



# OP-249

DUAL, PRECISION

JFET HIGH-SPEED OPERATIONAL AMPLIFIER

Precision Monolithics Inc.

## FEATURES

- **Fast Slew Rate** ..... 22V/ $\mu$ s Typ
- **Settling Time (0.01%)** ..... 1.2 $\mu$ s Max
- **Offset Voltage** ..... 300 $\mu$ V Max
- **High Open-Loop Gain** ..... 1000V/mV Min
- **Low Total Harmonic Distortion** ..... 0.002% Typ
- **Improved Replacement for AD712, LT1057, OP-215, TL072, and MC34082**
- Available in Die Form

## APPLICATIONS

- Output Amplifier for Fast D/As
- Signal Processing
- Instrumentation Amplifiers
- Fast Sample/Holds
- Active Filters
- Low Distortion Audio Amplifiers
- Input Buffer for A/D Converters
- Servo Controllers

## GENERAL DESCRIPTION

The OP-249 is a high-speed, precision dual JFET op amp, similar to the popular single op amp, the OP-42. The OP-249 outperforms available dual amplifiers by providing superior speed with excellent DC performance. Ultra-high open-loop gain (1 kV/mV minimum), low offset voltage, and superb gain linearity, makes the OP-249 the industry's first true precision, dual high-speed amplifier.

With a slew rate of 22V/ $\mu$ s typical, and a fast settling time of less than 1.2 $\mu$ s maximum to 0.01%, the OP-249 is an ideal choice for high-speed bipolar D/A and A/D converter applications. The excellent DC performance of the OP-249 allows the full accuracy of high-resolution CMOS D/As to be realized.

Symmetrical slew rate, even when driving large loads, such as 600 $\Omega$ , or 200pF of capacitance, and ultra-low distortion, make the OP-249 ideal for professional audio applications, active filters, high-speed integrators, servo systems, and buffer amplifiers.

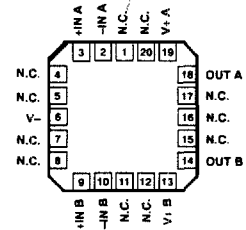
The OP-249 provides significant performance upgrades to the TL072, AD712, OP-215, MC34082 and the LT1057.

## PIN CONNECTIONS

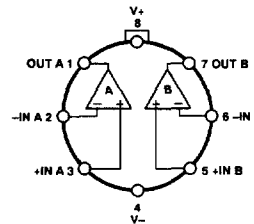


8-PIN CERDIP (Z-Suffix)

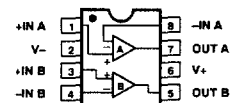
8-PIN EPOXY MINI-DIP (P-Suffix)



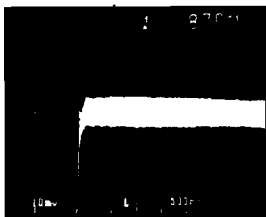
20-CONTACT LCC (RC-Suffix)



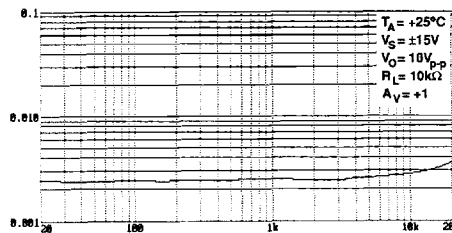
TO-99 (J-Suffix)



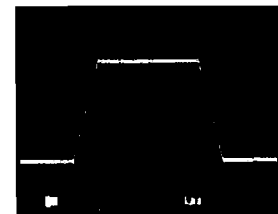
8-PIN SO (S-Suffix)



FAST SETTLING (0.01%)



LOW DISTORTION  $A_V = +1, R_L = 10\text{k}\Omega$



EXCELLENT OUTPUT DRIVE  $R_L = 600\Omega$

ORDERING INFORMATION <sup>1</sup>

TO-99	PACKAGE			OPERATING TEMPERATURE RANGE
	CERDIP 8-PIN	PLASTIC 8-PIN	LCC 20-CONTACT	
OP249AJ*	OP249AZ*	-	OP249ARC/883	MIL
OP249EJ	-	-	-	XIND
OP249FJ	OP249FZ	-	-	XIND
-	-	OP249GP	-	XIND
-	-	OP249GS††	-	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 commercial and industrial temperature range parts in CerDIP, plastic DIP, and TO-can packages. For ordering information, see PMI's Data Book, Section 2.

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

## ABSOLUTE MAXIMUM RATINGS (Note 1)

Supply Voltage	±18V
Input Voltage (Note 2)	±18V
Differential Input Voltage (Note 2)	36V
Output Short-Circuit Duration	Indefinite
Storage Temperature Range	-65°C to +175°C

## Operating Temperature Range

OP-249A (J, Z, RC)	-55°C to +125°C
OP-249E, F (J, Z)	-40°C to +85°C
OP-249G (P, S)	-40°C to +85°C

## Junction Temperature

OP-249 (J, Z, RC)	-65°C to +175°C
OP-249 (P, S)	-65°C to +150°C

## Lead Temperature Range (Soldering, 60 sec) 300°C

PACKAGE TYPE	$\theta_{JA}$ (Note 3)	$\theta_{JC}$	UNITS
TO-99 (J)	145	16	°C/W
8-Pin Hermetic DIP (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:

- Absolute maximum ratings apply to both DICE and packaged parts, unless otherwise noted.
- For supply voltages less than ±18V, the absolute maximum input voltage is equal to the supply voltage.
- $\theta_{JA}$  is specified for worst case mounting conditions, i.e.,  $\theta_{JA}$  is specified for device in socket for TO, CerDIP, P-DIP, and LCC packages;  $\theta_{JA}$  is specified for device soldered to printed circuit board for SO package.

ELECTRICAL CHARACTERISTICS at  $V_S = \pm 15V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-249A			OP-249E			OP-249F			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Offset Voltage	$V_{OS}$		-	0.2	0.5	-	0.1	0.3	-	0.2	0.7	mV
Long Term Offset Voltage	$V_{OS}$	(Note 1)	-	-	0.8	-	-	0.6	-	-	1.0	mV
Offset Stability			-	1.5	-	-	1.5	-	-	1.5	-	μV/Month
Input Bias Current	$I_B$	$V_{CM} = 0V$ , $T_J = +25^\circ C$	-	30	75	-	20	50	-	30	75	pA
Input Offset Current	$I_{OS}$	$V_{CM} = 0V$ , $T_J = +25^\circ C$	-	6	25	-	4	15	-	6	25	pA
Input Voltage Range	IVR	(Note 2)	±11	+12.5 -12.5	-	±11	+12.5 -12.5	-	±11	+12.5 -12.5	-	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	80	90	-	86	95	-	80	90	-	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 4.5V$ to ±18V	-	12	31.6	-	9	31.6	-	12	50	μV/V
Large-Signal Voltage Gain	$A_{VO}$	$V_O = \pm 10V$ $R_L = 2k\Omega$	1000	1400	-	1000	1400	-	500	1200	-	V/mV
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	±12.0	+12.5 -12.5	-	±12.0	+12.5 -12.5	-	±12.0	+12.5 -12.5	-	V
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	±20	+36 -33	±50	±20	+36 -33	±50	±20	+36 -33	±50	mA
Supply Current	$I_{SY}$	No Load $V_O = 0V$	-	5.6	7.0	-	5.6	7.0	-	5.6	7.0	mA
Slew Rate	SR	$R_L = 2k\Omega$ , $C_L = 50pF$	18	22	-	18	22	-	18	22	-	V/μs
Gain-Bandwidth Product	GBW	(Note 4)	3.5	4.7	-	3.5	4.7	-	3.5	4.7	-	MHz
Settling Time	$t_s$	10V Step 0.01% (Note 3)	-	0.9	1.2	-	0.9	1.2	-	0.9	1.2	μs
Phase Margin	$\theta_o$	0dB Gain	-	55	-	-	55	-	-	55	-	Deg

**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $T_A = +25^\circ C$ , unless otherwise noted. *Continued*

PARAMETER	SYMBOL	CONDITIONS	OP-249A			OP-249E			OP-249F			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Differential Input Impedance	$Z_{IN}$		-	$10^{12}  6$	-	-	$10^{12}  6$	-	-	$10^{12}  6$	-	$\Omega  pF$
Open-Loop Output Resistance	$R_O$		-	35	-	-	35	-	-	35	-	$\Omega$
Voltage Noise	$e_{n\ p-p}$	0.1Hz to 10Hz	-	2	-	-	2	-	-	2	-	$\mu V_{p-p}$
Voltage Noise Density	$e_n$	$f_O = 10Hz$	-	75	-	-	75	-	-	75	-	-
		$f_O = 100Hz$	-	26	-	-	26	-	-	26	-	$nV/\sqrt{Hz}$
		$f_O = 1kHz$	-	17	-	-	17	-	-	17	-	-
		$f_O = 10kHz$	-	16	-	-	16	-	-	16	-	-
Current Noise Density	$i_n$	$f_O = 1kHz$	-	0.003	-	-	0.003	-	-	0.003	-	$pA/\sqrt{Hz}$
Voltage Supply Range	$V_S$		$\pm 4.5$	$\pm 15$	$\pm 18$	$\pm 4.5$	$\pm 15$	$\pm 18$	$\pm 4.5$	$\pm 15$	$\pm 18$	V

**NOTES:**

1 Long term offset voltage is guaranteed by a 1000 HR life test performed on 3 independent wafer lots at  $+125^\circ C$  with a LTPD of 3.

