Precision, Single Supply Op Amp

FEATURES

- Single Supply Operation
  - Input Voltage Range Extends to Ground
  - Output Swings to Ground while Sinking Current
- *Guaranteed* Offset Voltage: 50μV Max
- *Guaranteed* Low Drift: 1.3μV/°C Max
- *Guaranteed* Offset Current: 0.5nA Max
- *Guaranteed* High Gain
  - 5mA Load Current: 1.5 Million Min
  - 17mA Load Current: 0.8 Million Min
- *Guaranteed* Low Supply Current: 520μA Max
- Supply Current can be Reduced by a Factor of 4
- Low Voltage Noise, 0.1Hz to 10Hz: 0.55μV_{P-P}
  - Low Current Noise—
  - Better than OP-07: 0.07pA/$\sqrt{Hz}$ at 10Hz
- High Input Impedance: 250MΩ Min
- Minimum Supply Voltage: 2.7V Min

APPLICATIONS

- Low Power Sample-and-Hold Circuits
- Battery-Powered Precision Instrumentation
  - Strain Gauge Signal Conditioners
  - Thermocouple Amplifiers
- 4mA to 20mA Current Loop Transmitters
- Active Filters

DESCRIPTION

The LT®1006 is the first precision single supply operational amplifier. Its design has been optimized for single supply operation with a full set of specifications at 5V. Specifications at ±15V are also provided.

The LT1006 has a low offset voltage of 20μV, drift of 0.2μV/°C, offset current of 120pA, gain of 2.5 million, common mode rejection of 114dB and power supply rejection of 126dB.

Although supply current is only 340μA, a novel output stage can source or sink in excess of 20mA while retaining high voltage gain. Common mode input range includes ground to accommodate low ground-referenced inputs from strain gauges or thermocouples, and output can swing to within a few millivolts of ground. If a higher slew rate (in excess of 1V/μs) or micropower operation (supply current down to 90μA) is required, the operating currents can be modified by connecting an external optional resistor to Pin 8.

For similar single supply precision dual and quad op amps, please see the LT1013/LT1014 data sheet. For micropower dual and quad op amps, please see the LT1078/LT1079 data sheet.

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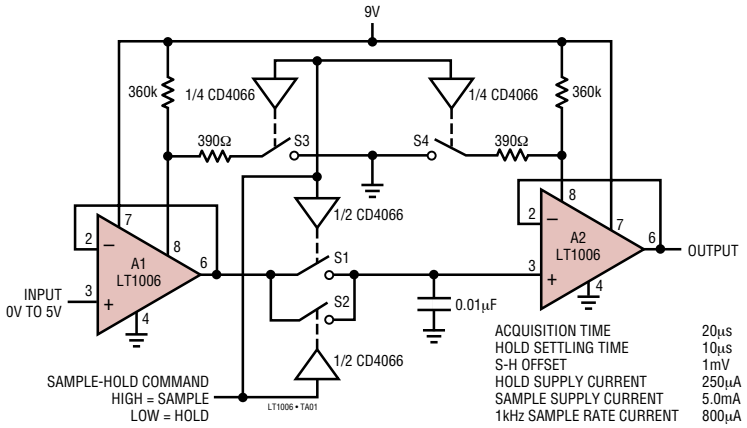
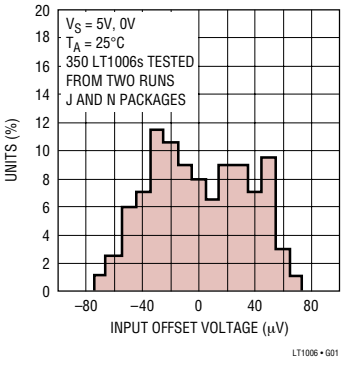
TYPICAL APPLICATION

LT1006 Single Supply, Micropower Sample and Hold



Distribution of Input Offset Voltage

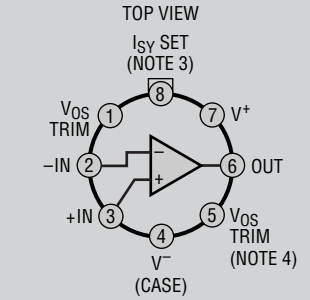


ABSOLUTE MAXIMUM RATINGS (Note 1)

Supply Voltage ..... ±22V
Input Voltage ..... Equal to Positive Supply Voltage
Input Voltage ..... 5V Below Negative Supply Voltage
Differential Input Voltage 30V
Output Short-Circuit Duration ..... Indefinite

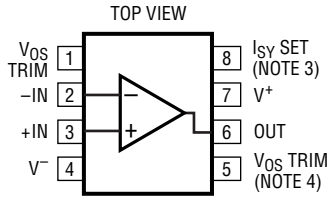
Operating Temperature Range
LT1006AM/LT1006M **(OBSOLETE)**....–55°C to 125°C
LT1006AC/LT1006C/LT1006S8 ..... 0°C to 70°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec)..... 300°C

PACKAGE/ORDER INFORMATION



H PACKAGE
8-LEAD TO-5 METAL CAN
T_{JMAX} = 150°C, θ_{JA} = 150°C, θ_{JC} = 45°C

ORDER PART NUMBER
LT1006AMH LT1006MH LT1006ACH LT1006CH



N8 PACKAGE
8-LEAD PDIP

S8 PACKAGE
8-LEAD PLASTIC SO

T_{JMAX} = 100°C, θ_{JA} = 130°C/W (N8)
T_{JMAX} = 150°C, θ_{JA} = 200°C/W (S8)

J8 PACKAGE 8-LEAD CERDIP
T_{JMAX} = 100°C, θ_{JA} = 130°C/W

ORDER PART NUMBER
LT1006CN8 LT1006S8
S8 PART MARKING
1006
LT1006AMJ8 LT1006MJ8 LT1006ACJ8 LT1006CJ8

OBSOLETE PACKAGES
Consider the N8 or S8 Package for Alternate Source

Consult LTC Marketing for parts specified with wider operating temperature ranges.

ELECTRICAL CHARACTERISTICS

V_S = 5V, V_{CM} = 0V, V_{OUT} = 1.4V, T_A = 25°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	LT1006AM/AC MIN	LT1006AM/AC TYP	LT1006AM/AC MAX	LT1006M/C MIN	LT1006M/C TYP	LT1006M/C MAX	UNITS
V_{OS}	Input Offset Voltage			20	50		30	80	µV
		LT1006S8					80	400	µV
$\frac{\Delta V_{OS}}{\Delta Time}$	Long-Term Input Offset Voltage Stability			0.4			0.5		µV/Mo
		LT1006S8					0.7		µV/Mo
I_{OS}	Input Offset Current			0.12	0.5		0.15	0.9	nA
I_B	Input Bias Current			9	15		10	25	nA
e_n	Input Noise Voltage	0.1Hz to 10Hz		0.55			0.55		μV_{P-P}
	Input Noise Voltage Density	f_O = 10Hz		23	32		23	32	$nV/\sqrt{Hz}$
		f_O = 1000Hz		22	25		22	25	$nV/\sqrt{Hz}$
i_n	Input Noise Current Density	f_O = 10Hz		0.07			0.08		$pA/\sqrt{Hz}$
	Input Resistance	(Note 2)							
	Differential Mode		180	400		100	300		MΩ
	Common Mode			5			4		GΩ

ELECTRICAL CHARACTERISTICS

V_S = 5V, V_{CM} = 0V, V_{OUT} = 1.4V, T_A = 25°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	LT1006AM/AC MIN	LT1006AM/AC TYP	LT1006AM/AC MAX	LT1006M/C MIN	LT1006M/C TYP	LT1006M/C MAX	UNITS
	Input Voltage Range		3.5 0	3.8 –0.3		3.5 0	3.8 –0.3		V V
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 3.5V	100	114		97	112		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	106	126		103	124		dB
A_{VOL}	Large-Signal Voltage Gain	V_O = 0.03V to 4V, R_L = 10k V_O = 0.03V to 3.5V, R_L = 2k	1.0 0.5	2.5 2.0		0.7 0.3	2.0 1.8		V/µV V/µV
	Maximum Output Voltage Swing	Output Low, No Load Output Low, 600Ω to GND Output Low, I_{SINK} = 1mA Output High, No Load Output High, 600Ω to GND	 4.0 3.4	15 5 220 4.4 4.0	25 10 350 	 4.0 3.4	15 5 220 4.4 4.0	25 10 350 	mV mV mV V V
SR	Slew Rate		0.25	0.4		0.25	0.4		V/µs
I_S	Supply Current	R_{SET} = ∞ R_{SET} = 180k Pin 8 to Pin 7 (Note 3)		340 90	520		350 90	570	µA µA
	Minimum Supply Voltage		2.7			2.7			V

