7	1	1	1

Table 6. Pin Description

Pin Number	Pin Name	Definition
1	DGND	Connected to the ground return
2, 24	N/C	These pins should be left open.
3	SHIELDEN	Used to enable the shield signal
4,5,6	C, B, A	Controls electrode or reference activity
7	LEVEL	This is the detected, amplified, and offset representation of the signal voltage on the selected electrode
8	LPCAP	A capacitor on this pin forms a low pass filter with the internal series resistance from the detector to this pin
9	ROSC	A resistor from this pin to circuit ground determines the operating frequency of the oscillator
10	VDDCAP	A 47μF capacitor is connected to this pin to filter the internal analog regulated supply
11	VPWR	12 V power applied to this pin will be converted to the internal regulated voltages needed to operate the part
12	VCCCAP	A 47μF capacitor is connected to this pin and VCCCAP provides a regulated 5.0 V to power external circuits 75 mA Max
13	AGND	Connected to the ground return of the analog circuitry
14	SHIELD	Connects to cable shields to cancel cable capacitance.
15	GND	Main IC ground
16	TEST	Connect to circuit ground
17-23	E1–E7	Electrode pins

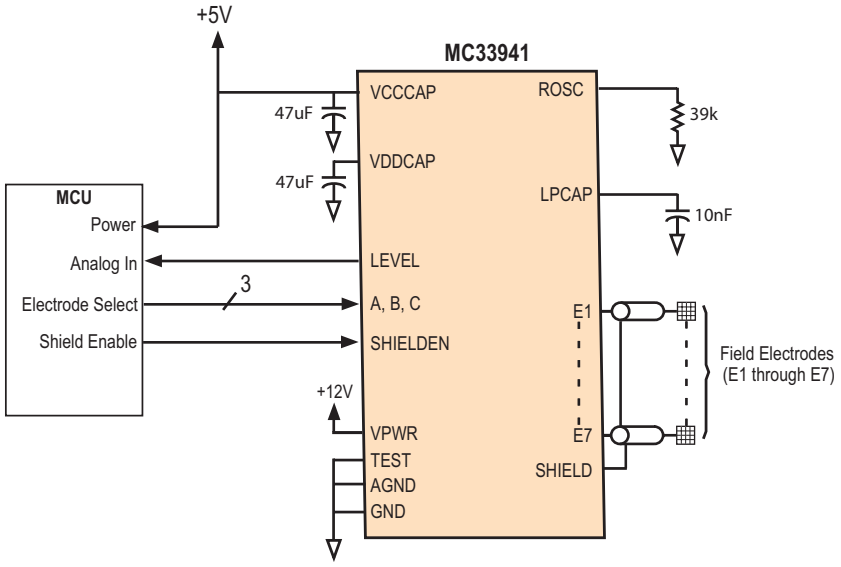

Figure 6 . Simplified Application Diagram

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Document Number: MC34940
Rev 4, 11/2006

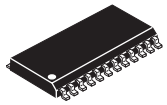
RoHS

Electric Field Imaging Device

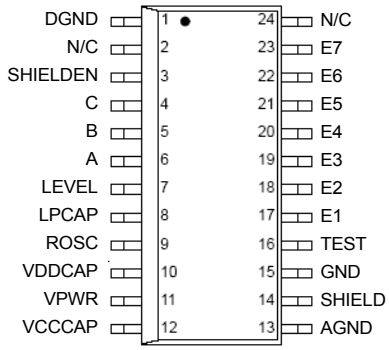
The MC34940 is intended for cost-sensitive applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created. The MC34940 detects objects in this electric field. The IC generates a low-frequency sine wave, which is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference. The MC34940 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

MC34940

ELECTRONIC FIELD IMAGING DEVICE



EG SUFFIX (Pb-FREE)
24-TERMINAL SOICW
CASE 751E-04



Pin Connections

Features

- Supports up to 7 Electrodes
- Shield Driver for Driving Remote Electrodes Through Coaxial
- High-Purity Sine Wave Generator Tunable with External Resistor
- Response Time Tunable with External Capacitor
- Can support up to 28 touch pad sensors
- Pb-Free and RoHS compliant

Typical Applications

- Appliance Control Panels and Touch Sensors
- Linear and Rotational Sliders
- Spill Over Flow Sensing Measurement
- Refrigeration Frost Sensing
- Industrial Control and Safety Systems Security
- Proximity Detection for Wake-Up Features
- Touch Screens
- Garage Door Safety Sensing
- PC Peripherals
- Patient Monitoring
- Point of Sale Terminals
- Size Detection
- Liquid Level Sensing

ORDERING INFORMATION			
Device Name	**Temperature Range**	**Drawing**	**Package**
MC34940EG/R2	0 to 90°C	CASE 751E-04	SOICW-24

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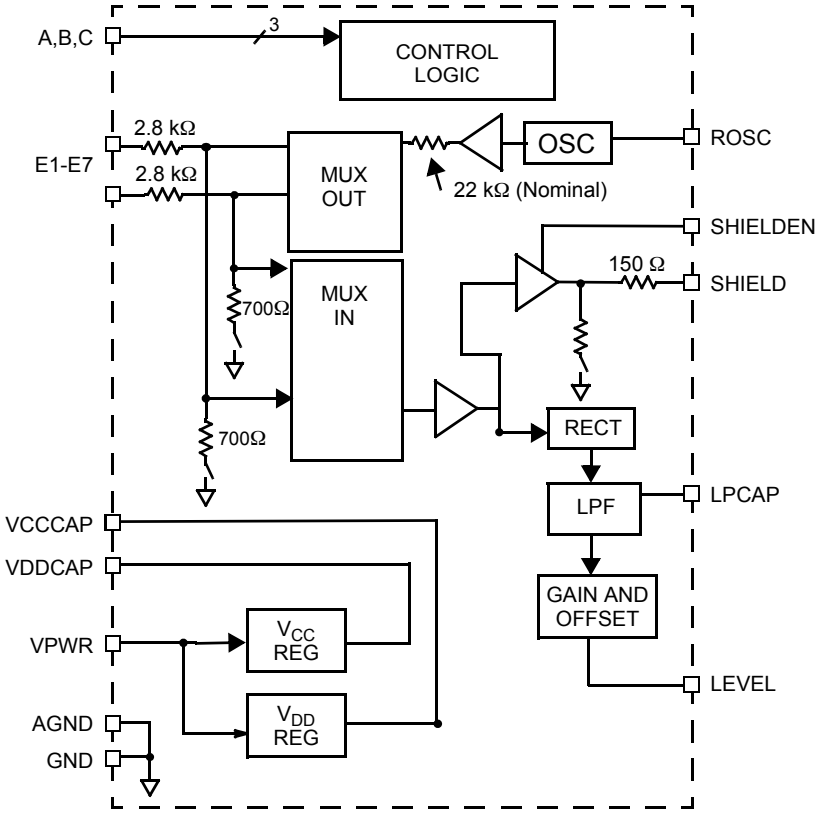

Figure 1. Simplified Functional Block Diagram

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Table 1. Maximum Ratings

All voltages are with respect to ground unless otherwise noted. Exceeding these ratings may cause a malfunction or permanent damage to the device.

Rating	Symbol	Value	Unit
ELECTRICAL RATINGS			
Peak V_{PWR} Voltage	V_{PWRPK}	40	V
Double Battery 1 Minute Maximum T_A = 30°C	V_{DBLBAT}	 26.5	V
ESD Voltage Human Body Model (C_{ZAP} = 100 pF, R_{ZAP} = 1500 Ω) Machine Model (C_{ZAP} = 200 pF, R_{ZAP} = 0 Ω) Charge Device Model (CDM), Robotic (C_{ZAP} = 4.0 pF)	V_{ESD}	 ±2000 ±200 ±1200	V
THERMAL RATINGS			
Storage Temperature	T_{STG}	-55 to 150	°C
Operating Ambient Temperature	T_A	-0 to 90	°C
Operating Junction Temperature	T_J	-0 to 150	°C
Thermal Resistance Junction-to-Ambient (1) Junction-to-Case (2) Junction-to-Board (3)	 $R_{\theta JA}$ $R_{\theta JC}$ $R_{\theta JB}$	 41 0.2 3.0	°C/W
Soldering Temperature (4)	T_{SOLDER}	260	°C

Notes

1. Junction temperature is a function of on-chip power dissipation, package thermal resistance, mounting site (board) temperature, ambient temperature, air flow, power dissipation of other components on the board, and board thermal resistance. In accordance with SEMI G38-87 and JEDEC JESD51-2 with the single layer board horizontal.
2. Indicates the average thermal resistance between the die and the case top surface as measured by the cold plate method (MILSPEC 883 Method 1012.1) with the cold plate temperature used for the case temperature.
3. Thermal resistance between the die and the printed circuit board per JEDEC JESD51-8. Board temperature is measured on the top surface of the board near the package.
4. Terminal soldering temperature limit is for 10 seconds maximum duration. The device is not designed for immersion soldering. Exceeding these limits may cause malfunction or permanent damage to the device.

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Table 2. Static Electrical Characteristics

Characteristics noted under conditions 5.5 V ≤ V_{SUP} ≤ 18 V, 0°C ≤ T_A ≤ 90°C, GND = 0 V unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under nominal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
SUPPLY (V_{PWR})					
Supply Voltage	V_{PWR}	9.0	12	18	V
I_{DD} (V_{PWR} = 14 V) (Quiescent supply current measured over temperature. Assumes that no external devices connected to internal voltage regulators)	I_{DD}	6.0	7.0	8.0	mA
ELECTRODE SIGNALS (E1–E7)					
Total Variance Between Electrode Measurements (5) All C_{LOAD} = 15 pF	ELV_{VAR}	–	–	3.0	%
Electrode Maximum Harmonic Level Below Fundamental (5) 5.0 pF ≤ C_{LOAD} ≤ 150 pF	EL_{HARM}	–	-20	–	dB
Electrode Transmit Output Range 5.0 pF ≤ C_{LOAD} ≤ 150 pF	EL_{TXV}	1.0	–	8.0	V
Receive Input Voltage Range	RX_V	0	–	9.0	V
Grounding Switch on Voltage (6) I_{SW} = 1.0 mA	SW_{VON}	–	–	5.0	V
LOGIC I/O (C, B, A)					
CMOS Logic Input Low Threshold	V_{THL}	0.3	–	–	V_{CC}
Logic Input High Threshold	V_{THH}	–	–	0.7	V_{CC}
Voltage Hysteresis	V_{HYS}	–	0.06	–	V_{CC}
Input Current V_{IN} = V_{CC} V_{IN} = 0 V	I_{IN}	10 -5.0	– –	50 5.0	μA
SIGNAL DETECTOR (LPCAP)					
Detector Output Resistance	DET_{RO}	–	50	–	kΩ
LPCAP to LEVEL Gain	A_{REC}	3.6	4.0	4.4	A_V
LPCAP to LEVEL Offset	V_{RECOFF}	-3.3	-3.0	-2.7	V

Notes

5. Verified by design and characterization. Not tested in production.
6. Current into grounded terminal under test = 1.0 mA.

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Table 3. Dynamic Electrical Characteristics

Characteristics noted under conditions 5.5 V ≤ V_{SUP} ≤ 18 V, 0°C ≤ T_A ≤ 90°C, GND = 0 V unless otherwise noted. Typical values noted reflect the approximate parameter means at T_A = 25°C under nominal conditions unless otherwise noted.

Characteristic	Symbol	Min	Typ	Max	Unit
OSC (ROSC)					
OSC Frequency Stability	f_{STAB}	–	–	10	%
OSC Center Frequency ROSC = 39 kΩ ROSC = 20 kΩ ROSC = 82 kΩ	f_{OSC}	 – – –	 120 240 60	 – – –	kHz
Harmonic Content 2nd through 4th Harmonic Level 5th and Higher	$OSCH_{ARM}$	 – –	 – –	 -20 -60	dB
SHIELD DRIVER (SHIELD)					
Shield Driver Maximum Harmonic level below Fundamental 10 pF ≤ C_{LOAD} ≤ 500 pF	SD_{HARM}	–	-20	–	dB
Shield Driver Gain Bandwidth Product Measured at 120 kHz	SD_{GBW}	–	4.5	–	MHz

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PRINCIPLE OF OPERATION

The MC34940 generates a low radio frequency sine wave with nominal 5.0 V peak-to-peak amplitude. The frequency is set by an external resistor and is optimized for 120 kHz. An internal multiplexer routes the signal to one of the 7 terminals under control of the ABC input terminals. A receiver multiplexer simultaneously connected to the selected electrode routes its signal to a detector, which converts the sine wave to a DC level. The DC level is filtered by an external capacitor, is multiplied and offset to increase sensitivity. All electrode outputs are grounded internally by the device when not selected.

The amplitude and phase of the sinusoidal wave at the electrode are affected by objects in proximity. A “capacitor” is formed between the driving electrode and the object, each forming a “plate” that holds the electric charge. The voltage measured is an inverse function of the capacitance between the electrode being measured, the surrounding electrodes and other objects in the electric field surrounding the electrode. Increasing capacitance results in decreasing voltage. The value of the series resistor (22 kΩ) was chosen to provide a near linear relationship at 120 kHz over a range of 10 pF to 70 pF.

While exploring applications using the E-Field chip, it is always useful to approach the problem using the capacitor model.

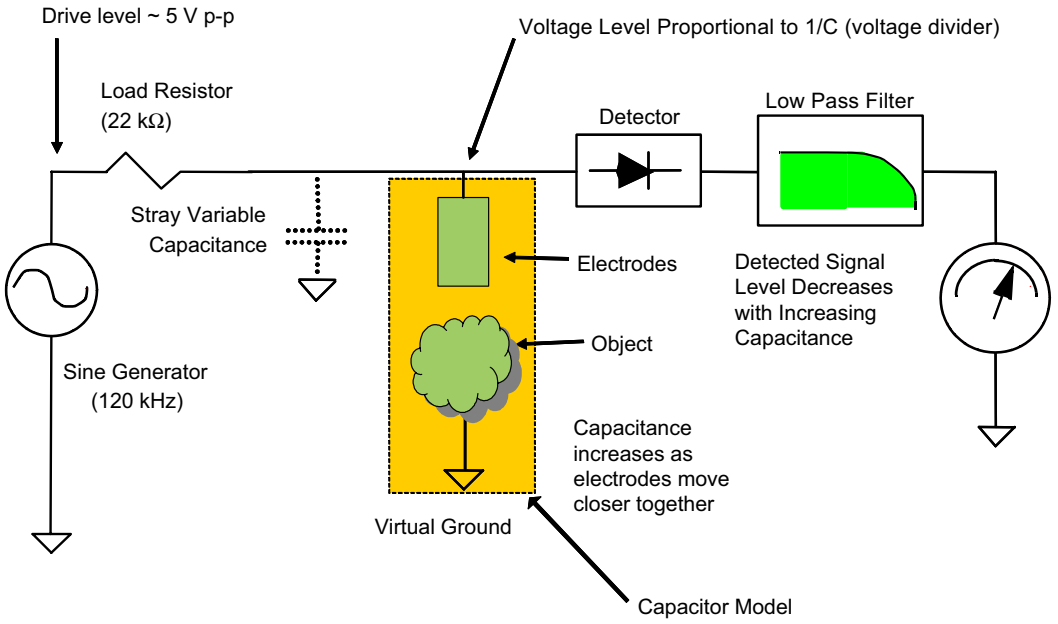


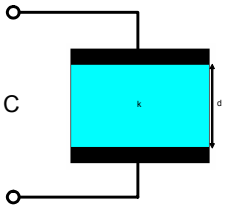
Figure 2. Conceptual Block Diagram

CAPACITOR MODEL

The capacitance measured by the E-Field IC is:

- Proportional to the area of the electrode
- Proportional to the dielectric constant of the material between the electrodes
- Inversely proportional to the distance between the objects

$$C = \frac{k\varepsilon_0 A}{d}$$



C = The Capacitance in Farads (F)
A = The area of the plates in square meters (m2)
d = The distance between the plates in meters (m)
k = The dielectric constant of the material separating the plates
0 = Is the permittivity of free space (8.85 x 10-12 F/m)

Figure 3. Capacitor Model

Table 4. Dielectric Constants of Various Materials

Dielectric Material	Thickness (mil)	*k*
Acrylic	84.5	2.4-4.5
Glass	74.5	7.5
Nylon Plastic	68	3.0-5.0
Polyester Film	10	3.2
Flexible Vinyl Film	9	2.8-4.5
Air	-	1.0
Water	-	80
Ice	-	3.2
Automotive Oil	-	2.1

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FEATURES

SHIELD DRIVER

A shield driver is included to minimize the electrode signal along wires. This circuit provides a buffered version of the returned AC signal from the electrode. Since it has nearly the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals thereby canceling out any electric field. In effect, the shield drive isolates the electrode signal from external virtual grounds. A common application is to connect the Shield Driver to the shield of a coax cable used to connect an electrode to the corresponding electrode terminal. Another typical use is to drive a ground plane that is used behind an array of touch sensor electrodes in order to cancel out any virtual grounds that could attenuate the AC signal.

TUNABLE FREQUENCY

The MC34940 offers 3 operating frequencies. In addition to the default frequency of 120 kHz, the MC34940 has also been characterized to work in two other frequencies (240 kHz and 60 kHz) for applications with specific needs. These frequencies are tunable by attaching a 20k and 82k resistor at ROSC respectively. If a wider capacitance range is needed, simply change the ROSC resistor value to 82k to have the signal generator operate at 60 kHz which will extend the capacitance range to 150 pF as seen on Figure 4. The figure also shows that one can achieve higher sensitivity at lower capacitances by setting the ROSC resistor value to 20k. All resistor values listed above are for 5% tolerance resistors.

ADJUSTABLE RESPONSE TIME

The rectified sine wave is filtered by a Low Pass Filter formed by an internal resistor and an external capacitor attached to LP_CAP. The value of the external capacitor is selected to allow the designer to optimize the balance between noise and settling time. A typical value for the external capacitor is 10 nF and in practice it will have a response time of 2.5 ms. If faster response time is required a 1.0 nF capacitor can be used and it will have response times around 500 μs. Please note that reducing the LP_CAP capacitor value increases noise accordingly.

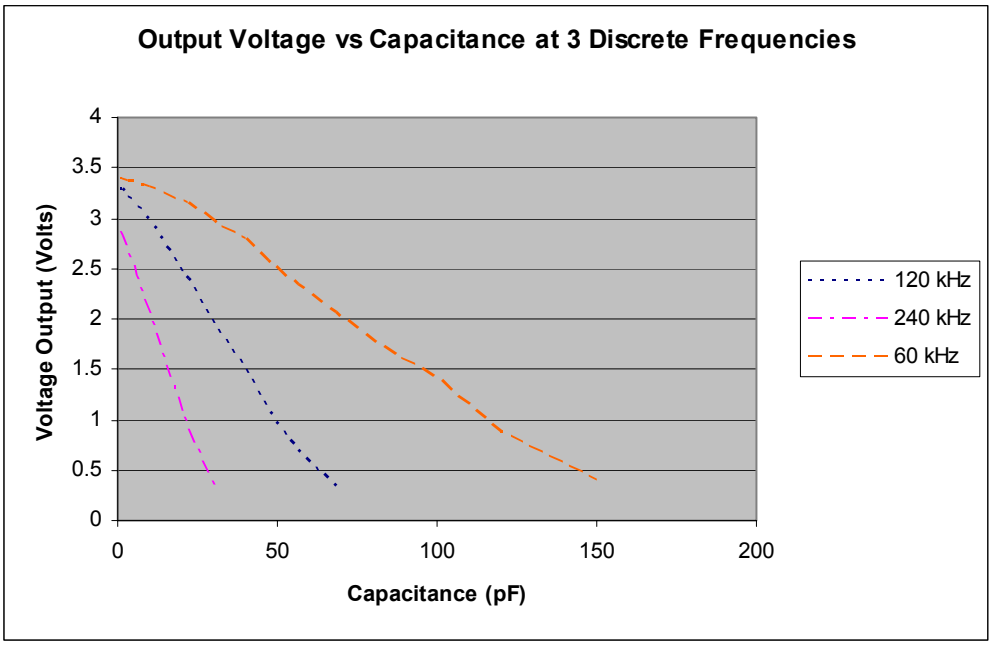

Figure 4. Output Voltage vs. Capacitance at 3 Discrete Frequencies

PIN DESCRIPTIONS

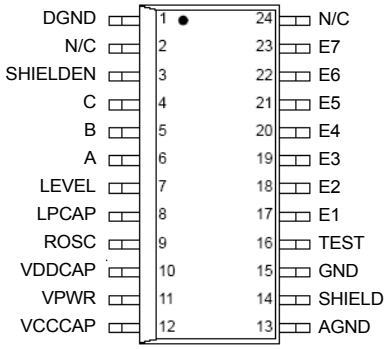

Figure 5. Pin Descriptions

Table 5. Electrode Selection

Terminal/SIGNAL	C	B	A
No electrodes selected	0	0	0
E1	0	0	1
E2	0	1	0
E3	0	1	1
E4	1	0	0
E5	1	0	1
E6	1	1	0
E7	1	1	1

Table 6. Pin Description

Pin Number	Pin Name	Definition
1	DGND	Connected to the ground return
2, 24	N/C	These pins should be left open.
3	SHIELDEN	Used to enable the shield signal
4,5,6	C, B, A	Controls electrode or reference activity
7	LEVEL	This is the detected, amplified, and offset representation of the signal voltage on the selected electrode
8	LPCAP	A capacitor on this pin forms a low pass filter with the internal series resistance from the detector to this pin
9	ROSC	A resistor from this pin to circuit ground determines the operating frequency of the oscillator
10	VDDCAP	A 47 μF capacitor is connected to this pin to filter the internal analog regulated supply
11	VPWR	12 V power applied to this pin will be converted to the internal regulated voltages needed to operate the part
12	VCCCAP	A 47 μF capacitor is connected to this pin to filter the internal digital regulated supply
13	AGND	Connected to the ground return of the analog circuitry
14	SHIELD	Connects to cable shields to cancel cable capacitance.
15	GND	Main IC ground
16	TEST	Connect to circuit ground
17-23	E1–E7	Electrode pins

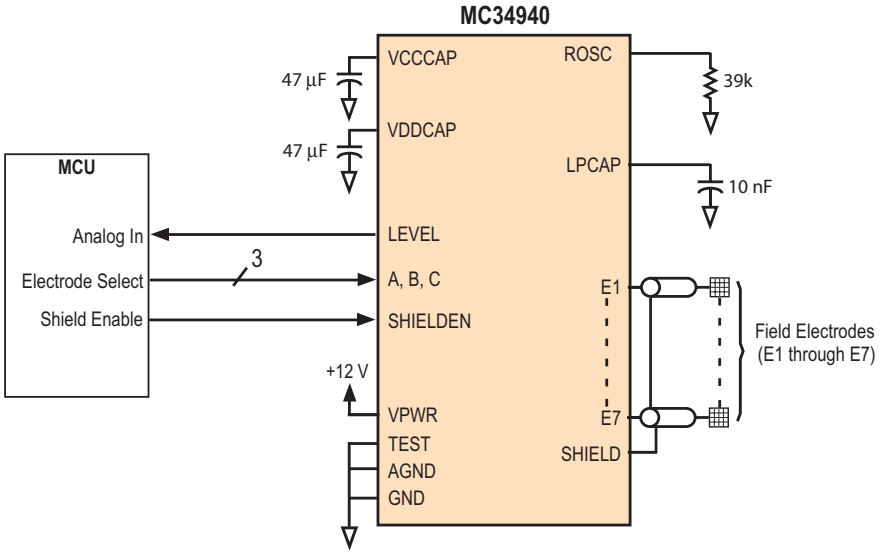

Figure 6. Simplified Application Diagram

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Rev. 4, 11/2006

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Touch Panel Applications Using MC34940/MC33794 E-Field ICs

The MC34940/MC33794 are intended for cost-sensitive applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created. The MC34940/MC33794 detects objects in this electric field. The IC generates a low-frequency sine wave, which is adjustable by using an external resistor and is optimized for 120 kHz. The sine wave has very low harmonic content to reduce harmonic interference. The MC34940/MC33794 also contains support circuits for a microcontroller unit (MCU) to allow the construction of a two-chip E-field system.

Features

- Supports 7 or 9 Electrodes
- Shield Driver for Driving Remote Electrodes Through Coaxial
- High-Purity Sine Wave Generator Tunable with External Resistor
- Response Time Tunable with External Capacitor
- Can support up to 28 touch pad sensors (MC34940)
- Pb-Free and RoHS compliant (MC34940)

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1.0 E-Field Sensing: An Alternative Solution to Control Panel Applications

Human touch can be a useful tool. Control panels, appliances, heavy machinery, toys, lighting controls, and anything that has a mechanical switch or push button requires some sort of human interaction to operate. Traditionally, push buttons are made out of mechanical switches and/or multi-layer resistive touch pads that can deteriorate and become less dependable over time. This is because most of these switches require physical displacement and pressure which are susceptible to wear-out, contact bounce, corrosion and arcing.

The MC34940/MC33794 Electric Field Imaging devices from Freescale offer an alternative to mechanical push buttons for control panel applications. The MC34940/MC33794 Integrated Circuits (IC) contain the circuitry necessary to generate a low level electric field and measure the field loading caused by objects moving into or out of the field. It is ideal for applications that require non-contact sensing, proximity detection, and three-dimensional e-field imaging. The ICs integrate support for a microcontroller and 7 to 9 electrodes, which can be used independently to determine the size or location of an object in a weak electric field.

With the MC34940/MC33794, membrane switches and resistive touch pads can be replaced with an array of touch pads consisting of conductive electrodes embedded beneath an insulating surface. Since it has the capability of sensing touch and proximity through the insulating surface, without direct electrical contact with the electrode metal, problems of wear, contamination, and corrosion are eliminated. This capability is also important for sophisticated touch control applications, including a user interface panel that is sensitive to different degrees of proximity — enabling the system to go from standby to active mode as a finger approaches the panel.

Further, one of the MC34940/MC33794 key features that surpass simple capacitive-based sensors is its on-board shield driver. Touch pads do not have to be combined and located at one centralized location. With proper shielding, coaxial cables or PCB layers can be used to connect remote touch pads up to a few meters away, while obtaining measurements as accurately as if the touch pads were directly connected to the IC. The MC34940/MC33794 does this by driving a signal on the shield of the coax or a PCB trace which closely follows the signal conductor voltage. The current which flows through the electric field between two conductors is proportional to the voltage difference between them. With little or no voltage difference between them, there is little or no current flow between the electrode conductor and the shielding trace or coax shield. In a cook top application, for example, this capability allows the activation touch pads for an individual burner to be in different places, rather than at the usual centralized location, without requiring a separate IC at each location. The same IC could be used to activate the down-draft vent and oven with their touch control near what they are controlling.

The potential for the chip goes well beyond touch panel applications. Target applications of the IC includes appliances, machine tools, security systems, and automotive safety systems. From liquid level sensing, to occupant classification, to theft detection, the applications list for the MC34940/MC33794 are growing.

2.0 How the MC34940/MC33794 E-Field Sensors Work

The MC34940/MC33794 electric field is derived by the oscillator circuitry within the IC which generates a high purity, low frequency, 5 V peak-to-peak sine wave. This frequency is tunable by

an external resistor and is optimized for 120 kHz. This AC signal is fed through an internal 22 kΩ resistor, to a multiplexer which directs the signal to the selected electrode or reference pin or to an internal measurement node. Unselected electrodes are automatically connected to the circuit ground by the IC.

These deselected electrodes can act as the return path needed to create the electric field current, since in order to create current flow, the current must follow a complete path: out of the electrode pin and back to the common ground of the IC GND pin. Thus, an electric field will cause a current to flow between the active electrode and any object with an electrical path to the IC ground, including deselected electrodes.

The current flowing between the electrode and its surrounding grounds will result in a voltage drop across the internal resistance. This, in turn, results in a voltage change at the pin. An on-board detector in the IC converts the AC signal to DC level. The DC level is then low-pass filtered using an internal series resistor and an external parallel capacitor. This DC voltage is multiplied, offset and sent to the LEVEL pin of the IC.

To help reduce application development cycle times, Freescale offers an evaluation module for the MC33794, called KIT33794DWBEVM and an evaluation model for the MC34940 called DEMO1985MC34940. This application note will focus on the use of the KIT33794DWBEVM, however the same principles apply for the evaluation kit DEMO1985MC34940 for the MC34940. Besides the different E-Field sensor IC, the main difference between the kits is the resolution of the onboard MCU. The KIT33794 uses an 8-bit ADC while the DEMO1985MC34940 uses a 10-bit ADC. When applying the data in the application note to the DEMO1985MC34940 please note that all the values in this note were recorded in an 8-bit ADC while all data reported by the DEMO1985MC34940 are reported in 10- or 12-bit values.

The KIT33794DWBEVM kit includes an MC33794DWB, a preprogrammed Freescale 68HC908QY4 8-bit microcontroller, an RS-232 communication IC, and other passive supporting components on a Printed Circuit Board. The 8-bit microcontroller converts the analog signal from the MC33794 into a 8-bit byte. The MCU transmits this value to a computer via its COM port. A Windows type program is included in the kit. This program displays the measured A-to-D value in real time along with its corresponding analog bar graph. The program can be made to scan all of the electrodes.

