ANALOG DEVICES

Dual Low Bias Current Precision Operational Amplifier

OP-297

FEATURES

- **Precision Performance in Standard SO-8 Pinout**
- **Low Offset Voltage** .... **50μV Max**
- **Low Offset Voltage Drift** .... **0.6μV/°C Max**
- **Very Low Bias Current**
  +25°C .... **100pA Max**
  –55°C to +125°C .... **450pA Max**
- **Very High Open-Loop Gain** .... **2000V/mV Min**
- **Low Supply Current (Per Amplifier)** .... **625μA Max**
- **Operates From ±2V to ±20V Supplies**
- **High Common-Mode Rejection** .... **120dB Min**
- **Pin Compatible to LT1013, AD706, AD708, OP-221, LM158, and MC1458/1558 with Improved Performance**
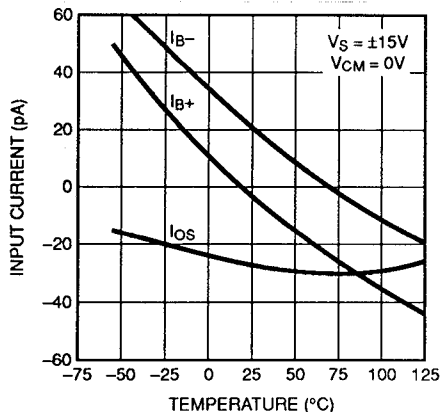
APPLICATIONS

- **Strain Guage and Bridge Amplifiers**
- **High Stability Thermocouple Amplifiers**
- **Instrumentation Amplifiers**
- **Photo-Current Monitors**
- **High-Gain Linearity Amplifiers**
- **Long-Term Integrators/Filters**
- **Sample-and-Hold Amplifiers**
- **Peak Detectors**
- **Logarithmic Amplifiers**
- **Battery-Powered Systems**

GENERAL DESCRIPTION

The OP-297 is the first dual op amp to pack precision performance into the space-saving, industry standard 8-pin SO package. Its combination of precision with low power and extremely low input bias current makes the dual OP-297 useful in a wide variety of applications.
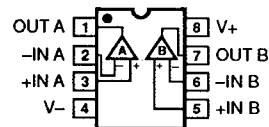
Precision performance of the OP-297 includes very low offset, under 50μV, and low drift, below 0.6μV/°C. Open-loop gain exceeds 2000V/mV insuring high linearity in every application. Errors due to common-mode signals are eliminated by the OP-297's common-mode rejection of over 120dB. The OP-297's power supply rejection of over 120dB minimizes offset voltage changes experienced in battery powered systems. Supply current of the OP-297 is under 625μA per amplifier and it can operate with supply voltages as low as ±2V. *Continued*

PIN CONNECTIONS
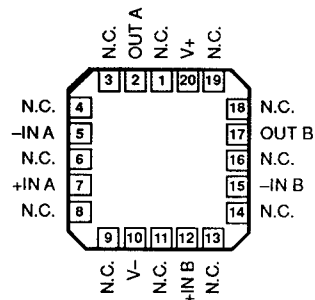

OUT A [1] V+ [8]
–IN A [2] A B OUT B [7]
+IN A [3] –IN B [6]
V– [4] +IN B [5]

PLASTIC MINI-DIP (P-Suffix)

8-PIN CERDIP (Z-Suffix)

8-PIN SO (S-Suffix)
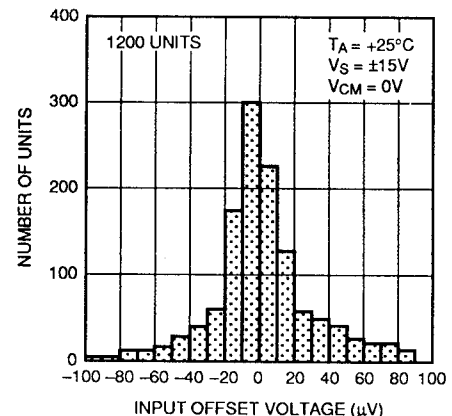
N.C. [4] N.C. [18]
–IN A [5] OUT B [17]
N.C. [6] N.C. [16]
+IN A [7] –IN B [15]
N.C. [8] N.C. [14]

LCC (RC-Suffix)

LOW BIAS CURRENT OVER TEMPERATURE

TEMPERATURE (°C)

VERY LOW OFFSET

INPUT OFFSET VOLTAGE (μV)

OP-297

GENERAL DESCRIPTION *Continued*

The OP-297 utilizes a super-beta input stage with bias current cancellation to maintain picoamp bias currents at all temperatures. This is in contrast to FET input op amps whose bias currents start in the picoamp range at 25°C, but double for every 10°C rise in temperature, to reach the nanoamp range above 85°C. Input bias current of the OP-297 is under 100pA at 25°C and is under 450pA over the military temperature range.

Combining precision, low power and low bias current, the OP-297 is ideal for a number of applications including instrumentation amplifiers, log amplifiers, photo-diode preamplifiers and long-term integrators. For a single device, see the OP-97; for a quad, see the OP-497.

ORDERING INFORMATION†

$T_A = +25°C$ V_{OS} MAX (µV)	PACKAGE			OPERATING TEMPERATURE RANGE
	CERDIP 8-PIN	PLASTIC 8-PIN	LCC 20-CONTACT	
50	OP297AZ/883*	—	OP297ARC/883*	MIL
50	OP297AZ	—	—	MIL
50	OP297EZ	—	—	MIL
100	OP297FZ	OP297FP	—	XIND
200	—	OP297GP	—	XIND
200	—	OP297GS††	—	XIND

* For devices processed in total compliance to MIL-STD-883, add /883 after part number. Consult factory for 883 data sheet.

† Burn-in is available on extended industrial temperature range parts in CerDIP, and plastic DIP packages. For ordering information, see PMI's Data Book, Section 2.

†† For availability and burn-in information on SO packages, contact your local sales office.

ABSOLUTE MAXIMUM RATINGS (Note 1)

Supply Voltage .... ±20V
Input Voltage (Note 2) .... ±20V
Differential Input Voltage (Note 2) 40V
Output Short-Circuit Duration .... Indefinite
Storage Temperature Range
  Z, RC-Package .... −65°C to +175°C
  P, S-Package .... −65°C to 150°C
Operating Temperature Range
  OP-297A (Z, RC) .... −55°C to +125°C
  OP-297E, F (Z) .... −40°C to +85°C
  OP-297F, G (P, S) .... −40°C to +85°C
Junction Temperature
  Z, RC-Package .... −65°C to +175°C
  P, S-Package .... −65°C to +150°C
Lead Temperature Range (Soldering, 60 sec) .... 300°C

PACKAGE TYPE	Θ_{jA} (Note 3)	Θ_{jC}	UNITS
8-Pin CerDIP (Z)	134	12	°C/W
8-Pin Plastic DIP (P)	96	37	°C/W
20-Contact LCC (RC)	88	33	°C/W
8-Pin SO (S)	150	41	°C/W

NOTES:
1. Absolute maximum ratings apply to both DICE and packaged parts, unless otherwise noted.
2. For supply voltages less than ±20V, the absolute maximum input voltage is equal to the supply voltage.
3. 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.

ELECTRICAL CHARACTERISTICS at $V_S = ±15V$, $T_A = +25°C$, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-297A/E			OP-297F			OP-297G			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	V_{OS}		–	25	50	–	50	100	–	80	200	µV
Long-Term Input Voltage Stability			–	0.1	–	–	0.1	–	–	0.1	–	µV/mo
Input Offset Current	I_{OS}	$V_{CM} = 0V$	–	20	100	–	35	150	–	50	200	pA
Input Bias Current	I_B	$V_{CM} = 0V$	–	20	±100	–	35	±150	–	50	±200	pA
Input Noise Voltage	$e_{n\,p-p}$	0.1Hz to 10Hz	–	0.5	–	–	0.5	–	–	0.5	–	µV$_{p-p}$
Input Noise Voltage Density	e_n	$f_O = 10Hz$ $f_O = 1000Hz$	– –	20 17	– –	– –	20 17	– –	– –	20 17	– –	nV/$\sqrt{Hz}$
Input Noise Current Density	i_n	$f_O = 10Hz$	–	20	–	–	20	–	–	20	–	fA/$\sqrt{Hz}$
Input Resistance Differential Mode	R_{IN}		–	30	–	–	30	–	–	30	–	MΩ
Input Resistance Common-Mode	R_{INCM}		–	500	–	–	500	–	–	500	–	GΩ
Large-Signal Voltage Gain	A_{VO}	$V_O = ±10V$ $R_L = 2kΩ$	2000	4000	–	1500	3200	–	1200	3200	–	V/mV

