

# LMP2011,LMP2012

*LMP2011 Single/LMP2012 Dual High Precision, Rail-to-Rail Output  
Operational Amplifier*



Literature Number: SNOSA71I

# LMP2011 Single/LMP2012 Dual High Precision, Rail-to-Rail Output Operational Amplifier

## General Description

The LMP201x series are the first members of National's new LMP™ precision amplifier family. The LMP201X series offers unprecedented accuracy and stability in space-saving miniature packaging while also being offered at an affordable price. This device utilizes patented techniques to measure and continually correct the input offset error voltage. The result is an amplifier which is ultra stable over time and temperature. It has excellent CMRR and PSRR ratings, and does not exhibit the familiar 1/f voltage and current noise increase that plagues traditional amplifiers. The combination of the LMP201X characteristics makes it a good choice for transducer amplifiers, high gain configurations, ADC buffer amplifiers, DAC I-V conversion, and any other 2.7V-5V application requiring precision and long term stability.

Other useful benefits of the LMP201X are rail-to-rail output, a low supply current of 930  $\mu$ A, and wide gain-bandwidth product of 3 MHz. These extremely versatile features found in the LMP201X provide high performance and ease of use.

## Features

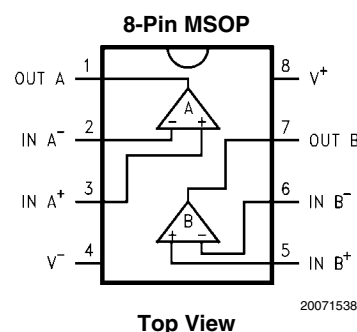
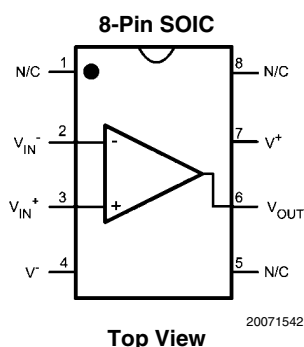
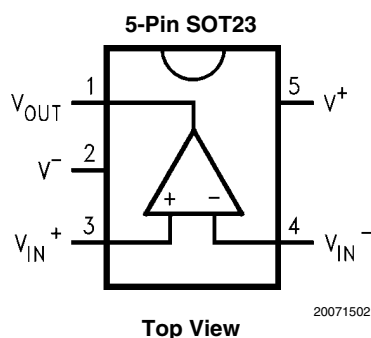
(For  $V_S = 5V$ , Typical unless otherwise noted)

- Low guaranteed  $V_{OS}$  over temperature 60  $\mu$ V
- Low noise with no 1/f 35nV/ $\sqrt{Hz}$
- High CMRR 130 dB
- High PSRR 120 dB
- High  $A_{VOL}$  130 dB
- Wide gain-bandwidth product 3MHz
- High slew rate 4V/ $\mu$ s
- Low supply current 930 $\mu$ A
- Rail-to-rail output 30mV
- No external capacitors required

## Applications

- Precision instrumentation amplifiers
- Thermocouple amplifiers
- Strain gauge bridge amplifier

## Connection Diagrams



## Ordering Information

Package	Part Number	Temperature Range	Package Marking	Transport Media	NSC Drawing
5-Pin SOT23	LMP2011MF	-40°C to 125°C	AN1A	1k Units Tape and Reel	MF05A
	LMP2011MFX			3k Units Tape and Reel	
8-Pin MSOP	LMP2012MM		AP1A	1k Units Tape and Reel	MUA08A
	LMP2012MMX			3.5k Units Tape and Reel	
8-Pin SOIC	LMP2011MA		LMP2011MA	95 Units/Rail	M08A
	LMP2011MAX			2.5k Units Tape and Reel	
	LMP2012MA		LMP2012MA	95 Units/Rail	
	LMP2012MAX			2.5k Units Tape and Reel	

**Absolute Maximum Ratings** (Note 1)

If Military/Aerospace specified devices are required,  
please contact the National Semiconductor Sales Office/  
Distributors for availability and specifications.

ESD Tolerance

Human Body Model 2000V

Machine Model 200V

Supply Voltage 5.8V

Common-Mode Input Voltage  $-0.3 \leq V_{CM} \leq V_{CC} + 0.3V$ Lead Temperature (soldering  
10 sec.) +300°C

Differential Input Voltage

Current at Input Pin 30 mA

Current at Output Pin 30 mA

Current at Power Supply Pin 50 mA

**Operating Ratings** (Note 1)

Supply Voltage 2.7V to 5.25V

Storage Temperature Range -65°C to 150°C

Operating Temperature Range -40°C to 125°C

**2.7V DC Electrical Characteristics**

Unless otherwise specified, all limits guaranteed for  $T_J = 25^\circ\text{C}$ ,  
 $V^+ = 2.7V$ ,  $V^- = 0V$ ,  $V_{CM} = 1.35V$ ,  $V_O = 1.35V$  and  $R_L > 1\text{ M}\Omega$ . **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
$V_{OS}$	Input Offset Voltage (LMP2011 only)			0.8	25 <b>60</b>	$\mu\text{V}$
	Input Offset Voltage (LMP2012 only)			0.8	36 <b>60</b>	
	Offset Calibration Time			0.5	10 <b>12</b>	ms
$TCV_{OS}$	Input Offset Voltage			0.015		$\mu\text{V}/^\circ\text{C}$
	Long-Term Offset Drift			0.006		$\mu\text{V}/\text{month}$
	Lifetime $V_{OS}$ Drift			2.5		$\mu\text{V}$
$I_{IN}$	Input Current			-3		pA
$I_{OS}$	Input Offset Current			6		pA
$R_{IND}$	Input Differential Resistance			9		$\text{M}\Omega$
CMRR	Common Mode Rejection Ratio	$-0.3 \leq V_{CM} \leq 0.9V$	95	130		dB
		$0 \leq V_{CM} \leq 0.9V$	<b>90</b>			
PSRR	Power Supply Rejection Ratio		95 <b>90</b>	120		dB
$A_{VOL}$	Open Loop Voltage Gain	$R_L = 10\text{ k}\Omega$	95 <b>90</b>	130		dB
		$R_L = 2\text{ k}\Omega$	90 <b>85</b>	124		
$V_O$	Output Swing (LMP2011 only)	$R_L = 10\text{ k}\Omega$ to 1.35V $V_{IN}(\text{diff}) = \pm 0.5V$	2.665 <b>2.655</b>	2.68		V
				0.033	0.060 <b>0.075</b>	
		$R_L = 2\text{ k}\Omega$ to 1.35V $V_{IN}(\text{diff}) = \pm 0.5V$	2.630 <b>2.615</b>	2.65		V
				0.061	0.085 <b>0.105</b>	
	Output Swing (LMP2012 only)	$R_L = 10\text{ k}\Omega$ to 1.35V $V_{IN}(\text{diff}) = \pm 0.5V$	2.64 <b>2.63</b>	2.68		V
				0.033	0.060 <b>0.075</b>	
		$R_L = 2\text{ k}\Omega$ to 1.35V $V_{IN}(\text{diff}) = \pm 0.5V$	2.615 <b>2.6</b>	2.65		V
				0.061	0.085 <b>0.105</b>	

