Section 3 - Applications

3

Section 3 - Applications

Introduction

Solid-state switches have been available for many years. In various applications, Hall- Effect Sensors (Hall ICs) have replaced mechanical contact switches completely. In the mid 1980's the ignition points in automobiles were replaced by Hall ICs. The automotive market now consumes more than 40 million Hall ICs per year. Melexis has been manufacturing high quality Hall-Effect Sensors and signal conditioning ASICs for nearly a decade, and has pioneered the next generation of programmable sensors and sensor interfaces.

This section contains some fundamental information about Hall-Effect sensors, magnetics, and the added value of programmable sensors and sensor interfaces. It is intended to be useful for the novice as well as the expert.

Design Kit Materials

This section refers to magnets and devices which are included in the Melexis Hall-Effect Sensor Design Kit or the MLX90308 demo kit. Contents of these kits are listed below. These items can be ordered directly from the factory by contacting Melexis at (603) 223-2362.

Hall-Effect Sensor Design Kit

Square Neodymium, sample magnet "A" (approximately 200mT)
Cylindrical Neodymium, sample magnet "B" (approximately 380mT)
Gauss meter circuit diagram
MLX90215 linear Hall Effect sensor and calibration chart
Samples of various Melexis Hall ICs

Sensor Interface Demo Kit

MLX90308 demo board
Serial interface cable
MLX90308 programming software (31/2" Diskette)
*Note: Kit requires IBM compatible PC with a free COM port*

Melexis Reference Magnets

Melexis offers calibrated magnets for use as a reference magnetic field available in 3 ranges. These are for reference only, and are not calibrated from a traceable source nor are they intended for calibration of any type of instrumentation. They are intended for programming MLX linear Hall ICs, and for general lab reference.

SDAP-RM-10   10mT calibrated reference magnet
SDAP-RM-50   50mT calibrated reference magnet
SDAP-RM-100   100mT calibrated reference magnet

The Hall-Effect

The Hall-Effect principle is named for physicist **Edwin Hall**. In 1879 he discovered that when a conductor or semiconductor with current flowing in one direction was introduced perpendicular to a magnetic field a voltage could be measured at right angles to the current path.

No Magnetic Field

South Magnetic Field

North Magnetic Field
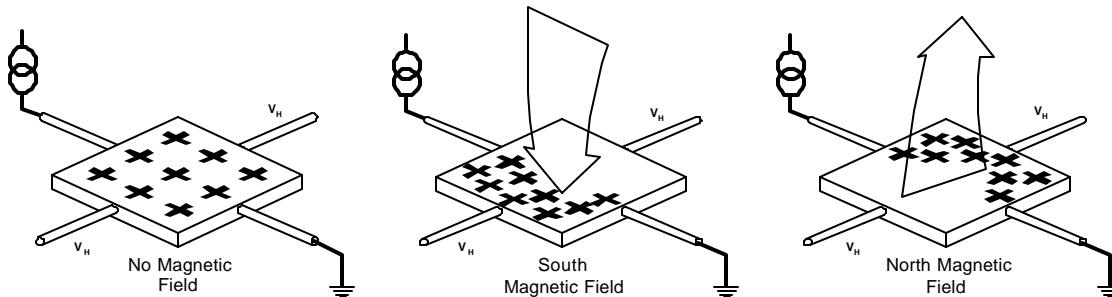
The Hall voltage can be calculated from $V_{Hall} = \sigma B$ where:

V_{Hall} = emf in volts

σ = sensitivity in Volts/Gauss

B = applied field in Gauss

I = bias current

The initial use of this discovery was for the classification of chemical samples. The development of indium arsenide semiconductor compounds in the 1950's led to the first useful Hall effect magnetic instruments. Hall effect sensors allowed the measurement of DC or static magnetic fields with requiring motion of the sensor. In the 1960's the popularization of silicon semiconductors led to the first combinations of Hall elements and integrated amplifiers. This resulted in the now classic digital output Hall switch. (right)
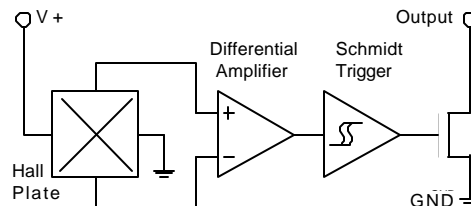
Digital Hall Effect Switch

The continuing evolution of Hall transducers technology saw a progression from single element devices to dual orthogonally arranged elements. This was done to minimize offsets at the Hall voltage terminals. The next progression brought on the quadratic of 4 element transducers. These used 4 elements orthogonally arranged in a bridge configuration. All of these silicon sensors were built from bipolar junction semiconductor processes. A switch to CMOS processes allowed the implementation of chopper stabilization to the amplifier portion of the circuit. This helped reduce errors by reducing the input offset errors at the op amp. All errors in the circuit non chopper stabilized circuit result in errors of switch point for the digital or offset and gain errors in the linear output sensors. The current generation of CMOS Hall sensors also include, a scheme that actively switched the direction of current through the Hall elements. This scheme eliminates the offset errors typical of semiconductor Hall elements. It also actively compensates for temperature and strain induced offset errors. The overall effect of active plate switching and chopper stabilization yields Hall-Effect sensors with an order of magnitude improvement in drift of switch points or gain and offset errors.

Melexis uses the CMOS process exclusively, for best performance and smallest chip size. The developments to Hall-Effect sensor technology can be credited mostly to the integration of sophisticated signal conditioning circuits to the Hall IC. Recently Melexis introduced the world's first programmable linear Hall IC, which offered a glimpse of future technology. Future sensors will programmable and have integrated microcontroller cores to make an even "smarter" sensor.

How Does it Work?
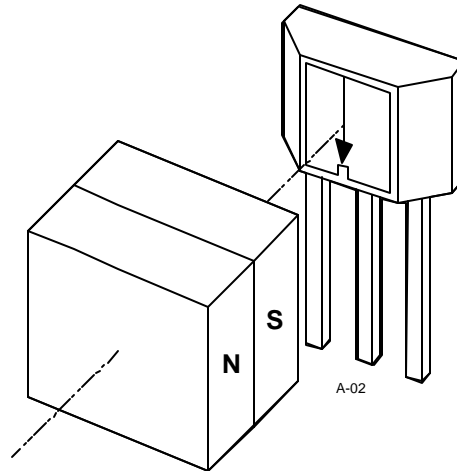
A Hall IC switch is OFF with no magnetic field and ON in the presence of a magnetic field, as seen in Figure 1. The Earth's field will not operate a Hall IC Switch, but a common refrigerator magnet will provide sufficient strength to actuate the sensor.

Figure 1, How it Works

Figure 1

A-01

S

N

A-02
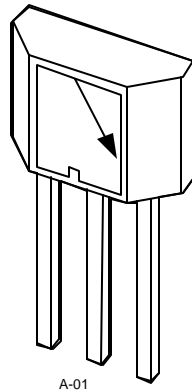
No magnetic field = OFF   South magnetic pole = ON

But How Much Do They Cost?

The cost of a Hall IC depends on the application. Automotive Hall ICs may cost $0.35 to $1.50 or more, while Hall ICs for Industrial and Consumer applications, such as appliances, game machines, industrial manufacturing, instrumentation, telecom and computers, cost $0.20 or less.

Automotive chip costs are higher because of the unique requirements for shorted loads, reverse battery, double battery voltage, load dump, 100% test at three temperatures and temperature operation up to 200°C. Devices that do not meet the stringent automotive specifications are more than adequate for other environments, such as in industrial and consumer products. Melexis products are created primarily to meet automotive specifications, with off-spec parts sold at a lower price. The cost directly reflects how well the part performs versus the severity of the operating environment.

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Activation - Using Hall-Effect Switches

A switch requires a Hall IC, a magnet and a means of moving the magnet or the magnetic field. Figures 2, 3 and 4 show several ways by which a magnet can control the Hall IC switch. The following examples are similar in principle to most real applications. Slide-by, proximity and interrupt configurations represent the three basic mechanical configurations for moving the magnet in relation to the Hall IC.

Slide-by Switch

In the Slide-by configuration, the motion of the magnet changes the field from North to South within a small range of motion. This configuration provides a well defined position and switching relationship. The minimum required motion may be as little as 1 or 2 mm.

Figure 2, Slide-by Switch

In Figure 2A, the South magnetic pole is too far away, so the switch stays OFF. In Figure 2B, the South magnetic pole turns the switch ON.
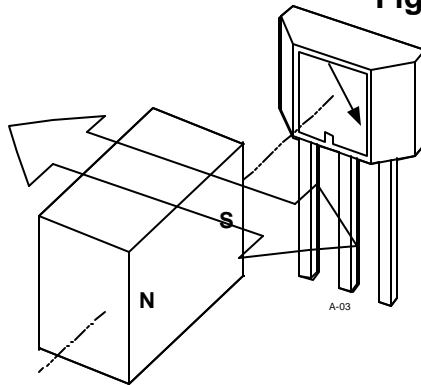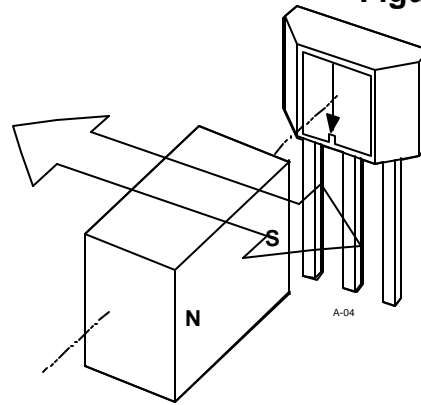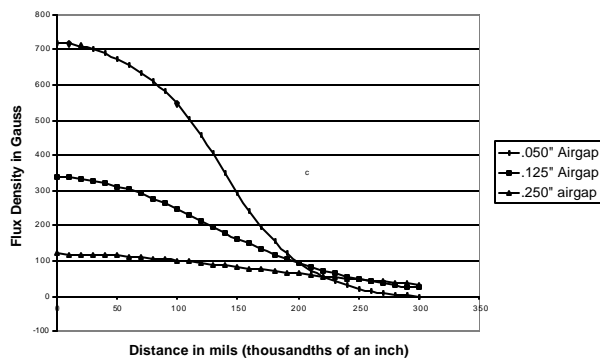
Figure 2A

Figure 2B

Linear Slide-By, Alnico8

Flux Density in Gauss

- .050" Airgap
- .125" Airgap
- .250" airgap

Distance in mils (thousandths of an inch)

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Proximity Switch

The proximity configuration is the simplest, though it requires the greatest amount of physical movement. It is also less precise in terms of the position that results in turning the sensor ON and OFF. The magnetic field intensity is greatest when the magnet is against the branded face of the Hall IC and decreases exponentially as the magnet is moved away.

Figure 3, Proximity Switch

In Figure 3A, the South magnetic pole is close to the Hall IC, so the switch turns ON. In Figure 3B, the South magnetic pole has moved too far away, so the switch turns OFF.

Figure 3A

Figure 3B

Linear Slide-By, Alnico8

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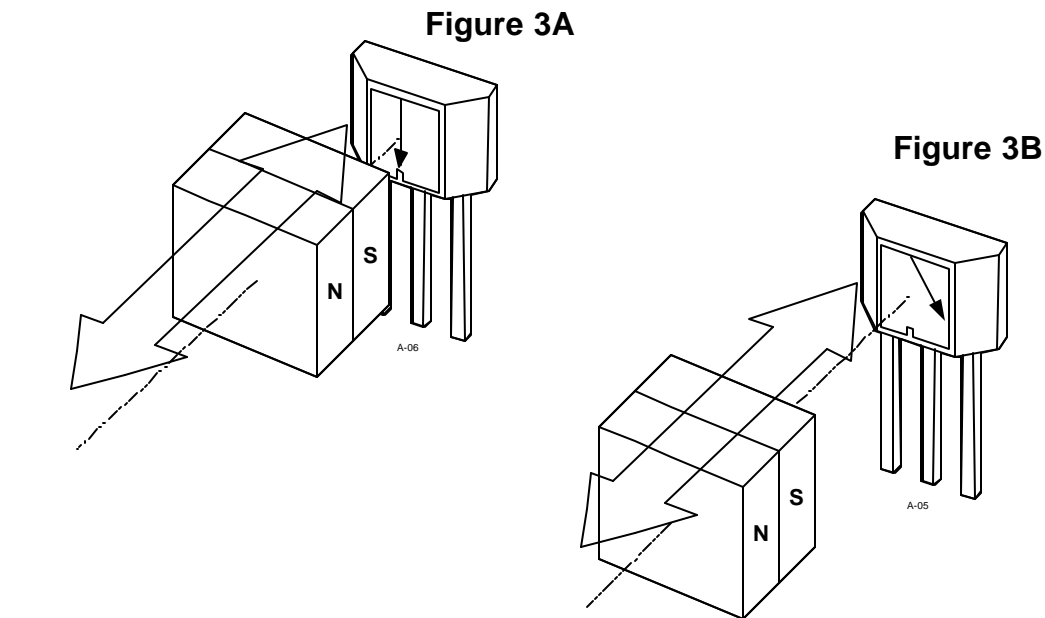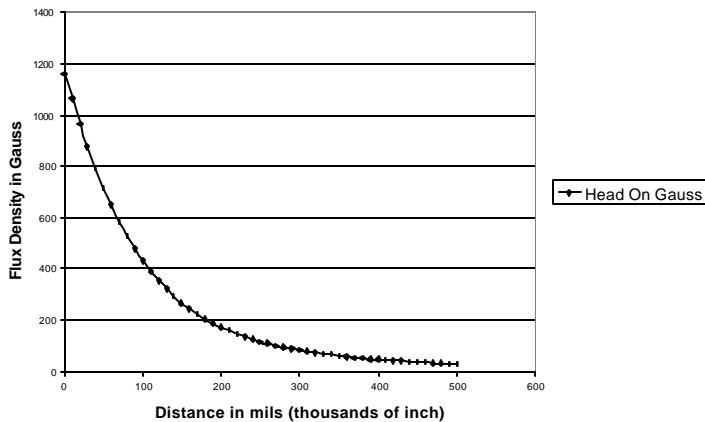
An invisible or sealed switch may be made with either configuration. The Hall IC may be inside a sealed container to shield it from oil or water, while the magnetic field penetrates or "sees" through the sealed enclosure. Refer to **Figure 4.**

Figure 4, Sealed Box

The Hall IC can be shielded from the elements and remain sensitive to magnetic fields.
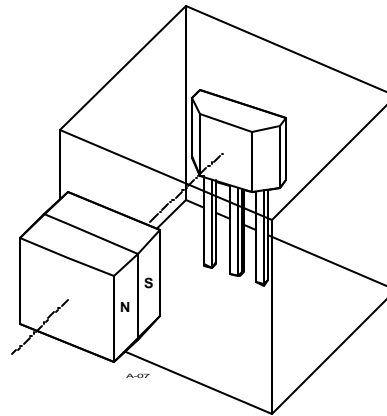
Interrupt Switch

When the Hall IC and magnet are fixed, the Hall IC can be activated using a ferrous vane. This system, composed of a Hall IC, magnet and ferrous vane is called an interrupt switch. In the interrupt switch the magnet is positioned so the South pole turns ON the switch while the Hall IC and magnet positions are fixed relative to each other. When a vane made of a ferrous material is placed between the magnet and Hall IC, the magnetic field is shunted or reduced to a very small fraction of the maximum field, turning the switch OFF. This vane is shown in Figure 5 as a notched interrupter. This switch is an effective way to sense position.

