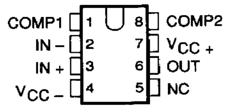
PICOAMP INPUT CURRENT, MICROVOLT OFFSET LOW-NOISE OPERATIONAL AMPLIFIERS

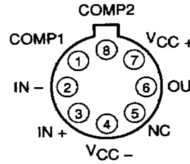
D3233, MAY 1988 – REVISED FEBRUARY 1989

- **Input Bias Current . . . ± 30 pA Typ, ± 100 pA Max at 25°C**
- **Input Offset Voltage . . . 30 µV Typ, 120 µV Max at 25°C**
- **Offset Voltage Temperature Coefficient . . . 1.5 µV/°C Max**
- **Low Peak-to-Peak Noise Voltage at 0.1 Hz to 10 Hz . . . 0.5 µV**
- **Low Supply Current . . . 380 µA Typ, 600 µA Max at 25°C**
- **Supply Voltage Rejection Ratio . . . 114 dB Min at 25°C**
- **Common-Mode Rejection Ratio . . . 114 dB Min at 25°C**
- **High Voltage Amplification with 5-mA Load Current**
- **Applications:**
  - **Precision Instrumentation**
  - **Charge Integrators**
  - **Wide-Dynamic-Range Logarithmic Amplifiers**
  - **Light Meters**
  - **Low-Frequency Active Filters**
  - **Standard Cell Buffers**
  - **Thermocouple Amplifiers**

JG OR P PACKAGE
(TOP VIEW)

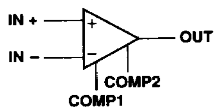


L PACKAGE
(TOP VIEW)



NC – No internal connection
Pin 4 (L Package) is in electrical contact with the case.

symbol



description

The LT1008 is a precision operational amplifier that can be used in practically all precision applications. The LT1008 offers picoampere bias currents (maintained over the full temperature range), microvolt offset voltage, low offset voltage temperature coefficient and long-term drift, low voltage and current noise, and low power dissipation. Additionally, the LT1008's precision specifications include high common-mode and supply voltage rejection ratios. The LT1008 can deliver a 5-mA load current with high voltage amplification.

The LT1008 is externally compensated with a single capacitor to add flexibility in shaping the frequency response of the amplifier. The LT1008 is a pin-for-pin replacement for the LM108 series.

The LT1008M is characterized for operation over the full military temperature range of –55°C to 125°C. The LT1008C is characterized for operation from 0°C to 70°C.

AVAILABLE OPTIONS

T_A	PACKAGE		
	CERAMIC DIP (JG)	METAL CAN (L)	PLASTIC DIP (P)
0°C to 70°C	LT1008CJG	LT1008CL	LT1008CP
– 55°C to 125°C	LT1008MJG	LT1008ML	LT1008MP

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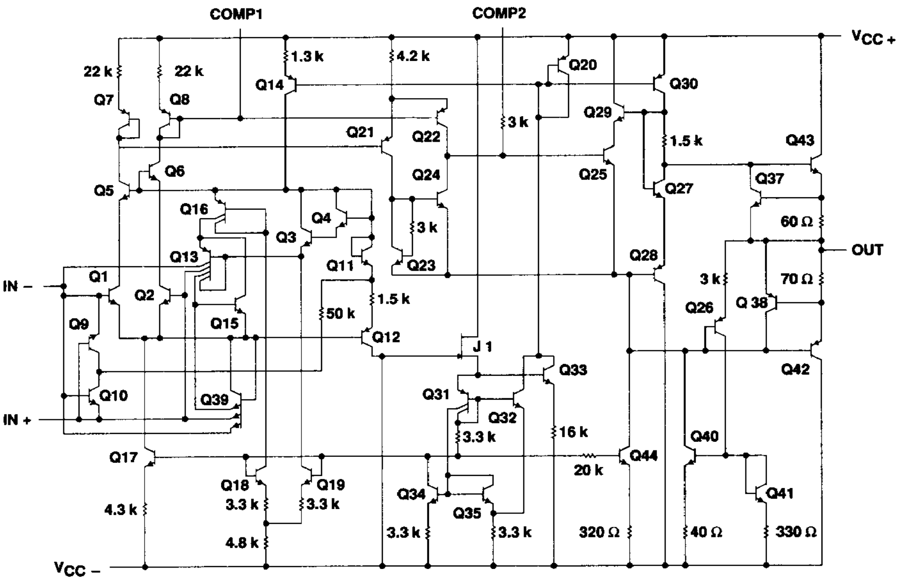
schematic



All resistor values shown are nominal and in ohms.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

Supply voltage, V_{CC+} (see Note 1) .... 20 V
Supply voltage, V_{CC-} .... − 20 V
Input voltage range, V_I .... ± 20 V
Differential input current (see Note 2) .... ± 10 mA
Duration of output short-circuit at (or below) 25°C (see Note 3) .... unlimited
Operating free-air temperature, T_A: LT1008M .... − 55°C to 125°C
LT1008C .... 0°C to 70°C
Storage temperature range .... − 65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: JG or L package .... 300°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: P package .... 260°C

NOTES: 1. All voltage values are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential input voltages greater than 1 V will cause excessive current to flow through the input protection diodes unless current-limiting resistors are used.
3. The output may be shorted to either supply.

recommended operating conditions

		LT1008M			LT1008C			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	
Supply voltage, V_{CC}				± 20			± 20	V
Common-mode input voltage, V_{IC}	$V_{CC\pm} = \pm 15$ V			± 13.5	− 15		± 13.5	V
Operating free-air temperature, T_A		− 55		125	0		70	°C

electrical characteristics, $V_{CC\pm}$ = ± 15V, V_{IC} = 0 (unless otherwise noted)

