Dual 135µA, 14nV/√Hz, Rail-to-Rail Output Precision Op Amp

FEATURES

- **75µV Maximum Offset Voltage**
- **900pA Maximum Input Bias Current**
- **135µA Supply Current per Amplifier**
- **Rail-to-Rail Output Swing**
- 120dB Minimum Voltage Gain, $V_S = \pm 15V$
- 0.8µV/°C Maximum V_{OS} Drift
- 14nV/√Hz Input Noise Voltage
- 0.4µV/Month Long-Term V_{OS} Stability
- 2.7V to ±18V Supply Voltage Operation
- Space Saving 3mm × 3mm DFN Package
- Operating Temperature Range: –40°C to 85°C

APPLICATIONS

- Thermocouple Amplifiers
- Precision Photo Diode Amplifiers
- Instrumentation Amplifiers
- Battery-Powered Precision Systems

DESCRIPTION

The LT®6011 dual op amp combines low noise and high precision input performance with low power consumption and rail-to-rail output swing.

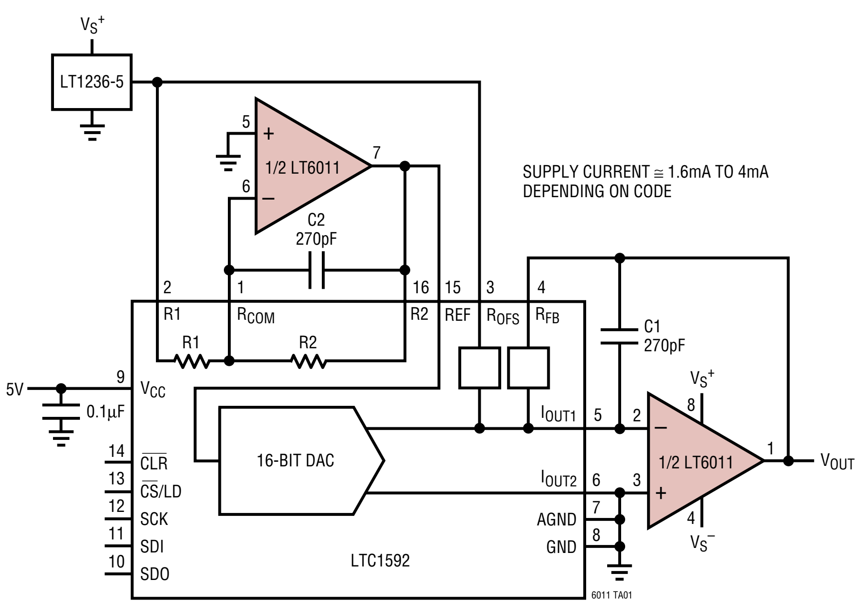
Input offset voltage is trimmed to less than 75µV. The low drift and excellent long-term stability guarantee a high accuracy over temperature and time. The 900pA maximum input bias current and 120dB minimum voltage gain further maintain this precision over operating conditions.

The LT6011 works on any power supply voltage from 2.7V to 36V and draws only 135µA of supply current on a 5V supply. The output voltage swings to within 40mV of either supply rail, making the amplifier a good choice for low voltage single supply operation.

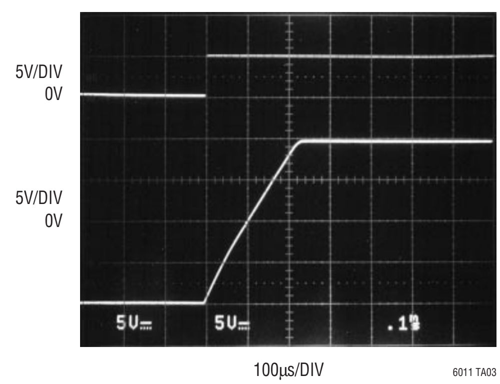
The LT6011 is fully specified at 5V and ±15V supplies and from –40°C to 85°C. The device is available in SO-8 and space saving 3mm × 3mm DFN packages.

TYPICAL APPLICATION

Low Power Programmable Output Range 16-Bit SoftSpan™ DAC



20V Output Step Response

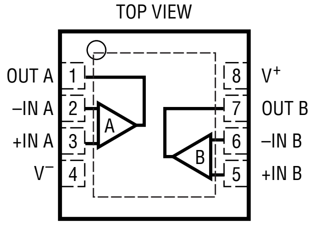
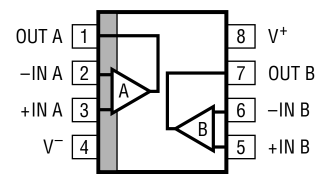


ABSOLUTE MAXIMUM RATINGS (Note 1)

Total Supply Voltage (V^+ to V^-) 40V
Differential Input Voltage (Note 2) 10V
Input Voltage .... V^+ to V^-
Input Current (Note 2) .... ±10mA
Output Short-Circuit Duration (Note 3) .... Indefinite
Operating Temperature Range (Note 4) .. –40°C to 85°C
Specified Temperature Range (Note 5) ... –40°C to 85°C

Maximum Junction Temperature
DD Package .... 125°C
SO-8 Package .... 150°C
Storage Temperature Range
DD Package .... –65°C to 125°C
SO-8 Package .... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) .... 300°C

PACKAGE/ORDER INFORMATION

	ORDER PART NUMBER		ORDER PART NUMBER
TOP VIEW  DD PACKAGE 8-LEAD (3mm × 3mm) PLASTIC DFN T_{JMAX} = 125°C, θ_{JA} = 160°C/W UNDERSIDE METAL CONNECTED TO V^-	LT6011CDD LT6011IDD DD PART MARKING* LACD	TOP VIEW  S8 PACKAGE 8-LEAD PLASTIC SO T_{JMAX} = 150°C, θ_{JA} = 190°C/W	LT6011CS8 LT6011IS8 S8 PART MARKING 6011 6011I