3.0 Using the MC34940/MC33794 for Touch Control Applications

The MC34940/MC33794 can detect anything that is either conductive or has different dielectric properties than the electrodes' surroundings. Human beings are well suited for e-field imaging. This is because the human body is composed mainly of water that has a high dielectric constant and contains ionic matter which gives it good conductivity. The body also provides good electrical coupling to earth ground which can be connected to the ground return of the IC. Thus, when a finger is brought close to a metal electrode, an electrical path is formed, producing a change in electric field current that is detected by the MC34940/MC33794 and translated to a different output voltage.

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The things which need to be determined in the development of an MC34940/MC33794 touch panel application are:

1. Touch pad electrode layout and design.
2. The different dielectric materials for the surface of the panel.
3. The effect on e-field measurements of various environmental conditions.

The above matters were investigated using the available KIT33794DWBEVM evaluation module. **Figure 1** displays the general setup using the kit.

Throughout the tests, all the generated data was obtained using a “calibrated” artificial finger equivalent to medium pressure applied by a finger based on actual tests and data. The artificial finger was designed to make the pressure applied to the panel consistent. The artificial finger was connected to ground and made from a copper rod with a surface area of 0.26 in^2 and mass of 62 grams.

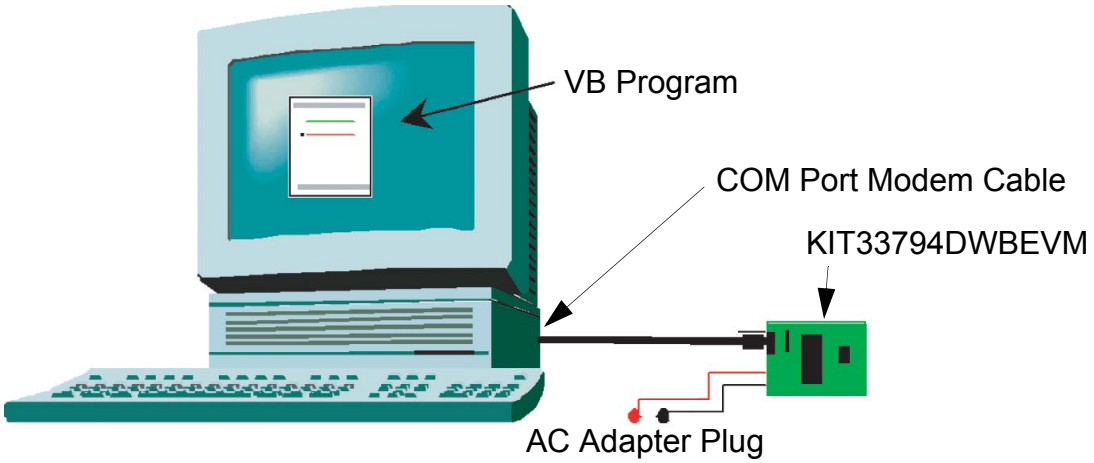

Figure 1. E-Field Evaluation Module Setup

3.1 Electrode Design

To understand how electrode designs effect the IC’s capabilities, it is important to understand the basic definition of a capacitor. A common capacitor uses an electric field and an insulating dielectric to allow current conduction to occur. It can be made by placing two metal plates in parallel with each other if the plates are separated by a distance “d” with each plate having an area of “A.”

The capacitance of the capacitor can be calculated using the formula:

$$C = (kA\varepsilon)/d$$

where

C is the capacitance of the capacitor in Farads
A is the area of the plates in $meter^2$
d is the distance between the plates in meters
k is the dielectric constant of the material between the plates

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ε is the permittivity (8.85 x 10^{-12} F/m)

From the above equation, it can be seen that area (*A*), distance/spacing (*d*), and the dielectric constant (*k*) are the three factors that affect the magnitude of the capacitance. At a given frequency and voltage of an applied signal, the capacitance controls the resulting electric field current flow. The output of the MC34940/MC33794 responds to variations in this current.

3.1.1 Size Matters

An electrode can be anything that is electrically conductive. When designing the electrodes for any application, one must take into account the physical size of the conductive electrode. The larger the electrode, the more range and sensitivity will be obtained. However, as the electrode size is increased, so is its susceptibility to interference, electrical noise, and “stray” electric-field paths in its surroundings. One of the key practices regarding electrode design is for the electrode’s area to correspond with the surface area of the object being detected. Touch pads for touch panel applications, for example, would only require a size that suits the surface area of a finger.

3.1.2 Spacing

The area of the touch pads only needs to accommodate the contact area of the finger. This limits its usable size. Therefore, the distance or spacing factor will play a significant role on how the electrode should be laid out. Another factor which needs to be considered is how the fringing between the patterns adds to electric field current.

Some of the electric field current will flow in the fringing field between a pair of electrodes. **Figure 2** shows the direct field path between two conductors which are end-to-end and a few of the fringing field paths between the electrodes. If the ratio of the fringing field path to the direct path is held constant, the height of the fringing field relative to the plane of the electrodes increases in direct proportion with the spacing. **Figure 2** shows pictorially how the height of the fringing field relative to the electrodes becomes greater as the two electrodes are moved further away from each other.

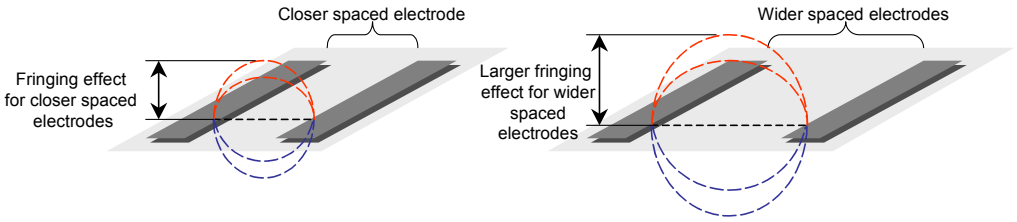

Figure 2. Fringing Fields and the Effects of Spacing

This fringing field allows an ungrounded object to be sensed in the “third” dimension above the essentially two dimensional array of electrodes, and the relative sensitivity for a given height above the plane of the electrodes increases with electrode spacing. It is important to note that the total current flow decreases with increased spacing. The point of this is that there is interaction between electrode size and spacing and their ability to sense objects in the third dimension. In the case of a grounded object, the fringing field will not play as much of a role since

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some of the current will flow directly to the grounded object from the electrode, but good electrode design should keep both of these effects in mind.

The MC34940/MC33794 works best when the total capacitance between an electrode and ground or another electrode close to 50 pF, when the finger is in the “activate” range. The total system capacitance should be below 75 pF and preferably below 65 pF for best sensitivity. This includes the IC pin, PWB trace, wire, and any other stray capacitance. Large electrodes should be used when distances are great, and small electrodes when distances are small.

3.1.3 Significance of Ground — Single Electrode Sensing

The placement of ground is important. As mentioned earlier, electric field currents can exist between the active electrode and any grounded object. By intertwining the electrode with ground, the essential ground source needed to create an e-field is directly accessible to the electrode. This path is less variable than the path through a body and earth and provides a more predictable and less noisy path.

To investigate how variables in ground can effect the e-field measurement, we tested the ground phenomena with a two electrode design, a spiral and an inter-digitated layout. In addition, the width of the ground electrode intertwined with a signal electrode was varied to determine how much ground area affects the readings. One electrode-ground test configuration was designed with ground having the same width as the electrode, and another with the ground electrode thinner than the signal electrode. We designed touch pads which had an area large enough to accommodate a typical finger in a square shape with a length and width of 0.6 in. The dimensions of the electrodes are displayed in **Figure 3**.

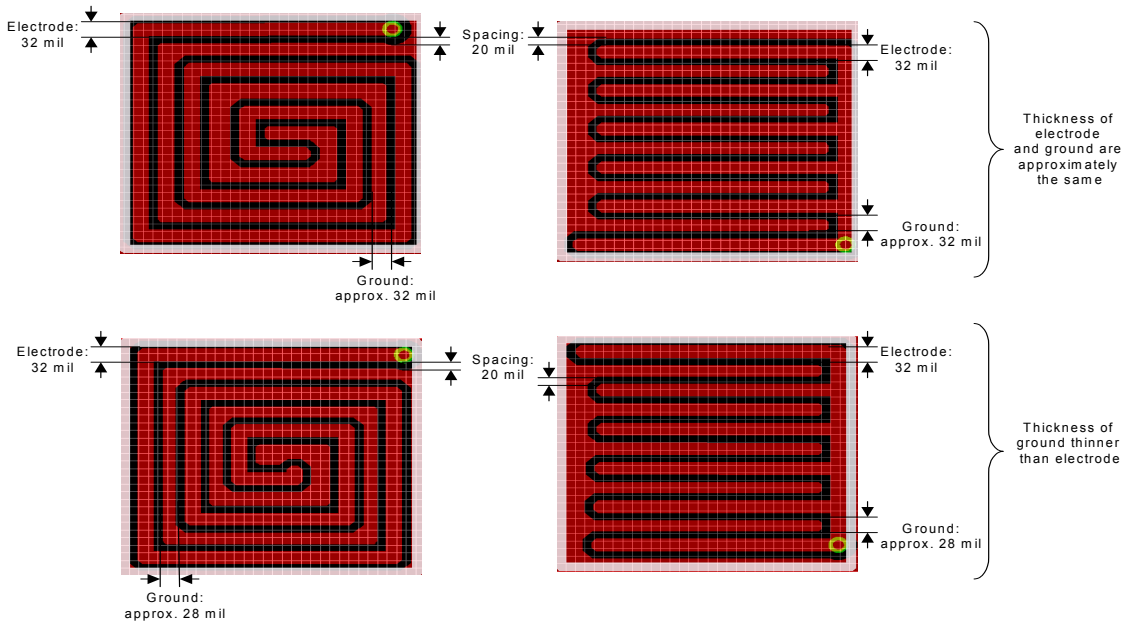

Figure 3. Intertwined Electrode and Ground Designs and Dimensions

The e-field loading for each touch pad is displayed in **Figure 4**. This figure shows the difference in measurement, not the absolute reading of the electrodes. A 4.5 mil (“.0045) thick vinyl film was

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used as an insulator over the patterns. The 2 top bars show the readings for a ground with the same width as the electrodes. The bottom 2 are for the electrodes where the grounded electrode is thinner than the signal electrode. The bar graph shows that the layout with the narrower ground electrode provided a slightly greater amount of difference in comparison to the design with ground having the same width.

The practice of intertwining electrodes with ground is more important when the electrodes connected to the IC's pins are at a distance from each other. When electrodes are close to each other, the adjacent electrodes could act as the ground source needed to create the field current. This is due to the IC connecting the deselected electrodes to ground; making the deselected electrode often act as the ground return path needed to allow an electric field current to flow.

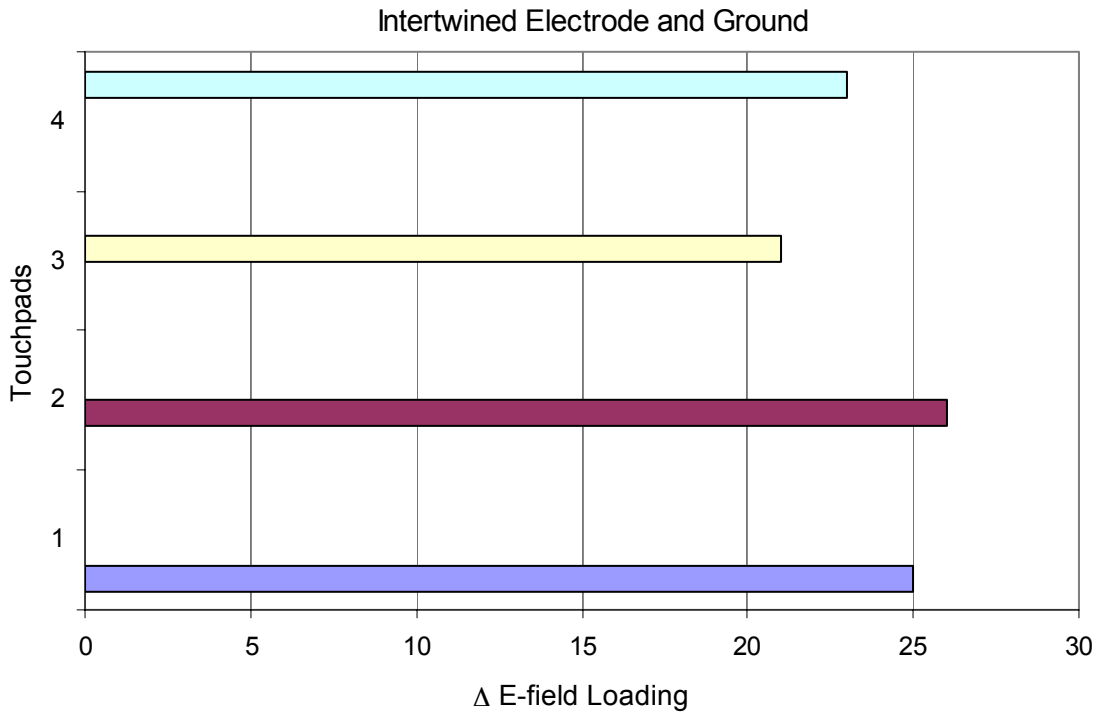

Figure 4. Results of Electrode-Ground Configuration Multiplexed Electrodes

3.1.4 Multiplexed Electrodes

A single MC34940/MC33794 can support as many as 7/11 electrodes which can be used independently to map the location and area of an object. By employing multiple electrodes, it is possible to get an idea about the size and shape of an object influencing the MC34940/MC33794's electric field depending on which electrodes indicate a change in their electric field current.

A panel that requires only a few push buttons could use a single electrode for each touch pad. Doing this would limit an application using a single MC34940/MC33794 to a maximum of 7/11 simple single element electrode buttons, corresponding to the 7/11 available electrode pins in the

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IC. By intertwining multiple electrodes in each touch pad, many more touch pads could be supported by a single MC34940/MC33794.

To determine the best method to maximize the use of the available electrode connections on the IC, a number of design layouts were analyzed. For this investigation, we designed touch pads that had two, three, and four intertwined electrodes.

When integrating multiple electrodes in one touch pad, the electrode was laid out so that when a finger is over a touch pad, there is an even distribution of the finger's surface area over each of the electrodes. Numerous geometric arrangements and shapes were investigated to determine the best way to construct the electrodes in a square area. The inter-digitated configuration like the two right side drawings in **Figure 4** were found to be the best layout for intertwining two electrodes when a thin membrane is used to cover the touch pads. When a thick overlay (4 mm glass) is placed above the touch pads, it is best to use a pattern that maximizes the surface area of the button. The inter-digitated had two comb-like patterns with the teeth of the combs meshed with each other but not touching each other. An inter-digitated configuration allows for an exact distribution of each electrode and allows the system to detect the same loading from each electrode when in the presence of a finger.

Further extending this idea, two electrodes in a single touch pad could be organized by multiplexing the electrode following a column-row configuration. Increasing the number of rows and/or columns in the array will provide more electrode combinations. With this configuration, a single IC could detect as many as 20 individual push buttons. **Figure 5** highlights the column-row configurations.

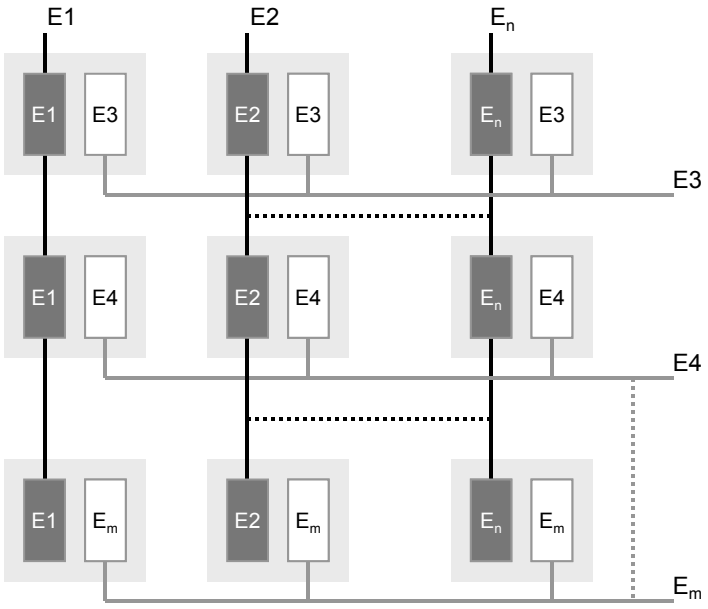

Figure 5. Multiplexed Electrodes Following a Column-Row Configuration

The electrode layout gets more complex as the number of electrodes in each touch pad increases. For three intertwined electrodes, a spiral like geometry is suitable as shown in **Figure 6**. Although the exposed electrode surface areas are not exactly equal to each other, when a finger is placed over the center of the pad, the currents will be reasonably close to the same. For four intertwined electrodes, the layout design had electrodes following an "S" shape.

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Again, when a finger is over the center of the pad, it would be able to cover the majority of each electrode's exposed area.

When intertwining five or more electrodes, the design gets more complex. One must take into account the size of the available area for the touch pads when determining the maximum number of electrodes in a touch pad. The number of electrodes is limited by the width and spacing requirements of the electrodes and the minimum area of each electrode for the required sensitivity.

Earlier, we discussed electrodes which were intertwined with ground in order to form a path for the field current. In a multiplexing configuration, a separate ground does not have to be intertwined because the IC automatically connects the unselected electrodes to ground. For example, in the case of the two intertwined electrodes following an inter-digitated configuration and connected to *E1* and *E2,* when *E1* is selected, *E2* (the deselected electrode) acts as the ground return to produce the field current between the two electrodes. After the system has gone through the measurement process for *E1,* the role of the two electrodes are then reversed (e.g. *E2* is selected for measurement while *E1* is connected to ground). The same phenomenon is present for touch pads with three and four intertwined electrodes.

These layouts were tested using a 4.5 mil vinyl covering. The difference in loading can be seen in the graph of **Figure 6**.

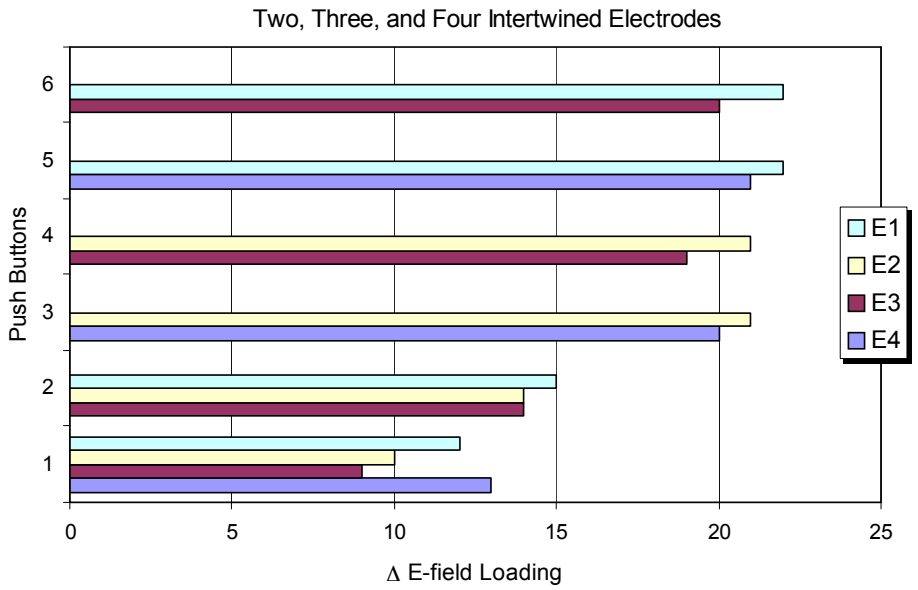

Figure 6. Difference in E-Field Loading Resulting from 2, 3, and 4 Intertwined Electrodes in a Push Button

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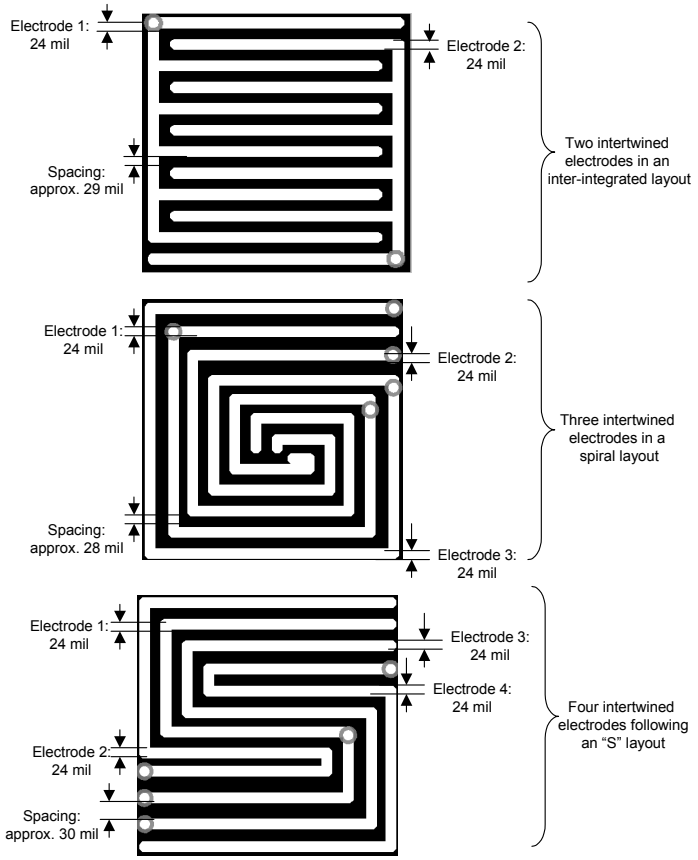

Figure 7. Two, Three, and Four Electrodes Ideally Intertwined to Form a Touch Pads

The top four bar pairs of the graph display the value obtained having two intertwined electrodes (like **Figure 3**). The measurements are very similar to each other. For the three intertwined electrodes, the difference in measurement is still visible, having about a third less magnitude than the ones with two intertwined electrodes. The reading from a touch pad with four intertwined electrodes shows even lower sensitivity. The reduction in sensitivity as the number of intertwined electrodes is increased is due to the reduction of area in each of the electrodes.

The reduction of sensitivity as the number of intertwined electrodes is increased can be offset by a thinner or higher dielectric constant cover over the touch pads. Conversely, the thickness and dielectric constant of the covering may limit the number of inter-twined electrodes.

The electrode layout and design used to measure the data in **Figure 6** is displayed in **Figure 7**. Where 2 bars are together in **Figure 6**, the bars are showing the different measurements for each electrode when using 2 intertwined electrodes in the touch pads. Three bars together are for 3 intertwined electrodes and the group of four are for 4 intertwined electrodes in touch pads.

The number of touch pads supported by the available electrode connections is more than a simple multiplexing scheme might appear to indicate. Touch pads made of 1, 2, 3, 4 or more electrodes can all be used in the same system. For instance *E1* could be intertwined with a circuit ground electrode to form a touch pad which would show only *E1* being affected when it is selected by a finger. In the same application *E1* and *E2* can be intertwined to form a touch pad so that a finger selecting it would affect both electrodes. Since both electrodes are affected in this

touch pad and only *E1* was affected in the other touch pads, the one being selected can be determined.

Table 1 shows the 45 touch pads electrode combinations possible using 1 and 2 electrodes per touch pad with the 9 electrodes available on the MC33794. This gives some idea of the power of electric field multiplexing. If combinations of 1, 2 and 3 electrodes were used per touch pad, the number of possible unique touch pads a single MC33794 could support grows to 126!

Table 1. 1 and 2 Electrode Touch Pad Combinations

Electrode=>	A	B	C	D	E	F	G	H	I	Electrodes
touch pads										touch pads
↓										↓
1	X									1
2		X								1
3			X							1
4				X						1
5					X					1
6						X				1
7							X			1
8								X		1
9									X	1
10	X	X								2
11	X		X							2
12	X			X						2
13	X				X					2
14	X					X				2
15	X						X			2
16	X							X		2
17	X								X	2
18		X	X							2
19		X		X						2
20		X			X					2
21		X				X				2
22		X					X			2
23		X						X		2
24		X							X	2
25			X	X						2
26			X		X					2
27			X			X				2
28			X				X			2
29			X					X		2
30			X						X	2
31				X	X					2
32				X		X				2
33				X			X			2
34				X				X		2
35				X					X	2
36					X	X				2
37					X		X			2
38					X			X		2
39					X				X	2

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Table 1. 1 and 2 Electrode Touch Pad Combinations (continued)

Electrode=>	A	B	C	D	E	F	G	H	I	Electrodes
40						X	X			2
41						X		X		2
42						X			X	2
43							X	X		2
44							X		X	2
45								X	X	2

3.1.5 Electrode—Isolated or a Unit?

Electrically conductive electrodes can be attached directly to the MC34940/MC33794 electrode pins via wire or coax cable. The IC SHIELD pin allows coaxial cable to be used without reducing sensitivity or adding variations due to changes in the coax capacitance. The signal from the SHIELD pin is a buffered version of the signal driving the selected electrode. It has the same amplitude and phase. This reduces amplitude of the electric field between the center conductor and the shield of the coax to nearly 0. This results in nearly zero field current between them and doesn't add to the field current at the electrodes.

The electrodes of a touch pad can be formed directly on Printed Circuit Boards (PCB) using copper circuit traces. We formed the electrodes used in **Figure 3** (electrode intertwined with ground) and **Figure 6** (two, three, four intertwined electrodes) this way. The field current of the wires used to connect the IC pins to the electrodes was reduced by placing a copper layer connected to the shield pin over the signal traces. This is shown in **Figure 8**. This practice also hides the exposed wires from the plate to be contacted by the user. This prevents false indications of a touch when a finger touches an area above the routing traces.

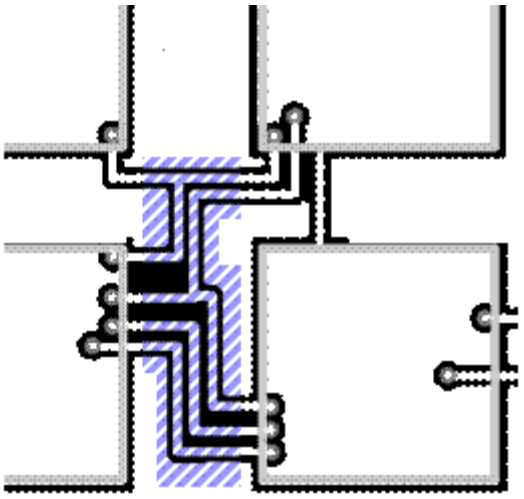

Figure 8. Wires Covered with Conductive Plate Connected to the SHIELD Pin to Minimize Effective Capacitance of Wire

Further, an electric current could flow in the field created from the touch pad to an object above or below it. Since we want the field to only propagate on top of the touch pads, **Figure 9** shows how we eliminated the effective capacitance on the back side of the touch pad by placing a conductive layer under all of the touch pads and connected it to the shield driver pin of the IC.

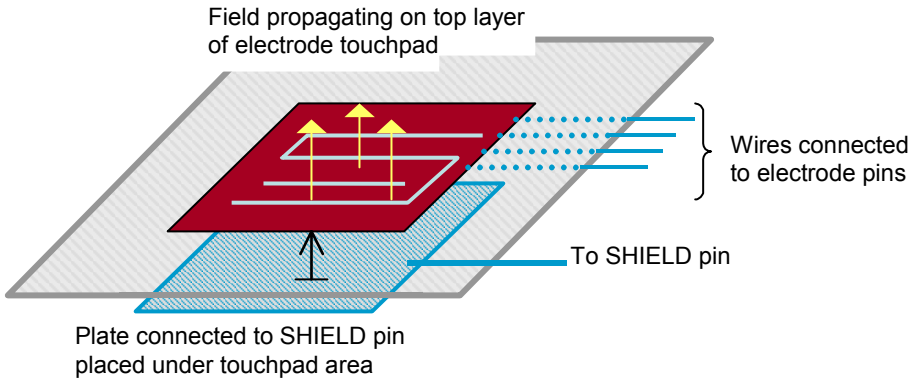

Figure 9. Shielded Conductive Plate Placed Under Touch Pads to Remove Bottom Fringing Path

When touch pads are close together, it is possible that a finger could be over more than one touch pad at a time. In this case, the analog levels from the IC can be used to determine which of the electrodes has more coverage. In a column-row configuration, for example, when a finger with its surface area distributed between buttons A and B (as in **Figure 10**), *E1* will attain a great amount of loading, while *E3* and *E4* will also detect some difference in measurements. Software can determine which of the electrodes (*E3* or *E4*) will have a higher amount of loading difference. The higher reading of *E3* or *E4*, when combined with *E1* would then be chosen to perform whatever particular task was intended.