PARAMETER		TEST CONDITIONS	T_A†	LT1008M MIN	LT1008M TYP	LT1008M MAX	LT1008C MIN	LT1008C TYP	LT1008C MAX	UNIT
V_{IO}	Input offset voltage	$V_{CC\pm}$ = ± 15 V, V_{IC} = 0	25°C		30	120		30	120	µV
			Full range			250			180	
		$V_{CC\pm}$ = ± 15 V, V_{IC} = ±13.5 V	25°C		40	180		40	180	
			Full range			320			250	
		$V_{CC\pm}$ = ± 2 V to ± 20 V	25°C		40	180		40	180	
		$V_{CC\pm}$ = ± 2.5 V to ± 20 V	Full range			320			250	
α_{VIO}	Average temperature coefficient of input offset voltage		Full range		0.2	1.5		0.2	1.5	µV/°C
	Long-term drift of input offset voltage		25°C		0.3			0.3		µV/mo
I_{IO}	Input offset current	$V_{CC\pm}$ = ± 15 V, V_{IC} = 0	25°C		30	100		30	100	pA
			Full range			250			180	
		$V_{CC\pm}$ = ± 15 V, V_{IC} = ±13.5 V	25°C		40	150		40	150	
			Full range			350			250	
		$V_{CC\pm}$ = ± 2 V to ± 20 V	25°C		40	150		40	150	
		$V_{CC\pm}$ = ± 2.5 V to ± 20 V	Full range			350			250	
α_{IIO}	Average temperature coefficient of input offset current		Full range		0.4	2.5		0.4	2.5	pA/°C
I_{IB}	Input bias current	$V_{CC\pm}$ = ± 15 V, V_{IC} = 0	25°C		± 30	± 100		± 30	± 100	pA
			Full range			± 600			± 180	
		$V_{CC\pm}$ = ± 15 V, V_{IC} = ±13.5 V	25°C		± 40	± 150		± 40	± 150	
			Full range			± 800			± 250	
		$V_{CC\pm}$ = ± 2 V to ± 20 V	25°C		± 40	± 150		± 40	± 150	
		$V_{CC\pm}$ = ± 2.5 V to ± 20 V	Full range			± 800			± 250	
α_{IIB}	Average temperature coefficient of input bias current		Full range		0.6	6		0.4	2.5	pA/°C
V_{ICR}	Common-mode input voltage range		25°C	± 13.5	± 14		± 13.5	± 14		V
			Full range	± 13.5			± 13.5			
V_{OM}	Maximum peak output voltage swing	R_L = 10 kΩ	25°C	± 13	± 14		± 13	± 14		V
			Full range	± 13			± 13			
A_{VD}	Large-signal differential voltage amplification	V_O = ± 12 V, R_L ≥ 10 kΩ	25°C	200	2000		200	2000		V/mV
			Full range	100			150			
		V_O = ± 10 V, R_L ≥ 2 kΩ	25°C	120	600		120	600		
CMRR	Common-mode rejection ratio	V_{IC} = ±13.5 V	25°C	114	132		114	132		dB
			Full range	108			110			
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm} / \Delta V_{IO}$)	$V_{CC\pm}$ = ± 2 V to ± 20 V	25°C	114	132		114	132		dB
		$V_{CC\pm}$ = ± 2.5 V to ± 20 V	Full range	108			110			
I_{CC}	Supply current	$V_{CC\pm}$ = ± 15 V, V_{IC} = ±13.5 V	25°C		380	600		380	600	µA
		$V_{CC\pm}$ = ± 2 V to ± 20 V	25°C		380	600		380	600	
		$V_{CC\pm}$ = ± 15 V, V_{IC} = 0	Full range			800			800	

†Full range is −55°C to 125°C for the LT1008M and 0°C to 70°C for the LT1008C.

operating characteristics, $V_{CC\pm} = \pm 15$ V, $T_A = 25°C$ (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
SR	Slew rate at unity gain	C_f = 30 pF, See Figure 29(a)	0.1	0.2		V/μs
V_{NPP}	Peak-to-peak equivalent input noise voltage	f = 0.1 Hz to 10 Hz		0.5		μV
V_n	Equivalent input noise voltage	f = 10 Hz		17	30	nV/√Hz
		f = 1 kHz		14	22	
I_n	Equivalent input noise current	f = 10 Hz		20		fA/√Hz

TYPICAL CHARACTERISTICS

table of graphs

			FIGURE
V_{IO}	Input offset voltage	vs Temperature	1
		vs Source resistance	5
ΔV_{IO}	Change in input offset voltage	vs Time – minutes	2
		vs Time – months	3
α_{VIO}	Temperature coefficient of input offset voltage	vs Source resistance	6
I_{IB}	Input bias current	vs Common-mode input voltage	7
		vs Temperature	8
A_{VD}	Differential voltage amplification	vs Load resistance	9
		vs Frequency	10, 11, 12
CMRR	Common-mode rejection ratio	vs Frequency	13
k_{SVR}	Supply-voltage rejection ratio	vs Frequency	14
I_{OS}	Short-circuit output current	vs Time	15
I_{CC}	Supply current	vs Supply voltage	4
SR	Slew rate	vs Compensation capacitance	16
V_{NPP}	Peak-to-peak equivalent input noise voltage	vs Time	17
V_n, I_n	Equivalent input noise voltage and equivalent input noise current	vs Frequency	18
	Total equivalent input noise voltage	vs Source resistance	19
	Phase shift	vs Frequency	11, 12
	Pulse response	Small-signal	20, 21, 22
		Large-signal	23, 24