Figure 5, Interrupt Switch

In Figure 5A, the South magnetic pole is exposed to the Hall IC through the vane, so the switch turns ON. In figure 5B, the switch turns OFF because the magnetic field is blocked by ferrous material.

Figure 5A   **Figure 5B**

3-5   *Section 3 - Applications*
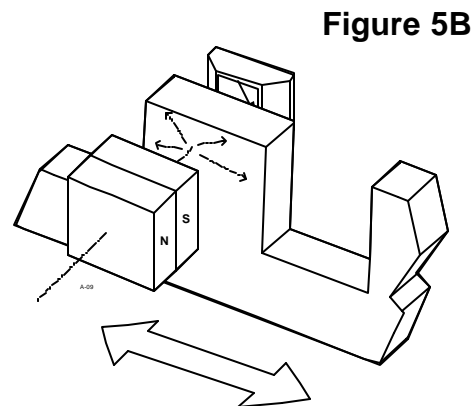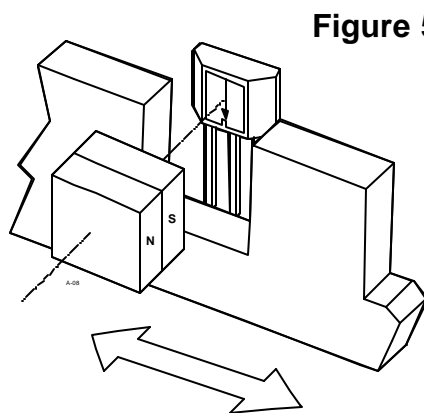
Rotary Interrupt Switch

The interrupt switch can be incorporated in applications of speed or position sensing, generally of rotating objects. The Rotary Interrupt Switch, in Figure 6, uses a toothed ring to interrupt the magnetic field reaching the Hall IC. When a solid piece of steel (ferrous vane) blocks the magnetic field, the switch turns OFF. During the gaps, or spaces in the steel, the South magnetic pole turns ON the switch. This is the system commonly used for automotive ignition and many industrial applications, where accurate position is critical.

Figure 6, Rotary Interrupt Switch

Figure 6 uses a notched
interrupter on a rotating
shaft to activate the device.
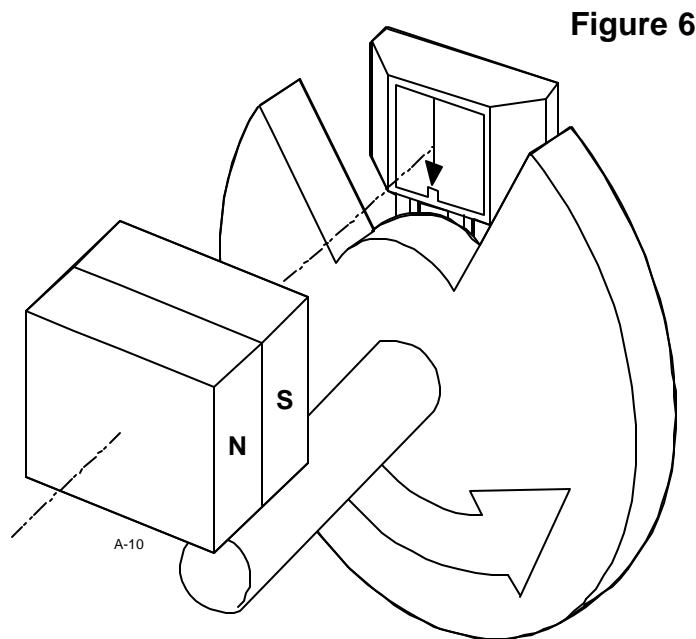
Figure 6

Figure 7, Rotary Slide-by Switch
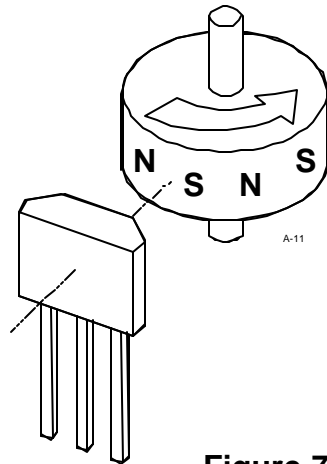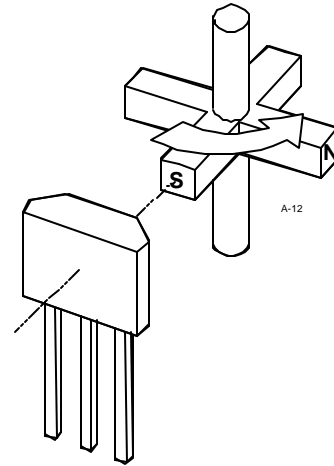
Figure 7A   **Figure 7B**

The Rotary Slide-by Switch in Figure 7 is generally used to measure rotary speed to synchronize switching with position. The Hall IC is activated by a rotating magnet. When the South pole passes by the Hall IC, the IC is switched ON. As the North pole passes, the Hall IC is switched OFF. The solid circular magnet, shown in Figure 7A, is called a Ring Magnet. A ring magnet has alternating North and South poles. Ring magnets may have from two poles to thirty-six or more, depending on size. Graph 1, below illustrates the transition between North and South polarity at various air gaps. Notice the transition point is similar at the various gaps.

Graph 1, Rotary Slide-by vs. Air gap

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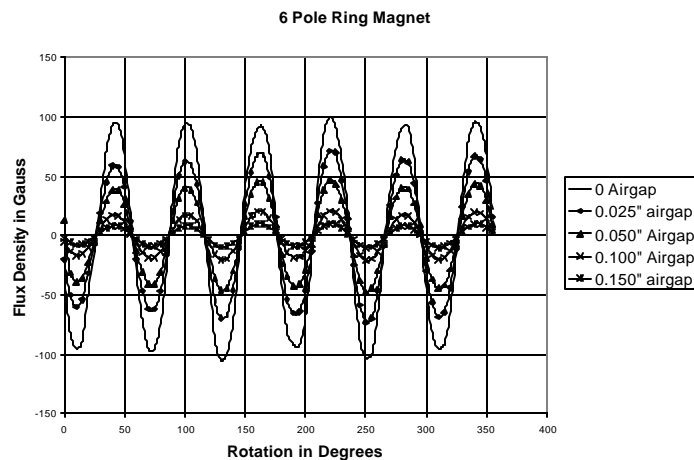
Working With Magnetic Fields

How Do They Work?

A magnetic field will convert electrical energy to mechanical energy, attract ferromagnetic objects and serves as an input for Hall-Effect Sensors. A magnetic field is described in terms of **flux**. Flux lines are imaginary lines of magnetic force, originating at the North pole of a magnet and ending at the South pole of the magnet. These lines represent the physical force exerted by the magnet. When these magnetic flux lines pass through a plate of semiconductor material, electrons are forced to one side of the plate resulting in a voltage potential. This phenomenon is known as the Hall-Effect.

Flux density is measured in units of Gauss or milliTesla. The intensity of the magnetic field depends on many variables, such as cross-sectional area, length, shape, material and ambient temperature. Each one of these variables must be considered when designing the Hall Effect sensor integrated circuit and magnetic system for your application. The following section is intended to explain some fundementals which are useful in Hall Sensor designs and applications.
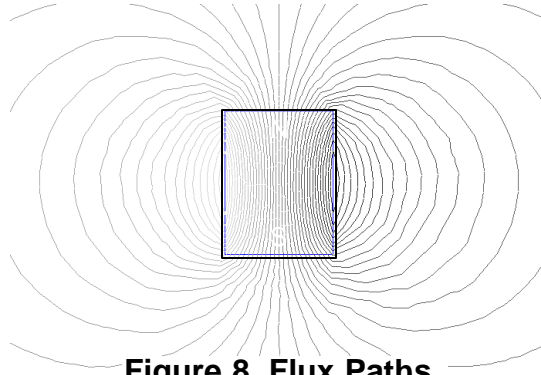
Figure 8, Flux Paths

Figure 9, Magnetic Spectrum

	Bio Signals									Strongest Electro Magnet	
				Earth's Field	Rare Earth Magnets (Neo, SmCo)					Solar Flares	
					Alnico Magnets						
					Ferrite Magnets						
					Ceramic Magnets						

SQUIDs
(Superconducting Quantum Interface Devices)

Reed Switch

Fluxgate Magnetometer

Nuclear Magnetic Resonance

Giant Magnetoresister

Inductive Sensors

Magnetoresister

Hall-Effect Sensors

| .000001 | .001 | .01 | .1 | 1 | 10 | 100 | 1K | 10K | 100K | **Gauss** |
| .0000001 | .0001 | .001 | .01 | .1 | 1 | 10 | 100 | 1K | 10K | **milliTesla** |

Evolution of Magnetics

Modern society would not exist in its present form if not for the development of permanent magnet technology. Many of the major advances in the last century can be traced to the development of yet better grades of magnet materials. The earliest magnets were naturally occurring iron ore chunks mostly originating in Magnesia hence the name *magnes*. We now know these materials to be Fe3O4, a form of magnetite. Their unique properties were considered to be supernatural. Compasses based on these *magnes* were called *lodestones* after the *lodestar* or guidestar. They were highly prized by the early sailing captains.

The Pioneers

More sophisticated magnets did not come into use until the 15th century when **William Gilbert** made scientific studies of magnets and published the results. He found that heating iron bars and allowing them to cool while aligned to the earth's field would create a stronger magnet than a naturally occurring lodestone. His magnet technology however remained a curiosity until the 19th century when **Hans Christian Oersted** developed the idea that electricity and magnetism were related. He was the first to determine that magnetic fields surround a current carrying wire. It would require the development of atomic particle theories before scientific explanations of permanent magnets made further advances. The practical applications for magnets continued throughout the 19th century.

Magnetism in a solid object seems to defy rational explanation. The magnetism is developed in a manner similar to electrons moving through a coil of wire, magnetic fields are created by electrons in motion around the atomic nucleus. This nuclear model of an atom with electrons spinning in orbit around a nucleus provides a source of charges in motion. In most materials however, the number of electrons moving in one direction equals that moving oppositely and hence their magnet fields cancel. This results in no overall magnetic field for the material. It takes many electrons spinning in the same direction to generate a measurable field. Unfortunately there are kinetic forces at work causing atoms to constantly vibrate and rotate resulting in random alignment. The higher the temperature the more kinetic energy and the more difficult it is to maintain alignment. Fortunately soldsme materials exhibit an electrostatic property known as exchange interaction which serves to maintain parallel alignment of groups of atoms. This force only works over short distances amounting to a few million billion atoms. This may sound like a large quantity but on an atomic scale it is a relatively small amount. These groups are known as dipoles and are the fundamental building blocks that determine the properties and behavior of permanent magnet.

Relative Magnetic Properties

Magnets and magnetic materials are classified by many terms which describe many different properties, some of which are explained and used in this book. Perhaps the most commonly asked question about a magnet is "How strong is it?" Although this can lead to a complex explanation, Figure 9 is an excellent guide to the relative strength of magnetic forces, from strongest magnetic forces known such as solar flares to the nearly undetectable magnetic signals passing through the neuro network of our bodies.

The Hysteresis Curve

A solid block of magnetic material is composed of multiple dipoles wherein the alignment of all of the dipoles results in a constant field of maximum value. This maximum field attainable is known as the saturation field. This condition is obtained by placing a sample of material in a sufficiently strong electromagnetic field and increasing the electric current through the magnetizing coil. As the samples dipoles begin to align a function for the relationship between the magnetizing field and the field in the sample becomes apparent. In the low field levels the slope of the curve is very steep.

This relates to the rapid alignment with the magnetizing field of a majority of dipoles. As current levels increase

linearly the number of dipoles aligning decreases. The result is a shallow slope to the function curve. At some point, related to the material properties, increases in current through the magnetizing coil will not increase the value of the field in the magnet. This is the **saturation value** for the material. When the external magnetizing field is removed the magnetic field value of the sample "relaxes" to a steady state known as the B_r value, or **residual flux value.**

An analogy to charging a battery is appropriate. At some level the battery is fully charged and will not accept any more energy. It is an amazing thing however that the magnet will never lose its charge unless it is subjected to a larger field of opposite polarity, or if the temperature is raised above the point known as the **Curie Temperature.** This temperature varies depending on the material and is specified in all manufacturers data sheets.

In summary we have discussed two of the three forces at work, one the magnetizing force measured in oersteds with cgs units or ampere turns/meter in the SI system. The second is the resultant or induced field in the sample, this is measured with gauss in cgs units and Teslas in the SI system (see Tables 1 and 2, below).

