Chipsmall Limited consists of a professional team with an average of over 10 year of expertise in the distribution of electronic components. Based in Hongkong, we have already established firm and mutual-benefit business relationships with customers from,Europe,America and south Asia,supplying obsolete and hard-to-find components to meet their specific needs.

With the principle of “Quality Parts,Customers Priority,Honest Operation,and Considerate Service”,our business mainly focus on the distribution of electronic components. Line cards we deal with include Microchip,ALPS,ROHM,Xilinx,Pulse,ON,Everlight and Freescale. Main products comprise IC,Modules,Potentiometer,IC Socket,Relay,Connector.Our parts cover such applications as commercial,industrial, and automotives areas.

We are looking forward to setting up business relationship with you and hope to provide you with the best service and solution. Let us make a better world for our industry!

Contact us

Tel: +86-755-8981 8866 Fax: +86-755-8427 6832
Email & Skype: info@chipsmall.com Web: www.chipsmall.com
Address: A1208, Overseas Decoration Building, #122 Zhenhua RD., Futian, Shenzhen, China

Single, Dual and Quad, 1.8V, 13µA Precision Rail-to-Rail Op Amps

FEATURES

- **Ideal for Battery-Powered Applications**
  - **– Low Voltage: 1.8V to 16V Operation**
  - **– Low Current: 16µA/Amplifier Max**
  - **– Small Packages: DFN, MSOP, SSOP**
  - **– Shutdown to 1.5µA Max (LT6000, LT6001DD)**
- **Low Offset Voltage: 600µV Max**
- Rail-to-Rail Input and Output
- Fully Specified on 1.8V and 5V Supplies
- Operating Temperature Range: –40°C to 85°C
- Single Available in DFN
  Dual Available in MSOP and DFN
  Quad Available in SSOP and DFN

APPLICATIONS

- Gas Sensing
- Portable Instrumentation
- Battery- or Solar-Powered Systems
- Low Voltage Signal Processing
- Micropower Active Filters

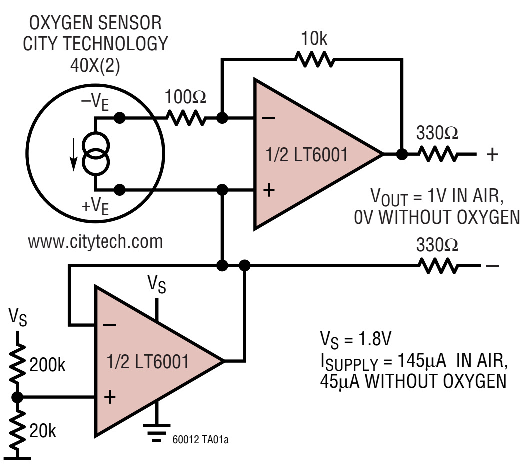
DESCRIPTION

The LT®6000/LT6001/LT6002 are single, dual and quad precision rail-to-rail input and output operational amplifiers. Designed to maximize battery life in always-on applications, the devices will operate on supplies down to 1.8V while drawing only 13µA quiescent current. The low supply current and low voltage operation is combined with precision specifications; input offset is guaranteed less than 600µV. The performance on 1.8V supplies is fully specified and guaranteed over temperature. A shutdown feature available in the LT6000 and the 10-lead dual LT6001 version can be used to extend battery life by allowing the amplifiers to be switched off during periods of inactivity.

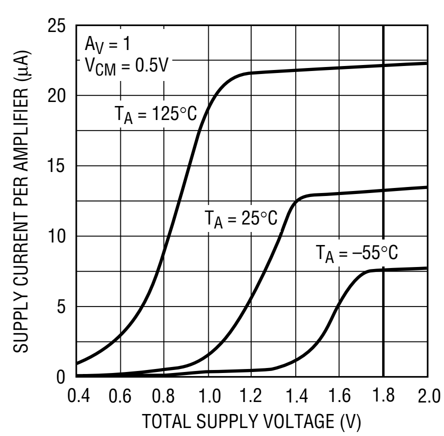
The LT6000 is available in a tiny, dual fine pitch leadless DFN package. The LT6001 is available in the 8-pin MSOP package; a 10-lead version with the shutdown feature is available in DFN package. The quad LT6002 is available in the 16-pin SSOP package and the 16-pin DFN package. These devices are specified over the commercial and industrial temperature range.

TYPICAL APPLICATION

Micropower Oxygen Sensor



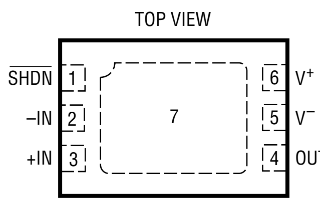
Start-Up Characteristics Supply Current vs Supply Voltage



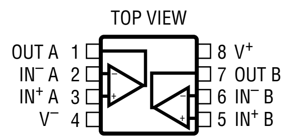
ABSOLUTE MAXIMUM RATINGS (Note 1)

Total Supply Voltage (V^+ to V^-) 18V
Input Current .... ±10mA
$\overline{\text{SHDN}}$ Pin Voltage (Note 7) .... V^- to V^+
Output Short Current Duration (Note 2) .... Indefinite
Operating Temperature Range (Note 3) ... –40°C to 85°C
Specified Temperature Range (Note 4) .... –40°C to 85°C
Junction Temperature .... 150°C
Junction Temperature (DFN Packages) .... 125°C
Storage Temperature Range .... –65°C to 150°C
Storage Temperature Range
DFN Packages .... –65°C to 125°C
Lead Temperature (Soldering, 10 sec)
MSOP, SSOP Packages .... 300°C

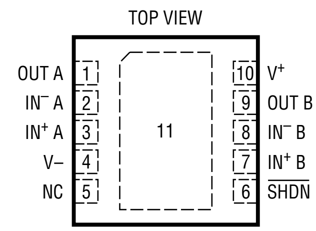
PACKAGE/ORDER INFORMATION



DCB PACKAGE
6-LEAD (2mm × 3mm) PLASTIC DFN
T_{JMAX} = 125°C, θ_{JA} = 160°C/W (NOTE 2)
EXPOSED PAD (PIN 7) IS CONNECTED TO V– (PIN 5)

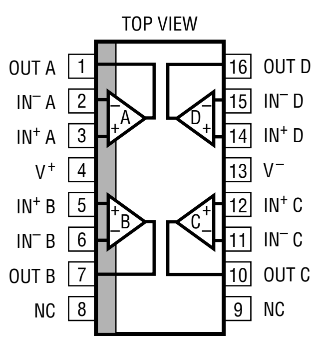


MS8 PACKAGE
8-LEAD PLASTIC MSOP
T_{JMAX} = 150°C, θ_{JA} = 250°C/W

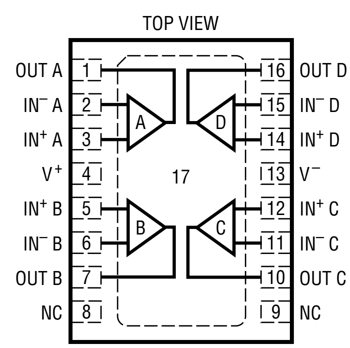


DD PACKAGE
10-LEAD (3mm × 3mm) PLASTIC DFN
T_{JMAX} = 125°C, θ_{JA} = 160°C/W (NOTE 2)
EXPOSED PAD (PIN 11) IS CONNECTED TO V– (PIN 4)

ORDER PART NUMBER	DCB PART MARKING*	ORDER PART NUMBER	MS8 PART MARKING*	ORDER PART NUMBER	DD PART MARKING*
LT6000CDCB LT6000IDCB	LCDM LCDM	LT6001CMS8 LT6001IMS8	LTBVD LTBVD	LT6001CDD LT6001IDD	LBVH LBVH



GN PACKAGE
16-LEAD NARROW PLASTIC SSOP
T_{JMAX} = 150°C, θ_{JA} = 135°C/W



DHC PACKAGE
16-LEAD (5mm × 3mm) DFN
T_{JMAX} = 125°C, θ_{JA} = 160°C/W (NOTE 2)
EXPOSED PAD (PIN 17) IS CONNECTED TO V– (PIN 13)

ORDER PART NUMBER	GN PART MARKING	ORDER PART NUMBER	DHC PART MARKING*
LT6002CGN LT6002IGN	6002 6002I	LT6002CDHC LT6002IDHC	6002 6002

Order Options Tape and Reel: Add #TR
Lead Free: Add #PBF Lead Free Tape and Reel: Add #TRPBF
Lead Free Part Marking: http://www.linear.com/leadfree/