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
$I_O$	Output Current	Sourcing, $V_O = 0V$ $V_{IN}(\text{diff}) = \pm 0.5V$	5 <b>3</b>	12		mA
		Sinking, $V_O = 5V$ $V_{IN}(\text{diff}) = \pm 0.5V$	5 <b>3</b>	18		
$I_S$	Supply Current per Channel			0.919	1.20 <b>1.50</b>	mA

## 2.7V AC Electrical Characteristics

$T_J = 25^\circ\text{C}$ ,  $V^+ = 2.7V$ ,  $V^- = 0V$ ,  $V_{CM} = 1.35V$ ,  $V_O = 1.35V$ , and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
GBW	Gain-Bandwidth Product			3		MHz
SR	Slew Rate			4		V/ $\mu\text{s}$
$\theta_m$	Phase Margin			60		Deg
$G_m$	Gain Margin			-14		dB
$e_n$	Input-Referred Voltage Noise			35		nV/ $\sqrt{\text{Hz}}$
$i_n$	Input-Referred Current Noise					pA/ $\sqrt{\text{Hz}}$
$e_{n,p-p}$	Input-Referred Voltage Noise	$R_S = 100\Omega$ , DC to 10 Hz		850		nV <sub>pp</sub>
$t_{rec}$	Input Overload Recovery Time			50		ms

## 5V DC Electrical Characteristics

Unless otherwise specified, all limits guaranteed for  $T_J = 25^\circ\text{C}$ ,  $V^+ = 5V$ ,  $V^- = 0V$ ,  $V_{CM} = 2.5V$ ,  $V_O = 2.5V$  and  $R_L > 1\text{M}\Omega$ . **Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
$V_{OS}$	Input Offset Voltage (LMP2011 only)			0.12	25 <b>60</b>	$\mu\text{V}$
	Input Offset Voltage (LMP2012 only)			0.12	36 <b>60</b>	
	Offset Calibration Time			0.5	10 <b>12</b>	ms
$TCV_{OS}$	Input Offset Voltage			0.015		$\mu\text{V}/^\circ\text{C}$
	Long-Term Offset Drift			0.006		$\mu\text{V}/\text{month}$
	Lifetime $V_{OS}$ Drift			2.5		$\mu\text{V}$
$I_{IN}$	Input Current			-3		pA
$I_{OS}$	Input Offset Current			6		pA
$R_{IND}$	Input Differential Resistance			9		M $\Omega$
CMRR	Common Mode Rejection Ratio	$-0.3 \leq V_{CM} \leq 3.2$ $0 \leq V_{CM} \leq 3.2$	100 <b>90</b>	130		dB
PSRR	Power Supply Rejection Ratio		95 <b>90</b>	120		dB
$A_{VOL}$	Open Loop Voltage Gain	$R_L = 10\text{ k}\Omega$	105 <b>100</b>	130		dB
		$R_L = 2\text{ k}\Omega$	95 <b>90</b>	132		

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
$V_O$	Output Swing (LMP2011 only)	$R_L = 10\text{ k}\Omega$ to 2.5V $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	4.96 <b>4.95</b>	4.978		V
				0.040	0.070 <b>0.085</b>	
		$R_L = 2\text{ k}\Omega$ to 2.5V $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	4.895 <b>4.875</b>	4.919		V
				0.091	0.115 <b>0.140</b>	
	Output Swing (LMP2012 only)	$R_L = 10\text{ k}\Omega$ to 2.5V $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	4.92 <b>4.91</b>	4.978		V
				0.040	0.080 <b>0.095</b>	
		$R_L = 2\text{ k}\Omega$ to 2.5V $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	4.875 <b>4.855</b>	4.919		V
				0.091	0.125 <b>0.150</b>	
$I_O$	Output Current	Sourcing, $V_O = 0\text{V}$ $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	8 <b>6</b>	15		mA
		Sinking, $V_O = 5\text{V}$ $V_{IN}(\text{diff}) = \pm 0.5\text{V}$	8 <b>6</b>	17		
$I_S$	Supply Current per Channel			0.930	1.20 <b>1.50</b>	mA

**5V AC Electrical Characteristics**  $T_J = 25^\circ\text{C}$ ,  $V^+ = 5\text{V}$ ,  $V^- = 0\text{V}$ ,  $V_{CM} = 2.5\text{V}$ ,  $V_O = 2.5\text{V}$ , and  $R_L > 1\text{M}\Omega$ .  
**Boldface** limits apply at the temperature extremes.

Symbol	Parameter	Conditions	Min (Note 3)	Typ (Note 2)	Max (Note 3)	Units
GBW	Gain-Bandwidth Product			3		MHz
SR	Slew Rate			4		V/ $\mu\text{s}$
$\theta_m$	Phase Margin			60		deg
$G_m$	Gain Margin			-15		dB
$e_n$	Input-Referred Voltage Noise			35		$\text{nV}/\sqrt{\text{Hz}}$
$i_n$	Input-Referred Current Noise					$\text{pA}/\sqrt{\text{Hz}}$
$e_{n,p-p}$	Input-Referred Voltage Noise	$R_S = 100\Omega$ , DC to 10 Hz		850		$\text{nV}_{pp}$
$t_{rec}$	Input Overload Recovery Time			50		ms

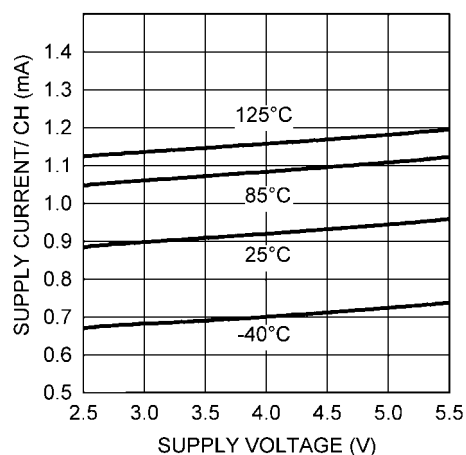
**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage may occur. Operating Ratings indicate conditions for which the device is intended to be functional, but specific performance is not guaranteed. For guaranteed specifications and test conditions, see the Electrical Characteristics.

**Note 2:** Typical values represent the most likely parametric norm.

**Note 3:** Limits are 100% production tested at  $25^\circ\text{C}$ . Limits over the operating temperature range are guaranteed through correlations using statistical quality control (SQC) method.