*Temperature grades are identified by a label on the shipping container.
Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = 5V, 0V; V_{CM} = 2.5V; R_L to 0V; unless otherwise specified. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6011S8			25	75	µV
		T_A = 0°C to 70°C	●			100	µV
		T_A = –40°C to 85°C	●			125	µV
		LT6011DD			25	125	µV
		T_A = 0°C to 70°C	●			175	µV
		T_A = –40°C to 85°C	●			210	µV
$\Delta V_{OS}/\Delta T$	Input Offset Voltage Drift (Note 6)	LT6011S8	●		0.2	0.8	µV/°C
		LT6011DD	●		0.2	1.3	µV/°C
I_{OS}	Input Offset Current				150	900	pA
		T_A = 0°C to 70°C	●			1200	pA
		T_A = –40°C to 85°C	●			1500	pA
I_B	Input Bias Current				±150	±900	pA
		T_A = 0°C to 70°C	●			±1200	pA
		T_A = –40°C to 85°C	●			±1500	pA
	Input Noise Voltage	0.1Hz to 10Hz			400		nV_{P-P}
e_n	Input Noise Voltage Density	f = 1kHz			14		$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f = 1kHz			0.1		$pA/\sqrt{Hz}$
R_{IN}	Input Resistance	Common Mode, V_{CM} = 1V to 3.8V		10	120		GΩ
		Differential			20		MΩ

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = 5V, 0V; V_{CM} = 2.5V; R_L to 0V; unless otherwise specified. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
C_{IN}	Input Capacitance				4		pF
V_{CM}	Input Voltage Range (Positive) Input Voltage Range (Negative)	Guaranteed by CMRR Guaranteed by CMRR	● ●	3.8	4 0.7	 1	V V
CMRR	Common Mode Rejection Ratio	V_{CM} = 1V to 3.8V	●	107	135		dB
	Minimum Supply Voltage	Guaranteed by PSRR	●		2.4	2.7	V
PSRR	Power Supply Rejection Ratio	V_S = 2.7V to 36V, V_{CM} = 1/2V_S	●	112	135		dB
A_{VOL}	Large-Signal Voltage Gain	R_L = 10k, V_{OUT} = 1V to 4V R_L = 2k, V_{OUT} = 1V to 4V	● ●	300 250	2000 2000		V/mV V/mV
	Channel Separation	V_{OUT} = 1V to 4V	●	110	140		dB
V_{OUT}	Maximum Output Swing (Positive, Referred to V^+)	No Load, 50mV Overdrive	 ●		35	55 65	mV mV
		I_{SOURCE} = 1mA, 50mV Overdrive	 ●		120	170 220	mV mV
	Maximum Output Swing (Negative, Referred to 0V)	No Load, 50mV Overdrive	 ●		40	55 65	mV mV
		I_{SINK} = 1mA, 50mV Overdrive	 ●		150	225 275	mV mV
I_{SC}	Output Short-Circuit Current (Note 3)	V_{OUT} = 0V, 1V Overdrive, Source	 ●	10 4	14		mA mA
		V_{OUT} = 5V, –1V Overdrive, Sink	 ●	10 4	21		mA mA
SR	Slew Rate	A_V = –10, R_F = 50k, R_G = 5k T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●	0.06 0.05 0.04	0.09		V/µs V/µs V/µs
GBW	Gain Bandwidth Product	f = 10kHz	 ●	250 225	330		kHz kHz
t_s	Settling Time	A_V = –1, 0.01%, V_{OUT} = 1.5V to 3.5V			45		µs
t_r, t_f	Rise Time, Fall Time	A_V = 1, 10% to 90%, 0.1V Step			1		µs
ΔV_{OS}	Offset Voltage Match (Note 7)	LT6011S8 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		50	150 200 250	µV µV µV
		LT6011DD T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		50	250 350 420	µV µV µV
ΔI_B	Input Bias Current Match (Note 7)	 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		250	1800 2400 3000	pA pA pA
ΔCMRR	Common Mode Rejection Ratio Match (Note 7)		●	101	135		dB
ΔPSRR	Power Supply Rejection Ratio Match (Note 7)		●	106	135		dB
I_S	Supply Current	per Amplifier T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		135	150 190 210	µA µA µA

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = ±15V, V_{CM} = 0V, R_L to 0V, unless otherwise specified. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6011S8 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		25	150 175 200	µV µV µV
		LT6011DD T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		25	200 250 275	µV µV µV
$\Delta V_{OS}/\Delta T$	Input Offset Voltage Drift (Note 6)	LT6011S8 LT6011DD	● ●		0.2 0.2	0.8 1.3	µV/°C µV/°C
I_{OS}	Input Offset Current	 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		150	900 1200 1500	pA pA pA
I_B	Input Bias Current	 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		±150	±900 ±1200 ±1500	pA pA pA
	Input Noise Voltage	0.1Hz to 10Hz			400		nV_{P-P}
e_n	Input Noise Voltage Density	f = 1kHz			13		$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f = 1kHz			0.1		$pA/\sqrt{Hz}$
R_{IN}	Input Resistance	Common Mode, V_{CM} = ±13.5V Differential		50	400 20		GΩ MΩ
C_{IN}	Input Capacitance				4		pF
V_{CM}	Input Voltage Range	Guaranteed by CMRR	●	±13.5	±14		V
CMRR	Common Mode Rejection Ratio	V_{CM} = –13.5V to 13.5V	●	115	135		dB
	Minimum Supply Voltage	Guaranteed by PSRR	●		±1.2	±1.35	V
PSRR	Power Supply Rejection Ratio	V_S = ±1.35V to ±18V	●	112	135		dB
A_{VOL}	Large-Signal Voltage Gain	R_L = 10k, V_{OUT} = –13.5V to 13.5V	 ●	1000 600	2000		V/mV V/mV
		R_L = 5k, V_{OUT} = –13.5V to 13.5V	 ●	500 300	1500		V/mV V/mV
	Channel Separation	V_{OUT} = –13.5V to 13.5V	●	120	140		dB
V_{OUT}	Maximum Output Swing (Positive, Referred to V^+)	No Load, 50mV Overdrive	 ●		45	80 100	mV mV
		I_{SOURCE} = 1mA, 50mV Overdrive	 ●		140	195 240	mV mV
	Maximum Output Swing (Negative, Referred to V^-)	No Load, 50mV Overdrive	 ●		45	80 100	mV mV
		I_{SINK} = 1mA, 50mV Overdrive	 ●		150	250 300	mV mV
I_{SC}	Output Short-Circuit Current (Note 3)	V_{OUT} = 0V, 1V Overdrive (Source)	 ●	10 5	15		mA mA
		V_{OUT} = 0V, –1V Overdrive (Sink)	 ●	10 5	20		mA mA
SR	Slew Rate	A_V = –10, R_F = 50k, R_G = 5k T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●	0.08 0.07 0.05	0.11		V/µs V/µs V/µs