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TYPICAL CHARACTERISTICS†

INPUT OFFSET VOLTAGE
OF REPRESENTATIVE UNITS
vs
FREE-AIR TEMPERATURE

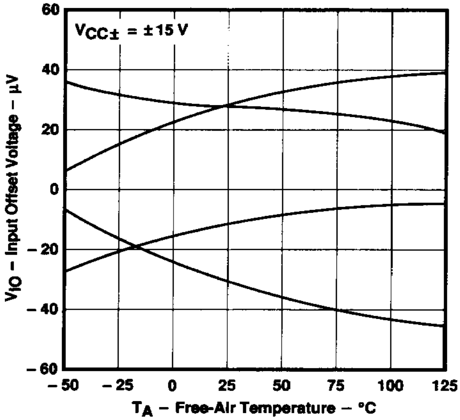

FIGURE 1

WARM-UP CHANGE IN
INPUT OFFSET VOLTAGE
vs
ELAPSED TIME

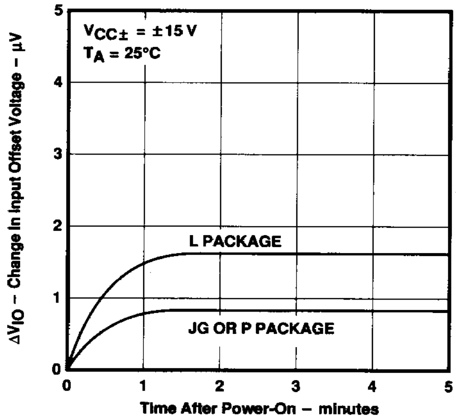

FIGURE 2

LONG-TERM DRIFT OF
INPUT OFFSET VOLTAGE
OF REPRESENTATIVE UNITS

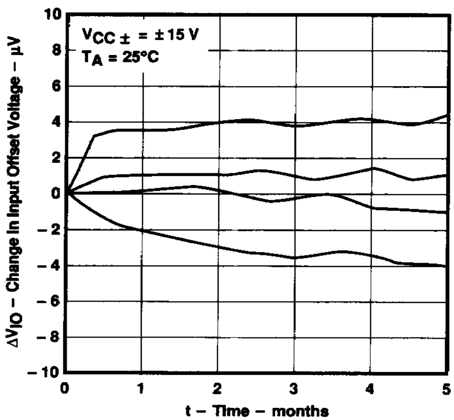

FIGURE 3

SUPPLY CURRENT
vs
SUPPLY VOLTAGE

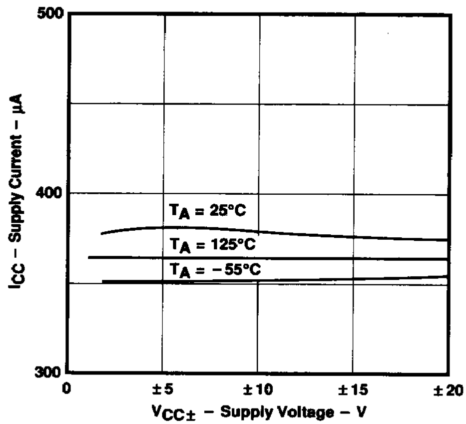

FIGURE 4

†Data for temperatures below 0°C and above 70°C are applicable to the LT1008M only.

TYPICAL CHARACTERISTICS†

INPUT OFFSET VOLTAGE
vs
SOURCE RESISTANCE

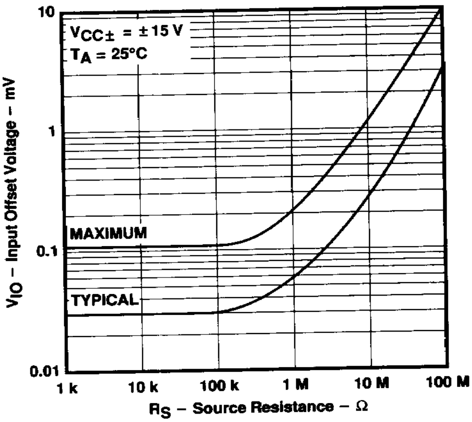

FIGURE 5

AVERAGE TEMPERATURE COEFFICIENT
OF INPUT OFFSET VOLTAGE
vs
SOURCE RESISTANCE

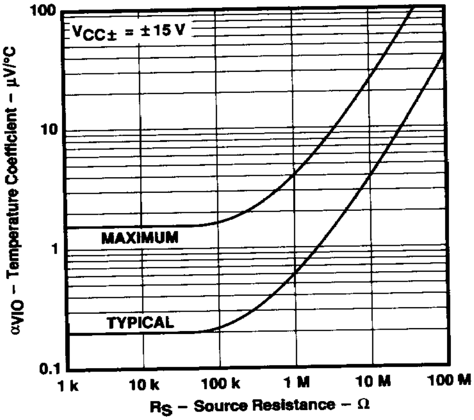

FIGURE 6

INPUT BIAS CURRENT
vs
COMMON-MODE INPUT VOLTAGE

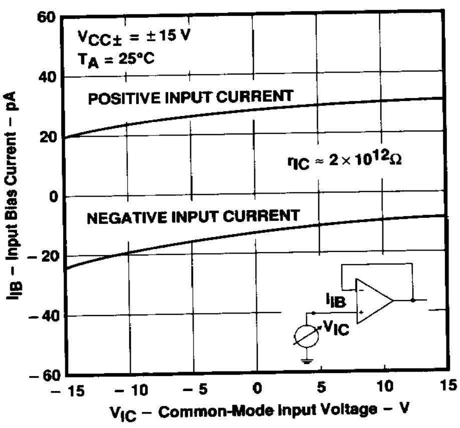

FIGURE 7

INPUT BIAS CURRENT
vs
FREE-AIR TEMPERATURE

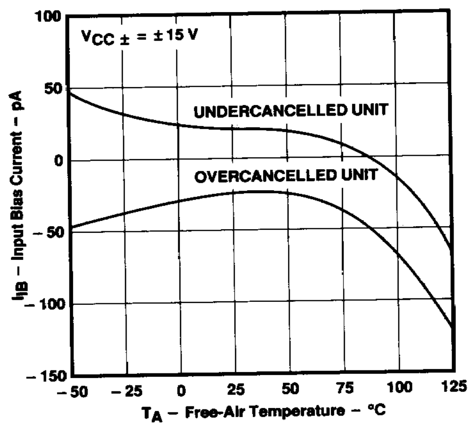

FIGURE 8

†Data for temperatures below 0°C and above 70°C are applicable to the LT1008M only.

TYPICAL CHARACTERISTICS†

LARGE-SIGNAL
DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
LOAD RESISTANCE