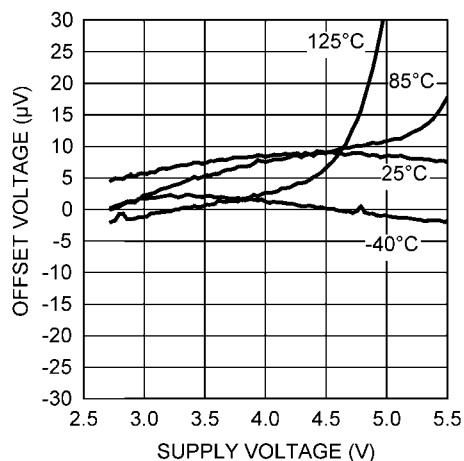
# Typical Performance Characteristics $T_A=25^\circ\text{C}$ , $V_S=5\text{V}$ unless otherwise specified.

## Supply Current vs. Supply Voltage



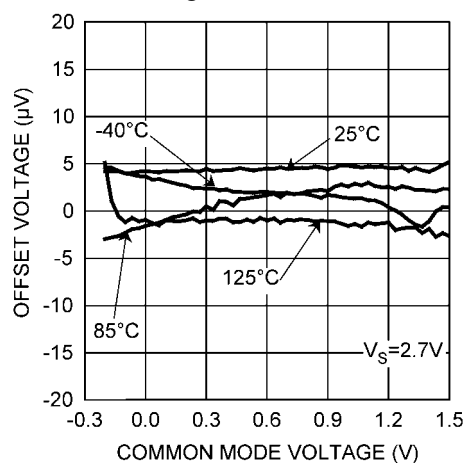
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## Offset Voltage vs. Supply Voltage



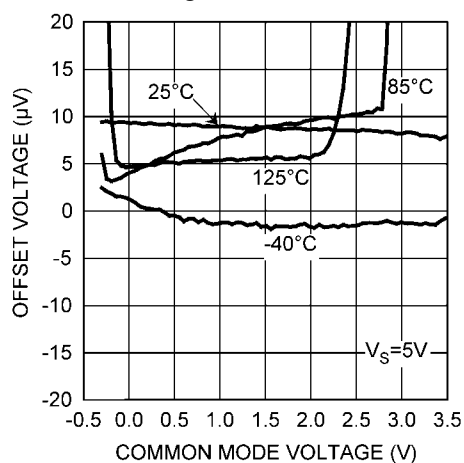
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## Offset Voltage vs. Common Mode



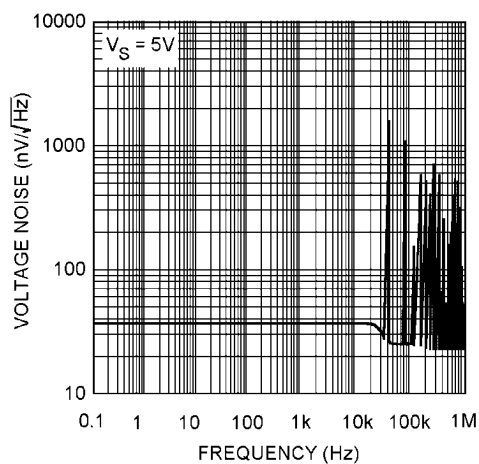
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## Offset Voltage vs. Common Mode



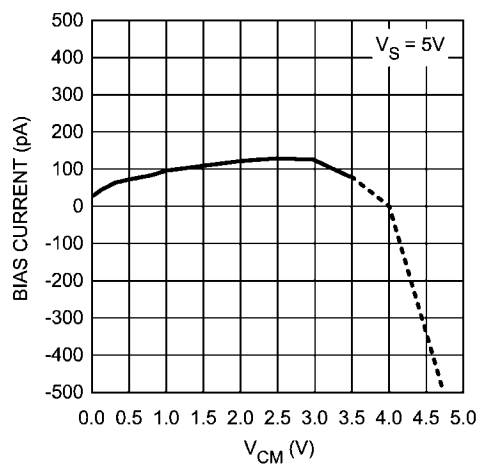
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## Voltage Noise vs. Frequency

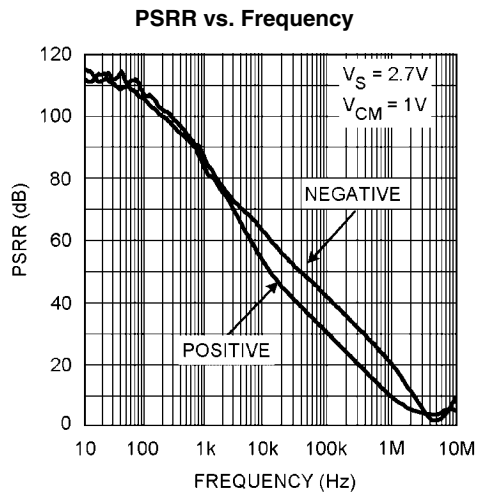


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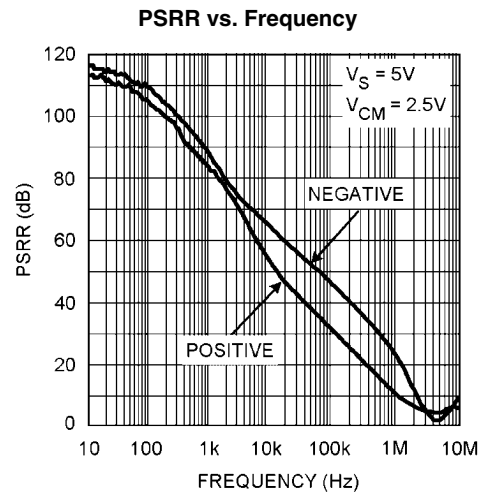
## Input Bias Current vs. Common Mode