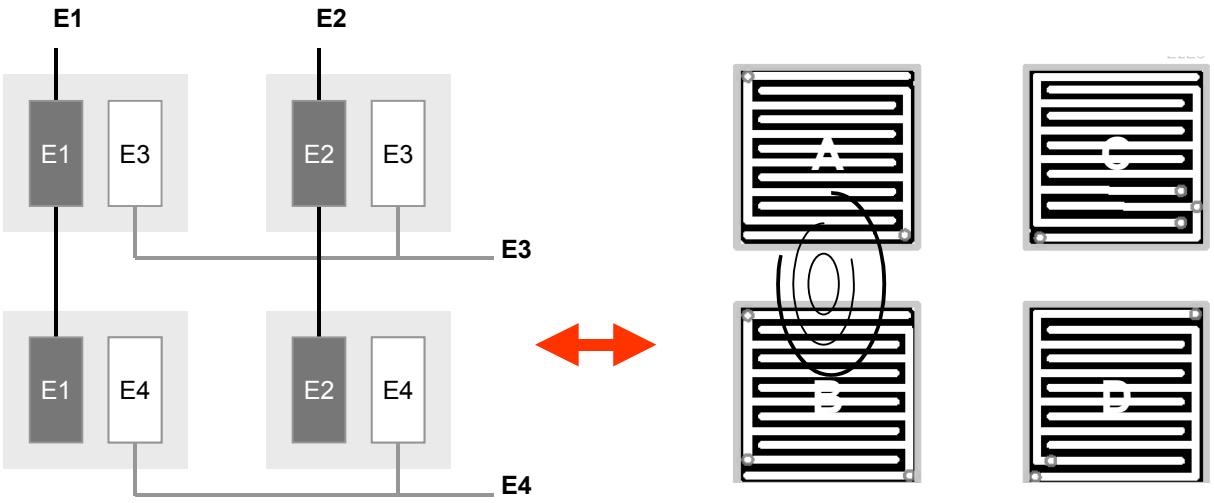

Figure 10. An Array of 2x2 Inter-Integrated Electrodes Following a Column-Row Configuration

3.2 Dielectric Material for Panel Coverings

In order to have a non-direct electrical connection, electrodes must be covered with an insulator. When selecting the proper material for the surface of the touch panel, one must take into

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consideration the thickness and the composition of the material. The thickness and the dielectric constant of the insulator both play a significant role in the sensitivity of the system.

To determine how the e-field is affected by the insulator's thickness and composition, we tested the touch panel setup with the different materials and thicknesses listed in **Table 2**.

Table 2. Dielectric Materials with Different Thicknesses and Dielectric Constants

Dielectric Material	Thickness (mil)	*k*
Acrylic	84.5	2.7-4.5
Glass	74.5	7.5
Nylon Plastic	68.0	3.0-5.0
Polycarbonate	61.0	2.9-3
PVC (Polyvinyl chloride)	59.5	3.18
Polystyrene	43.0	2.4-2.6
Soft Neoprene Rubber	38.0	5
Polypropylene	14.0	1.5
Polyester Film	10.0	3.2
Flexible Vinyl Film	9.0	2.8-4.5
Air	-	1
Water	-	80
Ice	-	3.2

Data for **Figure 12** through **Figure 16** was obtained using an inter-digitated touch pad configuration with the same dimensions as in **Figure 3**. Note that throughout the experiment, the existence of air (k = 1) was minimized between the cover and the electrode in order to obtain the best results.

3.2.1 Dielectric Constant

A material with high dielectric constant (k) will help propagate the field through to the front of the panel better than a low dielectric constant material, enabling the system to better detect an object at the surface.

As seen in **Figure 12**, the difference in e-field measurements was quite noticeable between polypropylene, polyester film, and flexible vinyl film. Also notice that despite the greater thickness of the flexible neoprene rubber, a very large difference in loading was noted. This is due to its high dielectric constant and, perhaps, its pliable nature. Neoprene (k = 5) allows the field to propagate through it with around 3 times the magnitude of polypropylene plastic (k = 1.5).

In general, the results show what we would expect. Increasing thickness reduces sensitivity. Increasing dielectric constant increases sensitivity. A good example is the comparison between glass and nylon. The glass is thicker than the nylon but shows a larger change because of its higher dielectric constant.

3.2.2 Insulation Thickness

An interesting exception to this generalization is soft neoprene rubber. Its dielectric constant is, at best only twice that of flexible vinyl film but its thickness is more than 4 times as much. The sensitivity is around twice as much. It would be expected to be half as sensitive. One possible explanation for this is the compliance of the rubber and its porosity. As the rubber is compressed, the small internal air pockets get squeezed such that more of the path is through the solid part of the rubber which has a much higher dielectric constant. If this theory is correct, the dielectric

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constant effectively increases as pressure is put on it. Further, the thickness is reduced as pressure is put on the rubber which would also increase the amount of change. The bottom line is that soft neoprene rubber would make a great covering for the electrodes.

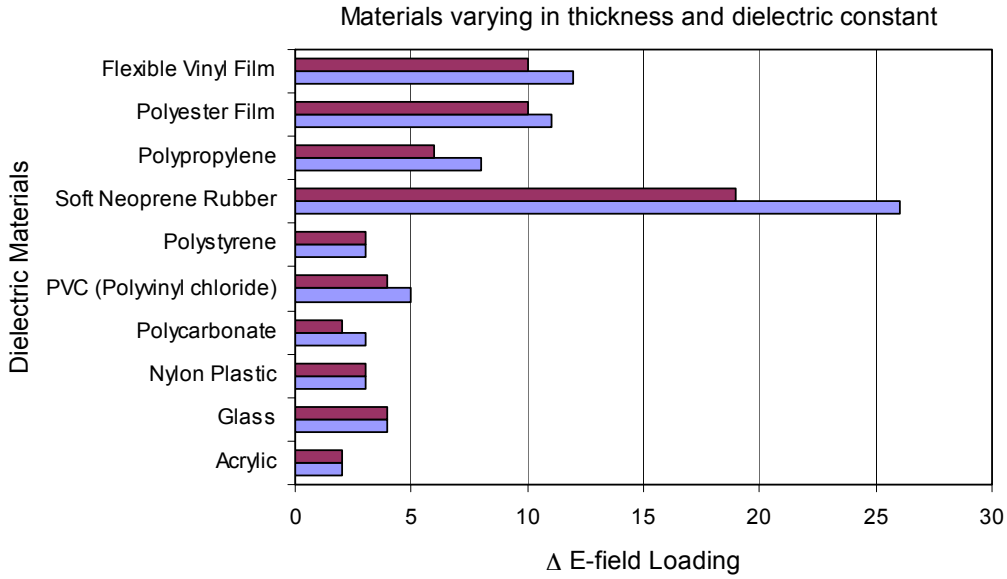

Figure 11. Difference in E-Field Loading with Varying Materials as Panel

In general, the thinner the insulation, the more sensitive the touch pads are to touch. In order to investigate this more thoroughly, the same test was applied for polyester film (k = 3.2) with thicknesses that varied from 1 mil to 10 mils. The tests were done using 2 inter-digitated electrodes. The results are shown in **Figure 12**. The strong relationship between thickness and sensitivity is quite visible in this curve.

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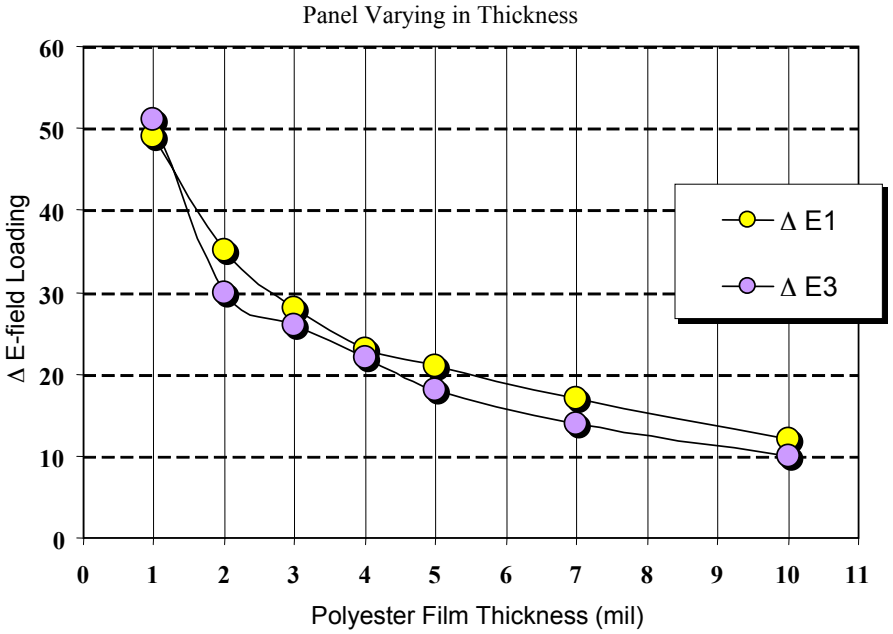

Figure 12. Data with Polyester Film (k = 3.2) Varying in Thickness

3.3 Environment Effects

The different dielectric materials from **Table 1** were tested under various conditions to determine the effect of moisture or oil on the surface and for the effect of gloves. This was done to measure how naturally occurring conditions might affect an application using this technology. Moisture is often encountered in outdoor applications, and oils can build up when people touch the panel.

3.3.1 Influence of Oil and Moisture

Figure 13 shows the results obtained with oil on the surface. The oil did not significantly affect the readings, due to the low dielectric constant of oil (vegetable oil, k = 3). Comparing the results with that of **Figure 11**, it can be seen that the oil film on top of the material actually improved the detection of the finger. This is due to the oil filling the air gaps in the finger print. Its higher dielectric constant increased the amount of current created by the field.

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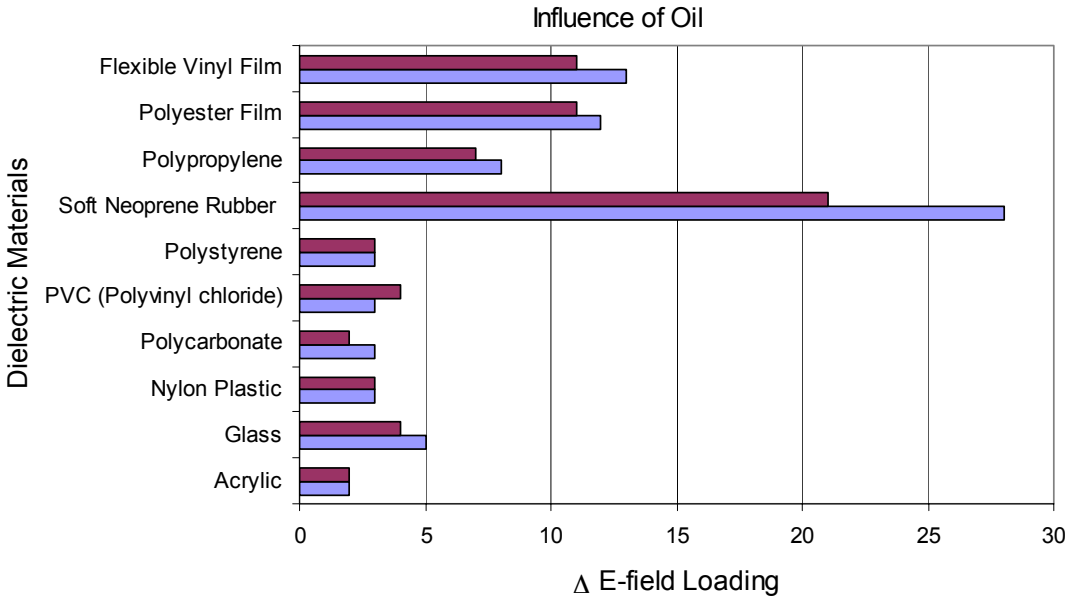

Figure 13. Difference in E-Field Loading Under Influence of Oil (k = 3)

Water was put on the surface of the panel and the data in **Figure 14** was obtained. The amount of change in the output was better than when using oil. It was noticed that there was more effect on the adjacent touch pads. This is probably due to the higher current path provided by the high dielectric constant water from the finger to the other electrodes. This could be a problem requiring some change in the physical design of the panel. Wider separation of the touch pads reduces the effect. The slope of the panel to make water run off it would help. A material which “sheds” water might also be beneficial.

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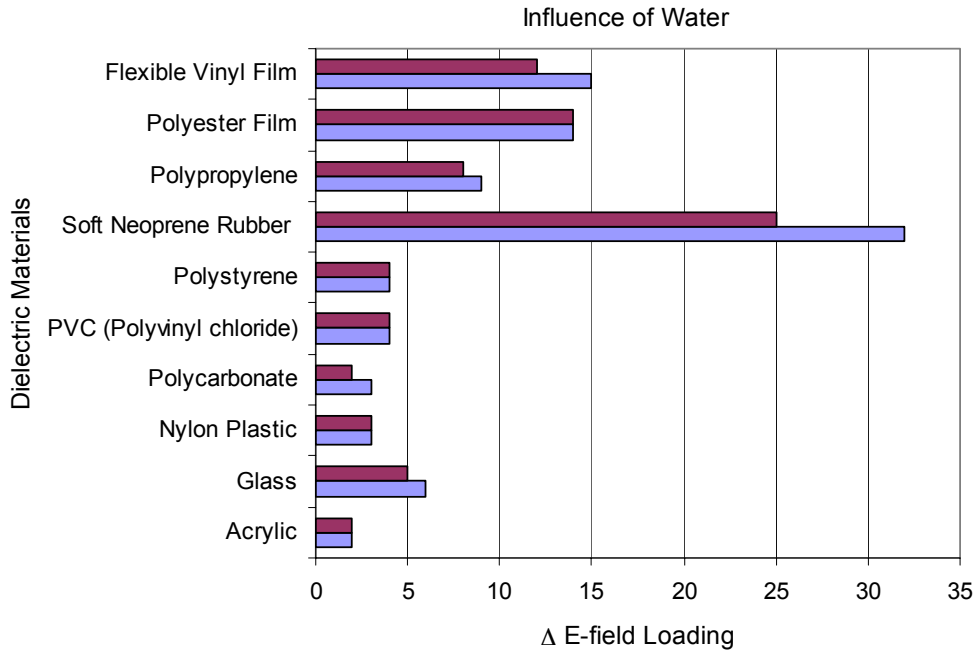

Figure 14. Difference in E-Field Loading Under the Influence of Water (k = 80)

3.3.2 Effect of Gloves

Another test applied to the system was that of using a gloved finger. The data shows that a gloved finger is difficult to detect. The gloves add distance between the surface of the panel and the finger. The glove used in the experiment was rather thick and was made of cotton materials with dielectric constant close to air (k = 1.3-1.4). The data is shown in **Figure 15**.

For this application an electrode that is responsive to a degree of pressure would be more suitable. Instead of depending on the finger's capacitance, a conductive membrane could be embedded behind a flexible panel and would alter the reading based on the applied pressure.

Another option is based on the large amount of change that was detected from the soft neoprene rubber. This gave rise to another experiment. A piece of neoprene was placed above the electrode in such a way that there was a gap of air between the electrode and the rubber. When pressure was placed on top of the rubber by a finger, the air between the rubber and the electrode was eliminated and a great amount of difference (almost a count of 40) was detected. This was because the field current is primarily limited by the low dielectric constant of air in the gap between the neoprene and the touch pads. When pressure was applied by the finger, the rubber closed this air-gap providing a lower impedance to the field current between the interwoven ground and sense electrodes.

[1]All the generated data was obtained using a "calibrated" artificial finger equivalent to a medium pressure applied by a finger based on actual tests and data. The rod finger is designed in an effort to keep the pressure controlled. The artificial finger is connected to ground and is made out of copper rod with a surface area of 0.26 in^2 and mass of 61900.76 mg.

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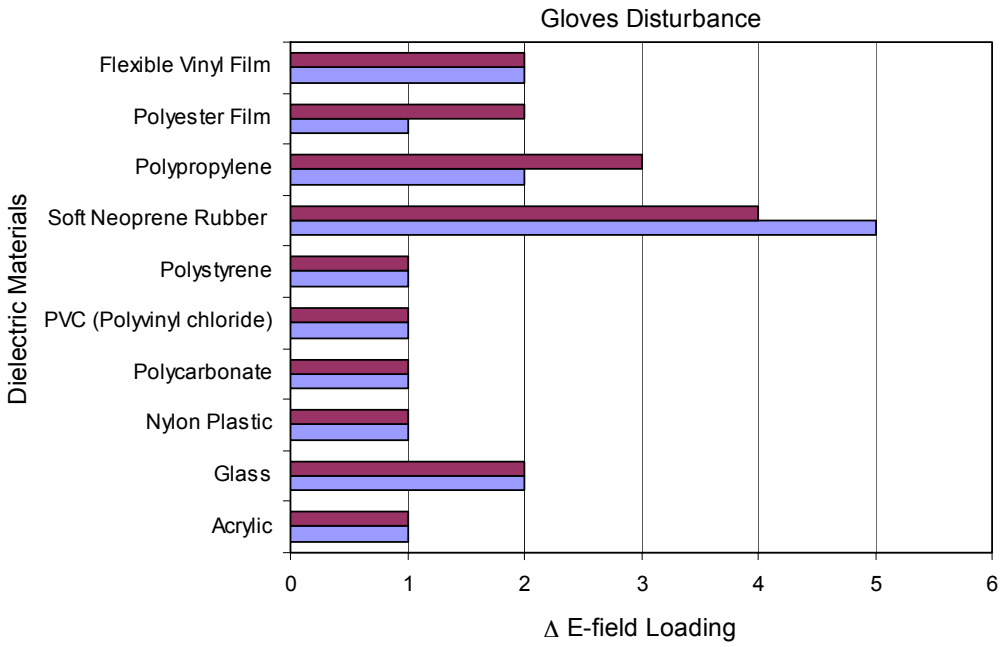

Figure 15. Difference in E-Field Loading Measured with the Presence of a Gloved Finger

3.3.3 Effects of Temperature

Another test that was conducted was observing how the MC34940/MC33794 system was affected by heat and frost.

The first occurrence observed was how the references reach a particular value for every given temperature, as shown in **Table 3**.

Frequency and other component values may change over time or be affected by environmental variables such as temperature and humidity. To compensate for this, the MC33794 relies on two reference inputs, Ref A and Ref B, that would be connected to temperature stable capacitors. When using the MC34940, simply connect the capacitors to regular electrode inputs. When selecting the electrode to read the capacitor, allow enough time for the capacitor to charge before taking a reading. One capacitor is chosen with a capacitance near the expected minimum capacitance, while the other is chosen with a capacitance near the maximum capacitance to be expected at the electrodes. These reference capacitances and their corresponding measured voltages provide a pair of value that can be used to correct errors in the electrode measurements caused by temperature, aging or other component related changes.

The curves in **Figure 16** display the occurrence of increasing reference A and B values with decreasing temperature.

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Table 3. Ref A and B versus Temperature Table

deg. Fahrenheit	-5	0	10	20	30	40	50	60	70	80	90	100	110
deg. Celcius	-20	-18	-12	-7	-1	4	10	16	21	27	32	38	43
Ref A	179	178	178	177	176	175	174	173	173	172	171	170	169
Ref B	75	74	72	69	66	64	61	58	55	52	50	47	45

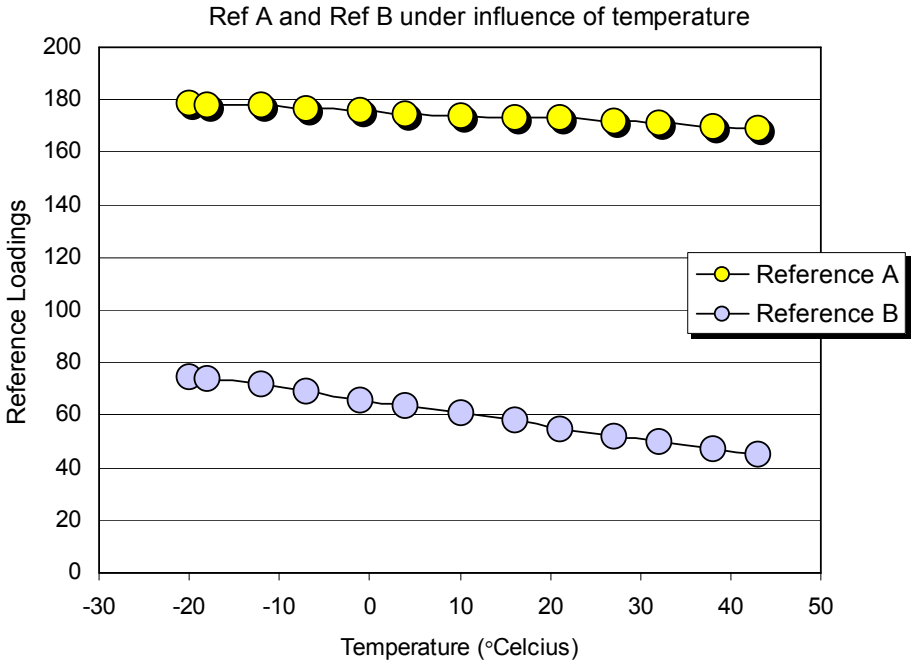

Figure 16. A-to-D Value of Ref A and Ref B Based on Varying Temperature

From the above lists of materials, neoprene, polypropylene, polyester and vinyl film were also tested to determine the effect on e-field measurements with variations in temperature (-20°C to 43°C).

Figure 17 highlights the difference in loading for a touch pad with inter-digitated electrodes for different insulation materials over varying temperature. Note that the curves in **Figure 16** and **Figure 17** have opposite temperature coefficients. This is how the correction can be done. Since the capacitors don't change their capacitance over temperature, the current through them would be expected to stay the same. Since the readings do change, it can be assumed that the measurements of the unknown field currents would change a proportionate amount. The correction method is to subtract the change in the reference capacitor from the readings taken. In other words, if the reference readings go up by 3 counts, subtract 3 counts from the electrode values to obtain a "corrected" value. The best correction would use a "normalization" technique using the 2 reference values to correct for both offset and gain drift.

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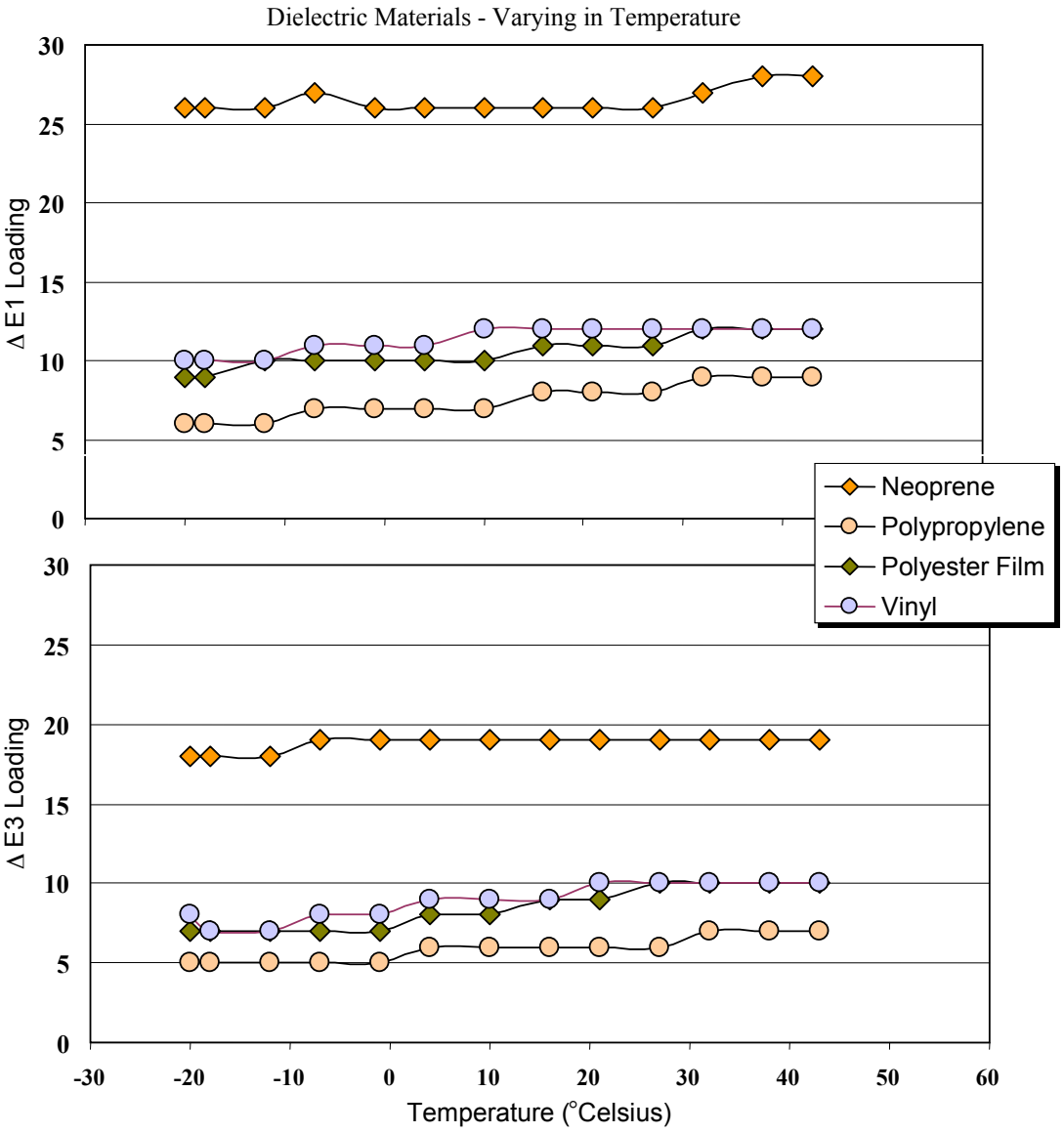

Figure 17. Difference in E-Field Loading with System Under the Influence of Varying Temperature

4.0 Summary

When developing a touch panel using the MC34940/MC33794 ICs the following key points should be kept in mind:

- The size of the electrode should correspond to the size of the object operating the panel, such as a finger or palm. The area of the electrodes should be made as large as possible within this constraint.
- The insulator over the touch pads should be as thin as possible with as high a dielectric constant as possible.
- Multiplexing can dramatically increase the number of touch pads supported by a single IC.

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- If you anticipate that the device will be affected by excessive moisture make sure the panel is mounted at an angle to aid in water run-off.
- The reference correction method should be used to offset the effects of temperature and component drift.
- The MC34940/MC33794 can support many other things than touch controls. These devices can be maximized by using any left over electrodes for liquid level sensing and proximity detection.

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Touch Panel System Using MC34940/MC33794 E-Field Sensors

Reference Manual

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PREFACE

This Reference Manual provides all the design guidelines and considerations when designing a touch panel application using E-field sensors, which include the MC34940 and the MC33794. The manual also includes the installation and setup instructions for the Touch Panel System using MC33794 E-Field Sensor, MC68HC908QB8 Embedded MCU and the MC33993 Multiple Switch Detection Interface. It describes how to easily program the embedded MCU and the basic hardware configurations to start the demo.

Even though this demo was designed with the Mc33794, all the principles used in this design also apply when using the MC34940. When replacing the MC33794 with the MC34940 in this reference design, be cautious of:

- Different pinout
- 7 electrodes instead of 11
- 3 MUX select lines (A,B,C) instead of 4 (A, B, C, D)

AUDIENCE

This document is intended for application developers who are setting up Freescale's RDMC33794/MC34940 Reference Design.

SUGGESTED READING

- Additional documentation may be found at www.freescale.com
- Design Reference manual.
- Application note, AN1985: Touch Panel Applications using The E-field IC

CONVENTIONS

This document uses the following conventions:

Term or Value	Definition	Examples
Terminal Names	Terminal names are the physical connections and are shown in text as all upper case.	... the external supply voltage VSUP1.
Terminal Values	Terminal values are the currents to/from a terminal and are shown as upper and subscripted text.	In Stop Mode the voltage regulator still supplies the MCU with V_{DD}
Decimal Values	No special symbol attached to the number	1.0 34
Numbers	Considered positive unless specifically noted as a negative value	5.0 -10
Blue Text	Linkable on-line	... refer to Table 1, page 2

Chapter 1 Touch Panel System using the MC33794/MC34940 E-field Sensor

1.1 Designer Reference Manual

This printed copy may be out of date. To verify you have the latest information available please refer to http://www.freescale.com for the most current revision.