2. Guaranteed by CMR test.

3. Settling-time is statistically tested.

4. Guaranteed by design and by inference from the slew rate measurement.

**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-249G			UNITS
			MIN	TYP	MAX	
Offset Voltage	$V_{OS}$		-	0.4	2.0	mV
Input Bias Current	$I_B$	$V_{CM} = 0V$ , $T_I = +25^\circ C$	-	40	75	$\mu A$
Input Offset Current	$I_{OS}$	$V_{CM} = 0V$ , $T_I = +25^\circ C$	-	10	25	$\mu A$
Input Voltage Range	IVR	(Note 1)	$\pm 11$	+12.5 -12.0	-	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	76	90	-	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 4.5V$ to $\pm 18V$	-	12	50	$\mu V/V$
Large-Signal Voltage Gain	$A_{VO}$	$V_O = \pm 10V$ $R_L = 2k\Omega$	500	1100	-	V/mV
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	$\pm 12.0$	+12.5 -12.5	-	V
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	$\pm 20$	+36 -33	$\pm 50$	mA
Supply Current	$I_{SY}$	No Load $V_O = 0V$	-	5.6	7.0	mA
Slew Rate	SR	$R_L = 2k\Omega$ , $C_L = 50pF$	18	22	-	V/ $\mu s$
Gain-Bandwidth Product	GBW		-	4.7	-	MHz
Settling Time	$t_s$	10V Step 0.01%	-	0.9	-	$\mu s$
Phase Margin	$\theta_0$	0dB Gain	-	55	-	Deg

**NOTES:**

1. Guaranteed by CMR test.

**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $T_A = +25^\circ C$ , unless otherwise noted. *Continued*

PARAMETER	SYMBOL	CONDITIONS	OP-249G			UNITS
			MIN	TYP	MAX	
Differential Input Impedance	$Z_{IN}$		—	$10^{12}    6$	—	$\Omega    pF$
Open-Loop Output Resistance	$R_O$		—	35	—	$\Omega$
Voltage Noise	$e_{n\ p-p}$	0.1Hz to 10Hz	—	2	—	$\mu V_{p-p}$
Voltage Noise Density	$e_n$	$f_O = 10Hz$	—	75	—	$nV/\sqrt{Hz}$
		$f_O = 100Hz$	—	26	—	
		$f_O = 1kHz$	—	17	—	
		$f_O = 10kHz$	—	16	—	
Current Noise Density	$i_r$	$f_O = 1kHz$	—	0.003	—	$pA/\sqrt{Hz}$
Voltage Supply Range	$V_S$		$\pm 4.5$	$\pm 15$	$\pm 18$	V

**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $-40^\circ C \leq T_A \leq +85^\circ C$  for E/F grades, and  $-55^\circ C \leq T_A \leq +125^\circ C$  for A grade, unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-249A			OP-249E			OP-249F			UNITS
			MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	MAX	
Offset Voltage	$V_{OS}$		—	0.12	1.0	—	0.1	0.5	—	0.5	1.1	mV
Offset Voltage Temperature Coefficient	$TCV_{OS}$		—	1	5	—	1	3	—	1.2	6	$\mu V/^\circ C$
Input Bias Current	$I_B$	(Note 1)	—	4	20	—	0.25	3.0	—	0.3	4.0	nA
Input Offset Current	$I_{OS}$	(Note 1)	—	0.04	4	—	0.01	0.7	—	0.02	1.2	nA
Input Voltage Range	IVR	(Note 2)	$\pm 11$	+12.5 -12.5	—	$\pm 11$	+12.5 -12.5	—	$\pm 11$	+12.5 -12.5	—	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	76	110	—	86	100	—	76	95	—	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 4.5V$ to $\pm 18V$	—	5	50	—	5	50	—	7	100	$\mu V/V$
Large-Signal Voltage Gain	$A_{VO}$	$R_L = 2k\Omega$ $V_O = \pm 10V$	500	1400	—	750	1400	—	250	1200	—	V/mV
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	$\pm 12.0$	+12.5 -12.5	—	$\pm 12.0$	+12.5 -12.5	—	$\pm 12.0$	+12.5 -12.5	—	V
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	$\pm 10$	—	$\pm 60$	$\pm 18$	—	$\pm 60$	$\pm 18$	—	$\pm 60$	mA
Supply Current	$I_{SY}$	No Load $V_O = 0V$	—	5.6	7.0	—	5.6	7.0	—	5.6	7.0	mA

**NOTES:**

- $T_I = 85^\circ C$  for E/F Grades;  $T_I = 125^\circ C$  for A Grade.
- Guaranteed by CMR test.

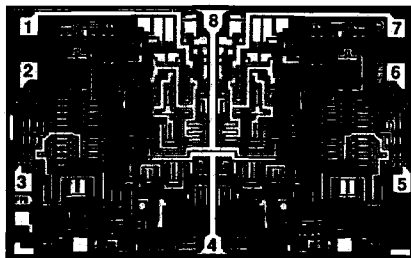
**ELECTRICAL CHARACTERISTICS** at  $V_S = \pm 15V$ ,  $-40^\circ C \leq T_A \leq +85^\circ C$ , unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-249G			UNITS
			MIN	TYP	MAX	
Offset Voltage	$V_{OS}$		–	1.0	3.6	mV
Offset Voltage Temperature Coefficient	$TCV_{OS}$		–	6	25	$\mu V/^\circ C$
Input Bias Current	$I_B$	(Note 1)	–	0.5	4.5	nA
Input Offset Current	$I_{OS}$	(Note 1)	–	0.04	1.5	nA
Input Voltage Range	IVR	(Note 2)	$\pm 11.0$	+12.5 –12.5	–	V
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	76	95	–	dB
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 4.5V$ to $\pm 18V$	–	10.0	100	$\mu V/V$
Large-Signal Voltage Gain	$A_{VO}$	$R_L = 2k\Omega$ $V_O = \pm 10V$	250	1200	–	V/mV
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	$\pm 12.0$	+12.5 –12.5	–	V
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	$\pm 18$	–	$\pm 60$	mA
Supply Current	$I_{SY}$	No Load $V_O = 0V$	–	5.6	7.0	mA

**NOTES:**

- $T_J = 85^\circ C$ .
- Guaranteed by CMR test.

## DICE CHARACTERISTICS



DIE SIZE 0.072 x 0.112 inch, 8,064 sq. mils  
(1.83 x 2.84 mm, 5.2 sq. mm)

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 ordering information,  
refer to PMI's Data Book, Section 2.

WAFER TEST LIMITS at  $V_S = \pm 15V$ ,  $T_J = +25^\circ C$ , unless otherwise noted.