Table 1, Magnetic Units Comparison

Unit	Symbol	cgs System	SI System	English System
Flux	Φ	Maxwell	weber	Maxwell
Flux Density	B	Gauss	Tesla	lines/in^2
Magnetizing Force	H	Oersted	ampere turns/m	ampere turns/in

Table 2, Magnetic Units Conversion

Multiply	By	To obtain
lines/in^2	0.155	Gauss
lines/in^2	1.55×10^{-5}	Tesla
Gauss	6.45	lines/in^2
Gauss	10^{-4}	Tesla
Oersteds	79.577	Ampere turns/m
Ampere turns/in	0.495	Oersteds
Ampere turns/in	39.37	Ampere turns/m

The third is **reluctance** or its' reciprocal permeability, think of this as the magnetic resistance per unit volume of the sample being magnetized. Now that we have a magnetized magnet we can consider what occurs when forces act to de-magnetize it. If we reverse the direction of current flow in the magnetizing coil a negative field is created. As the negative current is increased the dipole alignment is reversed or undone. A curve results which is similar to the magnetizing curve but in mirror image form. When the samples' flux value is completely demagnetized the demagnetizing force at that instant is the coercive force -HC. This force is also measured like the magnetizing force in Oersteds. Increasing the negative current level in the magnetizing coil.

This brings us once again to Br or the residual flux value, the pole orientation is now opposite the first saturation state. Finally reversing the current back to its original direction we can exercise the sample through the curve once more and pass through the +HC value to arrive once again at the Br value. We have now completed the hysteresis loop for the material and can draw a curve relating B to H as shown in figure "y".

Figure 10, Hysteresis Loop

Before magnetic force is applied (current), domains are randomly oriented and no energy is created.

When magnetic force is applied, domains become oriented in the direction of the applied field.

When magnetic force (current) is removed, domains don't completely randomize, therefor retaining some of the energy.

When magnetic force (current) is reversed, and released, the inverse of the above occurs, creating the complete hysteresis loop.
The hysteresis loop is unique to all magnetic materials. This diagram does not illustrate any specific material or magnetic circuit

B_r = residual inductance
H_c = coercive force

This curve is fundamental to characterizing and comparing classes and grades of magnetic materials.
An important aspect of magnetic materials behavior is dependent on the physical arrangement of the magnet in the application. In a motor the permanent magnet is operating in a magnetic circuit with mostly low reluctance paths for the field to circulate through. In many sensor applications however the magnet operates with little or no magnetic circuit. This operating condition is known as open loop operation.

A magnet in a closed high permeability magnetic circuit (an iron bar connecting the north to the south pole) will operate at or near the Br value. A magnet with no pole pieces will operate with a flux density down the demagnetization curve from the Br value, how far down is dependant on the aspect ratio or the ratio of the length to the diameter. Short wide magnets will generate lower flux than tall skinny magnets of the same volume.

The concept of the load line and the operating point on the demagnetization curve will influence many magnetic parameters. These include the flux density available to actuate a sensor and the reversible temperature coefficient.

Temperature Effects

Graphical representations are often used to determine the operating point on the demagnetization curve. Temperature effects on permanent magnets are dependent on the type of material considered. Manufacturers will specify various figures of merit to describe the temperature performance of magnet materials. Among these are the Reversible losses that are represented by Tc. The term refers to the losses in the Br and the Hc. A calculation can show that for every incremental change in temperature the magnet will lose a proportion of its strength. This loss will be recovered completely so long as the temperature does not exceed the Tmax or maximum practical operating temperature in air. The Tmax value is dependent on the magnets operating point on the demagnetization curve. A magnet operating closer to Br can have a higher Tmax. Irreversible losses are described as losses that can only be recovered by re-magnetizing the sample to saturation with an electromagnetic field. These losses occur when the operating point falls below the "knee" on the demagnetization curve. This can occur due to temperature and inefficient magnetic circuit design. An important feature of magnet materials is the Curie temperature, TCurie,. This is a temperature at which the metallurgical properties of the sample are adversely effected. In most applications the ambient temperature can never approach the Curie temperature without completely destroying the electronic components first.

Losses Over Time

Time has minimal effect on the strength of permanent magnets. Long term studies in the industry have shown that at 100,000 hours the losses for Rare Earth Samarium Cobalt magnets were essentially zero and for Alnico 5 were less than 3%. In the case of Rare Earth Neodymium materials the losses are compounded by internal corrosion.

Corrosion & Coatings

It is often necessary to provide coatings to these materials to minimize the corrosion that results from the Iron content. We lay-people refer to this stuff as rust. The options for coatings include epoxies, zinc and nickel. The best of these is nickel however it is slightly magnetic and marginally reduces the available field. Coatings can also be useful with Rare Earth Samarium to minimize "spalling" or the fracture of tiny slivers from the corners of this brittle, hard material.

In many sensor applications these characteristics are of little significance but as with all engineering tasks it is up to the design engineer to know what can safely be ignored and what must be consider for the projects success.

Many texts are available to aid in a complete understanding of magnets. The Magnetic Material Producers Association is a trade group that establishes and maintains standards for basic grades and classes of materials. Their reference booklets are an excellent source for detailed technical data on the various generic classes of materials. Certain manufacturers also provide excellent databooks with helpful applications and design sections. These include Arnold Engineering Company, Magnet Sales & Manufacturing, Magnetfabrik Schramberg, Hitachi Metals; Magnetic Materials Division and Widia Magnettechnik.

Table 3, Magnetic Suppliers

Company Name	Address	Phone & Fax	Types of Magnets
Arnold Engineering Company	300 North West St., Marengo Il 60152	(815) 568-2000 (815) 568-2236	Alnico, Ceramic, Multipole Ring Magnets, Flexible Magnets
Boxmag Magnets	Chester St., Aston, Birmingham B6 4AJ, United Kingdom	(+44) 121-3595061 (+44) 121-3593501	Injection Molded Rings, NdFeB
Crucible Magnetics	101 Magnet Drive, Elizabethtown, KY 42701	(502) 769-1333 (502) 765-3118	Alnico (Cast), Rare Earth
Dexter Magnetic Materials Division	48460 Kato Road, Fremont CA 94538	(510) 656-5700 (510) 656-5889	Magnetic Material Distributor, Ceramic, Alnico, Rare Earth
Electrodyne Company	4188 Taylor Rd., Batavia, OH	(513) 732-2822 (513) 732-6953	Flexible Magnets, Multipole Ring Magnets
Hitachi Magnetics Corp.	7800 Neff Rd., Edmore, MI 48829	(517) 427-5151 (51) 427-5571	Alnico, Cermaic, NdFeB, Samarium Cobalt
Louis Magnet Supplies Ltd.	Hong Kong, China	011-852-2482-33290 11-852-2482-0806	NdFeB
Magnet Applications	415 Sargon Way, Suite G, Horsham, PA	(215) 441-7704 (215) 441-7734	Ceramic, Alnico, NdFeB, Samarium Cobalt
Magnet Sales & Manufacturing	11248 Playa Court, Culver City, CA 90230	(310) 391-7213 (310) 390-357	Ceramic, Alnico, NdFeB, Samarium Cobalt
Magnetfabrik Schramberg	Max Planck Strasse 15, D-78713 Schramberg-Sulgen, Germany	(+49) 7422-5190 (+49) 7422-51960	Hard Ferrite, Samarium Cobalt, NdFeB, Plastic Bonded Ferrite
Magnequench International	6435 Scatterfield Rd, Anderson, IN 46013	(317) 646-5000 (317) 646-5060	NdFeB
Neomet Corporation	PO Box 425, Route 551, Edinburg, PA 16116	(412) 667-3000 (312) 667-3001	NdFeB
Polymag	685 Station Rd. Bellport, NY 11713	(516) 286-4111 (516)286-0607	Alnico, Flexible Magnets, Magnet Sheeting, Ceramic
SG Magnets	Tesla House, 85 Ferry Lane, Rainham, Essex RM13 9XH, United Kingdom	(+44) 1708-558411 (+44) 1708-554021	Ferrite, Ceramic, Molded NdFeB, Alnico
SG Armtek	4-6 Pheasent Run, Newtown, PA 18940	(215) 504-1000 (215) 504-1001	Ferrite, Ceramic, Molded NdFeB, Alnico
Shin Etsu Magnetics	2362 Quame Dr., Suite A, San Jose CA 95131	(408) 383-9420 (408) 383-0203	NdFeB, Samarium Cobalt
Stackpole Magnetic Systems	700 Elk Avenue, Kane, PA 16735	(814) 837-7000 814) 837-0203	Ceramic, Ferrite, Alnico
Sumitomo Special Metals America	23326 Hawthorne Blvd., Suite 360, Torrance CA 90505	(310) 378-7886 (310) 378-0108	NdFeB, Samarium Cobalt
TDK Corporation of America	1600 Fehanville Dr. Mount Prospect, IL 60056	(708) 390-4374 (708) 803-6296	NdFeB, Samarium Cobalt
Tengam Engineering	545 Washington St., Otsego, MI 49078	(616) 694-9466 (616) 694-2196	Plastic Barium Ferrite, Strontium Ferrite, Custom Injection Molded Magnets
Ugimag	405 Elm St., Valparaiso, IN 46383	(219) 462-3131 (219) 462-2569	Alnico, NdFeB
Vacuumschmelze	186 Wood Avenue South, Iselin, NJ 08830	(908) 494-3530 (908) 603-5994	Alnico, NdFeB, Samarium Cobalt
Widia Magnettechnik	Muncher Str. 90, D-45145 Essen, Germany	(+49) 201-7253348 (+49) 201-7253925	Alnico, NdFeB, Samrium Cobalt, Sintered and Bonded Ferrite
Xolox Corporation	6932 Gettysberg Pike, Fort Wayne, IN 46804	(219) 432-0661 (219) 432-0828	Barium Ferrite, NdFeB, Injection Molded Magnets

Choosing A Magnet

Common Magnetic Materials

There are four classes of commercial permanent magnet materials. They are:

Ceramic

Alnico

Neodymium Iron Boron

Samarium Cobalt

Depending on the application at hand, the use of one material over another may have its benefits. The two sample magnets provided with The Melexis Hall Effect Sensor Design Kit are both Neodymium 35 magnets. They have very high flux densities for their size and should be handled with caution. These magnets have been provided to assist in the design and construction of a Hall Effect Sensor System. The square magnet will be referred to as magnet A, while the cylindrical magnet will be referred to as magnet B. Graphs 1 through 4 are constructed using magnets A and B. South poles are marked with a do of red paint.

Melexis provides two types of neodymium magnets in the design kit chosen for low cost and high performance, up to 80^0C. Neodymium is preferred for small-size magnets typically used with Hall ICs. If larger magnet sizes or higher temperature ranges are necessary, Alnico or ceramic would be a better choice of material.

Figure 11, Sample Magnets

Magnet A, Square   Magnet B, Cylindrical
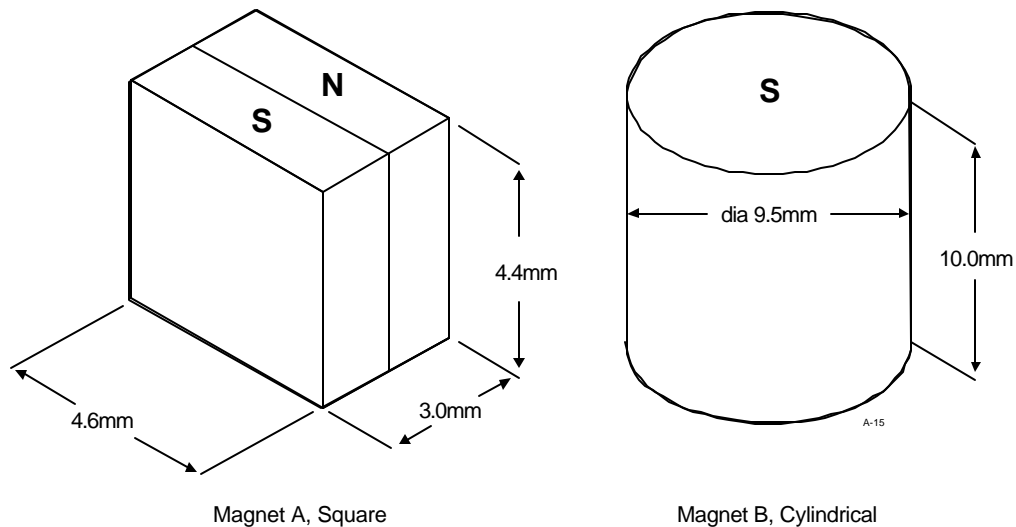
Rare-Earth Magnets

Neodymium Iron Boron

Attributes of Neodymium

Low cost

Very high resistance to demagnetization

High energy for size

Good in ambient temperature

Material is corrosive and should be coated for long-term maximum energy output

Low working temperature

Applications of Neodymium

Magnetic separators

Linear actuators

Servo motors

DC motors (automotive starters)

Computer rigid disk drives

Samarium Cobalt

Attributes of Samarium

High resistance to demagnetization

High energy (magnetic strength is strong for its siz

Good temperature stability

Expensive material

Applications of Samarium

Computer disk drives

Automotive high-temperature environments

Traveling-wave tubes

Linear actuators

Satellite systems

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Alnico Magnets

Attributes of Both Cast and Sintered Alnico (Large Magnets)

Very stable, great for high temperature applications

Maximum working temperature 524^0C to 549^0C

May be ground to size

Does not lend itself to conventional machining (hard & brittle)

High residual induction and energy product, compared to ceramic material

Low coercive force, compared to ceramic and rare-earth materials (more subject to demagnetization)

Most common grades of Alnico are 5 & 8

Applications of Alnico Magnets

Magnetos	Security systems
Coin acceptors	Clutches and bearings
Distributors	Microphones
DC motors	

Ceramic Magnets

Attributes of Ceramic Magnets

High intrinsic coercive force

Tooling is expensive

Least expensive material, compared to Akbuci and rare-earth magnets

Limited to simple shapes, due to manufacturing process

Lower service temperature than Alnico,.greater than rare-earth magnets

Finishing requires diamond cutting or grinding wheel

Lower energy product than Alnico and rare-earth magnets

Most common grades of ceramic are 5 & 8 (1-8 possible)

Grade 8 is the strongest ceramic material available

Applications of Ceramic Magnets

Speaker magnets

DC brushless motors

Magnetic Resonance Imaging (MRI)

Magnetos used on lawnmowers and outboard motors

DC permanent-magnet motors (used in cars)

Separators (separate ferrous material from nonferrous)