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

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full specified temperature range, otherwise specifications are T_A = 25°C. V_S = 1.8V, 0V, V_{CM} = V_{OUT} = 0.5V. For the LT6000 and the LT6001DD, $V_{\overline{SHDN}}$ = V^+, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6001MS8 0°C ≤ T_A ≤ 70°C –40°C ≤ T_A ≤ 85°C	 ● ●		200	600 800 950	µV µV µV
		LT6000DCB, LT6001DD, LT6002GN 0°C ≤ T_A ≤ 70°C –40°C ≤ T_A ≤ 85°C	 ● ●		250	750 1000 1200	µV µV µV
		LT6002DHC 0°C ≤ T_A ≤ 70°C –40°C ≤ T_A ≤ 85°C	 ● ●		300	900 1100 1300	µV µV µV
		V_{CM} = V^+ LT6001MS8	 ●		 400	 1000 1300	 µV µV
		V_{CM} = V^+ LT6000DCB, LT6001DD, LT6002GN	 ●		 500	 1200 1550	 µV µV
		V_{CM} = V^+ LT6002DHC	 ●		 500	 1300 1700	 µV µV
$\Delta V_{OS}/\Delta T$	Input Offset Voltage Drift (Note 5)	V_{CM} = 0.5V	●		2	5	µV/°C
I_B	Input Bias Current	V_{CM} = 0.5V V_{CM} = V^- V_{CM} = V^+	● ● ●	–5 –5	–2 –2 4	 10	nA nA nA
I_{OS}	Input Offset Current	V_{CM} = 0.5V V_{CM} = V^- V_{CM} = V^+	● ● ●		0.2 0.2 0.4	1 1 2	nA nA nA
	Input Noise Voltage	0.1Hz to 10Hz			1.2		$µV_{P-P}$
e_n	Input Voltage Noise Density	f = 1kHz			75		$nV/\sqrt{Hz}$
i_n	Input Current Noise Density	f = 1kHz			25		$fA/\sqrt{Hz}$
R_{IN}	Input Resistance	Common Mode (V_{CM} = 0V to 0.6V) Differential		 10	3.5 25		GΩ MΩ
C_{IN}	Input Capacitance				5		pF
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 0.6V, 0°C ≤ T_A ≤ 70°C V_{CM} = 0.1V to 0.6V, –40°C ≤ T_A ≤ 85°C V_{CM} = 0V to 1.8V	● ● ●	82 82 60	96 96 78		dB dB dB
	Input Voltage Range		●	0		1.8	V
PSRR	Power Supply Rejection Ratio	V_S = 1.8V to 16V V_{CM} = V_O = 0.5V	●	86	100		dB
	Minimum Supply	V_{CM} = V_O = 0.5V	●	1.8			V
A_{VOL}	Large-Signal Gain	V_O = 0.25V to 1.25V R_L = 100k to GND R_L = 100k to GND R_L = 10k to GND R_L = 10k to GND	 ● ●	 25 20 40 25	 65 125		 V/mV V/mV V/mV V/mV
V_{OL}	Output Swing Low (Note 6)	Input Overdrive = 30mV No Load I_{SINK} = 100µA	 ● ●		 30 120	 60 200	 mV mV
V_{OH}	Output Swing High (Note 6)	Input Overdrive = 30mV No Load I_{SOURCE} = 100µA R_L = 10k to GND	 ● ● ●		 30 140 160	 60 225 250	 mV mV mV

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full specified temperature range, otherwise specifications are T_A = 25°C. V_S = 1.8V, 0V, V_{CM} = V_{OUT} = 0.5V. For the LT6000 and the LT6001DD, $V_{\overline{SHDN}}$ = V^+, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
I_{SC}	Short-Circuit Current	Short to GND		2	4		mA
		0°C ≤ T_A ≤ 70°C	●	1			mA
		–40°C ≤ T_A ≤ 85°C	●	0.4			mA
		Short to V^+		0.7	2		mA
		0°C ≤ T_A ≤ 70°C	●	0.4			mA
		–40°C ≤ T_A ≤ 85°C	●	0.15			mA
I_S	Supply Current per Amplifier				13	16	µA
		0°C ≤ T_A ≤ 70°C	●			22	µA
		–40°C ≤ T_A ≤ 85°C	●			24	µA
	Total Supply Current in Shutdown (Note 7)	$V_{\overline{SHDN}}$ = 0.3V	●		0.8	1.5	µA
$I_{\overline{SHDN}}$	$\overline{\text{SHDN}}$ Pin Current (Note 7)	$V_{\overline{SHDN}}$ = 1.8V	●		0	30	nA
		$V_{\overline{SHDN}}$ = 0V	●	–300	–200		nA
	Shutdown Output Leakage Current (Note 7)	$V_{\overline{SHDN}}$ = 0.3V (V^- ≤ V_{OUT} ≤ V^+)	●		20		nA
V_L	$\overline{\text{SHDN}}$ Pin Input Low Voltage (Note 7)		●			0.3	V
V_H	$\overline{\text{SHDN}}$ Pin Input High Voltage (Note 7)		●	1.5V			V
t_{ON}	Turn On Time (Note 7)	$V_{\overline{SHDN}}$ = 0V to 1.8V, R_L = 10k			400		µs
t_{OFF}	Turn Off Time (Note 7)	$V_{\overline{SHDN}}$ = 1.8V to 0V, R_L = 10k			100		µs
GBW	Gain Bandwidth Product (Note 8)	Freq = 1kHz		32	50		kHz
		0°C ≤ T_A ≤ 70°C	●	28			kHz
		–40°C ≤ T_A ≤ 85°C	●	24			kHz
SR	Slew Rate	A_V = –1, V_{OUT} = 0.25V to 1.5V		9	15		V/ms
		Measure 0.5V to 1.25V, 0°C ≤ T_A ≤ 70°C	●	7			V/ms
		–40°C ≤ T_A ≤ 85°C	●	5			V/ms
FPBW	Full Power Bandwidth (Note 9)	V_{OUT} = 1.25V_{P-P}		2.3	3.8		kHz

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full specified temperature range, otherwise specifications are T_A = 25°C. V_S = 5V, 0V, V_{CM} = V_{OUT} = 1/2 Supply. For the LT6000 and the LT6001DD, $V_{\overline{SHDN}}$ = V^+, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	LT6001MS8			200	600	µV
		0°C ≤ T_A ≤ 70°C	●			800	µV
		–40°C ≤ T_A ≤ 85°C	●			950	µV
		LT6000DCB, LT6001DD, LT6002GN			250	750	µV
		0°C ≤ T_A ≤ 70°C	●			1000	µV
		–40°C ≤ T_A ≤ 85°C	●			1200	µV
		LT6002DHC			300	900	µV
		0°C ≤ T_A ≤ 70°C	●			1100	µV
		–40°C ≤ T_A ≤ 85°C	●			1300	µV
		V_{CM} = V^+ LT6001MS8			400	1000	µV
			●			1300	µV
		V_{CM} = V^+ LT6000DCB, LT6001DD, LT6002GN			500	1200	µV
			●			1550	µV
		V_{CM} = V^+ LT6002DHC			500	1300	µV
			●			1700	µV
$\Delta V_{OS}/\Delta T$	Input Offset Voltage Drift (Note 5)	V_{CM} = V_S/2	●		2	5	µV/°C
I_B	Input Bias Current	V_{CM} = V_S/2	●	–6	–2		nA
		V_{CM} = $V^–$	●	–6	–2		nA
		V_{CM} = V^+	●		4	12	nA
I_{OS}	Input Offset Current	V_{CM} = V_S/2	●		0.2	1.2	nA
		V_{CM} = $V^–$	●		0.2	1.2	nA
		V_{CM} = V^+	●		0.4	2.4	nA
	Input Noise Voltage	0.1Hz to 10Hz			1.2		$µV_{P-P}$
e_n	Input Voltage Noise Density	f = 1kHz			75		nV/√Hz
i_n	Input Current Noise Density	f = 1kHz			25		fA/√Hz
R_{IN}	Input Resistance	Common Mode (V_{CM} = 0V to 3.8V)			3.5		GΩ
		Differential	●	8.5	25		MΩ
C_{IN}	Input Capacitance				5		pF
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 3.8V, 0°C ≤ T_A ≤ 70°C	●	90	105		dB
		V_{CM} = 0.1V to 3.8V, –40°C ≤ T_A ≤ 85°C	●	90	105		dB
		V_{CM} = 0V to 5V	●	68	86		dB
	Input Voltage Range		●	0		5	V
PSRR	Power Supply Rejection Ratio	V_S = 1.8V to 16V V_{CM} = V_O = 0.5V	●	86	100		dB
	Minimum Supply		●	1.8			V
A_{VOL}	Large-Signal Gain	V_O = 0.5V to 4.5V					
		R_L = 100k to V_S/2		30	60		V/mV
		R_L = 100k to V_S/2	●	25			V/mV
		R_L = 10k to V_S/2		16	25		V/mV
		R_L = 10k to V_S/2	●	10			V/mV
		R_L = 10k to GND		160	1000		V/mV
		R_L = 10k to GND	●	80			V/mV
V_{OL}	Output Swing Low (Note 6)	Input Overdrive = 30mV					
		No Load	●		30	60	mV
		I_{SINK} = 100µA	●		120	200	mV
		I_{SINK} = 500µA	●		180	300	mV

ELECTRICAL CHARACTERISTICS

The ● denotes specifications which apply over the full specified temperature range, otherwise specifications are T_A = 25°C. V_S = 5V, 0V, V_{CM} = V_{OUT} = 1/2 Supply. For the LT6000 and the LT6001DD, $V_{\overline{SHDN}}$ = V^+, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
V_{OH}	Output Swing High (Note 6)	Input Overdrive = 30mV					
		No Load	●		30	60	mV
		I_{SOURCE} = 100µA	●		140	225	mV
		R_L = 10k to GND	●		160	400	mV
I_{SC}	Short-Circuit Current	Short to GND		5	10		mA
		0°C ≤ T_A ≤ 70°C	●	4			mA
		–40°C ≤ T_A ≤ 85°C	●	3			mA
		Short to V^+		3.5	7.5		mA
		0°C ≤ T_A ≤ 70°C	●	2.5			mA
		–40°C ≤ T_A ≤ 85°C	●	1.5			mA
I_S	Supply Current per Amplifier				15	18	µA
		0°C ≤ T_A ≤ 70°C	●			24	µA
		–40°C ≤ T_A ≤ 85°C	●			27	µA
		V_S = ±8V			20	25	µA
			●			34	µA
	Total Supply Current in Shutdown (Note 7)	$V_{\overline{SHDN}}$ = 0.3V	●		3	5	µA
$I_{\overline{SHDN}}$	$\overline{SHDN}$ Pin Current (Note 7)	$V_{\overline{SHDN}}$ = 5V	●		0	30	nA
		$V_{\overline{SHDN}}$ = 0V	●	–1000	–650		nA
	Shutdown Output Leakage Current (Note 7)	$V_{\overline{SHDN}}$ = 0.3V (V^- ≤ V_{OUT} ≤ V^+)	●		20		nA
V_L	$\overline{SHDN}$ Pin Input Low Voltage (Note 7)		●			0.3	V
V_H	$\overline{SHDN}$ Pin Input High Voltage (Note 7)		●	4.7			V
t_{ON}	Turn On Time (Note 7)	$V_{\overline{SHDN}}$ = 0V to 5V, R_L = 10k			400		µs
t_{OFF}	Turn Off Time (Note 7)	$V_{\overline{SHDN}}$ = 5V to 0V, R_L = 10k			100		µs
GBW	Gain Bandwidth Product	Freq = 1kHz		40	60		kHz
		0°C ≤ T_A ≤ 70°C	●	35			kHz
		–40°C ≤ T_A ≤ 85°C	●	30			kHz
SR	Slew Rate	A_V = –1, V_{OUT} = 0.5V to 4.5V		11	18		V/ms
		Measure 1V to 4V, 0°C ≤ T_A ≤ 70°C	●	8			V/ms
		–40°C ≤ T_A ≤ 85°C	●	6			V/ms
FPBW	Full Power Bandwidth (Note 9)	V_{OUT} = $4V_{P-P}$		0.87	1.4		kHz

