Ultraprecision Operational Amplifier

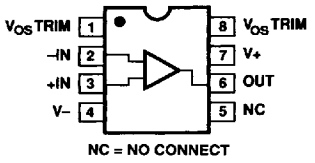
OP177

FEATURES

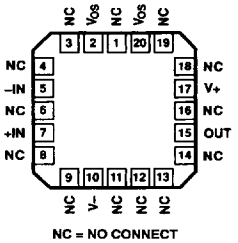
Ultralow Offset Voltage:
T_A = +25°C: 10 μV max
−55°C ≤ T_A ≤ +125°C: 20 μV max
Outstanding Offset Voltage Drift: 0.1 μV/°C max
Excellent Open-Loop Gain and Gain Linearity:
12 V/μV typ
CMRR: 130 dB min
PSRR: 120 dB min
Low Supply Current: 2.0 mA max
Fits Industry Standard Precision Op Amp Sockets (OP07/OP77)

PIN CONNECTIONS

Epoxy Mini-DIP (P Suffix)
8-Pin Hermetic DIP (Z-Suffix)
8-Pin SO (S-Suffix)



OP177BRC/883 LCC (RC Suffix)



GENERAL DESCRIPTION

The OP177 features the highest precision performance of any op amp currently available. Offset voltage of the OP177 is only 10 μV max at room temperature and 20 μV max over the full military temperature range of −55°C to +125°C. The ultralow V_{OS} of the OP177, combines with its exceptional offset voltage drift (TCV_{OS}) of 0.1 μV/°C max, to eliminate the need for external V_{OS} adjustment and increases system accuracy over temperature.

The OP177's open-loop gain of 12 V/μV is maintained over the full ±10 V output range. CMRR of 130 dB min, PSRR of 120 dB min, and maximum supply current of 2 mA are just a few examples of the excellent performance of this operational amplifier. The OP177's combination of outstanding specifications insure accurate performance in high closed-loop gain applications.

This low noise bipolar input op amp is also a cost effective alternative to chopper-stabilized amplifiers. The OP177 provides chopper-type performance without the usual problems of high noise, low frequency chopper spikes, large physical size, limited common-mode input voltage range, and bulky external storage capacitors.

The OP177 is offered in both the −55°C to +125°C military, and the −40°C to +85°C extended industrial temperature ranges. This product is available in 8-pin ceramic and epoxy DIPs, as well as the space saving 8-pin Small-Outline (SO) and the Leadless Chip Carrier (LCC) packages.

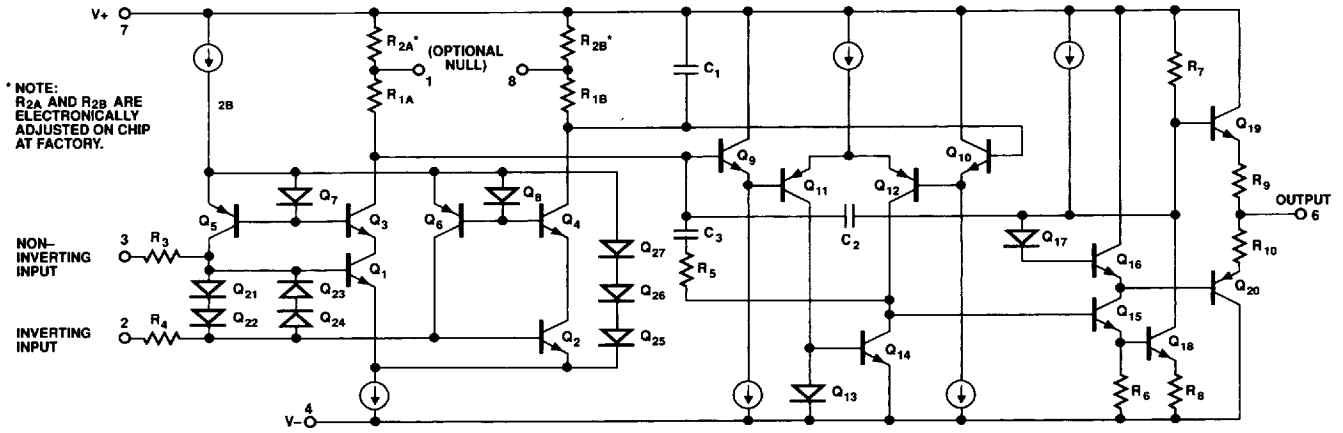


Figure 1. Simplified Schematic

REV. B

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OP177–SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (@ V_S = ±15 V, T_A = +25°C, unless otherwise noted)

Parameter	Symbol	Conditions	OP177A Min	OP177A Typ	OP177A Max	OP177B Min	OP177B Typ	OP177B Max	Units
Input Offset Voltage	V_{OS}			4	10		10	25	µV
Long-Term Input Offset Voltage Stability	ΔV_{OS}/Time	(Note 1)		0.2			0.2		µV/Mo
Input Offset Current	I_{OS}			0.3	1.0		0.3	1.5	nA
Input Bias Current	I_B		–0.2		1.5	–0.2		2.0	nA
Input Noise Voltage	e_n	f_o = 1 Hz to 100 Hz[2]		118	150		118	150	nV rms
Input Noise Current	i_n	f_o = 1 Hz to 100 Hz[2]		3	8		3	8	pA rms
Input Resistance Differential-Mode	R_{IN}	(Note 3)	26	45		26	45		MΩ
Input Resistance Common-Mode	R_{INCM}			200			200		GΩ
Input Voltage Range	IVR	(Note 4)	±13	±14		±13	±14		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	130	140		130	140		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V	120	125		115	125		dB
Large Signal Voltage Gain	A_{VO}	$R_L \geq 2$ kΩ, V_O = ±10 V[5]	5000	12000		5000	12000		V/mV
Output Voltage Swing	V_O	$R_L \geq 10$ kΩ	±13.5	±14.0		±13.5	±14.0		V
		$R_L \geq 2$ kΩ	±12.5	±13.0		±12.5	±13.0		V
		$R_L \geq 1$ kΩ	±12.0	±12.5		±12.0	±12.5		V
Slew Rate	SR	$R_L \geq 2$ kΩ[2]	0.1	0.3		0.1	0.3		V/µs
Closed-Loop Bandwidth	BW	A_{VCL} = +1[2]	0.4	0.6		0.4	0.6		MHz
Open-Loop Output Resistance	R_O			60			60		Ω
Power Consumption	P_D	V_S = ±15 V, No Load		50	60		50	60	mW
		V_S = ±3 V, No Load		3.5	4.5		3.5	4.5	mW
Supply Current	I_{SY}	V_S = ±15 V, No Load		1.6	2.0		1.6	2.0	mA
Offset Adjustment Range		Rp = 20 kΩ		±3			±3		mV