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at T_A = 25°C. V_S = ±15V, V_{CM} = 0V, R_L to 0V, unless otherwise specified. (Note 5)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
GBW	Gain Bandwidth Product	f = 10kHz 	 ●	275 250	350		kHz kHz
t_S	Settling Time	A_V = –1, 0.01%, V_{OUT} = 0V to 10V			85		µs
t_r, t_f	Rise Time, Fall Time	A_V = 1, 10% to 90%, 0.1V Step			1		µs
ΔV_{OS}	Offset Voltage Match (Note 7)	LT6011S8 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		50	300 350 400	µV µV µV
		LT6011DD T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		50	400 500 550	µV µV µV
ΔI_B	Input Bias Current Match (Note 7)	 T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		250	1800 2400 3000	pA pA pA
ΔCMRR	Common Mode Rejection Ratio Match (Note 7)		●	109	135		dB
ΔPSRR	Power Supply Rejection Ratio Match (Note 7)		●	106	135		dB
I_S	Supply Current	per Amplifier T_A = 0°C to 70°C T_A = –40°C to 85°C	 ● ●		260	330 380 400	µA µA µA

Note 1: Absolute Maximum Ratings are those beyond which the life if the device may be impaired.

Note 2: The inputs are protected by back-to-back diodes and internal series resistors. If the differential input voltage exceeds 10V, the input current must be limited to less than 10mA.

Note 3: A heat sink may be required to keep the junction temperature below absolute maximum ratings.

Note 4: Both the LT6011C and LT6011I are guaranteed functional over the operating temperature range of –40°C to 85°C.

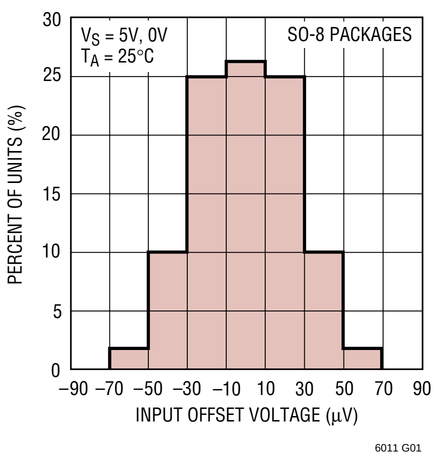
Note 5: The LT6011C is guaranteed to meet the specified performance from 0°C to 70°C and is designed, characterized and expected to meet specified performance from –40°C to 85°C but is not tested or QA sampled at these temperatures. The LT6011I is guaranteed to meet specified performance from –40°C to 85°C.

Note 6: This parameter is not 100% tested.

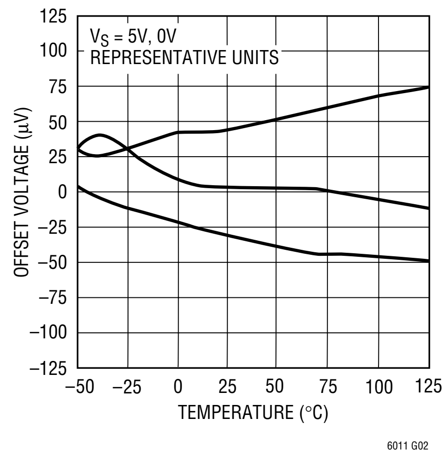
Note 7: Matching parameters are the difference between the two amplifiers. ΔCMRR and ΔPSRR are defined as follows: (1) CMRR and PSRR are measured in µV/V for the individual amplifiers. (2) The difference between matching amplifiers is calculated in µV/V. (3) The result is converted to dB.

TYPICAL PERFORMANCE CHARACTERISTICS

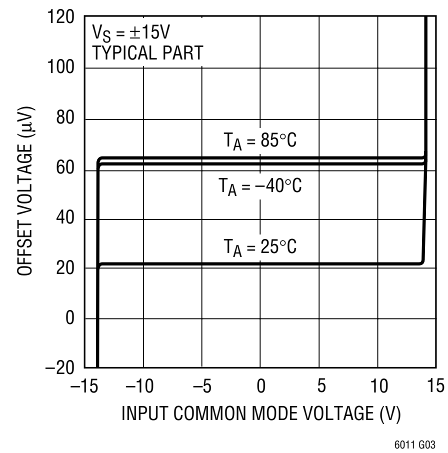
Distribution of Input Offset Voltage



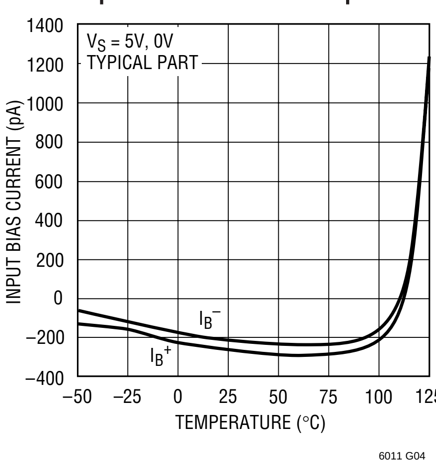
Input Offset Voltage vs Temperature



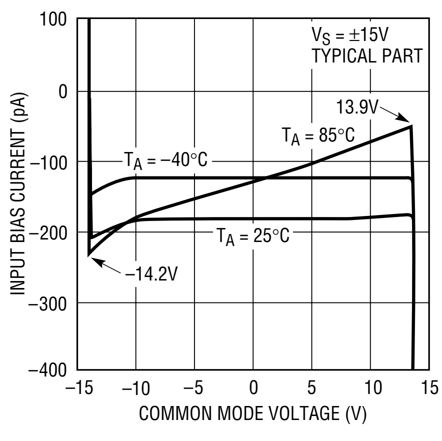
Offset Voltage vs Input Common Mode Voltage