Used in magnetic assemblies designed for lifting, holding, retrieving and separating

Table 4, Magnetic Characteristics

Magnetic Material	Density		Maximum Energy Product $BH_{(max)}$	B_r Reversible Coefficient	Residual Induction B_r	Coercive Force H_c	Intrinsic Coercive Force H_{ci}	Maximum Operating Temperature		Curie Temperature	
	lbs/in³	g/cm³	MGO	%/°C	Gauss	Oersteds	Oersteds	°F	°C	°F	°C
SmCo 18	0.296	8.2	18.0	-0.04	8700	8000	20000	482	250	1382	750
SmCo 20	0.296	8.2	20.0	-0.035	9000	8500	15000	482	250	1382	750
SmCo 24	0.304	8.4	24.0	-0.035	10200	9200	18000	572	300	1517	825
SmCo 26	0.304	8.4	26.0	-0.035	10500	9000	11000	572	300	1517	825
Neodymium 27	0.267	7.4	27.0	-0.12	10800	9300	11000	176	80	536	280
Neodymium 27H	0.267	7.4	27.0	-0.12	10800	9800	17000	212	100	572	300
Neodymium 30	0.267	7.4	30.0	-0.12	11000	10000	18000	176	80	536	280
Neodymium 30H	0.267	7.4	30.0	-0.12	11000	10500	17000	212	100	572	300
Neodymium 35	0.267	7.4	35.0	-0.12	12300	10500	12000	176	90	536	280
Alnico 5 (cast)	0.264	7.3	5.5	-0.02	12800	640	640	975	525	1580	860
Alnico 8 (cast)	0.262	7.3	5.3	-0.025	8200	1650	1860	1020	550	1580	860
Alnico 5 (sintered)	0.250	6.9	3.9	-0.02	10900	620	630	975	525	1580	860
Alnico 8 (sintered)	0.252	7.0	4.0	-0.025	7400	1500	1690	1020	550	1580	860
Ceramic 1	0.177	4.9	1.05	-0.20	2300	1860	3250	842	450	842	450
Ceramic 5	0.177	4.9	3.4	-0.20	3800	2400	2500	842	450	842	450
Ceramic 8	0.177	4.9	3.5	-0.20	3850	2950	3050	842	450	842	450

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Magnetic Design

Input Characteristics

Digital Hall-Effect Sensors have specific magnetic response characteristics that govern their actuation from OFF to ON. These characteristics are classified in terms of operate point, release point and differential. The operate point, commonly referred to as BOP, is the point at which the magnetic flux density turns the Hall Sensor ON, allowing current to flow from the output to ground. Conversely, the release point, commonly referred to as BRP, is the point at which the magnetic flux density turns the Hall Sensor OFF. The absolute difference between BOP and BRP is referred to as Hysteresis, Bhys. The purpose of hysteresis is to eliminate false triggering, which can be caused by minor variations in input, electrical noise and mechanical vibration. There are three basic types of Digital Hall Sensors commonly used, as listed below:

Switch - (unipolar) Operates with a single magnetic pole. Guaranteed not to latch ON in the absence of a magnetic field. Opposing field has no effect. Generally used for mechanical switch replace ment.

Latch - (bipolar) responds to both magnetic poles. Turns on in the presence of North or south pole, and turns off only when the opposing field is sufficiently strong. Guaranteed to latch. Used primary ily in brushless DC motor applications.

Bipolar Switch - (unipolar or bipolar) described as a device which responds to the zero-crossing from North to South poles

The Hall-Effect Latch

The latch is a type of Hall IC which remains in either state (output ON or Off) until an opposite pole magnet is applied. A South magnetic pole turns the device ON (BOP). The device will stay ON until a North magnetic pole is applied and turns it OFF (BRP). Melexis manufactures two types of Hall Effect latches. designated for .2.2V to 18V operation. The US2880 series of Hall Effect Latches are designed for high sensitivity. For more information refer to the data sheet section of this manual.

The Hall Effect Switch

There are two types of Hall Effect Switches, unipolar. The unipolar switch is normally "OFF" in the absence of a magnetic field. The device turns ON (BOP) in the presence of a sufficiently strong South magnetic pole, and turns OFF BRP) in the presence of a weaker South magnetic pole. MELEXIS manufactures the US5881UA and US5881SO Hall Effect Switches. For more information refer to the data sheet section of this manual.

Magnetic Design Considerations

When designing a magnetic circuit, there are five considerations to be covered:

1. Cost of Hall IC, Magnet and Assembly
2. Temperature Range
3. Position Tolerance of Assembled Parts
4. Position Switching Accuracy
5. Tolerance Buildup

Cost

Hall IC cost will vary depending on the temperature specifications of BOP, BRP and Bhys. A loosely specified device may easily be one half to one third the cost of a tightly specified device, yet perform the same job. By providing steep slopes of flux density vs. distance and using strong magnets, the Hall IC cost may be reduced.

Temperature Range

Hall Effect Sensors are categorized into different temperature ranges for the use in application-specific design. It is very important that the Hall IC you select complies with your system's ambient temperature.

Position Tolerance

Depending on the application and how it is assembled, the position of components, such as the magnet, Hall IC and mechanical assembly, will determine the mechanical variations of the system. Some systems are more tolerant of changes in air gap and lateral motion than others.

Position Switching Accuracy

The requirement in angular (degree) or linear position ultimately governs the magnetic circuit and Hall IC specifications. That is if switching must repeat $\pm$0.1250in. or $\pm$0.1mm then the Hall IC specification will be much tighter than if the specification is $\pm$1.00 or $\pm$1.0mm.

Tolerance Buildup

Tolerance buildup is the sum of all the variables that determine the operate point and release point of a Hall IC. These variables include position tolerance,temperature coefficient, wear and aging of the assembly and magnet variations.

Total Effective Air Gap

As mentioned previously, both Magnet A and Magnet B in the design Kit are composed of the same material. Although the two magnets have similar characteristics, due to the difference in size and shape total Effective Air Gap (TEAG) will have different effects on each magnets' flux density vs. distance curve.

TEAG is defined as the sum of active area depth and the distance between the Hall IC's branded face to the surface of the magnet. TEAG = Air Gap + Active Area Depth. Active area depth is simply the distance from the branded face of the sensor to the actual Hall Cell within it. The TEAG should be as small as the physical system will allow, after taking into consideration factors such as the change in air gap with temperature due to mounting, vane or interrupt thickness and wear on mounting brackets.

Graph 2 is given to show the effects of air gap on the slope of a graph using a single-pole slide-by configuration with magnet A.

Graph 2, Slide-by Method with Magnet A Steep Slope vs. Shallow Slope
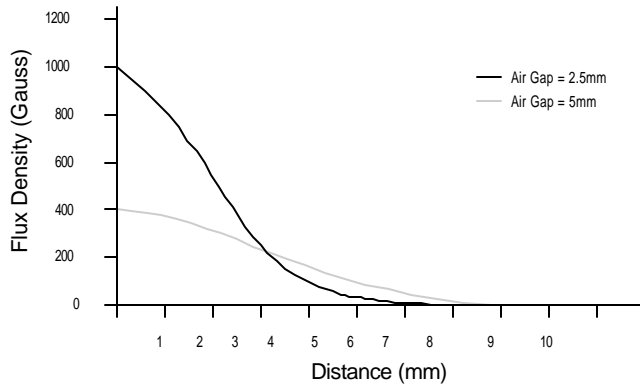
Graph 2 shows what happens to the slope of a flux density vs. distance graph by using different air gaps with the same magnet configuration.

Tolerances Build-up

The following examples incorporate many different factors in order to show how tolerance buildup can affect a Hall Effect system. Air gap tolerance, temperature range, and the temperature coefficient of the magnet will cause the activation distance of a US5881 EUA to vary, thus impacting switching accuracy.

Tolerances:

Air gap Tolerance = 3mm. ±1 mm. and 6mm. ±1mm.
US5881EUA B_{OP}/B_{RP} Range = 95G min. B_{RP} to 300G max. B_{OP}
(IC Temperature Selection (EUA) = -40°C to 85°C)
Temperature Range = -40°C to 85°C
Magnet Temp. Coefficient = -0.1098%/°C

The US5880 Hall-Effect Switch has a maximum BOP of 250 Gauss and a minimum BRP of 140 Gauss. If this part were to be actuated by sample Magnet B at an air gap of 3mm and 6mm, the following results would occur (See Graphs 3 and 4). Each graph has an air gap tolerance of ±1mm which could be due to a loosely fitted mechanical assembly. Notice the difference in distance and slope between Graphs 3 and 4.

Graph 3, Slide-by With Magnet A, Shallow Slope

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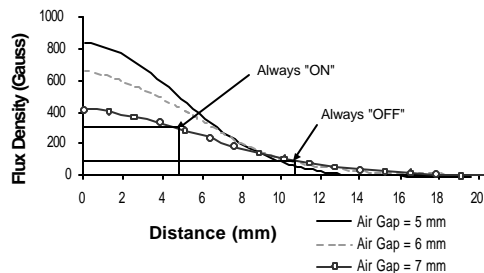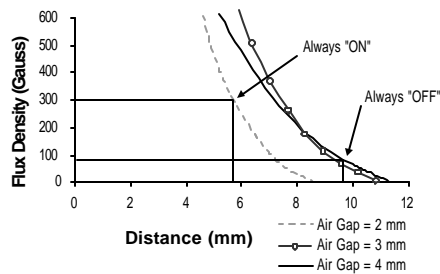
Graph 4, Slide-by With Magnet B, Steep Slope

The effects of mechanical tolerance on a Hall Effect System have just been illustrated. Temperature range can also affect this system. Temperature will expand or contract the mechanical assembly, but will also affect the field strength of the magnet and the distance from BOP t BRP of the Hall IC. The Neodymium sample magnets used in this kit have a temperature coefficient of -).1098%/0C. This means that as temperature increases by one degree Celsius, the Flux Density will decrease by 0.1098%.

Graph 5, Effects of Temperature on Flux Density
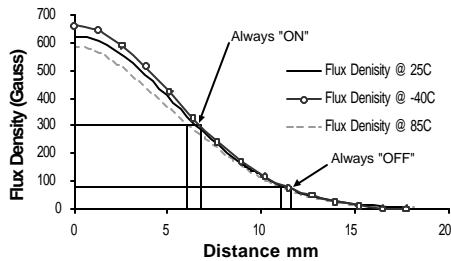
Due to the temperature coefficient, the magnet will have a difference in flux density of 30% and a change in activation distance of 1mm over this range of temperature. This may not appear tobe a significant difference in field strength or distance, but in conjunction with other mechanical factors, temperature could become a factor.

Design Example 2: Now that Design Example 1 illustrated the effects of mechanical, magnetic and Hall IC tolerances within a Hall Effect System. Design Example 2 illustrates how they produce tolerance buildup.

Tolerances:

Air Gap Tolerance = 2mm +0.5mm
US5881EUA BOP/BRP Range = 90G min. BRP to 300G max. BOP
(IC Temperature Selection (EUA) = -40oC to 85oC)
Temperature Range =-40oC to 85oC
Magnet Temp. Coefficient = -0.1098%/oC

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Sample Magnet A is used in the double-pole slide-by method to show the variation air gap may have in a mechanical system. These changes in air gap may be caused by factors such as vibration, wear, etc... Note the differences in each air gap's slope and maximum flux density. As the air gap distance becomes larger, a decrease in flux density slope will cause less accurate switching in a Hall Effect System. Graph 9
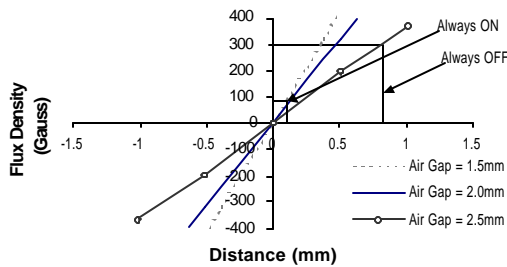
Graph 6, Slide-by with Sample Magnet A Air Gap Tolerance
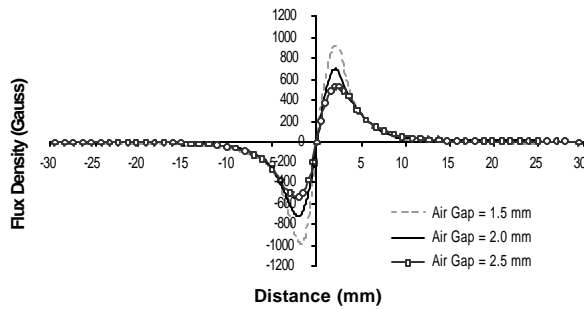
By zooming in on the previous graph, min. BRP and max. BOP of the Hall Effect System can be shown in greater detail and will also reveal the differences in activation distance at each air gap. See Graph 10.

Graph 7, Slide-by with Sample Magnet A
Change in Activation Distance with Air Gap

The plotted lines in Graph 7 do not include the effects of temperature. Graph 8 shows how temperature will change the magnet's flux density characteristics over the selected operating temperature range (-40^{0}C to 85^{0}C), thus affecting the activation distance at min. B_{RP} and max. B_{OP}. To simplify the graph, only the 2mm air gap is plotted.

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Graph 8, Slide-by with Magnet A
Change in Activation Distance With TC
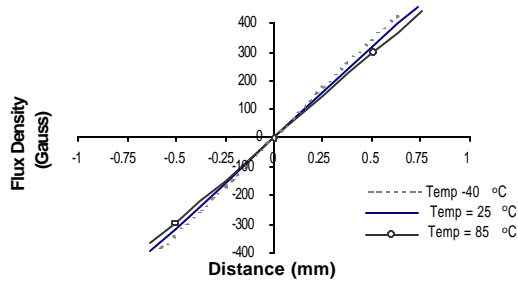
There is a 17% difference in flux density over the entire temperature range compared with the fixed-temperature case in Graph 7. Note that because of the negative temperature coefficient of the magnet, the negative temperature (-40°C) adds flux density to the magnet, while the positive temperature (85°C) reduces flux density.

Graph 9 shows how the air gap tolerance and temperature coefficient add together and cause tolerance buildup in the Hall Effect system.