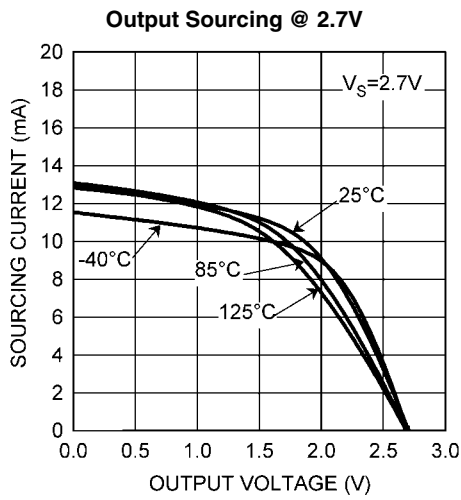
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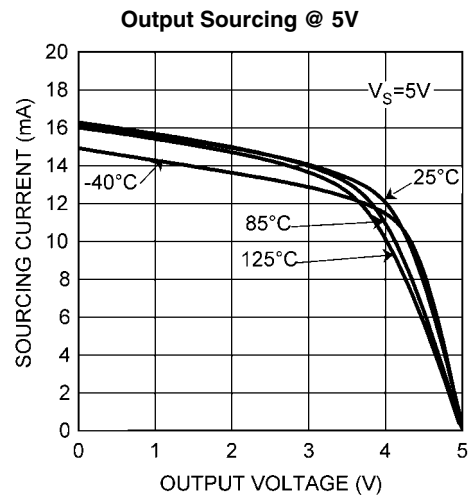
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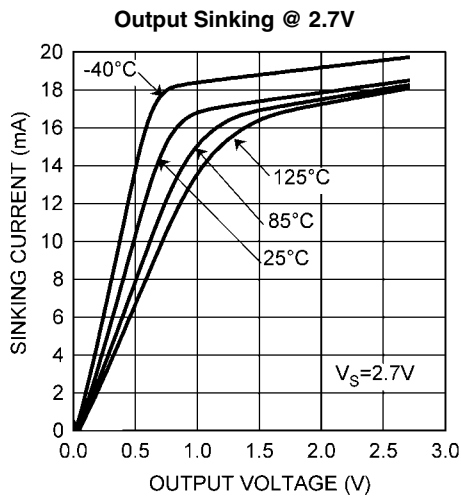
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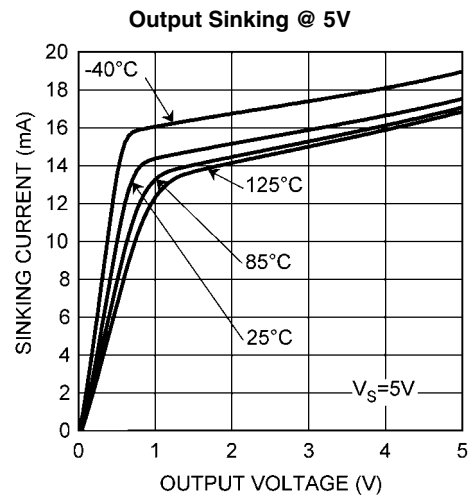
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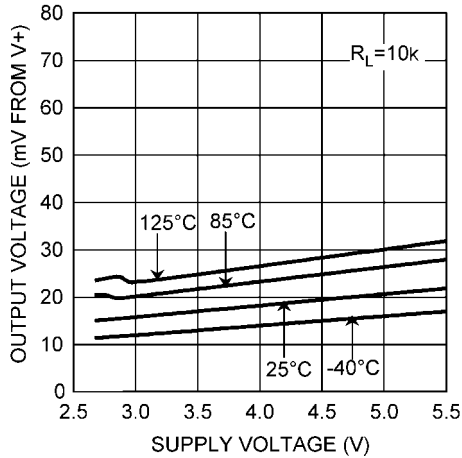


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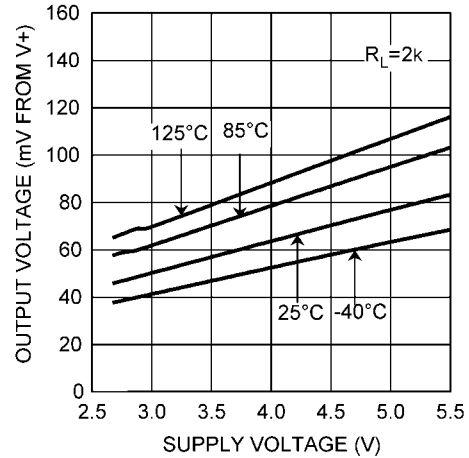
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Max Output Swing vs. Supply Voltage



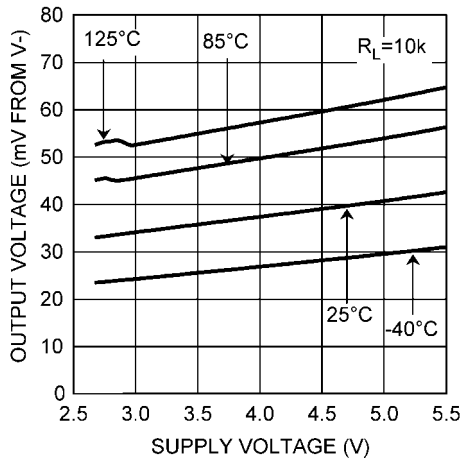
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Max Output Swing vs. Supply Voltage



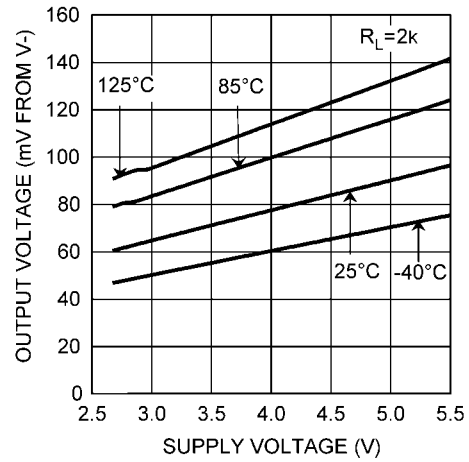
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Min Output Swing vs. Supply Voltage



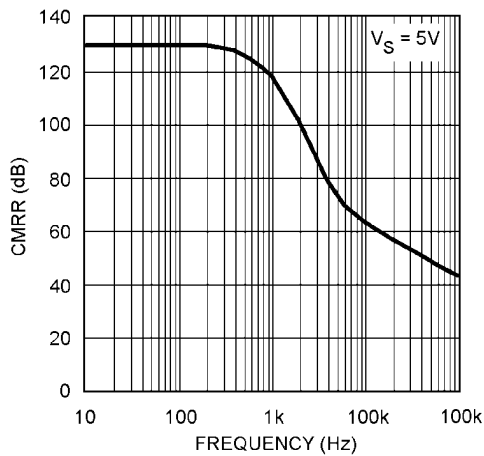
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Min Output Swing vs. Supply Voltage



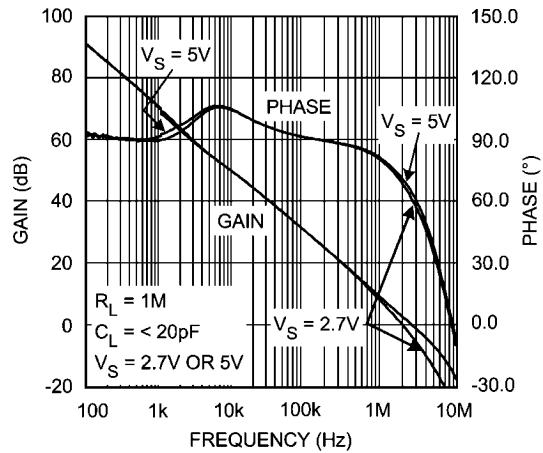
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CMRR vs. Frequency