PARAMETER	SYMBOL	CONDITIONS	OP-249GBC LIMITS	UNITS
Offset Voltage	$V_{OS}$		0.5	mV MAX
Offset Voltage Temperature Coefficient	$TCV_{OS}$	$-40^\circ C \leq T_J \leq 85^\circ C$	6.0	$\mu V/^\circ C$ MAX
Input Bias Current	$I_B$	$V_{CM} = 0V$	225	pA MAX
Input Offset Current	$I_{OS}$	$V_{CM} = 0V$	75	pA MAX
Input Voltage Range	IVR	(Note 1)	$\pm 11$	V MIN
Common-Mode Rejection	CMR	$V_{CM} = \pm 11V$	76	dB MIN
Power-Supply Rejection Ratio	PSRR	$V_S = \pm 4.5V$ to $\pm 18V$	100	$\mu V/V$ MAX
Large-Signal Voltage Gain	$A_{VO}$	$R_L = 2k\Omega$	250	V/mV MIN
Output Voltage Swing	$V_O$	$R_L = 2k\Omega$	$\pm 12.0$	V MIN
Short-Circuit Current Limit	$I_{SC}$	Output Shorted to Ground	$\pm 20/\pm 60$	mA MIN/MAX
Supply Current	$I_{SY}$	No Load $V_O = 0V$	7.0	mA MAX
Slew Rate	SR	$R_L = 2k\Omega$ , $C_L = 50pF$	16.5	V/ $\mu s$ MIN

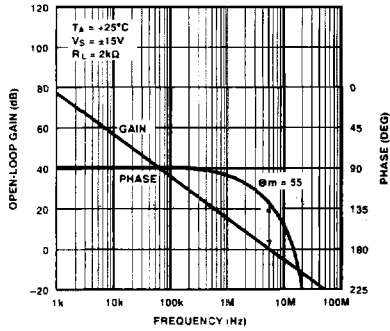
## NOTES:

1. Guaranteed by CMR test.

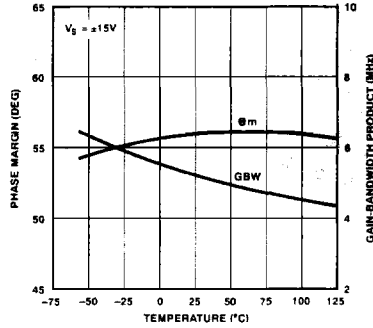
Electrical tests are performed at wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualifications through sample lot assembly and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

## TYPICAL PERFORMANCE CHARACTERISTICS

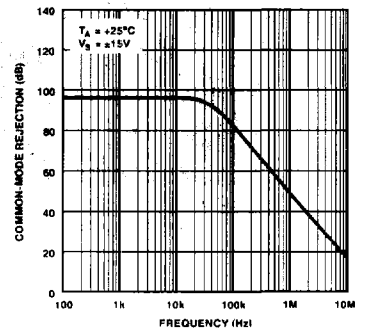
OPEN-LOOP GAIN, PHASE vs FREQUENCY



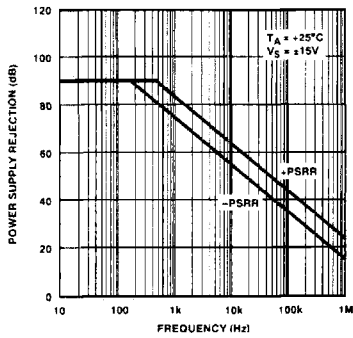
GAIN-BANDWIDTH PRODUCT, PHASE MARGIN vs TEMPERATURE