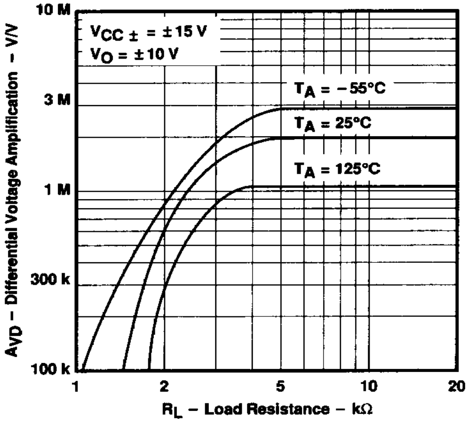

FIGURE 9

LARGE-SIGNAL DIFFERENTIAL
VOLTAGE AMPLIFICATION and PHASE SHIFT
vs
FREQUENCY

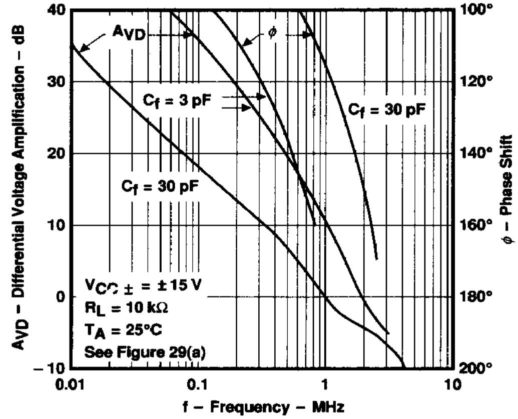

FIGURE 10

LARGE-SIGNAL
DIFFERENTIAL VOLTAGE AMPLIFICATION
vs
FREQUENCY

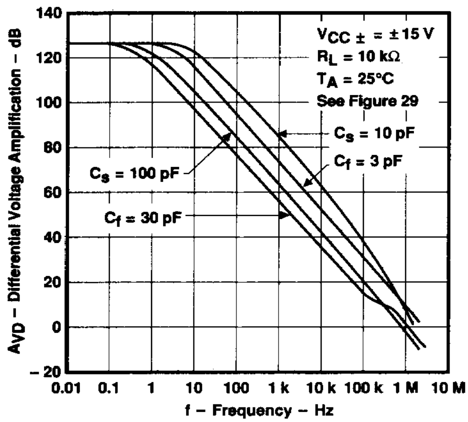

FIGURE 11

LARGE-SIGNAL DIFFERENTIAL
VOLTAGE AMPLIFICATION and PHASE SHIFT
vs
FREQUENCY

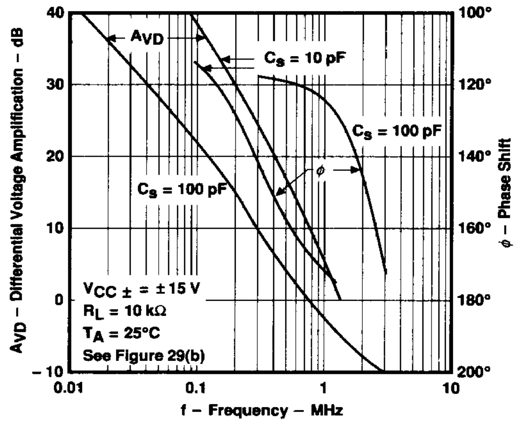

FIGURE 12

†Data for temperatures below 0°C and above 70°C are applicable to the LT1008M only.

TYPICAL CHARACTERISTICS†

COMMON-MODE REJECTION RATIO
vs
FREQUENCY

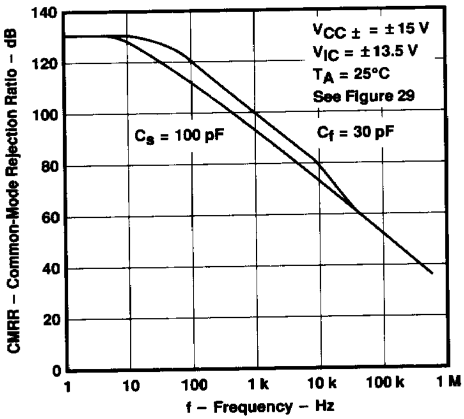

FIGURE 13

SUPPLY-VOLTAGE REJECTION RATIO
vs
FREQUENCY

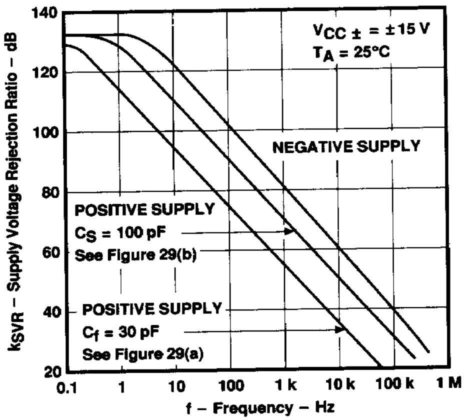

FIGURE 14

SHORT-CIRCUIT OUTPUT CURRENT
vs
ELAPSED TIME

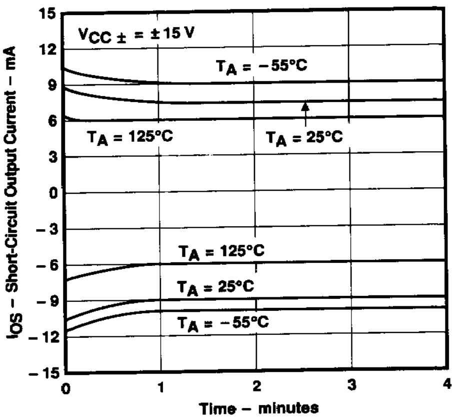

FIGURE 15

SLEW RATE
vs
COMPENSATION CAPACITANCE

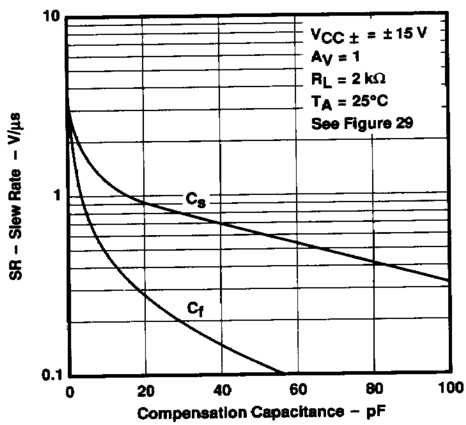

FIGURE 16

†Data for temperatures below 0°C and above 70°C are applicable to the LT1008M only.