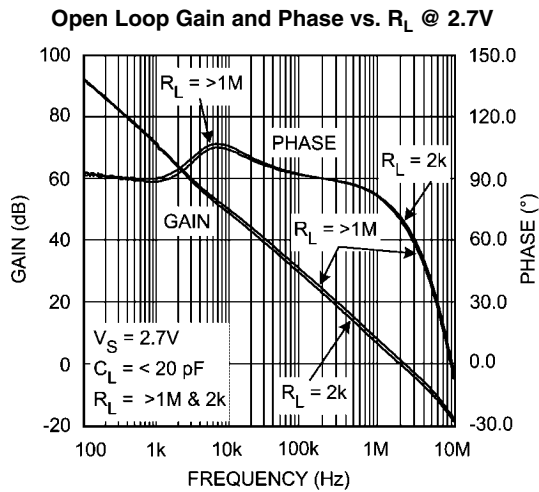
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Open Loop Gain and Phase vs. Supply Voltage

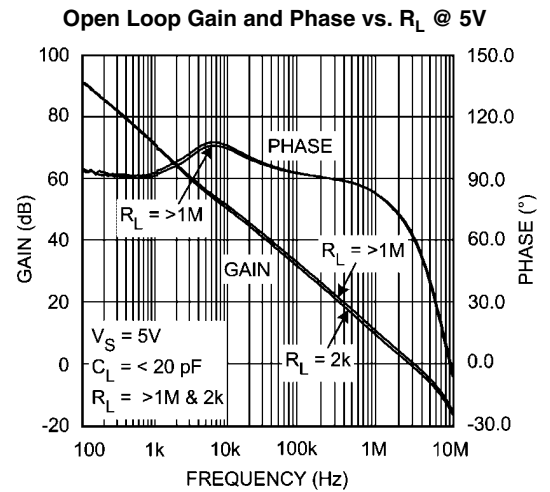


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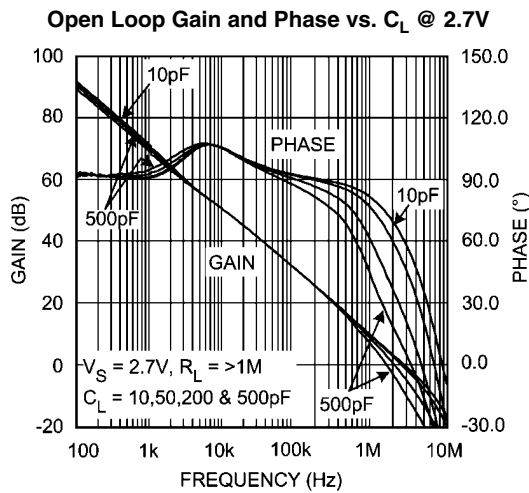




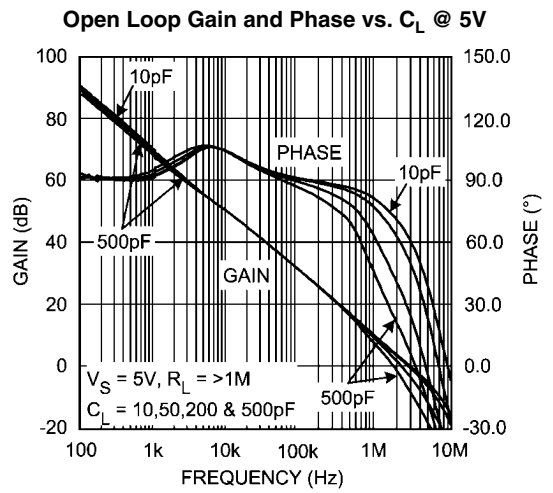
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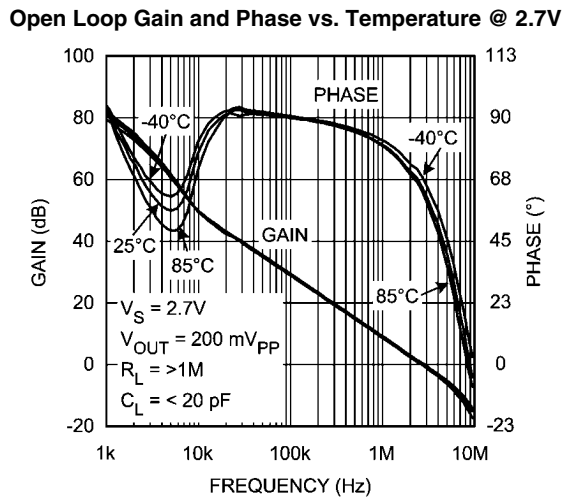
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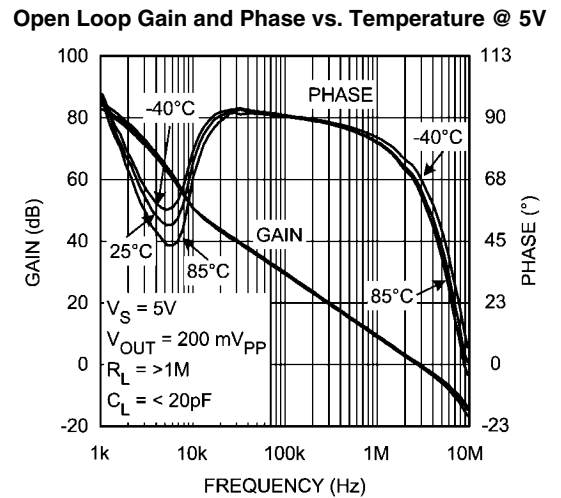
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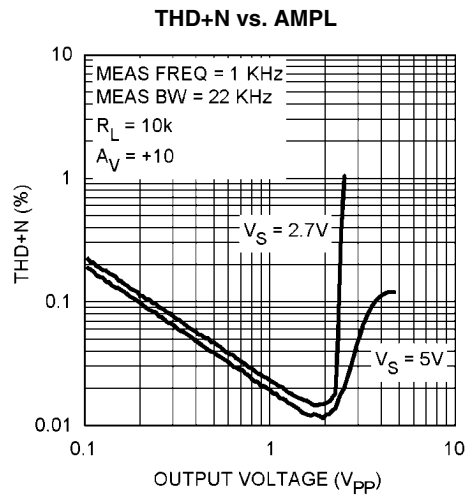
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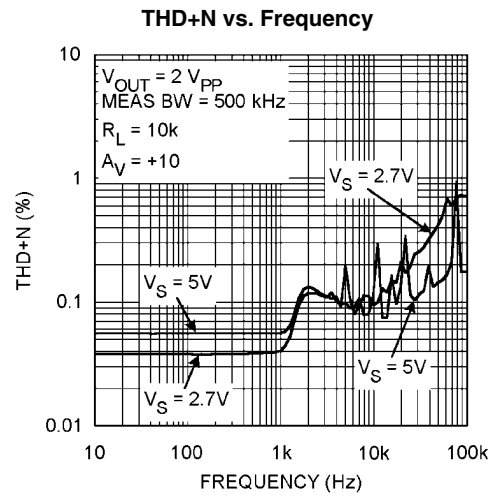
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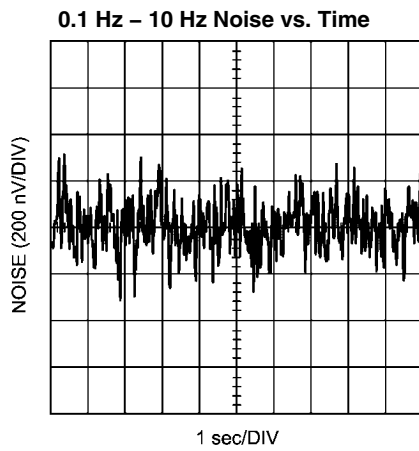
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## Application Information