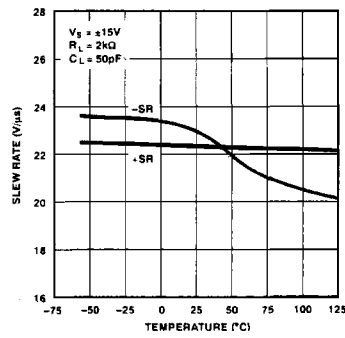
COMMON-MODE REJECTION vs FREQUENCY



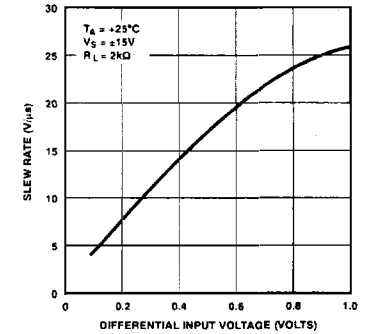
POWER SUPPLY REJECTION vs FREQUENCY



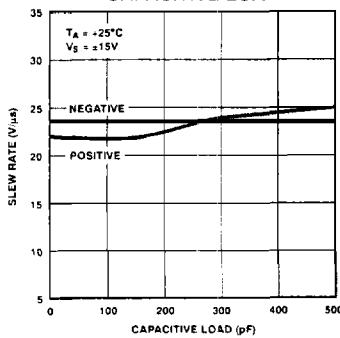
SLEW RATE vs TEMPERATURE



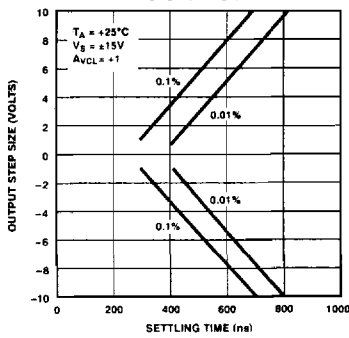
SLEW RATE vs DIFFERENTIAL INPUT VOLTAGE



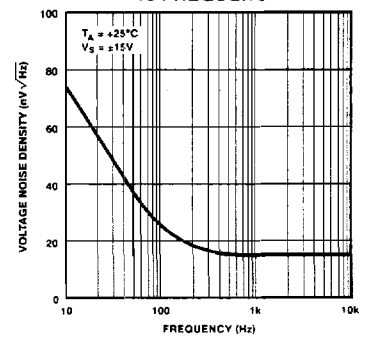
SLEW RATE vs CAPACITIVE LOAD



SETTLING TIME vs STEP SIZE

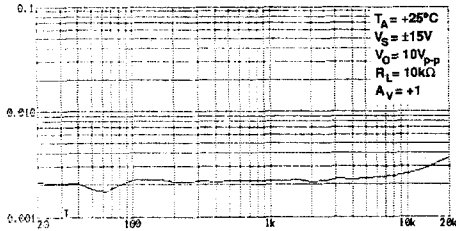


VOLTAGE NOISE DENSITY vs FREQUENCY

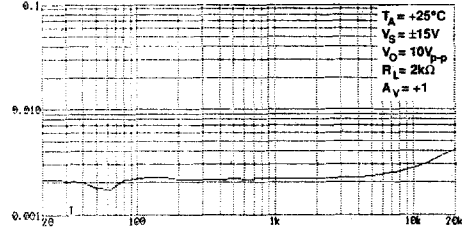


TYPICAL PERFORMANCE CHARACTERISTICS *Continued*

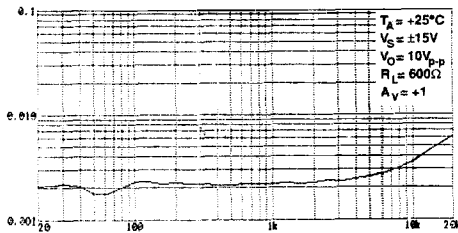
DISTORTION vs FREQUENCY



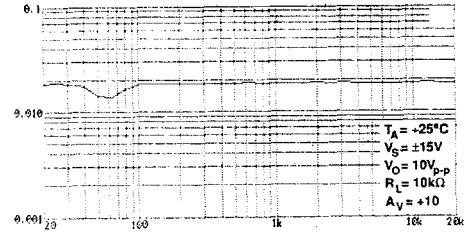
DISTORTION vs FREQUENCY



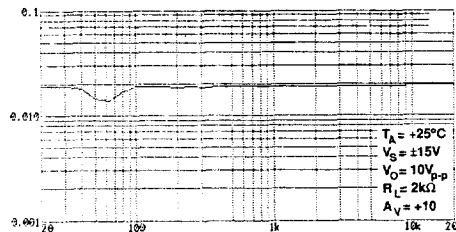
DISTORTION vs FREQUENCY



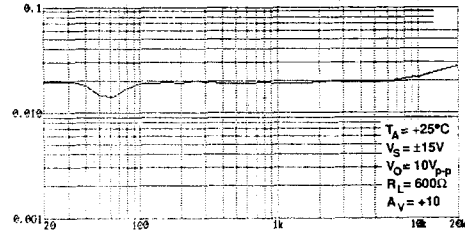
DISTORTION vs FREQUENCY



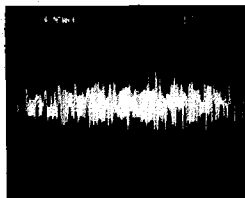
DISTORTION vs FREQUENCY



DISTORTION vs FREQUENCY

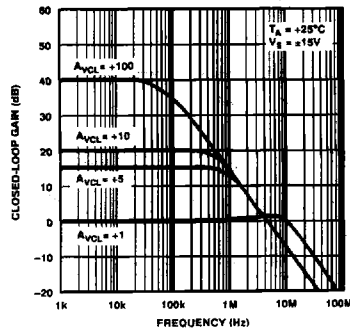


LOW FREQUENCY NOISE

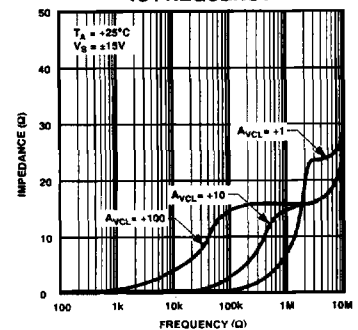


BANDWIDTH (0.1Hz TO 10Hz)  
 $T_A = +25^\circ\text{C}$   $V_S = \pm 15\text{V}$

CLOSED-LOOP GAIN vs FREQUENCY

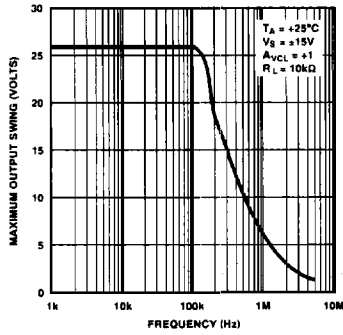
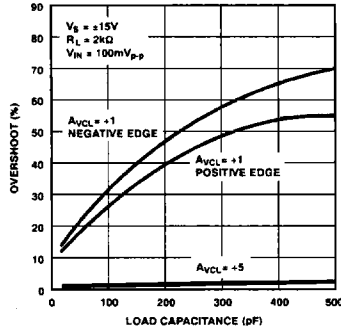
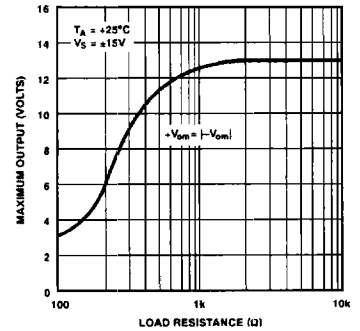
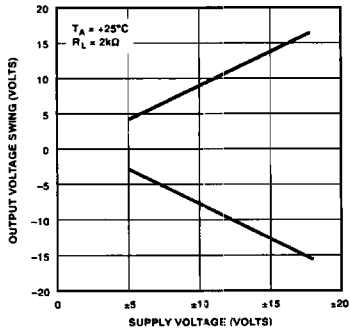
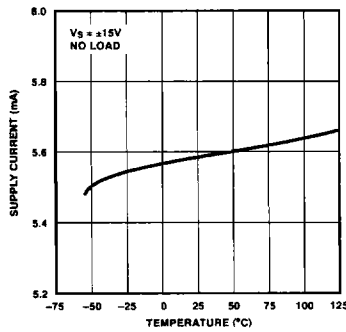
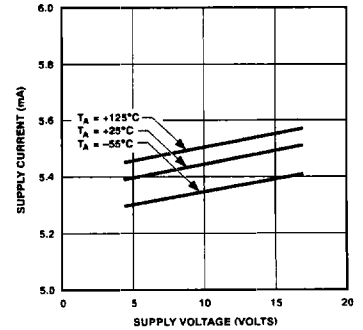
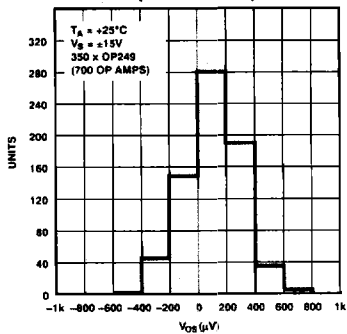
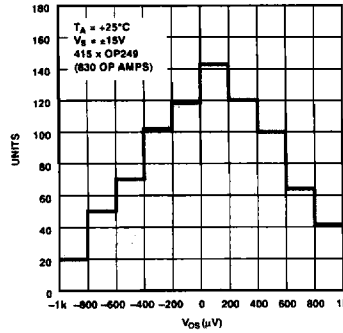
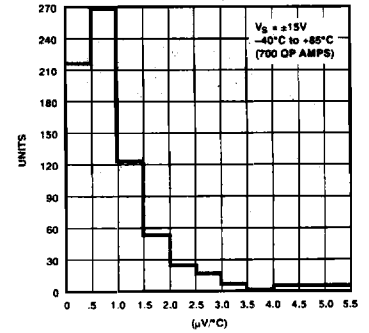


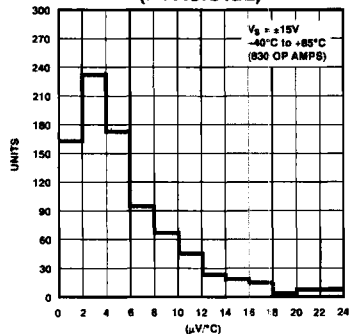
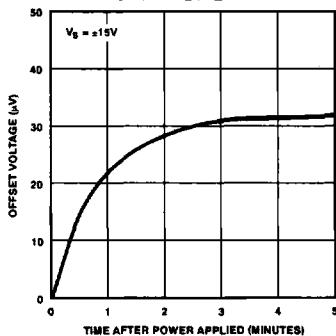
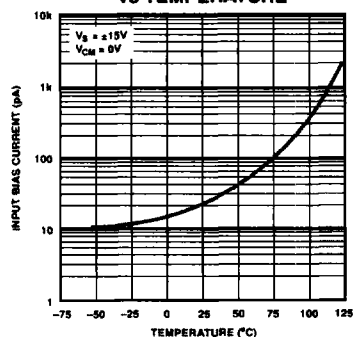
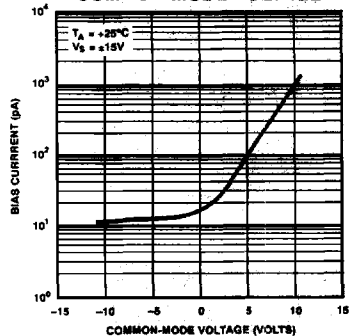
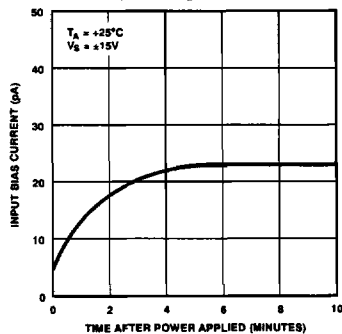
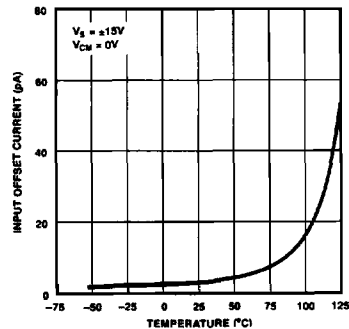
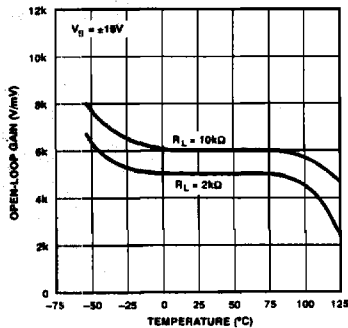
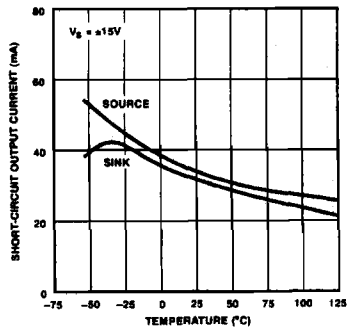
CLOSED-LOOP OUTPUT IMPEDANCE vs FREQUENCY

