

TL087, TL088, TL287, TL288 JFET-INPUT OPERATIONAL AMPLIFIERS

D2484, MARCH 1979—REVISED MARCH 1989

- Low Input Offset Voltage . . . 0.5 mV Max
- Low Power Consumption
- Wide Common-Mode and Differential Voltage Ranges
- Low Input Bias and Offset Currents
- High Input Impedance . . . JFET-Input Stage
- Internal Frequency Compensation
- Latch-Up-Free Operation
- High Slew Rate . . . 18 V/ μ s Typ
- Low Total Harmonic Distortion . . . 0.003% Typ

description

These JFET-input operational amplifiers incorporate well-matched high-voltage JFET and bipolar transistors in a monolithic integrated circuit. They feature low input offset voltage, high slew rate, low input bias and offset currents, and low temperature coefficient of input offset voltage. Offset-voltage adjustment is provided for the TL087 and TL088.

The M-suffix devices are characterized for operation over the full military temperature range of -55°C to 125°C . The I-suffix devices are characterized for operation from -40°C to 85°C , and the C-suffix devices are characterized for operation from 0°C to 70°C .

AVAILABLE OPTIONS

T _A	TYPE	V _{IO} MAX AT 25°C	PACKAGE				
			SMALL OUTLINE (D)	CERAMIC DIP (JG)	METAL CAN (L)	PLASTIC DIP (P)	FLAT (U)
0°C to 70°C	Single	0.5 mV 1 mV	TL087CD TL088CD	TL087CJG TL088CJG	TL087CL TL088CL	TL087CP TL088CP	
	Dual	0.5 mV 1 mV	TL287CD TL288CD	TL287CJG TL288CJG	TL287CL TL288CL	TL287CP TL288CP	
-40°C to 85°C	Single	0.5 mV 1 mV	TL087ID TL088ID	TL087IJG TL088IJG	TL087IL TL088IL	TL087IP TL088IP	
	Dual	0.5 mV 1 mV	TL287ID TL288ID	TL287IJG TL288IJG	TL287IL TL288IL	TL287IP TL288IP	
-55°C to 125°C	Single	1 mV		TL088MJG	TL088ML		TL088MU
	Dual	1 mV		TL288MJG	TL288ML		TL288MU

The D package is available taped and reeled. Add the suffix R to the device type (e.g., TL087CDR).

PRODUCTION DATA documents contain information current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

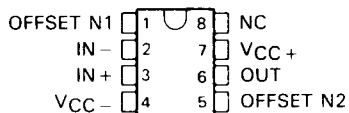
TEXAS
INSTRUMENTS

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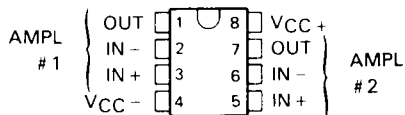
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TL087, TL088, TL287, TL288 **JFET-INPUT OPERATIONAL AMPLIFIERS**

TL087, TL088
D, JG, OR P PACKAGE
(TOP VIEW)

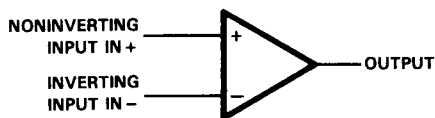


TL287, TL288
D, JG, OR P PACKAGE
(TOP VIEW)

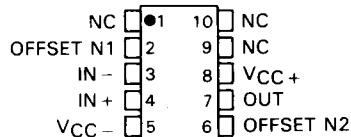


NC—No internal connection

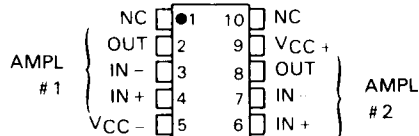
symbol (each amplifier)



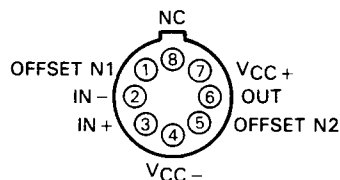
TL088M
U PACKAGE
(TOP VIEW)



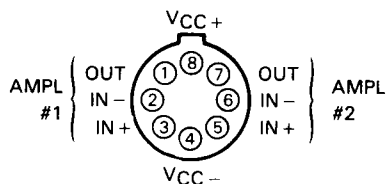
TL288M
U PACKAGE
(TOP VIEW)



TL087, TL088
L PACKAGE
(TOP VIEW)



TL287, TL288
L PACKAGE
(TOP VIEW)



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

TL087, TL088, TL287, TL288 JFET-INPUT OPERATIONAL AMPLIFIERS

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

		TL088M TL288M	TL087I TL088I TL287I TL288I	TL087C TL088C TL287C TL288C	UNIT
Supply voltage, V_{CC+} (see Note 1)		18	18	18	V
Supply voltage, V_{CC-} (see Note 1)		− 18	− 18	− 18	V
Differential input voltage (see Note 2)		± 30	± 30	± 30	V
Input voltage (see Notes 1 and 3)		± 15	± 15	± 15	V
Input current, I_I (each input)		± 1	± 1	± 1	mA
Output current, I_O (each output)		± 80	± 80	± 80	mA
Total V_{CC+} terminal current		160	160	160	mA
Total V_{CC-} terminal current		− 160	− 160	− 160	mA
Duration of output short circuit (see Note 4)		unlimited	unlimited	unlimited	
Continuous total dissipation		See Dissipation Rating Table			
Operating free-air temperature range		− 55 to 125	− 25 to 85	0 to 70	°C
Storage temperature range		− 65 to 150	− 65 to 150	− 65 to 150	°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds	JG, L, or U package	300	300	300	°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	D or P package		260	260	°C

- NOTES: 1. All voltage values, except differential voltages, are with respect to the midpoint between V_{CC+} and V_{CC-} .
2. Differential voltages are at the noninverting input terminal with respect to the inverting input terminal.
3. The magnitude of the input voltage must never exceed the magnitude of the supply voltage or 15 V, whichever is less.
4. The output may be shorted to ground or to either supply. Temperature and/or supply voltages must be limited to ensure that the dissipation rating is not exceeded.