Graph 9, Slide-by Method with Magnet A
Change in Activation distance with Air Gap & TC
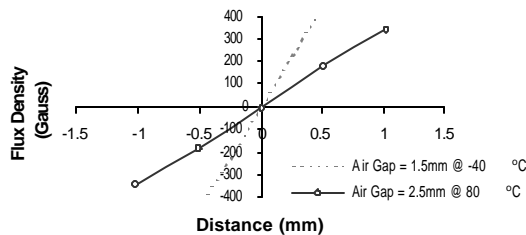
The two plotted lines in Graph 9 show the minimum and maximum possible cases when temperature and air gap are considered. The overall difference in distance between min. BRP and max. BOP is slightly larger because of the sum of tolerances being considered. This design example has shown the tolerance buildup of air gap, benefits of slope, Hall IC BOP to BRP variations and magnet Tc. We have not considered the variation of initial flux density, which you must obtain from a magnet supplier.

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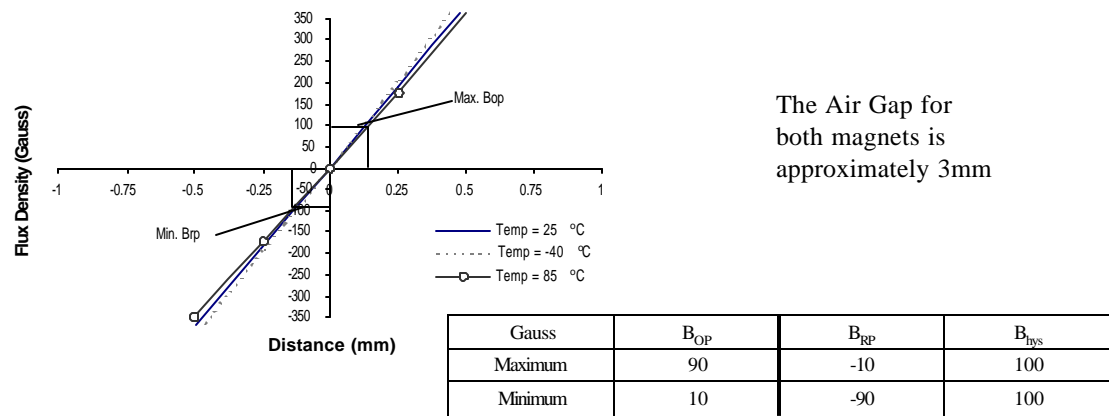
The Push-Pull Method

Graph 10 shows the push-pull method. A South magnetic pole, perpendicular to the branded face, is used in conjunction with a North magnetic pole at the opposite face. The two magnets in the single-pole slide-by configuration are moved in the X-direction with respect to a stationary Hall IC.

Graph 10, Push-Pull Activation Using Slide-by Method with Magnet A
The Push-Push Method

The Air Gap for both magnets is approximately 6.3mm
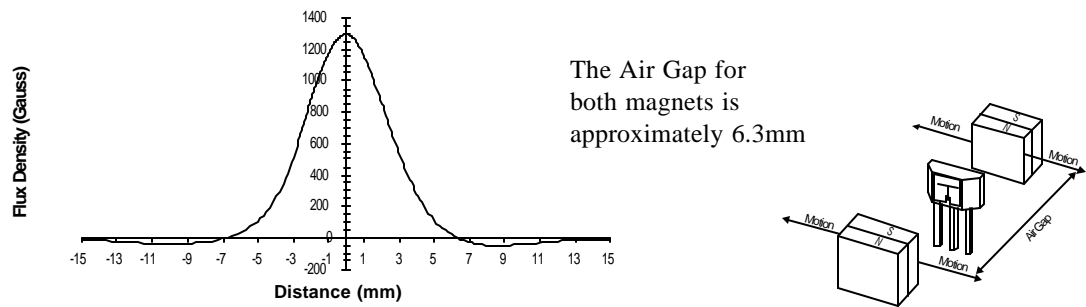
The push-push method is similar in configuration to push-pull, but requires a South pole located at the branded face along with a South pole at the opposite side of the Hall IC. When the Hall IC is centered between these two South magnetic poles, their flux density cancels out leaving zero flux density at this position. If the two magnets maintain the same distance between each other and are moved in the head-on method in either direction, the flux vs. distance graph will be linear.

Graph 11, Push-Push Activation Using Head-On Mode

The Air Gap for both magnets is approximately 3mm

| Gauss	B_{OP}	B_{RP}	B_{hys}
Maximum	90	-10	100
Minimum	10	-90	100

The US3881EUA Hall Effect Latch has maximum BOP of 90 Gauss and a minimum BRP of -90Gauss over the temperature range of -400C to 850C. Due to the temperature coefficient of -0.1098%/0C, the magnet will have a difference in flux density of 8% over this distance range. The distance necessary to fully actuate a US3881EUA Hall Effect Latch is approximately 0.35mm from max. BOP to min. BRP. This is an extremely large increase in performance from the previous example.

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Biased Operation

Biased operation is a method of controlling the magnetic field surrounding a Hall IC and is quite similar to the Push-Push Method. For example, if a South Pole were attached to the reverse side of a Hall Effect Switch, the Hall IC would be held on the "OFF" position until a South pole of a larger magnitude is introduced to the branded face of the sensor and cancels out the opposing magnetic flux. This can be a very important concept if a Hall IC were located within an electronic system with other opposing magnetic fields. It will ensure that the Hall Sensor cannot switch accidentally. Figure 11 is an example of the bias method. In Figure 11, the push-button uses a bias magnet to ensure that the button is in the Off position until being pressed. When the button is pressed, the magnet adjacent to the branded face moves in the head-on configuration closer to the Hall IC. This positive flux density will cancel out the negative flux density provided by the bias magnet, eventually turning the button ON. Once the button is released, the two opposing South magnetic fields will repel each other and send the button to its original OFF position.

Figure 11, Push-button with Bias Magnet

If the US5881 Hall Effect Switch were tobe used in this bias magnet configuration, this switch would remain in the OFF position until the button is pressed. If the magnet adjacent to the branded face of the Hall IC has an air gap of 2.0mm before being pressed, the switch will be exposed to a flux density of approximately - 200Gauss. the button will need to be moved a distance of 0.75mm inward to exceed 250 Gauss and turn ON. After being released, the magnets will repel and turn OFF the Hall IC at a distance of 1.7 mm away from the branded face.

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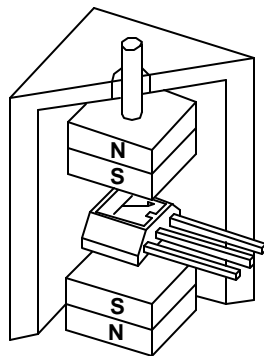
Flux Concentrators

A flux concentrator, or pole piece, is a ferrous material used to significantly increase the performance of a Hall Effect Sensor System. When a flux concentrator is placed opposite the pole face of a magnet, the magnetic field channels through the concentrator, thereby increasing the flux density between the concentrator and the pole face.

Figure 13, Flux Concentrator
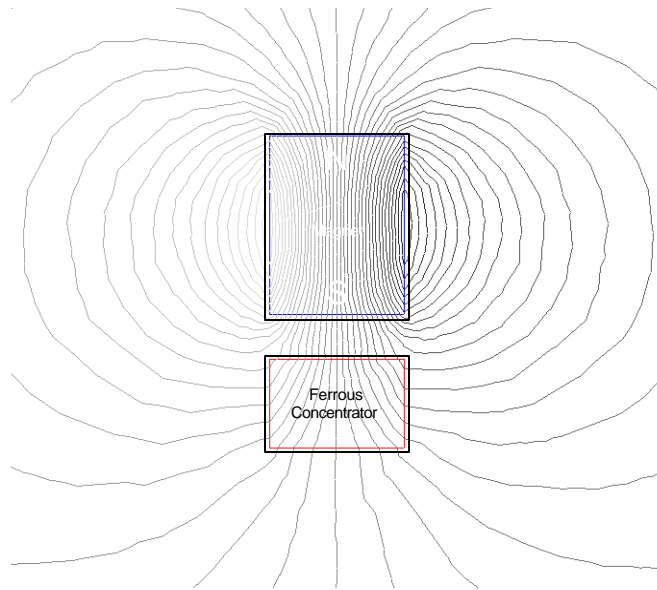
The reason this magnetic flux channels through the concentrator is because of the reluctance of the ferrous material. Reluctance is the resistance that magnetic flux lines experience as they flow from the North pole into the South pole of a magnet. Ferromagnetic materials have lower reluctance than air, therefore a pole piece provides an easier path for the flux to flow through, while increasing the flux density at the same time. There are three benefits to adding a flux concentrator to a magnetic circuit. First, a less sensitive Hall Effect Sensor can be implemented, a result of the increased flux density. The second benefit of using a flux concentrator is that Hall Effect Sensor with a specific operate level can be actuated a greater distance from the magnet, than if one were not in use. The addition of a pole piece also allows the use of a magnet with a lower field intensity. A flux concentrator makes it possible to use a smaller magnet or a magnet of different material to achieve the same operating characteristics as one with higher flux density or a larger size. When choosing materials for a pole piece, pay attention to the following characteristics: The permeability and reluctance of the material will affect its performance as a flux concentrator. Also, pay close attention to the mechanical characteristics of machining and corrosion. These properties are very important when selecting an alloy.

Section 3 - Applications

Electromagnets

Another method of actuating Hall Effect Sensors is through the use of electromagnets. They are especially useful in circuit-breaking or current-sensing applications because their magnetism can be "turned on" or "turned off" at will. An electromagnet consists of a coil of wire which may be wrapped around ferrous material or core. The strength of this magnetic field is dependent on many variables, such as the permeability of the ferrous material, the number of times the coil is wrapped around the material, the amount of current flowing through the coil and the length of the core. These variables are related to each other in the same way for all types of electromagnets, but the formulas differ slightly due to the variance of shape in core material.

Figure 14, Common Electromagnet Shapes

Where: B = magnetic flux density
u0 = permeability of core material
N = number of turns made by coil
i = amount of current in coil
R = mean radius of toroid
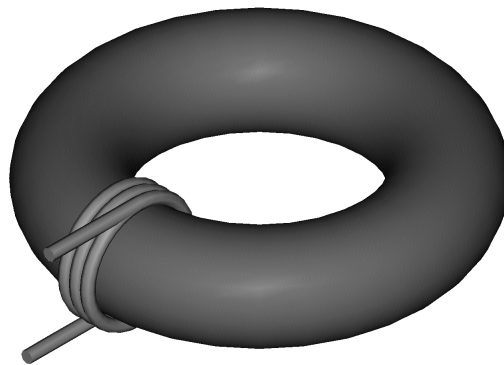
Where:
B = magnetic flux density
u0 = permeability of core material
N = number of turns made by coil
i = amount of current in coil
l = length of cylindrical core
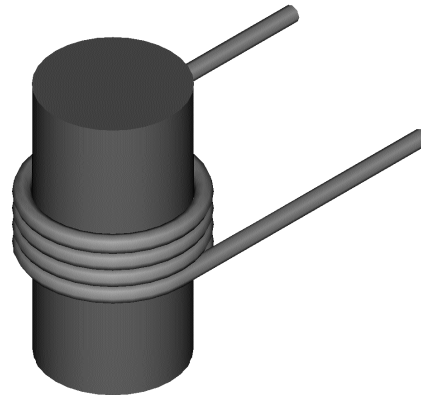
After choosing a core that will physically fit into the proposed current-sensing system, the values of length of radius, permeability and at what value the current limiter is to operate will be known. The operate point and release point for each Melexis Hall IC can be located in the datasheet section of this manual. By knowing this information, it is now possible to calculate how many turns of wire will be required to produce enough flux density to actuate the Hall Effect Sensor. When designing an electromagnet use materials with the following properties: High saturation induction and high permeability will produce strong magnetic fields resulting in a smaller device that will operate with little energy. When an electromagnet is being switched on and off, use a material with a low coercive force for faster magnetization and demagnetization. Also pay attention to magnetic aging and mechanical characteristics such as corrosion. This is

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Measuring Flux Density

The Melexis Hall-Effect design kit is supplied with a linear Hal-Effect sensor which has been calibrated to 1mV/G, making it very easy to build a circuit which will measure flux density. This is done with the fully programmable MLX90215, programmed in this case to deliver exactly 2.5V at zero magnetic field rising 1mV for every 1 Gauss applied.

If a field of 100 Gauss is applied, the output will increase 100mV. Similarly, if a field of -100 Gauss is applied, the output will decrease 100mV. It is very important to maintain a regulated supply voltage of 5V because the output has no internal regulator and is ratiometric. The Hall IC's output is exactly $V_{DD}/2$, so if the supply voltage changes the output voltage also changes.
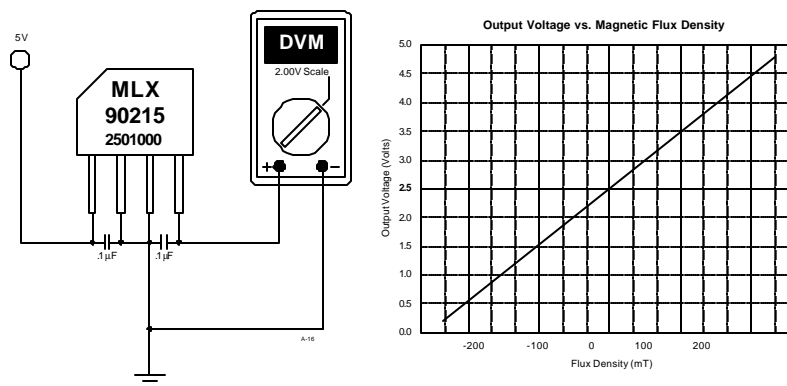
Figure 15, Flux Measurement

Figure 9 shows a circuit which allows the Voltmeter to be calibrated to read in units of Gauss. Shifting the ground reference of the Voltmeter to exactly the quiescent voltage of the Hall IC makes the 2.5V VOQ appear to be zero. The potentiometer allows this to be set to exactly zero. When a magnetic field is applied, the DVM will display units of Gauss in a range of +/- 2000 Gauss. The resistor network is to divide the output voltage by 10 so it can be measured by 200mV meter. If your meter is 2V range, this divider is not used. This circuit can be built into a small case with a battery and voltage regulator for a very inexpensive flux measuring device.