REV. B

ELECTRICAL CHARACTERISTICS at $V_S = \pm15V$, $T_A = +25°C$, unless otherwise noted. *Continued*

PARAMETER	SYMBOL	CONDITIONS	OP-297A/E			OP-297F			OP-297G			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Input Voltage Range	IVR	(Note 1)	±13	±14	–	±13	±14	–	±13	±14	–	V
Common-Mode Rejection	CMR	$V_{CM} = \pm13V$	120	140	–	114	135	–	114	135	–	dB
Power Supply Rejection	PSR	$V_S = \pm2V$ to ±20V	120	130	–	114	125	–	114	125	–	dB
Output Voltage Swing	V_O	$R_L = 10k\Omega$	±13	±14	–	±13	±14	–	±13	±14	–	V
		$R_L = 2k\Omega$	±13	±13.7	–	±13	±13.7	–	±13	±13.7	–	
Supply Current Per Amplifier	I_{SY}	No Load	–	525	625	–	525	625	–	525	625	µA
Supply Voltage	V_S	Operating Range	±2	–	±20	±2	–	±20	±2	–	±20	V
Slew Rate	SR		0.05	0.15	–	0.05	0.15	–	0.05	0.15	–	V/µs
Gain Bandwith Product	GBWP	$A_V = +1$	–	500	–	–	500	–	–	500	–	kHz
Channel Separation	CS	$V_O = 20V_{p-p}$ $f_O = 10Hz$	–	150	–	–	150	–	–	150	–	dB
Input Capacitance	C_{IN}		–	3	–	–	3	–	–	3	–	pF

NOTE:
1. Guaranteed by CMR test.

ELECTRICAL CHARACTERISTICS at $V_S = \pm15V$, $-55°C \leq T_A \leq +125°C$ for OP-297A, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-297A			UNITS
			MIN	TYP	MAX	
Input Offset Voltage	V_{OS}		–	45	100	µV
Average Input Offset Voltage Drift	TCV_{OS}		–	0.2	0.6	µV/°C
Input Offset Current	I_{OS}	$V_{CM} = 0V$	–	60	450	pA
Input Bias Current	I_B	$V_{CM} = 0V$	–	60	±450	pA
Large-Signal Voltage Gain	A_{VO}	$V_O = \pm10V$, $R_L = 2k\Omega$	1200	2700	–	V/mV
Input Voltage Range	IVR	(Note 1)	±13	±13.5	–	V
Common-Mode Rejection	CMR	$V_{CM} = \pm13$	114	130	–	dB
Power Supply Rejection	PSR	$V_S = \pm2.5V$ to ±20V	114	125	–	dB
Output Voltage Swing	V_O	$R_L = 10k\Omega$	±13	±13.4	–	V
Supply Current Per Amplifier	I_{SY}	No Load	–	575	750	µA
Supply Voltage	V_S	Operating Range	±2.5	–	±20	V

NOTE:
1. Guaranteed by CMR test.

OP-297

ELECTRICAL CHARACTERISTICS at $V_S = \pm15V$, $-40°C \le T_A \le +85°C$ for OP-297E/F/G, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-297E			OP-297F			OP-297G			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Input Offset Voltage	V_{OS}		–	35	100	–	80	300	–	110	400	µV
Average Input Offset Voltage Drift	TCV_{OS}		–	0.2	0.6	–	0.5	2.0	–	0.6	2.0	µV/°C
Input Offset Current	I_{OS}	$V_{CM} = 0V$	–	50	450	–	80	750	–	80	750	pA
Input Bias Current	I_B	$V_{CM} = 0V$	–	50	±450	–	80	±750	–	80	±750	pA
Large-Signal Voltage Gain	A_{VO}	$V_O = \pm10V$, $R_L = 2k\Omega$	1200	3200	–	1000	2500	–	800	2500	–	V/mV
Input Voltage Range	IVR	(Note 1)	±13	±13.5	–	±13	±13.5	–	±13	±13.5	–	V
Common-Mode Rejection	CMR	$V_{CM} = \pm13V$	114	130	–	108	130	–	108	130	–	dB
Power Supply Rejection	PSR	$V_S = \pm2.5V$ to $\pm20V$	114	0.15	–	108	0.15	–	108	0.3	–	dB
Output Voltage Swing	V_O	$R_L = 10k\Omega$	±13	±13.4	–	±13	±13.4	–	±13	±13.4	–	V
Supply Current Per Amplifier	I_{SY}	No Load	–	550	750	–	550	750	–	550	750	µA
Supply Voltage	V_S	Operating Range	±2.5	–	±20	±2.5	–	±20	±2.5	–	±20	V

NOTE:
1. Guaranteed by CMR test.

CHANNEL SEPARATION TEST CIRCUIT

$$\text{CHANNEL SEPARATION} = 20 \log\left(\frac{V_1}{V_2/10000}\right)$$

–4–

REV. B
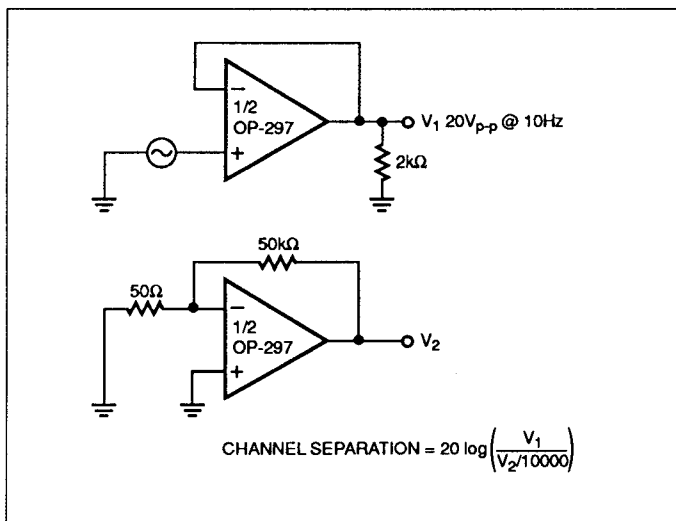
DICE CHARACTERISTICS
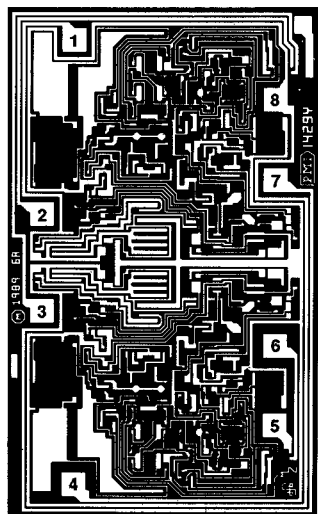
1. OUT A
2. –IN A
3. +IN A
4. V–
5. +IN B
6. –IN B
7. OUT B
8. V+

For additional DICE information, refer to PMI's Data Book, Section 2.

DIE SIZE 0.071 x 0.114 inch, 8,094 sq. mils
(1.80 x 2.90 mm, 5.22 sq. mm)

WAFER TEST LIMITS at $V_S = \pm15V$, $T_A = +25°C$, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-297GBC LIMIT	UNITS
Input Offset Voltage	V_{OS}		200	µV MAX
Input Offset Current	I_{OS}	$V_{CM} = 0V$	200	pA MAX
Input Bias Current	I_B	$V_{CM} = 0V$	±200	pA MAX
Large-Signal Voltage Gain	A_{VO}	$V_O = \pm10V$, $R_L = 2k\Omega$	1200	V/mV MIN
Input Voltage Range	IVR	(Note 1)	±13	V MIN
Common-Mode Rejection	CMR	$V_{CM} = \pm13V$	114	dB MIN
Power Supply Rejection	PSR	$V_S = \pm2V$ to $\pm18V$	114	dB MIN
Output Voltage Swing	V_O	$R_L = 10k\Omega$ $R_L = 2k\Omega$	±13 ±13	V MIN
Supply Current Per Amplifier	I_{SY}	No Load	625	µA MAX

NOTES:
1. Guaranteed by CMR test.
Electrical tests are performed at wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualifications through sample lot assembly and testing.