Note 1: Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

Note 2: A heat sink may be required to keep the junction temperature below the absolute maximum. This depends on the power supply voltage and how many amplifiers are shorted. The θ_{JA} specified for the DD and DHC packages is with minimal PCB heat spreading metal. Using expanded metal area on all layers of a board reduces this value.

Note 3: The LT6000C/LT6000I/LT6001C/LT6001I and LT6002C/LT6002I are guaranteed functional over the temperature range of –40°C to 85°C.

Note 4: The LT6000C/LT6001C/LT6002C is guaranteed to meet specified performance from 0°C to 70°C. The LT6000C/LT6001C/LT6002C are designed, characterized and expected to meet specified performance from –40°C to 85°C but are not tested or QA sampled at these temperatures. The LT6000I/LT6001I/ LT6002I is guaranteed to meet specified performance from –40°C to 85°C.

Note 5: This parameter is not 100% tested.

Note 6: Output voltage swings are measured between the output and power supply rails.

Note 7: Specifications apply to the LT6000 or the LT6001DD with shutdown.

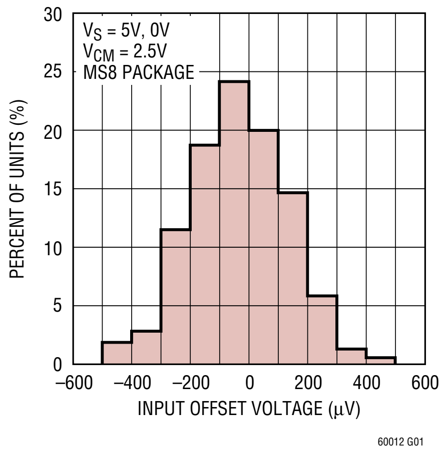
Note 8: Guaranteed by correlation to slew rate at V_S = 1.8V and GBW at V_S = 5V.

Note 9: Full-power bandwidth is calculated from the slew rate:

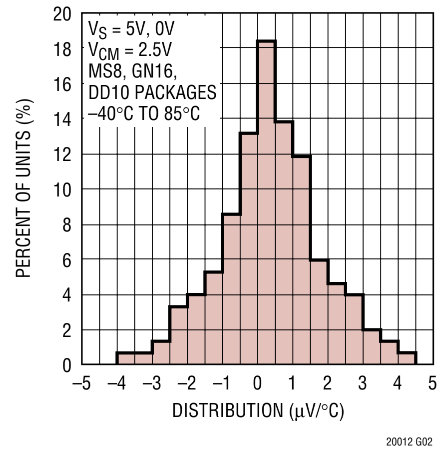
$$FPBW = SR/\pi V_{P-P}.$$

TYPICAL PERFORMANCE CHARACTERISTICS

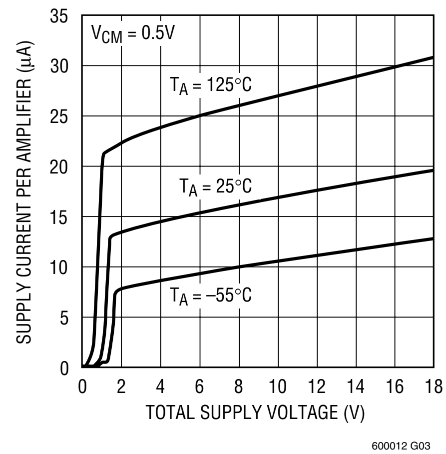
V_{OS} Distribution



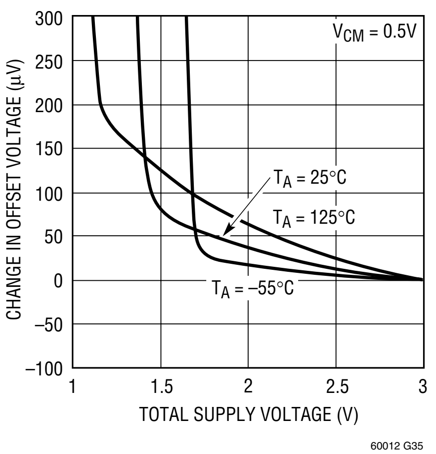
TC V_{OS} Distribution



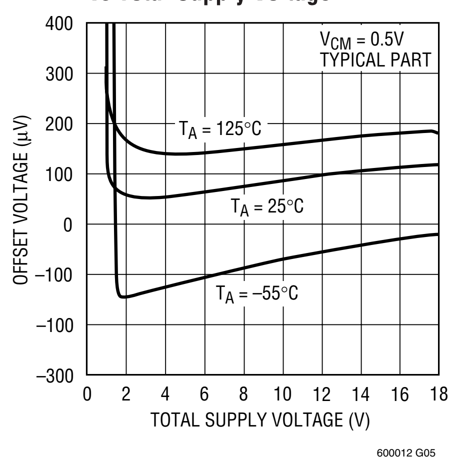
Supply Current vs Supply Voltage



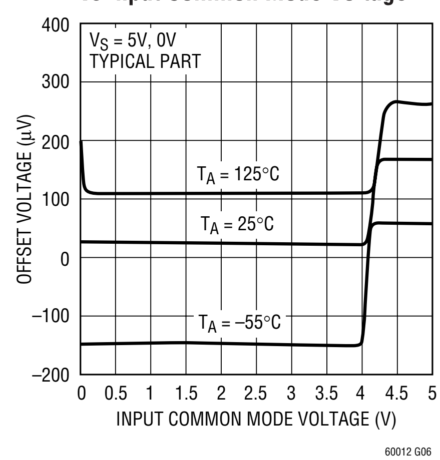
Change in Input Offset Voltage vs Total Supply Voltage



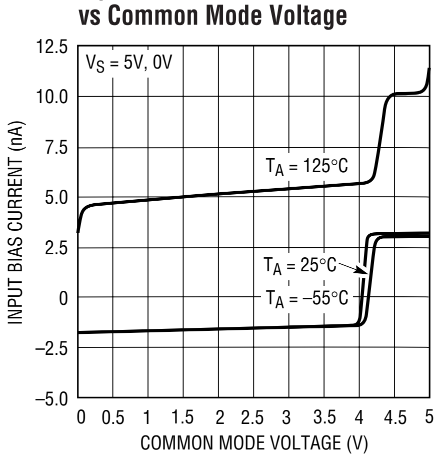
Input Offset Voltage vs Total Supply Voltage



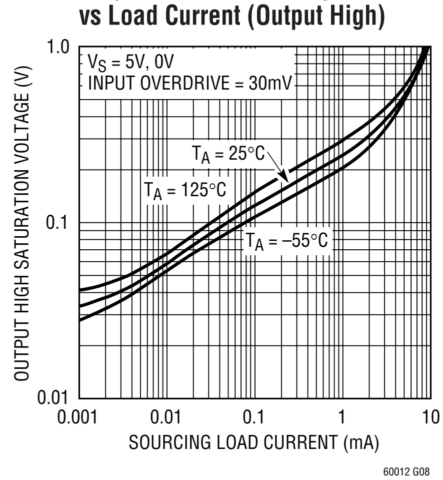
Input Offset Voltage vs Input Common Mode Voltage



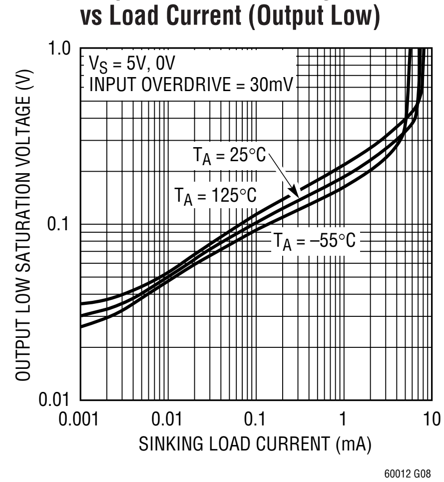
Input Bias Current vs Common Mode Voltage



Output Saturation Voltage vs Load Current (Output High)

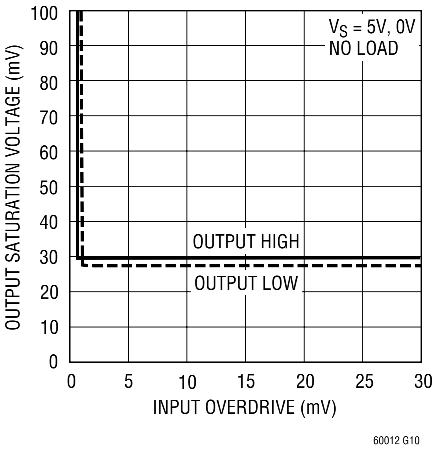


Output Saturation Voltage vs Load Current (Output Low)