The ● denotes the specifications which apply over the full operating temperature range. V_S = 5V, 0V; V_{CM} = 0.1V; V_O = 1.4V; –55°C ≤ T_A ≤ 125°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		LT1006AM MIN	LT1006AM TYP	LT1006AM MAX	LT1006M MIN	LT1006M TYP	LT1006M MAX	UNITS
V_{OS}	Input Offset Voltage		●		40	180		60	250	µV
$\frac{\Delta V_{OS}}{\Delta Temp}$	Input Offset Voltage Drift		●		0.2	1.3		0.3	1.8	µV/°C
I_{OS}	Input Offset Current		●		0.4	2.0		0.5	4.0	nA
I_B	Input Bias Current		●		13	25		16	40	nA
A_{VOL}	Large-Signal Voltage Gain	V_O = 0.05V to 3.5V, R_L = 2k	●	0.25	0.8		0.15	0.7		V/µV
CMRR	Common Mode Rejection Ratio	V_{CM} = 0.1V to 3.2V	●	90	103		87	102		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	●	100	117		97	116		dB
	Maximum Output Voltage Swing	Output Low, 600Ω to GND Output High, 600Ω to GND	● ●	 3.2	6 3.8	15 	 3.1	6 3.8	18 	mV V
I_S	Supply Current		●		380	630		400	680	µA

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range. V_S = 5V, 0V; V_{CM} = 0V; V_O = 1.4V; 0°C ≤ T_A ≤ 70°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		LT1006AC MIN	LT1006AC TYP	LT1006AC MAX	LT1006C MIN	LT1006C TYP	LT1006C MAX	UNITS
V_{OS}	Input Offset Voltage	J8/H Package N8 Package S8 Package	● ● ●		30	110		45 50 110	160 190 560	µV µV µV
$\frac{\Delta V_{OS}}{\Delta Temp}$	Input Offset Voltage Drift	J8/H Package N8 Package S8 Package	● ● ●		0.2	1.3		0.3 0.5 0.7	1.8 2.5 3.5	µV/°C µV/°C µV/°C
I_{OS}	Input Offset Current		●		0.25	1.2		0.3	2.5	nA
I_B	Input Bias Current		●		11	20		12	30	nA
A_{VOL}	Large-Signal Voltage Gain	V_O = 0.04V to 3.5V, R_L = 2k	●	0.35	1.3		0.25	1.2		V/µV
CMRR	Common Mode Rejection Ratio	V_{CM} = 0V to 3.4V	●	96	109		92	108		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	●	101	120		97	118		dB
	Maximum Output Voltage Swing	Output Low, 600Ω to GND Output High, 600Ω to GND	● ●	 3.3	6 3.9	13	 3.2	6 3.9	13	mV V
I_S	Supply Current		●		350	570		360	620	µA

V_S = ±15V, T_A = 25°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	LT1006AM/AC MIN	LT1006AM/AC TYP	LT1006AM/AC MAX	LT1006M/C MIN	LT1006M/C TYP	LT1006M/C MAX	UNITS
V_{OS}	Input Offset Voltage	 LT1006S8		30	100		50 100	180 525	µV µV
I_{OS}	Input Offset Current			0.1	0.5		0.15	0.9	nA
I_B	Input Bias Current			7.5	12.0		8	20	nA
	Input Voltage Range		13.5 –15.0	13.8 –15.3		13.5 –15.0	13.8 –15.3		V V
CMRR	Common Mode Rejection Ratio	V_{CM} = +13.5V, –15V	100	117		97	116		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	106	126		103	124		dB
A_{VOL}	Large Signal Voltage Gain	V_O = ±10V, R_L = 2k V_O = ±10V, R_L = 600Ω	1.5 0.8	5.0 1.5		1.2 0.5	4.0 1.0		V/µV V/µV
V_{OUT}	Maximum Output Voltage Swing	R_L = 2k	±13	±14		±12.5	±14		V
SR	Slew Rate	R_{SET} = ∞ R_{SET} = 390Ω Pin 8 to Pin 4	0.25 1.0	0.4 1.2		0.25 1.0	0.4 1.2		V/µs V/µs
I_S	Supply Current			360	540		360	600	µA

ELECTRICAL CHARACTERISTICS

The ● denotes the specifications which apply over the full operating temperature range. V_S = ±15V, –55°C ≤ T_A ≤ 125°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		LT1006AM MIN	LT1006AM TYP	LT1006AM MAX	LT1006M MIN	LT1006M TYP	LT1006M MAX	UNITS
V_{OS}	Input Offset Voltage		●		80	320		110	460	µV
$\frac{\Delta V_{OS}}{\Delta Temp}$	Input Offset Voltage Drift		●		0.5	2.2		0.6	2.8	µV/°C
I_{OS}	Input Offset Current		●		0.2	2.0		0.3	3.0	nA
I_B	Input Bias Current		●		9	18		11	27	nA
A_{VOL}	Large-Signal Voltage Gain	V_O = ±10V, R_L = 2k	●	0.5	1.5		0.25	1.0		V/µV
CMRR	Common Mode Rejection Ratio	V_{CM} = +13V, –14.9V	●	97	114		94	113		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	●	100	117		97	116		dB
	Maximum Output Voltage Swing	R_L = 2k	●	±12	±13.8		±11.5	±13.8		V
I_S	Supply Current		●		400	650		400	750	µA

The ● denotes the specifications which apply over the full operating temperature range. V_S = ±15V, 0°C ≤ T_A ≤ 70°C, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS		LT1006AC MIN	LT1006AC TYP	LT1006AC MAX	LT1006C MIN	LT1006C TYP	LT1006C MAX	UNITS
V_{OS}	Input Offset Voltage	J8/H Package	●		50	200		75	300	µV
		N8 Package	●					80	330	µV
		S8 Package	●					150	730	µV
$\frac{\Delta V_{OS}}{\Delta Temp}$	Input Offset Voltage Drift	J8/H Package	●		0.5	2.2		0.6	2.8	µV/°C
		N8 Package	●					0.7	3.5	µV/°C
		S8 Package	●					1.0	4.5	µV/°C
I_{OS}	Input Offset Current		●		0.15	1		0.25	2	nA
I_B	Input Bias Current		●		8	15		10	23	nA
A_{VOL}	Large-Signal Voltage Gain	V_O = ±10V, R_L = 2k	●	1	3		0.7	2.5		V/µV
CMRR	Common Mode Rejection Ratio	V_{CM} = 13V, –15V	●	98	116		94	114		dB
PSRR	Power Supply Rejection Ratio	V_S = ±2V to ±18V, V_O = 0V	●	101	120		97	118		dB
	Maximum Output Voltage Swing	R_L = 2k	●	±12.5	±13.9		±11.5	±13.8		V
I_S	Supply Current		●		370	600		380	660	µA

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

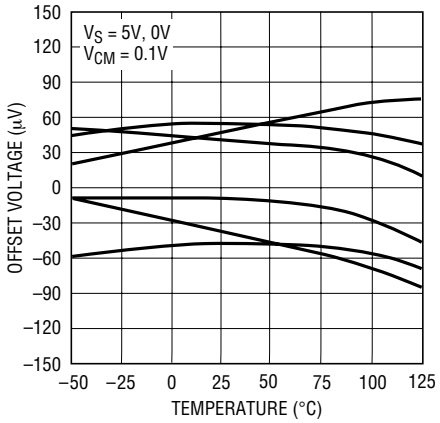
Note 2: This parameter is guaranteed by design and is not tested.

Note 3: Regular operation does not require an external resistor. In order to program the supply current for low power or high speed operation, connect an external resistor from Pin 8 to Pin 7 or from Pin 8 to Pin 4, respectively. Supply current specifications (for R_{SET} = 180k) do not include current in R_{SET}.