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25^\circ\text{C}$	DERATING FACTOR ABOVE $T_A = 25^\circ\text{C}$	$T_A = 70^\circ\text{C}$	$T_A = 85^\circ\text{C}$	$T_A = 125^\circ\text{C}$
	POWER RATING		POWER RATING	POWER RATING	POWER RATING
D	725 mW	5.8 mW/°C	464 mW	377 mW	N/A
JG	1050 mW	8.4 mW/°C	672 mW	546 mW	210 mW
L	650 mW	5.2 mW/°C	416 mW	338 mW	130 mW
P	1000 mW	8.0 mW/°C	640 mW	520 mW	N/A
U	675 mW	5.4 mW/°C	432 mW	351 mW	135 mW

recommended operating conditions

		M-SUFFIX			I-SUFFIX			C-SUFFIX			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	
Supply voltage, V_{CC}		± 5		± 15	± 5		± 15	± 5		± 15	V
Common-mode input voltage, V_{IC}	$V_{CC\pm} = \pm 5\text{ V}$	-1		4	-1		4	-1		4	V
	$V_{CC\pm} = \pm 15\text{ V}$	-11		11	-11		11	-11		11	V
Input voltage, V_I	$V_{CC\pm} = \pm 5\text{ V}$	-1		4	-1		4	-1		4	V
	$V_{CC\pm} = \pm 15\text{ V}$	-11		11	-11		11	-11		11	V
Operating free-air temperature, T_A		-55		125	-40		85	0		70	°C

TL087, TL088, TL287, TL288

JFET-INPUT OPERATIONAL AMPLIFIERS

electrical characteristics, $V_{CC} \pm = \pm 15 \text{ V}$

PARAMETER	TEST CONDITIONS†	TL088M TL288M		TL087I TL088I TL287I TL288I		TL087C TL088C TL287C TL288C		UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	
V_{IO} Input offset voltage	$R_S = 50 \Omega$, $V_O = 0$, $T_A = 25^\circ\text{C}$				0.1	0.5	0.1 0.5	
	$T_A = 25^\circ\text{C}$				0.1	1	0.1 1	mV
	$R_S = 50 \Omega$, $V_O = 0$, $T_A = \text{full range}$		0.1	3		2	1.5	
	$T_A = \text{full range}$			6		3	2.5	
	$T_A = \text{full range}$							
$\alpha_{V_{IO}}$ Temperature coefficient of input offset voltage	$R_S = 50 \Omega$, $T_A = 25^\circ\text{C}$ to MAX		10		8		8	$\mu\text{V}/^\circ\text{C}$
I_{IO} Input offset current	$T_A = 25^\circ\text{C}$		5		5	100	5 100	pA
I_{IB} Input bias current†	$T_A = \text{full range}$			25		3	2	nA
V_{ICR} Common-mode input voltage range	$T_A = 25^\circ\text{C}$		30	200		30 200	30 200	pA
V_{OPP} Maximum-peak-to-peak output voltage swing	$T_A = \text{full range}$			100		20	7	nA
A_{VD} Large-signal differential voltage amplification	$R_L \geq 2 \text{ k}\Omega$, $T_A = 25^\circ\text{C}$, $V_O = \pm 10 \text{ V}$	$V_{CC} - +4$ to $V_{CC} + -4$	50	105	$V_{CC} - +4$ to $V_{CC} + -4$	50 105	50 105	V/mV
B_1 Input resistance	$R_L \geq 2 \text{ k}\Omega$, $T_A = 25^\circ\text{C}$, $V_O = \pm 10 \text{ V}$	24 27	24	20	24 27	24 20	25	MHz
r_i Input resistance	$R_L \geq 2 \text{ k}\Omega$, $T_A = 25^\circ\text{C}$, $V_O = \pm 10 \text{ V}$	24 27	24	20	24 27	24 20	25	Ω
CMRR Common-mode rejection ratio	$R_L \geq 2 \text{ k}\Omega$, $T_A = 25^\circ\text{C}$, $V_O = \pm 10 \text{ V}$	80	93		80	93	80 93	dB
kSVR Supply voltage rejection ratio ($\Delta V_{CC} \pm / \Delta V_{IO}$)	$R_L \geq 2 \text{ k}\Omega$, $T_A = 25^\circ\text{C}$, $V_O = \pm 10 \text{ V}$	80	99		80	99	80 99	dB
I_{CC} Supply current (per amplifier)	No load, $T_A = 25^\circ\text{C}$, $V_O = 0$	2.6	2.8		2.6	2.8	2.6 2.8	mA

†All characteristics are measured under open-loop conditions with zero common-mode input voltage unless otherwise specified. Full range for T_A is -55°C to 125°C for TL088M; -40°C to 85°C for TL087I, TL088I, TL287I, and 0°C to 70°C for TL288I.

†Input bias currents of a FET-input operational amplifier are normal junction reverse currents, which are temperature sensitive. Pulse techniques must be used that will maintain the junction temperature as close to the ambient temperature as possible.