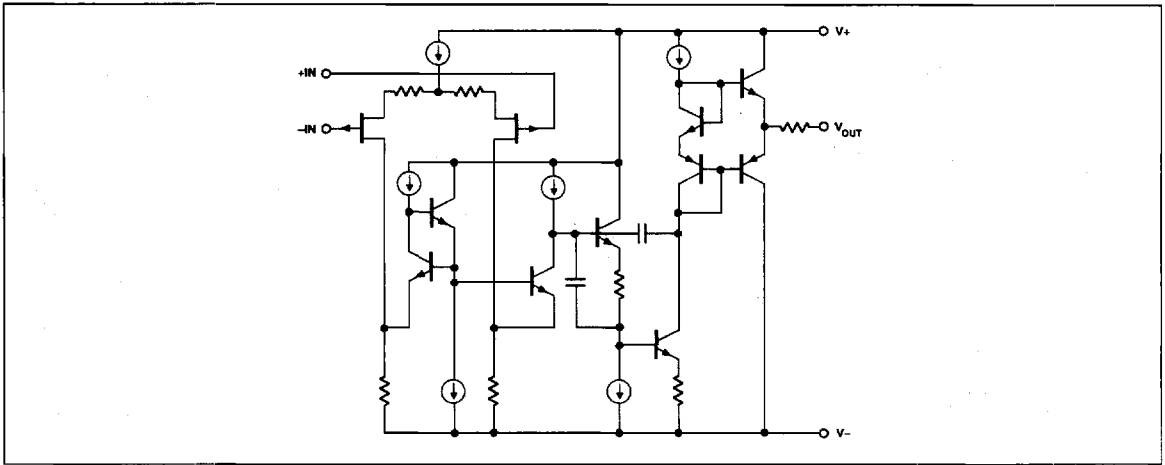
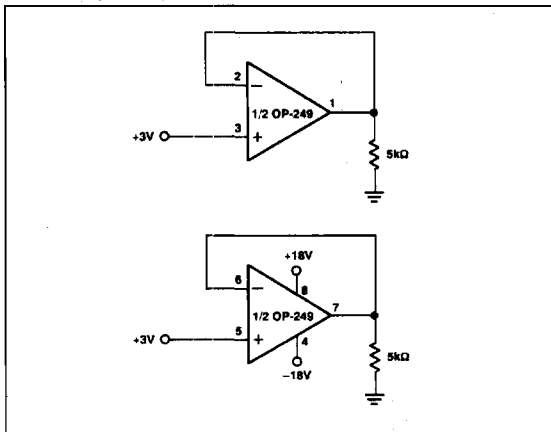


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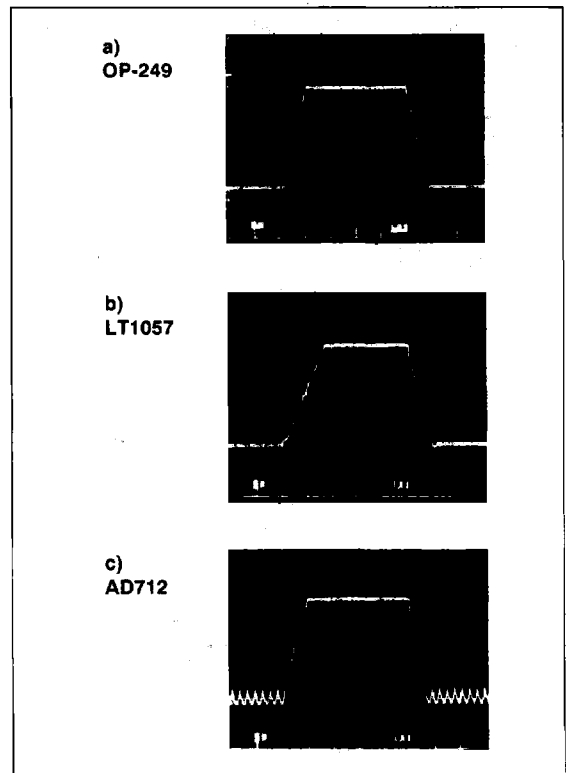
TYPICAL PERFORMANCE CHARACTERISTIC *Continued*
**MAXIMUM OUTPUT SWING vs FREQUENCY**

**SMALL-SIGNAL OVERSHOOT vs LOAD CAPACITANCE**

**MAXIMUM OUTPUT VOLTAGE vs LOAD RESISTANCE**

**OUTPUT VOLTAGE SWING vs SUPPLY VOLTAGE**

**SUPPLY CURRENT vs TEMPERATURE**

**SUPPLY CURRENT vs SUPPLY VOLTAGE**

**VO<sub>S</sub> DISTRIBUTION (J PACKAGE)**

**VO<sub>S</sub> DISTRIBUTION (P PACKAGE)**

**TCV<sub>OS</sub> DISTRIBUTION (J PACKAGE)**


TYPICAL PERFORMANCE CHARACTERISTICS *Continued*
**TCV<sub>OS</sub> DISTRIBUTION  
(P PACKAGE)**

**OFFSET VOLTAGE  
WARM-UP DRIFT**

**INPUT BIAS CURRENT  
vs TEMPERATURE**

**BIAS CURRENT vs  
COMMON-MODE VOLTAGE**

**BIAS CURRENT  
WARM-UP DRIFT**

**INPUT OFFSET CURRENT  
vs TEMPERATURE**

**OPEN-LOOP GAIN  
vs TEMPERATURE**

**SHORT-CIRCUIT  
OUTPUT CURRENT  
vs JUNCTION TEMPERATURE**


**SIMPLIFIED SCHEMATIC (1/2 OP-249)**

**BURN-IN CIRCUIT**

**APPLICATIONS INFORMATION**

The OP-249 represents a reliable JFET amplifier design, featuring an excellent combination of DC precision and high speed. A rugged output stage provides the ability to drive a 600Ω load and still maintain a clean AC response. The OP-249 features a large-signal response that is more linear and symmetric than previously available JFET input amplifiers – compare the OP-249's large-signal response, as illustrated in Figure 1, to other industry standard dual JFET amplifiers.

Typically, JFET amplifier's slewing performance is simply specified as just a number of volts/μs. There is no discussion on the quality, i.e., linearity, symmetry, etc. of the slewing response.



**FIGURE 1:** Large-Signal Transient Response,  $A_V = +1$ ,  $V_{IN} = 20V_{p-p}$ ,  $Z_L = 2k\Omega || 200pF$ ,  $V_S = \pm 15V$

The OP-249 was carefully designed to provide symmetrically matched slew characteristics in both the negative and positive directions, even when driving a large output load.

An amplifier's slewing limitation determines the maximum frequency at which a sinusoidal output can be obtained without significant distortion. It is, however, important to note that the nonsymmetric slewing typical of previously available JFET amplifiers adds a higher series of harmonic energy content to the resulting response – and an additional DC output component. Examples of potential problems of nonsymmetric slewing behaviour could be in audio amplifier applications, where a natural, low-distortion sound quality is desired, and in servo or signal processing systems where a net DC offset cannot be tolerated. The linear and symmetric slewing feature of the OP-249 makes it an ideal choice for applications that will exceed the full-power-bandwidth range of the amplifier.

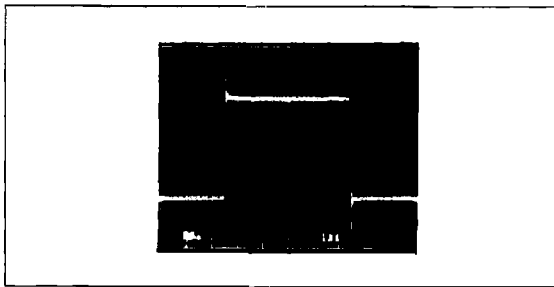


FIGURE 2: Small-Signal Transient Response,  $A_V = +1$ ,  $Z_L = 2k\Omega || 100pF$ , No Compensation,  $V_S = \pm 15V$

As with most JFET-input amplifiers, the output of the OP-249 may undergo phase inversion if either input exceeds the specified input voltage range. Phase inversion will not damage the amplifier, nor will it cause an internal latch-up condition.

Supply decoupling should be used to overcome inductance and resistance associated with supply lines to the amplifier. A 0.1  $\mu F$  and a 10  $\mu F$  capacitor should be placed between each supply pin and ground.

**OPEN-LOOP GAIN LINEARITY**

The OP-249 has both an extremely high open-loop gain of 1kV/mV minimum and constant gain linearity. This feature of the OP-249 enhances its DC precision, and provides superb accuracy in high closed-loop gain applications. Figure 3 illustrates the typical open-loop gain linearity – high gain accuracy is assured, even when driving a 600 $\Omega$  load.