1.2 Introduction and Setup

1.3 Introduction

The Touch Panel System (TPS) is a development platform for the MC33794/MC34940/MC34940 E-field sensor and MC68H908QB8 low cost 8-bit micro controller:

- MC33794/MC34940 can detect electric field variations in up to 9 electrodes and transform these variations into an analog signal. This signal can be interfaced directly with a 5V micro controller A/D module. Based on this E-Field sensor, this reference design detects human presence through glass or other dielectric materials.
- Uses Freescale's MC33993 for cost effectiveness.
- MC33993 is also called a multiple switch detection interface and can drive 22 outputs using its configurable internal current sources.
- Communicates directly with the MCU using a 4 wire SPI communication with no external components required.
- User interface consists of an audio transducer (piezoelectric horn), two seven segments displays and six general purpose LED's. The MC33993 device is used to drive both displays and the 6 LED's directly.
- Serial communication interface (SCI) is used for communication between the MCU and the PC and programs the micro controller using the serial bootloader software.
- Platform works with an external power supply or 9V battery.
- TPS is an enhanced version of KIT33794DWEVM. In addition to a battery operation option, user feedback is improved through 6 LED's, two seven segment displays and an audio transducer. The main MCU is upgraded to a MC68H908QB8 micro controller which has a 10 bit resolution ADC, SPI and ESCI modules on chip.
- TPS consists of two boards: the Analyzer Board (AB) and the Touch Panel Board (TPB). The Analyzer Board (AB) includes the E-field sensor, the micro controller, the MC33993, LED's, serial port, displays and all hardware required for the application. In essence, the Analyzer Board (AB) is responsible for processing data and control of the application.
- Second board is the Touch Panel board, which consists of the electrodes and a 15 terminal SMD connector to Analyzer Board.
- Analyzer Board was designed with flexibility in mind allowing several different boards to be connected to it. This allows different Touch Panel Board configurations to be substituted easily through the SMD connector.
- Demonstration software provides the electrode selection (multiplexing E-field inputs), output reading, calibration routines and user feedback control when a pressed condition is detected.

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Figure 1-1 below shows the TPS concept. The populated board is called the Analyzer Board (AB) while the electrodes board is called the Touch Panel Board (TPB).

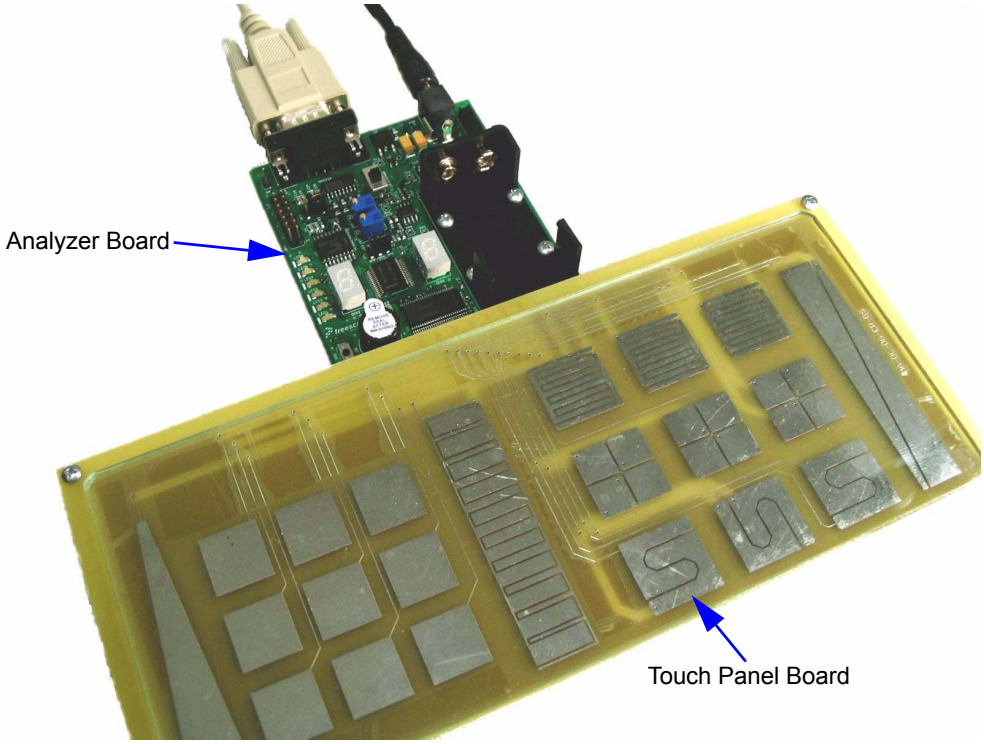

Figure 1-1. Touch Panel System concept

1.4 Analyzer Board (Key Features)

The Analyzer board is a general-purpose board composed by a MC68HC908QB8 low cost micro controller, a MC33794/MC34940 E-field sensor, a multiple switch detection interface (MC33993) and various other peripherals. The features of this development tool are:

- 10V power supply using integrated voltage doubler (charge pump)
- MC33993 Multiple switch detection interface
- MC68H908QB8 low-cost, low-terminal micro controller
- DPDT Monitor mode/User mode selection switch
- MON08 connector for debug and programming
- Op-amp with amplitude and offset adjustment
- One audio-transducer (piezoelectric horn)
- Serial port (ESCI hardware module)
- Two seven-segments displays
- Jack for External power supply
- MC33794/MC34940 E-field sensor
- SPST ON/OFF switch
- 15-terminal AB connector
- 5V Power supply
- 9v Battery holder
- Six LED’s

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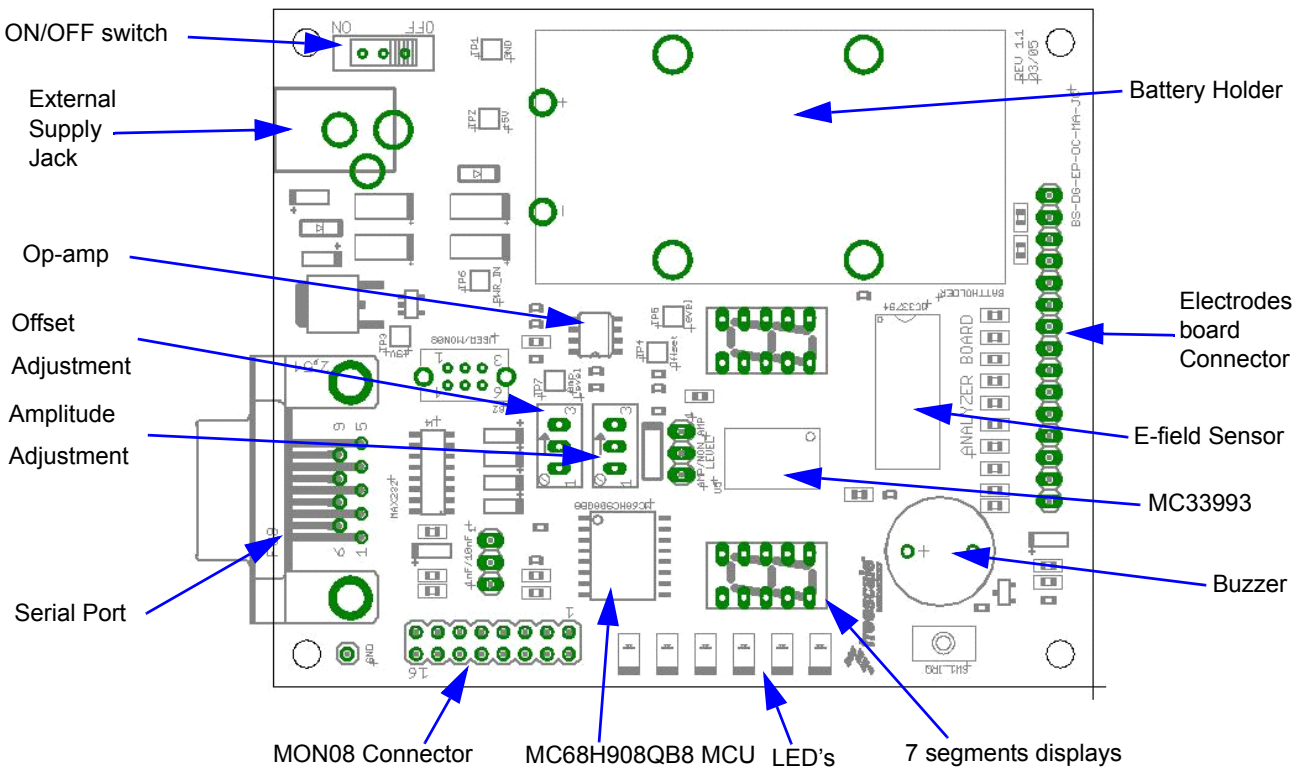

Figure 1-2. MC33794/MC34940 Analyzer Board features

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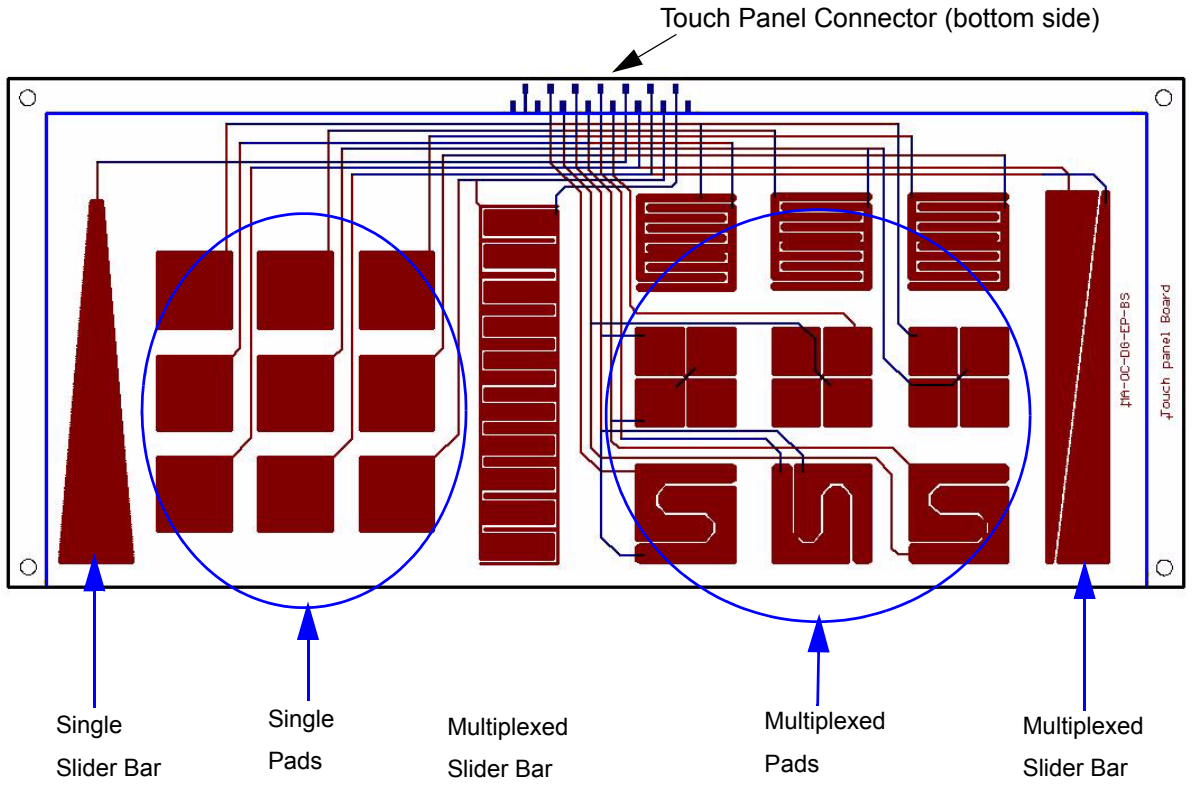

Figure 1-3. Touch Panel Board

1.5 E-field solution advantages

Advantages when using E-field sensor in touch panel applications compared to other solutions:

- Lower cost since a single chip might control a wide range of pads depending on multiplexing
- A wide range of objects and materials can be detected (people, metallic, non metallic, etc.)
- No switches or mechanical parts to wear out or corrode
- Physical wear and chemicals exposure protection
- Lower power consumption
- 3-D position determination
- Higher temperature range
- Reliable solution

1.5.1 Touch panel basics

The following points give an introduction to the basic principle of detecting human presence in a touch panel application.

Almost anything conductive can be part of an electric field sensor by being one of the capacitor plates. An electric dipole field created between an oscillating transmit electrode and virtual ground receiver electrode is intercepted by a hand.

The hand can be modeled as a capacitor to a “virtual ground”. In this case, the human finger is the grounded capacitor plate while Touch panel electrode forms the other capacitor plate.

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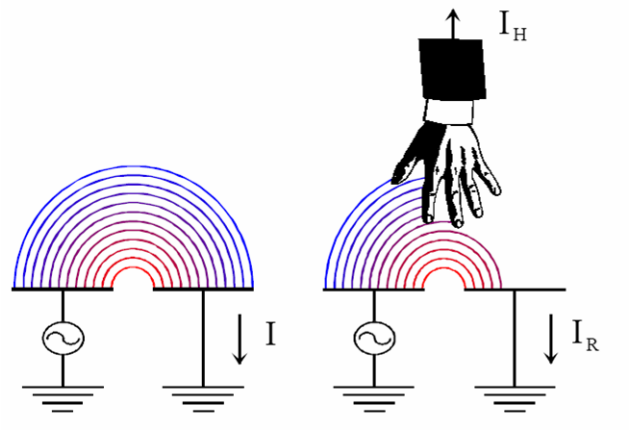

Figure 1-4. Touch Panel Basics

Recommended electrode size should be close to the size of a finger. The bigger the plate's area and the lower the distance between them, the higher the sensitivity. The size of the electrode should correspond to the size of the object operating the panel. The area of the electrodes should be made as large as possible within this constraint.

The number of possible touchpads can be increased by multiplexing electrodes. Potentiometers and slider bars can be simulated by changing the contact area within the electrode. For more information about multiplexing and continuous electrodes, See "Continuous Pads" on page 77.

1.6 Demonstrating Firmware

The demonstration firmware performs three tasks:

1. Reads electrode values.
2. Sends values to the SCI interface.
3. Display electrode changes in LED's and buzzer interfaces.

1.7 Setup Instruction User Guide

The following steps provide a basic procedure to run firmware within the Touch Panel System.

1. Unpack Touch Panel Board (TPB)
2. Unpack Analyzer Board (AB)
3. Connect the AB with the TPB using the 15-terminal connector "JP2" and the TPB connector.
4. Configure AB jumpers

The configuration jumpers in the analyzer board are JP1 and JP3.

JP1 selects if the input to Micro controller's AD channel is fed directly from the MC33794/MC34940 output terminal (LEVEL) or if the output signal is first amplified by the on-board op-amp with offset and amplitude adjustments.

JP3 selects between two values of LP_CAP, 10nF and 1nF, the recommended value in the datasheet is 10nF.

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The default jumper configuration is shown in Table 1-1 and Figure 1-5.

Table 1-1. default jumpers configuration

JP1	Position 1-2 (10nF)
JP3	Position 1-2 (Non-amp LEVEL)

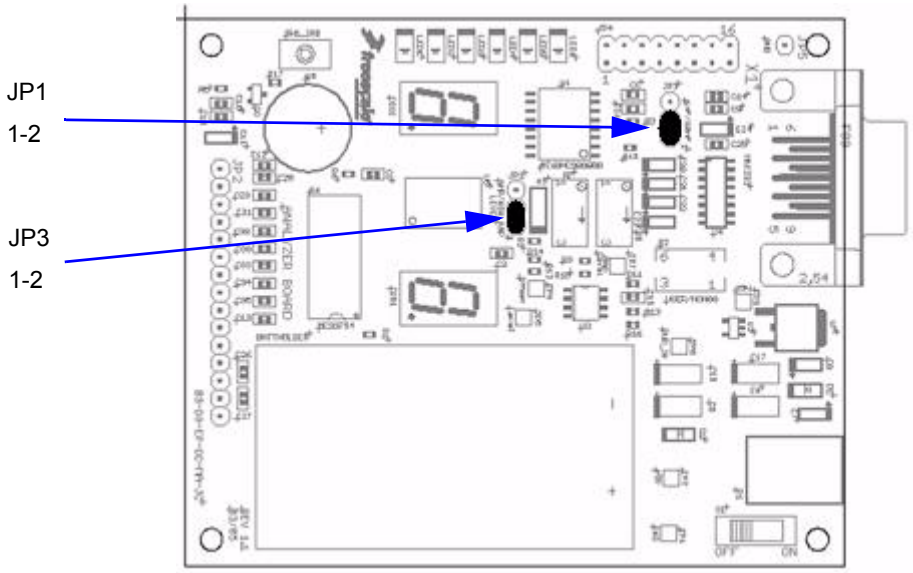

Figure 1-5. Default jumpers setup

5. Power On AB

- To power the AB make sure the battery or the external power supply does not exceed 15V
- Place a common 9 volt battery on the battery holder with the appropriate polarity,
- Or connect +9V center positive on the jack for external power supply.
- Move “S1” to the “ON” position.

NOTE: In order to avoid short circuit condition when connecting battery and external supply at the same time, the external power supply jack will disconnect the battery VCC terminal.

6. Configure User mode/MON08 Switch

When running the loaded program in the demo, the USER/MON08 switch “S2” should be on the USER position; USER mode is also used when programming the micro controller using the serial bootloader tool. MON08 position of “S2” is used to program or debug the MC68H908QB8 using a MON08 programming pod.

1.8 On Board Test Points

The Analyzer Board includes test points of the main signals. The purpose of these test points is for both testing the electrical performance of the board and to easily access the main signals involved in the application.

Table 1-2 shows a description of the signals that can be observed in the test points.

Table 1-2. Test points description

Test point number	Signal name	Description
TP1	GND	System Ground, electrical reference test point.
TP2	+5V	5V power supply output.

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TP3	+9V	External power supply or battery voltage. After ON/OFF switch and reverse battery protection stages.
TP4	Offset	DC signal entering Op-amp non-inverter inputs. Output of potentiometer R8.
TP5	Level	MC33794/MC34940's output. Check Figure 1-9.
TP6	PWR_IN	Charge pump output, 10 volts typically measured
TP7	Amp_Level	Amplifier stage output, MC33794/MC34940's output with adjustment in offset and amplitude. Check Figure 1-9 and Figure 1-1

1.9 Downloading software to Demo

To download the firmware using the bootloader tool:

1. Make sure all the required programs are available in the programmer PC. You must have the *. S19 file to be downloaded into the MCU, software used for serial communications (i.e. TeraTerm), and the required bootloader already programmed into the demo board MCU.
2. Open and configure serial communications software (i.e. TeraTerm), setting serial port baud rate at 9600 bps, 8 bit, no parity, 1 stop bit and flow control set to none. Make sure the transmit delay is set to 3ms/char and 3ms/line in order to ensure a proper communication.
3. Make sure demo board jumpers are configured as desired and that the USER/MONO8 switch is set to USER.
4. Turn on the demo board while holding the SW1_IRQ button pressed, a "(p)rogram (w)ipe e(x)it" message should appear into the terminal screen.
5. Press "w" to wipe any data already loaded into the MCU flash. Note: this operation does not erase the bootloader code.
6. Press "p" and a "waiting…" message will appear. Use the terminal's "Send File" option to send the.S19 file, a progress dialog will show up.
7. After code download the "(p)rogram (w)ipe e(x)it" message will appear again. Press "x" and the downloaded code will start running.
8. Each time the demo board is turned on without pressing the sw1_irq button at the same time the user code will be run directly.

To download the firmware using a MONO8 pod:

1. Make sure the USER/MONO8 switch is set to MONO8 position.
2. Hook the MONO8 adapter into the X1 connector. Make sure the connector terminal alignment is correct to avoid any MCU damage.
3. Using CodeWarrior download the code to the demo board. Since this operation will erase the bootloader, make sure the interrupt vectors are located on the standard interrupt vector area.
4. Unplug the MONO8 connector and set the switch to USER position.

1.10 Operational Description

1.10.1 Introduction

This section describes the electrical characteristics, user interfaces and connections for the Touch Panel System using E-field Sensors (TPS).

1.10.2 Analyzer Board Electrical characteristics

Table 1-3. AB Electrical Characteristics

Inputs/outputs	Min	Type	Max	Unit
Input voltage (battery and external power supply)	7.2	9	15	V
Board current consumption	-	43	-	mA
Charge pump output voltage (PWR_IN)	-	10	-	V

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Op-amp output	0.6	-	5.1	V

1.10.3 Jumpers and Switches description

Table 1-4. Analyzer Board jumpers and switches description

Jumper name	Functional description
JP1	• Position 1-2: Connects micro controller A/D input channel 3 to E-field output “LEVEL” directly. • Position 2-3: connects micro controller A/D input channel 3 to the Op-amp output. Op-amp adjusts gain and offset of “LEVEL” (E-field output). • Other: NOT valid
JP3	• Position 1-2: E-field LPF filter capacitor = 10nF. • Position 2-3: E-field LPF filter capacitor = 1nF. • Other: NOT valid
S1	• OFF: Power supply or battery is disconnected internally to all modules. • ON: Power up all AB modules
S2	• USER: Microprocessor in user mode, firmware running. Also used when programming using serial bootloader. • MON08: microprocessor is ready to be programmed using the MON08 connector.

1.10.4 MON08 Connector

MON08 Connector is a 16 terminal (8x2) male header, used for programming and debugging using the Multilink MON08 interface. The MON08 terminal header terminals are connected directly to some specific MCU terminals; those specific terminals are used by the micro controller to enter monitor mode and allow the flash programming and debugging modes. On the MC68HC908QB8 the MON08 connector follows the configuration shown in Table 1-5.

Table 1-5. MONO8 Interface to MC68HC908QB8

MON08 terminal number	MC68H908QB8 terminal number	MC68HC908QB8 terminal description
1	NC	-
2	16	VSS/GND
3	NC	-
4	NC	-
5	NC	-
6	9	IRQ/PTA2
7	NC	-
8	13	PTA0
9	NC	-
10	5	PTA4
11	NC	-
12	12	PTA1
13	4	PTA5/OSC1
14	NC	-
15	1	VDD
16	NC	-

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1.10.5 TPB Connector

The external connector JP2 is a 15x1 male terminal connector that extends electrodes terminals (E1-E9), Ref_A, Ref_B and Shield from the E-field sensor out the board. This connector is called TPB connector, since it is compatible with the 15 terminals female connector in the TPB.

Table 1-6. TPB connector terminal-out

terminal#	Description	terminal#	Description	terminal#	Description
1	GND	6	E3	11	E8
2	SHIELD	7	E4	12	E9
3	SHIELD	8	E5	13	REF_A
4	E1	9	E6	14	REF_B
5	E2	10	E7	15	GND

1.10.6 Power supply

There are two ways to power up the board; using a 9V battery or using a center positive 9V external power supply through the P1 jack.

When a 9V external power supply is used to power up the analyzer board, the battery holder is disconnected from the board to avoid a short circuit condition.

1.10.7 Charge Pump

The MC33794/MC34940 E-field sensor has a minimum requirement of 9.0V on Vpwr terminal. When using a 9V battery or an external power supply, fluctuations on the input voltage might make Vpwr voltage go out of specification.

An Integrated switched capacitor voltage converter, LM2767, is used to ensure VPWR terminal 1 has the required 9V. The LM2767 converts power from the regulated 5V power supply (MC7805) to a 10V power supply. If the 9V external supply or battery goes down, the E-field sensor will work correctly as soon as the minimum input voltage requirements of MC7805 are met.

NOTE: VPWR is the power supply of the analog portion of MC33794/MC34940

1.10.8 E-field Sensor (MC33794/MC34940)

Freescale Semiconductor's MC33794/MC34940 is intended for applications where non-contact sensing of objects is desired. When connected to external electrodes, an electric field is created.

The main features of MC33794/MC34940 include:

- Shield Driver for Driving Remote Electrodes Through Coaxial Cables
- High-Purity Sine Wave Generator Tunable with External Resistor
- Critical Internal Nodes Scaled and Selectable for Measurement
- Support for up to 9 Electrodes and 2 References
- +5.0 V Regulator to Power External Circuit
- Watchdog and Power-ON Reset Timer
- ISO-9141 Physical Layer Interface
- Lamp Driver Output

E1 through E9 are the E-field terminals designated for electrode placement. These terminals are responsible for detecting changes in the surrounding electric field. When a specific electrode channel is selected, all other unselected electrodes are grounded by an internal switch.

REF_A and REF_B are used as electrodes as well; Unlike E1 through E9, these terminals are not grounded when not selected. These terminals allow known capacitors to be measured. By using capacitors at the low and high end of the expected range, absolute values for the capacitance on the electrodes can be computed. In this specific application, no absolute capacitance measurement is required; so REF_A and REF_B are used as electrodes as well.

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Communication with the MCU is done via A, B, C, D and LEVEL terminals; A, B, C and D are 5V logic terminals that select the specific electrode while LEVEL terminal, analog output, outputs a DC value proportional to the electric field present in the electrode.

Other features of MC33794/MC34940, such as the ISO-9141 physical layer interface, the lamp driver, watchdog reset and Power-on time are not used in this application.

1.10.9 Op-amp

Depending on glass thickness, dielectric material or the specific application, the output voltage of the E-field sensor might require software algorithms or higher A/D resolution.

Based on the above, the Touch panel system using E-field Sensors (TPS) incorporates a low cost op-amp, TS972, in order to provide amplification and offset to the LEVEL signal before entering MCU A/D channel. An additional explanation of the op-amp configuration used can be found “Hardware Design Considerations” on page 71.

1.10.10 Multiple Switch Detection Interface MC33993 (MC33993)

LED’s are connected directly to SGx and SPx terminals (no external resistors are needed), configuring the wetting current, either on SG and SP terminals. A certain amount of current to the LED’s (16mA or 2mA) is injected and consequently they are turned On. To turn LED’s On/OFF the MC33993’s (MC33993) tri-state command is used.

1.11 Touch Panel Board

The Touch Panel Board (TPB) is a passive board that ties directly to some of the MC33794/MC34940 E-field sensor terminals. A 4mm glass covering the electrodes is used as the touch pad. The TPB includes different kinds of pads using E-field electrodes for experimentation. The design of these electrodes is described in, “Hardware Design Considerations” on page 71.

1.11.1 AB connector

Table 1-7 shows AB connector JP2 terminal-out. AB connector is a 15x1 female terminal header that connects TPB with AB.

Table 1-7. TPB to AB connector terminal-out

terminal#	Description	terminal#	Description	terminal#	Description
1	GND	6	E3	11	E8
2	SHIELD	7	E4	12	E9
3	SHIELD	8	E5	13	REF_A
4	E1	9	E6	14	REF_B
5	E2	10	E7	15	GND

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1.11.2 TPB Electrodes Distribution

Figure 1-6 shows the electrode layout within the Touch panel board (TPB).

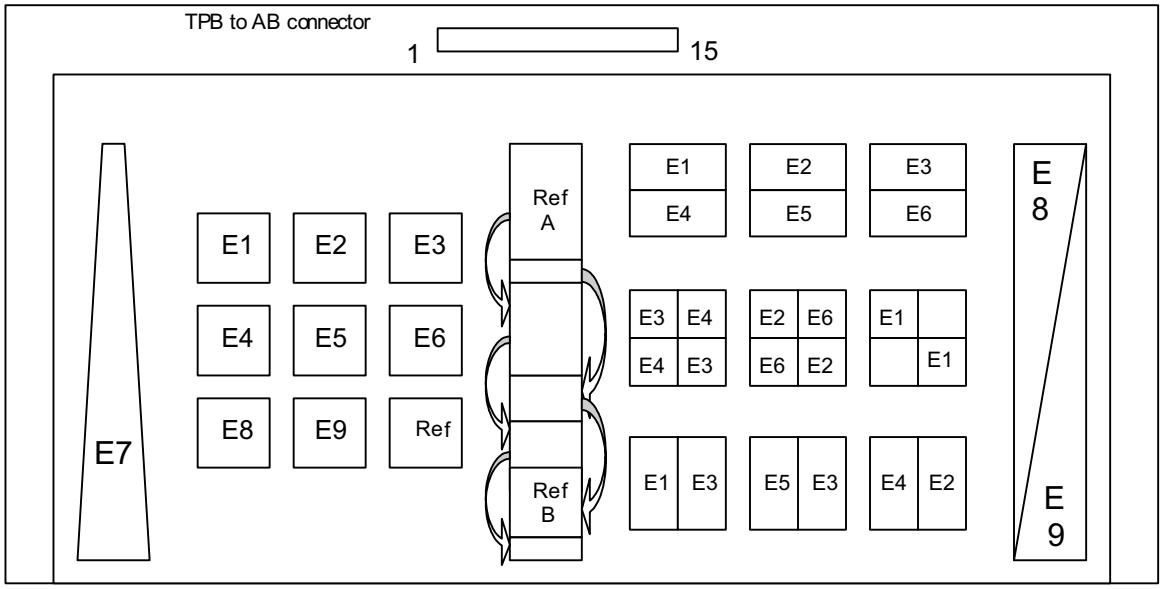

Figure 1-6. Touch Panel Board electrodes distribution

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1.11.3 Block Diagram

This section shows the block diagram of the Touch Panel System.