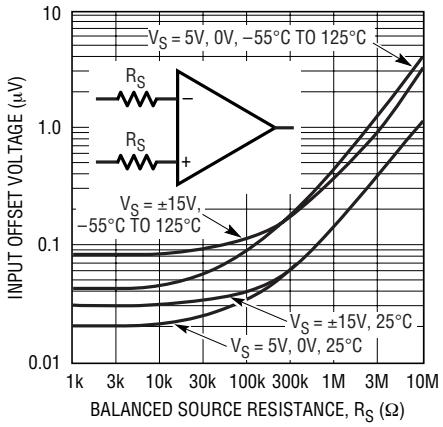
Note 4: Optional offset nulling is accomplished with a potentiometer connected between the trim terminals and the wiper to V^-. A 10k pot (providing a null range of ±6mV) is recommended for minimum drift of nulled offset voltage with temperature. For increased trim resolution and accuracy, two fixed resistors can be used in conjunction with a smaller potentiometer. For example, two 4.7k resistors tied to Pins 1 and 5, with a 500Ω pot in the middle, will have a null range of ±150µV.

TYPICAL PERFORMANCE CHARACTERISTICS

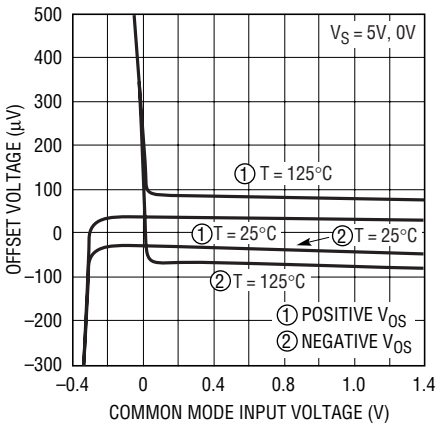
Offset Voltage Drift with Temperature of Representative Units



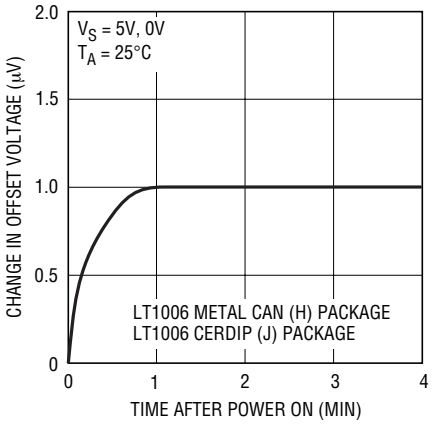
Offset Voltage vs Balanced Source Resistor



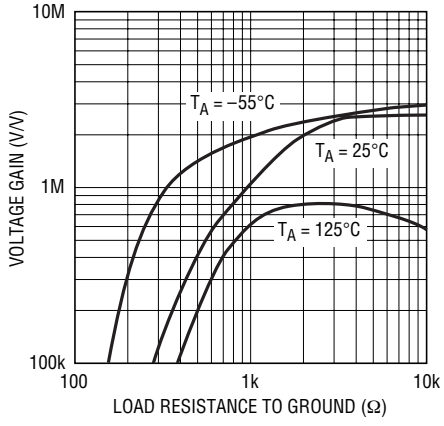
V_{OS} vs Common Mode Voltage vs Temperature



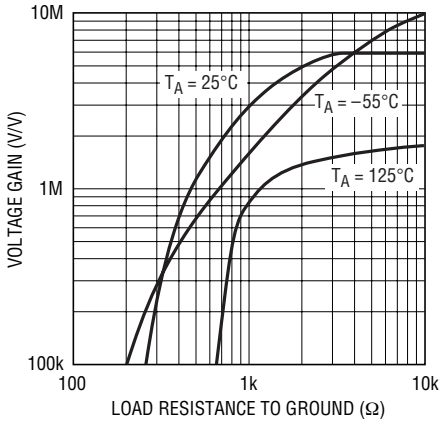
Warm-Up Drift



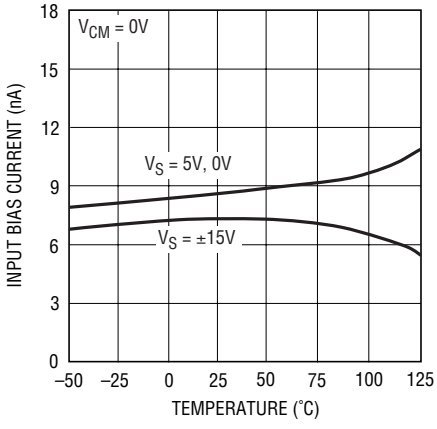
Voltage Gain vs Load Resistance, V_S = 5V, 0V



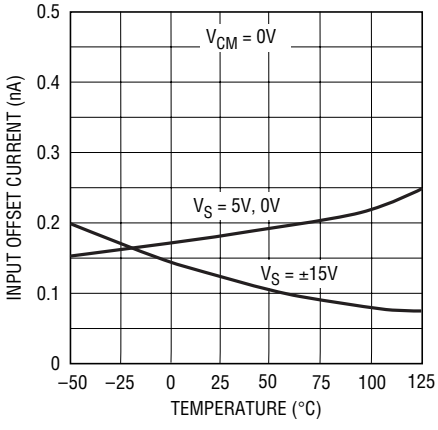
Voltage Gain vs Load Resistance with V_S = ±15V