OP-297

TYPICAL PERFORMANCE CHARACTERISTICS

TYPICAL DISTRIBUTION OF INPUT OFFSET VOLTAGE

1200 UNITS

$T_A = +25°C$
$V_S = ±15V$
$V_{CM} = 0V$

NUMBER OF UNITS

INPUT OFFSET VOLTAGE (µV)
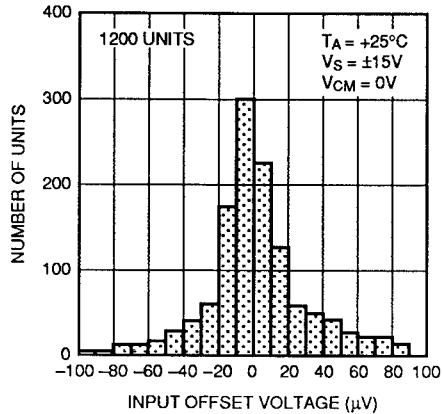
TYPICAL DISTRIBUTION OF INPUT BIAS CURRENT

1200 UNITS

$T_A = +25°C$
$V_S = ±15V$
$V_{CM} = 0V$

NUMBER OF UNITS

INPUT BIAS CURRENT (pA)

TYPICAL DISTRIBUTION OF INPUT OFFSET CURRENT

1200 UNITS

$T_A = +25°C$
$V_S = ±15V$
$V_{CM} = 0V$

NUMBER OF UNITS
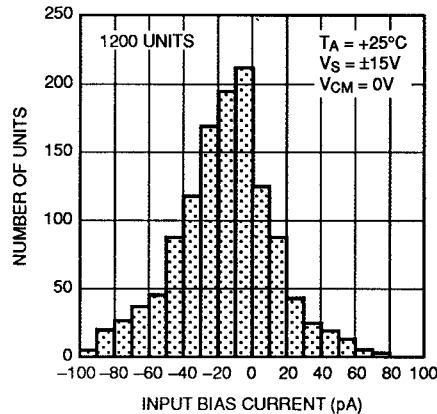
INPUT OFFSET CURRENT (pA)
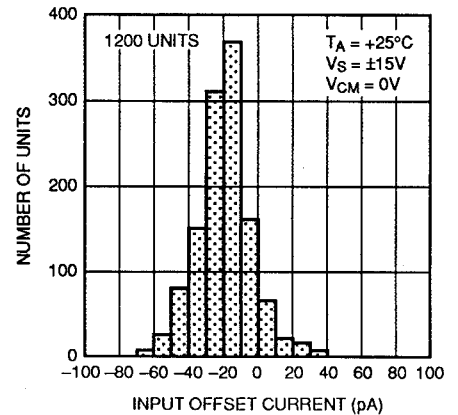
INPUT BIAS, OFFSET CURRENT vs TEMPERATURE

I_{B-}
I_{B+}
I_{OS}

$V_S = ±15V$
$V_{CM} = 0V$

INPUT CURRENT (pA)
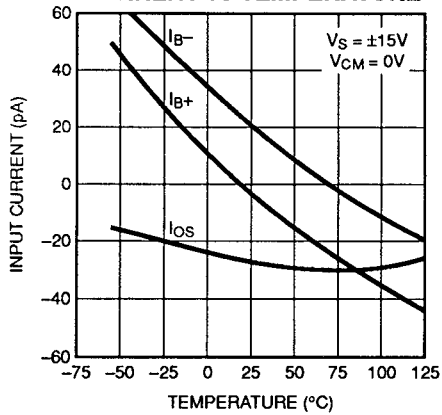
TEMPERATURE (°C)

INPUT-BIAS, OFFSET CURRENT vs COMMON-MODE VOLTAGE

$T_A = +25°C$
$V_S = ±15V$

I_{B-}
I_{B+}
I_{OS}

INPUT CURRENT (pA)

COMMON-MODE VOLTAGE (VOLTS)
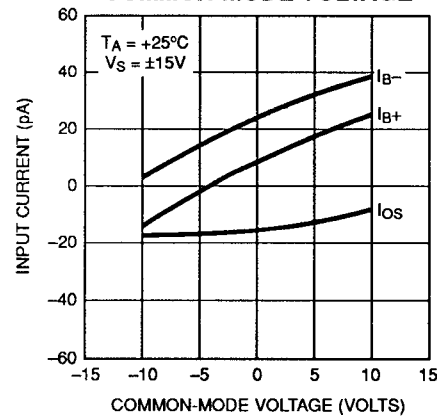
INPUT OFFSET VOLTAGE WARM-UP DRIFT

$T_A = +25°C$
$V_S = ±15V$
$V_{CM} = 0V$

DEVIATION FROM FINAL VALUE (µV)

TIME AFTER POWER APPLIED (MINUTES)
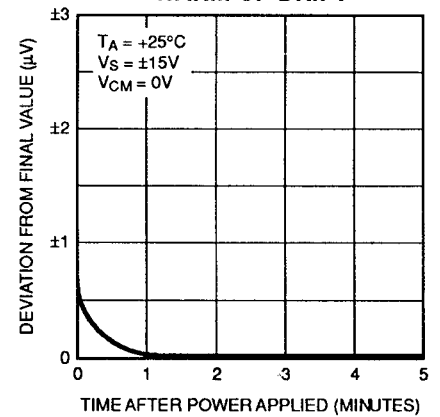
EFFECTIVE OFFSET VOLTAGE vs SOURCE RESISTANCE

BALANCED OR UNBALANCED
$V_S = ±15V$
$V_{CM} = 0V$

$-55°C ≤ T_A ≤ 125°C$

$T_A = +25°C$

EFFECTIVE OFFSET VOLTAGE (µV)

SOURCE RESISTANCE (Ω)
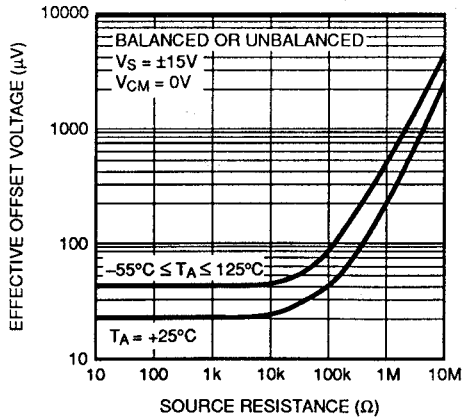
EFFECTIVE TCV$_{OS}$ vs SOURCE RESISTANCE

BALANCED OR UNBALANCED
$V_S = ±15V$
$V_{CM} = 0V$

EFFECTIVE OFFSET VOLTAGE DRIFT (µV/°C)

SOURCE RESISTANCE (Ω)
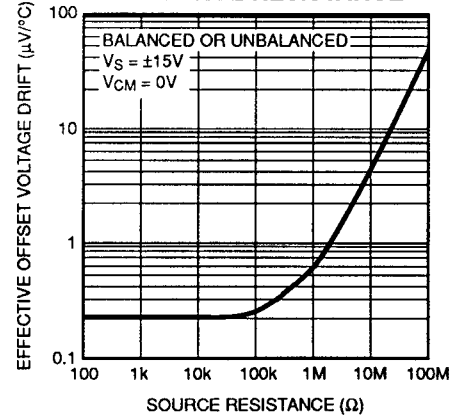
SHORT-CIRCUIT CURRENT vs TIME, TEMPERATURE

$T_A = -55°C$
$T_A = +25°C$
$T_A = +125°C$

$V_S = ±15V$
OUTPUT SHORTED
TO GROUND

$T_A = +125°C$
$T_A = +25°C$
$T_A = -55°C$

SHORT-CIRCUIT CURRENT (mA)

TIME FROM OUTPUT SHORT (MINUTES)

–6–
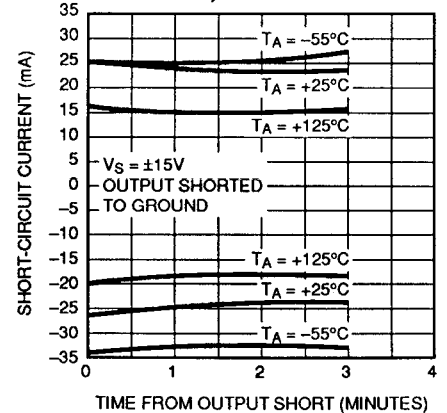
TYPICAL PERFORMANCE CHARACTERISTICS *Continued*