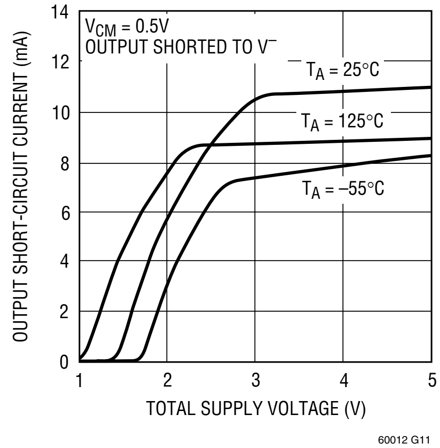


TYPICAL PERFORMANCE CHARACTERISTICS

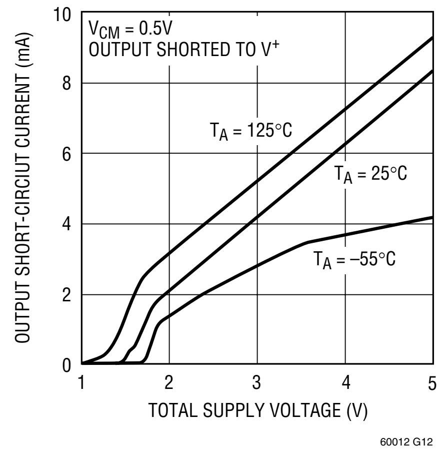
Output Saturation Voltage vs Input Overdrive



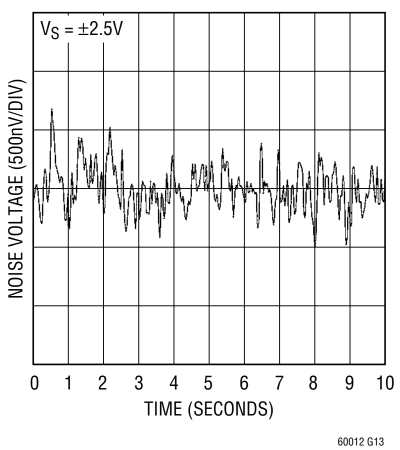
Output Short-Circuit Current vs Total Supply Voltage (Sourcing)



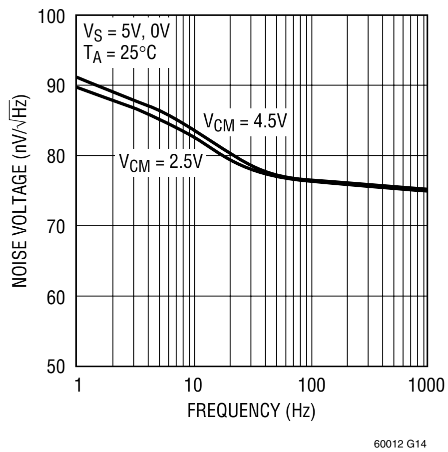
Output Short-Circuit Current vs Total Supply Voltage (Sinking)



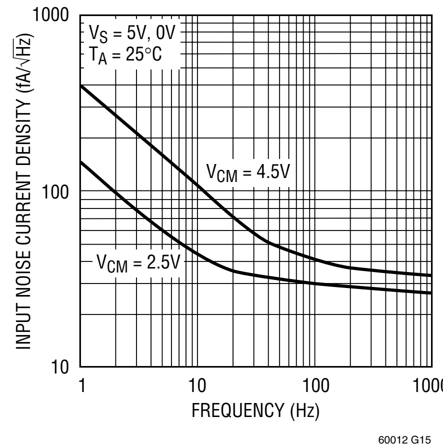
0.1Hz to 10Hz Output Voltage Noise



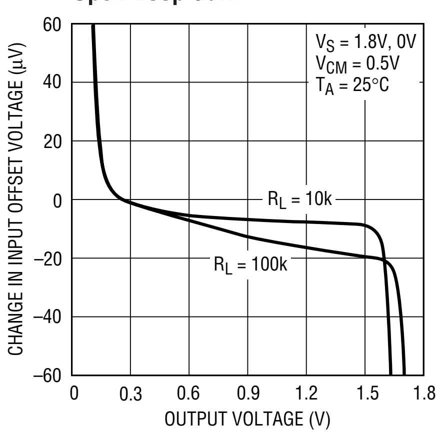
Noise Voltage Density vs Frequency



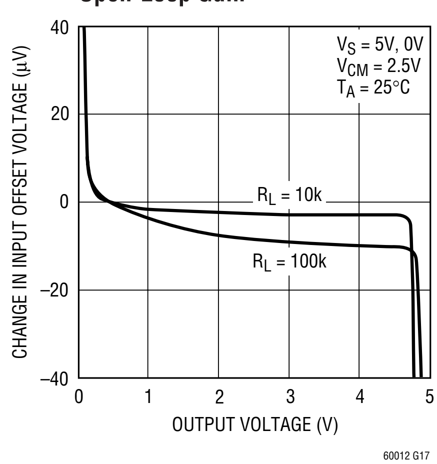
Input Noise Current vs Frequency



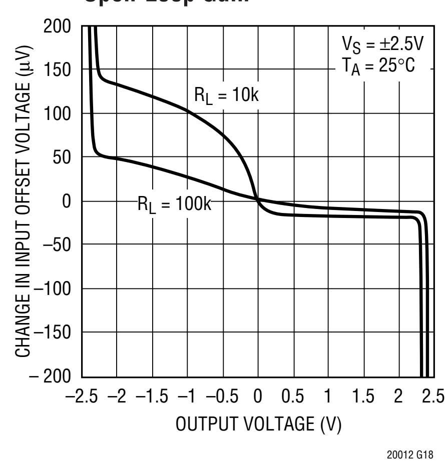
Open-Loop Gain



Open-Loop Gain

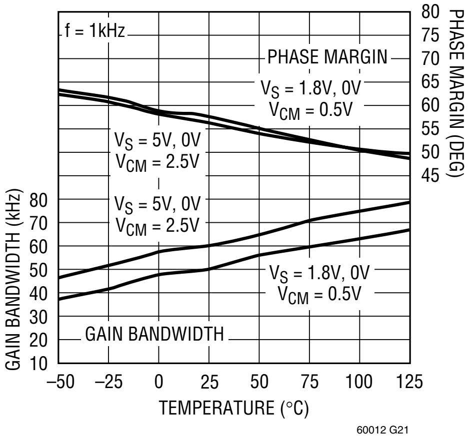


Open-Loop Gain

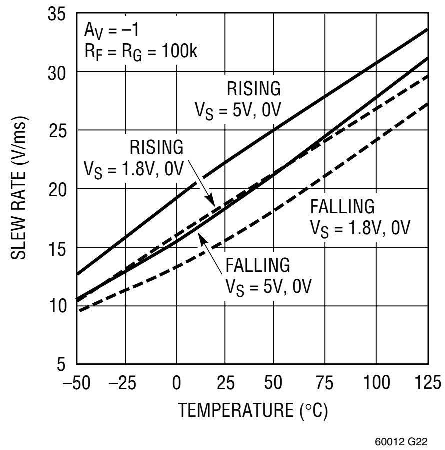


TYPICAL PERFORMANCE CHARACTERISTICS

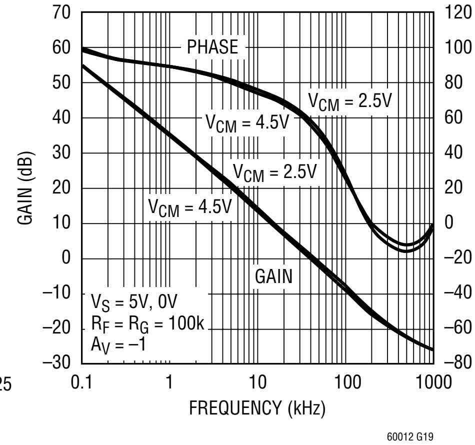
Gain Bandwidth and Phase Margin vs Temperature



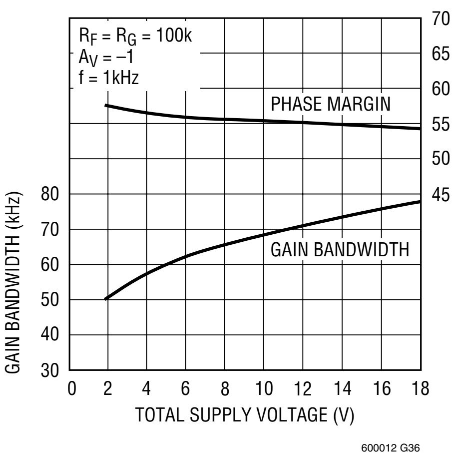
Slew Rate vs Temperature



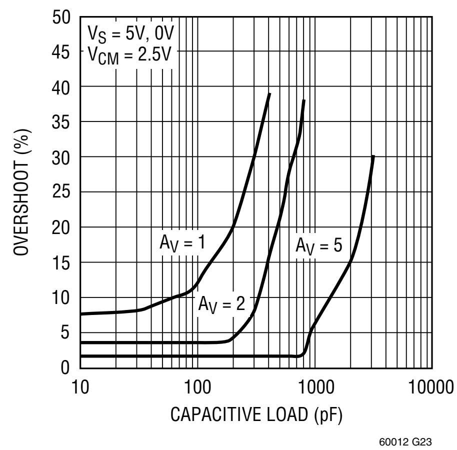
Gain and Phase vs Frequency



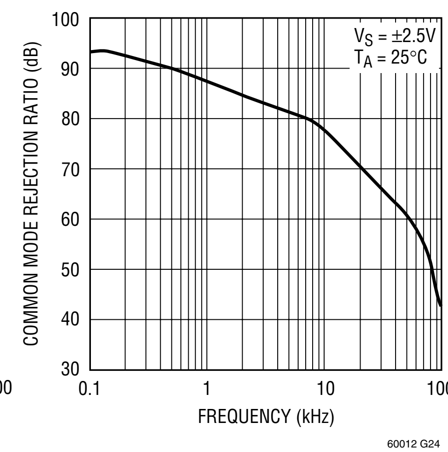
Gain Bandwidth and Phase Margin vs Supply Voltage