NOTES
[1]Long-Term Input Offset Voltage Stability refers to the averaged trend line of V_{OS} vs. Time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 operating days are typically less than 2.0 µV.
[2]Sample tested.
[3]Guaranteed by design.
[4]Guaranteed by CMRR test condition.
[5]To insure high open-loop gain throughout the ±10 V output range, A_{VO} is tested at –10 V ≤ V_O ≤ 0 V, 0 V ≤ V_O ≤ +10 V, and –10 V ≤ V_O ≤ +10 V.

Specifications subject to change without notice.

ELECTRICAL CHARACTERISTICS (@ V_S = ±15 V, –55°C ≤ T_A ≤ +125°C, unless otherwise noted)

Parameter	Symbol	Conditions	OP177A Min	OP177A Typ	OP177A Max	OP177B Min	OP177B Typ	OP177B Max	Units
Input Offset Voltage	V_{OS}			10	20		25	55	µV
Average Input Offset Voltage Drift	TCV_{OS}	(Note 1)		0.03	0.1		0.1	0.3	µV/°C
Input Offset Current	I_{OS}			0.5	1.5		0.5	2.0	nA
Average Input Offset Current Drift	TCI_{OS}	(Note 2)		1.5	25		1.5	25	pA/°C
Input Bias Current	I_B		–0.2	2.4	4	–0.2	2.4	4	nA
Average Input Bias Current Drift	TCI_B	(Note 2)		8	25		8	25	pA/°C
Input Voltage Range	IVR	(Note 3)	±13	±13.5		±13	±13.5		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	120	140		120	140		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V	120	125		110	120		dB
Large-Signal Voltage Gain	A_{VO}	$R_L \geq 2$ kΩ, V_O = ±10 V[4]	2000	6000		2000	6000		V/mV
Output Voltage Swing	V_O	$R_L \geq 2$ kΩ	±12	±13.0		±12	±13.0		V
Power Consumption	P_D	V_S = ±15 V, No Load		60	75		60	75	mW
Supply Current	I_{SY}	V_S = ±15 V, No Load		2.0	2.5		2.0	2.5	mA

NOTES
[1]TCV_{OS} is 100% tested.
[2]Guaranteed by endpoint limits.
[3]Guaranteed by CMRR test condition.
[4]To insure high open-loop gain throughout the ±10 V output range, A_{VO} is tested at –10 V ≤ V_O ≤ 0 V, 0 V ≤ V_O ≤ +10 V, and –10 V ≤ V_O ≤ +10 V.

Specifications subject to change without notice.

ELECTRICAL CHARACTERISTICS (@ V_S = ±15 V, T_A = +25°C, unless otherwise noted)

Parameter	Symbol	Conditions	OP177E			OP177F			OP177G			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	V_{OS}			4	10		10	25		20	60	µV
Long-Term Input Offset Voltage Stability	ΔV_{OS}/Time	(Note 1)		0.2			0.3			0.4		µV/Mo
Input Offset Current	I_{OS}			0.3	1.0		0.3	1.5		0.3	2.8	nA
Input Bias Current	I_B		–0.2	1.0	1.5	–0.2	1.2	2.0	–0.2	1.2	2.8	nA
Input Noise Voltage	e_n	f_o = 1 Hz to 100 Hz[2]		118	150		118	150		118	150	nV rms
Input Noise Current	i_n	f_o = 1 Hz to 100 Hz[2]		3	8		3	8		3	8	pA rms
Input Resistance Differential-Mode	R_{IN}	(Note 3)	26	45		26	45		18.5	45		MΩ
Input Resistance Common-Mode	R_{INCM}			200			200			200		GΩ
Input Voltage Range	IVR	(Note 4)	±13	±14		±13	±14		±13	±14		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	130	140		130	140		115	140		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V	120	125		115	125		110	120		dB
Large Signal Voltage Gain	A_{VO}	$R_L \geq 2$ kΩ, V_O = ±10 V[5]	5000	12000		5000	12000		2000	6000		V/mV
Output Voltage Swing	V_O	$R_L \geq 10$ kΩ	±13.5	±14.0		±13.5	±14.0		±13.5	±14.0		V
		$R_L \geq 2$ kΩ	±12.5	±13.0		±12.5	±13.0		±12.5	±13.0		V
		$R_L \geq 1$ kΩ	±12.0	±12.5		±12.0	±12.5		±12.0	±12.5		V
Slew Rate	SR	$R_L \geq 2$ kΩ[2]	0.1	0.3		0.1	0.3		0.1	0.3		V/µs
Closed-Loop Bandwidth	BW	A_{VCL} = +1[2]	0.4	0.6		0.4	0.6		0.4	0.6		MHz
Open-Loop Output Resistance	R_O			60			60			60		Ω
Power Consumption	P_D	V_S = ±15 V, No Load		50	60		50	60		50	60	mW
		V_S = ±3 V, No Load		3.5	4.5		3.5	4.5		3.5	4.5	mW
Supply Current	I_{SY}	V_S = ±15 V, No Load		1.6	2.0		1.6	2.0		1.6	2.0	mA
Offset Adjustment Range		R_P = 20 kΩ		±3			±3			±3		mV

NOTES

[1]Long-Term Input Offset Voltage Stability refers to the averaged trend line of V_{OS} vs. time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 operating days are typically less than 2.0 µV.