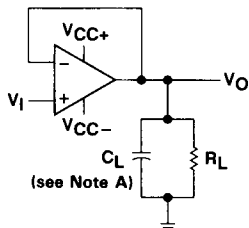
TL087, TL088, TL287, TL288
JFET-INPUT OPERATIONAL AMPLIFIERS

operating characteristics $V_{CC} = \pm 15\text{ V}$, $T_A = 25^\circ\text{C}$

PARAMETER	TEST CONDITIONS	TL088M, TL288M			TL087I, TL087C TL088I, TL088C			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	
SR Slew rate at unity gain	$V_I = 10\text{ V}$, $R_L = 2\text{ k}\Omega$, $C_L = 100\text{ pF}$, $A_{VD} = 1$		18		8	18		$\text{V}/\mu\text{s}$
t_r Rise time	$V_I = 20\text{ mV}$, $R_L = 2\text{ k}\Omega$, $C_L = 100\text{ pF}$, $A_{VD} = 1$		55			55		ns
Overshoot factor			25%			25%		
V_n Equivalent input noise voltage	$R_S = 100\ \Omega$, $f = 1\text{ kHz}$		19			19		$\text{nV}/\sqrt{\text{Hz}}$



PARAMETER MEASUREMENT INFORMATION



NOTE A: C_L includes fixture capacitance.

FIGURE 1. SLEW RATE, RISE/FALL TIME, AND OVERSHOOT TEST CIRCUIT

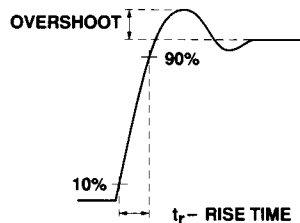


FIGURE 2. RISE TIME AND OVERSHOOT WAVEFORM

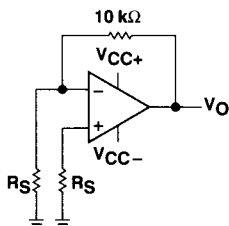


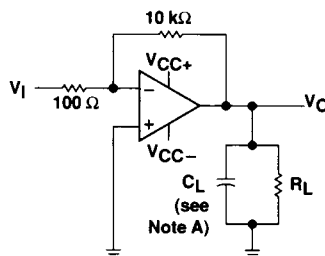
FIGURE 3. NOISE VOLTAGE TEST CIRCUIT

typical values

Typical values as presented in this data sheet represent the median (50% point) of device parametric performance.

input bias and offset current

At the picoamp bias current level typical of these JFET operational amplifiers, accurate measurement of the bias current becomes difficult. Not only does this measurement require a picoammeter, but test socket leakages can easily exceed the actual device bias currents. To accurately measure these small currents, Texas Instruments uses a two-step process. The socket leakage is measured using picoammeters with bias voltages applied, but with no device in the socket. The device is then inserted in the socket and a second test that measures both the socket leakage and the device input bias current is performed. The two measurements are then subtracted algebraically to determine the bias current of the device.



NOTE A: C_L includes fixture capacitance.

FIGURE 4. UNITY-GAIN BANDWIDTH AND PHASE MARGIN TEST CIRCUIT

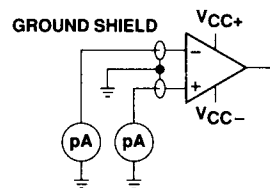


FIGURE 5. INPUT BIAS AND OFFSET CURRENT TEST CIRCUIT

TYPICAL CHARACTERISTICS

table of graphs

			FIGURE
$\alpha_{V_{IO}}$	Temperature coefficient of input offset voltage	Distribution	6, 7
I_{IO}	Input offset current	vs Temperature	8
I_{IB}	Input bias current	vs V_{IC}	9
		vs Temperature	8
V_I	Common-mode input voltage range limits	vs V_{CC}	10
		vs Temperature	11
V_{ID}	Differential input voltage	vs Output voltage	12
V_{OM}	Maximum peak output voltage swing	vs V_{CC}	13
		vs Output current	17
		vs Frequency	14, 15, 16
		vs Temperature	18
A_{VD}	Differential voltage amplification	vs R_L	19
		vs Frequency	20
		vs Temperature	21
z_o	Output impedance	vs Frequency	24
CMRR	Common-mode rejection ratio	vs Frequency	22
		vs Temperature	23
k_{SVR}	Supply-voltage rejection ratio	vs Temperature	25
I_{OS}	Short-circuit output current	vs V_{CC}	26
		vs Time	27
		vs Temperature	28
I_{CC}	Supply current	vs V_{CC}	29
		vs Temperature	30
SR	Slew Rate	vs R_L	31
		vs Temperature	32
	Overshoot factor	vs C_L	33
V_n	Equivalent input noise voltage	vs Frequency	34
THD	Total harmonic distortion	vs Frequency	35
B_1	Unity-gain bandwidth	vs V_{CC}	36
		vs Temperature	37
ϕ_m	Phase margin	vs V_{CC}	38
		vs C_L	39
		vs Temperature	40
	Phase shift	vs Frequency	20
	Pulse response	Small-signal	41
		Large-signal	42