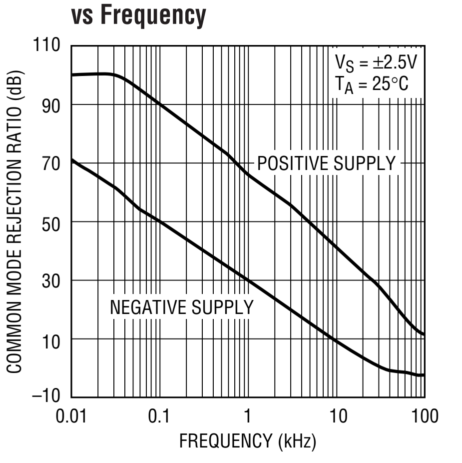
Capacitive Load Handling Overshoot vs Capacitive Load



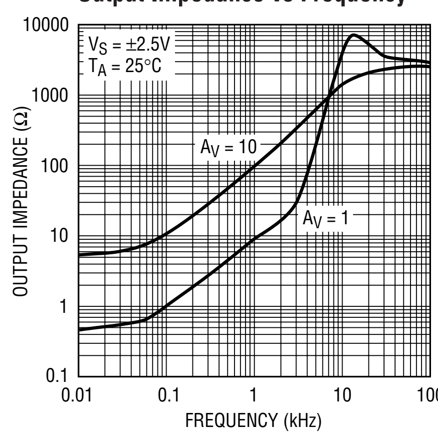
Common Mode Rejection Ratio vs Frequency



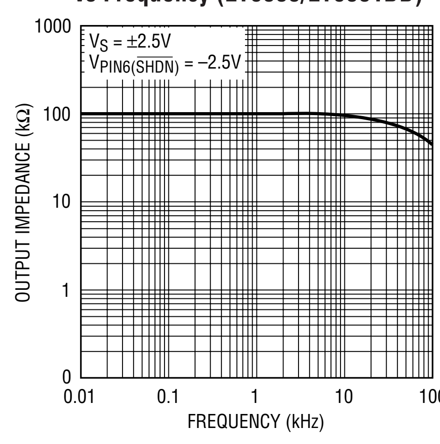
Power Supply Rejection Ratio vs Frequency



Output Impedance vs Frequency

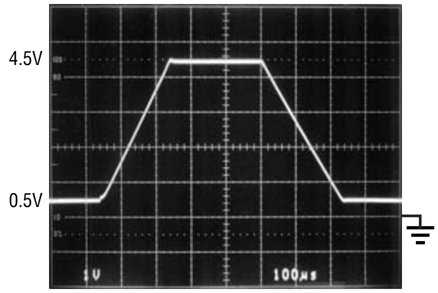


Disabled Output Impedance vs Frequency (LT6000/LT6001DD)



TYPICAL PERFORMANCE CHARACTERISTICS

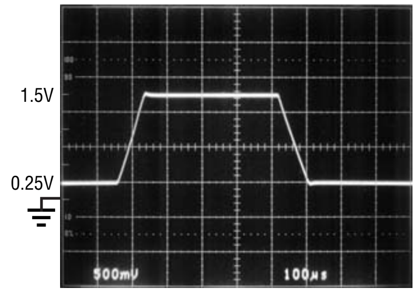
Large-Signal Response



$A_V = 1$ 100µs/DIV
$V_S = 5V, 0V$
$C_L = 100pF$
$R_L = 10k$

60012 G28

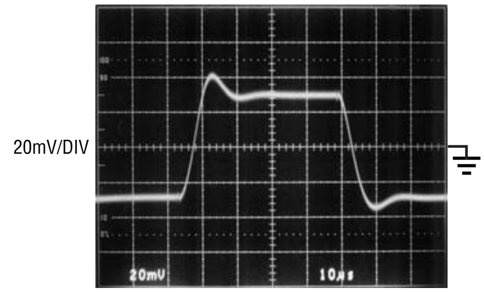
Large-Signal Response



$A_V = 1$ 100µs/DIV
$V_S = 1.8V, 0V$
$C_L = 100pF$
$R_L = 10k$

60012 G29

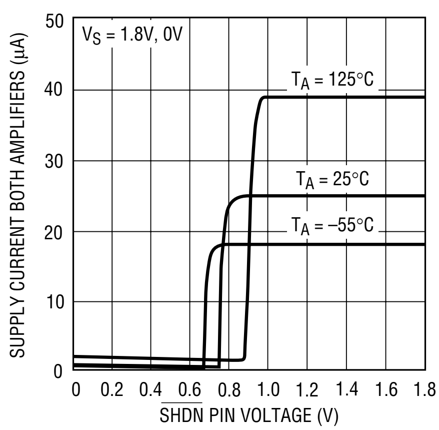
Small-Signal Response



$A_V = 1$ 10µs/DIV
$V_S = ±2.5V$
$C_L = 100pF$
$R_L = 100k$

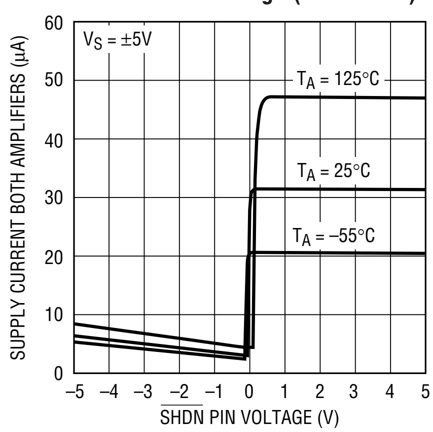
60012 G30

Total Supply Current vs $\overline{SHDN}$ Pin Voltage (LT6001DD)



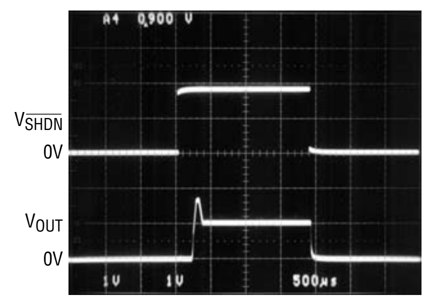
60012 G31

Total Supply Current vs $\overline{SHDN}$ Pin Voltage (LT6001DD)



60012 G32

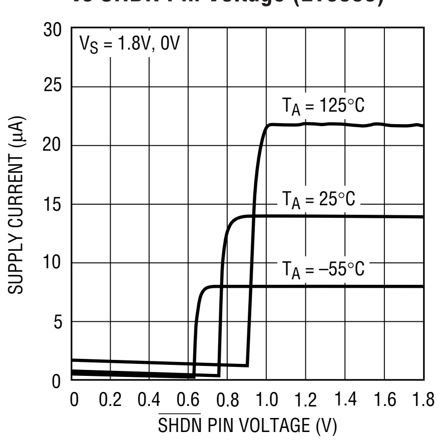
Shutdown Response (LT6000/LT6001DD)



$V_{IN} = 1V$ 500µs/DIV
$A_V = 1$
$V_S = 1.8V, 0V$
$R_L = 100k$

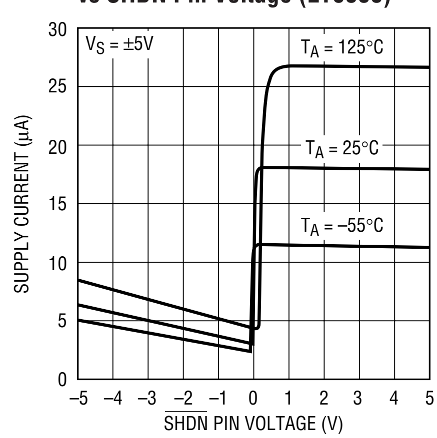
60012 G33

Supply Current vs $\overline{SHDN}$ Pin Voltage (LT6000)



60012 G37

Supply Current vs $\overline{SHDN}$ Pin Voltage (LT6000)