Figure 16, Flux
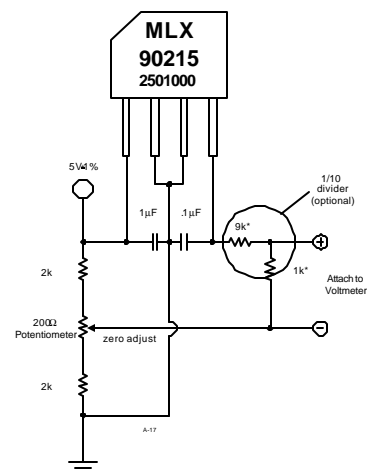
With no divider used:

Full Scale: (2.00V)	+/-2000 Gauss
	+/-200 mT
1 Gauss =	1 mV
1 mT =	0.1 mV

With 1/10 divider used:

|	
Full Scale: (200mV)	+/-2000 Gauss
	+/-200 mT
1 Gauss =	0.1 mV
1 mT =	0.01 mV

1mT = 10Gauss, exactly

Applications

Balance, Level, Vibration, Acceleration

A magnet suspended from a pendulum, free to move in the X - Y plane, may be used to detect level position, acceleration and vibration. Figure 12 shows a magnet with the center as a North pole and an outer ring of South pole. In a level, stable condition, the North pole turns OFF the switch. Motion will cause the magnet to move in such a way that the South pole is over the Hall IC, turning the switch ON. Obviously, the mechanical configuration is not trivial, and will vary greatly depending on the application. Switches like this are used in some washing machines.

Figure 17, Level and Motion Switch

A-18
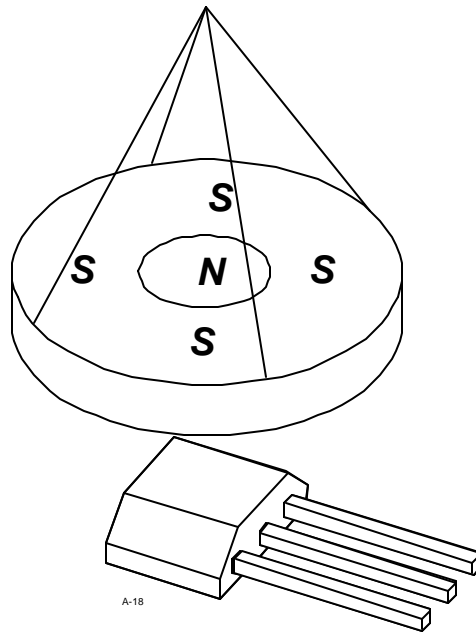
The magnet is free to move relative to the Hall IC.
Any force disturbing the magnet may result in a South pole
facing the Hall IC, resulting in an ON condition

Section 3 - Applications

Programmable Isolated Current Sensor

Hall Effect Sensors can be used in conjunction with an electromagnet to make a very efficient, isolated current-sensing device. This can be used to protect components from damage such as overheating.

The only components needed, as in Figure 13, are a Hall IC and a slotted ferrite toroid core driving an indicator, relay or a logic-level fault signal. The ideal Hall IC in this application is a programmable linear device, which would allow accurate calibration of the sensor and also versatility. For example, the diagram below shows a toroid with 4 turns of wire. If a current of 10A was applied to the coil, the field at the sensor would be about 6mT. The Hall IC can be programmed to give the desired response to this magnetic range. If the desired voltage swing is 0.5V (or 500mV) and the magnetic swing is 6mT, then the device can be programmed to 83mV/mT to give the correct response.

By varying the number of windings and the programming codes, rages as small as 100mA and as large as 500A can be achieved.

If used with a linear Hall-Effect sensor, the output voltage will be proportional to the current flowing through the windings on the toroid. This Voltage can be used to indicate current level, or trigger a shut-down circuit.

Figure 18, Programmable Current Sensor

PTC™
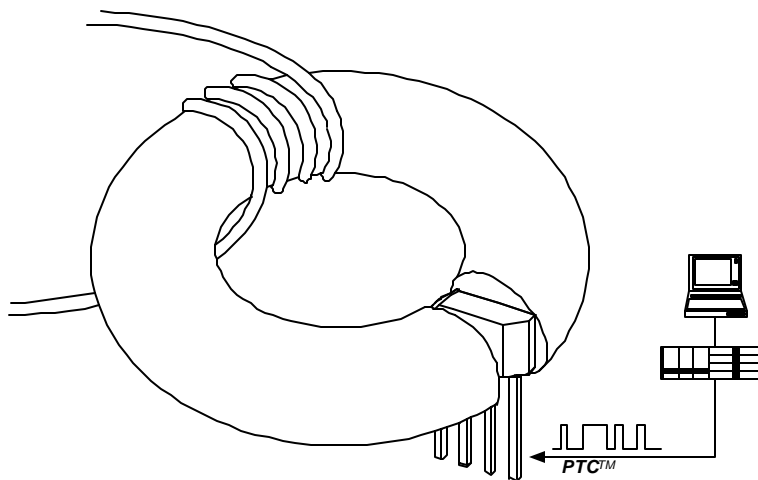
Current Indicator/Limiter

If only a current indicator or limiter is needed, a simple circuit can be built with a Hall switch, and requires no programming. In **Figure 13**, each complete turn of coil around the core, with a current of 1 Amp flowing through it, will produce a flux density of approximately .6 mT upon the Hall Effect Switch. By adjusting the number of coil turns around the core, the Hall Effect switch can act as either a current indicator or current limiter.

Example:

Under normal operation a current of 10 Amps is delivered to a motor by some wire. Wrapping four turns of the wire around the core will produce a magnetic field of 24 mT upon the Hall IC, which will activate the device to ON. This can be used to illuminate an LED to symbolizing "normal" current. The LED will remain ON until the field drops to about 18mT or about 7.5 Amps.
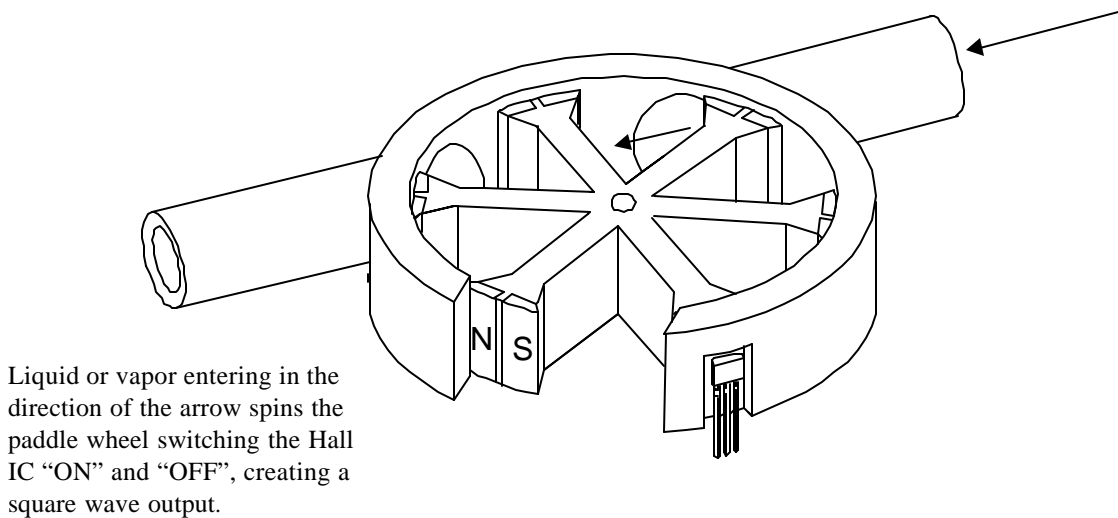
To use as a limiter, simply drop one turn of wire, which will require a higher current to turn the Hall switch ON. With 1 turn removed, the switch will require 13 Amps to turn ON, and will remain on until the current level drops below 1Amp.

Flow Meter

One popular device that uses a Hall IC is a flow meter (Figure 15). The spoked wheel (paddle wheel), is driven by some type of medium flowing through the pipe. A magnet is attached at the tip of each spoke. In the presence of moving vapor or liquid, the magnets spin at a speed related to the viscosity of the medium flowing through the device. The spinning magnets will switch the Hall IC, producing a square wave output, with a frequency proportional to the flow rate.

Figure 19, Flow Meter

Liquid or vapor entering in the direction of the arrow spins the paddle wheel switching the Hall IC "ON" and "OFF", creating a square wave output.

Power Control

Many switches must control significant power. A Hall IC can do this only through a relay or Power FET. For a component cost of $1.00, an isolated 50 Volt, 50 Amp switch can be made.

Figure 20, Power Switch


3-19

Section 3 - Applications
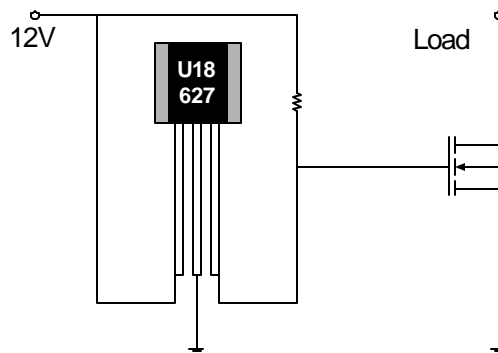
Push-button

The common push-button switch may be rep;aced with a Hall IC and magnet, as shown in two configurations, **Figure 17**. The slide-by case, **Figure 17A**, requires a mechanical return spring, returning the push button after it is depressed, but **Figure 17B** uses repelling magnets to activate the switch and return the push-button.

Figure 21, Push-button
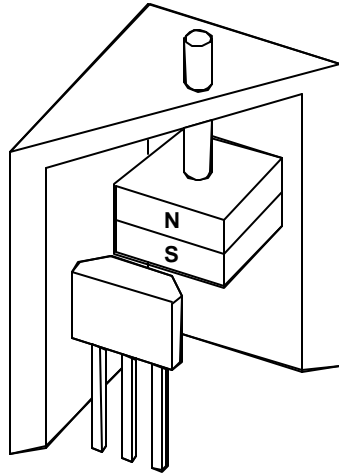
Figure 21A

A mechanical spring is required in order to eturn the button to its off location.
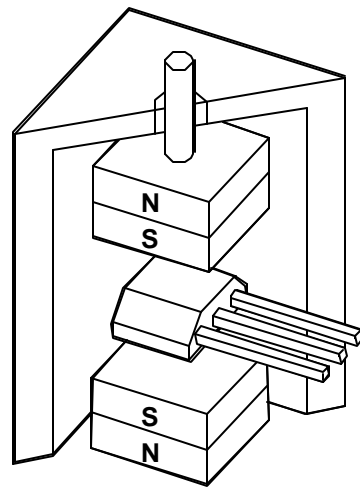
Figure 21B
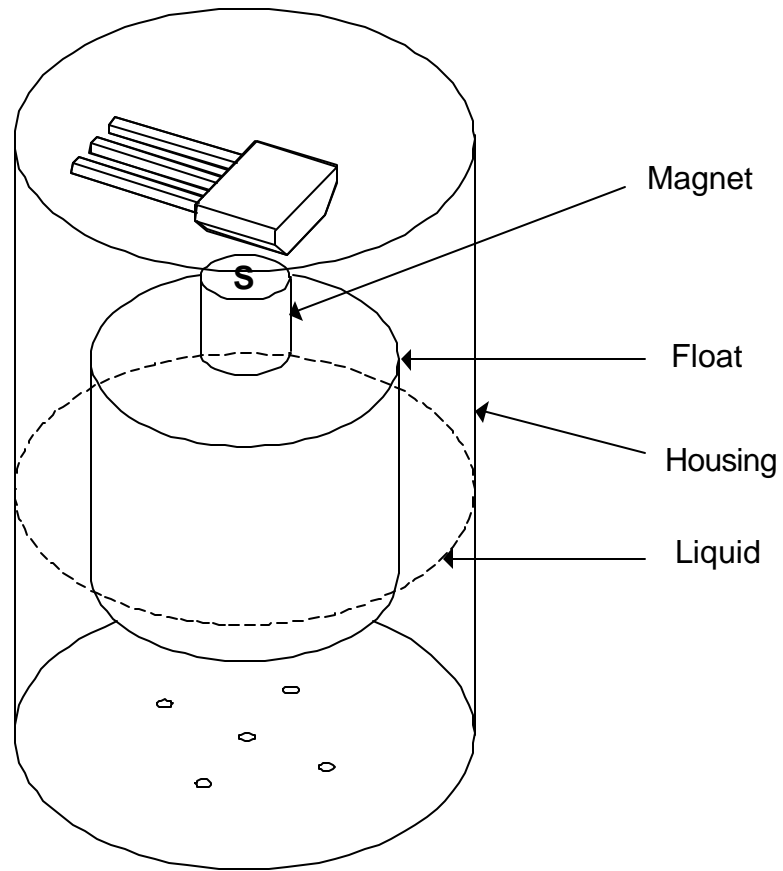
Repelling South poles take the place of a mechanical spring to return the button to

Liquid Level Detector/Alarm

By attaching a magnet to a float, as in **Figure 18**, the proximity method of actuation is used to turn on the Hall IC as the liquid level rises within the housing.

**Figure 22, Liquid Level Detector**

Magnet

Float

Housing

Liquid

Section 3 - Applications

Position Sensor

As shown in **Figure 19**, a hydraulic or air-piston is moved downward until reaching the specified position set by the Hall IC. This could be a useful application in robotic assembly machines, where accuracy of position is extremely important.