### THE BENEFITS OF LMP201X NO 1/f NOISE

Using patented methods, the LMP201X eliminates the 1/f noise present in other amplifiers. That noise, which increases as frequency decreases, is a major source of measurement error in all DC-coupled measurements. Low-frequency noise appears as a constantly-changing signal in series with any measurement being made. As a result, even when the measurement is made rapidly, this constantly-changing noise signal will corrupt the result. The value of this noise signal can be surprisingly large. For example: If a conventional amplifier has a flat-band noise level of  $10\text{ nV}/\sqrt{\text{Hz}}$  and a noise corner of 10 Hz, the RMS noise at 0.001 Hz is  $1\text{ }\mu\text{V}/\sqrt{\text{Hz}}$ . This is equivalent to a 0.50  $\mu\text{V}$  peak-to-peak error, in the frequency range 0.001 Hz to 1.0 Hz. In a circuit with a gain of 1000, this produces a 0.50 mV peak-to-peak output error. This number of 0.001 Hz might appear unreasonably low, but when a data acquisition system is operating for 17 minutes, it has been on long enough to include this error. In this same time, the LMP201X will only have a 0.21 mV output error. This is smaller by 2.4 x. Keep in mind that this 1/f error gets even larger at lower frequencies. At the extreme, many people try to reduce this error by integrating or taking several samples of the same signal. This is also doomed to failure because the 1/f nature of this noise means that taking longer samples just moves the measurement into lower frequencies where the noise level is even higher.

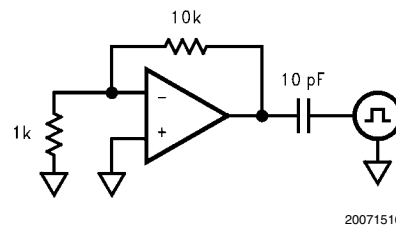
The LMP201X eliminates this source of error. The noise level is constant with frequency so that reducing the bandwidth reduces the errors caused by noise.

Another source of error that is rarely mentioned is the error voltage caused by the inadvertent thermocouples created when the common "Kovar type" IC package lead materials are soldered to a copper printed circuit board. These steel-based leadframe materials can produce over  $35\text{ }\mu\text{V}/^\circ\text{C}$  when soldered onto a copper trace. This can result in thermocouple noise that is equal to the LMP201X noise when there is a temperature difference of only  $0.0014^\circ\text{C}$  between the lead and the board!

For this reason, the lead-frame of the LMP201X is made of copper. This results in equal and opposite junctions which cancel this effect. The extremely small size of the SOT-23 package results in the leads being very close together. This further reduces the probability of temperature differences and hence decreases thermal noise.

### OVERLOAD RECOVERY

The LMP201X recovers from input overload much faster than most chopper-stabilized op amps. Recovery from driving the amplifier to 2X the full scale output, only requires about 40 ms. Many chopper-stabilized amplifiers will take from 250 ms to several seconds to recover from this same overload. This is because large capacitors are used to store the unadjusted offset voltage.



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FIGURE 1. Overload Recovery Test

The wide bandwidth of the LMP201X enhances performance when it is used as an amplifier to drive loads that inject transients back into the output. ADCs (Analog-to-Digital Converters) and multiplexers are examples of this type of load. To simulate this type of load, a pulse generator producing a 1V peak square wave was connected to the output through a 10 pF capacitor. (Figure 1) The typical time for the output to recover to 1% of the applied pulse is 80 ns. To recover to 0.1% requires 860ns. This rapid recovery is due to the wide bandwidth of the output stage and large total GBW.

### NO EXTERNAL CAPACITORS REQUIRED

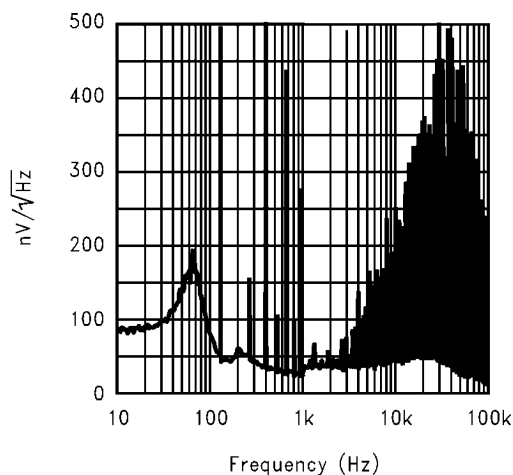
The LMP201X does not need external capacitors. This eliminates the problems caused by capacitor leakage and dielectric absorption, which can cause delays of several seconds from turn-on until the amplifier's error has settled.

### MORE BENEFITS

The LMP201X offers the benefits mentioned above and more. It has a rail-to-rail output and consumes only 950  $\mu\text{A}$  of supply current while providing excellent DC and AC electrical performance. In DC performance, the LMP201X achieves 130 dB of CMRR, 120 dB of PSRR and 130 dB of open loop gain. In AC performance, the LMP201X provides 3 MHz of gain-bandwidth product and 4 V/ $\mu\text{s}$  of slew rate.