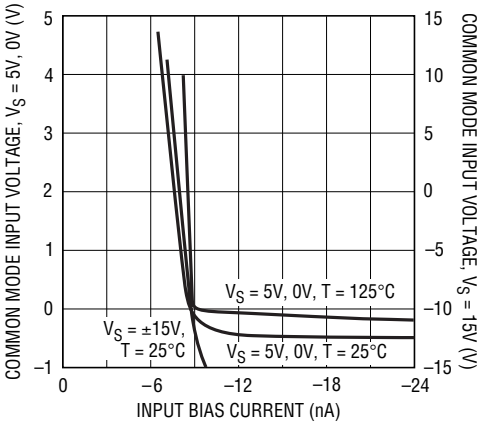
Input Bias Current vs Temperature



Input Offset Current vs Temperature

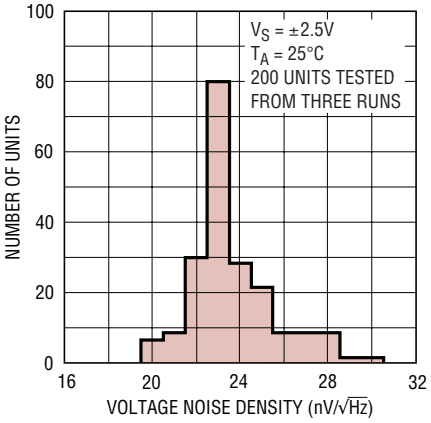


Input Bias Current vs Common Mode Voltage

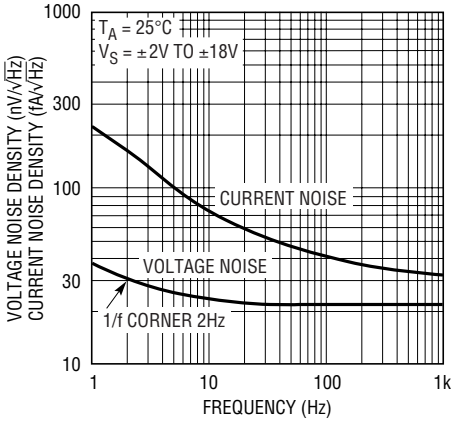


TYPICAL PERFORMANCE CHARACTERISTICS

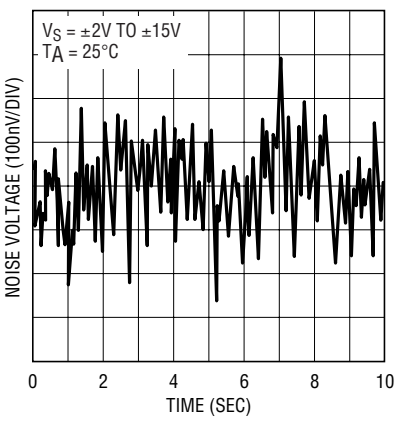
10Hz Voltage Noise Distribution



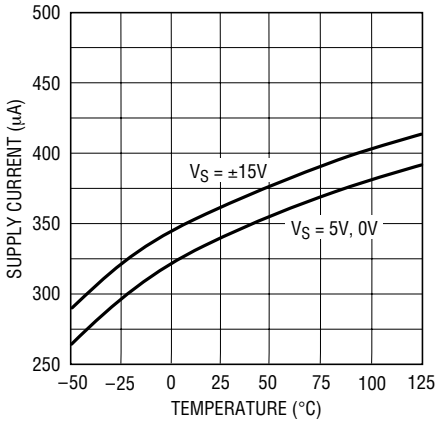
Noise Spectrum



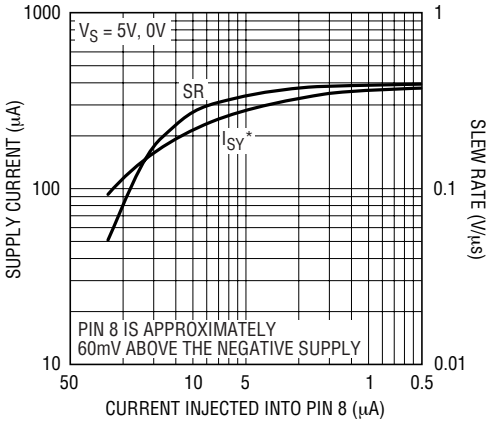
0.1Hz to 10Hz Noise



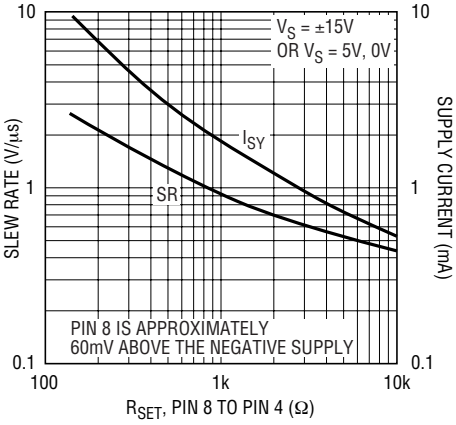
Supply Current vs Temperature



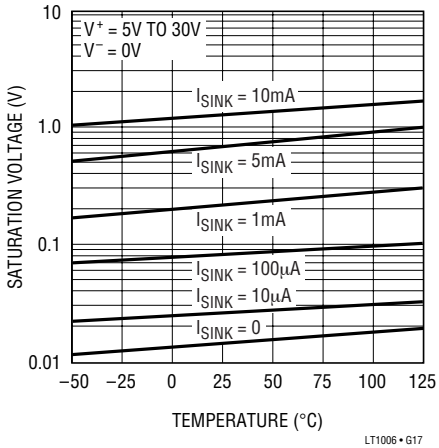
Reducing Power Dissipation



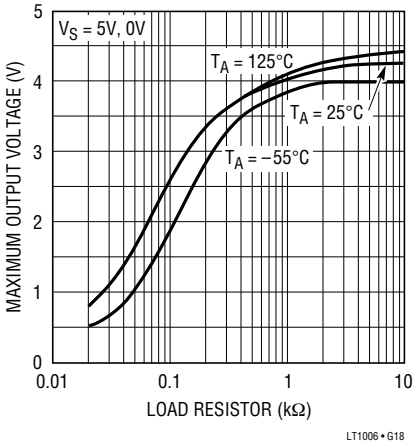
Increasing Slew Rate (R_{SET} to V^-)



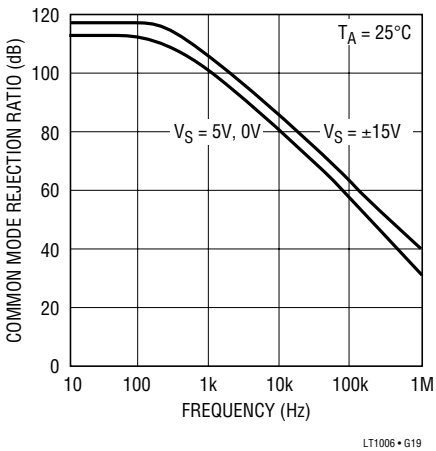
Output Saturation vs Sink Current vs Temperature



Maximum Output Swing vs Load Resistor

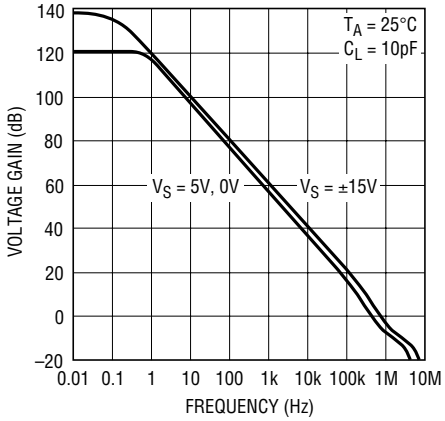


Common Mode Rejection Ratio vs Frequency

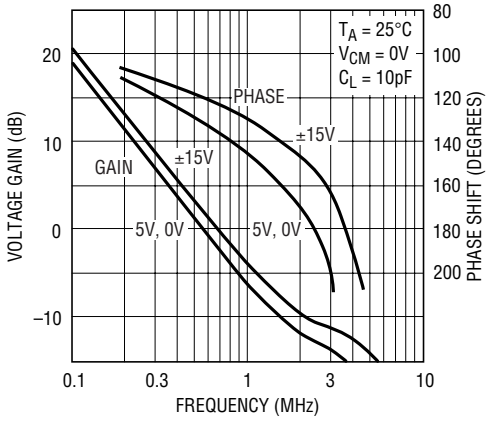


TYPICAL PERFORMANCE CHARACTERISTICS

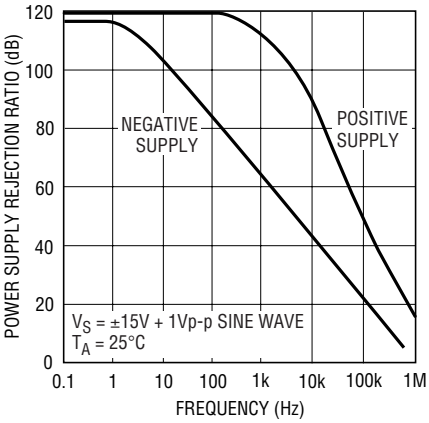
Voltage Gain vs Frequency



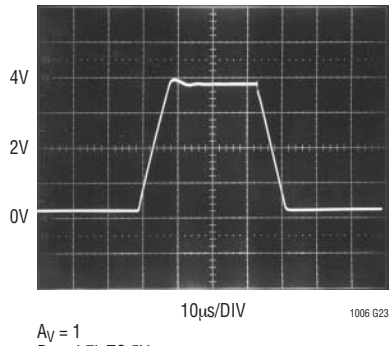
Gain, Phase vs Frequency



Power Supply Rejection Ratio vs Frequency

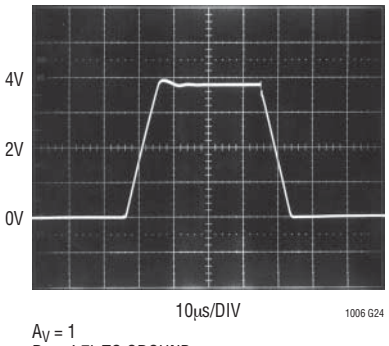


Large Transient Response, V_S = 5V, 0V



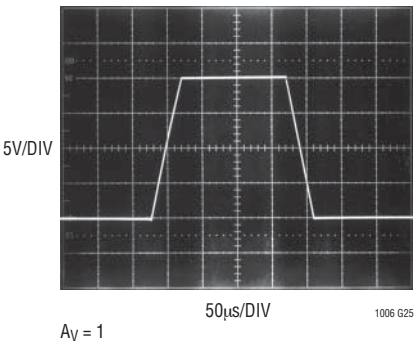
A_V = 1
R_L = 4.7k TO 5V
INPUT = 0V TO 3.8V