[2]Sample tested.

[3]Guaranteed by design.

[4]Guaranteed by CMRR test condition.

[5]To insure high open-loop gain throughout the ±10 V output range, A_{VO} is tested at –10 V ≤ V_O ≤ 0 V, 0 V ≤ V_O ≤ +10 V, and –10 V ≤ V_O ≤ +10 V.

Specifications subject to change without notice.

OP177–SPECIFICATIONS

ELECTRICAL CHARACTERISTICS (@ V_S = ±15 V, –40°C ≤ T_A ≤ +85°C, unless otherwise noted)

Parameter	Symbol	Conditions	OP177E			OP177F			OP177G			Units
			Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	V_{OS}			10	20		15	40		20	100	µV
Average Input Offset Voltage Drift	TCV_{OS}	(Note 1)		0.03	0.1		0.1	0.3		0.7	1.2	µV/°C
Input Offset Current	I_{OS}			0.5	1.5		0.5	2.2		0.5	4.5	nA
Average Input Offset Current Drift	TCI_{OS}	(Note 2)		1.5	25		1.5	40		1.5	85	pA/°C
Input Bias Current	I_B		–0.2	2.4	4	–0.2	2.4	4		2.4	±6.0	nA
Average Input Bias Current Drift	TCI_B	(Note 2)		8	25		8	40		15	60	pA/°C
Input Voltage Range	IVR	(Note 3)	±13	±13.5		±13	±13.5		±13.0	±13.5		V
Common-Mode Rejection Ratio	CMRR	V_{CM} = ±13 V	120	140		120	140		110	140		dB
Power Supply Rejection Ratio	PSRR	V_S = ±3 V to ±18 V	120	125		110	120		106	115		dB
Large-Signal Voltage Gain	A_{VO}	$R_L \geq 2$ kΩ, V_O = ±10 V[4]	2000	6000		2000	6000		1000	4000		V/mV
Output Voltage Swing	V_O	$R_L \geq 2$ kΩ	±12	±13.0		±12	±13.0		±12.0	±13.0		V
Power Consumption	P_D	V_S = ±15 V, No Load		60	75		60	75		60	75	mW
Supply Current	I_{SY}	V_S = ±15 V, No Load		2.0	2.5		2.0	2.5		2.0	2.5	mA

NOTES
[1]OP177E: TCV_{OS} is 100% tested.
[2]Guaranteed by endpoint limits.
[3]Guaranteed by CMRR test condition.
[4]To insure high open-loop gain throughout the ±10 V output range, A_{VO} is tested at –10 V ≤ V_O ≤ 0 V, 0 V ≤ V_O ≤ +10 V, and –10 V ≤ V_O ≤ +10 V.

Specifications subject to change without notice.

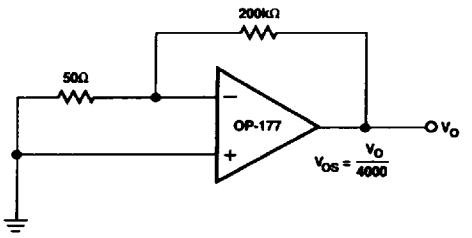


Figure 2. Typical Offset Voltage Test Circuit

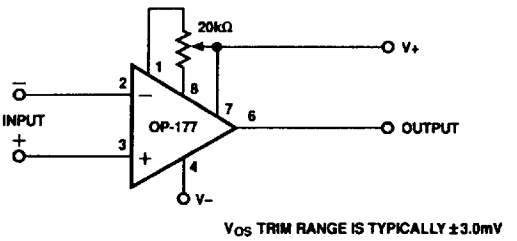


Figure 3. Optional Offset Nulling Circuit

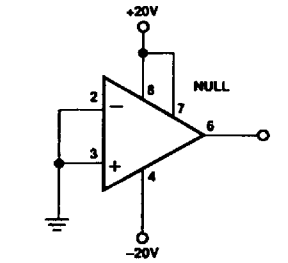


Figure 4. Burn-In Circuit

ABSOLUTE MAXIMUM RATINGS

Supply Voltage ..... ±22 V
Internal Power Dissipation[1] ..... 500 mW
Differential Input Voltage ..... ±30 V
Input Voltage ..... ±22 V
Output Short-Circuit Duration ..... Indefinite
Storage Temperature Range
  Z and RC Packages ..... –65°C to +150°C
  S, P Package ..... –65°C to +125°C
Operating Temperature Range
  OP177A, OP177B ..... –55°C to +125°C
  OP177E, OP177F, OP177G ..... –40°C to +85°C
Lead Temperature Range (Soldering, 60 sec) ..... +300°C
DICE Junction Temperature (T_J) ..... –65°C to +150°C

Package Type	θ_{JA}[2]	θ_{JC}	Units
8-Pin Hermetic DIP (Z)	148	16	°C/W
8-Pin Plastic DIP (P)	103	43	°C/W
20-Contact LCC (RC)	98	38	°C/W
8-Pin SO (S)	158	43	°C/W

NOTES
[1]For supply voltages less than ±22 V, the absolute maximum input voltage is equal to the supply voltage.
[2]θ_{JA} is specified for worst case mounting conditions, i.e., θ_{JA} is specified for device in socket for cerdip, P-DIP, and LCC packages; θ_{JA} is specified for device soldered to printed circuit board for SO package.