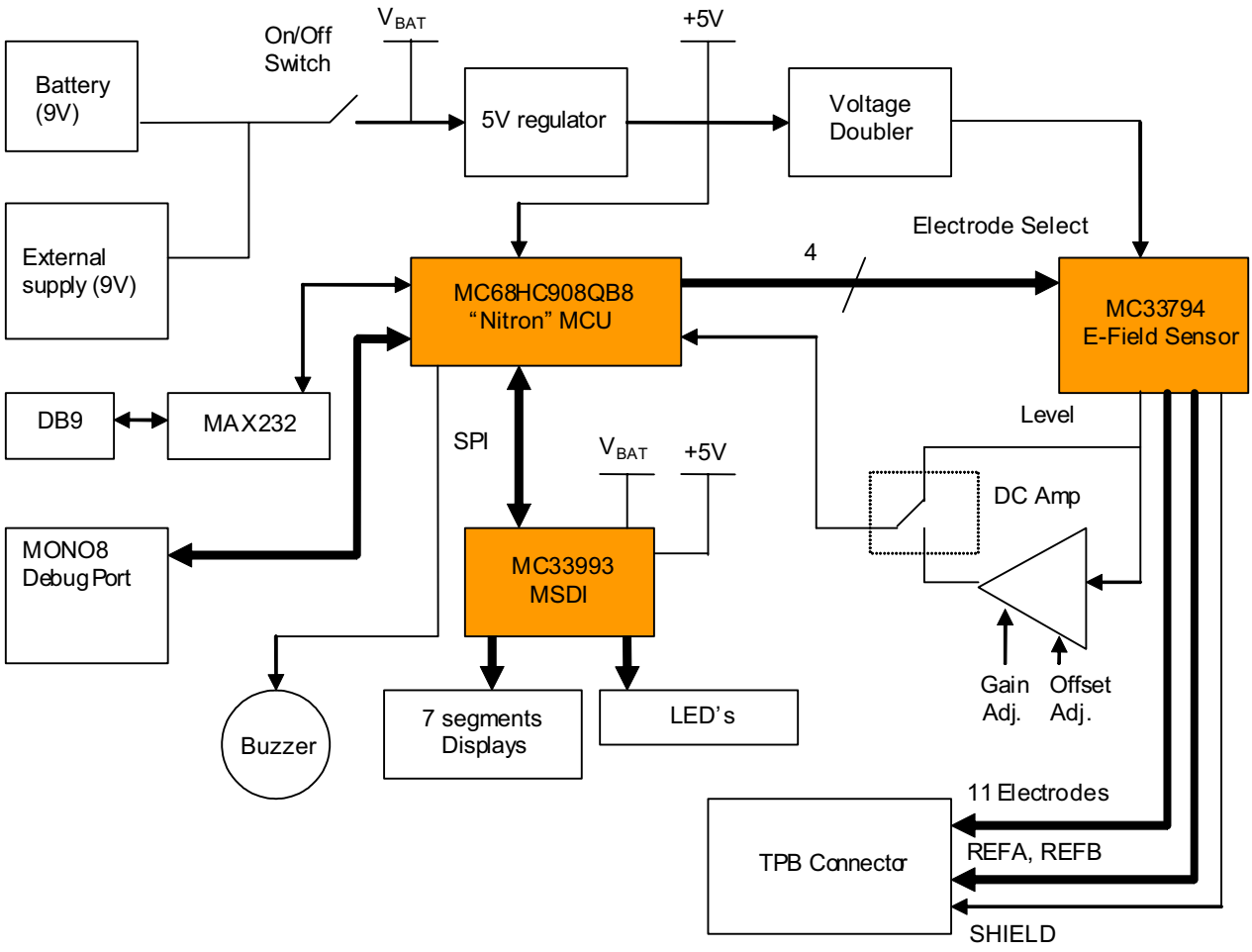

Figure 1-7. Touch Panel System block diagram

The main blocks are shown in Figure 1-7, orange blocks correspond to Freescale Semiconductor devices. A more detailed description is performed in "Hardware Design Considerations" on page 71.

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1.12 Schematics

1.12.1 Analyzer Board Schematics

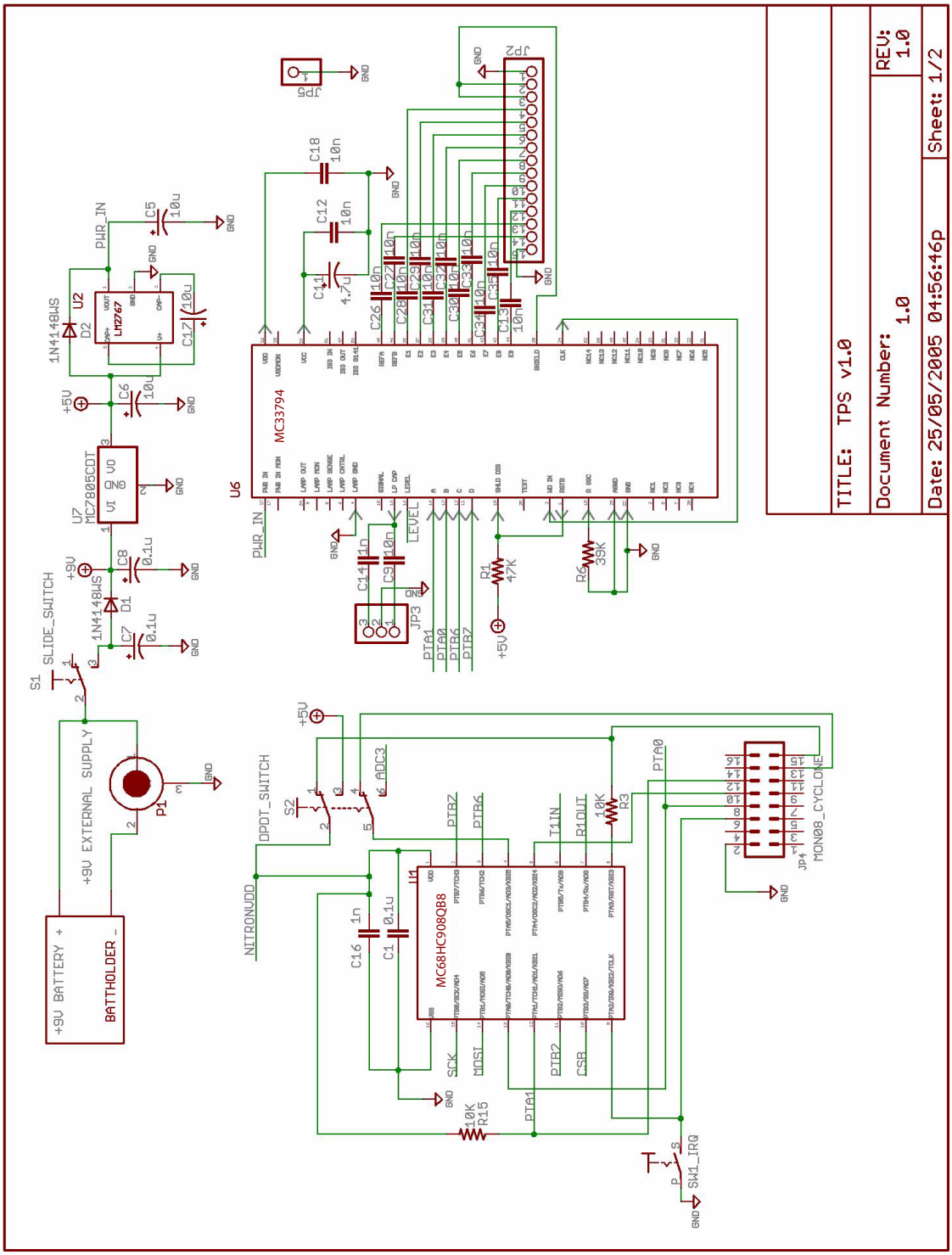

Figure 1-8. Schematics

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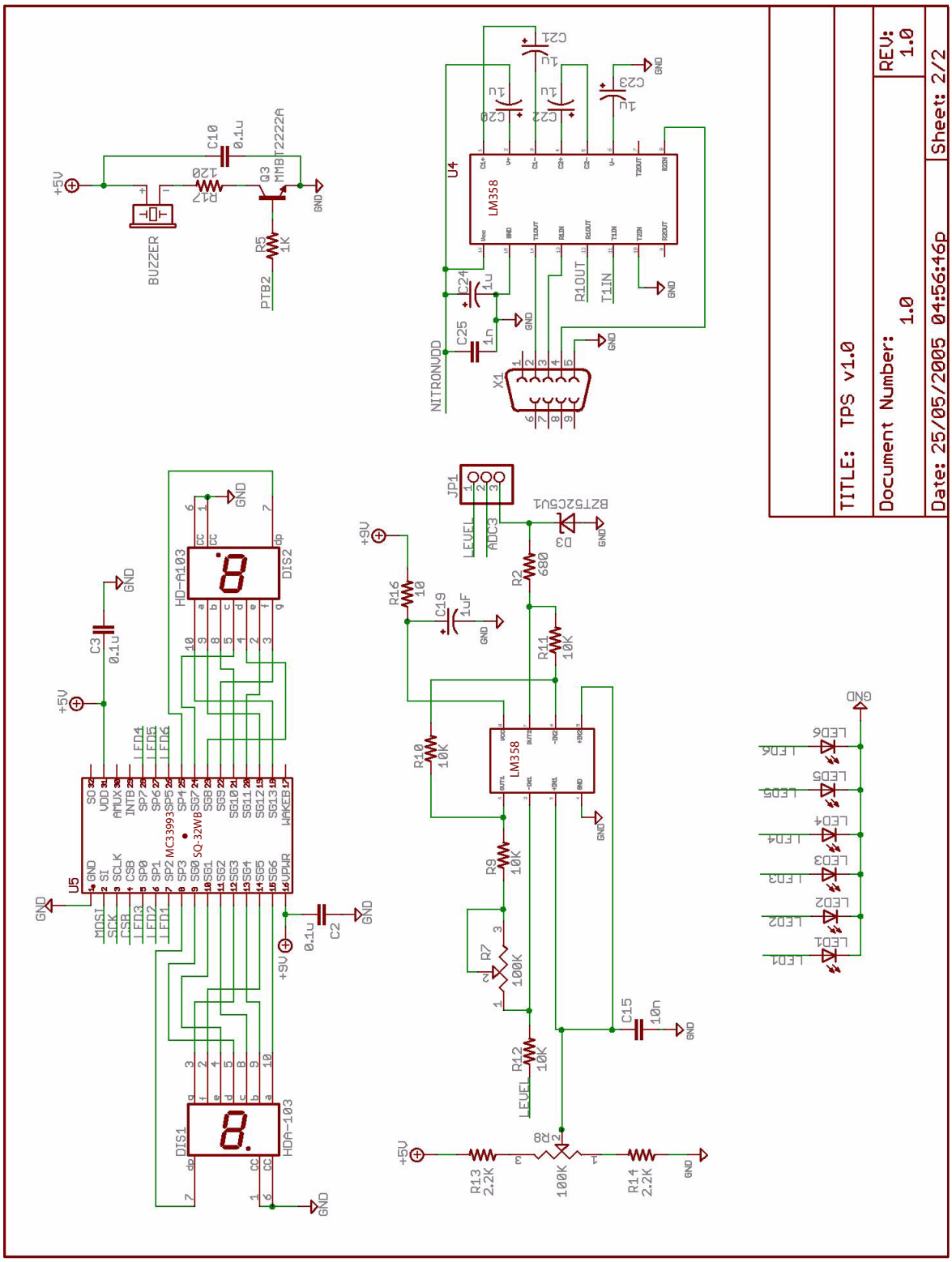

Figure 1-9. Schematics Continued

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1.13 Hardware Design Considerations

1.13.1 Analyzer Board

1.13.1.1 Introduction

The Analyzer Board uses the E-field sensor, the MC68HC908QB8 MCU, MC33993, audio transducer, serial port, etc. This section gives a quick explanation of each hardware block.

1.13.1.2 Op-Amp

The Analyzer Board includes an amplifier with offset and gain adjustment. The reason for this amplifier is to provide higher sensitivity to the signal read by the MCU ADC converter. The amplifier circuit enables the user to zoom in the voltage range of interest and consequently achieve higher electrode reading changes for easier detection.

Op-Amp provides offset adjustment and gain adjustment; offset adjustment is done by the potentiometer R8 while gain adjustment is by potentiometer R7.

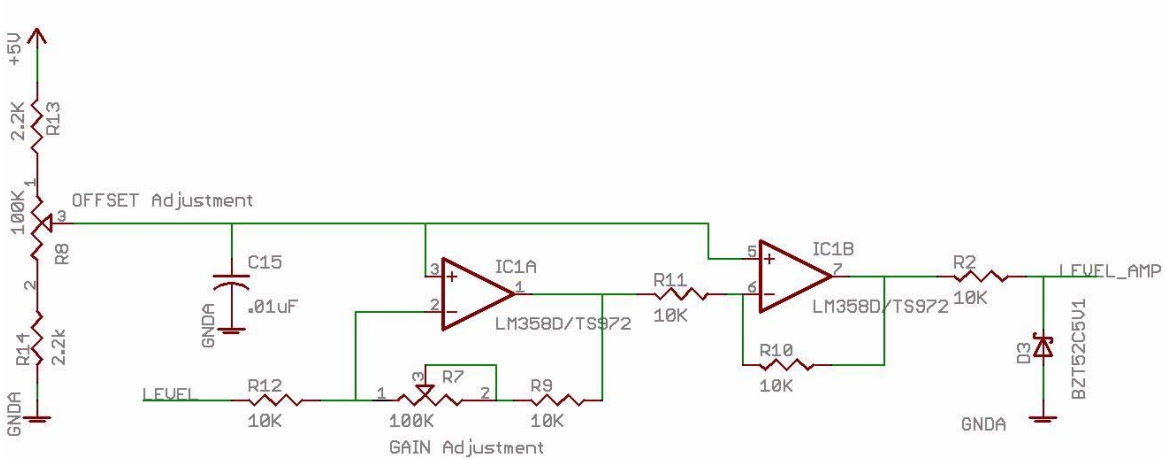

Figure 1-10. Op-Amp Circuitry

The amplifier follows the configuration of an inverter amplifier (IC1A). The gain adjustment (Av) goes from 1 to 11, while the offset adjustment goes from 0.1V to 4.89V. A unitary gain inverter (IC1B) is added after the first stage to reestablish signal polarity.

R2 and D3 are added at the op-amp output to protect MCU AD channel from voltages higher than 5.1V.

Sometimes the output signal cannot be amplified as high as the op-amp allows due to its intrinsic characteristics. The multiplexed signal varies over time and amplitude; these variations are dependent on the switching speed of the A, B, C and D signals and on the electrodes construction itself.

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Figure 1-11 shows an oscilloscope graph of the “Level” and “Amp Level” test points in the Analyzer Board after adjusting op-amp offset and amplitude. It can be observed that the signal is periodic due to the constant reading of the different electrodes; the voltage steps observed are proportional to the electric-field detected on each electrode.

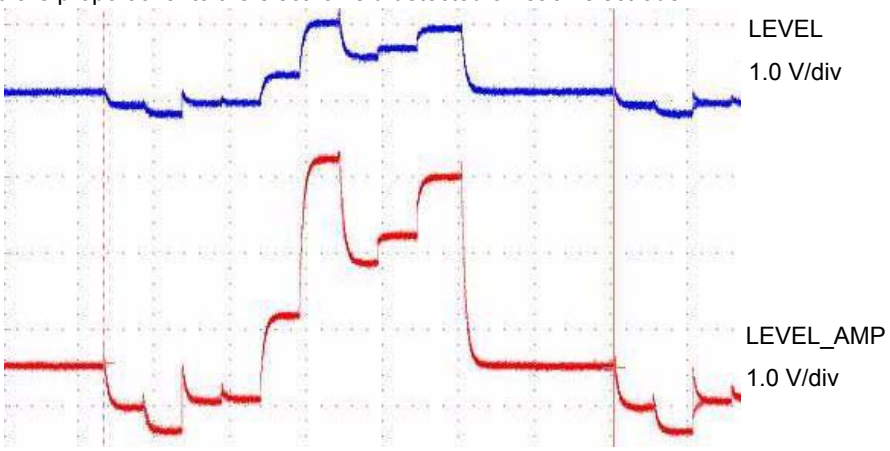

Figure 1-11. E-field sensor output LEVEL and its amplified version LEVEL_AMP

Op-amp power supply is a derivation of +9V after a Low-pass filtering used for DC coupling.

1.13.1.3 Power Supply

The board has two power supply sources, the +9V battery and external power supply. A charge pump after the +5V terminal generates the 10 volts input for the E-field sensor.

When the external jack is connected, the negative terminal of the battery holder is disconnected to prevent a short circuit.

+5V is used to power up the micro controller and RS232 transceiver when in USER mode. It is also the logic power supply VDD of MC33993, the piezo-electric buzzer and most of the 5V requiring circuitry.

The non-regulated +9V signal is used to power up op-amp and MC33993 power side.

For extra information about the charge pump, See “Charge Pump Circuitry” on page 74.

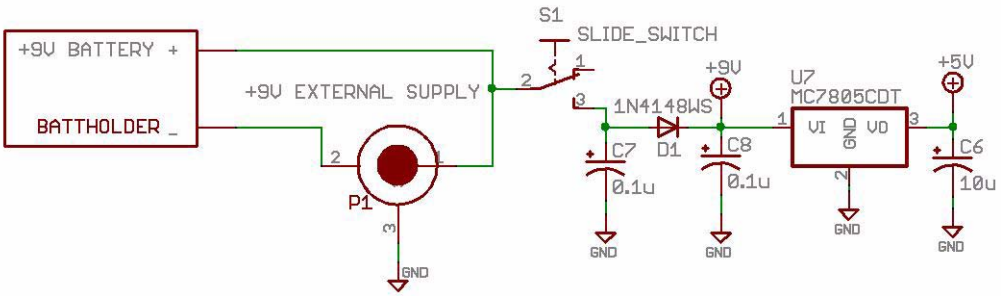

Figure 1-12. Power Supply Circuitry

1.13.1.4 Multiple Switch Detection Interface

The MC33993 Multiple Switch Detection Interface is designed to detect the closing and opening of up to 22 switch contacts. The switch status, either open or closed, is transferred to the microprocessor unit (MCU) through a serial peripheral interface (SPI); whenever a switch changes state, the micro controller is automatically alerted.

The multiple switch detection interface (MC33993) was specially designed for automotive applications, nevertheless its features allows it to be used on aircraft, industrial control, process control, security systems and on critical systems requiring switching status verification for safety or control purposes. In this application we use the internal configurable current sources (2mA or 16mA depending on the programmed wetting current) to drive LED’s. The MC33993 communicates with MCU using just 4 wires SPI (3 wires if no feedback from the MC33993 is required).

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Using the MC33993 to drive LED's have several advantages since just few MCU wires are used. Board space is reduced, no external polarization resistances are needed and current consumption and LED's brightening can be changed configuring the wetting current.

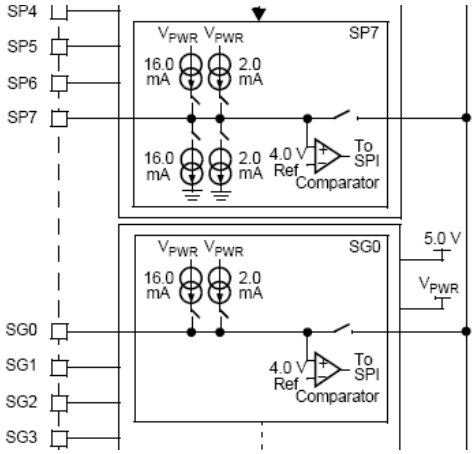

Figure 1-13. MC33993's SPx and SGx terminals internal diagram

Figure 1-14 shows the connection of the two 7 segments displays, and the general purpose LED's. Three SPI wires are used in the application (SI, SCK and CSB), SO is not used since we are just configuring MC33993 (sending commands through Slave input terminal) without feedback or status reading.

MC33993 is supplied by +5V for the logic side and unregulated +9V which is the internal voltage of the SGx and SPx terminals.

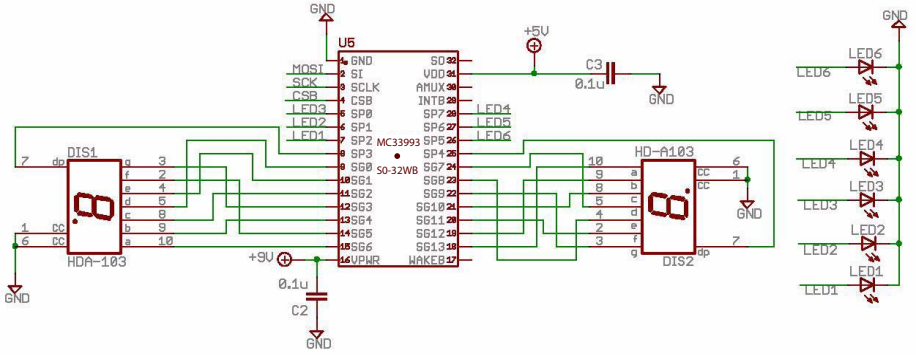

Figure 1-14. MC33993 driving LED's circuitry

1.13.1.5 E-field Sensor

The MC33794/MC34940 E-field sensor generates internally a 120Khz sine wave signal in an AC array to measure capacitance variations on each of the electrode channels. REFA and REFB terminals are used as electrodes terminals, as total 11 channels; REFA and REFB terminals can be individually selected to measure a known capacitance value. Unlike E1-E9, these two inputs are not grounded when not selected.

LP_CAP terminal requires an external capacitor which is used within a low pass filtering stage to condition the output signal. This terminal can be used to determine the detected level before amplification or offset is applied. A 10 nF capacitor (recommended value) connected to this terminal will smooth the rectified signal and more capacitance will increase the response time. By changing the position of JP3 two different capacitors can be selected; if JP3 is on position 1-2, LP_CAP will have a 10nF capacitor and by moving jumper JP3 to the 2-3 position the selected LP_CAP value is 1nF.

MC33794/MC34940's supply terminal (PWR_IN) is connected to the charge pump output, Charge pump assures a minimum 10V supply to the E-field sensor keeping the chip on its specified operational range regardless variations of the system power supply.

Other features like the lamp driver or the ISO-9141 transceiver available on MC33794/MC34940 are not used in this application.

E1 through E9, REFA, REFB, GND and Shield terminals are tied to the external connector JP2, which is a standard 15x1 terminal connector for attaching Touch panel board or any other customized electrodes board.

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Figure 1-15 shows the basic connections of the MC33794/MC34940 E-field sensor within the application.

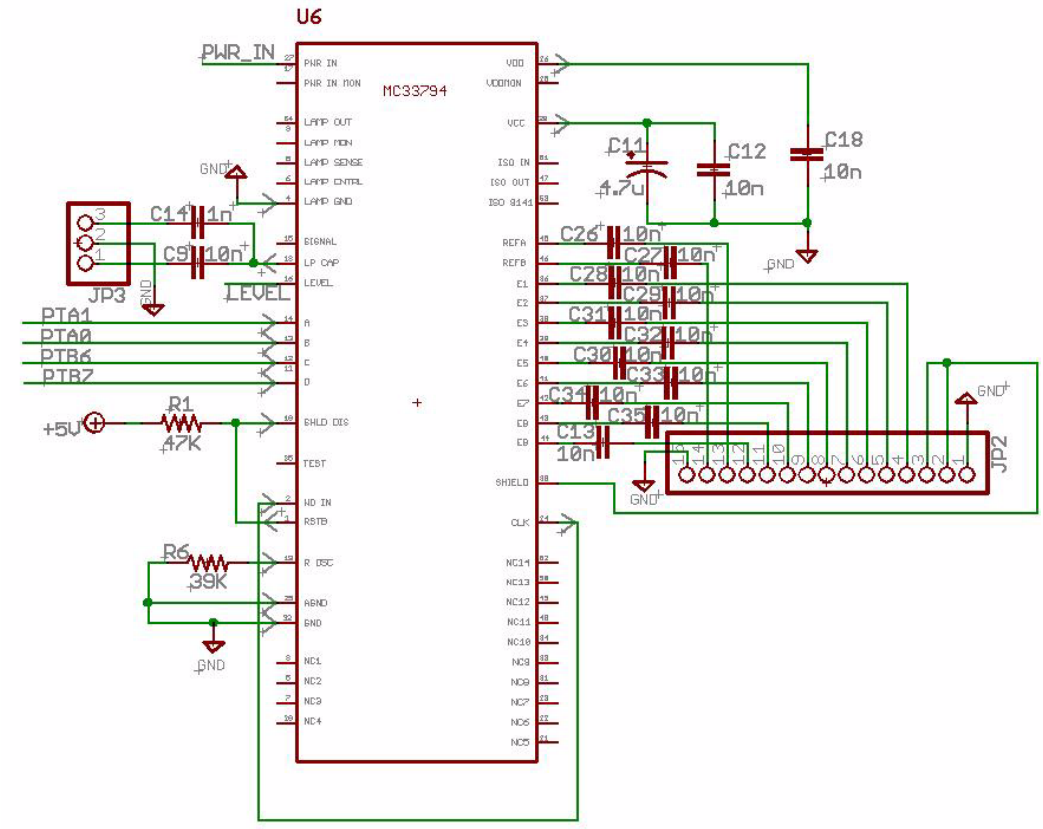

Figure 1-15. MC33794/MC34940 Circuitry

1.13.1.6 Charge Pump Circuitry

As mentioned in MC33794/MC34940 documentation, VPWR should be higher than 9V. In this case the Touch Panel System using E-field sensors is supplied either for an external power supply or a 9V battery. Fluctuations on this input voltage or simply low battery conditions may result in malfunction of MC33794/MC34940. The charge pump produces 10V to assure a proper supply to the device.

The charge pump is based on National Semiconductor's LM2767. This IC doubles the 5V regulated signal having 10V nominal voltage at Vout (Pwr_in signal to MC33794/MC34940).

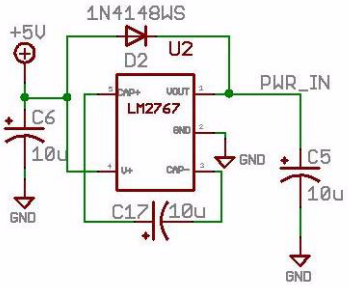

Figure 1-16. Charge pump circuitry

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1.13.1.7 Buzzer (piezoelectric horn) Circuitry

The buzzer is controlled directly by a GPIO terminal of the microprocessor (PTB2), an NPN transistor is used as buffer switching ON/OFF.

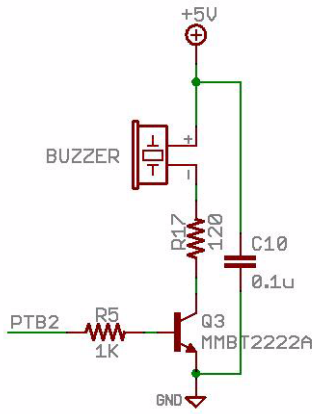

Figure 1-17. Buzzer circuitry

1.13.1.8 Serial Communication

In case it is necessary to share data with the PC or for programming flash using serial bootloader tool, serial communication interface (SCI) is included in the system.

Serial communication uses the ESCI module of the MC68H908QB8 micro controller, a RS232 transceiver and a DB9 connector.

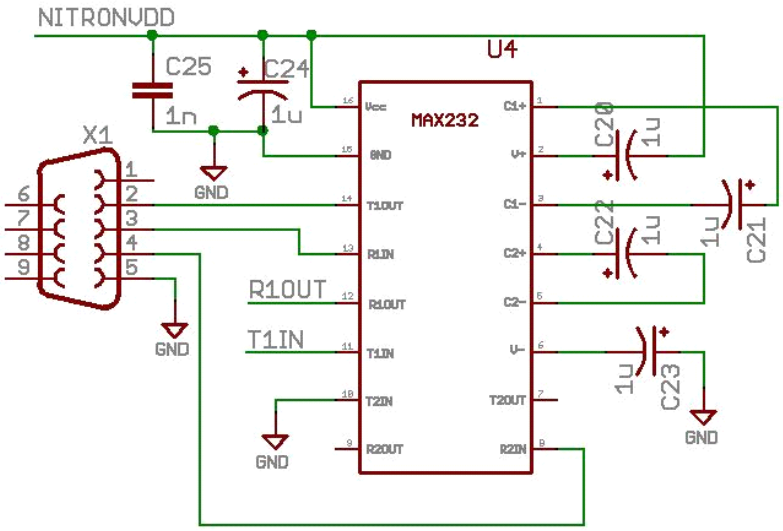

Figure 1-18. Serial communication circuitry

NOTE: Communication is allowed only in USER mode.

1.13.1.9 Micro Controller Programming and Debugging Circuitry

The system is based on a MC68HC908QB8, 8-bit, low cost micro controller. MCU selects each specific E-field channel, reads the output of the E-field sensor, and decides whether a touch or no-touch condition is present on each specific channel. It also sends commands to the MC33993 to drive the LED's, toggle ON/OFF buzzer, and perform serial communication.

The micro controller can be programmed using interface MON08 with the 16 terminals connector within Monitor mode or using serial bootloader tool in User mode. Selection between USER mode and MONITOR mode can be performed by switch "S2".

MC68HC908QB8 is used at 5V, no external crystal or oscillator is required running with internal oscillator.

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Figure 1-19 shows connection between MCU and the MON08 debug and programming interface.