TOTAL SUPPLY CURRENT vs SUPPLY VOLTAGE
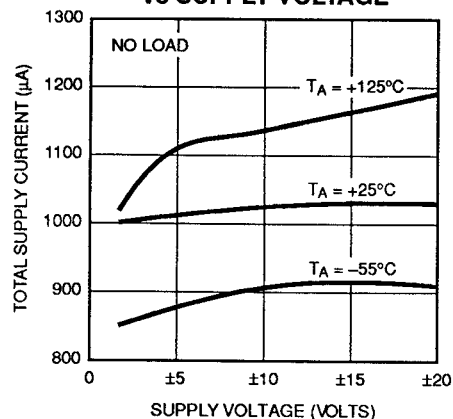
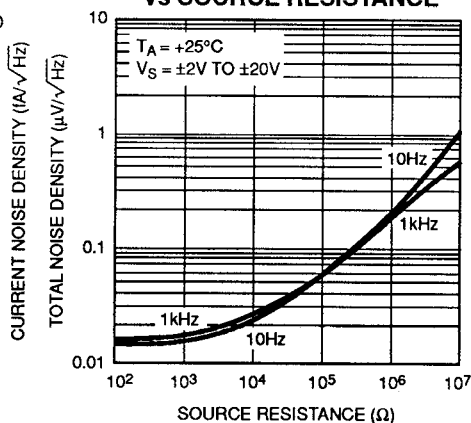### COMMON-MODE REJECTION vs FREQUENCY
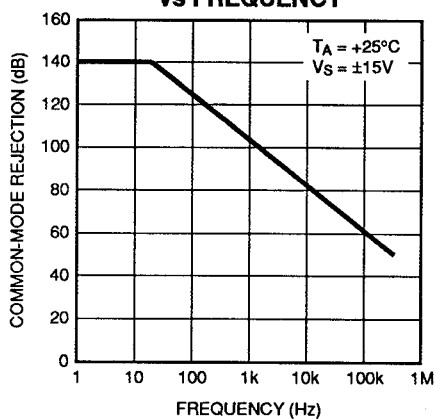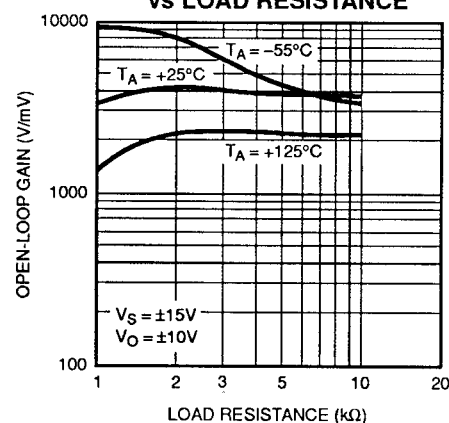
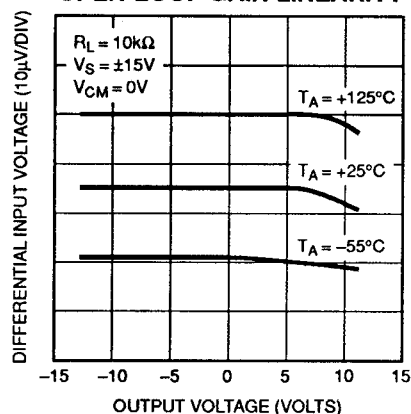### POWER SUPPLY REJECTION vs FREQUENCY
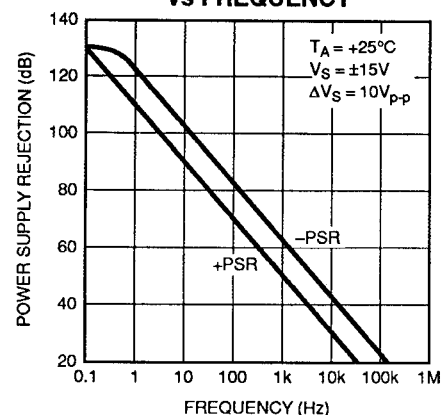
NOISE DENSITY vs FREQUENCY
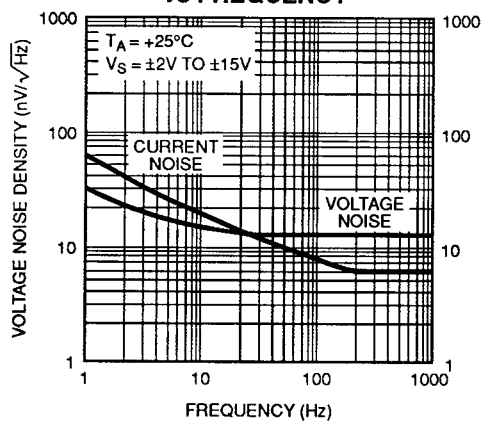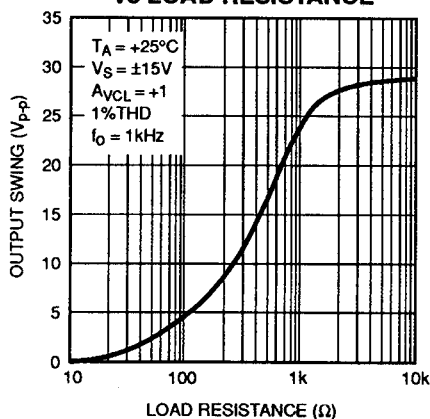
TOTAL NOISE DENSITY vs SOURCE RESISTANCE
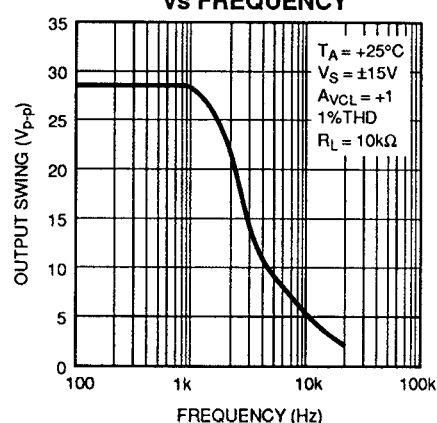
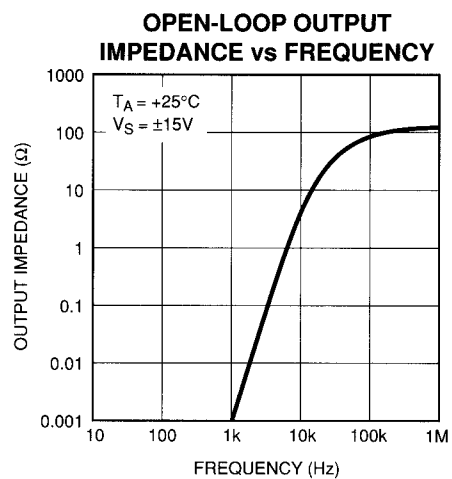### OPEN-LOOP GAIN vs LOAD RESISTANCE
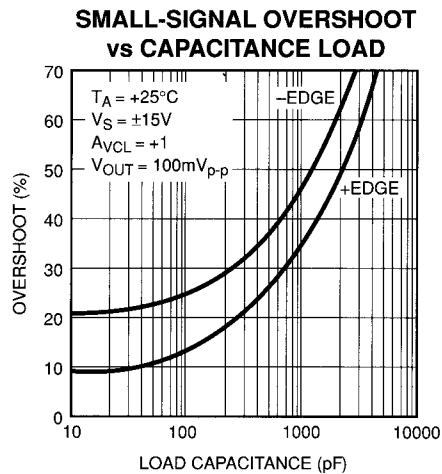
OPEN-LOOP GAIN LINEARITY

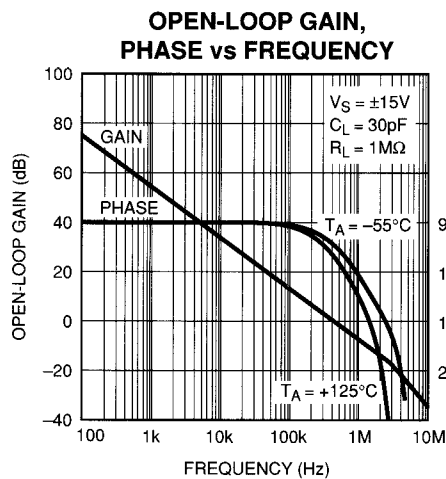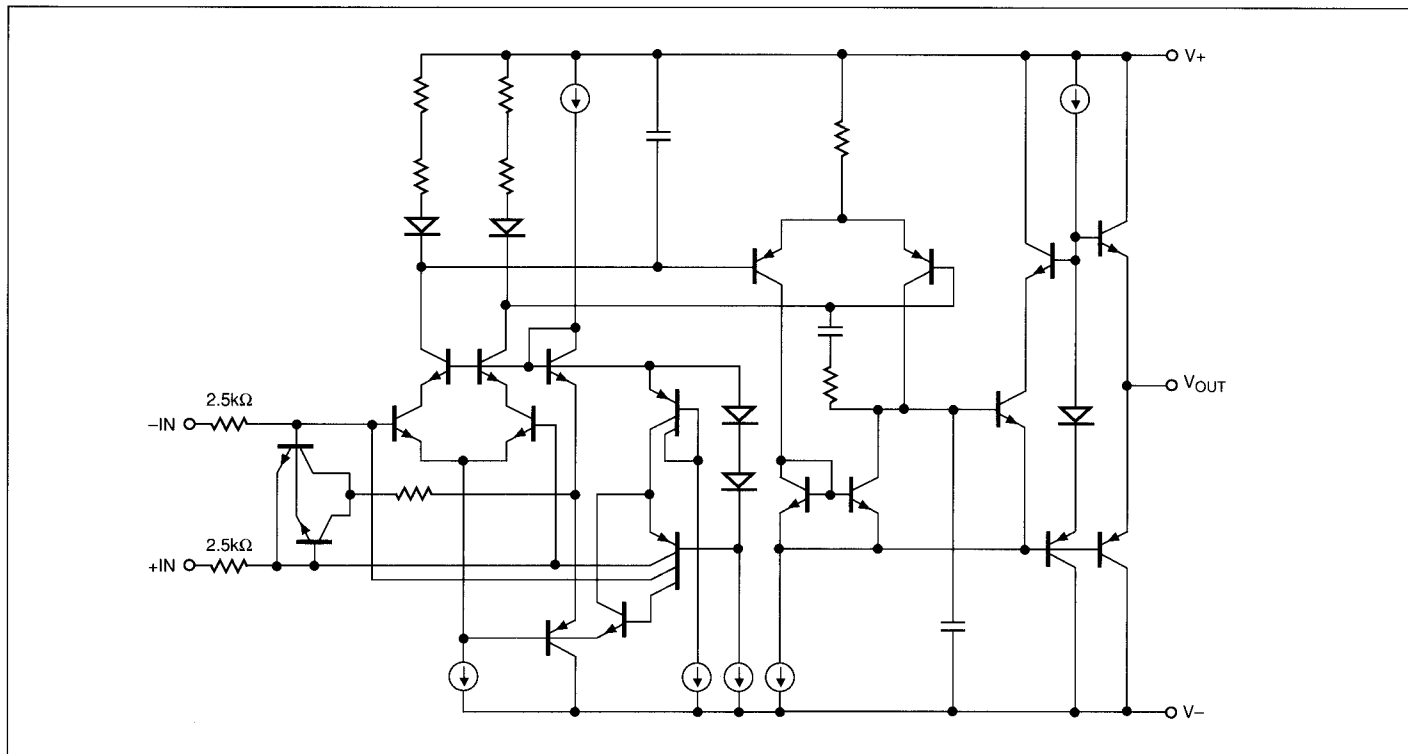### MAXIMUM OUTPUT SWING vs LOAD RESISTANCE