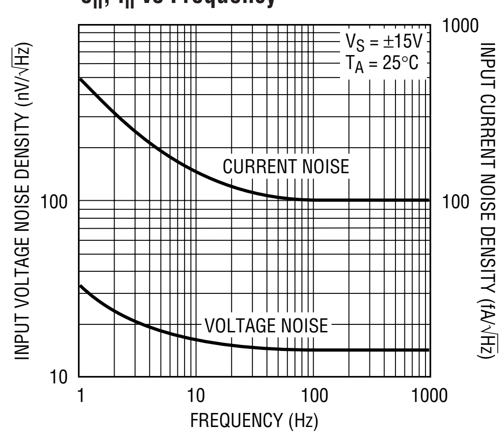
Input Bias Current vs Temperature



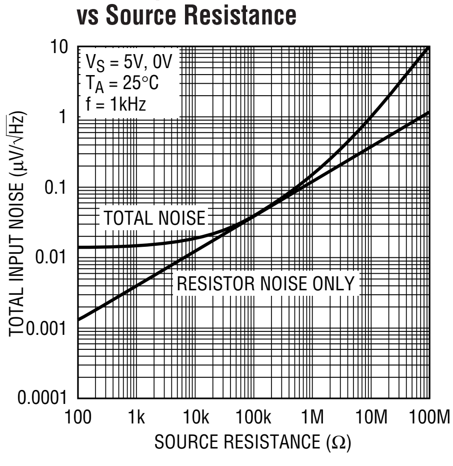
Input Bias Current vs Input Common Mode Voltage



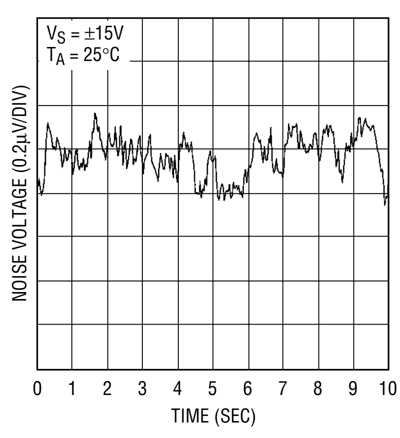
e_n, i_n vs Frequency



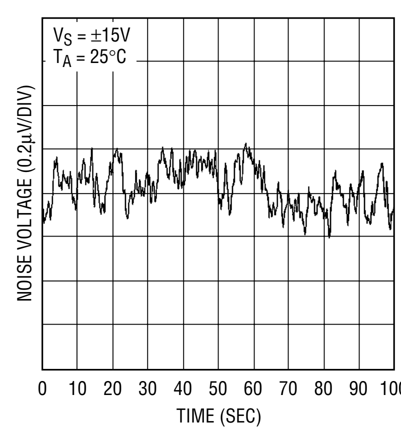
Total Input Noise vs Source Resistance



0.1Hz to 10Hz Noise

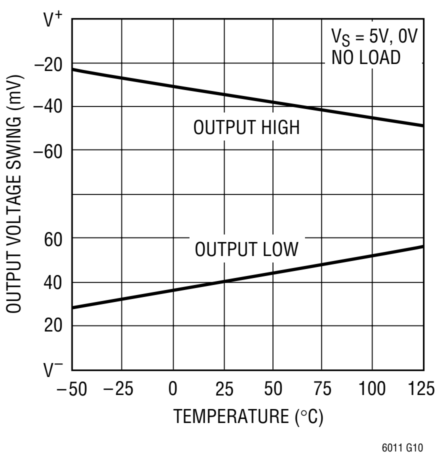


0.01Hz to 1Hz Noise

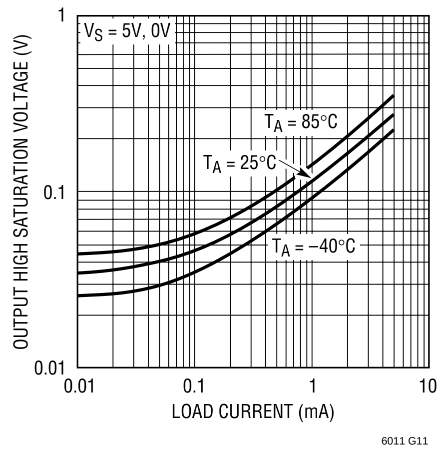


TYPICAL PERFORMANCE CHARACTERISTICS

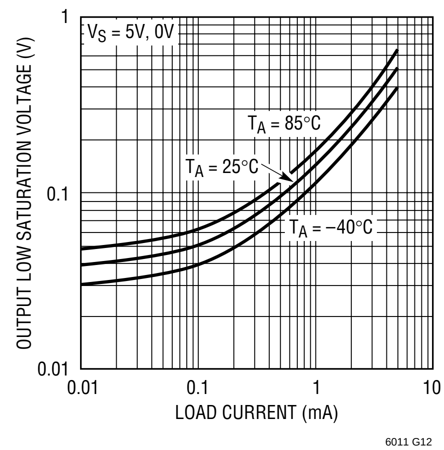
Output Voltage Swing vs Temperature



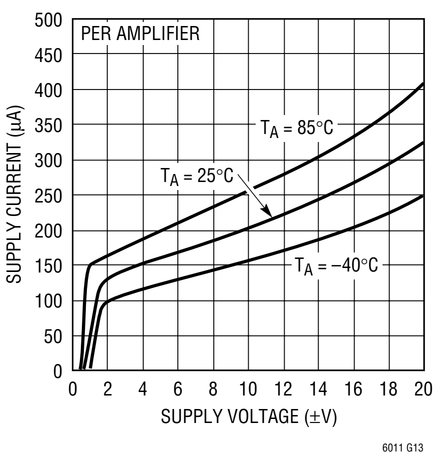
Output Saturation Voltage vs Load Current (Output High)



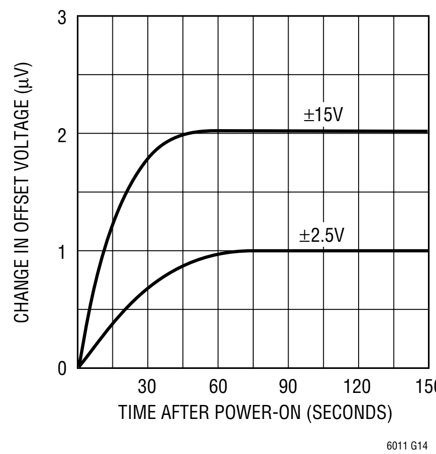
Output Saturation Voltage vs Load Current (Output Low)