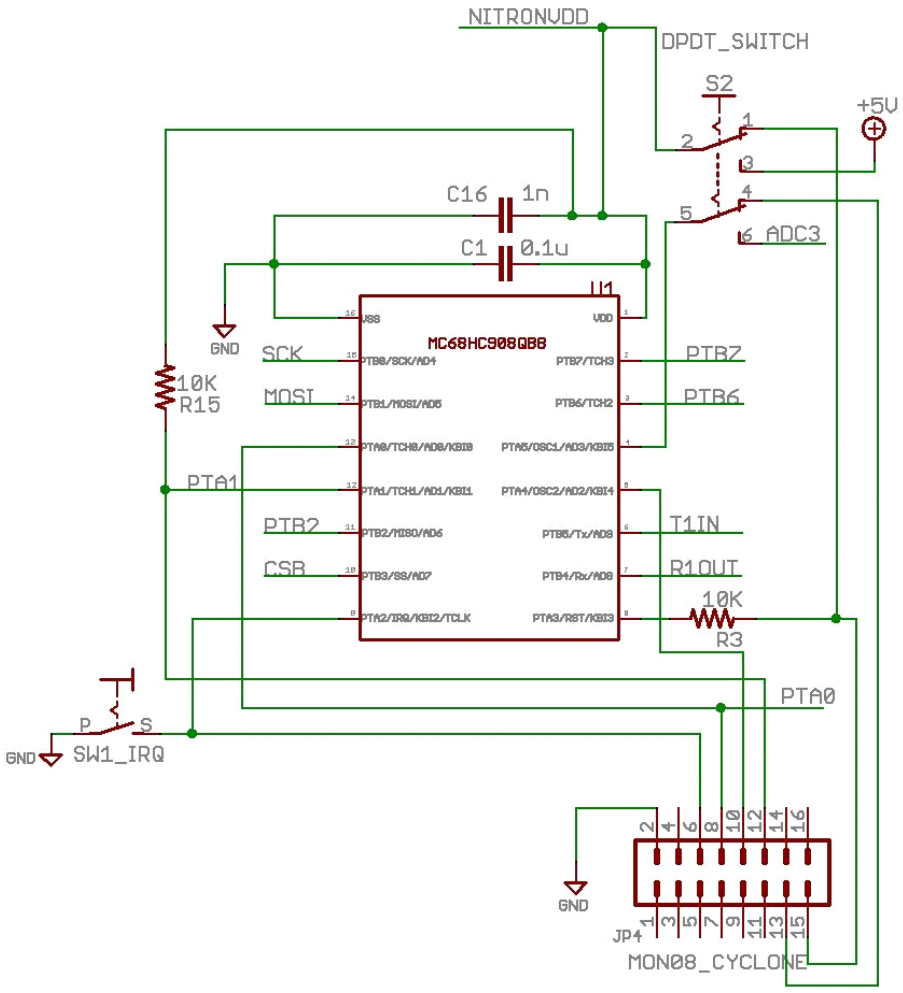

Figure 1-19. MCU debugging and programming circuitry

1.14 Touch Panel Board

1.14.1 Introduction

The Touch Panel Board has no components except for a 15x1 female terminal connector that attaches to the Analyzer Board. The TPB is just a simple double sized PCB with cooper traces. This section describes most of the considerations when designing electrodes for applications with MC33794/MC34940 and particularly the design of the touch pads.

1.14.1.1 Pads Design

The TPB uses tree types of pads: single, multiplexed and continuous pads. Each one of these types is described in this section.

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1.14.1.2 Single Pads

Single Pads are designed using one E-field electrode channel per pad. This design is very simple and limits the touch panel to 11 pads (E1, E2…, E9, REFA and REFB).

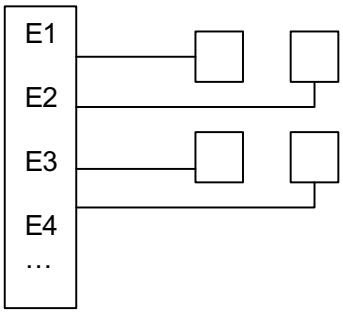

Figure 1-20. Single Electrodes concept

1.14.1.3 Multiplexed Pads

Multiplexed pads are formed by forming combinations of two or more electrodes per pad; this system is analogous to a matrix key pad where the number of touch pads can be increased using just a few electrodes terminals.

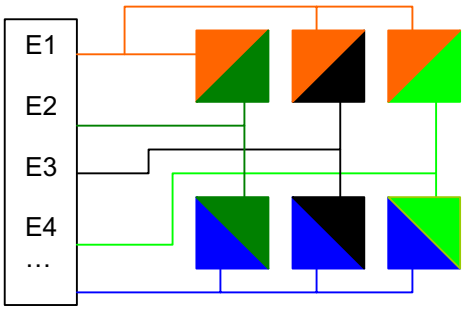

Figure 1-21. Multiplexed Electrodes Concept

For example, using two electrodes per pad, E1 and E2 form a touch pad, E1 and E3 form other pad, as well E1 and E4, and then the same with all other electrodes combinations, this way, a total of 57 pads using the 9 electrodes and 2 references can be archived.

Using “N” Electrodes per touch pad and “E” Electrode channels on the IC, the number of possible unique touch pads is given by:

$$\frac{E\ !}{N\ !\ (E\ -\ N\ )!} +\ N$$

The advantage of multiplexing electrodes is clear: the number of pads using a single E-field sensor can be highly increased. The major disadvantage is when multiplexing electrodes per pad, the area of the capacitor formed by each electrode is reduced and consequently reducing sensitivity.

1.14.1.4 Continuous Pads

Continuous electrodes can be designed either Single or multiplexed; the main characteristic of this kind of pad is that the value of the capacitance read is different depending on where specifically the electrodes are touched. The idea is to create a change in the DC value read as a finger is moved within the pad. Slider bars are used like slide potentiometers.

Figure 1-21 shows an example of continuous electrodes in both modalities: multiplexed and single.

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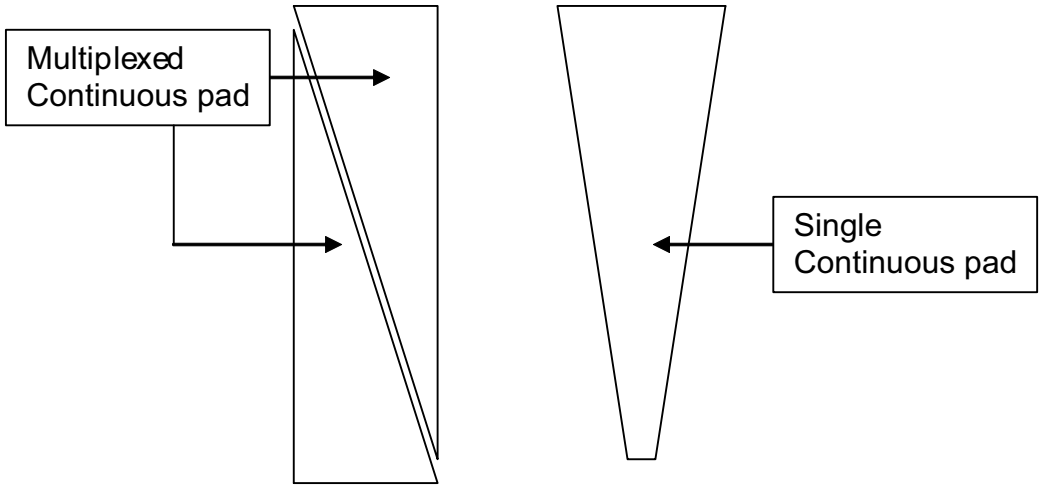

Figure 1-22. Continuous Pads concept

1.15 PCB Considerations

1.15.1 Electrode Size

When designing the electrodes for any application, one must take into account the physical size of the conductive electrode.

The larger the electrode, the more range and higher sensitivity will be obtained. However, as the electrode size is increased, so is its susceptibility to interference, electrical noise, and “stray” electric-field paths in its surroundings. One of the key practices regarding electrode design is for the electrode’s area to correspond to the surface area of the object being detected. Touchpad applications, for example, would only require a size that suits the surface area of a finger.

The size of the electrode should correspond to the size of the object operating the panel, such as a finger. The area of the electrodes should be made as large as possible within this constraint.

1.15.2 Routing

The electrodes of a touchpad can be formed directly on Printed Circuit Boards (PCB) using copper circuit traces. When routing pads to electrode terminals, each trace must be the same distance from the others and routed following a star configuration. Following this recommendation output of the different channels is almost the same and reduces capacitive loading.

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1.15.3 Grounding

The hand can be modeled as a capacitor to a “virtual ground”, being the first plate of the capacitor. The E-field electrode or touch pad is the second plate. The dielectric material is the glass or acrylic between the two plates.

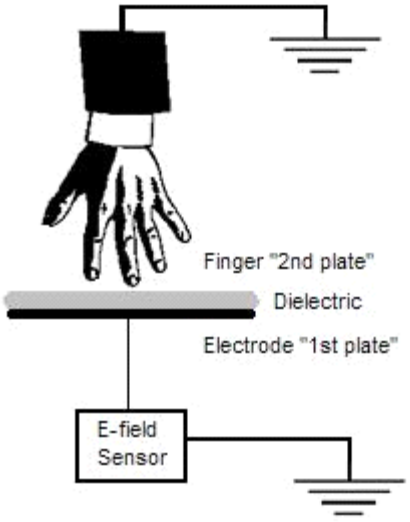

Figure 1-23. electrical grounding considerations

When a finger approaches the touch pad, it has to be referenced to the same E-field ground in order to find a return pad to the E-field sensor.

When running with external power supply most of the time this reference is intrinsic since external power supply is physically grounded, as well as human body in contact with a physical ground.

When running on external batteries this “reference” must be set externally since the battery is not physically grounded. It is recommended to reference the human body to the same Ground potential of the board. Analyzer board includes a GND terminal on the left upper corner as shown in Figure 1-24, GND terminal might be touched with left hand while the touch pads are used with the right one.

GND terminal

Note: Should be touched when running on batteries.

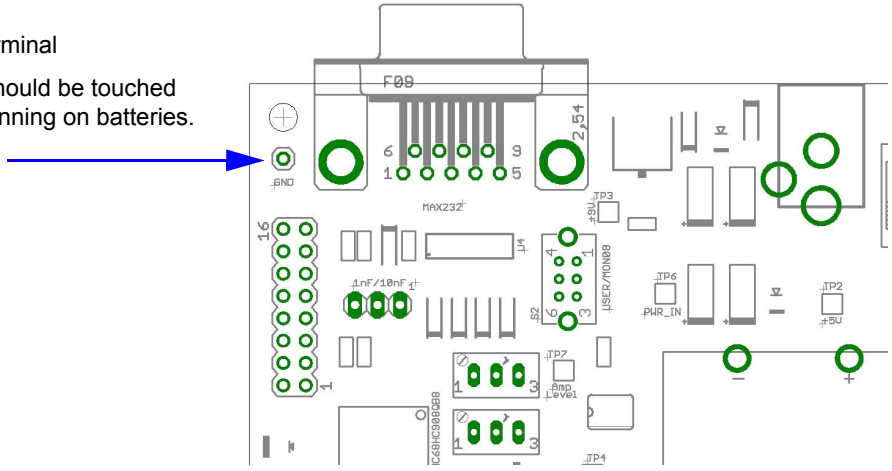

Figure 1-24. GND terminal within AB board; running on batteries effect

1.15.4 Shield

Shield terminal within the e-field sensor provides a buffered version of the returned AC signal from the electrode. Since it has nearly the same amplitude and phase as the electrode signal, there is little or no potential difference between the two signals thereby canceling out any electric field.

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In touch pads applications “Shield” is used to drive a ground plane that is used behind the touch sensors electrodes at the backside layer of PCB, to cancel out any virtual grounds that could attenuate the AC signal.

Typical application is to connect the Shield Drive to the shield of a coaxial cable used to connect an electrode to the corresponding electrode terminal. With correct shielding, coaxial cables or PCB layers can be used to connect remote electrodes up to a few meters away, while obtaining measurements as accurately as if the electrodes were directly connected to the IC.

1.16 Mechanical Considerations

1.16.1 Glass

Touch panel system using E-field sensors (TPS) was tested with common glass as the dielectric; using the system without amplifier an accurate detection through a 4mm glass was obtained. Using the amplifier with approximately a gain of two and a proper offset adjustment the detection was through approximately 10mm.

Glass is mounted over the PCB with the copper pads, the dimensions of the glass are shown in Figure 1-25.

For testing purposes, the glass was patched with the PCB using a thin double sided tape. In the final application, the mechanical designers should determinate the best way to mount the dielectric with the electrode pads.

The gap between glass and dielectric material and the PCB should be as constant as possible, even after a touch condition. Many times, when the panel is touched, variations in other electrodes or noise in the measurement can be presented if the gap is not constant. Minor changes in the gap between the plates of the capacitor will represent a considerable change in the E-field measurements; therefore mechanical design should be very strict regarding this constant.

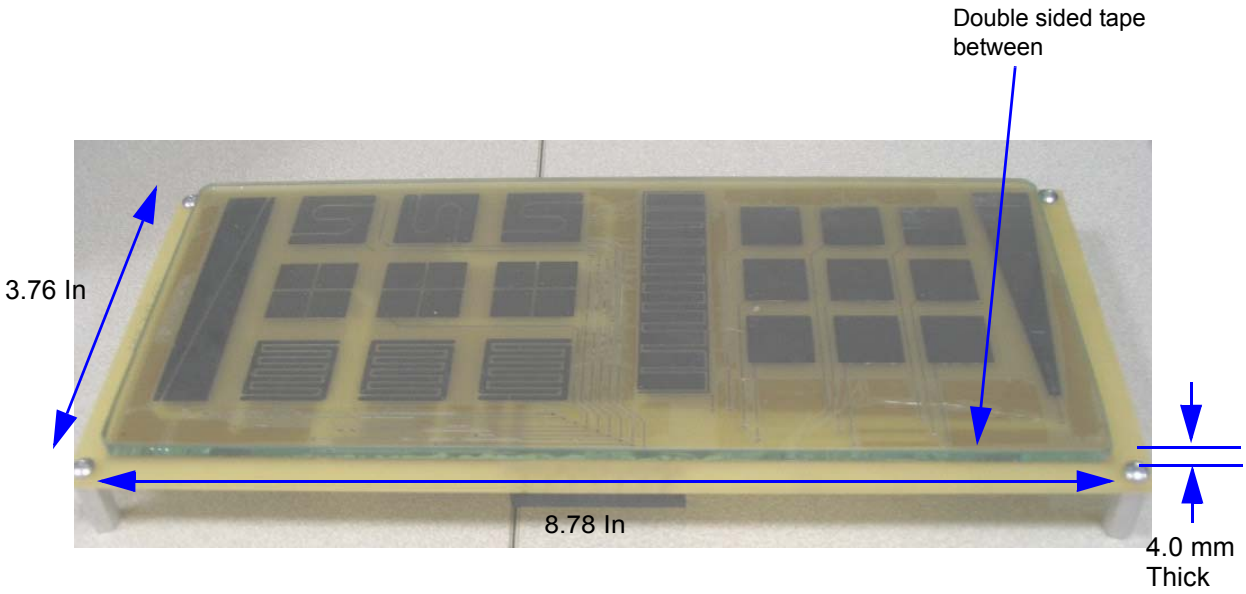

Figure 1-25. Touch panel board mechanical considerations

1.16.2 *TPB connector*

The TPB connector is an SMD 15 terminal connector mounted on the back side of the touch panel board (TPB). The TPB connector fits and is compatible with the 15 terminal connector JP2 in the analyzer board.

Special care must be taken when the two boards are attached to each other, bending or moving the Touch panel board from Analyzer board might detach the connector from the PCB.

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1.16.3 Other Considerations

Many of the problems presented when noise is present in the reading of the electrodes are related with mechanical design. Some important mechanical considerations are listed below.

The electrodes board should have a flat surface for the dielectric material mount. If vias are used on this board, shouldn't be manufactured manually to avoid solder joints to hinder the mounting of the dielectric material. For the same reason, if components are required on the back of electrodes board, all those should be Surface Mount Technology (SMT).

Touch pad electrode to glass gap must be constant, even after touch condition since small gap changes represent a considerable change in the output of the E-field sensor.

If using fumed or painted glass, the dielectric constant of the glass is affected, testing must be performed for any new variable or material applied to the touch panel.

1.17 Software Design Considerations

Demo board firmware demonstrates the functionality of the MC33794/MC34940DW device. Using the device as the main sensor for a 16 key keypad application, shows the possibilities of a larger system by multiplexing the electrodes. Two types of electrode configuration where used, a single electrode key configuration and two electrodes per key configuration.

- Electrode value reading is done by the MCU device, by selecting the appropriate channel lines and then reading the value on the MCU A/D module. Differences on the read value represent changes on the electrode field meaning the electrode might be near the presence of a human finger.
- Mixing different types of key configurations, multiplexed and not multiplexed results in a more complex software algorithm, for this project the routines where designed to get the best of both types of electrodes, but it is important to note that due to the mixed configuration the first thing to check is the key pressed configuration. And then use a different routine to find out the represented key according to the multiplexed or not multiplexed algorithm.
- The Demo board is designed to be used as a stand alone application by giving user feedback through on board displays and buzzer, the board can also be connected to another device via the SCI port.
- On Board displays are managed using an MC33993 device, which communicates to the MCU via an SPI bus while SCI communications are handled by the internal modules of the MCU.
- Demo firmware is grouped in 2 files communications.c and main.c.
- Communications.c is used for the SCI and SPI communication routines, as well as some timing delay routines.
- Main.c is where the main routines are located, along with the functions more related to the core functionality of the E-Field keypad application.
- ReadElectrode function is used to read the electrode values. This function will configure the electrode select lines PTA0, PTA1, PTB6 and PTB7 according to the desired electrode, and will wait to give some time to the electrode signal to stabilize, if needed this dead time can be used to send SCI data.
- 32 samples of the electrode channel level are acquired to make an average of this value; the resulting value is stored in the appropriate INT16evalues location.
- Sending data to the SCI interface is accomplished while waiting for the electrode value to stabilize in the function readElectrode. This implementation takes advantage of the periodicity in which the electrodes are readied in this application and at the same time improves the application using the dead time to accomplish this task. The standard SCI configuration is 8 bits, 9600 no parity, 1 stop bit.
- The displayData function is used to display electrode changes in the on-board displays. In order to display the correct electrode changes, this function requires some tasks to be accomplished before calling this function.
- Steps to make a valid use of displayData function:
- The call readValues() function read the electrode value of each channel using readElectrode function; after readValues is completed, actual electrode values of all channels will be present on the INT16evalues array.
- Call verifyElectrodes() searches for 3 electrode channels with greater value change using a delta value from the actual value and the calibration value of each channel. The electrodes will be registered on the MaxIndex1, MaxIndex2 and MaxIndex3 variables, the delta value will be stored according on the Max0,Max1 and Max2 variables.
- The calibration value is a register of the value of the electrodes with out any change applied. This calibration routine is called in the initialization routine.
- After MaxIndex variables are updated displayData function see if the keys are a valid combination and if the change is enough to consider the electrode touched. The functions verifyKeys() try to find a single electrode touched and if a possible multiplexed electrode is detected it will return the value 30 so verifyMuxKeys() must be called to find the multiplexed "button" value.

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- dispalyData() will then call the display function which will be responsible for sending the correct MC33993 commands to the MC33993D device to display in the on board display the change registered on the electrodes.
- The VerifyKeys and VerifyMuxKeys parameters can be adjusted in the settings.h file.
- Note: The firmware is designed to be downloaded into the board via serial port or using a MONO8 programmer. Using the serial boot loader requires a different interrupt vector location, for this propose the define of SERIAL_DOWNLOADER modifies the standard interrupt vectors location to a new location where the code is compatible with the serial boot loader. This change is not compatible if a MONO8 programmer is used so SERIAL_DOWNLOADER must not be defined if no boot loader is used.

1.17.1 Firmware Functional Description

Module:	**main.c**
Function:	barGraph
Syntax:	void barGraph(unsigned char led)
Parameters:	led
Return:	none
Description:	Routine to handle the six led bar, if WALKING_LED is defined just one LED is turned on at a time; else all the LED's below the received value are turned on.

Module:	**main.c**
Function:	calibrateElectrodes
Syntax:	void calibrateElectrodes(void)
Parameters:	none
Return:	none
Description:	Read each electrode value and store the result in the calibration register of each electrode.

Module:	**main.c**
Function:	display
Syntax:	void display(unsigned char left, unsigned char right)
Parameters:	left, right
Return:	none
Description:	Displays the hex value contained in the left and right bytes into the 7 segment displays using the MC33993 via SPI If a 255 value is received the display is turned off.

Module:	**main.c**
Function:	displayData
Syntax:	void displayData(void)
Parameters:	none
Return:	none
Description:	This function uses verifyKeys and verifyMuxKeys functions to find out if there is a key pad pressed. If a value different from 0 is found the corresponding value is displayed into the 7 segment displays and a beep is generated.

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Module:	main.c
Function:	initPorts
Syntax:	void initPorts(void)
Parameters:	none
Return:	none
Description:	Initialize GPIOs, Oscillator, A/D module, Timers and external MC33993 chip.

Module:	main.c
Function:	main
Syntax:	void main(void)
Parameters:	none
Return:	none
Description:	Set up peripherals, get calibration value of electrodes and continuously scan the keys and take the appropriate action.

Module:	main
Function:	readElectrode
Syntax:	void readElectrode(unsigned char channel)
Parameters:	channel
Return:	none
Description:	Reads the selected channel and places the result into INT16evalue, channel takes on value from 1 to NUMBER_OF_ELECTRODES

Module:	main.c
Function:	readValues
Syntax:	void readValues(void)
Parameters:	none
Return:	none
Description:	Reads all electrodes using the readElectrode function.

Module:	main.c
Function:	verifyElectrodes
Syntax:	void verifyElectrodes(void)
Parameters:	none
Return:	none
Description:	Finds the three highest electrode change values and the corresponding electrodes are stored in the global variables MaxIndex0..MaxIndex2. Delta values are stored in Max0..Max2

Module:	main.c

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Function:	verifyKeys
Syntax:	unsigned char verifyKeys(void)
Parameters:	none
Return:	Key pad number if any are valid, or 30 if a multiplexed pad is detected.
Description:	Evaluates the data in Max0 and Max1 global variables, returns the represented electrode if valid, and a 30 if the combination seems to be a multiplexed electrode key.

Module:	**main.c**
Function:	verifyMuxKeys
Syntax:	unsigned char veifyMuxKeys(void)
Parameters:	none
Return:	Key pad number represented by the electrode delta combination if any valid.
Description:	Verifies the values of Max0 and Max1 to find out if a valid key pad combination is present, returns the number of the key pad is any found.

Module:	**main.c**
Function:	_TOF_Interrupt
Syntax:	interrupt void _TOF_Interrupt(void)
Parameters:	none
Return:	none
Description:	Handler routine for the timer overflow interrupt, this routine stops the timer and turns off the beeper.

Module:	**main.c**
Function:	_KBD_Interrupt
Syntax:	interrupt void _KBD_Interrupt(void)
Parameters:	none
Return:	none
Description:	Handler routine for the keyboard interrupt, makes a beep and recalibrates the electrodes.

Module:	**communications.c**
Function:	delay10mS, delay100mS, delay1mS
Syntax:	void delay10mS(void), void delay100mS(void), void delay1mS(void)
Parameters:	none
Return:	none
Description:	Functions to wait for the specified amount of time using a for cycle.

Module:	**communications.c**
Function:	sendSCIchar
Syntax:	void sendSCIchar(unsigned char u8serialValue)
Parameters:	u8serialValue

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Return:	none
Description:	Sends via SCI the u8serialValue

Module:	**communications.c**
Function:	sendSCIValue
Syntax:	void sendSCIValue(int u16serialValue)
Parameters:	u16serialValue
Return:	none
Description:	Converts the 16 bit value into a 3 digit hex value, and sends the three digits via SCI.

Module:	**communications.c**
Function:	sendSPI
Syntax:	void sendSPI(void)
Parameters:	none
Return:	none
Description:	Sends via SPI the bytes located on the global variable MSDI[0].MSDI[2]

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1.18 Flow Diagrams

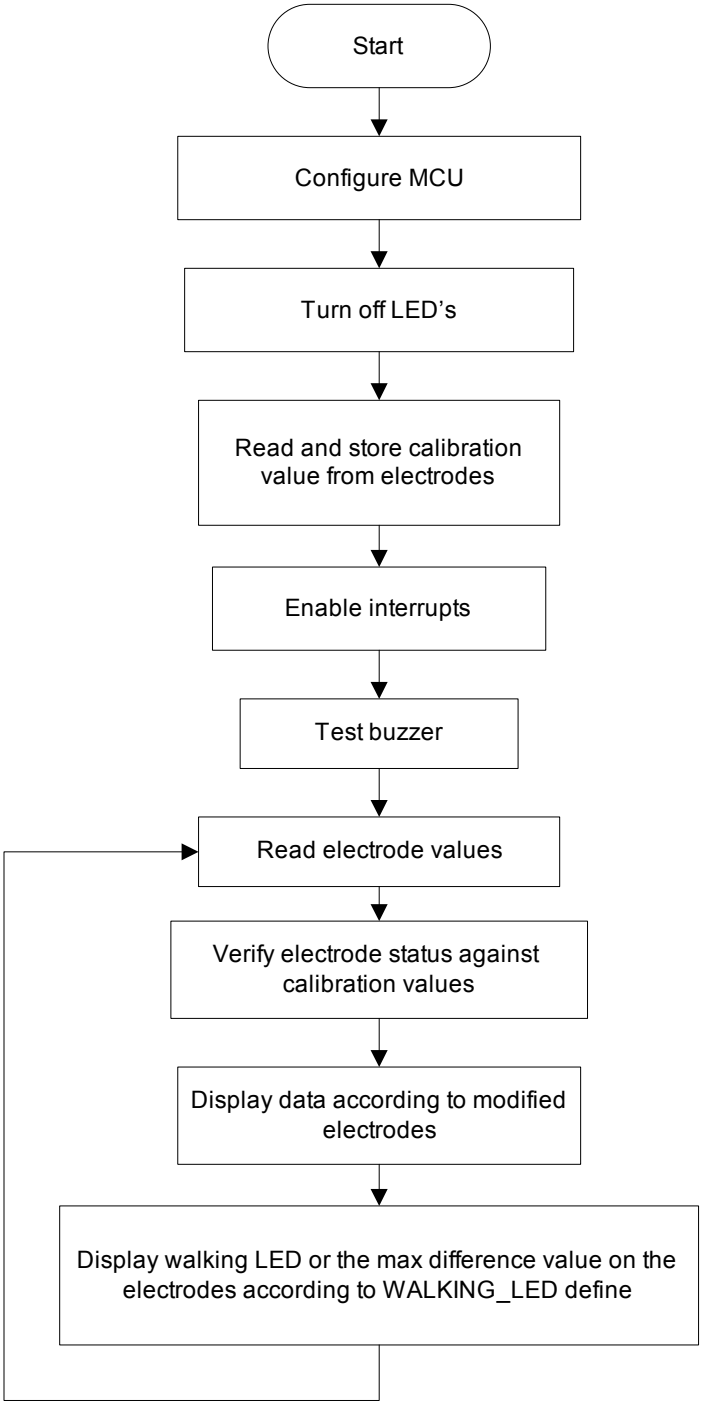

Figure 1-26. Main Program Flow

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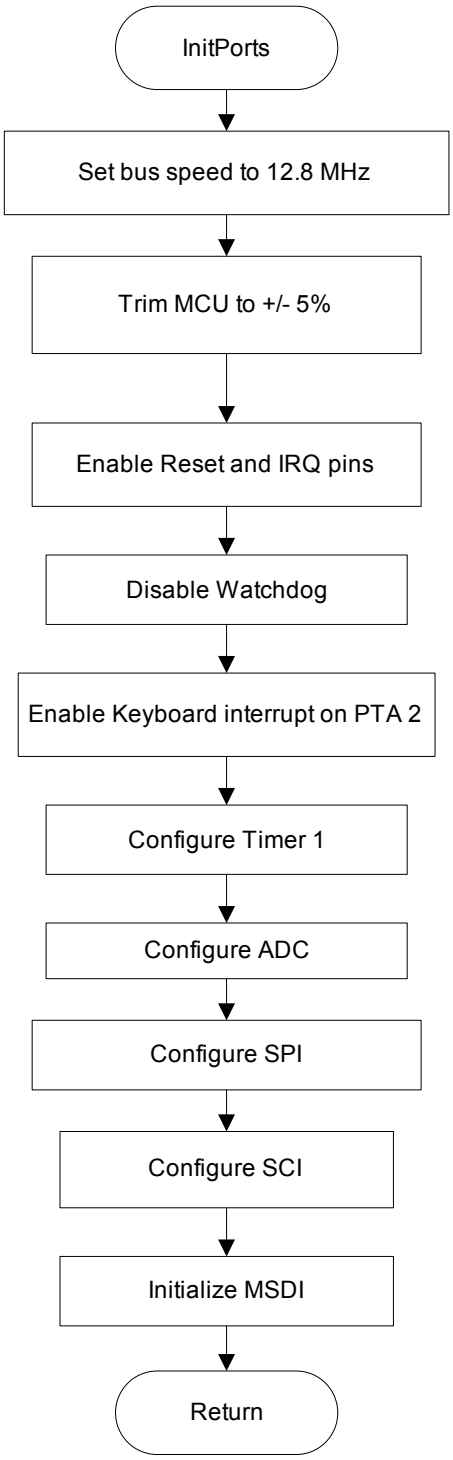