Figure 23, Position Sensor

Sealed Compression Chamber

Piston

Magnet

Hall IC

S
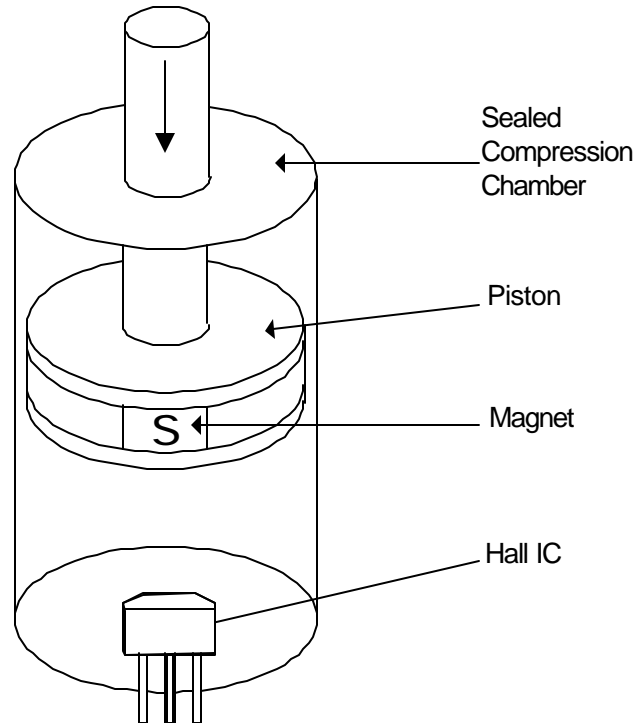
Geartooth Sensor
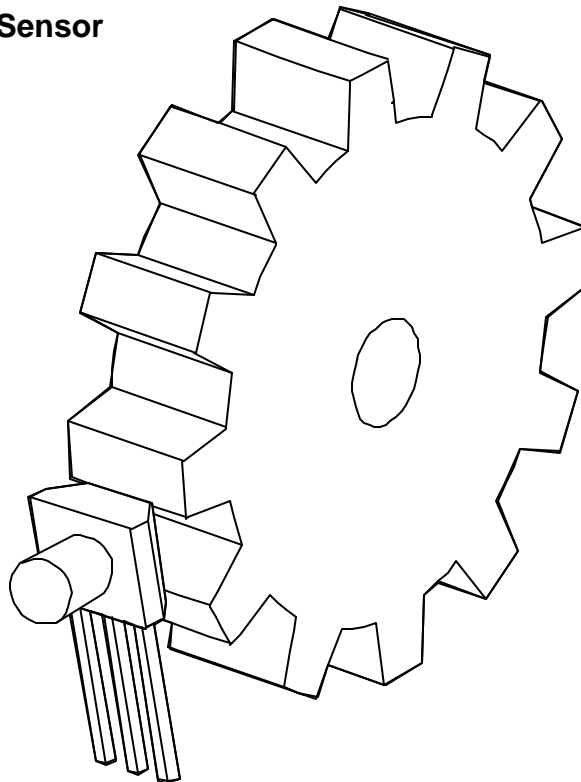
Magnetic Geartooth Sensing

The need to sense speed and position of ferrous gears occurs in numerous industries. The ability to convert the repetitive passing teeth to an electrical impulse has been sought for many decades. purely mechanical systems have been used with the attendant issue of wear and failure limiting its use to low speed and low duty cycle applications.

Hall-Effect geartooth sensing makes use of the Hall element to sense the variation in flux found in the air-gap between a magnet and passing ferrous gearteeth. A modern approach is to convert the signal from the Hall element to a digital value and then perform signal processing to create a digital output from that effort. In the case of the Melexis geartooth sensing scheme each time the signal changes direction a counter is reset. If the signal level changes beyond the preset magnitude from the positive or negative peak the output level is changed. This creates a digital zero speed peak detection speed sensor. It is immune to orientation requirements and cab follow the gear speed down to the cessation of motion. It will detect the first edge of the next tooth after immediately after power on. The digital signal processing does introduce an uncertainty from quantization that is greater at larger speeds. Extremely demanding timing requirements like those found in crank position sensors may suffer from the loss of accuracy at high speeds. Figure 24 shows the Melexis MLX90217 geartooth sensor operation.

Figure 24, Geartooth Sensor

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Gear Tooth Sensor Magnetics

In order to detect the passing gear teeth with a Hall effect sensor it is necessary to provide a source of magnetic energy. The simple way to do this is to arrange a permanent magnet such that the axis of magnetization is pointing toward to surface of the gear teeth. As a tooth moves across the surface of the magnet the flux will become attracted to the lower reluctance path provided by the ferrous steel structure. When this occurs the flux density measured by the Hall element between the face of the sensor and the gear tooth increases. Many schemes have been developed and some patented that use the various attributes of the vector flux field and its changing nature to create zero speed Hall effect gear tooth sensors. Melexis has chosen to work with digital signal processing schemes and in this way minimize the magnetic circuit manipulation required of the end user. Put simply, by applying silicon "smarts" the magnetic subtlety and slight of hand is nearly eliminated.

Figure 25, Geartooth Flux Transitions
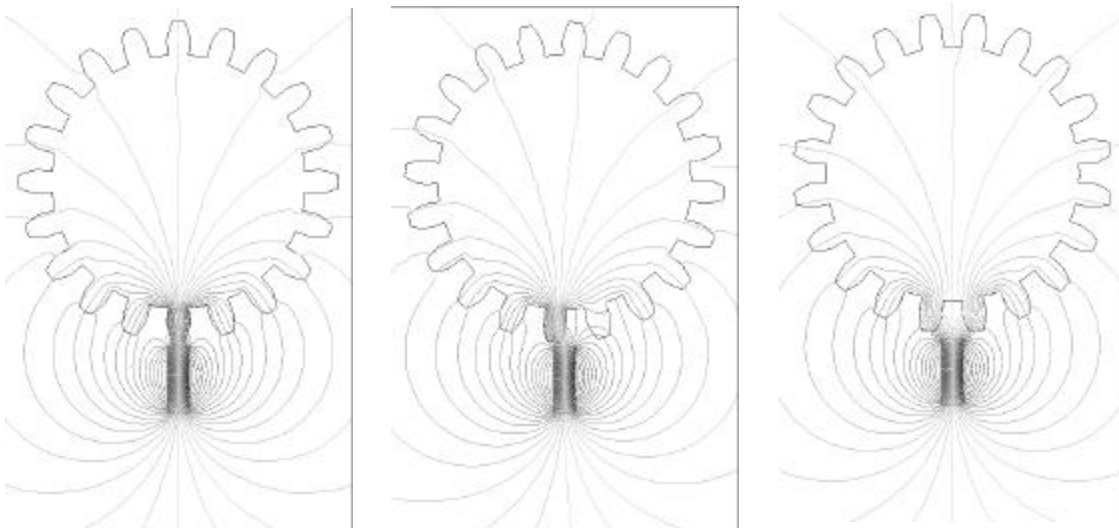
Magnetic modeling courtesy of AnSoft^{TM} magnetic modeling software.

Brushless DC Motor Sensors

The use of Hall Effect Sensors in DC motors eliminates the friction, electrical noise and power loss associated with other types of mechanical commutation, such as brushes. Hall ICs provide a long maintenance-free life and offer greater flexibility with respect to direst interface with digital commands.

Figure 26, Brushless DC Motor Sensor
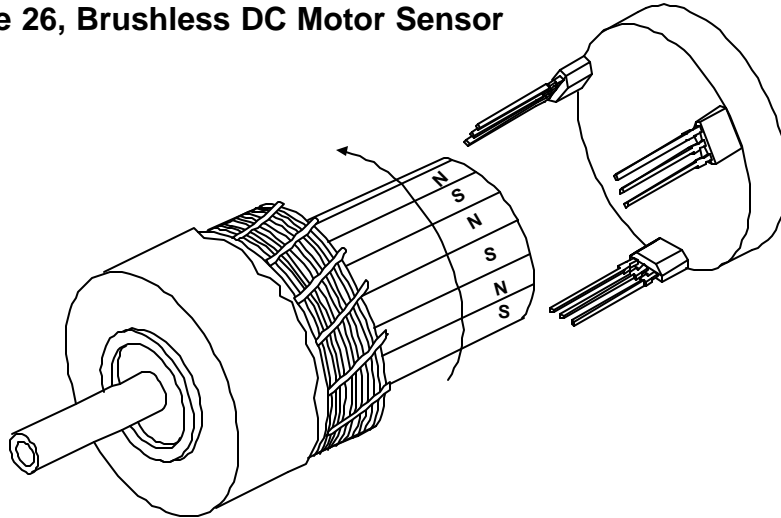
Figure 26, Brushless DC Motor Controller

The US8881 is a brushless DC motor driver that was designed to meet the needs of high volume, low cost motors which do not require the expensive options needed for servo or other closed loop applications. The US8881 works with 3 HallIC latches, and provides all motor control via 6 external N-channel FETs. A complete datasheet for this device is in section 4 of this book.

Figure 26, Brushless DC Motor Controller
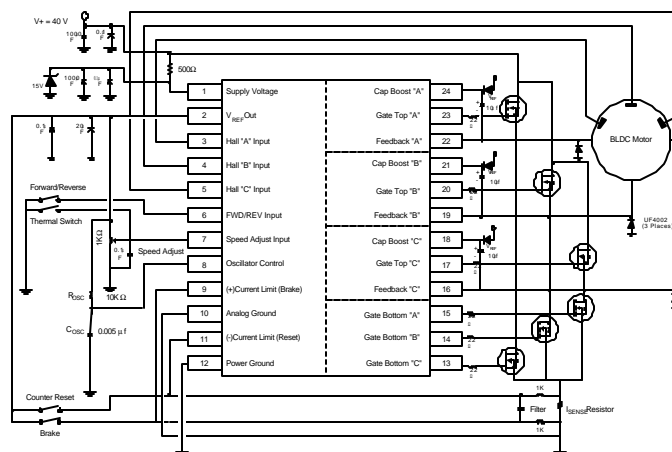
Programmable Motion Sensors

The use of Hall-Effect Sensors as an alternative to resistive potentiometers is a popular trend because of the advantages of non-contacting elements. in the past, linear Hall ICs were not very practical because of bad temperature prformance and the ned for disctete trimming methods.

Melexis created it's programmable linear Hall ICs to solve both problems, leaving the end-user a very accurate sensor which is stable over temperature.

The configurations are infinite, shown are two basic magntic circuits which will allow literally thousands of position sensing applications.

Rotary Motion

Figure 27 is the rotary method, where the Hall Ic is placed within a ring magnet, and the manetic field is linear to the rotary motion. Depending on the magnetic elements, this method can be linear up to 160°, but typically, as shown 45°-90° of linearity can be easily achieved. This configuration is suitable for any rotary position application.

Linear Motion

Figure 28 illustrates a linear position sensor, where a linear motion (as apposed to rotary motion) is translated to a liear voltage via the Hall IC. The magnetic circuit shown is linear for approximately 50% of the entire length of magnet. For example, if the magnets were 1" long, they can be used to measure 1/2" of motion.

Programming

To further enhance the system, the sensors are programmable to give optimal results. Details about programming are available in the MLX90215 and MLX90237 datasheets in section 4 of this book

Figure 27, Programmable Rotary Potentiometer
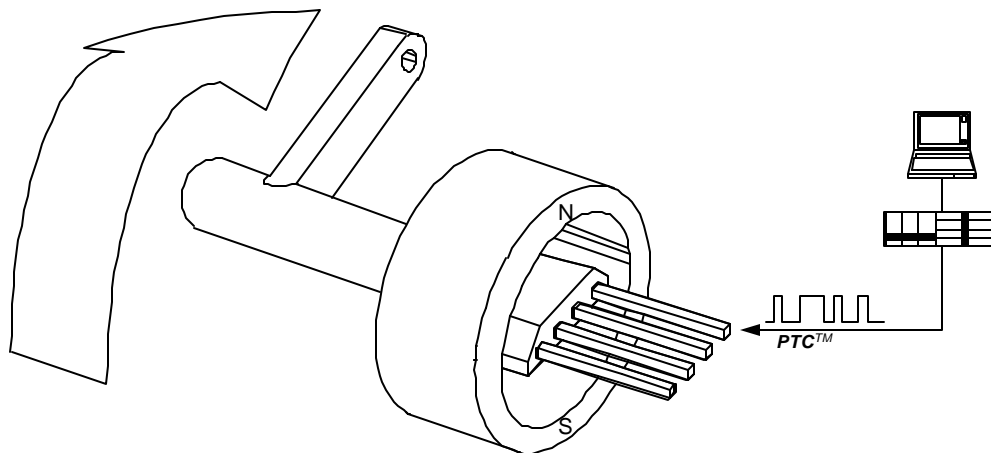
3-25   *Section 3 - Applications*

The use of Hall Effect Sensors in DC motors eliminates the friction, electrical noise and power loss associated with other types of mechanical commutation, such as brushes. Hall ICs provide a long maintenance-free life and offer greater flexibility with respect to direst interface with digital commands.