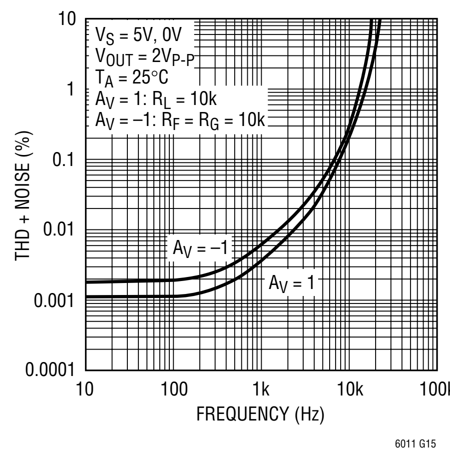
Supply Current vs Supply Voltage



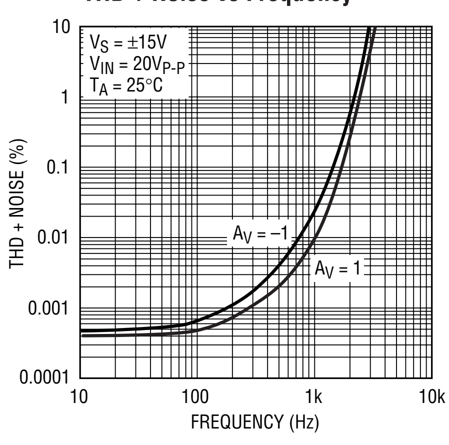
Warm-Up Drift



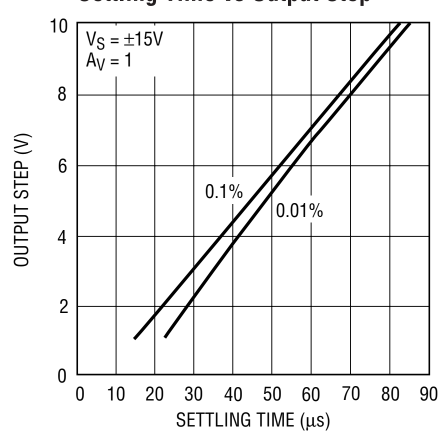
THD + Noise vs Frequency



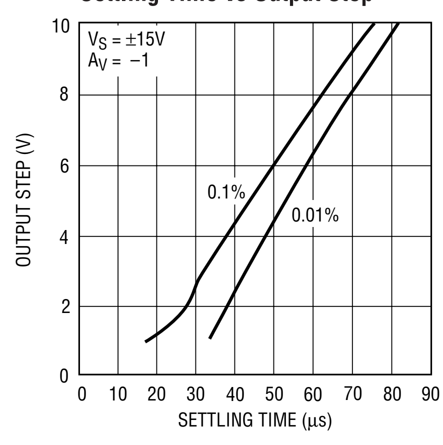
THD + Noise vs Frequency



Settling Time vs Output Step

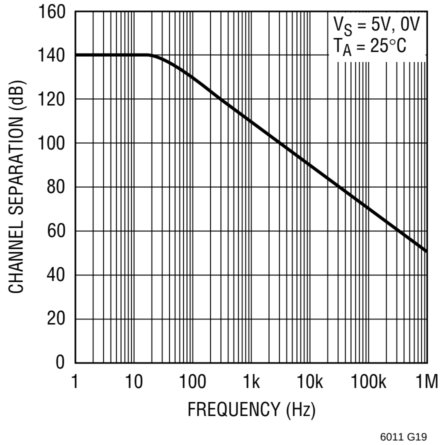


Settling Time vs Output Step

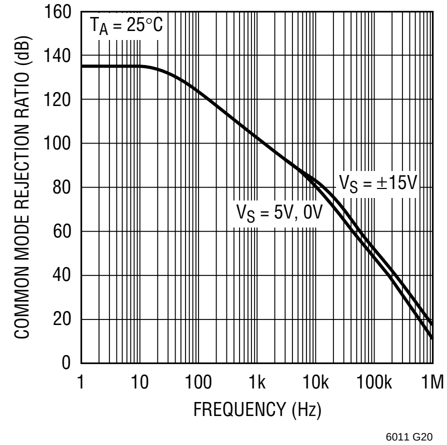


TYPICAL PERFORMANCE CHARACTERISTICS

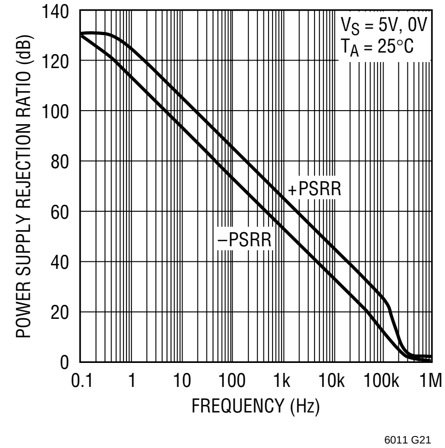
Channel Separation vs Frequency



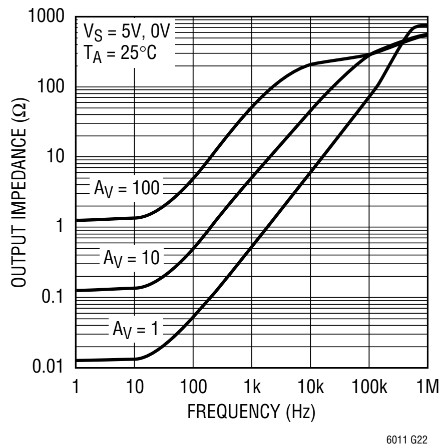
CMRR vs Frequency



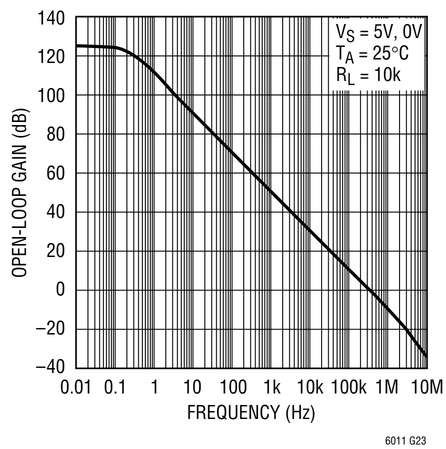
PSRR vs Frequency



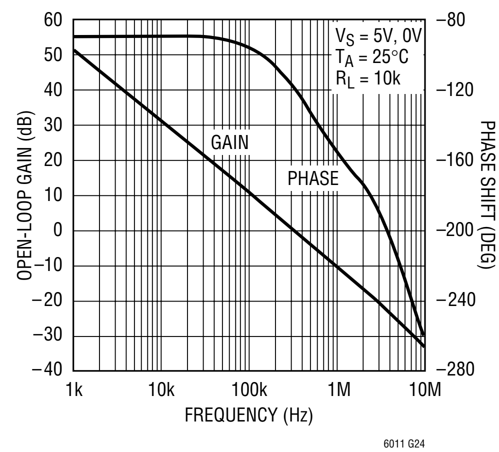
Output Impedance vs Frequency



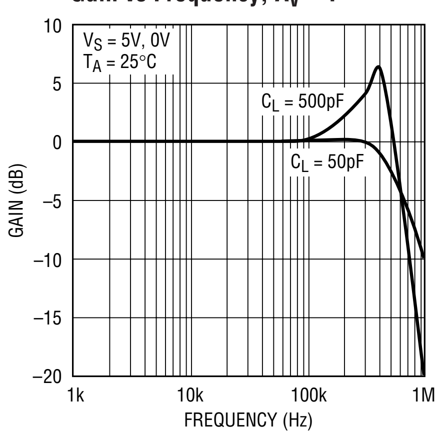
Open-Loop Gain vs Frequency



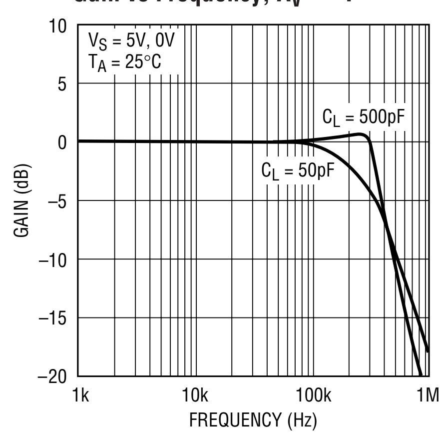
Gain and Phase vs Frequency



Gain vs Frequency, $A_V = 1$

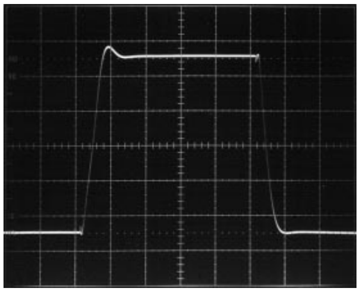


Gain vs Frequency, $A_V = -1$

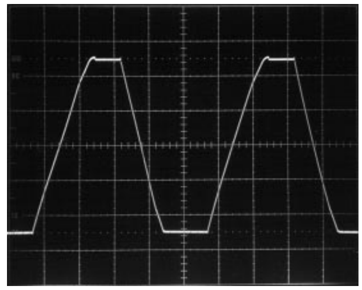


TYPICAL PERFORMANCE CHARACTERISTICS

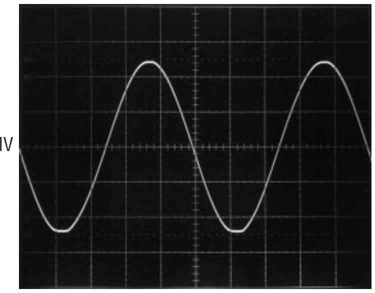
Small-Signal Transient Response



Large-Signal Transient Response



Rail-to-Rail Output Swing



APPLICATIONS INFORMATION

Preserving Input Precision

Preserving the input accuracy of the LT6011 requires that the applications circuit and PC board layout do not introduce errors comparable to or greater than the 25µV typical offset of the amplifiers. Temperature differentials across the input connections can generate thermocouple voltages of 10's of microvolts so the connections to the input leads should be short, close together and away from heat dissipating components. Air currents across the board can also generate temperature differentials.