ORDERING GUIDE

Model	Temperature Range	Package Description	Package Option
OP177AZ	–55°C to +125°C	8-Pin Cerdip	Q-8
OP177BZ	–55°C to +125°C	8-Pin Cerdip	Q-8
OP177EZ	–40°C to +85°C	8-Pin Cerdip	Q-8
OP177FZ	–40°C to +85°C	8-Pin Cerdip	Q-8
OP177GZ	–40°C to +85°C	8-Pin Cerdip	Q-8
OP177FP	–40°C to +85°C	8-Pin Plastic DIP	N-8
OP177GP	–40°C to +85°C	8-Pin Plastic DIP	N-8
OP177BRC/883	–55°C to +125°C	20-Pin LCC	E-20A
OP177FS	–40°C to +85°C	8-Pin SO	SO-8
OP177GS	–40°C to +85°C	8-Pin SO	SO-8

OP177–Typical Performance Characteristics

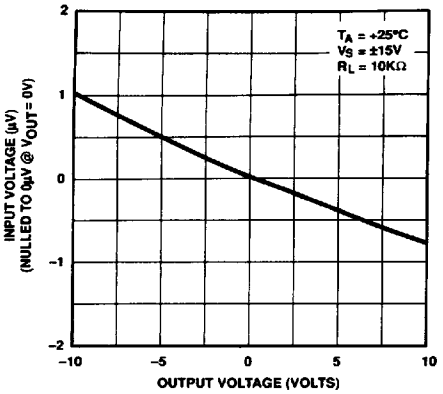


Figure 5. Gain Linearity (Input Voltage vs. Output Voltage)