Figure 28, Programmable Linear Potentiometer
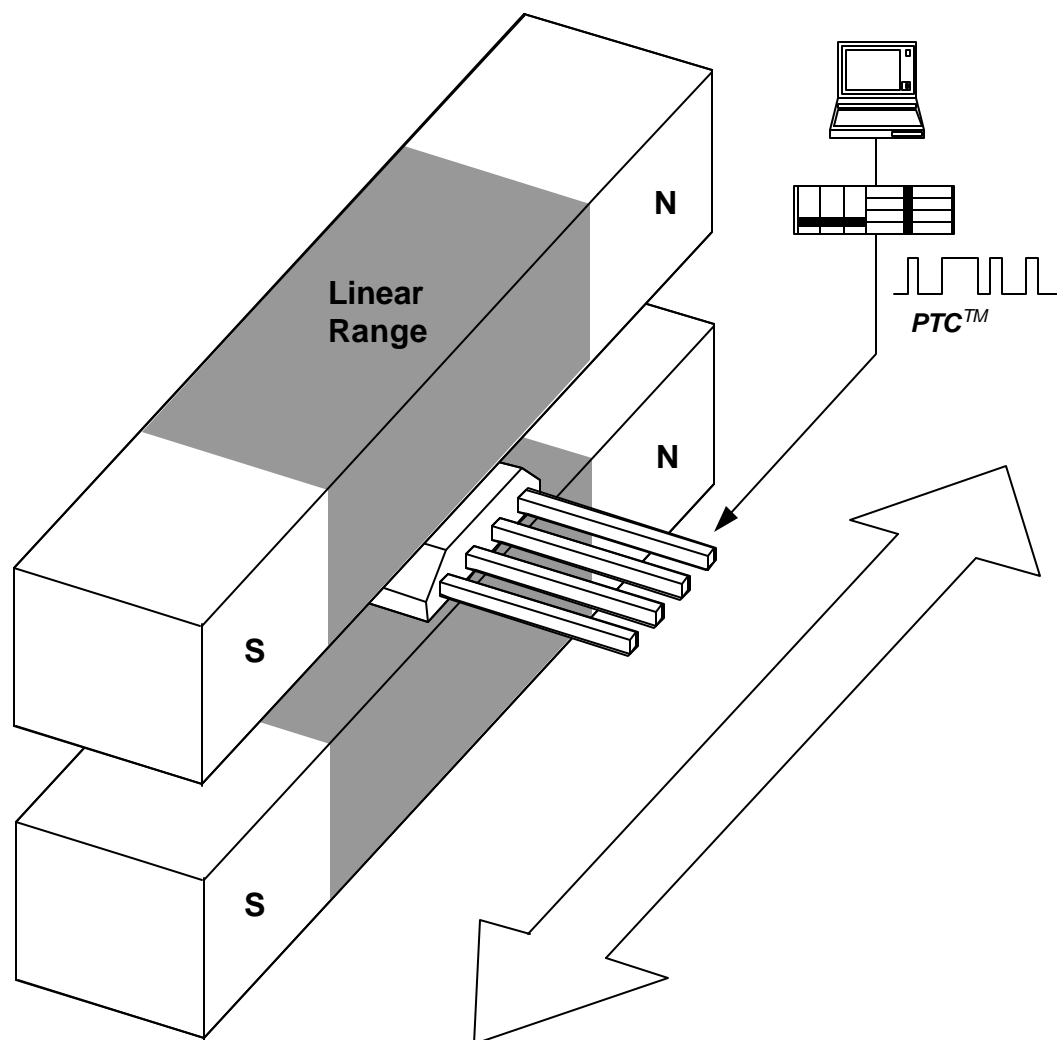
Other Applications

Some additional Hall Effect Sensor applications are listed below:

| Application:	Configuration:	Refer to Figure:
Aircraft/Automotive:		
Tachometer	Ring Magnet, Gear Tooth Sensor	7
Speed Indicator	Ring Magnet, Gear Tooth Sensor	7
Roll Indicator	Linear, Pendulum	12
Planing Angle Indicator	Linear, Pendulum	12
Acceleration Indicator, Linear	Pendulum	12
Fuel or Liquid-Level Sensor	Level Detector	18
Seat Belt Sensor	Proximity Switch	3
Airbag Ejection Sensor	Proximity Switch	3
Power Window Sensor	Proximity Switch	3
Door-Ajar Sensor	Proximity Switch	3
Appliances:		
Water/Liquid Flow	Digital, Ring Magnet	15
Washer Water Level	Digital Float	18
Washer Tilt Sensor	Digital, Pendulum	12
Washing Machine Motor	Latch, DC Motor	20
Air conditioning Blower	Latch, DC Motor	20
Refrigerator, Door Sensor	Proximity Switch	3
Home, Tools and Security:		
Security Door Sensor	Digital Vane Switch	5
Security Window Vibration	Linear, Pendulum	12
Circular Saw Motor	Latch, DC Motor	20
Overload Protection	Current Limiter	13
Digital Combination Lock	Rotary Switch	14
Mechanical Jam Protection	Current Limiter	13
Power controller	Switch with Circuit	16
Exercise Machine Counters	Slide-by Switch	2
Computer Key Pads	Push-button	17
Pinball Machine Buttons	Push-button	17

The Programmable Sensor Interface

A microcontroller sensor interface provides signal conditioning for a sensor element of any kind. Some types of sensor elements that can be used are pressure sensors, strain gauges, load cells, thermistors, and potentiometers (position sensing).

The MLX90308 sensor interface provides control over the offset, gain (or sensitivity), linearity and temperature compensation of the sensor's signal using a microcontroller.

In the past, such conditioning was done through discrete circuits. Such circuits required costly and unreliable trimming methods, not to mention component count on the PC board. Because the MLX90308 is a microcontroller, calibration is done digitally through a standard PC. The MLX90308 contains an 8-bit RISC core microcontroler, analog signal path, supply regulator, and EEPROM for storing compensation coefficients.
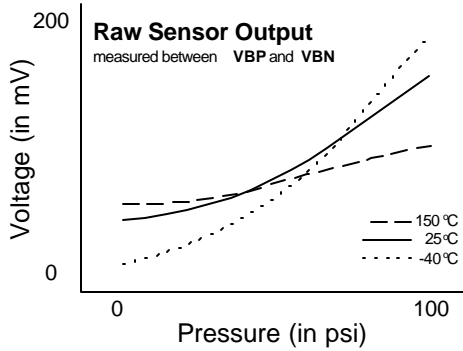
Figure 29 illustrates a fundamental application of the MLX90308 and a bridge type pressure sensor element. In this application, the 90308 uses an external FET as a pass transistor to regulate the voltage to the sensor and the analog portion of the IC. This is known as Absolute Voltage Mode, where voltage to the sensor and analog circuit is regulated, independent of the supply voltage. The 90308 can be operated in Ratiometric Voltage Mode, where the output (VMO) is tied to an A/Dconverter sharing the same Supply and GND reference. A third wiring
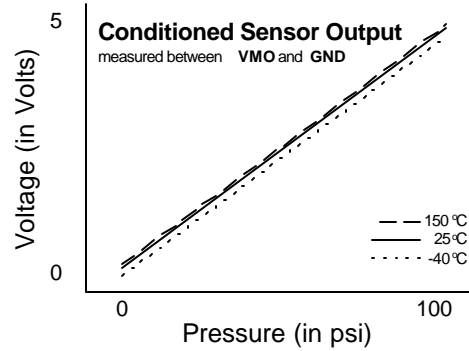
Figure 29 - Oil Pressure Gauge
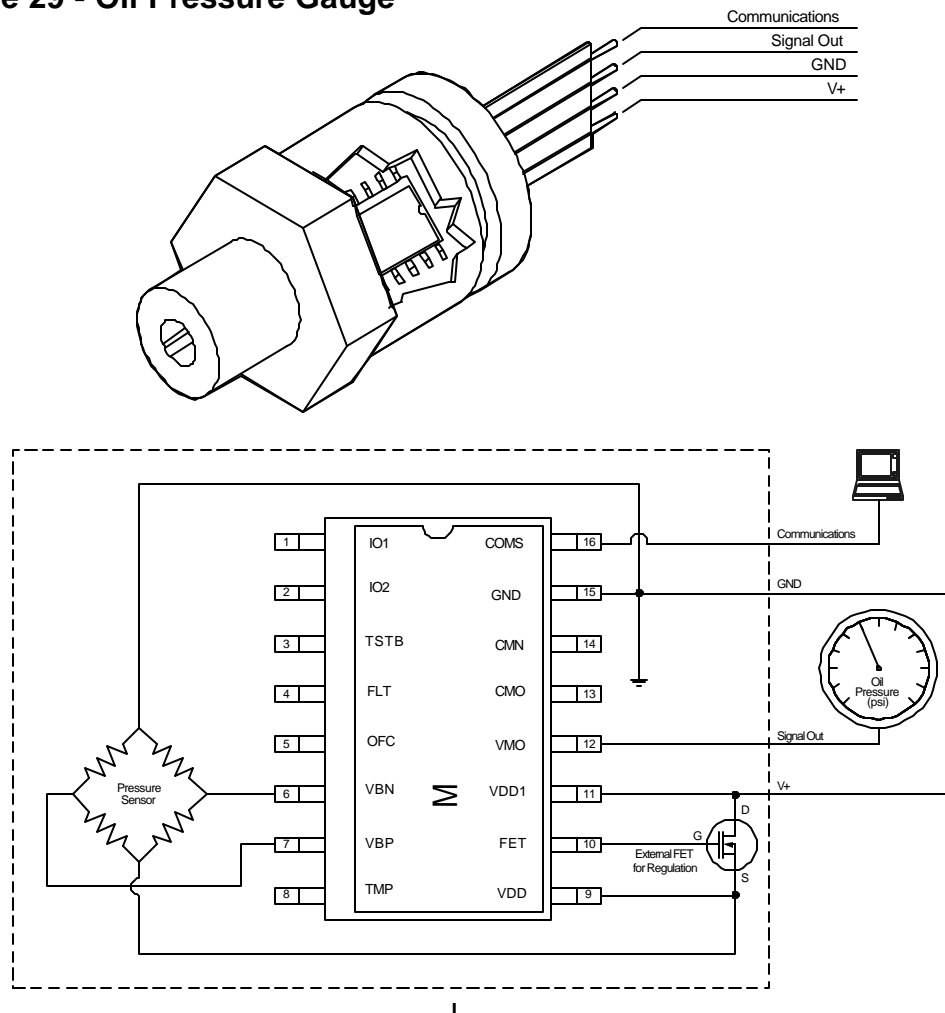
^{Hall Plate} option is Current Mode, which allows the user a 4mA to 20mA current range to use as a 2-wire analog sensor. These wiring examples as well as technical specifications are shown in section 4 of this book.

Figure 30a

Raw Sensor Output
measured between **VBP** and **VBN**

Voltage (in mV): 0 to 200
Pressure (in psi): 0 to 100

- - - 150 ℃
——— 25 ℃
······ -40 ℃

Figure 30b

Conditioned Sensor Output
measured between **VMO** and **GND**

Voltage (in Volts): 0 to 5
Pressure (in psi): 0 to 100

- - - 150 ℃
——— 25 ℃
······ -40 ℃

The figures above illustrate to performance of an unconditioned sensor output and a conditioned sensor output versus stimulus(pressure) and temperature. Notice that figure XXa has a range of only 200mV and has a non-linear response over a 0-100psi range. The sensitivity of the unconditioned output will also drift over temperature, as illustrated by the three slopes. The MLX90308 corrects thes errors and also amplifies the output to a more usable voltage range as shown in figure XXb.

Prototyping with the MLX90308

Melexis has available a MLX90308 evaluation kit which contains an evaluation circuit board, serial interface cable, and software diskette. The circuit board provides the neccessary circuitry for all three applications circuits shown in the MLX90308 datasheet (section 4 of this book). Also contained on theboard is level shifting and glue logic necessary for RS-232 communicatios.

The boaerd has a socket with a single MLX90308 installed, and direct access to the pins of the IC. The user can easily attach bridge sensor to the board for in-system evaluation. The serial interface cable connects the evaluation board directly to a PC's serial port for in-system calibration.

The software runs in the familiar Windows platform and allows for programming and evalution of all compensation parameters within the EEPROM of the MLX90308.

Microcontroller Family Overview

Melexis is offering custom and semi-custom microcontrollers for automotive applications. Custom microcontrollers provide the most cost affective solution by exactly matching the designers needs. Off-the-shelf microcontrollers typically force the customer to pay for features they don't need, or don't satisfy all of the system requirements and drive up the component count. Benefits such as increased reliability and design flexibility are realized using a custom microcontroller. Typical applications are small system control and smart sensor interfaces.

Melexis' custom microcontrollers are based on either an eight or sixteen bit RISC core. These can contain the exact analog and digital periphery the customer needs. Melexis is also embedding sensors on the same die. Chopper stabilized Hall effect sensors and temperature sensors are currently available. To withstand the automotive environment, these microcontrollers are designed to withstand an 80V load dump, -40°C to +150°C operating die temperature, 6V to 26V supply and output shorts to ground or the battery.

Current applications include controllers for dashboard indicators, air conditioning, solenoid valve system, heating system, electric window, sunroof and head cushion position, intelligent relay control, and sensor signal conditioning.

Memory

Versatile memory types and configurations are available. The microcontroller's I/O is entirely up to the customer. Melexis has a number of standard digital and analog interfaces available. Custom interfaces can be developed if needed. Typical implementations include:

	MX11 (8 bit core)	MLX16 (16 bit core)
RAM, (bytes)	128	256 - 512
ROM	2K	8 K
E2PROM	32	128 - 256
I/O(memory mapped)	8	16
PROM	2 K	8 K

Digital Interfaces

Logic I/O, up to 256 eight-bit ports are possible. The outputs can have high voltage (up to 80V), high current (up to 300 mA), or current limited capability. Also, digital outputs can have re-circulation diodes for driving relays.

Other digital function that are available are PWM outputs (0% to 100% duty cycle), timers, UART, watchdog timer and display interfaces.

Custom digital interfaces or functions can be implemented to meet the customer's needs. The logic can be designed by the customer and implemented using VHDL or schematic format.

Analog Interfaces

There is a wide range of analog interfaces that can be integrated with the microcontroller. Multi-channel A/D converters in both 8 and 10 bit resolution . Band gap references for absolute measurements. On chip temperature sensing for compensation of measurements, digital to analog conversion, phase locked loops (PLLs) as well as operational amplifiers and comparators. Oscillators can be implemented either with external frequency defining components or completely internal. Oscillators that are completely internal have frequency controlled from a value stored in EEPROM. Custom analog interfaces are also available to meet the customer's needs.

Power

Maximum power consumption depends on the microcontroller and its exact configuration, clock frequency, loads, etc. The minimum power needed can be as low as 150 μA in a sleep or power down mode with the core still active. Operating supply can be from 6 to 26 volts and load dump protection to 80 volts.

Development Tools

Melexis has developed a tools set and methodology which allows the user to develop their system concurrently with silicon development.

Software

Melexis has a full set of software tools to expedite the firmware development. For developing assembly language firmware, an assembler, linker and loader is used. A C compiler is also available for developing firmware. The firmware development can also be expedited by the software simulator. The simulator allows the developer to run or single step through the code as well as reading and forcing registers and memory locations.

Hardware

A development board is available which contains a processor core with all of the program memory and peripheral interfaces external to the processor. The processor core with the RAM and interrupt controller are contained in one Melexis chip. The firmware is executed from a user programmed PROM or EPROM. Peripheral interfaces and functions are implemented within a Xilinx PLA and discrete components. The PLA can be reprogrammed by the user to develop the exact logic and interfaces needed. In addition to the development board, there is an in circuit emulator (ICE) available. The ICE replaces an external PROM/EPROM and allows control over the program execution flow. The user can start, stop and single step though the program, similar to using the software simulator.

Prototype Devices

Development is also made easier by prototype devices. These devices have the internal busses brought out to package pins. This allows for use of external program memory or ICE while the peripheral interfaces are at their final implementation