Large-Signal Transient Response, V_S = 5V, 0V



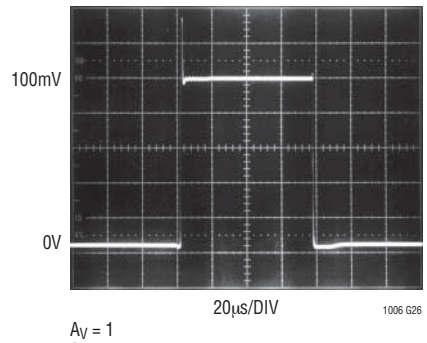
A_V = 1
R_L = 4.7k TO GROUND
INPUT = 0V TO 3.8V

Large-Signal Transient Response, V_S = ±15V



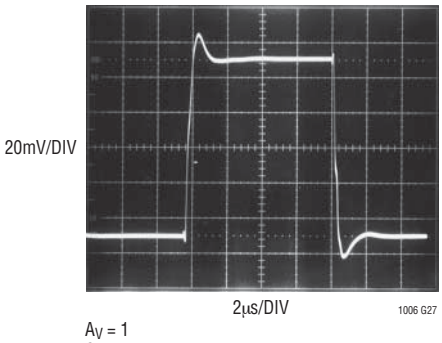
A_V = 1

Small-Signal Transient Response, V_S = 5V, 0V



A_V = 1
C_L = 10pF
R_L = 600Ω TO GND
INPUT = 0V TO 100mV PULSE

Small-Signal Transient Response, V_{CC} = ±2.5V to ±15V



A_V = 1
C_L = 10pF

APPLICATIONS INFORMATION

The LT1006 is fully specified for single supply operation, (i.e., when the negative supply is 0V). Input common mode range includes ground; the output swings within a few millivolts of ground. Single supply operation, however, can create special difficulties, both at the input and at the output. The LT1006 has specific circuitry which addresses these problems.

At the input, the driving signal can fall below 0V—inadvertently or on a transient basis. If the input is more than a few hundred millivolts below ground, two distinct problems can occur on previous single supply designs, such as the LM124, LM158, OP-20, OP-21, OP-220, OP-221, OP-420:

a) When the input is more than a diode drop below ground, unlimited current will flow from the substrate (V^- terminal) to the input. This can destroy the unit. On the LT1006, the 400Ω resistors, in series with the input (see Schematic Diagram), protect the devices even when the input is 5V below ground.

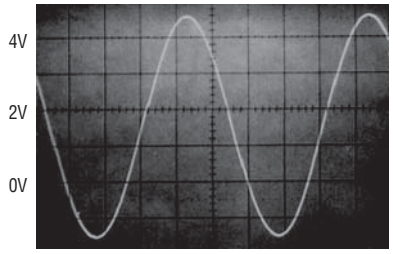
b) When the input is more than 400mV below ground (at 25°C), the input stage saturates (transistors Q3 and Q4) and phase reversal occurs at the output. This can cause lock-up in servo systems. Due to a unique phase reversal protection circuitry (Q21, Q22, Q27, Q28), the LT1006's output does not reverse, as illustrated below, even when the inputs are at –1.5V.

At the output, the aforementioned single supply designs either cannot swing to within 600mV of ground (OP-20) or cannot sink more than a few microamperes while swinging to ground (LM124, LM158). The LT1006's all-NPN output stage maintains its low output resistance and high gain characteristics until the output is saturated.

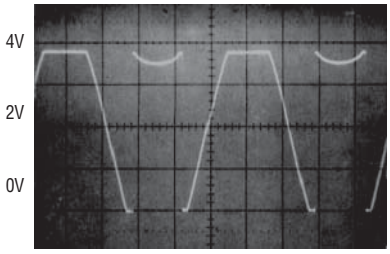
In dual supply operations, the output stage is crossover distortion free.

Since the output cannot go exactly to ground, but can only approach ground to within a few millivolts, care should be exercised to ensure that the output is not saturated. For example, a 1mV input signal will cause the amplifier to set up in its linear region in the gain 100 configuration shown below, but is not enough to make the amplifier function properly in the voltage follower mode.

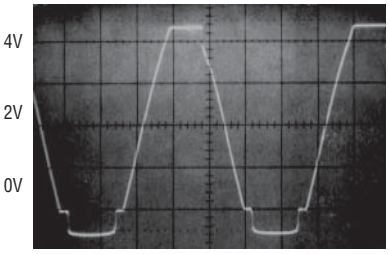
Voltage Follower with Input Exceeding the Negative Common Mode Range (V_S = 5V, 0V)



$6V_{P-P}$ INPUT, –1.5V TO 4.5V 1006 TA11a

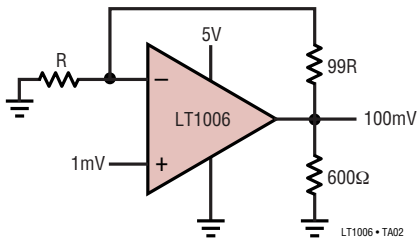


LM324, LM358, OP-20, OP-21 EXHIBIT OUTPUT PHASE REVERSAL 1006 TA11b

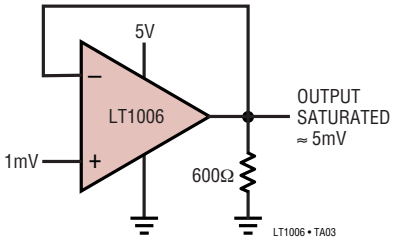


LT1006 NO PHASE REVERSAL 1006 TA11c

Gain 100 Amplifier



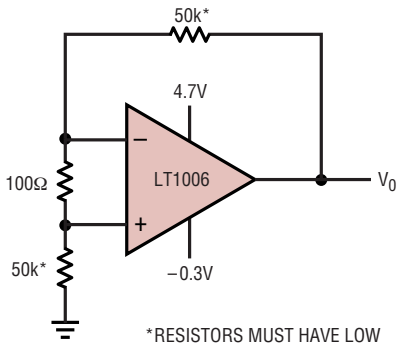
Voltage Follower



APPLICATIONS INFORMATION

In automated production testing the output is forced to 1.4V by the test loop; offset voltage is measured with a common mode voltage of zero and the negative supply at zero (Pin 4). Without the test loop, these exact conditions cannot be achieved. The test circuit shown ensures that the output will never saturate even with worst-case offset voltages (–250μV over the –55°C to 125°C range). The effective common mode input is 0.3V with respect to the negative supply. As indicated by the common mode rejection specifications the difference is only a few microvolts between the two methods of offset voltage measurement.

Test Circuit for Offset Voltage and Offset Drift with Temperature



*RESISTORS MUST HAVE LOW THERMOELECTRIC POTENTIAL.
**THIS CIRCUIT IS ALSO USED AS THE BURN-IN CONFIGURATION, WITH SUPPLY VOLTAGES INCREASED TO ± 20V
$V_O = 1000V_{OS}$

LT1006 • TA04

Low Supply Operation

The minimum guaranteed supply voltage for proper operation of the LT1006 is 2.7V. Typical supply current at this voltage is 320μA; therefore, power dissipation is only 860μW.

Noise Testing

For application information on noise testing and calculations, please see the LT1007 or LT1028 data sheet.

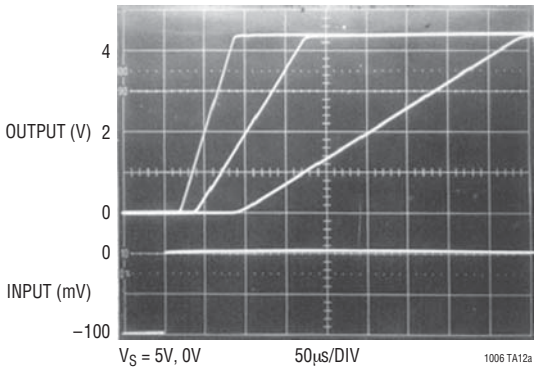
Supply Current Programming

Connecting an optional external resistor to Pin 8 changes the biasing of the LT1006 in order to increase its speed or to decrease its power consumption. If a higher slew rate is required, connect the external resistor for Pin 8 to Pin 4 [see performance curves for Increasing Slew Rate (R_{SET} to V^-)]. For lower power consumption, inject a current into Pin 8 (which is approximately 60mV above V^-) as shown on the Reducing Power Dissipation plot. This can be accomplished by connecting R_{SET} to the positive supply, or to save additional power, by obtaining the injected current from a low voltage battery.