TYPICAL CHARACTERISTICS†

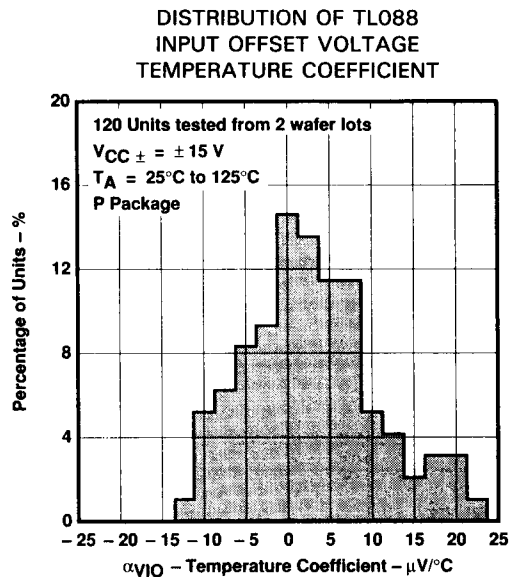


FIGURE 6

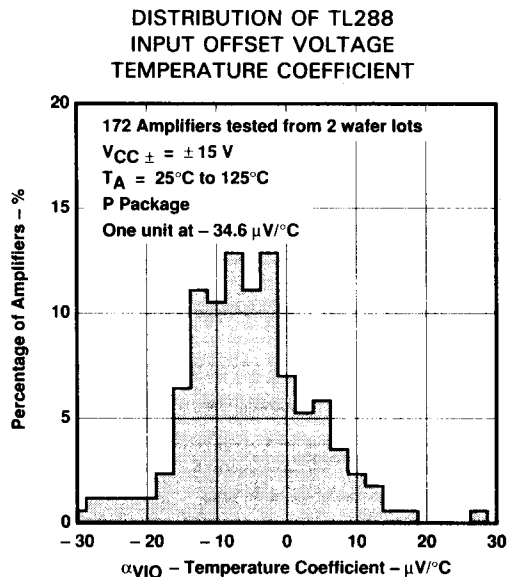


FIGURE 7

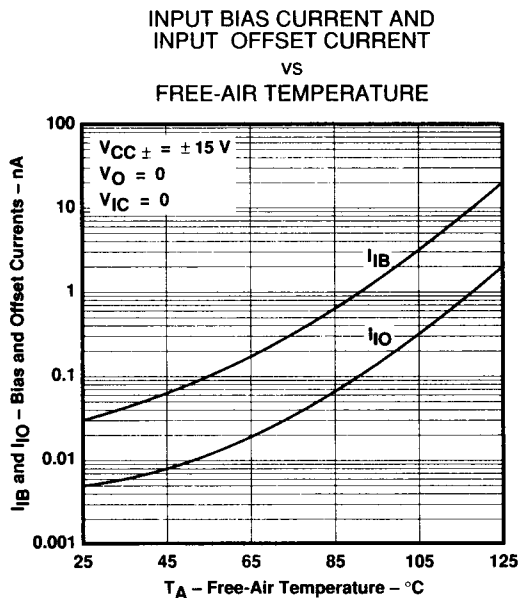


FIGURE 8

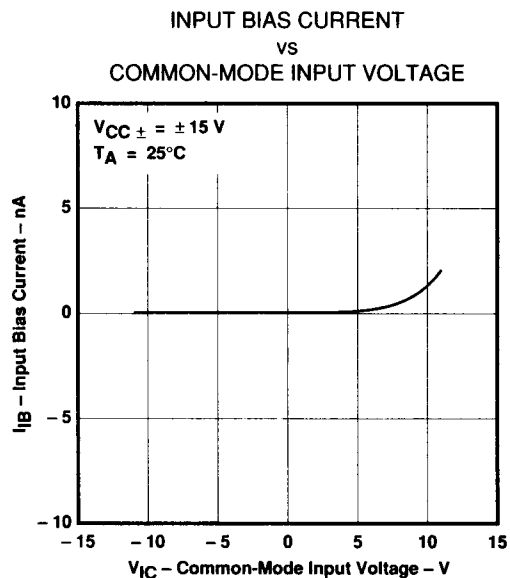


FIGURE 9

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

COMMON-MODE
INPUT VOLTAGE RANGE LIMITS
VS
SUPPLY VOLTAGE

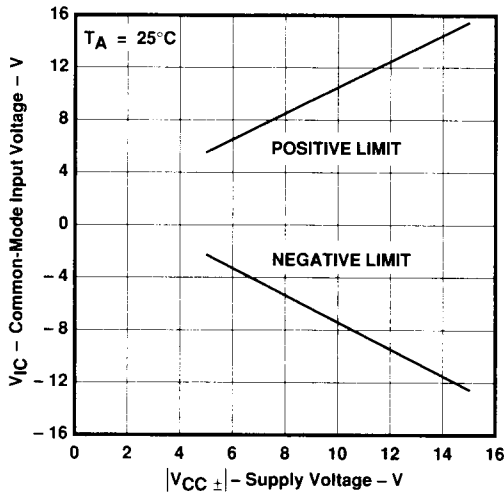


FIGURE 10

COMMON-MODE
INPUT VOLTAGE RANGE LIMITS
VS
FREE-AIR TEMPERATURE