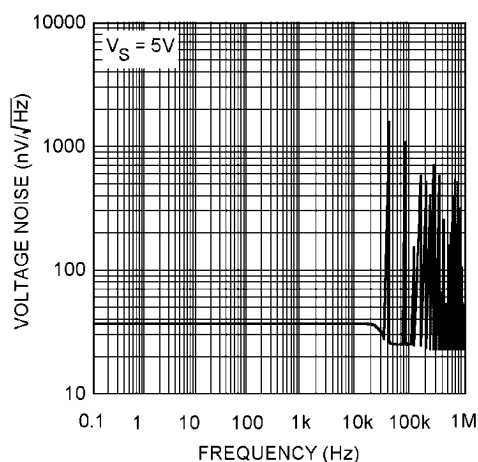
### HOW THE LMP201X WORKS

The LMP201X uses new, patented techniques to achieve the high DC accuracy traditionally associated with chopper-stabilized amplifiers without the major drawbacks produced by chopping. The LMP201X continuously monitors the input offset and corrects this error. The conventional chopping process produces many mixing products, both sums and differences, between the chopping frequency and the incoming signal frequency. This mixing causes large amounts of distortion, particularly when the signal frequency approaches the chopping frequency. Even without an incoming signal, the chopper harmonics mix with each other to produce even more trash. If this sounds unlikely or difficult to understand, look at the plot (Figure 2), of the output of a typical (MAX432) chopper-stabilized op amp. This is the output when there is no incoming signal, just the amplifier in a gain of -10 with the input grounded. The chopper is operating at about 150 Hz; the rest is mixing products. Add an input signal and the noise gets much worse. Compare this plot with Figure 3 of the LMP201X. This data was taken under the exact same conditions. The auto-zero action is visible at about 30 kHz but note the absence of mixing products at other frequencies. As a result, the LMP201X has very low distortion of 0.02% and very low mixing products.



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FIGURE 2. The Output of a Chopper Stabilized Op Amp (MAX432)



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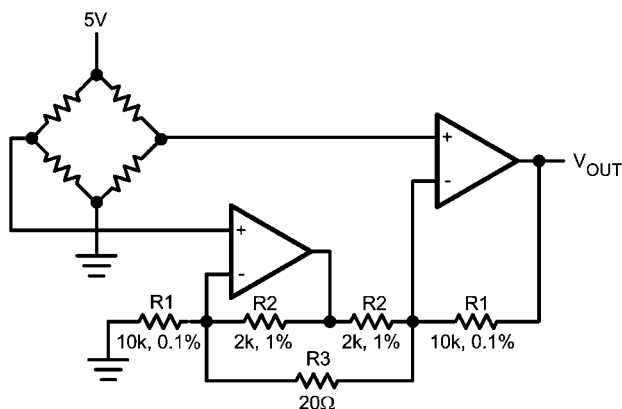
FIGURE 3. The Output of the LMP2011/LMP2012

#### INPUT CURRENTS

The LMP201X's input currents are different than standard bipolar or CMOS input currents in that it appears as a current flowing in one input and out the other. Under most operating conditions, these currents are in the picoamp level and will have little or no effect in most circuits. These currents tend to increase slightly when the common-mode voltage is near the minus supply. (See the typical curves.) At high temperatures such as 85°C, the input currents become larger, 0.5 nA typical, and are both positive except when the  $V_{CM}$  is near  $V^-$ . If operation is expected at low common-mode voltages and high temperature, do not add resistance in series with the inputs to balance the impedances. Doing this can cause an increase in offset voltage. A small resistance such as 1 k $\Omega$  can provide some protection against very large transients or overloads, and will not increase the offset significantly.

#### PRECISION STRAIN-GAUGE AMPLIFIER

This Strain-Gauge amplifier (Figure 4) provides high gain (1006 or ~60 dB) with very low offset and drift. Using the resistors' tolerances as shown, the worst case CMRR will be greater than 108 dB. The CMRR is directly related to the resistor mismatch. The rejection of common-mode error, at the output, is independent of the differential gain, which is set by R3. The CMRR is further improved, if the resistor ratio matching is improved, by specifying tighter-tolerance resistors, or by trimming.

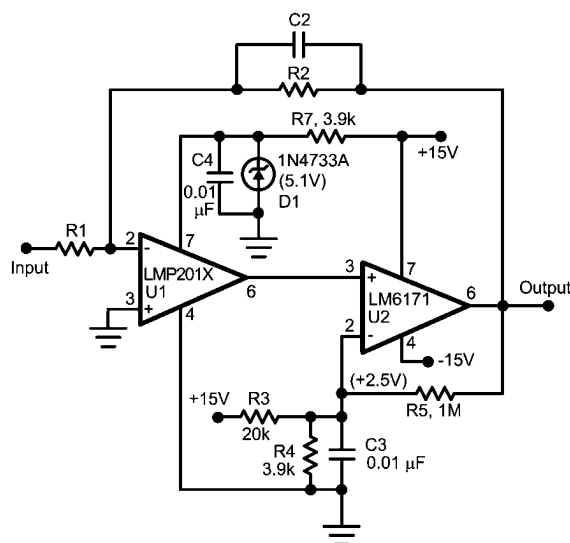


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FIGURE 4. Precision Strain Gauge Amplifier

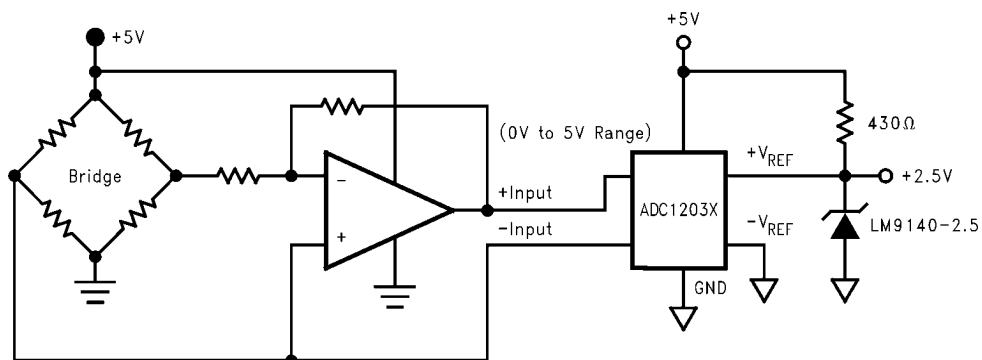
#### Extending Supply Voltages and Output Swing by Using a Composite Amplifier Configuration:

In cases where substantially higher output swing is required with higher supply voltages, arrangements like the ones shown in Figure 5 and Figure 6 could be used. These configurations utilize the excellent DC performance of the LMP201X while at the same time allow the superior voltage and frequency capabilities of the LM6171 to set the dynamic performance of the overall amplifier. For example, it is possible to achieve  $\pm 12V$  output swing with 300 MHz of overall GBW ( $A_V = 100$ ) while keeping the worst case output shift due to  $V_{OS}$  less than 4 mV. The LMP201X output voltage is kept at about mid-point of its overall supply voltage, and its input common mode voltage range allows the  $V^-$  terminal to be grounded in one case (Figure 5, inverting operation) and tied to a small non-critical negative bias in another (Figure 6, non-inverting operation). Higher closed-loop gains are also possible with a corresponding reduction in realizable bandwidth. Table 1 shows some other closed loop gain possibilities along with the measured performance in each case.



data conversion application accuracy (see discussion under "The Benefits of the LMP201X" section above).