MAXIMUM OUTPUT SWING vs FREQUENCY

OP-297

TYPICAL PERFORMANCE CHARACTERISTICS Continued

OPEN-LOOP GAIN, PHASE vs FREQUENCY

$V_S = \pm15V$
$C_L = 30pF$
$R_L = 1M\Omega$

GAIN

PHASE

$T_A = -55°C$

$T_A = +125°C$

OPEN-LOOP GAIN (dB)

PHASE SHIFT (DEG)

FREQUENCY (Hz)

SMALL-SIGNAL OVERSHOOT vs CAPACITANCE LOAD

$T_A = +25°C$
$V_S = \pm15V$
$A_{VCL} = +1$
$V_{OUT} = 100mV_{p-p}$

−EDGE

+EDGE

OVERSHOOT (%)

LOAD CAPACITANCE (pF)

OPEN-LOOP OUTPUT IMPEDANCE vs FREQUENCY

$T_A = +25°C$
$V_S = \pm15V$

OUTPUT IMPEDANCE (Ω)

FREQUENCY (Hz)

SIMPLIFIED SCHEMATIC (One Amplifier is Shown)

V+

V_OUT

V−

−IN

+IN

2.5kΩ

2.5kΩ

APPLICATIONS INFORMATION

Extremely low bias current over the full military temperature range makes the OP-297 attractive for use in sample-and-hold amplifiers, peak detectors, and log amplifiers that must operate over a wide temperature range. Balancing input resistances is not necessary with the OP-297. Offset voltage and TCV_{OS} are degraded only minimally by high source resistance, even when unbalanced.

The input pins of the OP-297 are protected against large differential voltage by back-to-back diodes and current-limiting resistors. Common-mode voltages at the inputs are not restricted, and may vary over the full range of the supply voltages used.

The OP-297 requires very little operating headroom about the supply rails, and is specified for operation with supplies as low as ±2V. Typically, the common-mode range extends to within one volt of either rail. The output typically swings to within one volt of the rails when using a 10kΩ load.

AC PERFORMANCE

The OP-297'S AC characteristics are highly stable over its full operating temperature range. Unity-gain small-signal response is shown in Figure 1. Extremely tolerant of capacitive loading on the output, the OP-297 displays excellent response even with 1000pF loads (Figure 2).
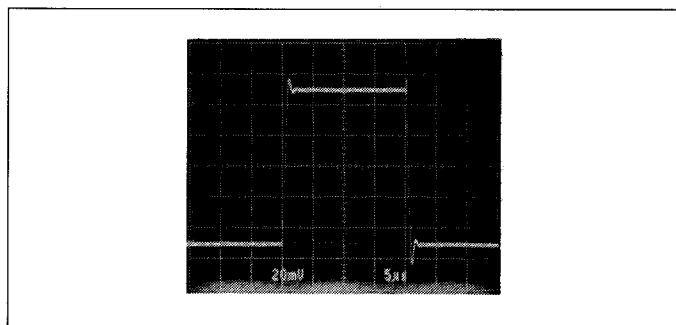
FIGURE 1: *Small-Signal Transient Response*
*(C_{LOAD} = 100pF, A_{VCL} = +1)*
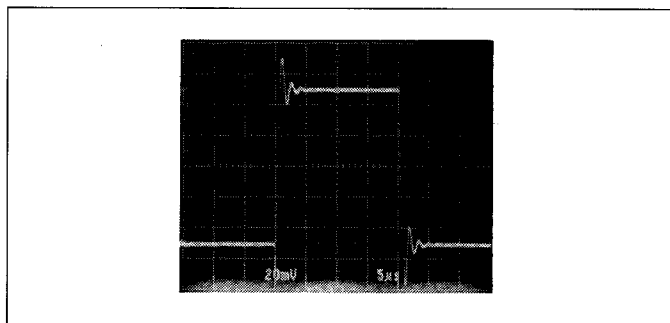
FIGURE 2: *Small-Signal Transient Response*
(C_{LOAD} = 1000pF, A_{VCL} = +1)
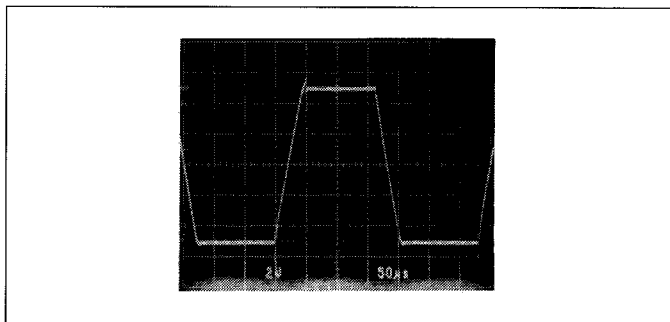
FIGURE 3: *Large-Signal Transient Response (A_{VCL} = +1)*

GUARDING AND SHIELDING

To maintain the extremely high input impedances of the OP-297, care must be taken in circuit board layout and manufacturing. Board surfaces must be kept scrupulously clean and free of moisture. Conformal coating is recommended to provide a humidity barrier. Even a clean PC board can have 100pA of leakage currents between adjacent traces, so guard rings should be used around the inputs. Guard traces are operated at a voltage close to that on the inputs, as shown in Figure 4, so that leakage currents become minimal. In noninverting applications, the guard ring should be connected to the common-mode voltage at the inverting input. In inverting applications, both inputs remain at ground, so the guard trace should be grounded. Guard traces should be on both sides of the circuit board.
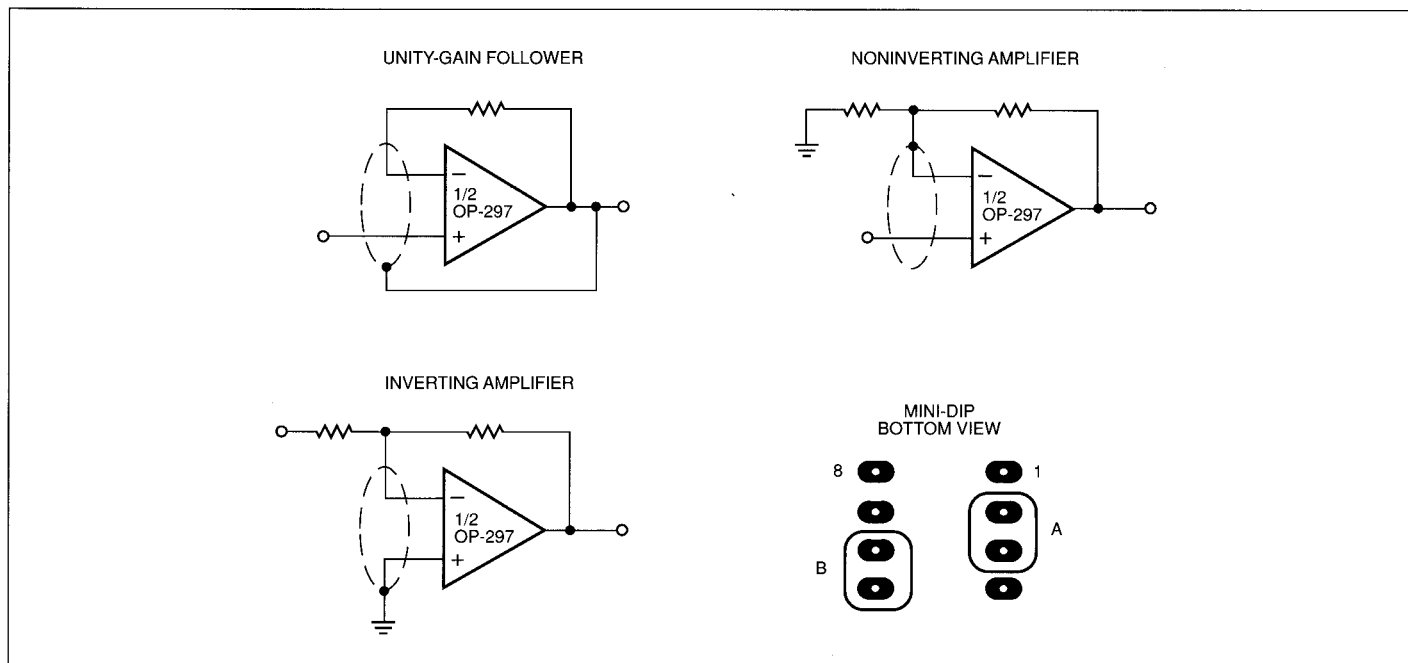
OP-297