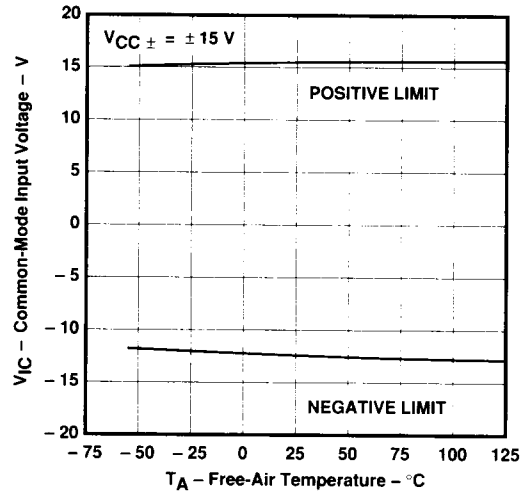


FIGURE 11

OUTPUT VOLTAGE
VS
DIFFERENTIAL INPUT VOLTAGE

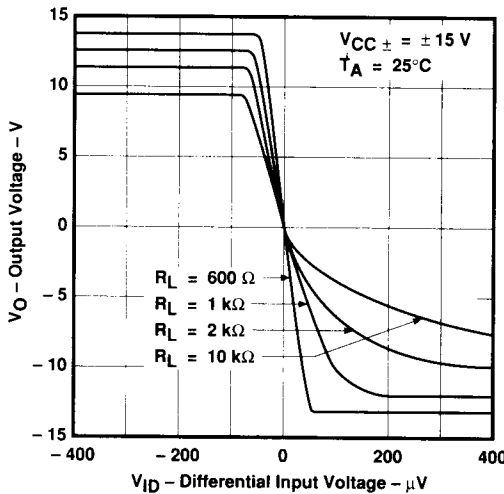


FIGURE 12

MAXIMUM PEAK OUTPUT VOLTAGE
VS
SUPPLY VOLTAGE

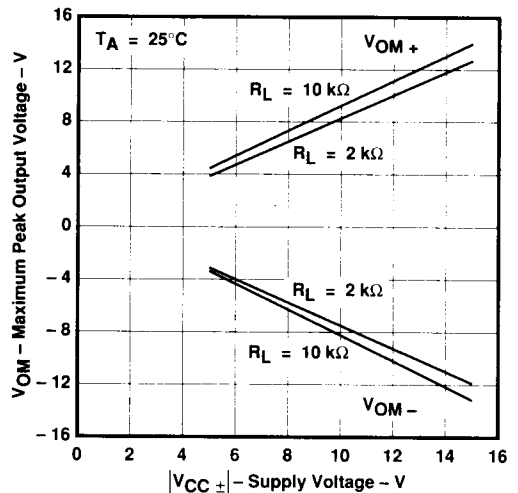


FIGURE 13

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
 VS
 FREQUENCY

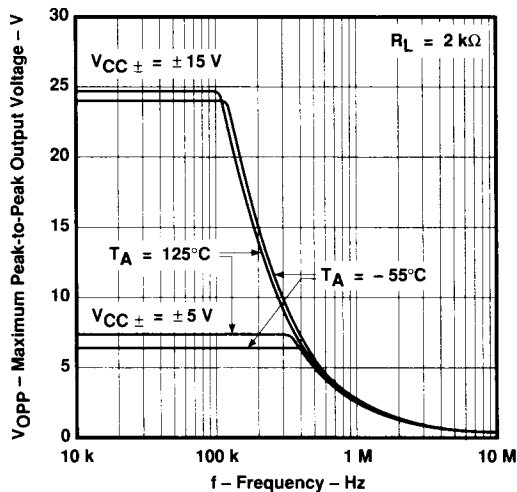


FIGURE 14

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
 VS
 FREQUENCY

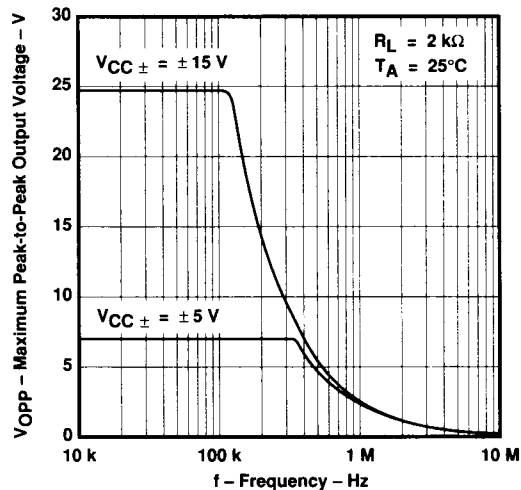