**OFFSET VOLTAGE ADJUSTMENT**

The inherent low offset voltage of the OP-249 will make offset adjustments unnecessary in most applications. However, where a lower offset error is required, balancing can be performed with simple external circuitry, as illustrated in Figures 4 and 5.

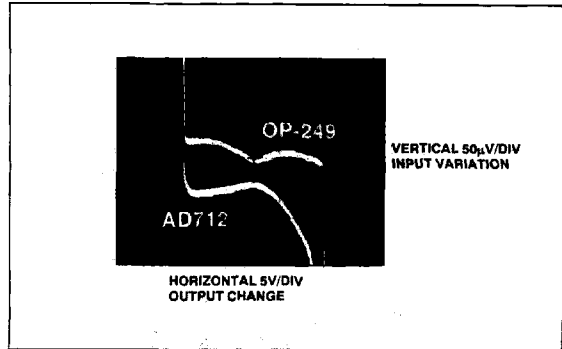


FIGURE 3: Open-Loop Gain Linearity. Variation in Open-Loop Gain Results in Errors in High Closed-Loop Gain Circuits.  $R_L = 600\Omega$ ,  $V_S = \pm 15V$

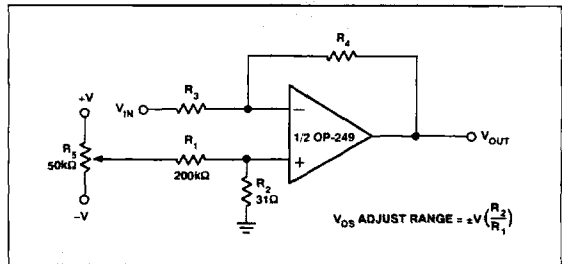


FIGURE 4: Offset Adjust for Inverting Amplifier Configuration

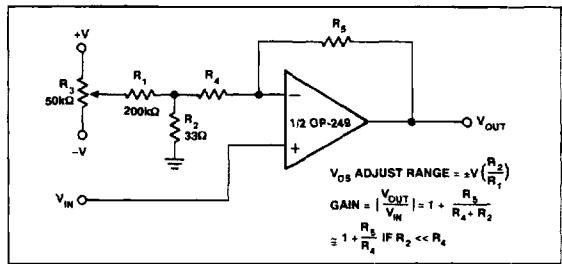


FIGURE 5: Offset Adjust for Noninverting Amplifier Configuration

In Figure 4, the offset adjustment is made by supplying a small voltage at the noninverting input of the amplifier. Resistors  $R_1$  and  $R_2$  attenuates the pot voltage, providing a  $\pm 2.5mV$  (with  $V_S = \pm 15V$ ) adjustment range, referred to the input. Figure 5 illustrates offset adjust for the noninverting amplifier configuration, also providing a  $\pm 2.5mV$  adjustment range. As indicated in the equations in Figure 5, if  $R_4$  is not much greater than  $R_2$ , there will be a resulting closed-loop gain error that must be accounted for.

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### SETTLING TIME

Settling time is the time between when the input signal begins to change and when the output permanently enters a prescribed error band. The error bands on the output are 5mV and 0.5mV, respectively, for 0.1% and 0.01% accuracy.

Figure 6 illustrates the OP-249's typical settling time of 870ns. Moreover, problems in settling response, such as thermal tails and long-term ringing are nonexistent.

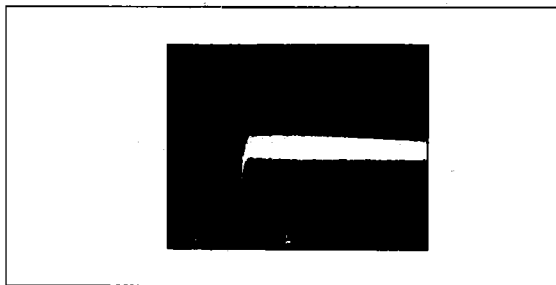


FIGURE 6: Settling Characteristics of the OP-249 to 0.01%

### DAC OUTPUT AMPLIFIER

Unity-gain stability, a low offset voltage of 300 $\mu$ V typical, and a fast settling time of 870ns to 0.01%, makes the OP-249 an ideal amplifier for fast digital-to-analog converters.

For CMOS DAC applications, the low offset voltage of the OP-249 results in excellent linearity performance. CMOS DACs, such as the PM-7545, will typically have a code-dependent output resistance variation between 11k $\Omega$  and 33k $\Omega$ . The change in output resistance, in conjunction with the 11k $\Omega$  feedback resistor, will result in a noise gain change. This causes variations in the offset error, increasing linearity errors. The OP-249 features low offset voltage error, minimizing this effect and maintaining 12-bit linearity performance over the full scale range of the converter.

Since the DAC's output capacitance appears at the operational amplifiers inputs, it is essential that the amplifier is adequately compensated. Compensation will increase the phase margin, and ensure an optimal overall settling response. The required lead compensation is achieved with capacitor C in Figure 7.

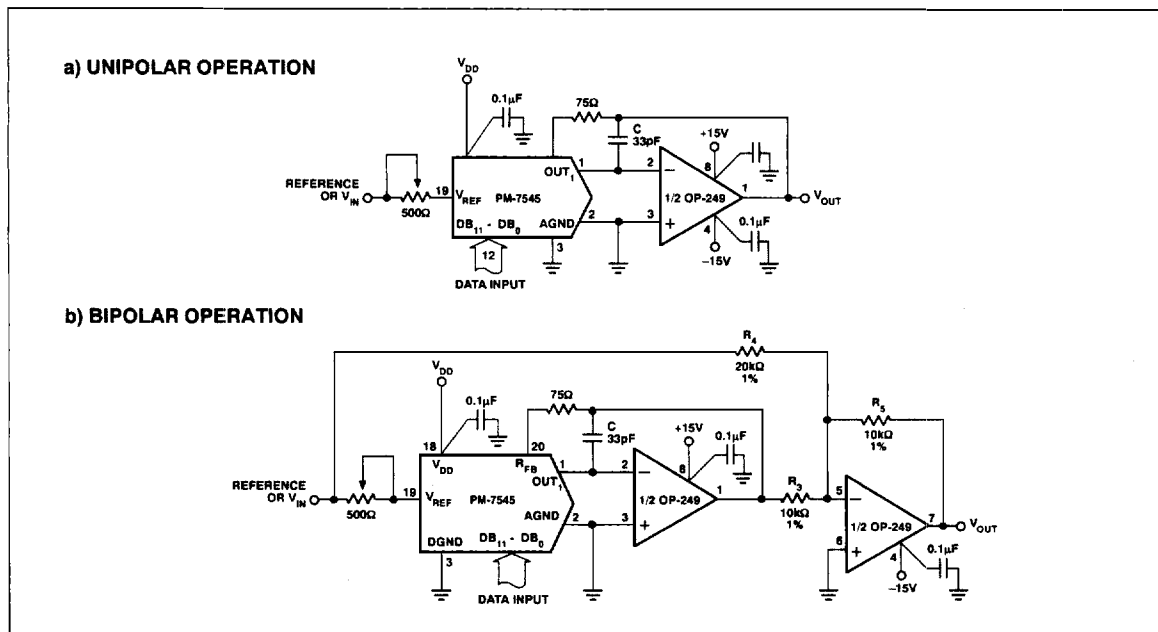


FIGURE 7: Fast Settling and Low Offset Error of the OP-249 Enhances CMOS DAC Performance

Figure 8 illustrates the effect of altering the compensation on the output response of the circuit in Figure 6a. Compensation is required to address the combined effect of the DAC's output capacitance, the op amp's input capacitance, and any stray capacitance. Slight adjustments to the compensation capacitor may be required to optimize settling response for any given application.