The extremely low input bias currents (150pA typical) allow high accuracy to be maintained with high impedance sources and feedback resistors. The LT6011 low input bias currents are obtained by a cancellation circuit on-chip. This causes the resulting I_B^+ and I_B^- to be uncorrelated, as implied by the I_{OS} specification being comparable to I_B. Do not try to balance the input resistances in each input lead; instead keep the resistance at either input as low as possible for maximum accuracy.

Leakage currents on the PC board can be higher than the LT6011's input bias current. For example, 10GΩ of leakage between a 15V supply lead and an input lead will generate 1.5nA! Surround the input leads with a guard ring driven to the same potential as the input common mode to avoid excessive leakage in high impedance applications.

Input Protection

The LT6011 features on-chip back-to-back diodes between the input devices, along with 500Ω resistors in series with either input. This internal protection limits the input current to approximately 10mA (the maximum allowed) for a 10V differential input voltage. Use additional external series resistors to limit the input current to 10mA in applications where differential inputs of more than 10V are expected. For example, a 1k resistor in series with each input provides protection against 30V differential voltage.

Input Common Mode Range

The LT6011 output is able to swing close to each power supply rail (rail-to-rail out), but the input stage is limited to operating between $V^- + 1V$ and $V^+ – 1.2V$. Exceeding this common mode range will cause the gain to drop to zero, however, no phase reversal will occur.