FIGURE 4: *Guard Ring Layout and Connections*

OPEN-LOOP GAIN LINEARITY

The OP-297 has both an extremely high gain of 2000V/mV minimum and constant gain linearity. This enhances the precision of the OP-297 and provides for very high accuracy in high closed-loop gain applications. Figure 5 illustrates the typical open-loop gain linearity of the OP-297 over the military temperature range.
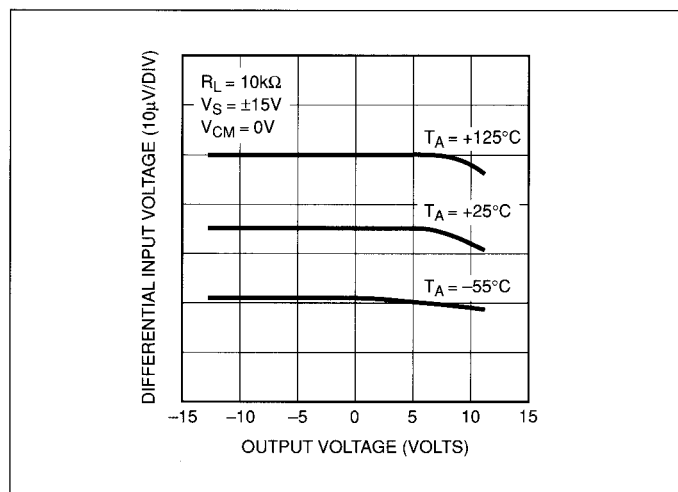

FIGURE 5: *Open-Loop Linearity of the OP-297*

APPLICATIONS

PRECISION ABSOLUTE VALUE AMPLIFIER

The circuit of Figure 6 is a precision absolute value amplifier with an input impedance of 30MΩ. The high gain and low TCV_{OS} of the OP-297 insure accurate operation with microvolt input signals. In this circuit, the input always appears as a common-mode signal to the op amps. The CMR of the OP-297 exceeds 120dB, yielding an error of less than 2ppm.
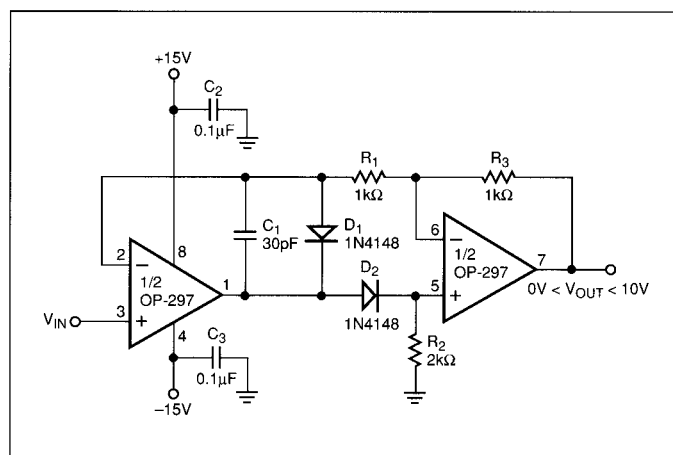
FIGURE 6: *Precision Absolute Value Amplifier*

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PRECISION CURRENT PUMP

Maximum output current of the precision current pump shown in Figure 7 is ±10mA. Voltage compliance is ±10V with ±15V supplies. Output impedance of the current transmitter exceeds 3MΩ with linearity better than 16 bits.

PRECISION POSITIVE PEAK DETECTOR

In Figure 8, 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 OP-297.
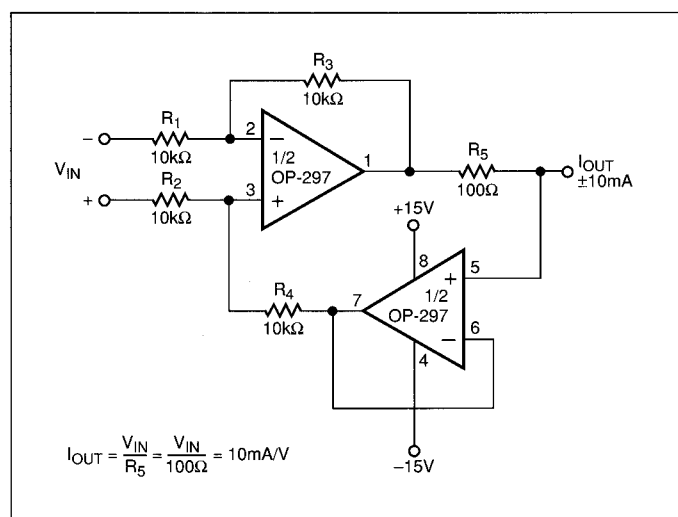

$$I_{OUT} = \frac{V_{IN}}{R_5} = \frac{V_{IN}}{100\Omega} = 10mA/V$$

FIGURE 7: Precision Current Pump

SIMPLE BRIDGE CONDITIONING AMPLIFIER

Figure 9 shows a simple bridge conditioning amplifier using the OP-297. The transfer function is:

$$V_{OUT} = V_{REF}\left(\frac{\Delta R}{R + \Delta R}\right)\frac{R_F}{R}$$

The REF-43 provides an accurate and stable reference voltage for the bridge. To maintain the highest circuit accuracy, R_F should be 0.1% or better with a low temperature coefficient.
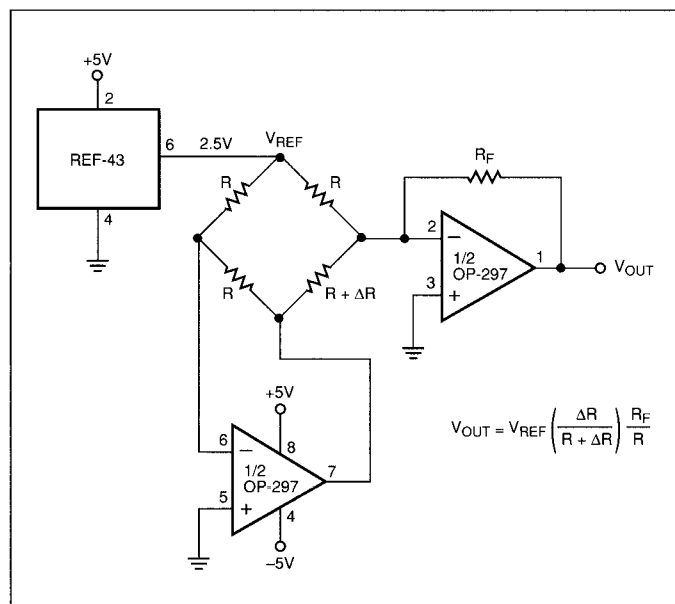