FIGURE 15

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
 VS
 FREQUENCY

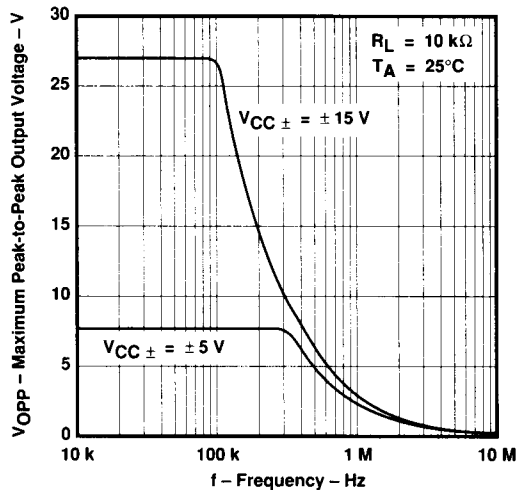


FIGURE 16

MAXIMUM PEAK OUTPUT VOLTAGE
 VS
 OUTPUT CURRENT

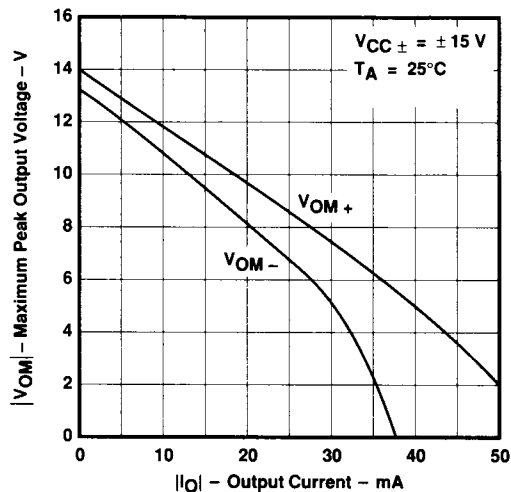


FIGURE 17

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

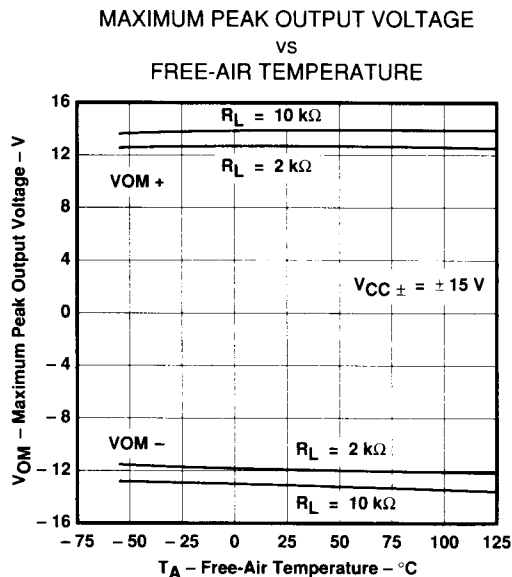


FIGURE 18

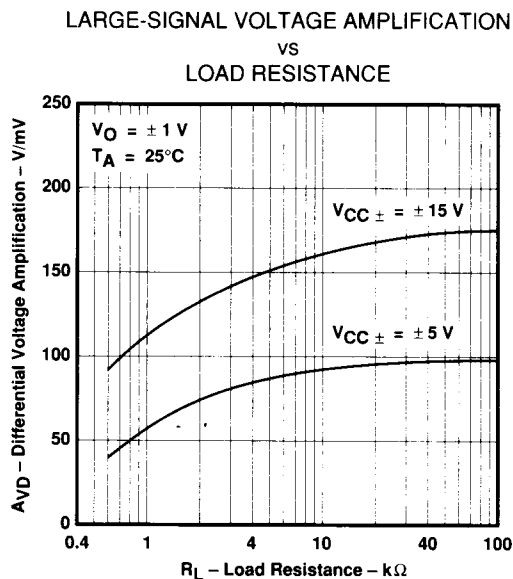


FIGURE 19

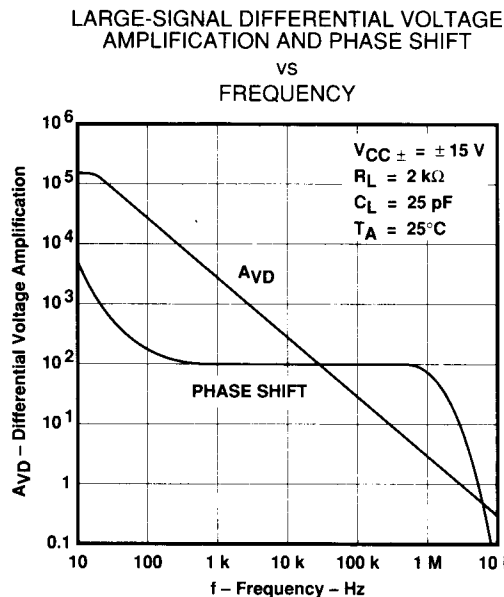


FIGURE 20

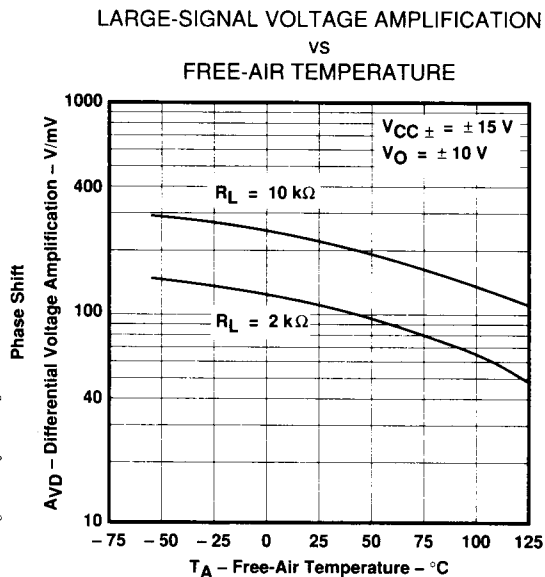