Total Input Noise

The LT6011 amplifier contributes negligible noise to the system when driven by sensors (sources) with impedance between 20kΩ and 1MΩ. Throughout this range, total input noise is dominated by the $4kTR_S$ noise of the source. If the source impedance is less than 20kΩ, the input voltage noise of the amplifier starts to contribute with a minimum noise of $14nV/\sqrt{Hz}$ for very low source impedance. If the source impedance is more than 1MΩ, the input current noise of the amplifier, multiplied by this high impedance, starts to contribute and eventually dominate. Total input noise spectral density can be calculated as:

$$v_{n(TOTAL)} = \sqrt{e_n^2 + 4kTR_S + (i_n R_S)^2}$$

APPLICATIONS INFORMATION

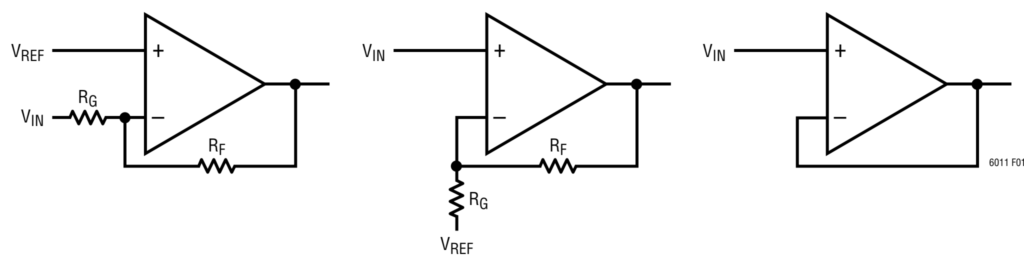
where $e_n = 14nV/\sqrt{Hz}$, $i_n = 0.1pA/\sqrt{Hz}$ and R_S is the total impedance at the input, including the source impedance.

Capacitive Loads

The LT6011 can drive capacitive loads up to 500pF in unity gain. The capacitive load driving capability increases as the amplifier is used in higher gain configurations. A small series resistance between the output and the load further increases the amount of capacitance that the amplifier can drive.

Rail-to-Rail Operation

The LT6011 outputs can swing to within millivolts of either supply rail, but the inputs can not. However, for most op amp configurations, the inputs need to swing less than the outputs. Figure 1 shows the basic op amp configurations, lists what happens to the op amp inputs and specifies whether or not the op amp must have rail-to-rail inputs. Select a rail-to-rail input op amp only when really necessary, because the input precision specifications are usually inferior.