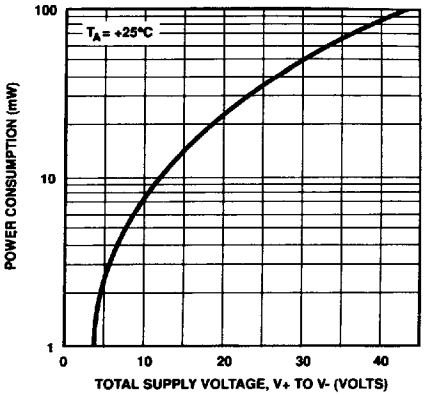


Figure 6. Power Consumption vs. Power Supply

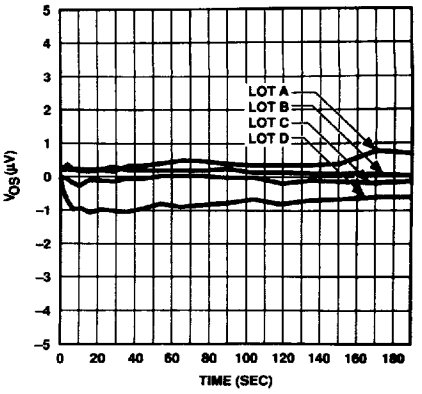


Figure 7. Warm-Up V_{OS} Drift (Normalized) Z Package

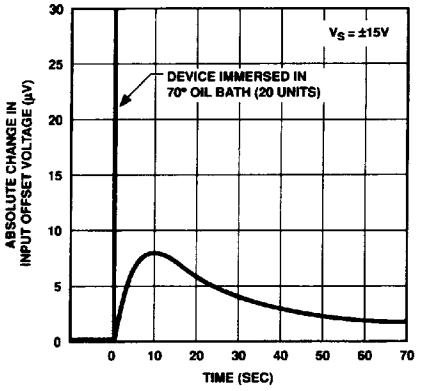


Figure 8. Offset Voltage Change Due to Thermal Shock

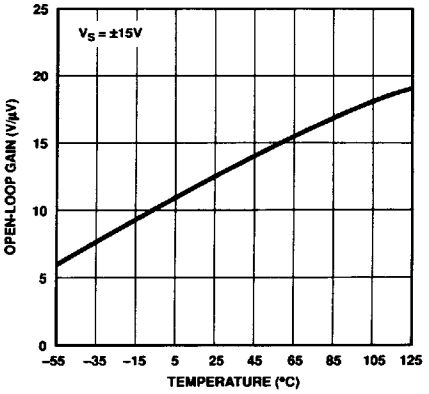


Figure 9. Open-Loop Gain vs. Temperature

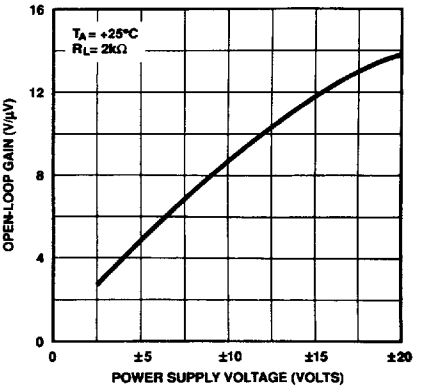


Figure 10. Open-Loop Gain vs. Power Supply Voltage

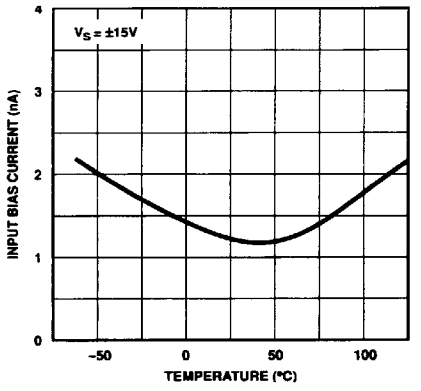


Figure 11. Input Bias Current vs. Temperature

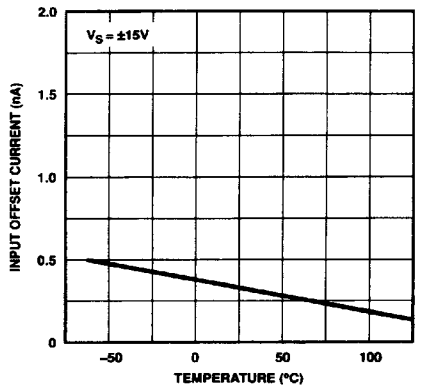


Figure 12. Input Offset Current vs. Temperature

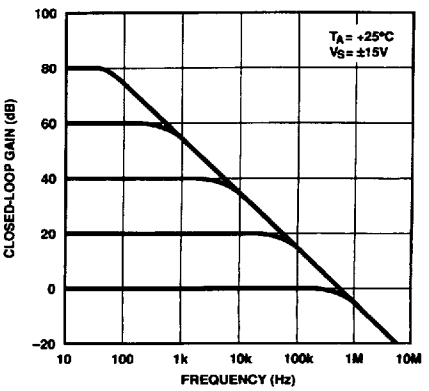


Figure 13. Closed-Loop Response for Various Gain Configurations

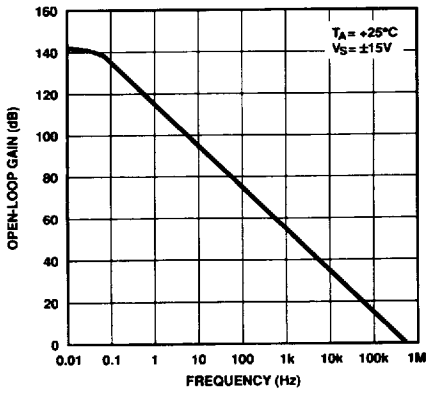


Figure 14. Open-Loop Frequency Response

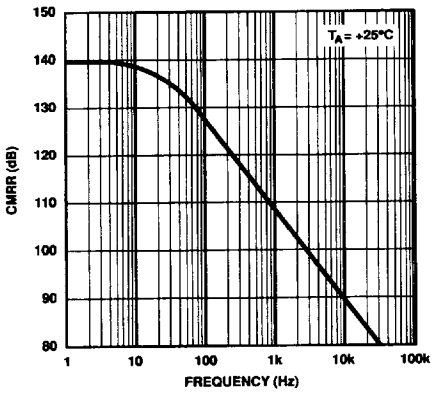


Figure 15. CMRR vs. Frequency

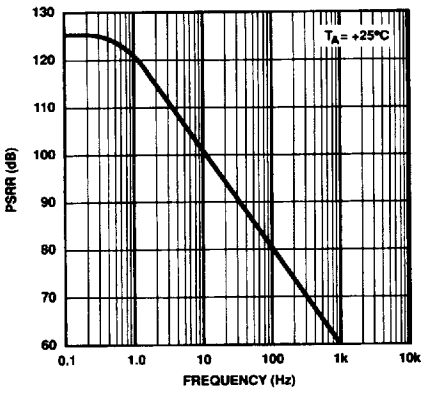


Figure 16. PSRR vs. Frequency

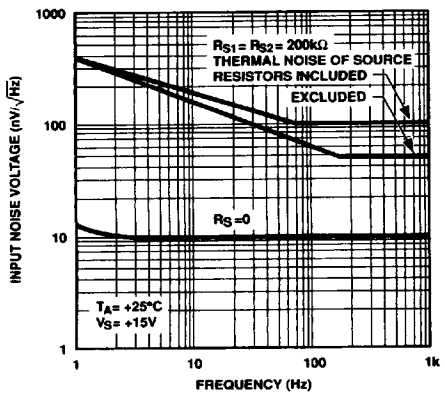


Figure 17. Total Input Noise Voltage vs. Frequency

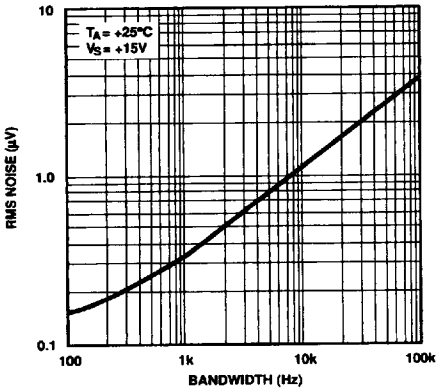


Figure 18. Input Wideband Noise vs. Bandwidth (0.1 Hz to Frequency Indicated)

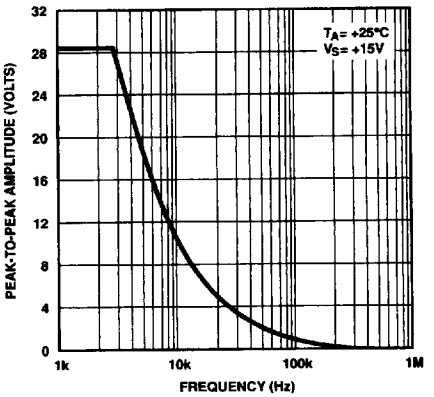


Figure 19. Maximum Output Swing vs. Frequency

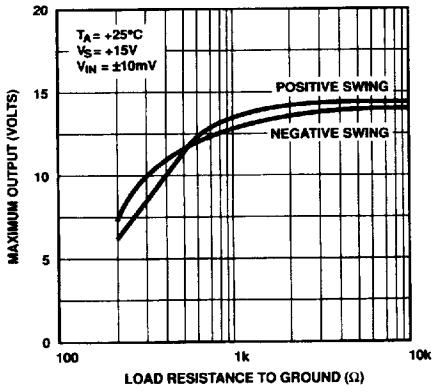


Figure 20. Maximum Output Voltage vs. Load Resistance

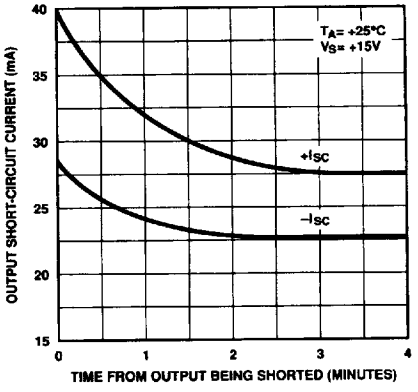


Figure 21. Output Short Circuit Current vs. Time

APPLICATIONS INFORMATION

Gain Linearity

The actual open-loop gain of most monolithic op amps varies at different output voltages. This nonlinearity causes errors in high closed-loop gain circuits.