60012 G34

SIMPLIFIED SCHEMATIC

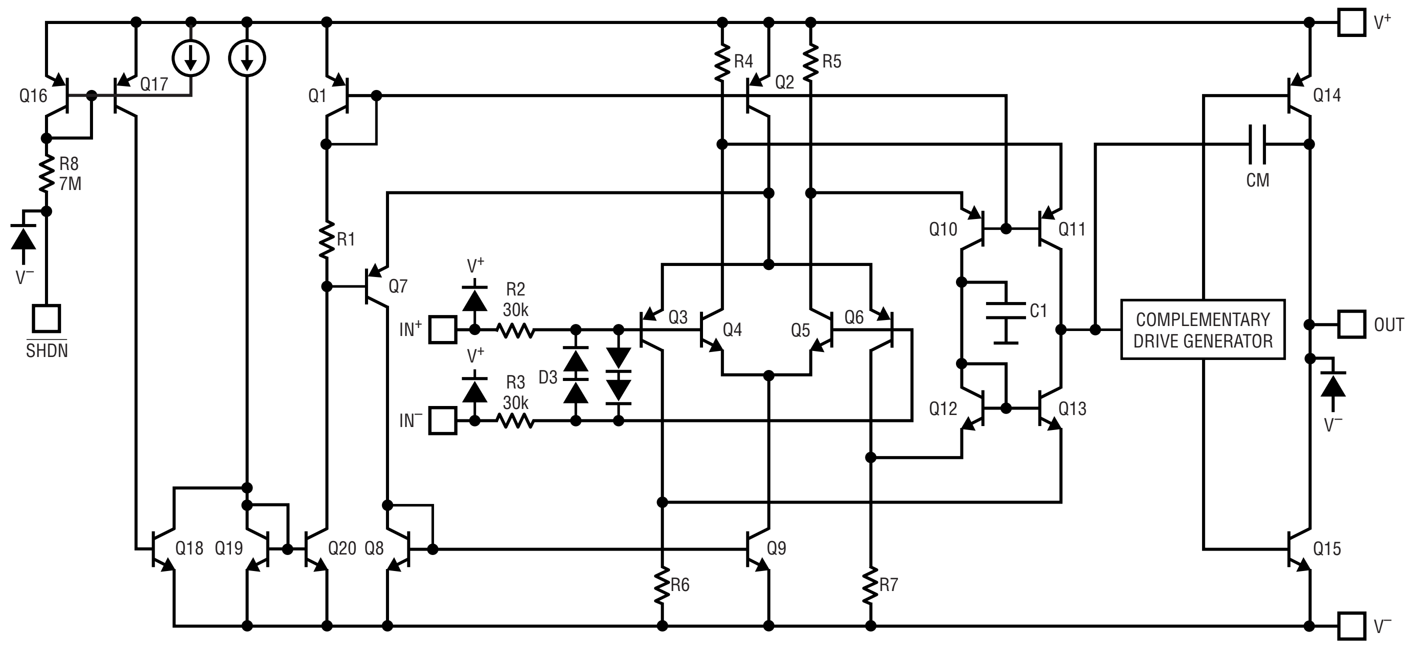


Figure 1

APPLICATIONS INFORMATION

Supply Voltage

The positive supply of the LT6000/LT6001/LT6002 should be bypassed with a small capacitor (about 0.01μF) within an inch of the pin. When driving heavy loads, an additional 4.7μF electrolytic capacitor should be used. When using split supplies, the same is true for the negative supply pin.

Rail-to-Rail Characteristics

The LT6000/LT6001/LT6002 are fully functional for an input signal range from the negative supply to the positive supply. Figure 1 shows a simplified schematic of the amplifier. The input stage consists of two differential amplifiers, a PNP stage Q3/Q6 and an NPN stage Q4/Q5 that are active over different ranges of the input common mode voltage. The PNP stage is active for common mode voltages, V_{CM}, between the negative supply to approximately 1V below the positive supply. As V_{CM} moves closer towards the positive supply, the transistor Q7 will steer Q2's tail current to the current mirror Q8/Q9, activating the NPN differential pair. The PNP pair becomes inactive for the rest of the input common mode range up to the positive supply.

The second stage is a folded cascode and current mirror that converts the input stage differential signals into a single ended output. Capacitor C1 reduces the unity cross frequency and improves the frequency stability without degrading the gain bandwidth of the amplifier. The complementary drive generator supplies current to the output transistors that swing from rail to rail.

Input

The input bias current depends on which stage is active. The input bias current polarity depends on the input common mode voltage. When the PNP stage is active, the input bias currents flow out of the input pins. They flow in the opposite direction when the NPN stage is active. The offset error due to the input bias currents can be minimized by equalizing the noninverting and inverting source impedance.

APPLICATIONS INFORMATION

The input offset voltage changes depending on which input stage is active; input offset voltage is trimmed on both input stages, and is guaranteed to be 600μV max in the PNP stage. By trimming the input offset voltage of both input stages, the input offset voltage over the entire common mode range (CMRR) is typically 400μV, maintaining the precision characteristics of the amplifier.

The input stage of the LT6000/LT6001/LT6002 incorporates phase reversal protection to prevent wrong polarity outputs from occurring when the inputs are driven up to 2V below the negative rail. 30k protective resistors are included in the input leads so that current does not become excessive when the inputs are forced below V^- or when a large differential signal is applied. Input current should be limited to 10mA when the inputs are driven above the positive rail.

Output

The output of the LT6000/LT6001/LT6002 can swing to within 30mV of the positive rail with no load and within 30mV of the negative rail with no load. When monitoring input voltages within 30mV of the positive rail or within 30mV of the negative rail, gain should be taken to keep the output from clipping. The LT6000/LT6001/LT6002 can typically source 10mA on a single 5V supply, sourcing current is reduced to 4mA on a single 1.8V supply as noted in the electrical characteristics.

The normally reverse-biased substrate diode from the output to V^- will cause unlimited currents to flow when the output is forced below V^-. If the current is transient and limited to 100mA, no damage will occur.

Start-Up and Output Saturation Characteristics

Micropower op amps are often not micropower during start-up characteristics or during output saturation. This can wreak havoc on limited current supplies, in the worst case there may not be enough supply current available to take the system up to nominal voltages. Also, when the output saturates, the part may draw excessive current and pull down the supplies, compromising rail-to-rail performance. Figure 1 shows the start-up characteristics of the LT6000/LT6001/LT6002 for three limiting cases. The circuits are shown in Figure 2. One circuit creates a positive offset forcing the output to come up saturated high. Another circuit creates a negative offset forcing the output to come up saturated low, while the last circuit brings the output up at 1/2 supply. In all cases, the supply current is well controlled and is not excessive when the output is on either rail.

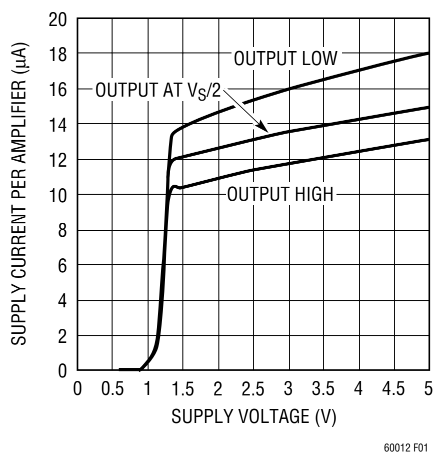
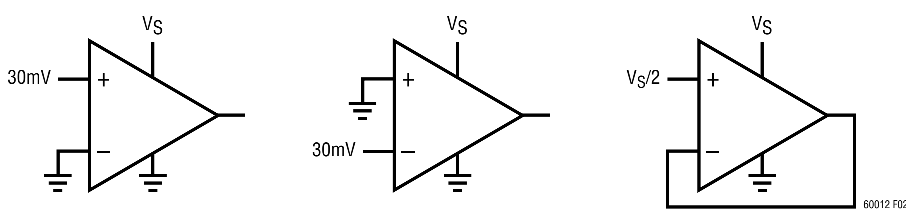


Figure 1. Start-Up Characteristics



Output High **Output Low** **Output at V_S/2**

Figure 2. Circuits for Start-Up Characteristics

APPLICATIONS INFORMATION

The LT6000/LT6001/LT6002 outputs can swing to within a respectable 30mV of each rail and draw virtually no excessive supply current. Figure 3 compares the dual LT6001 to a competitive part. Both op amps are in unity gain and their outputs are driven into each rail. The supply current is shown when the op amps are in linear operation and when they are driven into each rail. As can be seen from Figure 3, the supply current of the competitive part increases 3-fold or 5-fold depending on which rail the output goes to whereas the LT6001 draws virtually no excessive current.

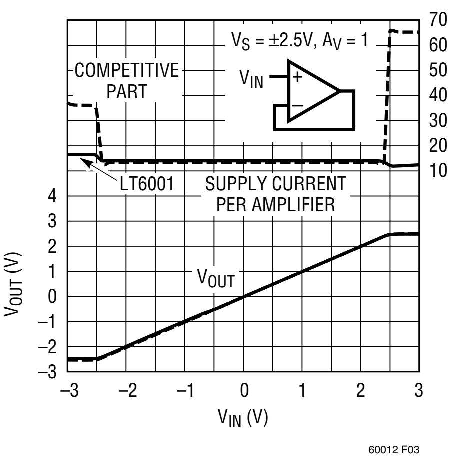


Figure 3. V_{OUT} and I_{CC} vs Input Voltage

Gain

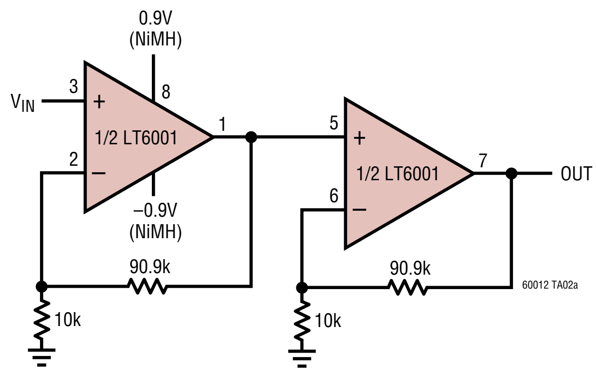
The open-loop gain is almost independent of load when the output is sourcing current. This optimizes performance in single supply applications where the load is returned to ground. The typical performance curve of Open-Loop Gain for various loads shows the details.