The settling time of the combination of the current output DAC and the op amp can be approximated by:

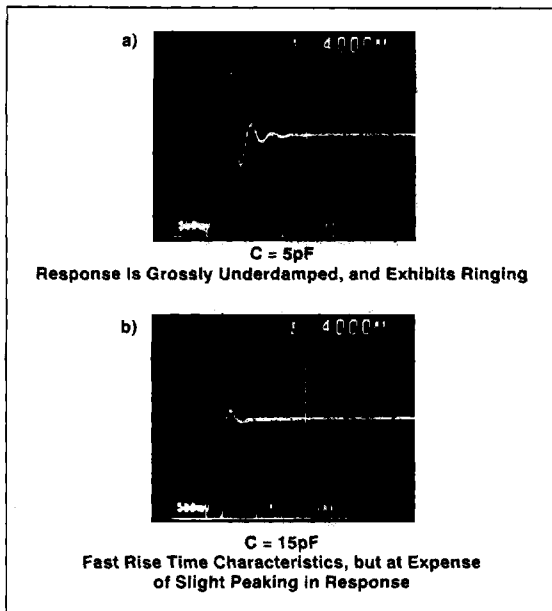
$$t_s \text{ TOTAL} = \sqrt{(t_s \text{ DAC})^2 + (t_s \text{ AMP})^2}$$

The actual overall settling time is affected by the noise gain of the amplifier, the applied compensation, and the equivalent input capacitance at the amplifier's input.

**DISCUSSION ON DRIVING A/D CONVERTERS**

Settling characteristics of operational amplifiers also include an amplifier's ability to recover, i.e., settle, from a transient current output load condition. An example of this includes an op amp driving the input from a SAR type A/D converter. Although the comparison point of the converter is usually diode clamped, the input swing of plus-and-minus a diode drop still gives rise to a significant modulation of input current. If the closed-loop output impedance is low enough and bandwidth of the amplifier is sufficiently large, the output will settle before the converter makes a comparison decision which will prevent linearity errors or missing codes.

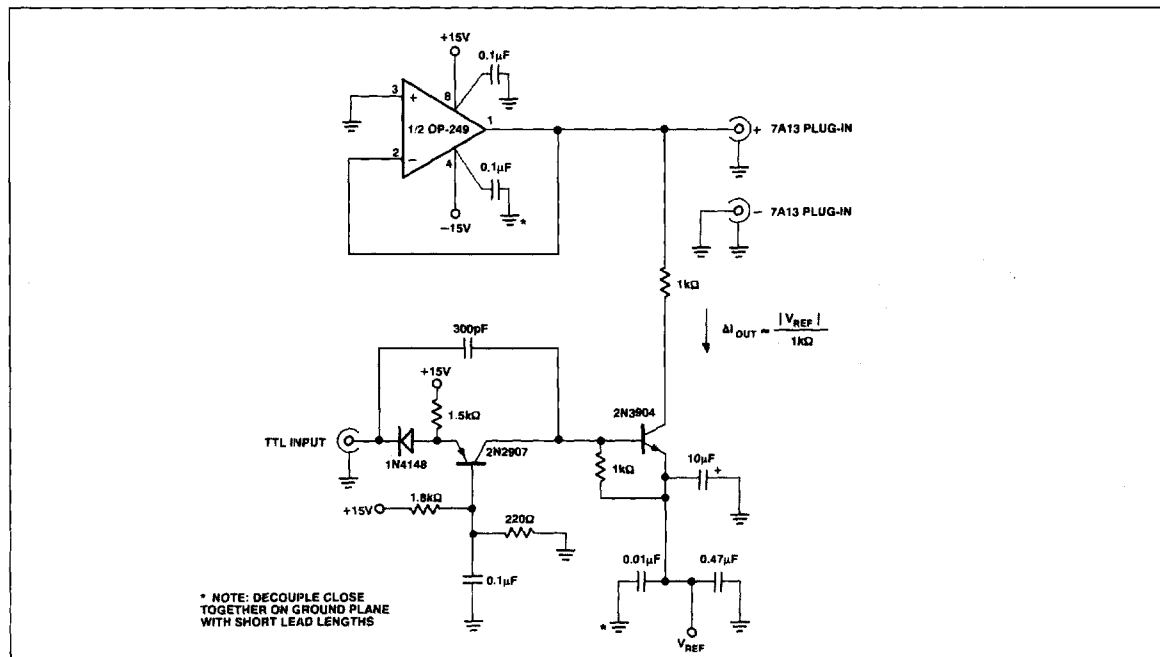
Figure 9 shows a settling measurement circuit for evaluating recovery from an output current transient. An output disturbing



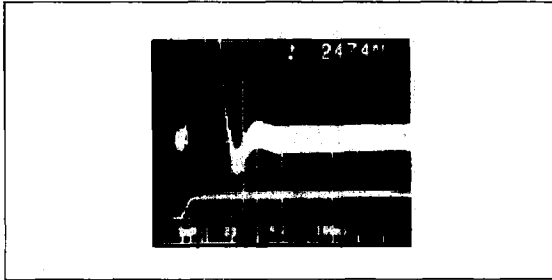
**FIGURE 8:** Effect of Altering Compensation from Circuit in Figure 7a – PM-7545 CMOS DAC with 1/2 OP-249, Unipolar Operation. Critically Damped Response Will Be Obtained with C ≈ 33pF



OPERATIONAL AMPLIFIERS/BUFFERS



**FIGURE 9:** Transient Output Impedance Test Fixture

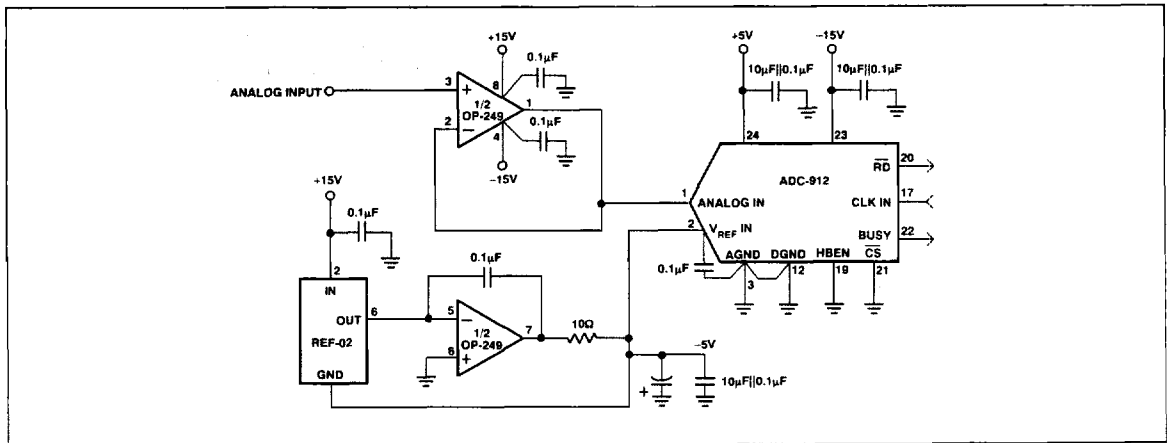


**FIGURE 10:** OP-249's Transient Recovery Time from a 1mA Load Transient to 0.01%

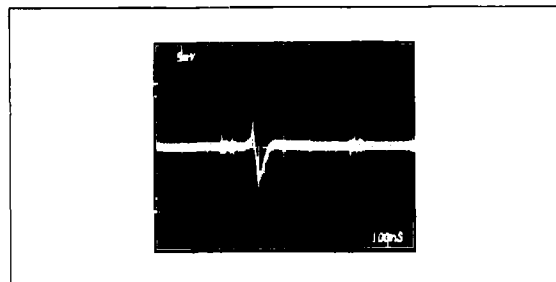
current generator provides the transient change in output load current of 1mA. As seen in Figure 10, the OP-249 has extremely fast recovery of 274ns (to 0.01%), for a 1mA load transient. The performance makes it an ideal amplifier for data acquisition systems.

The combination of high speed and excellent DC performance of the OP-249 makes it an ideal amplifier for 12-bit data acquisition systems. Examining the circuit in Figure 11, one amplifier in the OP-249 provides a stable  $-5V$  reference voltage for the  $V_{REF}$  input of the ADC-912. The other amplifier in the OP-249 performs high-speed buffering of the A/D's input.

Examining the worst case transient voltage error (Figure 12) at the Analog In node of the A/D converter: the OP-249 recovers in less than 100ns. The fast recovery is due to both the OP-249's wide bandwidth and low DC output impedance.