It is important to know that the manufacturer's A_{VO} specification is only a part of the solution, since all automated testers use endpoint testing and, therefore, only show the average gain. For example, Figure 22 shows a typical precision op amp with a respectable open-loop gain of 650 V/mV. However, the gain is not constant through the output voltage range, causing nonlinear errors. An ideal op amp would show a horizontal scope trace.

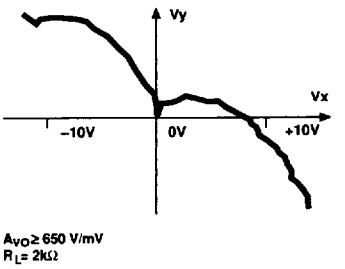


Figure 22. Typical Precision Op Amp

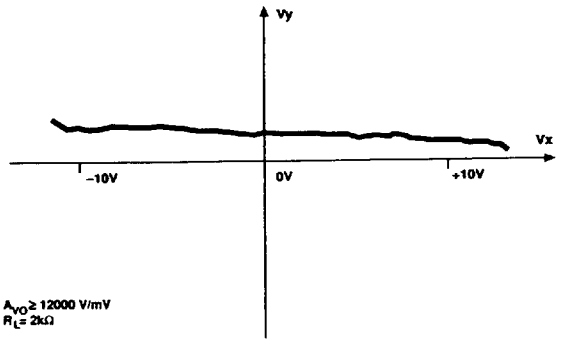


Figure 23. OP177's Output Gain Linearity Trace

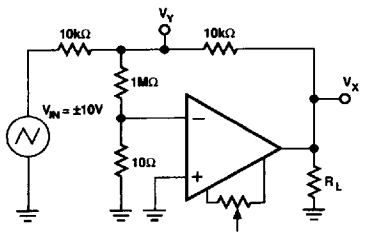


Figure 24. Open-Loop Gain Linearity Test Circuit

Figure 23 shows the OP177's output gain linearity trace with its truly impressive average A_{VO} of 12000 V/mV. The output trace is virtually horizontal at all points, assuring extremely high gain accuracy. PMI also performs additional testing to insure consistent high open-loop gain at various output voltages.

Figure 24 is a simple open-loop gain test circuit for your own evaluation.

THERMOCOUPLE AMPLIFIER WITH COLD-JUNCTION COMPENSATION

An example of a precision circuit is a thermocouple amplifier that must amplify very low level signals accurately without introducing linearity and offset errors to the circuit. In this circuit, an S-type thermocouple, which has a Seebeck coefficient of 10.3 µV/°C, produces 10.3 mV of output voltage at a temperature of 1,000°C. The amplifier gain is set at 973.16. Thus, it will produce an output voltage of 10.024 V. Extended temperature ranges to beyond 1,500°C can be accomplished by reducing the amplifier gain. The circuit uses a low-cost diode to sense the temperature at the terminating junctions and in turn compensates for any ambient temperature change. The OP177, with its high open-loop gain, plus low offset voltage and drift combines to yield a very precision temperature sensing circuit. Circuit values for other thermocouple types are shown in Table I.

Table I.

Thermocouple Type	Seebeck Coefficient	R1	R2	R7	R9
K	39.2 µV/°C	110 Ω	5.76 kΩ	102 kΩ	269 kΩ
J	50.2 µV/°C	100 Ω	4.02 kΩ	80.6 kΩ	200 kΩ
S	10.3 µV/°C	100 Ω	20.5 kΩ	392 kΩ	1.07 MΩ

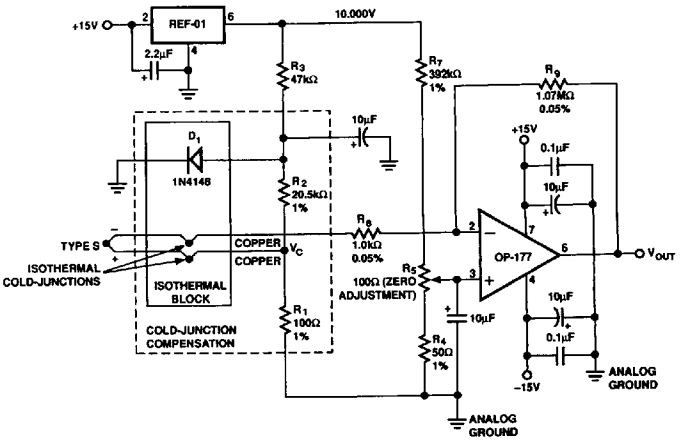


Figure 25. Thermocouple Amplifier with Cold Junction Compensation

PRECISION HIGH GAIN DIFFERENTIAL AMPLIFIER

The high gain, gain linearity, CMRR, and low TCV_{OS} of the OP177 make it possible to obtain performance not previously available in single stage, very high-gain amplifier applications. See Figure 26.

For best CMR, $\frac{R1}{R2}$ must equal $\frac{R3}{R4}$. In this example, with a 10 mV differential signal, the maximum errors are as listed in Table II.