Shutdown

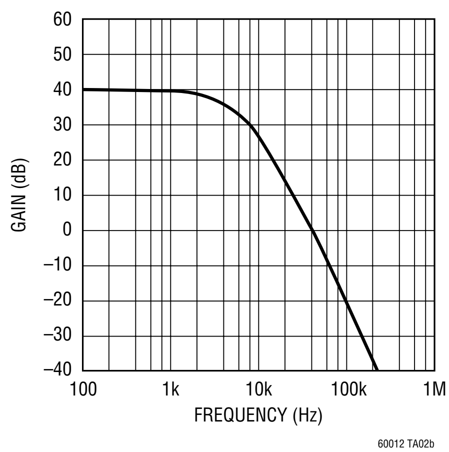
The single LT6000 and the 10-lead dual LT6001 include a shutdown feature that disables the part reducing quiescent current and makes the output high impedance. The devices can be shut down by bringing the $\overline{SHDN}$ pin within 0.3V of $V^–$. The amplifiers are guaranteed to shut down if the $\overline{SHDN}$ pin is brought within 0.3V of $V^–$. The exact switchover point will be a function of the supply voltage. See the Typical Performance Characteristics curves Supply Current vs Shutdown Pin Voltage. When shut down the total supply current is about 0.8μA and the output leakage current is 20nA ($V^– \le V_{OUT} \le V^+$). For normal operation the $\overline{SHDN}$ pin should be tied to V^+. It can be left floating, however, parasitic leakage currents over 1μA at the $\overline{SHDN}$ pin may inadvertently place the part into shutdown.

TYPICAL APPLICATION

Gain of 100 Amplifier (400kHz GBW on 30μA Supply)

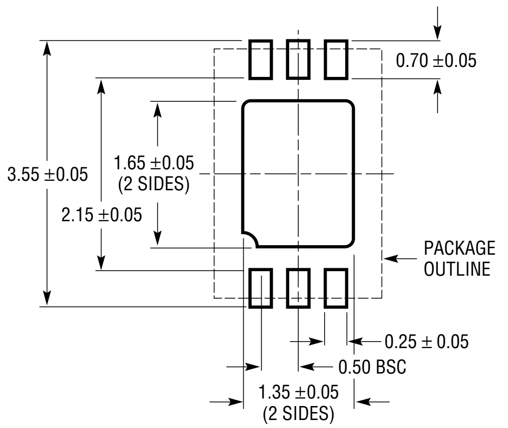


Gain vs Frequency

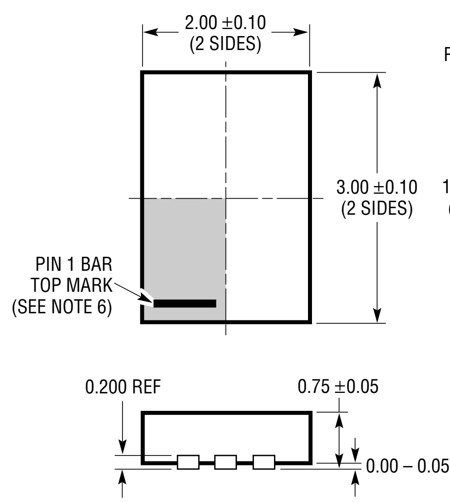


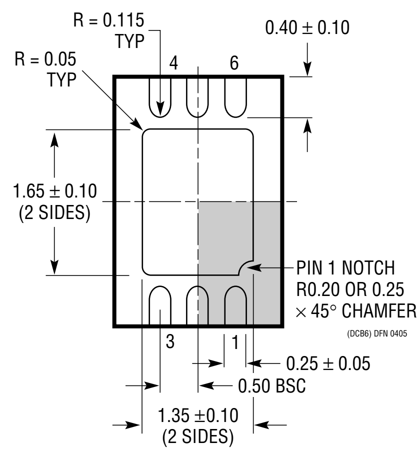
PACKAGE DESCRIPTION

DCB Package
6-Lead Plastic DFN (2mm × 3mm)
(Reference LTC DWG # 05-08-1715)



RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS



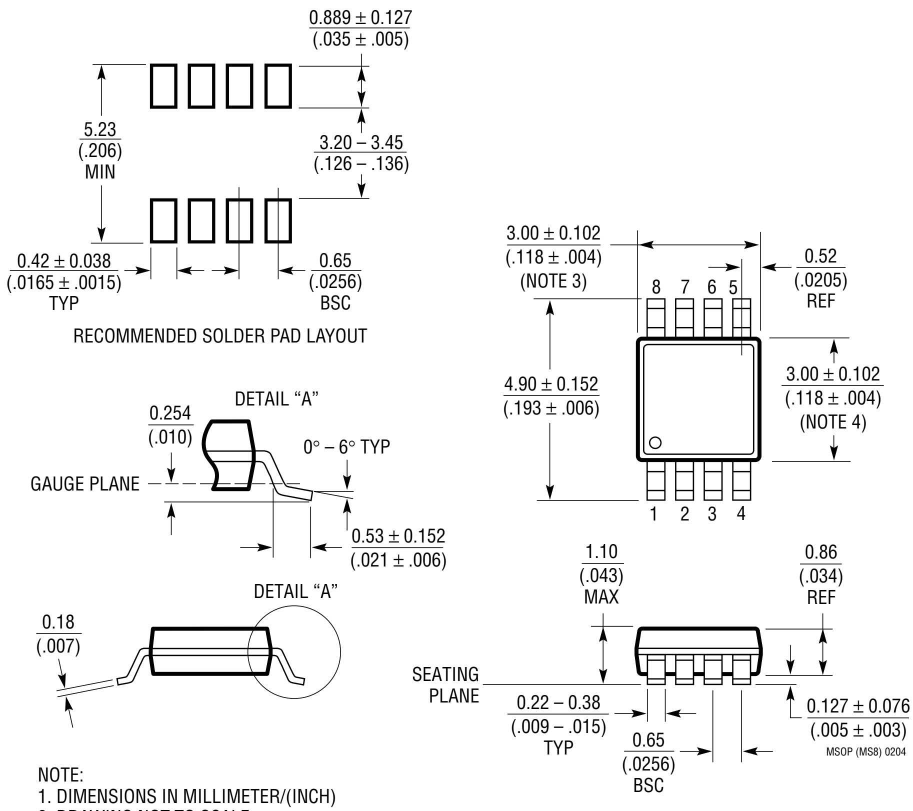


BOTTOM VIEW—EXPOSED PAD

NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (TBD)
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. 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
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE

PACKAGE DESCRIPTION

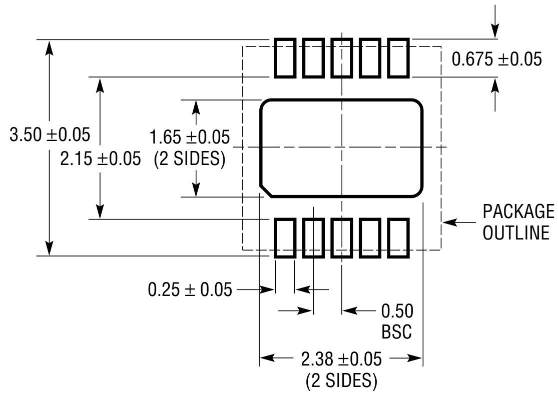
MS8 Package
8-Lead Plastic MSOP
(Reference LTC DWG # 05-08-1660)



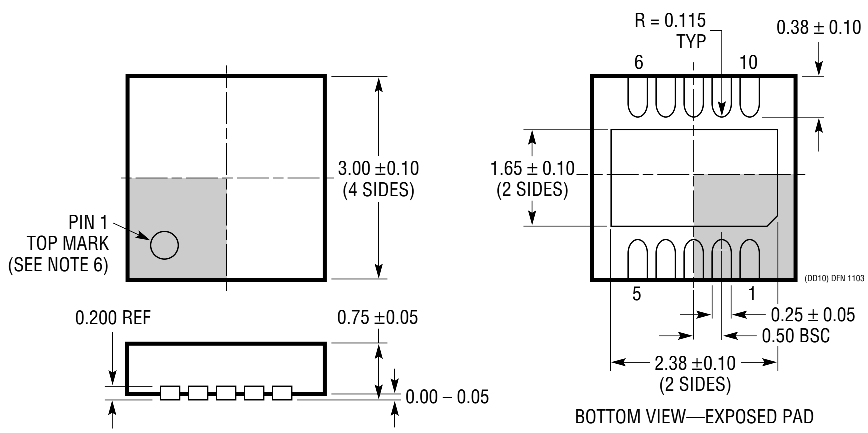
NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
   MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
   INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX

PACKAGE DESCRIPTION

DD Package
10-Lead (3mm × 3mm) Plastic DFN
(Reference LTC DWG # 05-08-1699)



RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS

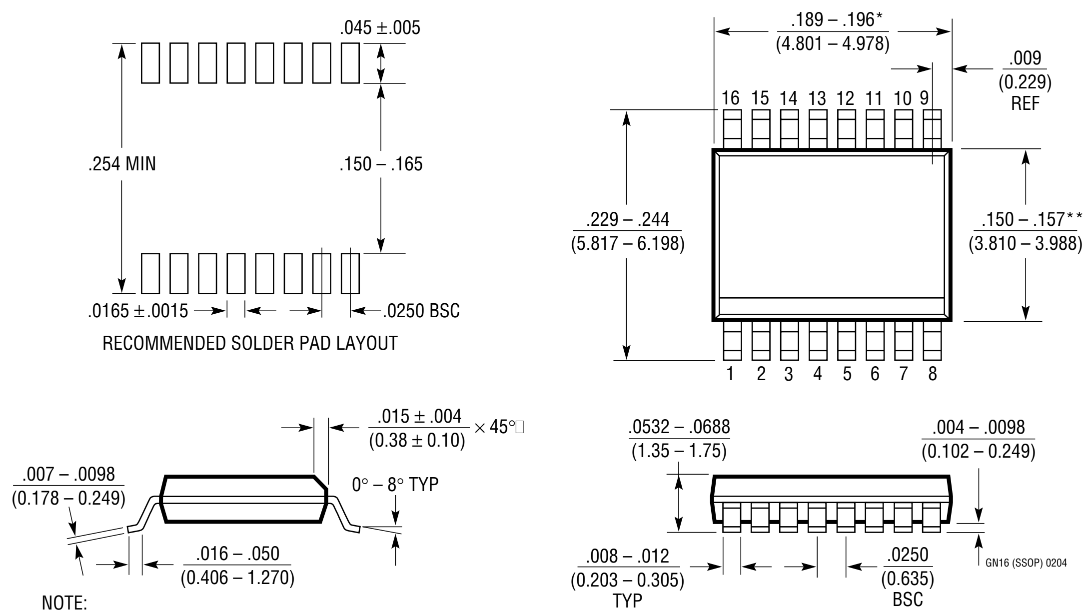


BOTTOM VIEW—EXPOSED PAD

NOTE:
1. DRAWING TO BE MADE A JEDEC PACKAGE OUTLINE M0-229 VARIATION OF (WEED-2).
   CHECK THE LTC WEBSITE DATA SHEET FOR CURRENT STATUS OF VARIATION ASSIGNMENT
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. 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
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE
   TOP AND BOTTOM OF PACKAGE