FIGURE 21

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

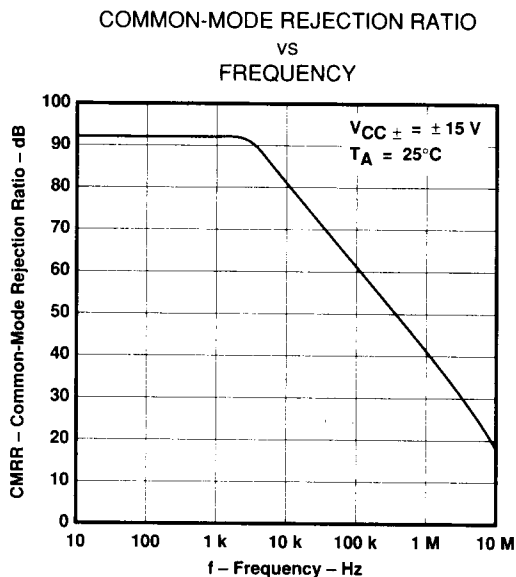


FIGURE 22

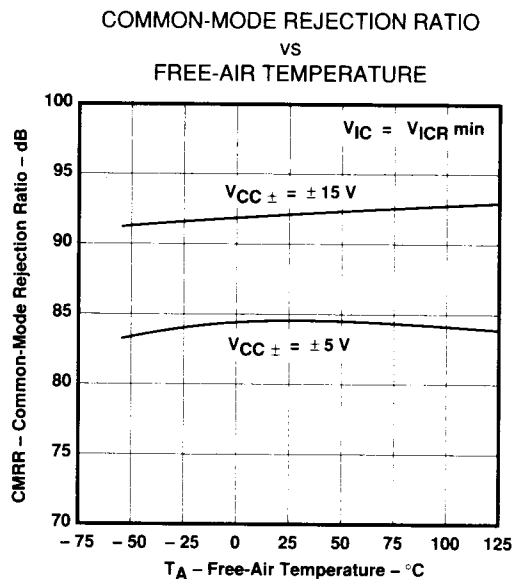


FIGURE 23

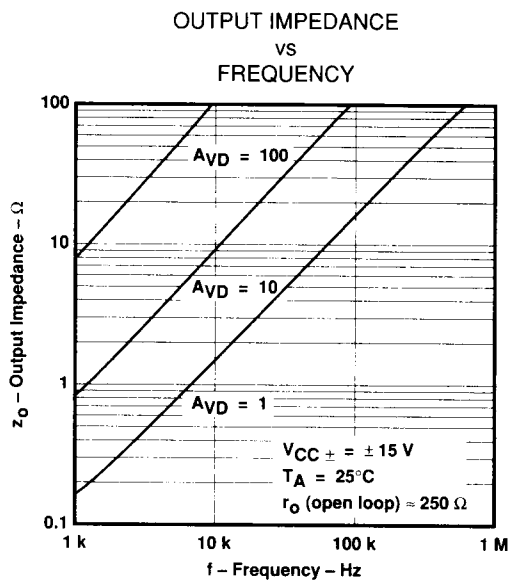


FIGURE 24

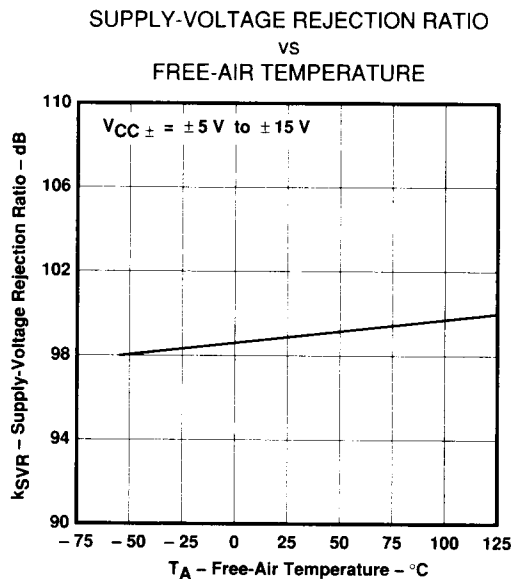


FIGURE 25

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

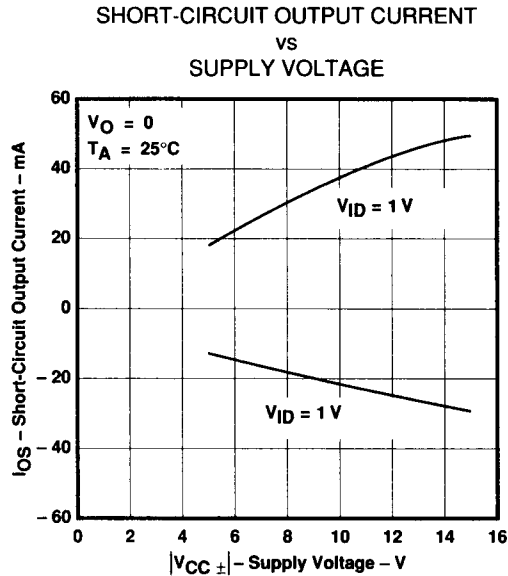


FIGURE 26

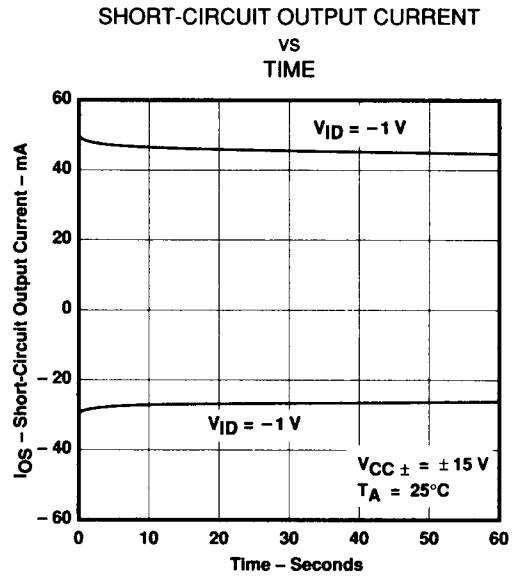


FIGURE 27