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TYPICAL CHARACTERISTICS

OUTPUT NOISE VOLTAGE
OVER A 10-SECOND PERIOD

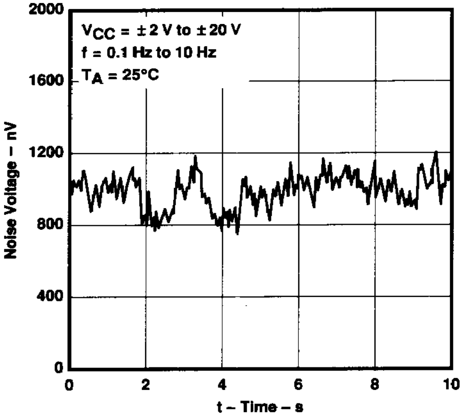

FIGURE 17

EQUIVALENT INPUT NOISE VOLTAGE
and EQUIVALENT INPUT NOISE CURRENT
vs
FREQUENCY

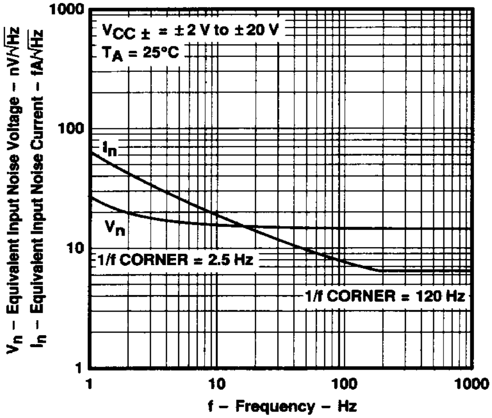

FIGURE 18

TOTAL EQUIVALENT INPUT NOISE VOLTAGE
vs
SOURCE RESISTANCE

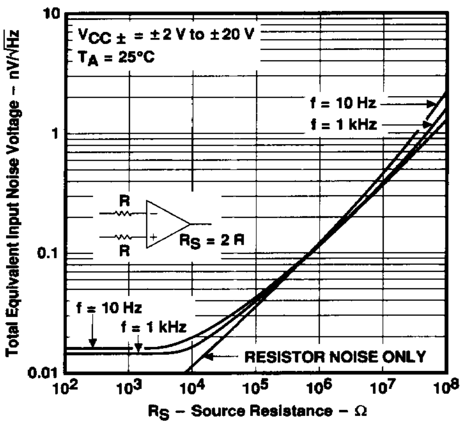

FIGURE 19

VOLTAGE-FOLLOWER
SMALL-SIGNAL
PULSE RESPONSE

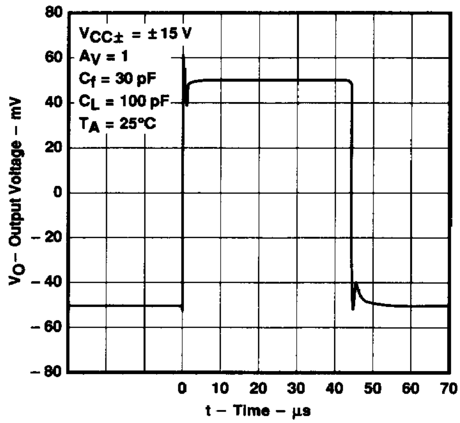

FIGURE 20

TYPICAL CHARACTERISTICS

VOLTAGE-FOLLOWER
SMALL-SIGNAL
PULSE RESPONSE

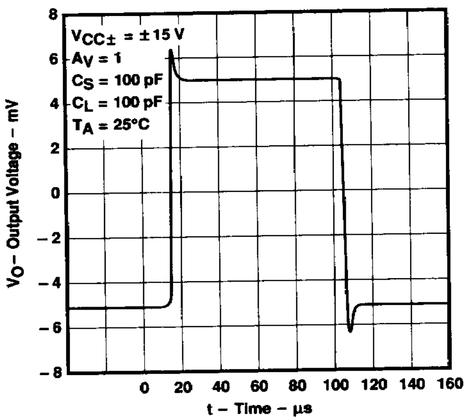

FIGURE 21

VOLTAGE-FOLLOWER
SMALL-SIGNAL
PULSE RESPONSE

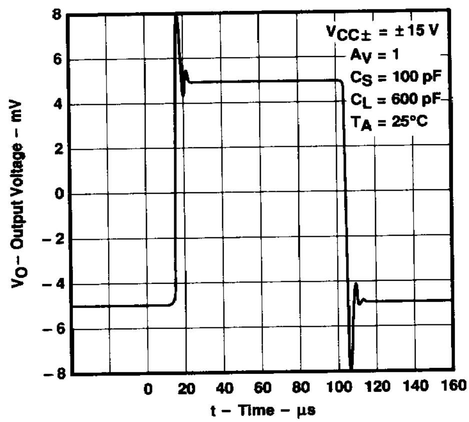

FIGURE 22

VOLTAGE-FOLLOWER
LARGE-SIGNAL
PULSE RESPONSE

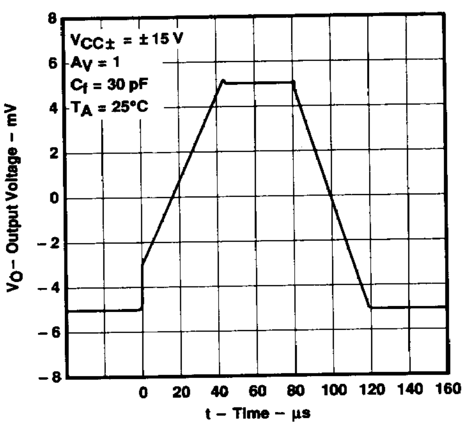

FIGURE 23

VOLTAGE-FOLLOWER
LARGE-SIGNAL
PULSE RESPONSE

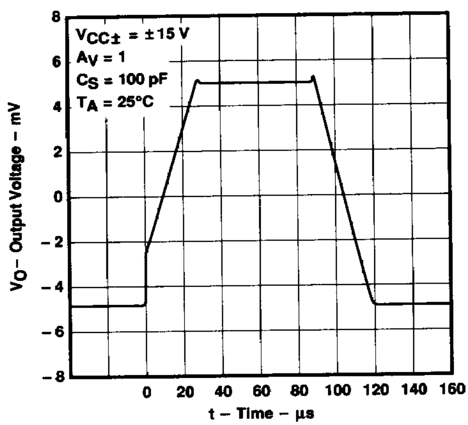

FIGURE 24

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TYPICAL APPLICATION DATA

achieving picoampere, microvolt performance

Proper care should be exercised to realize the picoampere, microvolt accuracy of the LT1008. Because leakage currents in external circuitry can significantly degrade performance, high-quality insulation should be used (e. g.,Teflon, Kel-F). All insulating surfaces should be cleaned to remove fluxes and other residues. Surface coating may be necessary to provide a moisture barrier in high-humidity environments.

Board leakage can be minimized by encircling the input circuitry with a guard ring operated at a potential close to that of the inputs (see Figure 25). In inverting configurations, the guard ring should be tied to ground; in noninverting configurations, the guard ring should be tied to the inverting input (pin 2). Both sides of the printed circuit board should be guarded. Bulk leakage reduction depends on the guard ring width. Nanoampere-level leakage into the compensation terminals can affect input offset voltage and its temperature coefficient (see Figure 26).

Microvolt-level error voltages can also be generated in the external circuitry. Thermocouple effects, caused by temperature gradients across dissimilar metals at the contacts to the input terminals, can exceed the inherent temperature coefficient of the amplifier. Air currents over device leads should be minimized, package leads should be short, and the two input leads should be as close together as possible and maintained at the same temperature. The LT1008 is specified over a wide range of supply voltages from ±2 V to ±18 V. Operation with lower supplies (down to ±1 V) is possible with two Ni-Cad batteries.