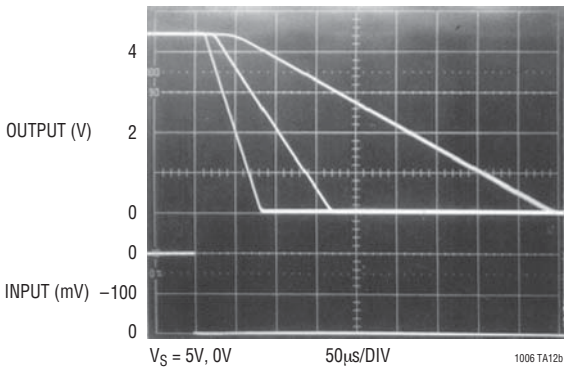
Comparator Applications

The single supply operation of the LT1006 and its ability to swing close to ground while sinking current lends itself to use as a precision comparator with TTL compatible output.

Comparator Rise Response Time to 10mV, 5mV, 2mV Overdrives

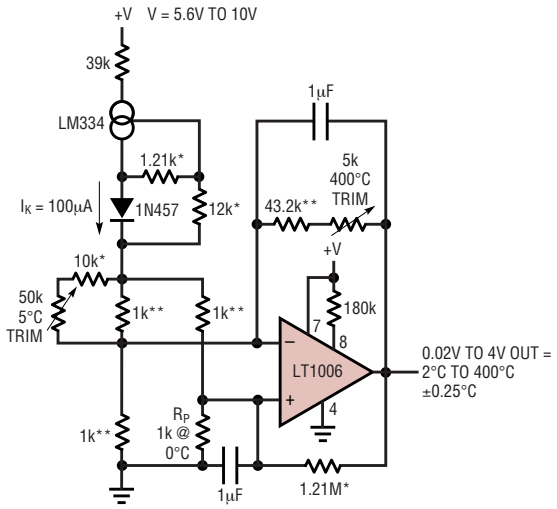


Comparator Fall Response Time to 10mV, 5mV, 2mV Overdrives

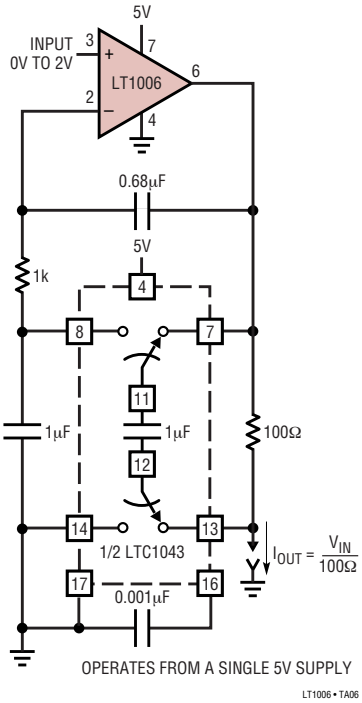


TYPICAL APPLICATIONS

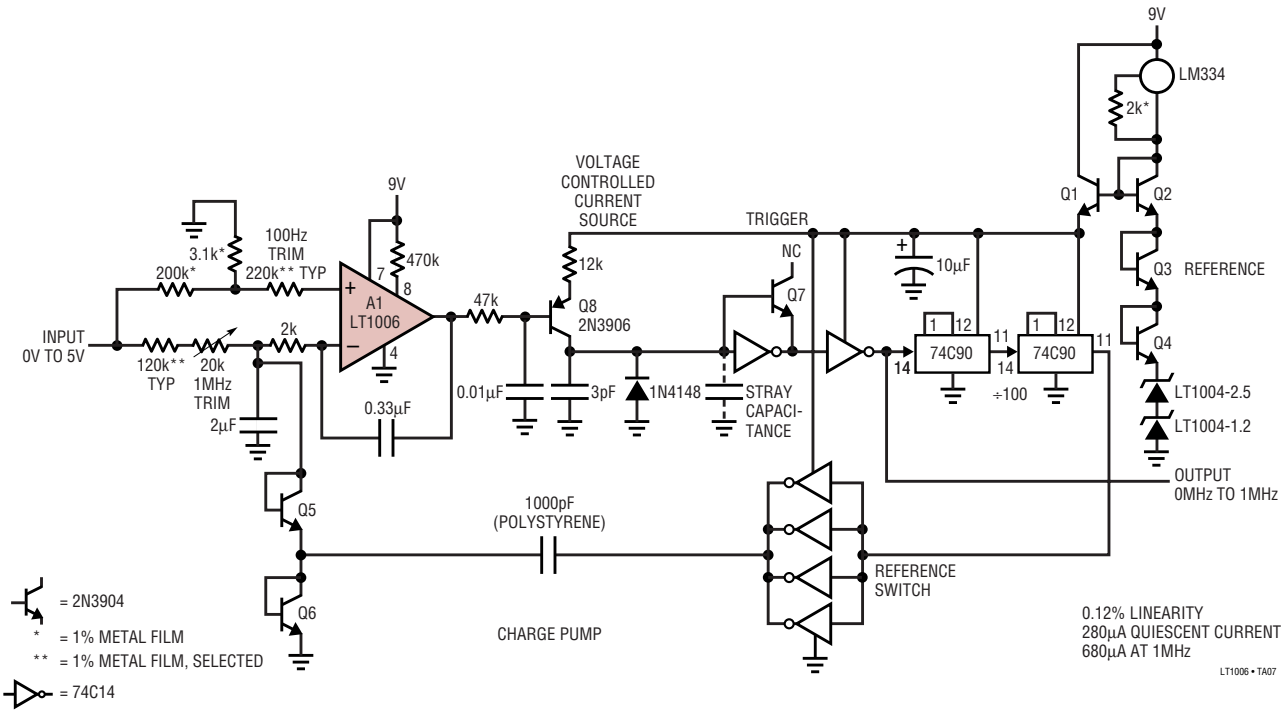
Platinum RTD Signal Conditioner with Curvature Correction