PACKAGE DESCRIPTION

GN Package
16-Lead Narrow Plastic SSOP
(Reference LTC DWG # 05-08-1641)



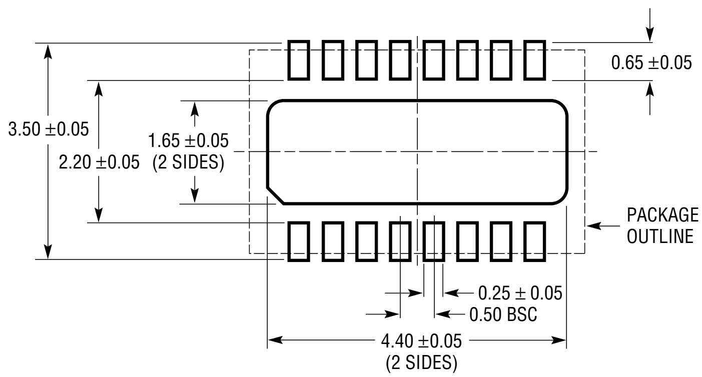
NOTE:
1. CONTROLLING DIMENSION: INCHES
2. DIMENSIONS ARE IN $\frac{\text{INCHES}}{\text{(MILLIMETERS)}}$
3. DRAWING NOT TO SCALE

*DIMENSION DOES NOT INCLUDE MOLD FLASH. MOLD FLASH SHALL NOT EXCEED 0.006" (0.152mm) PER SIDE

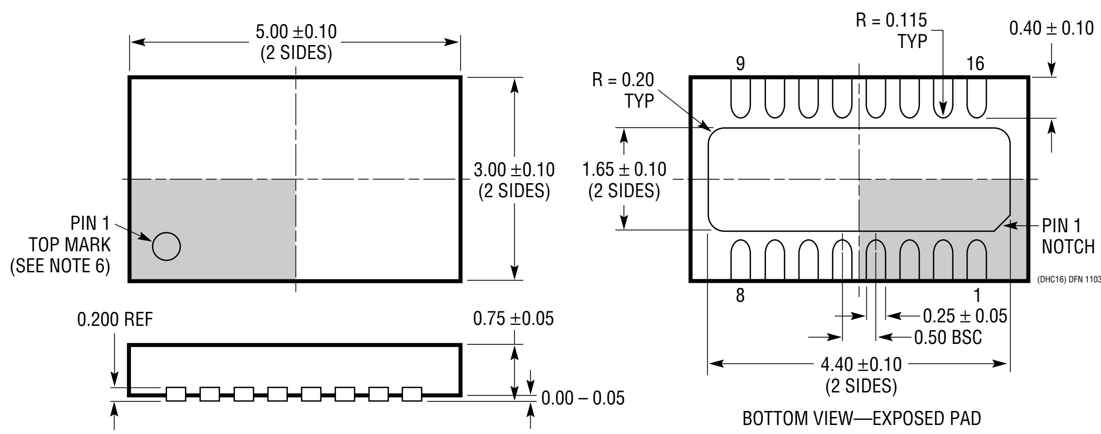
**DIMENSION DOES NOT INCLUDE INTERLEAD FLASH. INTERLEAD FLASH SHALL NOT EXCEED 0.010" (0.254mm) PER SIDE

PACKAGE DESCRIPTION

DHC Package
16-Lead (5mm × 5mm) Plastic DFN
(Reference LTC DWG # 05-08-1706)



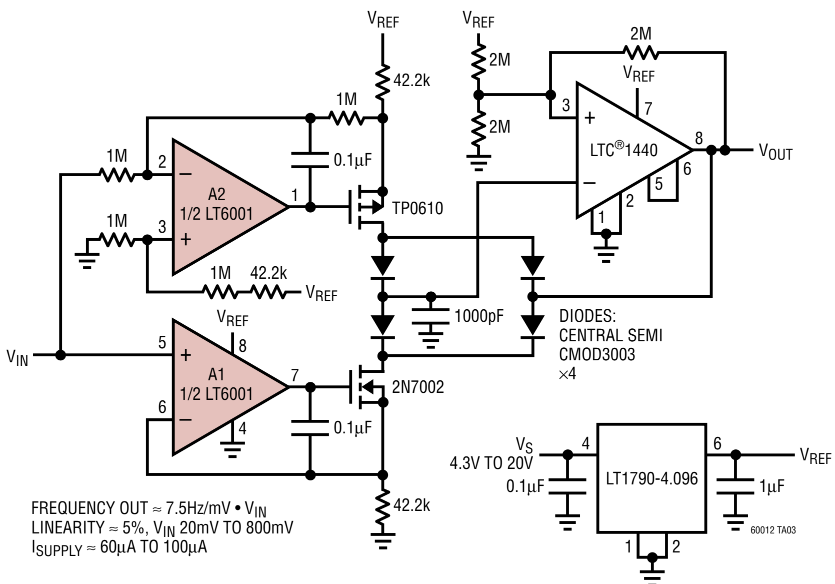
RECOMMENDED SOLDER PAD PITCH AND DIMENSIONS



NOTE:
1. DRAWING PROPOSED TO BE MADE VARIATION OF VERSION (WJED-1) IN JEDEC PACKAGE OUTLINE MO-229
2. DRAWING NOT TO SCALE
3. ALL DIMENSIONS ARE IN MILLIMETERS
4. 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
5. EXPOSED PAD SHALL BE SOLDER PLATED
6. SHADED AREA IS ONLY A REFERENCE FOR PIN 1 LOCATION ON THE TOP AND BOTTOM OF PACKAGE

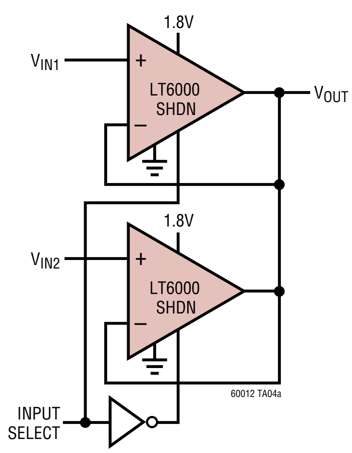
TYPICAL APPLICATION

Low Power V-to-F Converter

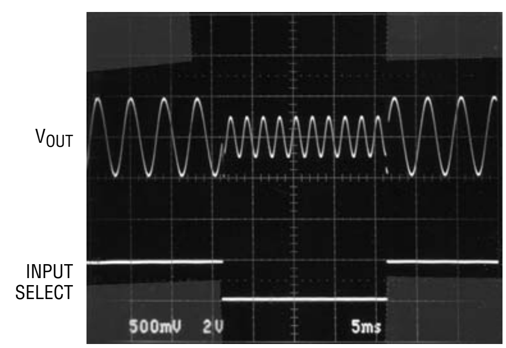


FREQUENCY OUT ≈ 7.5Hz/mV • V_{IN}
LINEARITY ≈ 5%, V_{IN} 20mV TO 800mV
I_{SUPPLY} ≈ 60μA TO 100μA

MUX Amplifier



MUX Amplifier Waveforms



V_S = 1.8V 5ms/DIV
V_{IN1} = 250Hz AT $1V_{P-P}$
V_{IN2} = 500Hz AT $0.5V_{P-P}$
INPUT SELECT = 25Hz AT $1.8V_{P-P}$

RELATED PARTS

PART NUMBER	DESCRIPTION	COMMENTS
LT2178/LT2179	17μA Dual/Quad Single Supply Op Amps	120μV $V_{OS(MAX)}$, Gain Bandwidth = 60kHz
LT1490A/LT1491A	50μA Dual/Quad Over-The-Top® Rail-to-Rail Input and Output Op Amps	950μV $V_{OS(MAX)}$, Gain Bandwidth = 200kHz
LT1494/LT1495/LT1496	1.5μA Max Single/Dual/Quad Over-The-Top Precision Rail-to-Rail Input and Output Op Amps	375μV $V_{OS(MAX)}$, Gain Bandwidth = 2.7kHz
LT1672/LT1673/LT1674	2μA Max, AV ≥ 5, Single/Dual/Quad Over-The-Top Precision Rail-to-Rail Input and Output Op Amps	Gain of 5 Stable, Gain Bandwidth = 12kHz
LT1782	Micropower, Over-The-Top SOT-23 Rail-to-Rail Input and Output Op Amps	SOT-23, 800μV $V_{OS(MAX)}$, I_S = 55μA (Max), Gain Bandwidth = 200kHz, Shutdown Pin

Over-The-Top is a registered trademark of Linear Technology Corporation.

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com
LT 0406 REV A • PRINTED IN USA