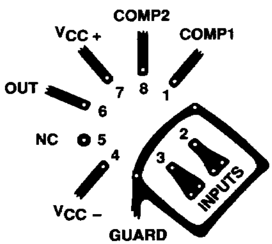
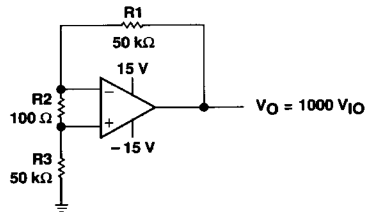


FIGURE 25. GUARD RING



NOTES: A. Resistors must have low thermoelectric potential.
B. This circuit is also used as the burn-in configuration for the LT1008, with supply voltages increased to ± 20 V, R1 = R3 = 20 kΩ, R2 = 200 Ω, and A_V = 100.

FIGURE 26. TEST CIRCUIT FOR V_{IO} AND α_{VIO}

noise testing

The peak-to-peak equivalent input noise voltage of the LT1008 is measured in the test circuit shown in Figure 27. The frequency response of this noise tester indicates that the 0.1-Hz to 10-Hz noise should not exceed 10 seconds, as this time limit acts as an additional zero to eliminate noise contributions from the frequency band below 0.1 Hz.

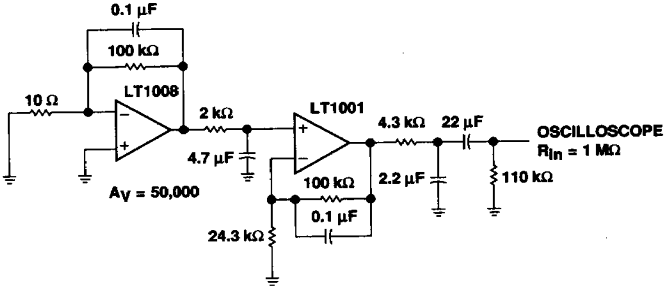
An input noise voltage test is recommended when measuring noise in a large number of units. A 10-Hz input noise voltage measurement correlates well with a 0.1-Hz peak-to-peak noise reading because both results are determined by the white noise and the location of the 1/f corner frequency.

Current noise is measured by the current shown in Figure 28 and calculated by the following formula in which the noise of the source resistors is subtracted:

$$I_n = \frac{[V_{no}{}^2 - (820\ \text{nV})^2]^{1/2}}{40\ \text{M}\Omega \times 100}$$

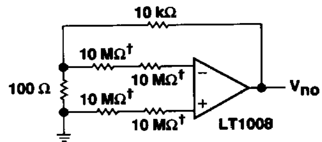
TYPICAL APPLICATION DATA

noise testing (continued)



NOTE A : All capacitor values are for nonpolarized capacitors only.

FIGURE 27. 0.1-Hz TO 10-Hz PEAK-TO-PEAK NOISE VOLTAGE TEST CIRCUIT



† Metal film.

FIGURE 28. NOISE CURRENT TEST CIRCUIT

frequency compensation

The LT1008 is externally frequency compensated with a single capacitor. The two compensation circuits shown in Figure 29 are identical to the frequency compensation circuits for the LM108A series. Therefore, the LT1008 operational amplifiers can be inserted directly into LM108A or LM308A sockets, with similar ac and upgraded dc performance.

(a) STANDARD COMPENSATION

(b) ALTERNATE COMPENSATION (see Note B)

NOTES: A. $C_f \geq (R1 \times C_O) / (R1 + R2)$, C_O = 30 pF. Bandwidth and slew rate are proportional to $1/C_f$.
B. This circuit improves the supply voltage rejection ratio by a factor of 5.
C. Bandwidth and slew rate are proportional to $1/C_S$.
D. For (R2/R1) > 200, no external frequency compensation is necessary.

FIGURE 29. FREQUENCY COMPENSATION CIRCUITS (see Note D)

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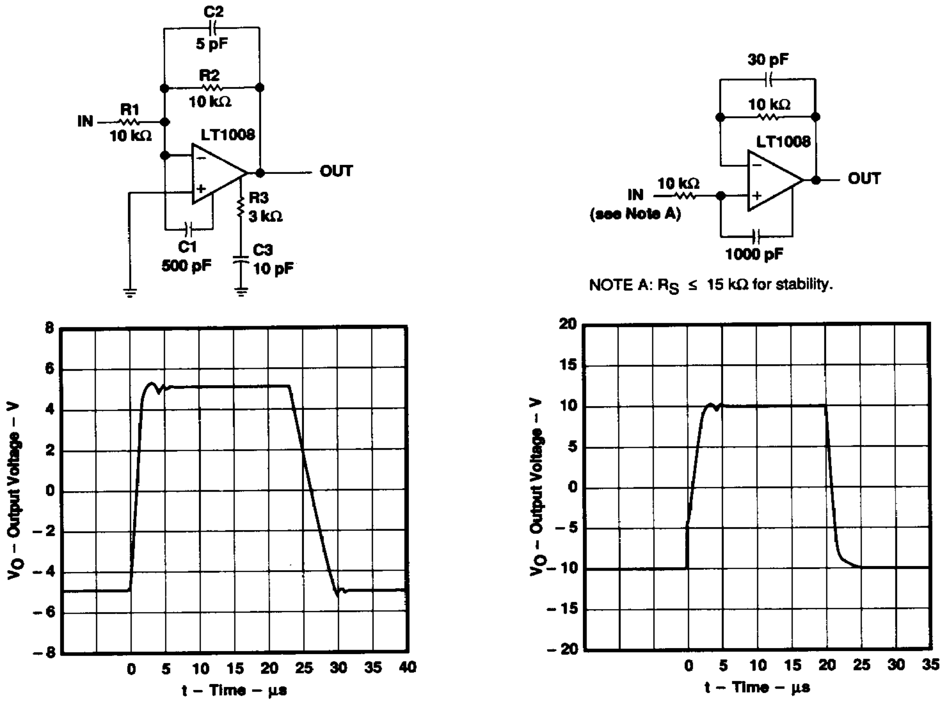
frequency compensation (continued)

External frequency compensation provides additional flexibility in shaping the frequency response of the amplifier. For example, for a voltage gain of 10 and C_f = 3 pF, a gain-bandwidth product of 5 MHz and slew rate of 1.2 V/μs can be realized. For closed-loop gains greater than 200, no external compensation is necessary, and the slew rate increases to 4 V/μs. The LT1008 can also be overcompensated (e.g., $C_f > 30$ pF or $C_S > 100$ pF) to improve capacitive-load-handling capability or to narrow noise bandwidth. In applications in which the feedback loop around the amplifier has gain, overcompensation can stabilize the circuit with a single capacitor.