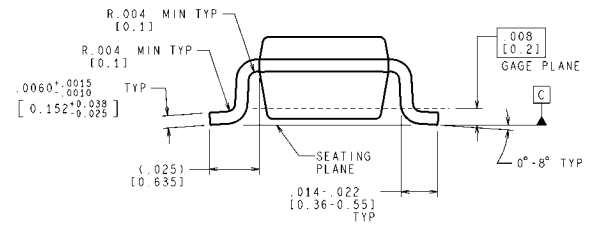
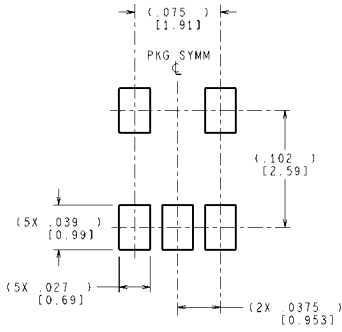
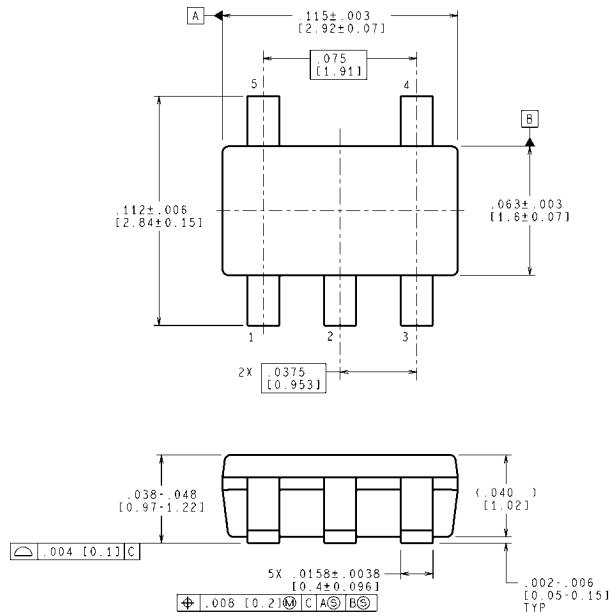
**E)** Rail-to-Rail output swing maximizes the ADC dynamic range in 5-Volt single-supply converter applications. Below are some typical block diagrams showing the LMP201X used as an ADC amplifier (*Figure 7* and *Figure 8*).



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**FIGURE 8. DC Coupled ADC Driver**

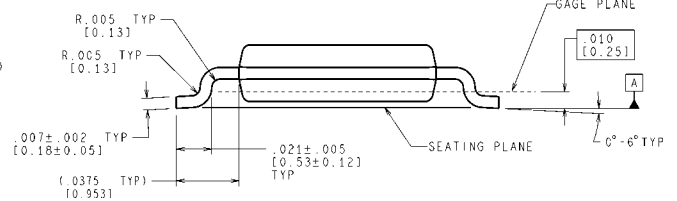
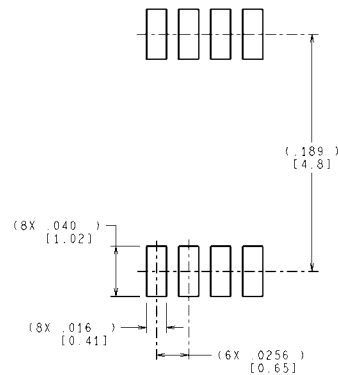
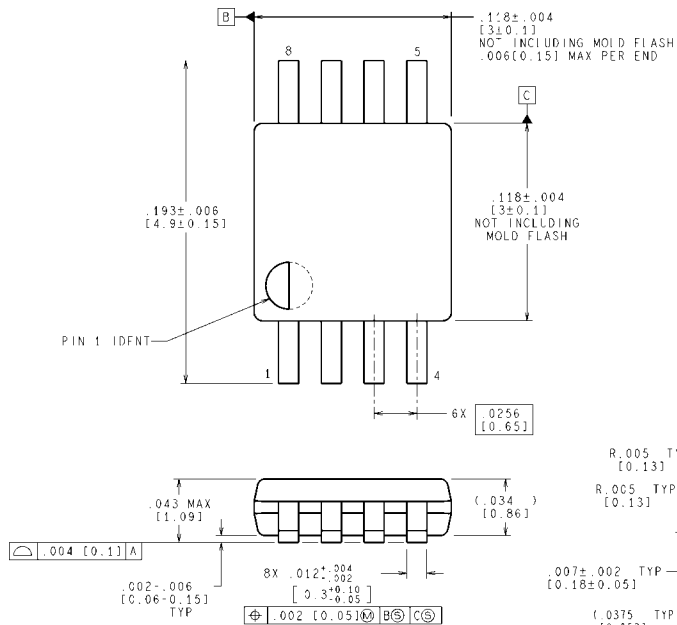
# Physical Dimensions inches (millimeters) unless otherwise noted



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MF05A (Rev C)

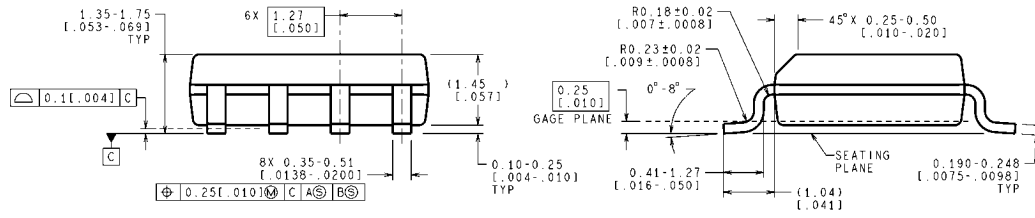
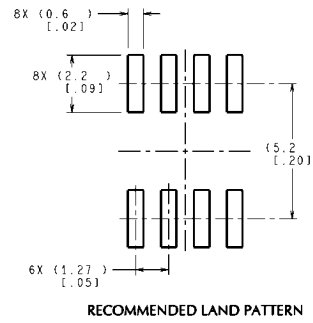
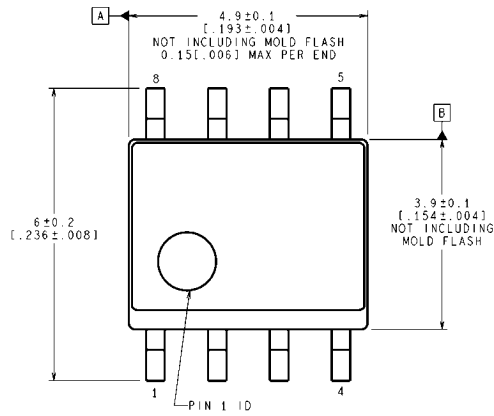
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