INVERTING: $A_V = -R_F/R_G$
OP AMP INPUTS DO NOT MOVE, BUT ARE FIXED AT DC BIAS POINT V_{REF}

INPUT DOES NOT HAVE TO BE RAIL-TO-RAIL

NONINVERTING: $A_V = 1 + R_F/R_G$
INPUTS MOVE BY AS MUCH AS V_{IN}, BUT THE OUTPUT MOVES MORE

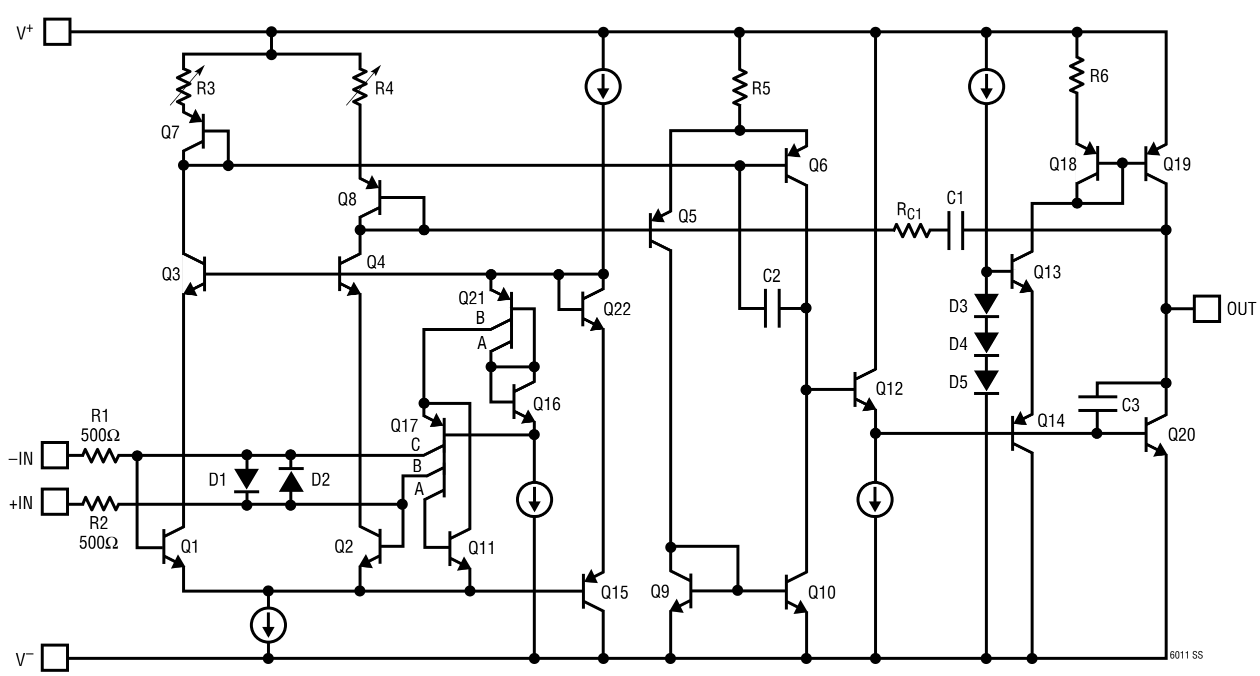
INPUT MAY NOT HAVE TO BE RAIL-TO-RAIL

NONINVERTING: $A_V = 1$
INPUTS MOVE BY AS MUCH AS OUTPUT

INPUT MUST BE RAIL-TO-RAIL FOR OVERALL CIRCUIT RAIL-TO-RAIL PERFORMANCE

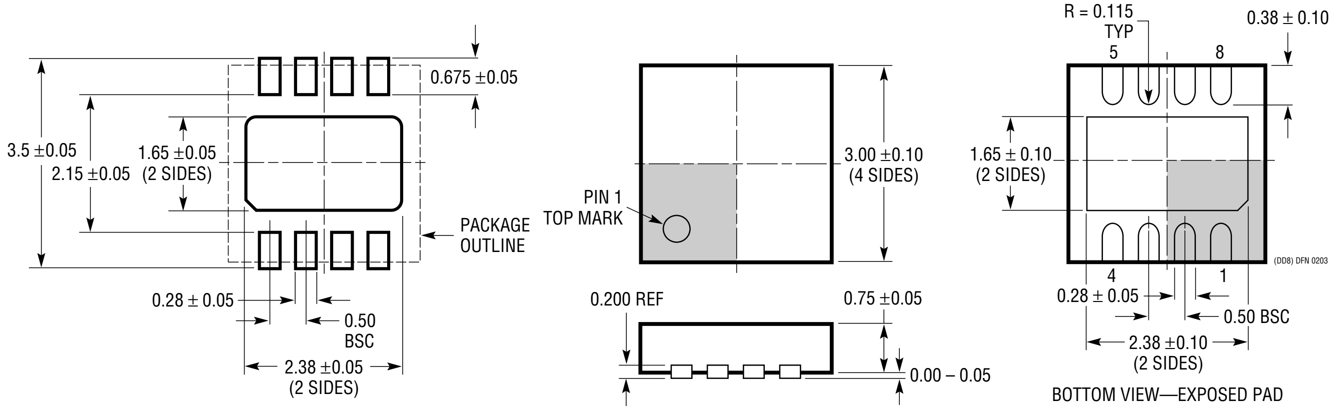
Figure 1. Some Op Amp Configurations Do Not Require Rail-to-Rail Inputs to Achieve Rail-to-Rail Outputs

SIMPLIFIED SCHEMATIC



PACKAGE DESCRIPTION

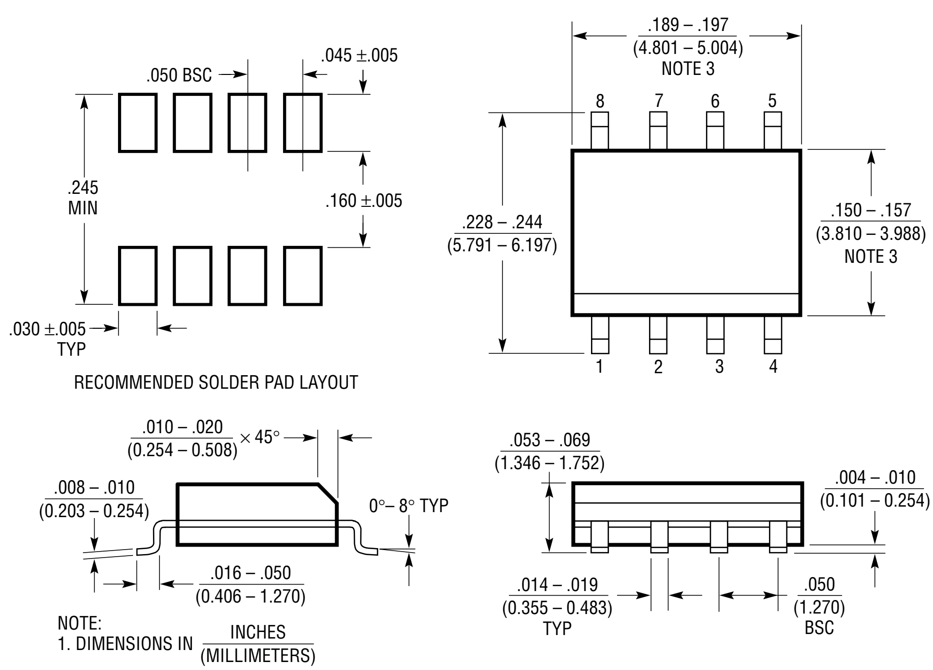
DD Package
8-Lead Plastic DFN (3mm × 3mm)
(Reference LTC DWG # 05-08-1698)



RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (WEED-1)
2. ALL DIMENSIONS ARE IN MILLIMETERS
3. DIMENSIONS OF EXPOSED PAD ON BOTTOM OF PACKAGE DO NOT INCLUDE MOLD FLASH. MOLD FLASH, IF PRESENT, SHALL NOT EXCEED 0.15mm ON ANY SIDE
4. EXPOSED PAD SHALL BE SOLDER PLATED

S8 Package
8-Lead Plastic Small Outline (Narrow .150 Inch)
(Reference LTC DWG # 05-08-1610)

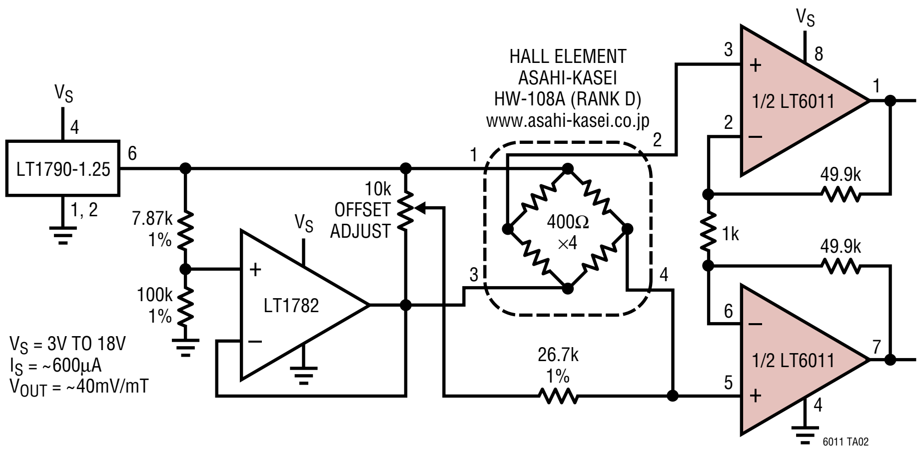


NOTE:
1. DIMENSIONS IN INCHES / (MILLIMETERS)
2. DRAWING NOT TO SCALE
3. THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS. MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .006" (0.15mm)

SO8 0303

TYPICAL APPLICATION

Low Power Hall Sensor Amplifier



RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT1112	Dual Low Power, Picoamp Input Precision Op Amp	250pA Input Bias Current
LT1880	Rail-to-Rail Output, Picoamp Input Precision Op Amp	SOT-23
LT1881	Dual Rail-to-Rail Output, Picoamp Input Precision Op Amp	C_{LOAD} Up to 1000pF
LT1884	Dual Rail-to-Rail Output, Picoamp Input Precision Op Amp	$9.5nV/\sqrt{Hz}$ Input Noise

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