The availability of the compensation terminals permits the use of feed-forward frequency compensation to enhance slew rate in low closed-loop-gain configurations (see Figure 30). The inverter slew rate is increased to 1.4 V/μs. The voltage-follower feed-forward scheme bypasses the amplifier's gain stages and slews at nearly 10 V/μs.



(a) INVERTER FEED-FORWARD

(b) VOLTAGE-FOLLOWER FEED-FORWARD

FIGURE 30. FREQUENCY COMPENSATION CIRCUITS and VOLTAGE-FOLLOWER PULSE RESPONSES

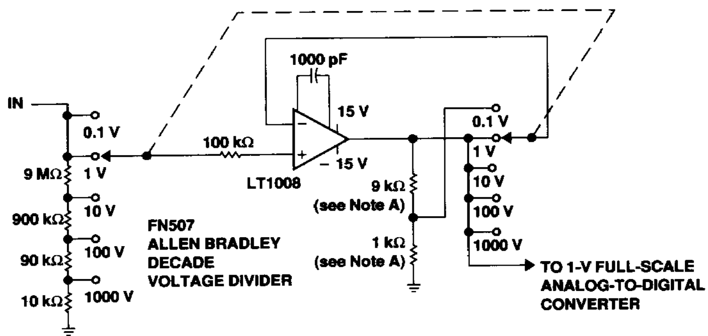
TYPICAL APPLICATION DATA

other considerations

The inputs of the LT1008 are protected by back-to-back diodes. Current-limiting resistors are not used because the leakage of these resistors would prevent the realization of picoampere-level bias currents at elevated temperatures. In the voltage-follower configuration, when the input is driven by a fast, large-signal pulse (> 1 V), the input protection diodes effectively short the output to the input during slewing, and a current, limited only by the output short-circuit protection, flows through the diodes.

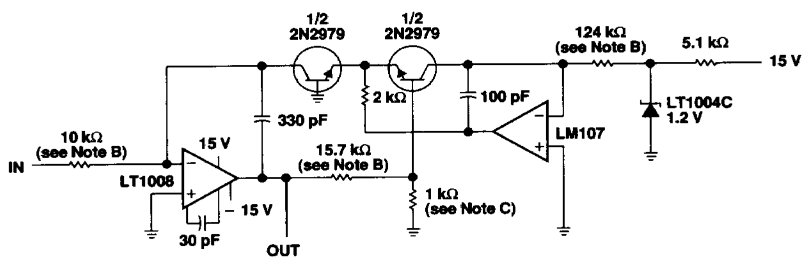
The use of a feedback resistor, as shown in the voltage-follower feed-forward diagram, is recommended because this resistor keeps the current below the short-circuit limit, resulting in faster recovery and settling of the output.

typical applications



NOTES: A. Ratio match ± 0.01 %.
B. This application requires low bias current, low offset voltage and offset voltage temperature coefficient, low noise, and low long-term offset voltage drift.

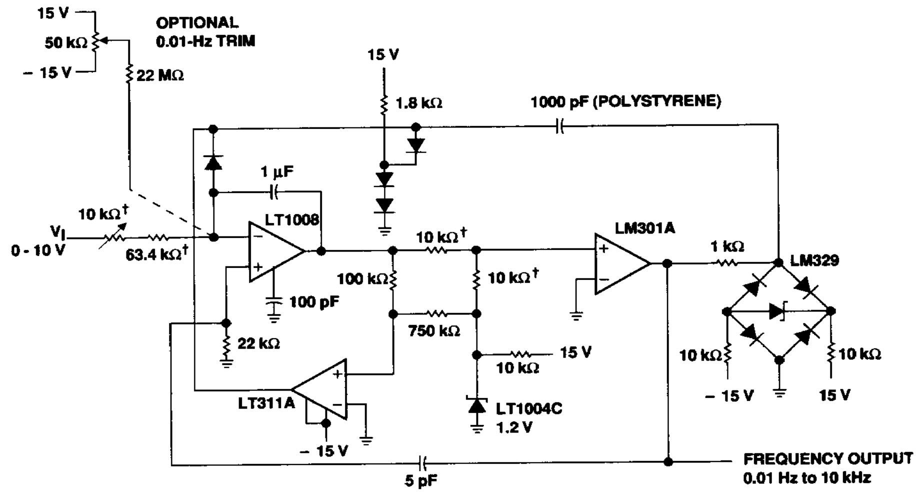
FIGURE 31. INPUT AMPLIFIER FOR 4 1/2-DIGIT VOLTMETER



NOTES: A. The low bias current and offset voltage of the LT1008 allow 4 1/2 decades of voltage input logging.
B. 1% film resistor.
C. Tel. Labs, Type Q81.

FIGURE 32. LOGARITHMIC AMPLIFIER

TYPICAL APPLICATION DATA



†1% metal film resistor

NOTES: A. The LT1008 integrator extends the low frequency range. The total dynamic range is 0.01 Hz to 10 kHz (or 120 dB) with 0.01% linearity.

B. All diodes 1N4148.

FIGURE 33. EXTENDED RANGE CHARGE PUMP VOLTAGE-TO-FREQUENCY CONVERTER

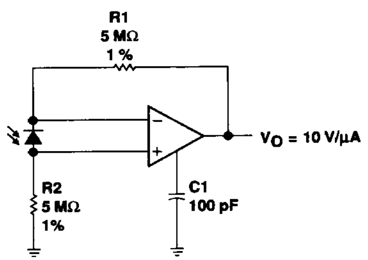
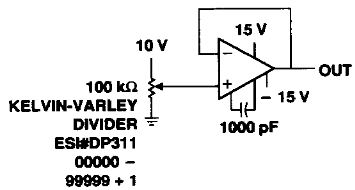