$$V_{OUT} = V_{REF}\left(\frac{\Delta R}{R + \Delta R}\right)\frac{R_F}{R}$$

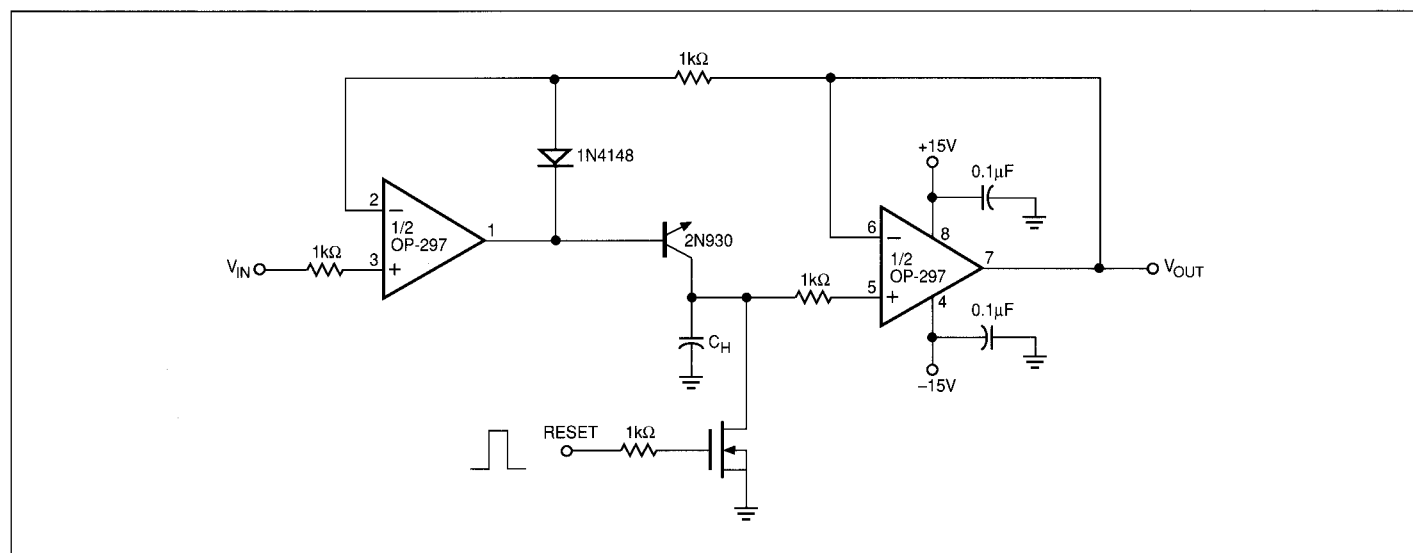FIGURE 9: A simple bridge conditioning amplifier using the OP-297.

FIGURE 8: Precision Positive Peak Detector

*Teflon is a registered trademark of the Dupont Company

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NONLINEAR CIRCUITS

Due to its low input bias currents, the OP-297 is an ideal log amplifier in nonlinear circuits such as the square and square-root circuits shown in Figures 10 and 11. Using the squaring circuit of Figure 10 as an example, the analysis begins by writing a voltage loop equation across transistors Q_1, Q_2, Q_3 and Q_4.

$$V_{T1} \ln\left(\frac{I_{IN}}{I_{S1}}\right) + V_{T2} \ln\left(\frac{I_{IN}}{I_{S2}}\right) = V_{T3} \ln\left(\frac{I_O}{I_{S3}}\right) + V_{T4} \ln\left(\frac{I_{REF}}{I_{S4}}\right)$$

All the transistors of the MAT-04 are precisely matched and at the same temperature, so the I_S and V_T terms cancel, giving:

$$2 \ln I_{IN} = \ln I_O + \ln I_{REF} = \ln (I_O \times I_{REF})$$

Exponentiating both sides of the equation leads to:

$$I_O = \frac{(I_{IN})^2}{I_{REF}}$$

Op amp A_2 forms a current-to-voltage converter which gives $V_{OUT} = R_2 \times I_O$. Substituting (V_{IN}/R_1) for I_{IN} and the above equation for I_O yields:

$$V_{OUT} = \left(\frac{R_2}{I_{REF}}\right)\left(\frac{V_{IN}}{R_1}\right)^2$$

A similar analysis made for the square-root circuit of Figure 11 leads to its transfer function:
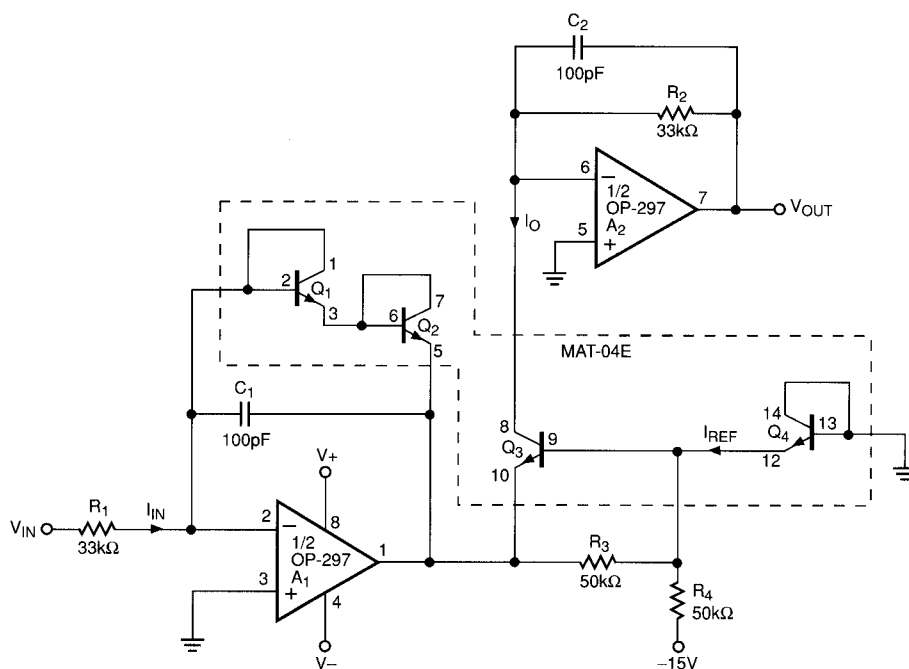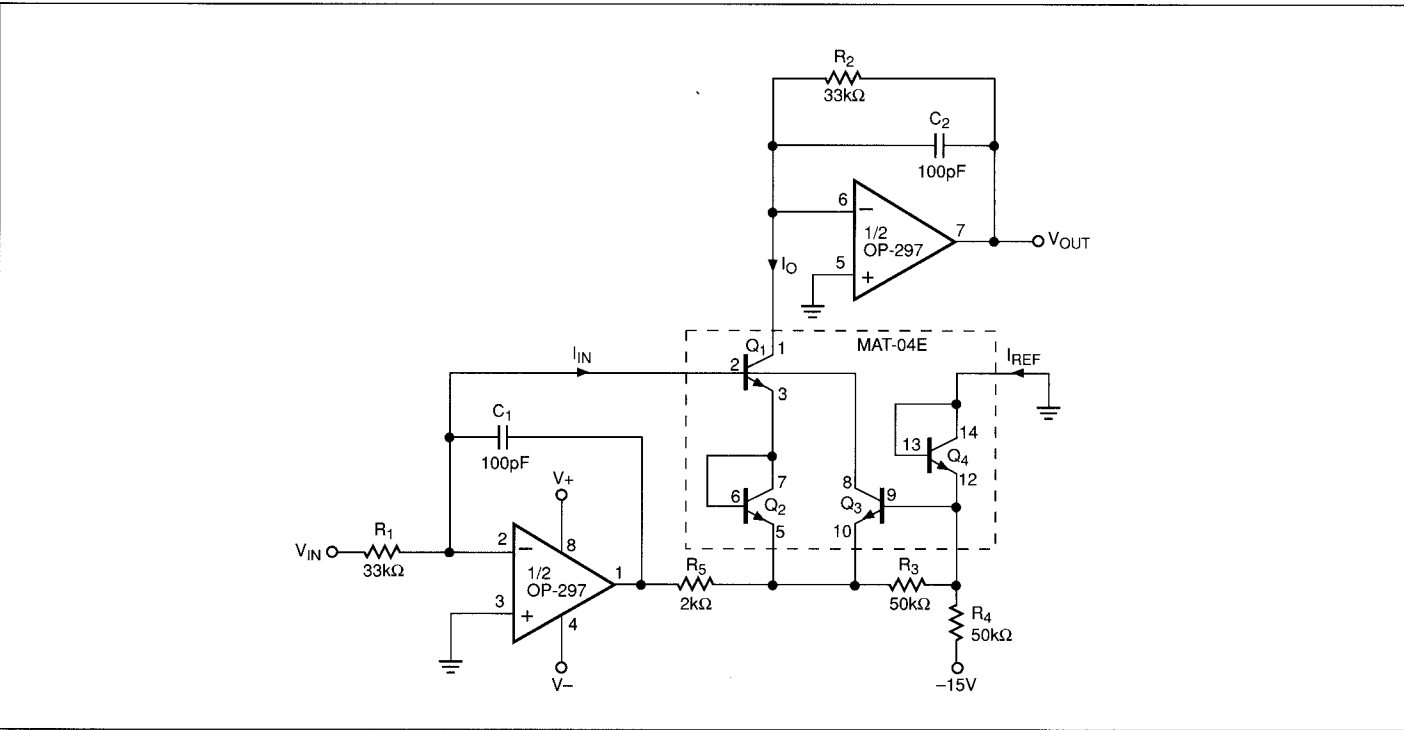
$$V_{OUT} = R_2 \sqrt{\frac{(V_{IN})(I_{REF})}{R_1}}$$

FIGURE 10: *Squaring Amplifier*

FIGURE 11: *Square-Root Amplifier*

In these circuits, I_{REF} is a function of the negative power supply. To maintain accuracy, the negative supply should be well regulated. For applications where very high accuracy is required, a voltage reference may be used to set I_{REF}. An important consideration for the squaring circuit is that a sufficiently large input voltage can force the output beyond the operating range of the output op amp. Resistor R_4 can be changed to scale I_{REF}, or R_1 and R_2 can be varied to keep the output voltage within the usable range.