Figure 1-27. Initialization Ports

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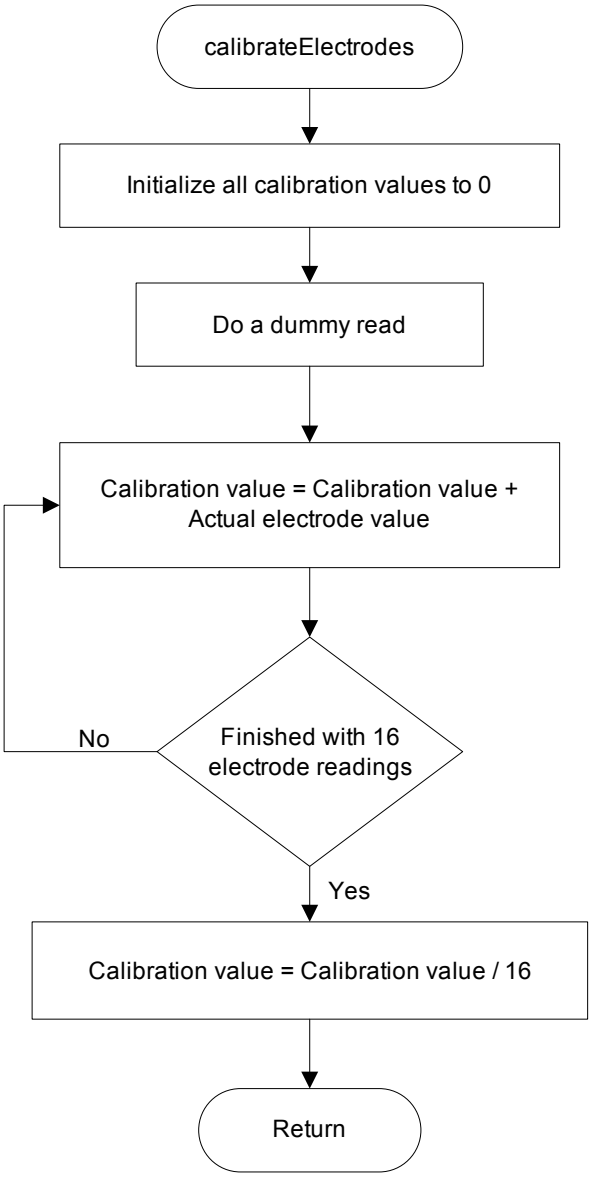

Figure 1-28. Calibrate Electrodes

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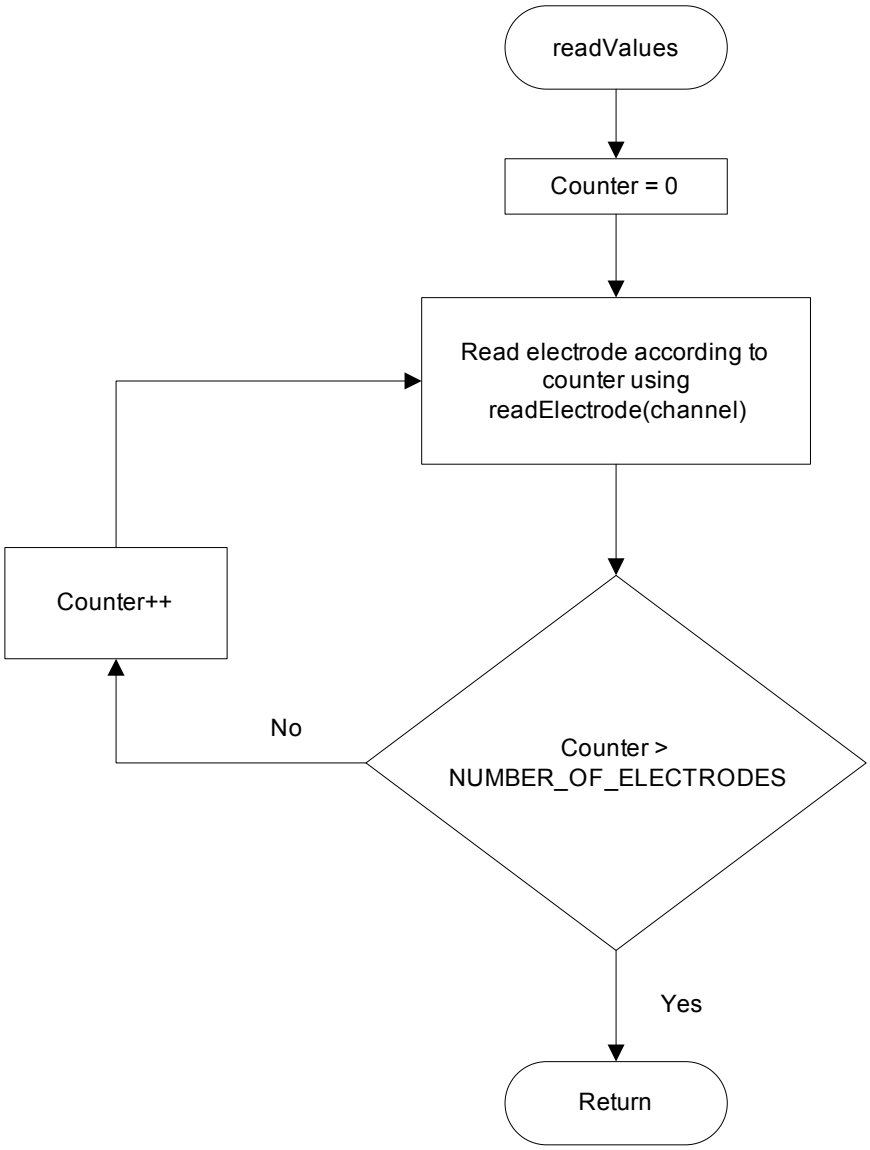

Figure 1-29. Read Values

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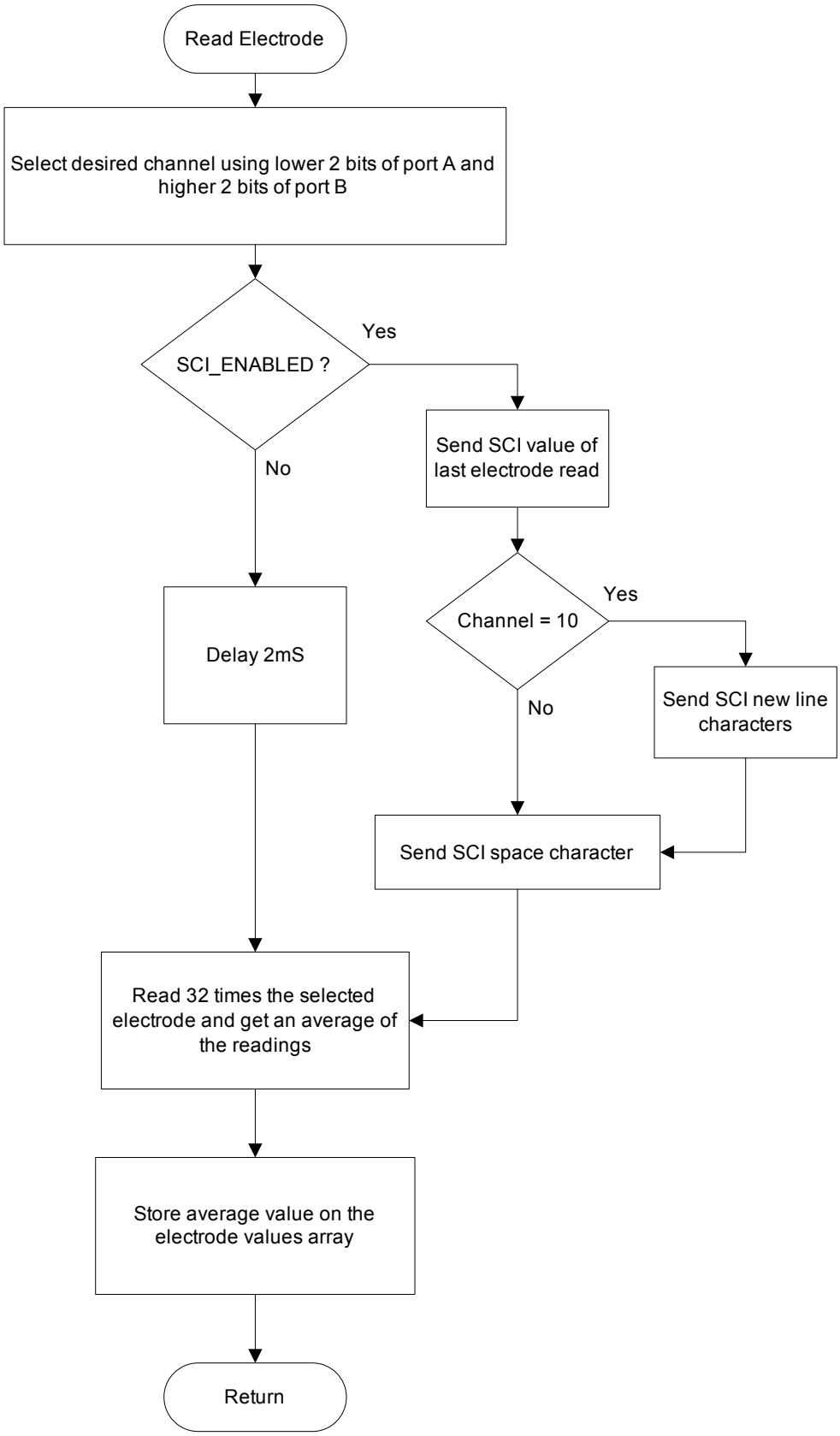

Figure 1-30. Read Electrode

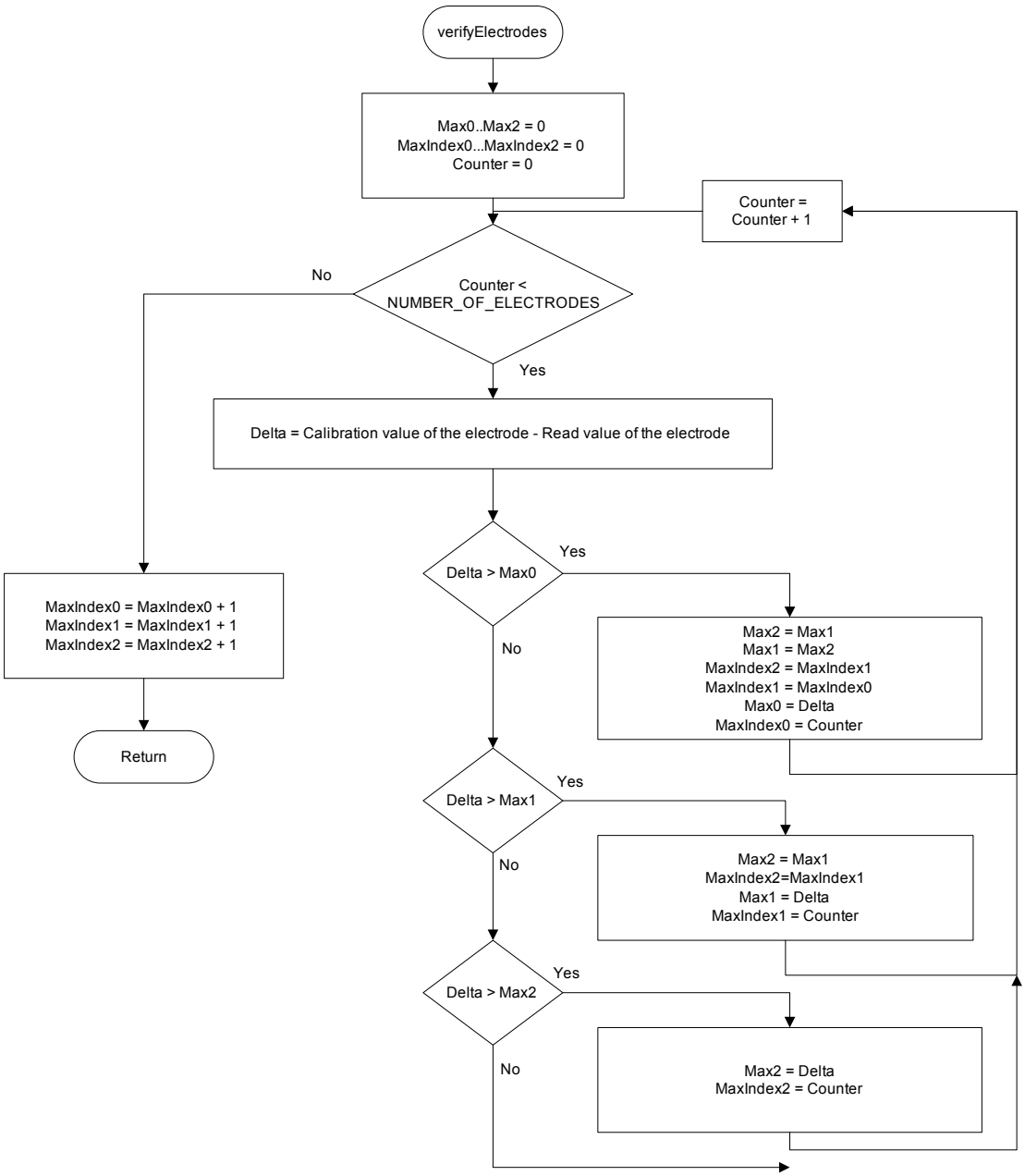

Figure 1-31. Verify Electrodes

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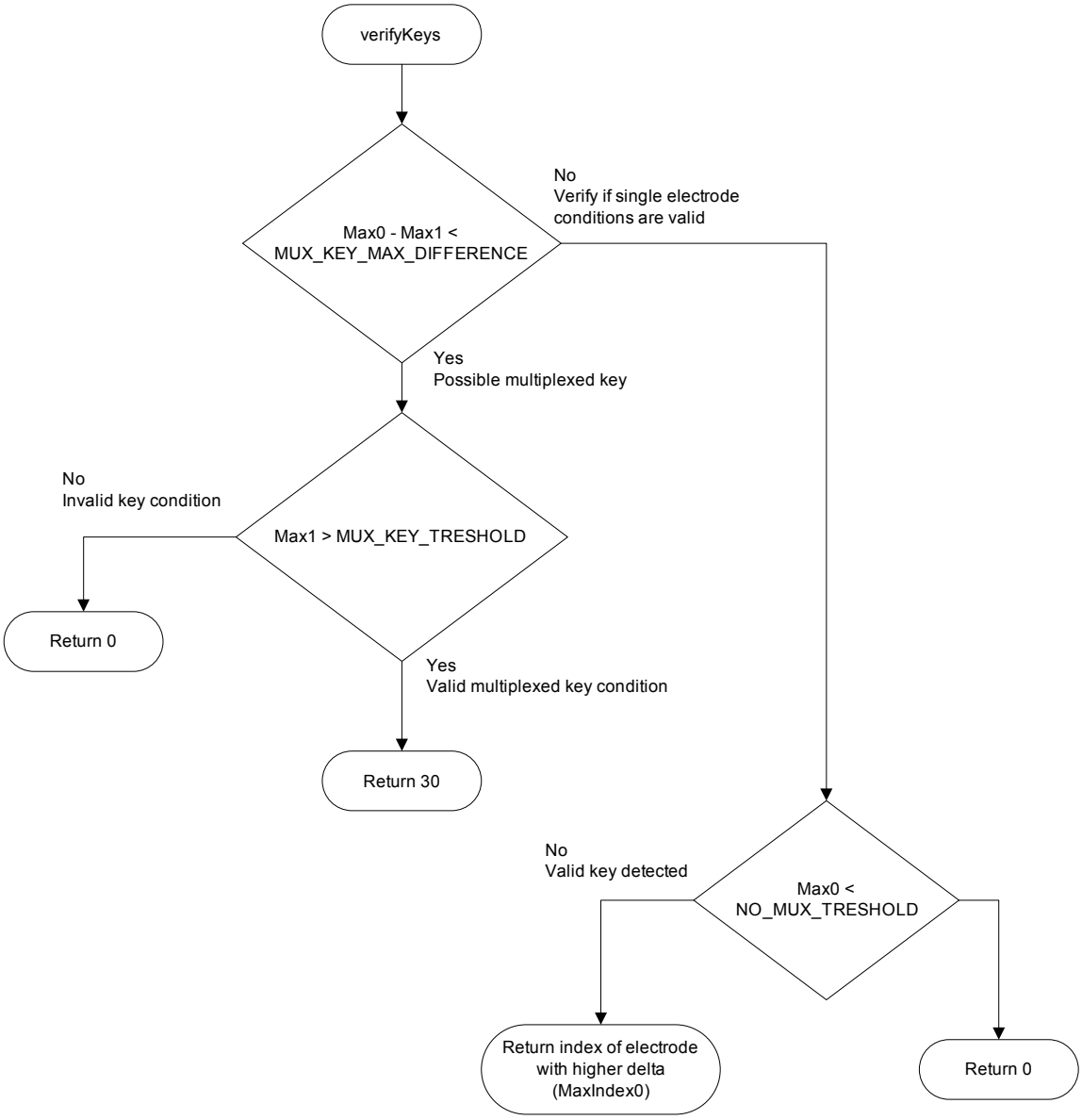

Figure 1-32. Verify Keys

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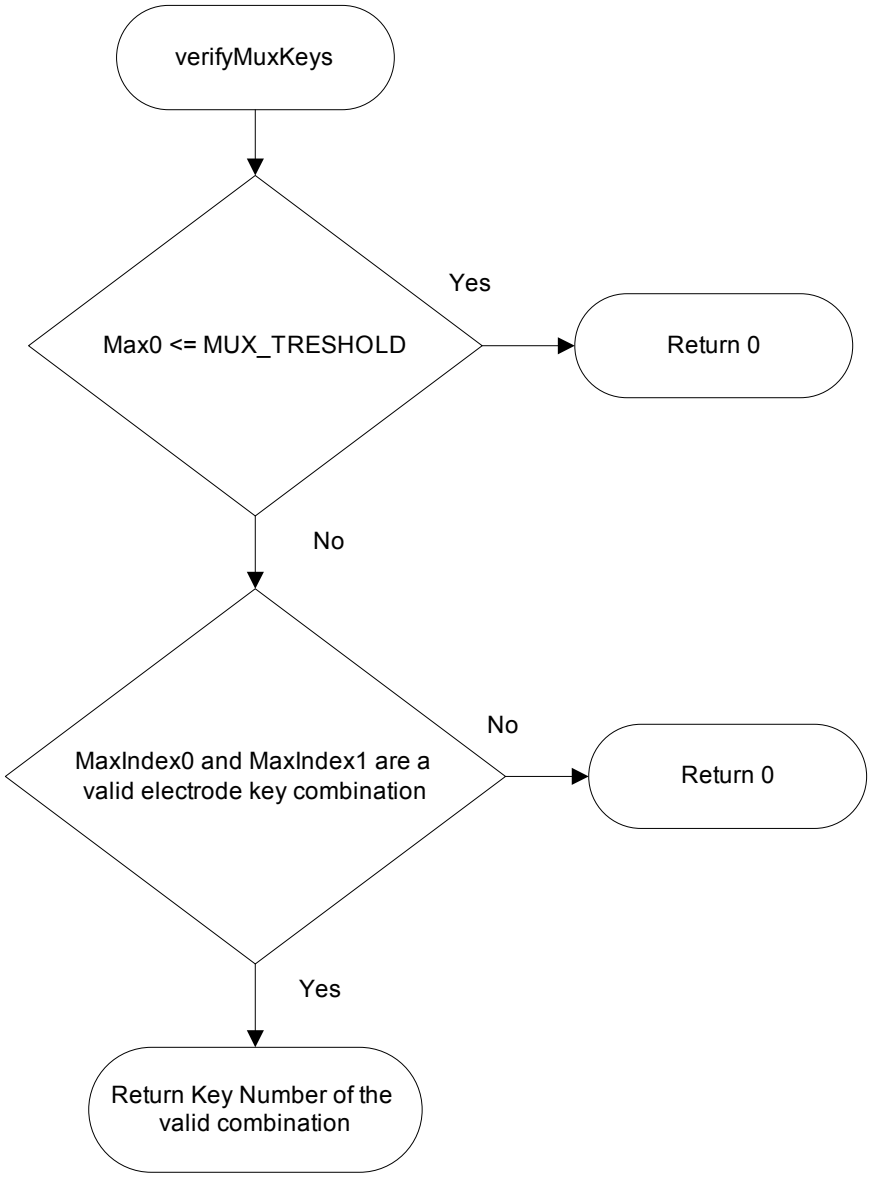

Figure 1-33. Verify Mux Keys

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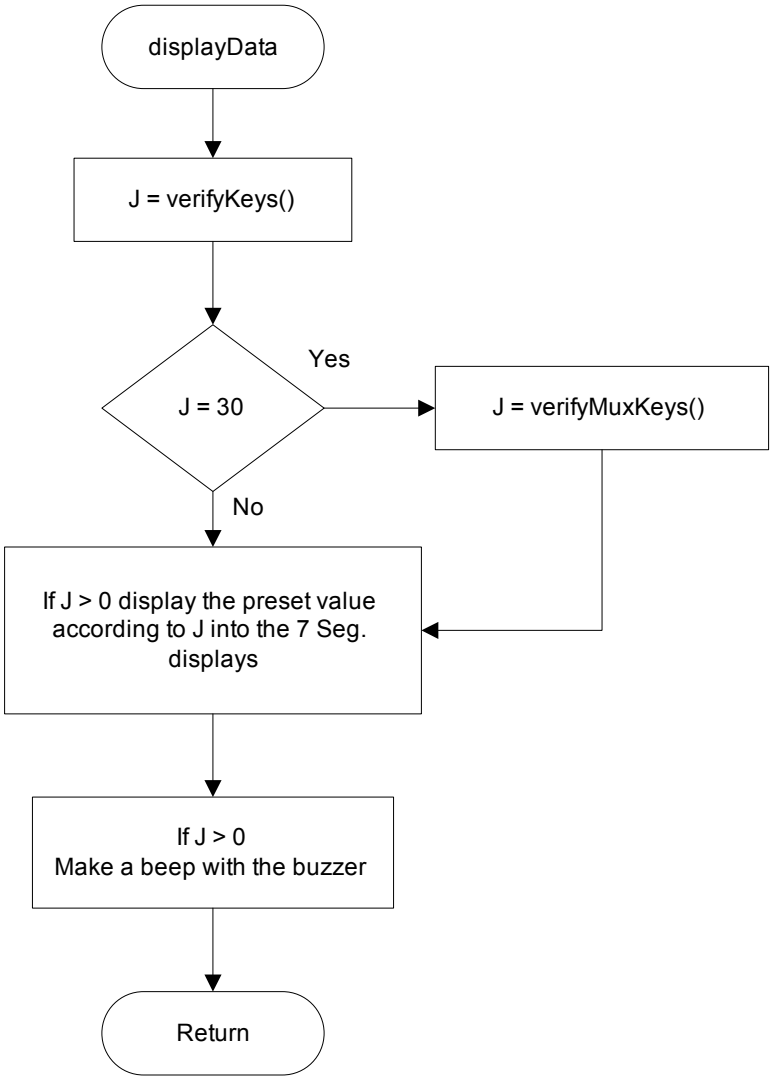

Figure 1-34. Display Data

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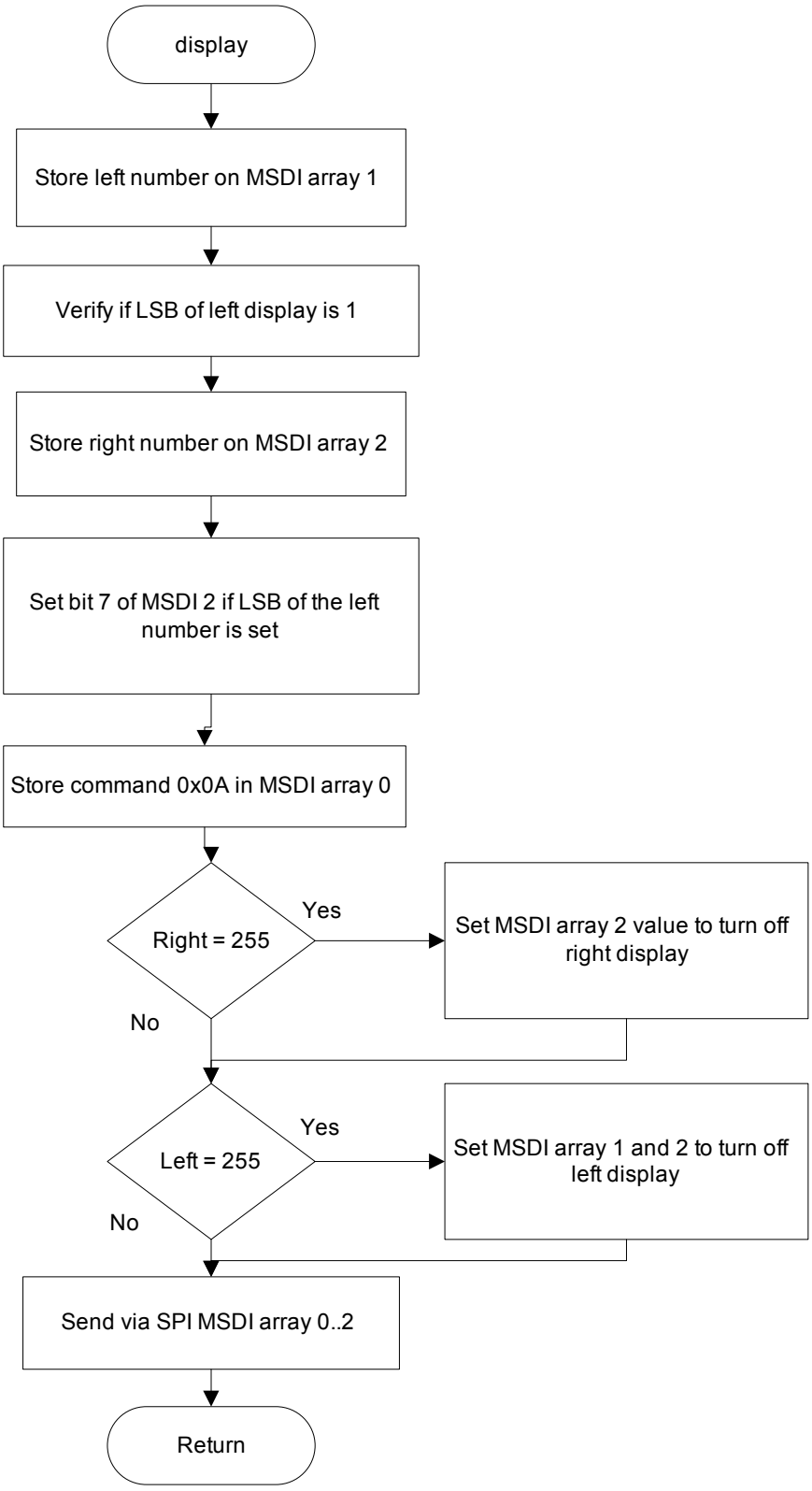

Figure 1-35. Display

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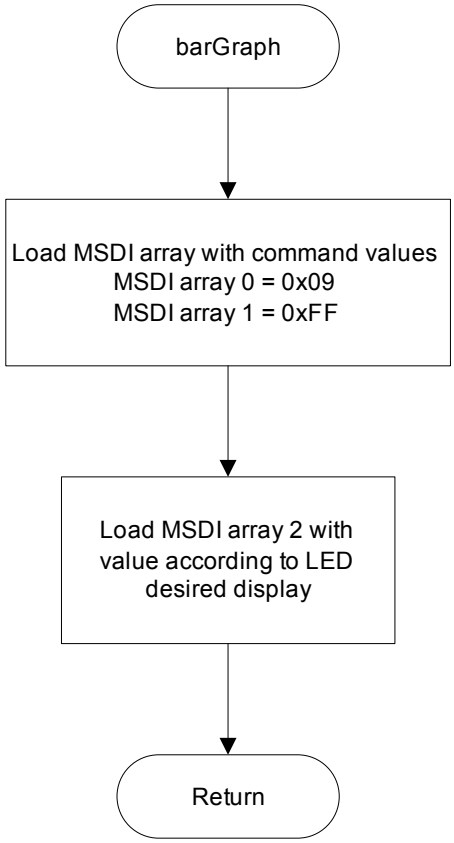

Figure 1-36. Bar Graph

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Appendix A Bill of Materials

Table A-1 shows the bill of materials for the Touch Panel System.