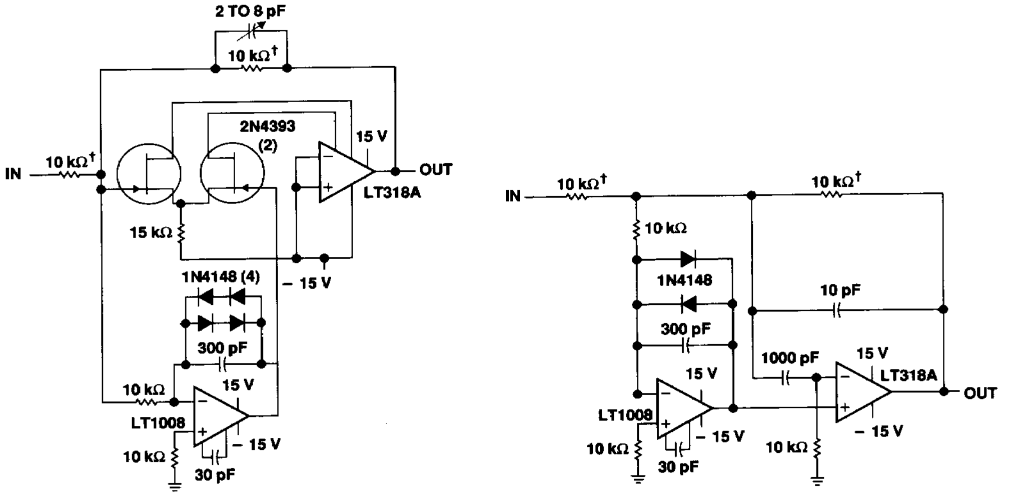
FIGURE 34. AMPLIFIER FOR PHOTODIODE SENSOR



NOTE A : Approximate error due to noise, bias current, common-mode rejection, and voltage gain of the amplifier is 1/5 of a least significant bit.

FIGURE 35. FIVE-DECADE KELVIN-VARLEY DIVIDER BUFFERED BY THE LT1008

TYPICAL APPLICATION DATA

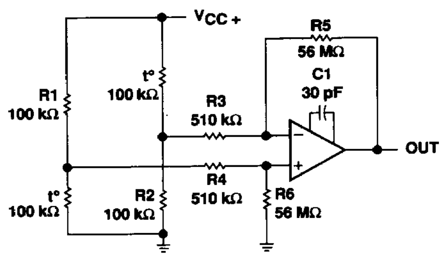


(a) SR = 100 V/µs
I_{IB} = 30 pA
V_{IO} = 30 µV
Settling = 5 µs to 0.01%/10-V step

(b) SR = 50 V/µs
I_{IB} = 30 pA
V_{IO} = 30 µV
αV_{IO} = 0.3 µV/°C
BW = 2 MHz
Settling = 12 µs to 0.01%/10-V step

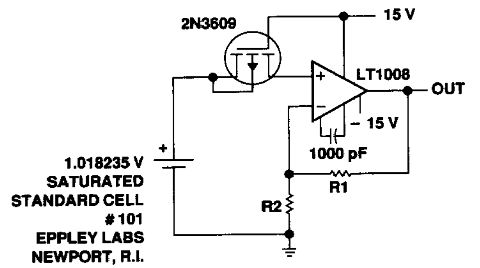
†1% metal film resistor.

FIGURE 36. FAST PRECISION INVERTERS



NOTE A : A_{VD} = 100.

FIGURE 37. AMPLIFIER FOR BRIDGE TRANSDUCERS



NOTE A : The typical 30-pA input bias current of the LT1008 will degrade the standard cell by only 1 ppm/year. Noise is a fraction of a ppm. Unprotected gate MOSFET isolates standard cell on power down.

FIGURE 38. SATURATED STANDARD-CELL AMPLIFIER

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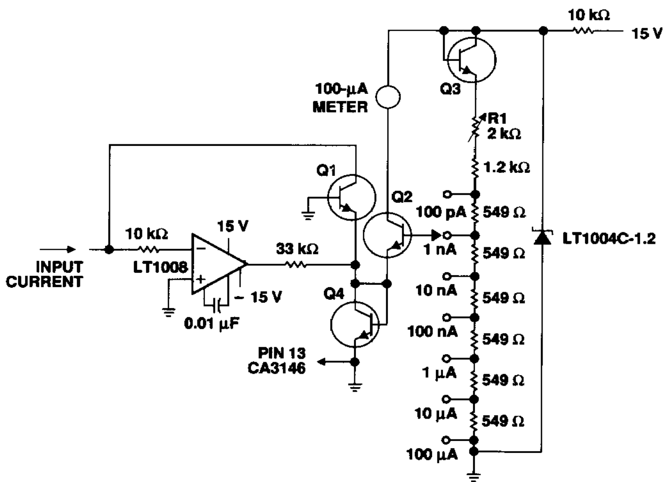
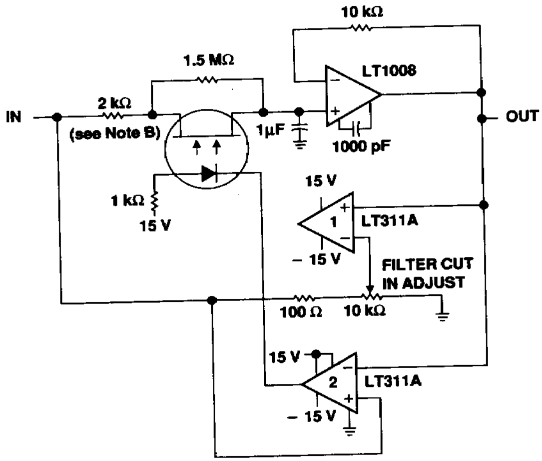


NOTES: A. This ammeter measures currents from 100 pA to 100 μA without the use of expensive high-value resistors. Accuracy at 100 μA is limited by the offset voltage between Q1 and Q2 and, at 100 pA, by the inverting bias current of the LT1008.
B. Q1-Q4 RCA CA3146 transistor array.
C. Adjust R1 for full-scale deflection with 1-μA input current.

FIGURE 39. AMMETER WITH 6-DECADE RANGE

TYPICAL APPLICATION DATA



NOTES: A. This circuit is useful where fast signal acquisition and high precision are required, as in electronic scales. The filter's time constant is set by the 2-kΩ resistor and the 1-µF capacitor until COMP1 switches. The time constant is then set by the 1.5-MΩ resistor and the 1-µF capacitor. COMP2 provides a quick reset. The circuit settles to a final value three times as fast as a simple 1.5-MΩ, 1-µF filter with almost no dc error.

B. OPTO-MOS switch, Type OFMIA, Theta-J Corp.

FIGURE 40. PRECISION, FAST-SETTLING, LOW-PASS FILTER.