Unadjusted accuracy of the square-root circuit is better than 0.1% over an input voltage range of 100mV to 10V. For a similar input voltage range, the accuracy of the squaring circuit is better than 0.5%.

OP-297 SPICE MACRO-MODEL

Figures 12 and 13 show the node and net list for a SPICE macromodel of the OP-297. The model is a simplified version of the actual device and simulates important DC parameters such as V_{OS}, I_{OS}, I_B, A_{VO}, CMR, V_O and I_{SY}. AC parameters such as slew rate, gain and phase response and CMR change with frequency are also simulated by the model.

The model uses typical parameters for the OP-297. The poles and zeros in the model were determined from the actual open and closed-loop gain and phase response of the OP-297. In this way, the model presents an accurate AC representation of the actual device. The model assumes an ambient temperature of 25°C.

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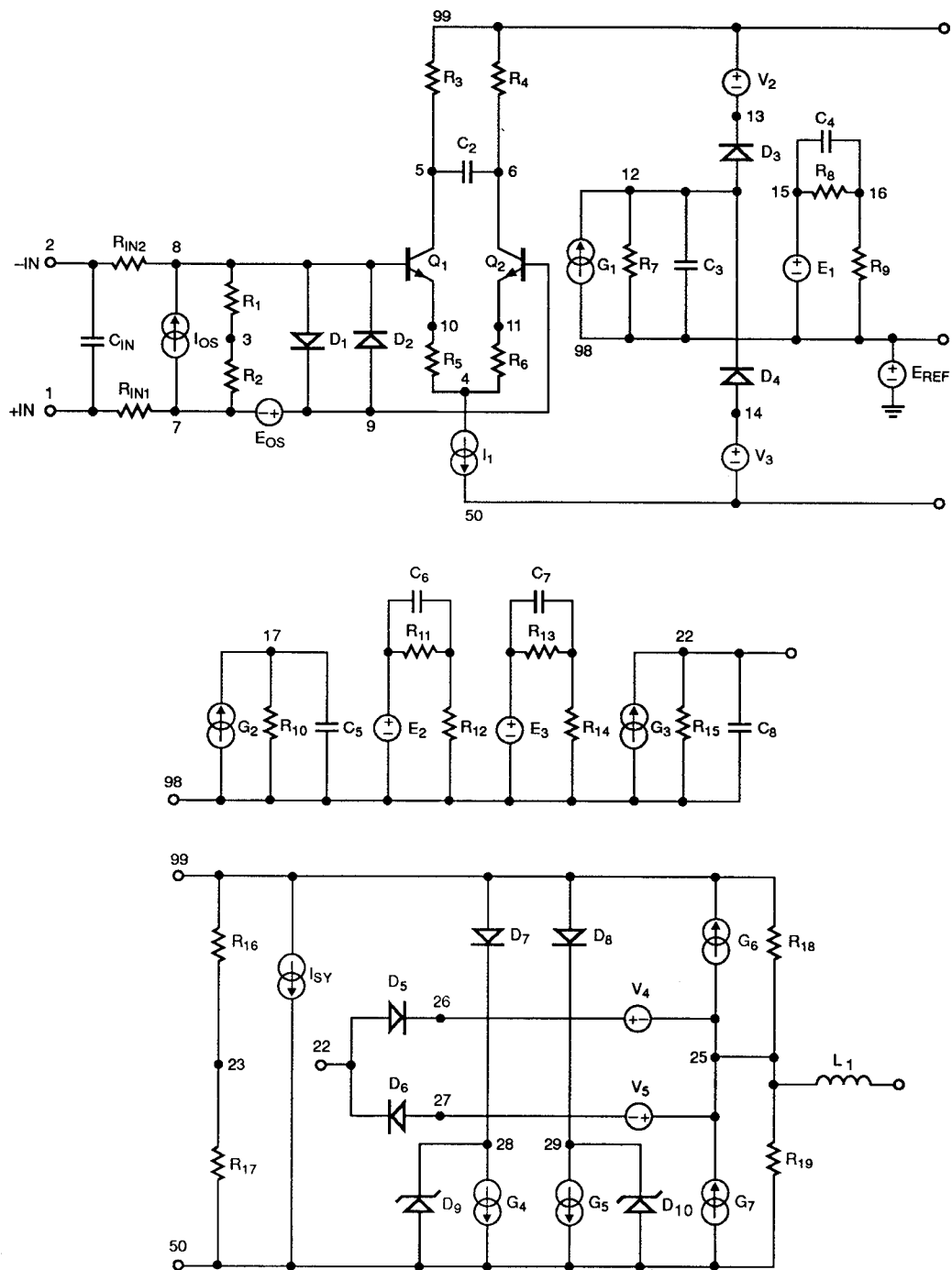**FIGURE 12:** *OP-297 Macro-Model*

```
* OP-297 SPICE MACRO-MODEL © PMI 1990
*
* NODE ASSIGNMENTS
*                         NONINVERTING INPUT
*                         |  INVERTING INPUT
*                         |  |  OUTPUT
*                         |  |  |  POSITIVE SUPPLY
*                         |  |  |  |  NEGATIVE SUPPLY
*                         |  |  |  |  |
* SUBCKT OP-297  1  2  30  99  50
*
* INPUT STAGE & POLE AT 6 MHZ
*
RIN1   1    7          2500
RIN2   2    8          2500
R1     8    3          5E11
R2     7    3          5E11
R3     5    99         612
R4     6    99         612
CIN    7    8          3E-12
C2     5    6          21.67E-12
I1     4    50         0.1E-3
IOS    7    8          20E-12
EOS    9    7          POLY(1) 19 23 25E-6 1
Q1     5    8    10    QX
Q2     6    9    11    QX
R5     10   4          96
R6     11   4          96
D1     8    9          DX
D2     9    8          DX
*
EREF   98   0          23 0 1
*
*GAIN STAGE & DOMINANT POLE AT 0.13 HZ
*
R7     12   98         2.45E9
C3     12   98         500E-12
G1     98   12         5 6 1.634E-3
V2     99   13         1.5
V3     14   50         1.5
D3     12   13         DX
D4     14   12         DX
*
*NEGATIVE ZERO AT –1.8 MHZ
*
R8     15   16         1E6
C4     15   16         –88.4E-15
R9     16   98         1
E1     15   98         12 23 1E6
*
```

```
*POLE AT 1.8 MHZ
*
R10    17   98         1E6
C5     17   98         88.4E-15
G2     98   17         16 23 1E-6
*
*COMMON-MODE GAIN NETWORK WITH ZERO AT 50 HZ
*
R11    18   19         1E6
C6     18   19         3.183E-9
R12    19   98         1
E2     18   98         3 23 100E-3
*
*POLE AT 6 MHZ
*
R15    22   98         1E6
C8     22   98         26.53E-15
G3     98   22         17 23 1E-6
*
*OUTPUT STAGE
*
R16    23   99         160K
R17    23   50         160K
ISY    99   50         331E-6
R18    25   99         200
R19    25   50         200
L1     25   30         1E-7
G4     28   50         22 25 5E-3
G5     29   50         25 22 5E-3
G6     25   99         99 22 5E-3
G7     50   25         22 50 5E-3
V4     26   25         1.8
V5     25   27         1.3
D5     22   26         DX
D6     27   22         DX
D7     99   28         DX
D8     99   29         DX
D9     50   28         DY
D10    50   29         DY
*
*MODELS USED
*
MODEL QX NPN (BF=2.5E6)
MODEL DX    D (IS=1E-15)
MODEL DY    D (IS=1E-15 BV=50)
ENDS OP-297
```

FIGURE 13: *OP-297 SPICE Net-List*