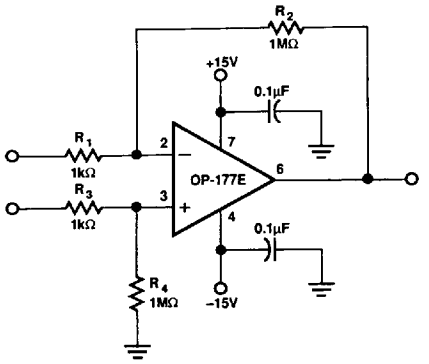


Figure 26. Precision High Gain Differential Amplifier

Table II. High Gain Differential Amp Performance

Type	Amount
Common-Mode Voltage	0.1%/V
Gain Linearity, Worst Case	0.02%
TCV_{OS}	0.0003%/°C
TCI_{OS}	0.008%/°C

ISOLATING LARGE CAPACITIVE LOADS

The circuit in Figure 27 reduces maximum slew-rate but allows driving capacitive loads of any size without instability. Because the 100 Ω resistor is inside the feedback loop, its effect on output impedance is reduced to insignificance by the high open-loop gain of the OP177.

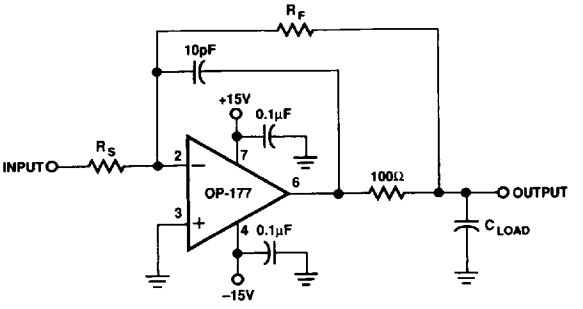


Figure 27. Isolating Capacitive Loads

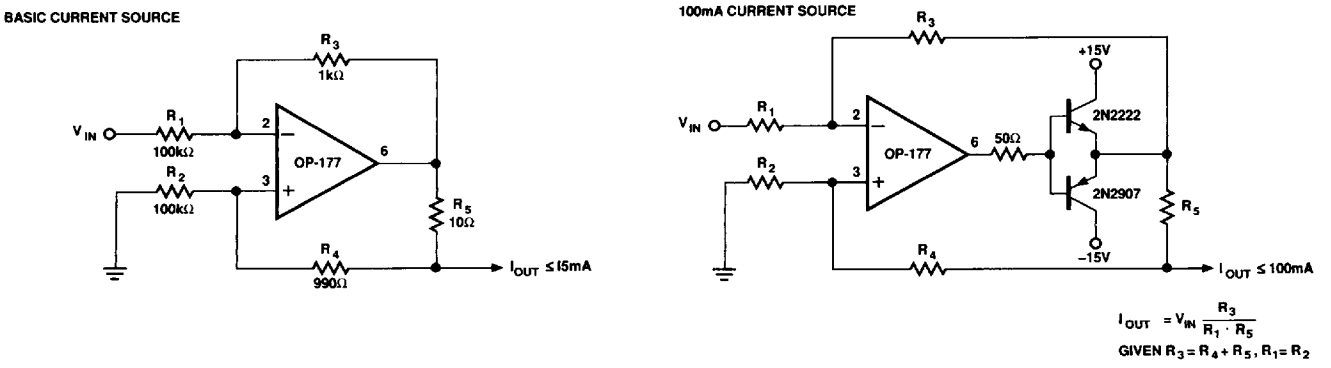


Figure 28. Bilateral Current Source

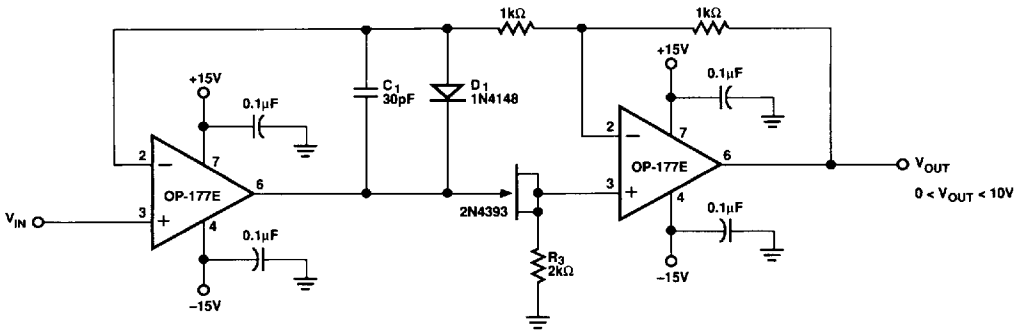


Figure 29. Precision Absolute Value Amplifier

BILATERAL CURRENT SOURCE

The current sources shown in Figure 28 will supply both positive and negative current into a grounded load.

Note that $Z_O = \dfrac{R5\left(\dfrac{R4}{R2}+1\right)}{\dfrac{R5+R4}{R2}-\dfrac{R3}{R1}}$

and that for Z_O to be infinite,

$$\frac{R5+R4}{R2} \text{ must} = \frac{R3}{R1}$$

PRECISION ABSOLUTE VALUE AMPLIFIER

The high gain and low TCV_{OS} assure accurate operation with inputs from microvolts to volts. In this circuit, the signal always appears as a common-mode signal to the op amps. The OP177E CMRR of 140 dB assures errors of less than 1 ppm. See Figure 29.