Voltage Controlled Current Source with Ground Referred Input and Output

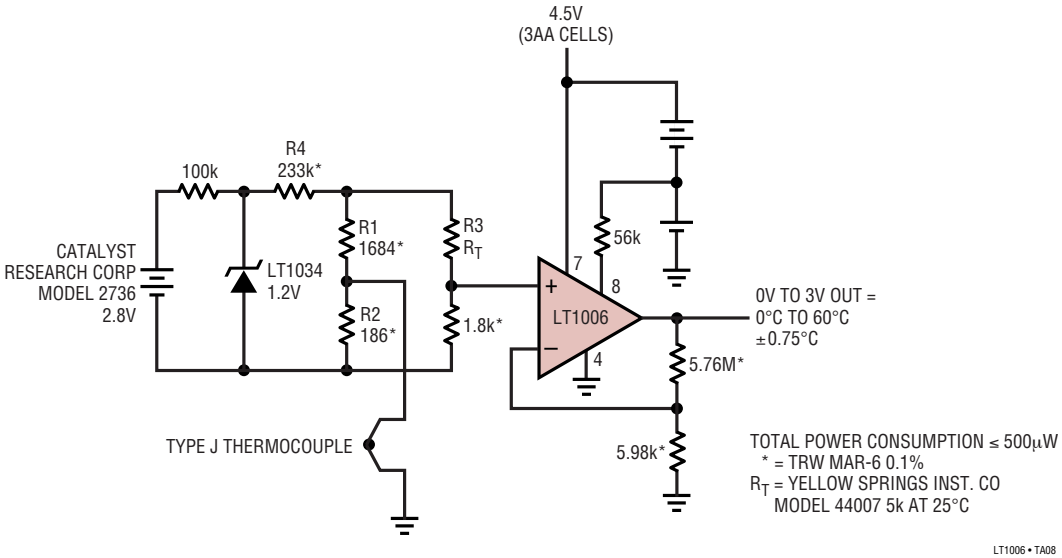


Micropower 1MHz V/F Converter

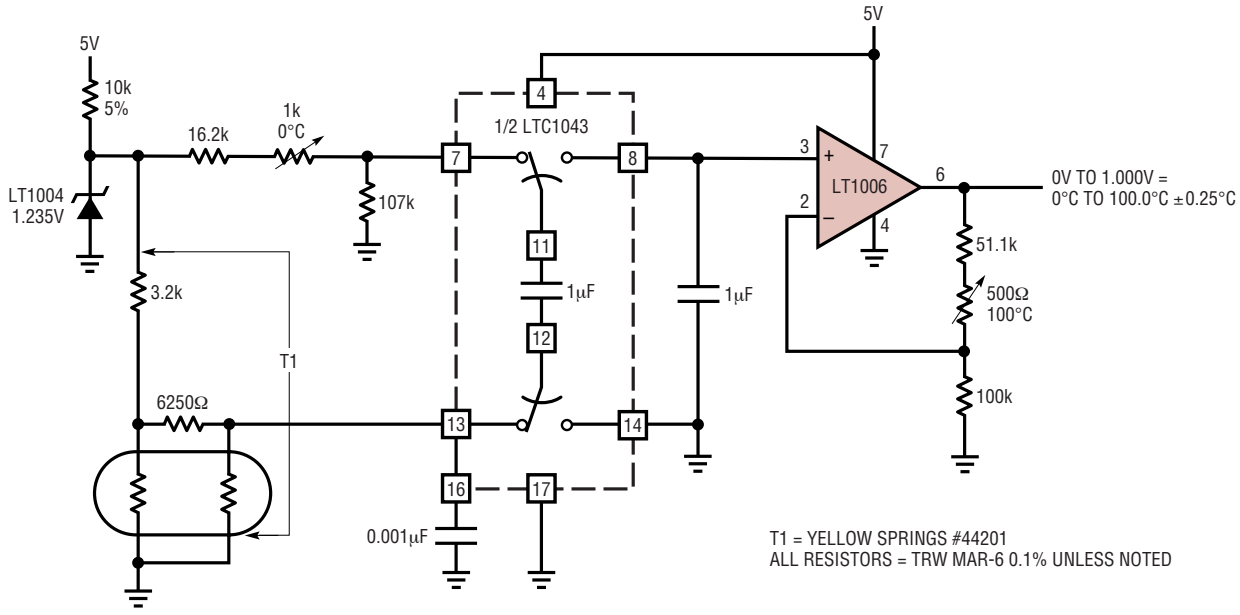


TYPICAL APPLICATIONS

Micropower Thermocouple Signal Conditioner with Cold Junction Compensation

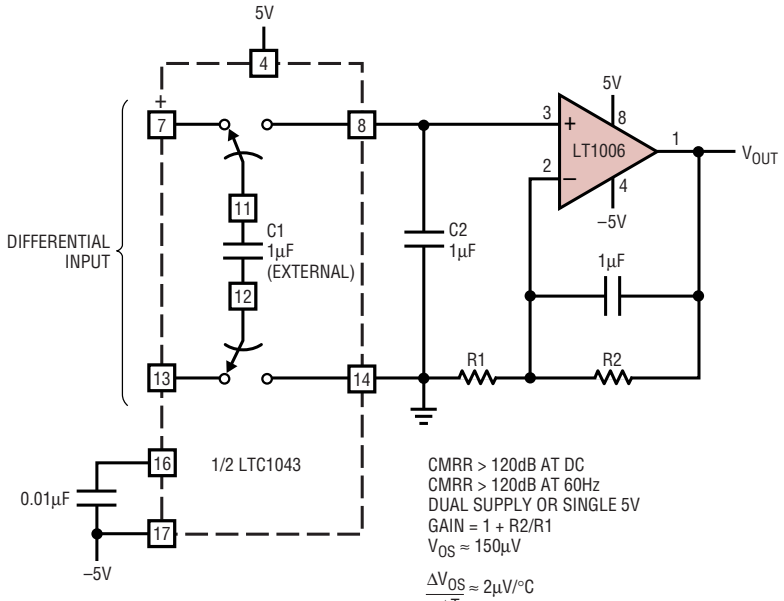


Linear Thermometer



TYPICAL APPLICATIONS

±5V Precision Instrumentation Amplifier



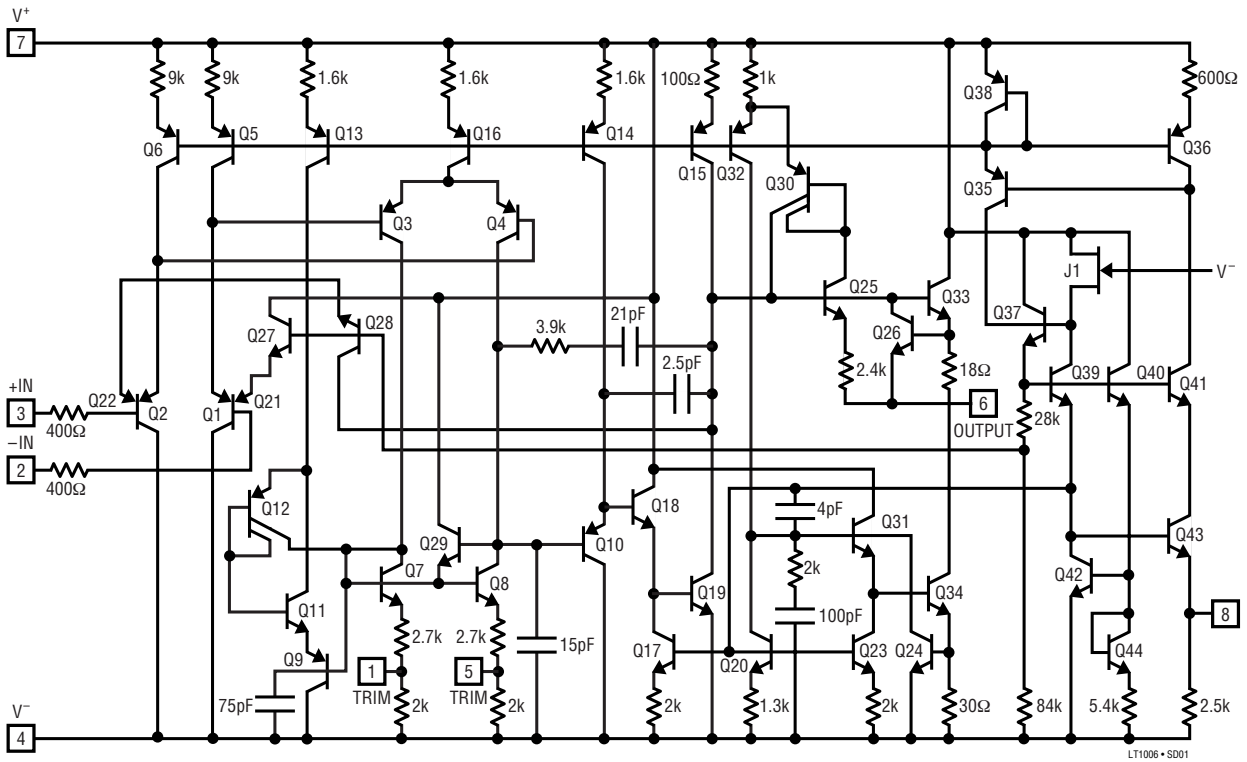
CMRR > 120dB AT DC
CMRR > 120dB AT 60Hz
DUAL SUPPLY OR SINGLE 5V
GAIN = 1 + R2/R1
$V_{OS} \approx 150\mu V$