Table A-1. Bill of Materials

Part	Value	Manufacturer Part #	Package	Description	Manufacturer
C1, C2, C3, C10	0.1uF	06032R104K7B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C5, C6, C17	10u	B45197A4106K309	C-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C7, C8	0.1uF	ECS-T1VY104R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C9, C12, C13, C15, C18, C26, C27, C28, C29, C30, C31, C32, C33, C34, C35	10nF	06032R103K9B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C11	4.7uF	ECS-T1AY475R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
C14, C16, C25	1nF	06032R102K9B20D	C0603	Surface Mount Ceramic ChipCap	ANY
C19, C20, C21, C22, C23, C24	1uF	ECS-T1CY105R	A-EIA	Surface Mount Tantalum Electrolytic Capacitor	ANY
D1, D2		1N4148WS	SOD323	Surface Mount Switching Diode	ANY
D3		BZT52C5V1	SOD123	5.1V SMD Diode	ANY
DIS1, DIS2		LSHD-A103		7 Segment LED Red Display	ANY
JP1, JP3		TSW-103-23-S-S		1x3 terminal Header	ANY
JP2		TSW-115-23-S-S		1x15 terminal Header	ANY
JP4		TSW-108-23-S-D		8x2 terminal Header	ANY
JP5		TSW-101-23-S-S		1x1 terminal Header	ANY
LED1, LED2, LED3, LED4, LED5, LED6		LNJ311G8TRU	1206	Surface Mount Green LED	ANY
P1		RAPC-722		Power Jack	ANY
R1	47K	ERJ-3GEYJ473V	R0603	Surface Mount Resistor	ANY
R2	680		R0603	Surface Mount Resistor	ANY
R3, R9, R10, R11, R12, R15	10K	ERJ-3GEYJ103V	R0603	Surface Mount Resistor	ANY
R5	1K	ERJ-3GEYJ102V	R0603	Surface Mount Resistor	ANY
R6	39K	ERJ-3GEYJ393V	R0603	Surface Mount Resistor	ANY
R7, R8	100k		3266Y-1-104	Trimming Potentiometer	ANY
R13, R14	2.2K	ERJ-3GEYJ222V	R0603	Surface Mount Resistor	ANY
R16	10		R0603	Surface Mount Resistor	ANY

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R17	120		R0603	Surface Mount Resistor	ANY
S1		EG1218		SPDT Slide Switch	E-Switch
S2		EG2207		DPDT Switch	E-Switch
SW1_IRQ		KSR221G		SPST Surface Mount Switch	ANY
U1		MC68HC908QB8	SOIC16W	Micro controller	Freescale Semiconductor
U2		LM2767M5	SOT23-5	Switching Capacitor Voltage Converter	ANY
U3		LM358AD	8-SO	IC Opamp Dual	ANY
U4		MAX232CSE	16-terminal SOICN	RS-232 Interface	Maxim
U5		MC33993DWB	32-SOICW	WB MC33993 in SO-32WB	Freescale Semiconductor
U6		MC33794/MC34940DWB	54-terminal SOIC	Electric Field Imaging Device (ODS)	Freescale Semiconductor
U7		MC7805CDT	D-PAK	5V Voltage Regulator	ANY
U8		PB-12N23P-05		Buzzer	Projects Unlimited
X1		182-009-212-531	D-type Female	RS-232 Connector	ANY
TPB connector		SSM-115-S-SV		SMD SOCKET STRIP, CENTERLINE: .100" (2,54MM), single row, 15 contacts	SAMTEC

Authors' Note: Freescale Competitor notation:

Freescale does not assume liability, endorse, or warrant components from external manufacturers that are referenced in circuit drawings or tables. While Freescale offers component recommendations in this configuration, it is the customer's responsibility to validate their application.

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REVISION HISTORY

Revision	Date	Description of Changes
0.2	Sept., 2005	Initial Release

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Touch Panel System Using E-Field Sensor Setup Instructions

Reference Design Documentation for the RDTOUCHEFRM

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PREFACE

This user's guide provides the installation and setup instructions for the Touch Panel System using the MC33794 E-Field Sensor. It describes how to easily program the embedded MCU and the basic hardware configurations to start the demo.

AUDIENCE

This document is intended for application developers who are setting up Freescale's E-Field Sensor Reference Design.

SUGGESTED READING

- Additional documentation may be found at www.freescale.com
- Design Reference manual.
- Application note, AN1985: Touch Panel Applications using the MC34940/MC33794 E-field IC.

CONVENTIONS

This document uses the following conventions:

Term or Value	Definition	Examples
Terminal Names	Terminal names are the physical connections and are shown in text as all upper case.	... the external supply voltage VSUP1.
Terminal Values	Terminal values are the currents to/from a terminal and are shown as upper and subscripted text.	In Stop Mode the voltage regulator still supplies the MCU with V_{DD}
Decimal Values	No special symbol attached to the number	1.0 34
Numbers	Considered positive unless specifically noted as a negative value	5.0 -10
Blue Text	Linkable on-line	... refer to Table 1, page 2

INTRODUCTION

DEFAULT SETTINGS

This kit contains everything you need to get started except the 9V battery. This document will guide you through the steps necessary to download your own program using Serial Bootloader Tool interface or MON08 Multi-link. The default jumper configuration is shown in table 1.

Default Jumper Configuration

JP1	Position 1-2 (10nF)
JP3	Position 1-2 (Non-amp LEVEL)

The configuration jumpers within the analyzer board are JP1 and JP3. JP1 selects if the input to Microcontroller's AD channel is feed directly from the output pin (LEVEL) or if the output signal is first amplified by the on board op-amp with adjustments in offset and amplitude, and then feed into the MCU (LEVEL_AMP).

JP3 selects between two values of LP_CAP, 10nF and 1nF, the recommended value in the data sheet is 10nF.

Source code is available on the design reference manual of the touch panel system using E-field sensors.

In order to start running the application, touch panel board (TPB) or a customized electrodes board should be connect to analyzer board (AB) using the 15-pins connector "JP2".

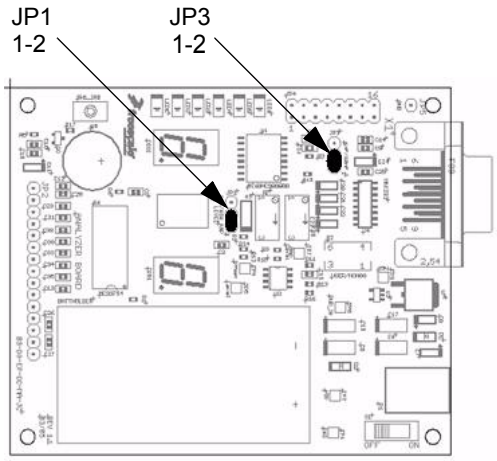

Figure 1. Default Jumper Configuration

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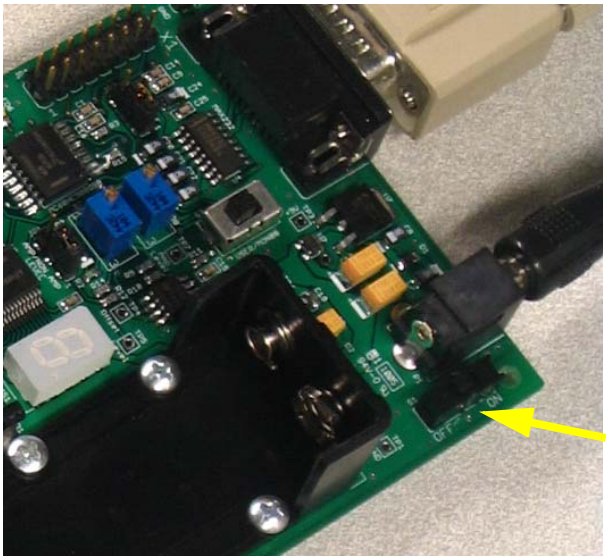
VOLTAGE SUPPLY

The first step is to prepare the Analyzer Board by plugging the 9V battery or connecting an external 9V source to the Jack “P1”, when connecting battery and external supply at the same time, the external power supply jack will disconnect the battery VCC terminal.



For powering Analyzer Board make sure power supply, either battery or external power supply doesn’t exceed 15V.Place a common 9 volts battery on the battery holder with the appropriate polarity, or connect +9V center positive on the jack for external power supply and then move “S1” to the “ON” position.

With the default firmware up into the microcontroller and the default settings described above, the application should be running; LED’s, 7 segments displays and audio transducer will provide feedback as the system detects a pressed condition within the touch pads.

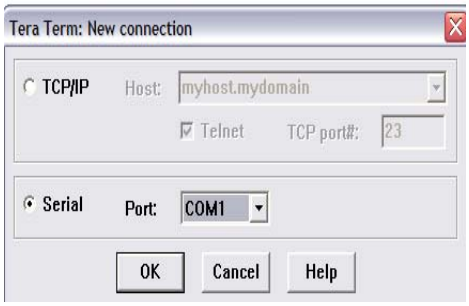
PROGRAMMING SETTINGS

PROGRAMMING THROUGH SERIAL BOOTLOADER TOOL

When running the loaded program in the demo, the USER/MON08 switch “S2” should be on the USER position; USER mode is also used when programming the microcontroller using the serial bootloader tool.

To download the firmware using the bootloader tool:

1. Make sure all the required programs are available in the programmer PC, you must have the *.S19 file to be downloaded into the MCU, TeraTerm software used for serial communications, and the required bootloader already programmed into the demo board MCU.
2. Open and configure TeraTerm software, a new connection window will appear, select on the same window “Serial”, select the serial port available at your computer and then press the [OK] button.



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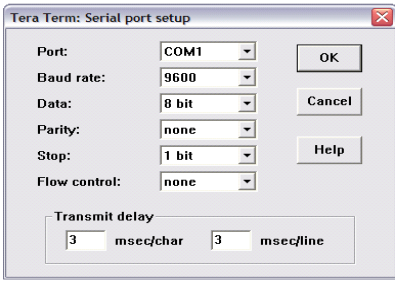
3. On the Setup menu, select *Serial Port*… and configure serial port with baud rate at 9600 bps, 8 bit, no parity, 1 stop bit and flow control set to none. Make sure the transmit delay is set to 3ms/char and 3ms/line in order to ensure a proper communication.



4. Make sure demo board jumpers are configured as default and that the USER/MONO8 switch “S2” is set to USER.
5. Turn on the demo board while holding the sw1_irq button pressed, a *(p)rogram (w)ipe e(x)it* message should appear into the TeraTerm screen.
6. Press *w* to wipe any data already loaded into the MCU flash, note this operation does not erase the bootloader code.
7. Press *p* and a waiting… message should appear, use the TeraTerm File->Send File option to send the.S19 file, a progress dialog will show up.
8. Once the code is downloaded the *(p)rogram (w)ipe e(x)it* message will appear again, press *x* and the downloaded code will start running.
9. Each time the demo board is turned on with out pressing the *sw1_irq* button at the same time the user code will be run directly.

PROGRAMMING USING MON08 MULTI-LINK INTERFACE

To download the firmware using a MONO8 pod:

1. Make sure the USER/MONO8 switch “S2” is set to MONO8 position.
2. Hook the MONO8 adapter into the *JP4* connector, make sure the connector pin alignment is correct to avoid any MCU damage. Apply power to the MON08 Multi-link interface and connect it to you PC port.
3. Using Code Warrior download the code to the demo board, since this operation will erase the bootloader if any was already on the MCU, make sure the interrupt vectors are located on the standard interrupt vector area.

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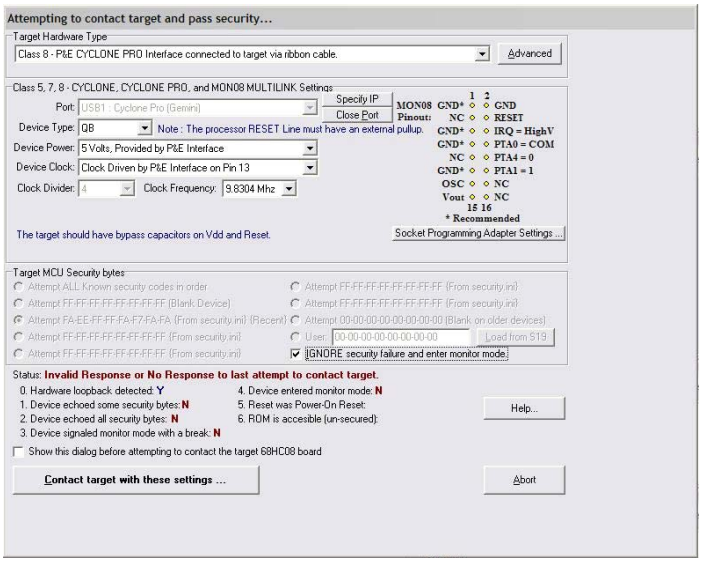
4. Within the Code Warrior project, click the “Debug” button in the menu bar under the project window, or hit F5. The “Attempting to contact target and pass security…” window should appear. If not, change the Debug mode to “In-Circuit Debug/Programming” in the PEDebug menu. Make sure you have the same values for the following options:



Target Hardware Type: Class VIII

LPTx: Parallel Port x

(Could vary depending on the PC Parallel port used)

Device Type: QB

Device Power: 5 Volts, provided by P&E Interface

Device Clock: 9.8304 MHz, provided by P&E Interface Pin13

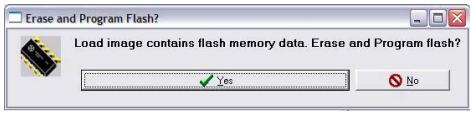
Clock Divider: 4

Target MCU Security Bytes:

“IGNORE security failure and enter monitor mode”

Finally click the “Contact target with these settings…” button and if you are asked to “Erase and program flash” click “Yes”. After that the MCU Flash will be programmed.

5. the following message should appear, press *yes* button to program flash memory.



6. Once the flash programming process is finished unplug the MONO8 connector and set the switch to USER position.

GENERAL BOARD CONFIGURATION

TOUCH PANEL BOARD CONNECTOR “JP2”

PIN#	Description	PIN#	Description	PIN#	Description
1	GND	6	E3	11	E8
2	SHIELD	7	E4	12	E9
3	SHIELD	8	E5	13	REF_A
4	E1	9	E6	14	REF_B
5	E2	10	E7	15	GND

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TEST POINTS DESCRIPTION

Test point number	Signal name	Description
TP1	GND	System Ground, electrical reference test point.
TP2	+5V	5V power supply output.
TP3	+9V	External power supply or battery voltage. After ON/OFF switch and reverse battery protection stages.
TP4	Offset	DC signal entering Op-amp non-inverter inputs. Output of potentiometer R8.
TP5	Level	output
TP6	PWR_IN	Charge pump output, 10 volts typically measured
TP7	Amp_Level	Amplifier stage output, output with adjustment in offset and amplitude.

ANALYZER BOARD JUMPERS AND SWITCHES

Jumper name	Functional description
JP1	**Position 1-2:** Connects microcontroller A/D input channel 3 to E-field output “LEVEL” directly. **Position 2-3:** connects microcontroller A/D input channel 3 to the Op-Amp output. Op-Amp adjusts gain and offset of “LEVEL” (E-field output). **Other:** NO valid
JP3	**Position 1-2:** E-field LPF filter capacitor = 10nF. **Position 2-3:** E-field LPF filter capacitor = 1nF. **Other:** NO valid
S1	**OFF:** Power supply or battery is disconnected internally to all modules. **ON:** Power up all AB modules
S2	**USER:** Microprocessor in user mode, firmware running. Also used when programming using serial bootloader. **MON08:** microprocessor is ready to be programmed using the MON08 connector.

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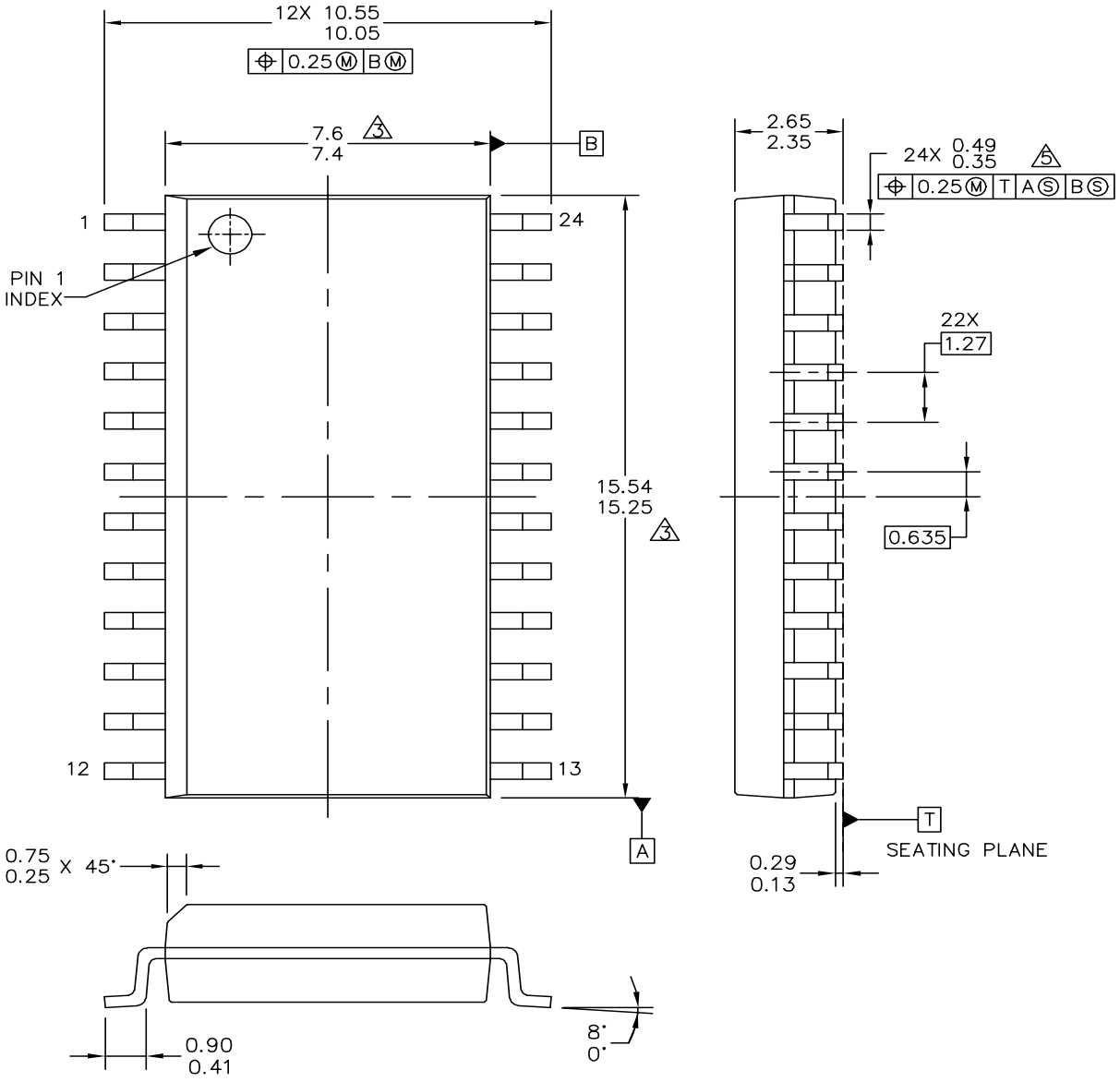
Package Dimensions



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TITLE: 24LD SOIC W/B, 1.27 PITCH 7.5 X 15.4 CASE–OUTLINE	DOCUMENT NO: 98ASB42344B	REV: F
	CASE NUMBER: 751E–04	26 APR 2005
	STANDARD: JEDEC MS–013 AD	

CASE 751-04
ISSUE F
24 LEAD SOIC

NOTES:

1. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
2. DIMENSIONS ARE IN MILLIMETERS.
3. THIS DIMENSION DO NOT INCLUDE MOLD PROTRUSION.
4. MAXIMUM MOLD PROTRUSION 0.15(0.006) PER SIDE.
5. THIS DIMENSION DOES NOT INCLUDE DAM BAR PROTRUSION. ALLOWABLE DAM BAR PROTRUSION SHALL BE 0.13(0.005) TOTAL IN EXCESS OF THIS DIMENSION AT MAXIMUM MATERIAL CONDITION.

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CASE 751E-04
ISSUE F
24 LEAD SOIC

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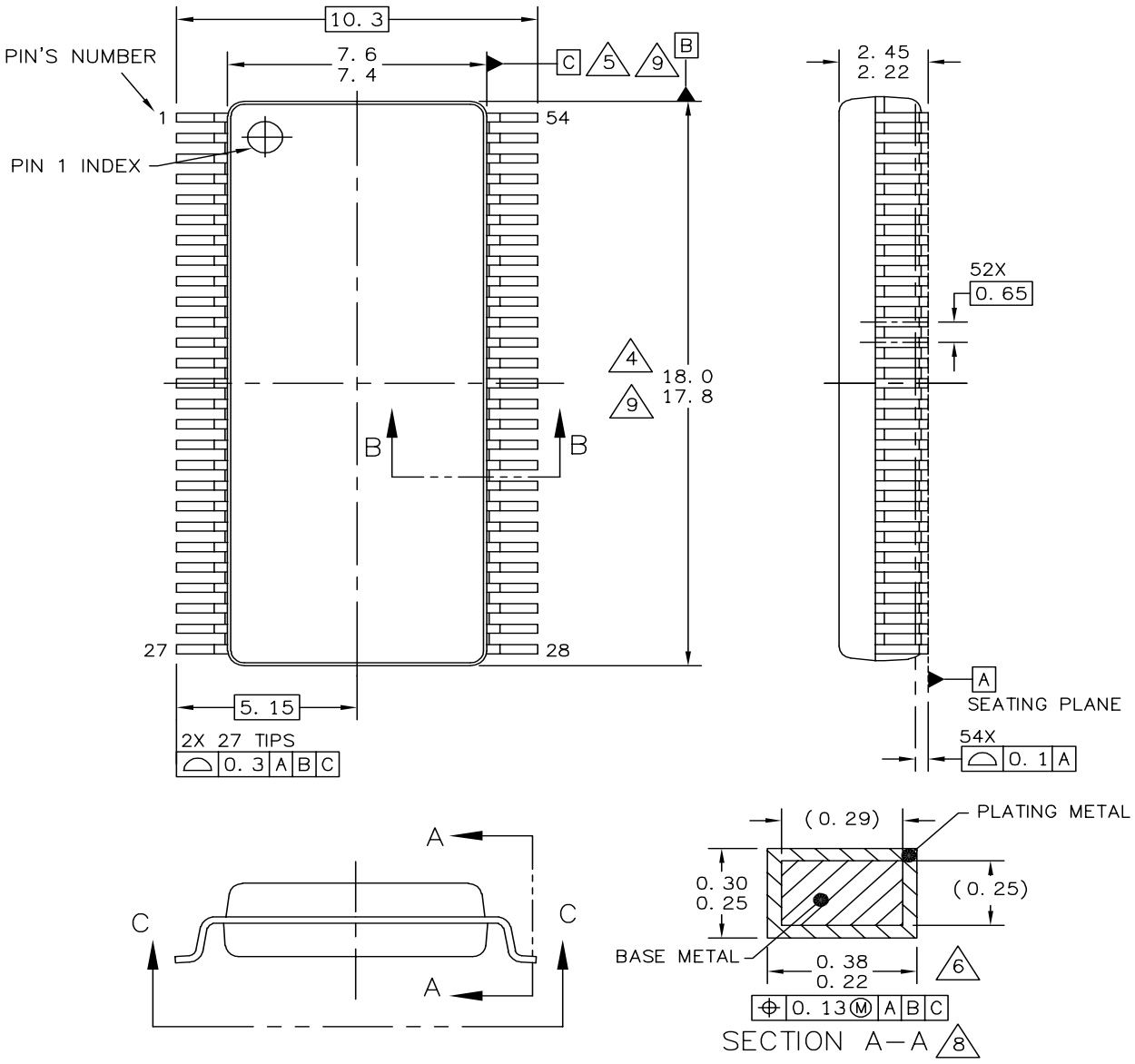
Package Dimensions



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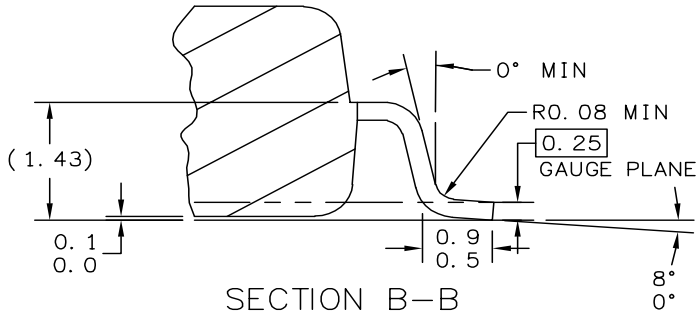
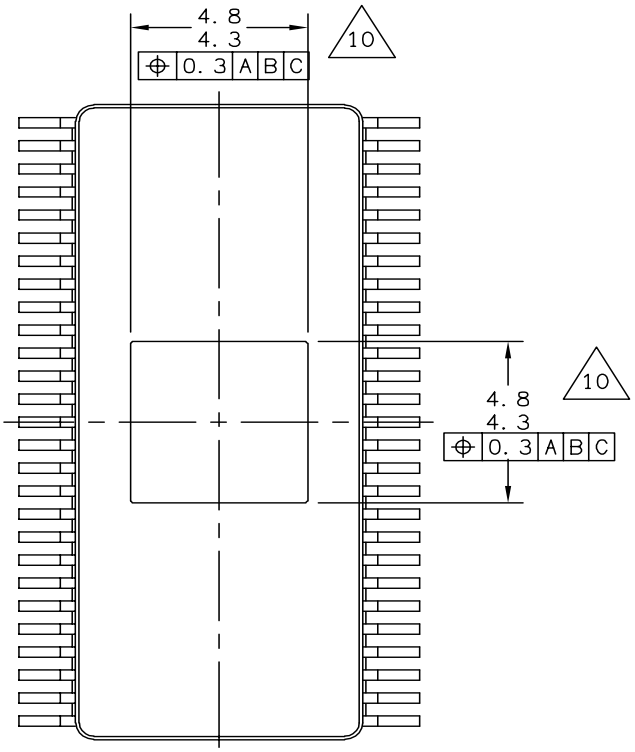
TITLE: 54LD SOIC W/B, 0.65 PITCH 4.6 X 4.6 EXPOSED PAD, CASE–OUTLINE	DOCUMENT NO: 98ASA10506D	REV: C
	CASE NUMBER: 1390–02	11 MAR 2005
	STANDARD: NON–JEDEC	

CASE 1390-02
ISSUE C
54 LEAD SOIC



SECTION B–B



VIEW C–C

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MECHANICAL OUTLINE	PRINT VERSION NOT TO SCALE

TITLE:	DOCUMENT NO: 98ASA10506D	REV: C
54LD SOIC W/B, 0.65 PITCH 4.6 X 4.6 EXPOSED PAD, CASE-OUTLINE	CASE NUMBER: 1390-02	11 MAR 2005
	STANDARD: NON-JEDEC	

CASE 1390-02
ISSUE C
54 LEAD SOIC

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Package Dimensions

NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
2. DIMENSIONING AND TOLERANCING PER ASME Y14.5M–1994.
3. DATUMS B AND C TO BE DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
4. THIS DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSION OR GATE BURRS. MOLD FLASH, PROTRUSION OR GATE BURRS SHALL NOT EXCEED 0.15 MM PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
5. THIS DIMENSION DOES NOT INCLUDE INTER–LEAD FLASH OR PROTRUSIONS. INTER–LEAD FLASH AND PROTRUSIONS SHALL NOT EXCEED 0.25 MM PER SIDE. THIS DIMENSION IS DETERMINED AT THE PLANE WHERE THE BOTTOM OF THE LEADS EXIT THE PLASTIC BODY.
6. THIS DIMENSION DOES NOT INCLUDE DAMBAR PROTRUSION. ALLOWABLE DAMBAR PROTRUSION SHALL NOT CAUSE THE LEAD WIDTH TO EXCEED 0.46 mm. DAMBAR CANNOT BE LOCATED ON THE LOWER RADIUS OR THE FOOT. MINIMUM SPACE BETWEEN PROTRUSION AND ADJACENT LEAD SHALL NOT BE LESS THAN 0.07 mm.
7. EXACT SHAPE OF EACH CORNER IS OPTIONAL.
8. THESE DIMENSIONS APPLY TO THE FLAT SECTION OF THE LEAD BETWEEN 0.1 mm AND 0.3 mm FROM THE LEAD TIP.
9. THE PACKAGE TOP MAY BE SMALLER THAN THE PACKAGE BOTTOM. THIS DIMENSION IS DETERMINED AT THE OUTERMOST EXTREMES OF THE PLASTIC BODY EXCLUSIVE OF MOLD FLASH, TIE BAR BURRS, GATE BURRS AND INTER–LEAD FLASH, BUT INCLUDING ANY MISMATCH BETWEEN THE TOP AND BOTTOM OF THE PLASTIC BODY.
10. THESE DIMENSIONS DEFINE THE PRIMARY SOLDERABLE SURFACE AREA.

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	CASE NUMBER: 1390–02	11 MAR 2005
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CASE 1390-02
ISSUE C
54 LEAD SOIC

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