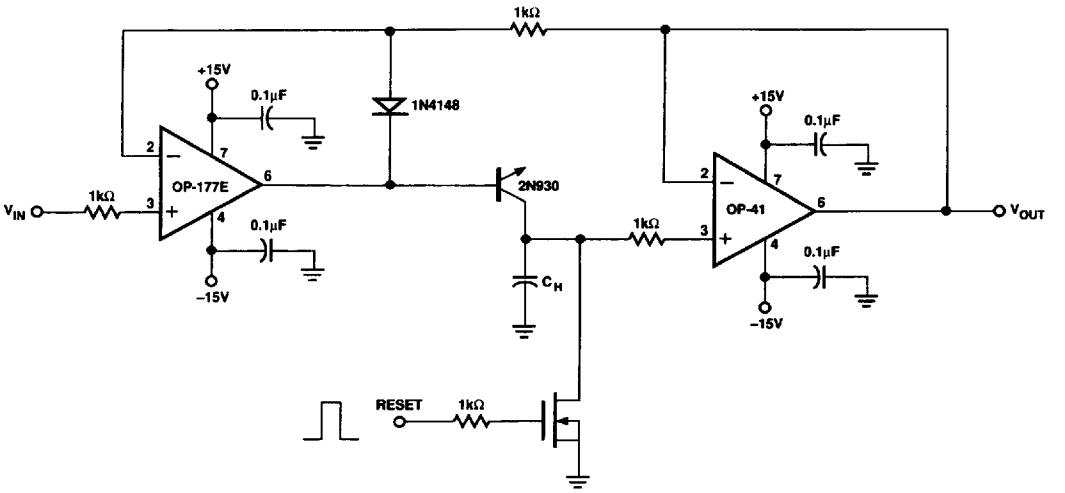


Figure 30. Precision Positive Peak Detector

PRECISION POSITIVE PEAK DETECTOR

In Figure 30, the C_H must be of polystyrene, Teflon*, or polyethylene to minimize dielectric absorption and leakage. The droop rate is determined by the size of C_H and the bias current of the OP41.

PRECISION THRESHOLD DETECTOR/AMPLIFIER

In Figure 32, when $V_{IN} < V_{TH}$, amplifier output swings negative, reverse biasing diode D_1. $V_{OUT} = V_{TH}$ if $R_L = \infty$. When $V_{IN} \geq V_{TH}$, the loop closes,

$$V_{OUT} = V_{TH} + \left(V_{IN} - V_{TH}\right)\left(1+\frac{R_F}{R_S}\right)$$

C_C is selected to smooth the response of the loop.

*Teflon is a registered trademark of the Dupont Company.

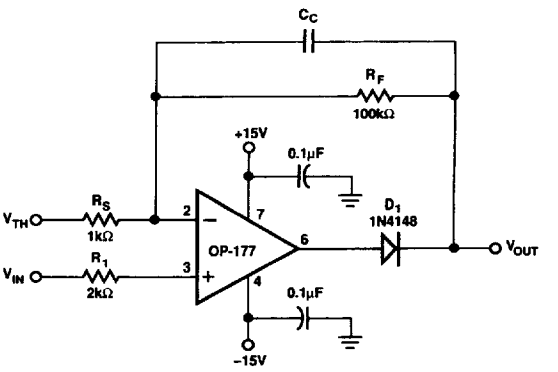
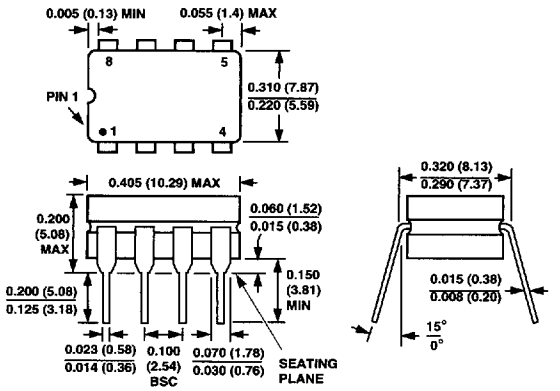


Figure 31. Precision Threshold Detector/Amplifier

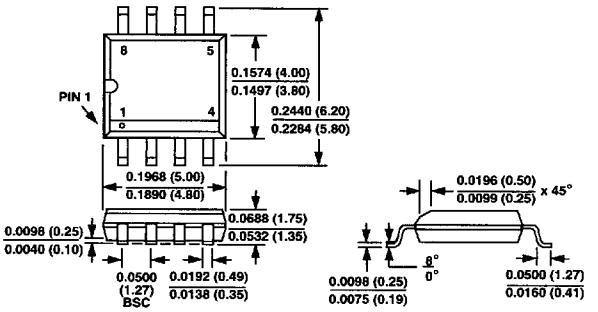
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

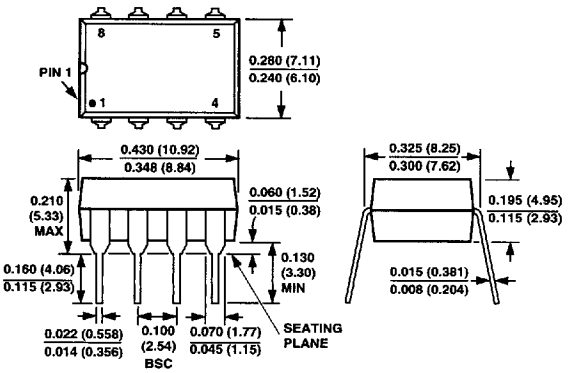
8-Pin Cerdip (Q-8)



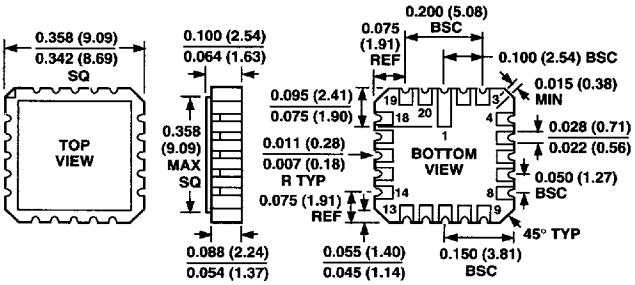
8-Pin SO (SO-08)



8-Pin Plastic DIP (N-8)



20-Pin LCC (E-20A)



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