**FIGURE 11:** OP-249 Dual Amplifiers Provide Both Stable  $-5V$  Reference Input, and Buffers Input to ADC-912



**FIGURE 12:** Worst Case Transient Voltage, at Analog In, Occurs at the Half-Scale Point of the A/D. OP-249 Buffers the A/D Input from Figure 11, and Recovers in Less than 100ns

#### OP-249 SPICE MACRO-MODEL

Figures 13 and 14 show the node and net list for a SPICE macro-model of the OP-249. 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  $I_{SV}$ . 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-249. The poles and zeros in the model were determined from the actual open and closed-loop gain and phase response of the OP-249. In this way the model presents an accurate AC representation of the actual device. The model assumes an ambient temperature of 25°C.

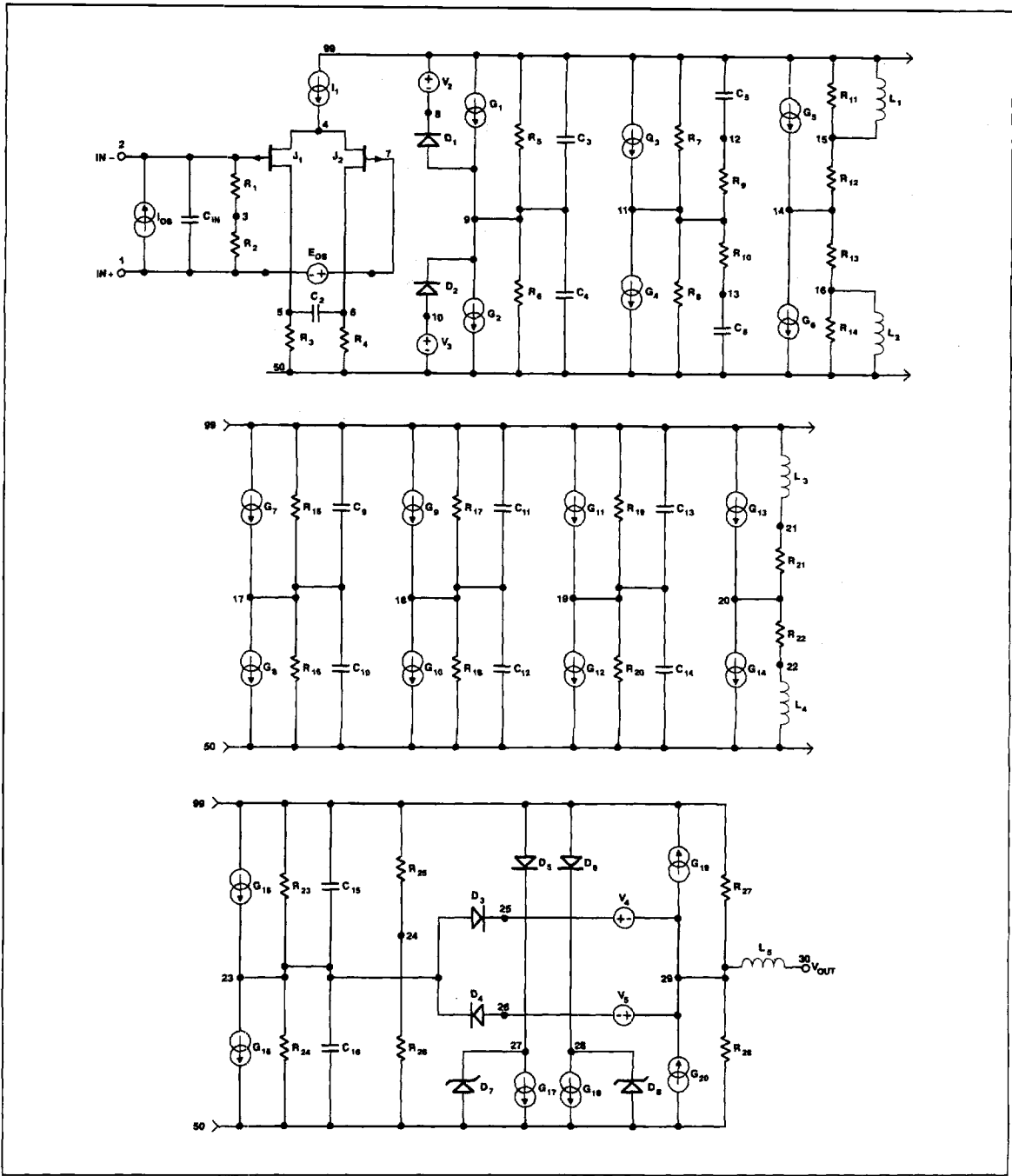


FIGURE 13: OP-249 Macro-Model

OPERATIONAL AMPLIFIERS/BUFFERS



OP-249 MACRO-MODEL ©PMI 1989

\* subckt OP-249 1 2 30 99 50

INPUT STAGE &amp; POLE AT 100MHZ

```

r1 2 3 5E11
r2 1 3 5E11
r3 5 50 652.3
r4 6 50 652.3
cin 1 2 5E-12
c2 5 6 1.22E-12
i1 99 4 1E-3
ios 1 2 3.1E-12
eos 7 1 poly(1) 20 24 150E-6 1
j1 5 2 4 jx
j2 6 7 4 jx
    
```

\* SECOND STAGE &amp; POLE AT 12.2Hz

```

r5 9 99 326.1E6
r6 9 50 326.1E6
c3 9 99 40E-12
c4 9 50 40E-12
g1 99 9 poly(1) 5 6 4.25E-3 1.533E-3
g2 9 50 poly(1) 6 5 4.25E-3 1.533E-3
v2 99 8 2.9
v3 10 50 2.9
d1 9 8 dx
d2 10 9 dx
    
```

\* POLE-ZERO PAIR AT 2MHz/4.0MHz

```

r7 11 99 1E6
r8 11 50 1E6
r9 11 12 1E6
r10 11 13 1E6
c5 12 99 37.79E-15
c6 13 50 37.79E-15
g3 99 11 9 24 1E-6
g4 11 50 24 9 1E-6
    
```

\* ZERO-POLE PAIR AT 4MHz/8MHz

```

r11 99 15 1E6
r12 14 15 1E6
r13 14 16 1E6
r14 50 16 1E6
i1 99 15 19.89E-3
i2 50 16 19.89E-3
g5 99 14 11 24 1E-6
g6 14 50 24 11 1E-6
    
```

\* POLE AT 20MHz

```

r15 17 99 1E6
r16 17 50 1E6
c9 17 99 7.96E-15
c10 17 50 7.96E-15
g7 99 17 14 24 1E-6
g8 17 50 24 14 1E-6
    
```

\* POLE AT 50MHz

```

r17 18 99 1E6
r18 18 50 1E6
c11 18 99 3.18E-15
c12 18 50 3.18E-15
g9 99 18 17 24 1E-6
g10 18 50 24 17 1E-6
    
```

\* POLE AT 50MHz

```

r19 19 99 1E6
r20 19 50 1E6
c13 19 99 3.18E-15
c14 19 50 3.18E-15
g11 99 19 18 24 1E-6
g12 19 50 24 18 1E-6
    
```

\* COMMON-MODE GAIN NETWORK WITH ZERO AT 60kHz

```

r21 20 21 1E6
r22 20 22 1E8
i3 21 99 2.65
i4 22 50 2.65
g13 99 20 3 24 1.78E-11
g14 20 50 24 3 1.78E-11
    
```

\* POLE AT 50MHz

```

r23 23 99 1E6
r24 23 50 1E6
c15 23 99 3.18E-15
c16 23 50 3.18E-15
g15 99 23 19 24 1E-6
g16 23 50 24 19 1E-6
    
```

\* OUTPUT STAGE

```

r25 24 99 135E3
r26 24 50 135E3
r27 29 99 70
r28 29 50 70
i5 29 30 4E-7
g17 27 50 23 29 14.3E-3
g18 28 50 29 23 14.3E-3
g19 29 99 99 23 14.3E-3
g20 50 29 23 50 14.3E-3
v4 25 29 .4
v5 29 26 .4
d3 23 25 dx
d4 26 23 dx
d5 99 27 dx
d6 99 28 dx
d7 50 27 dy
d8 50 28 dy
    
```

\* MODELS USED

```

* model jx PJF(BETA=1.175E-3 VTO=-2.000 IS=21E-12)
* model dx D(IS=1E-15)
* model dy D(IS=1E-15 BV=50)
* ends OP-249
    
```

FIGURE 14: OP-249 SPICE Net List



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\*\* HSPICE is a tradename of Meta-Software, Inc.