$\frac{\Delta V_{OS}}{\Delta T} \approx 2\mu V/°C$

COMMON MODE INPUT VOLTAGE INCLUDES THE SUPPLIES

LT1006 • TA10

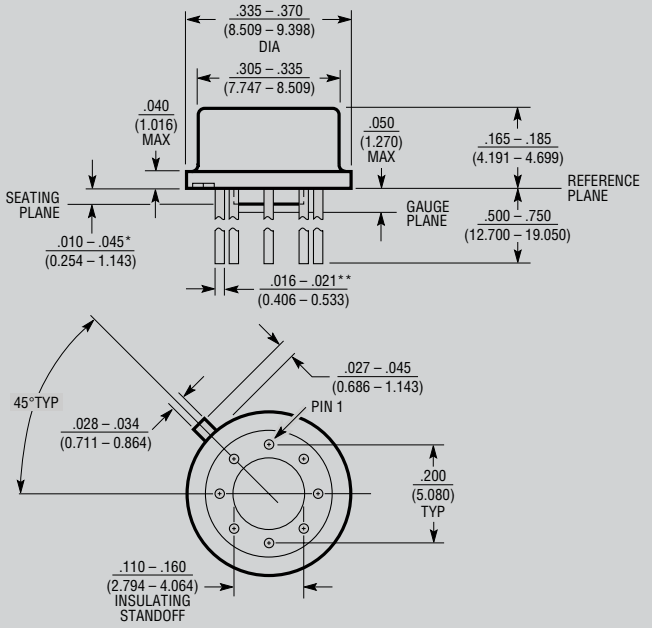
SCHEMATIC DIAGRAM



LT1006 • SD01

PACKAGE DESCRIPTION

H Package
8-Lead TO-5 Metal Can (.200 Inch PCD)
(Reference LTC DWG # 05-08-1320)

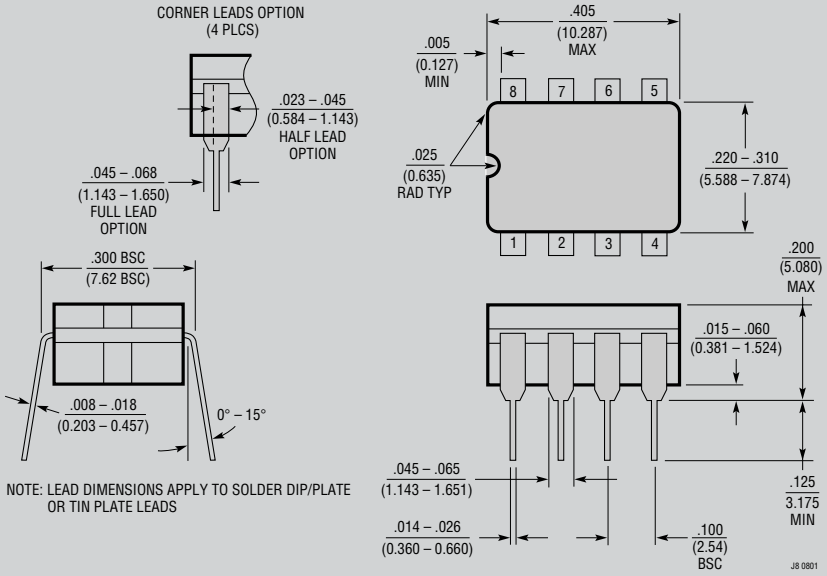


*LEAD DIAMETER IS UNCONTROLLED BETWEEN THE REFERENCE PLANE AND THE SEATING PLANE

**FOR SOLDER DIP LEAD FINISH, LEAD DIAMETER IS .016 – .024 (0.406 – 0.610)

H8(TO-5) 0.200 PCD 0801

J8 Package
8-Lead CERDIP (Narrow .300 Inch, Hermetic)
(Reference LTC DWG # 05-08-1110)



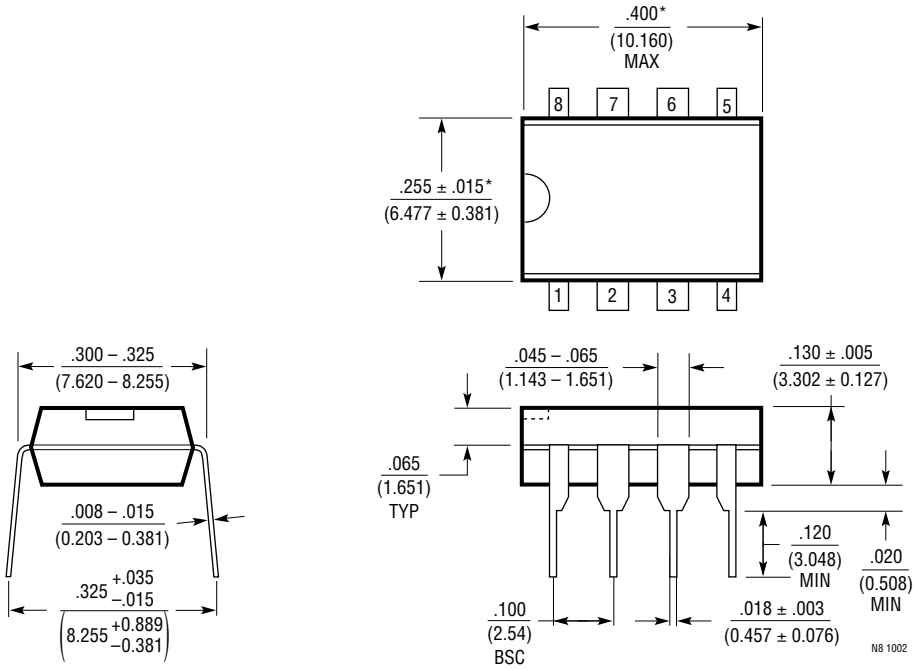
NOTE: LEAD DIMENSIONS APPLY TO SOLDER DIP/PLATE OR TIN PLATE LEADS

J8 0801

OBSOLETE PACKAGES

PACKAGE DESCRIPTION

N8 Package
8-Lead PDIP (Narrow .300 Inch)
(Reference LTC DWG # 05-08-1510)



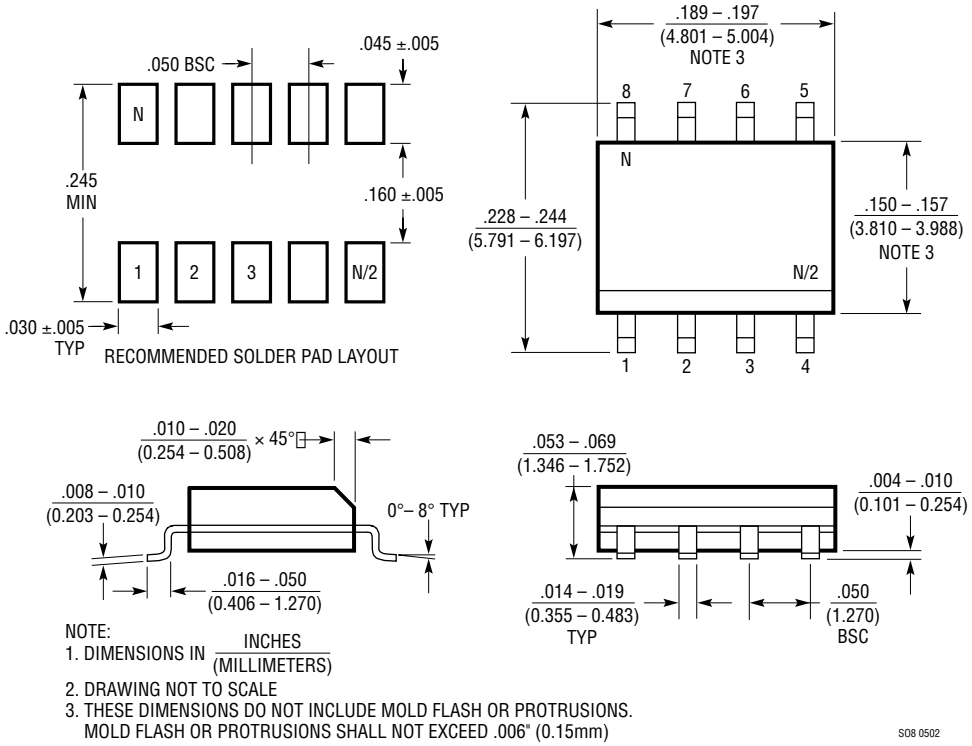
NOTE:
1. DIMENSIONS ARE INCHES / MILLIMETERS

*THESE DIMENSIONS DO NOT INCLUDE MOLD FLASH OR PROTRUSIONS.
MOLD FLASH OR PROTRUSIONS SHALL NOT EXCEED .010 INCH (0.254mm)

Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

PACKAGE DESCRIPTION

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 0502

Linear Technology Corporation
1630 McCarthy Blvd., Milpitas, CA 95035-7417
(408) 432-1900 • FAX: (408) 434-0507 • www.linear.com

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