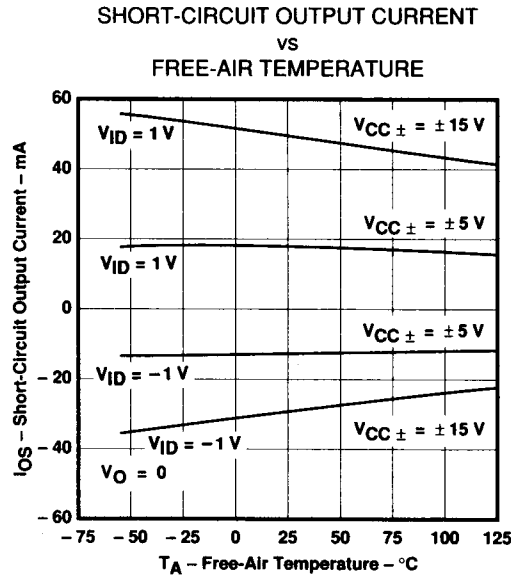
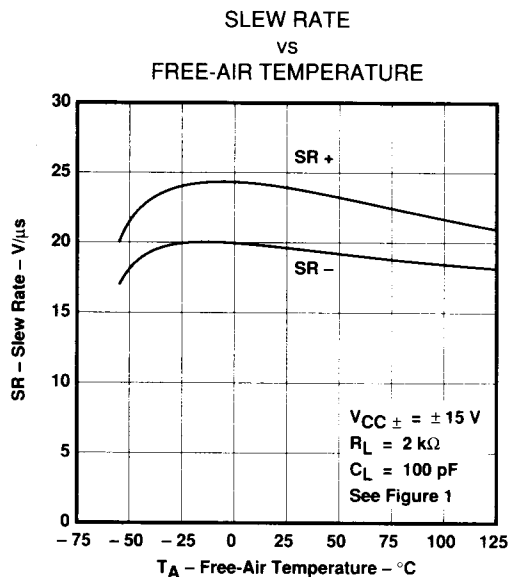
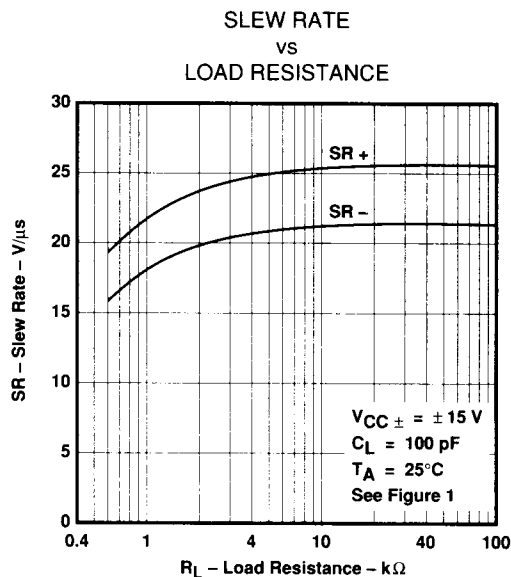
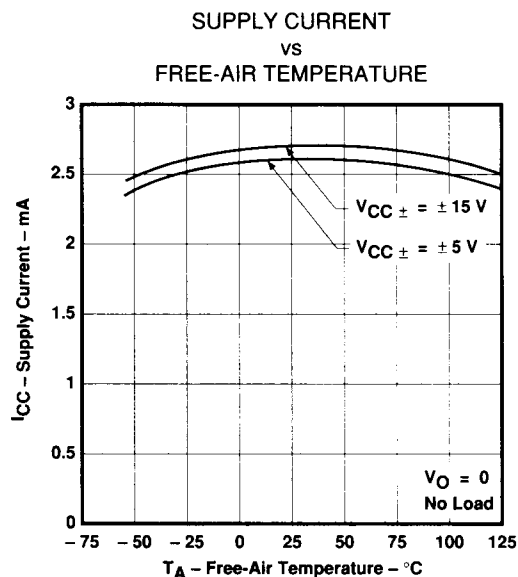
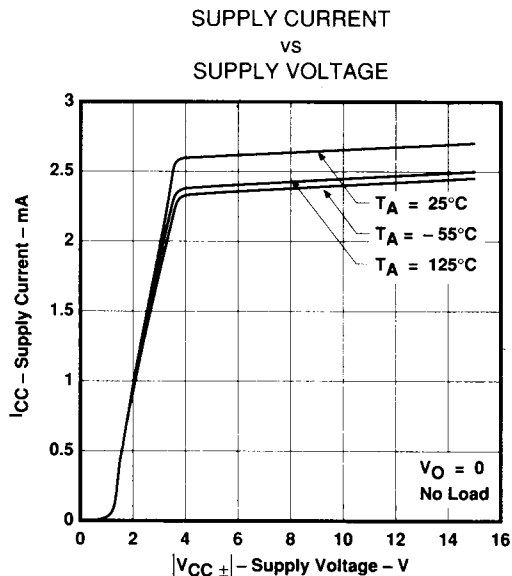


FIGURE 28

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†



†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

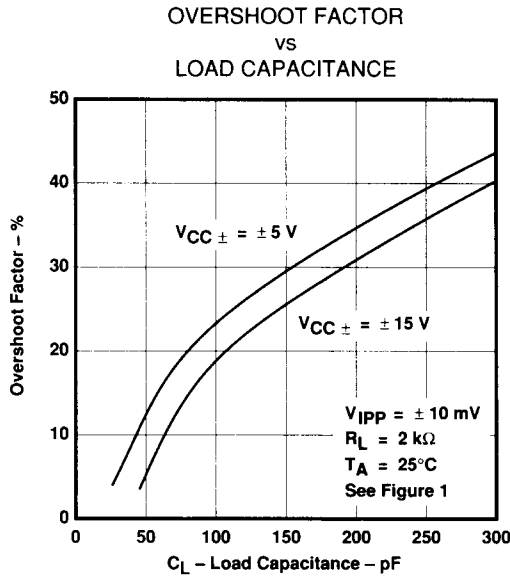


FIGURE 33

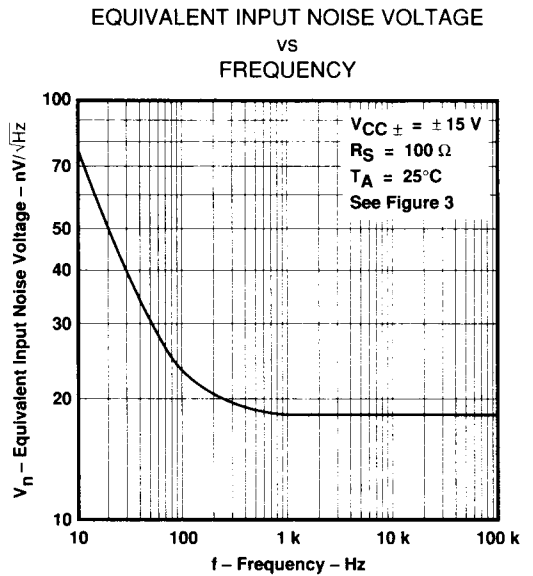


FIGURE 34

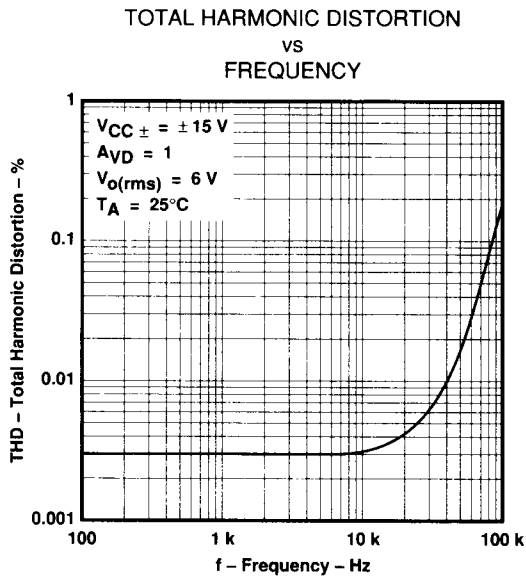


FIGURE 35

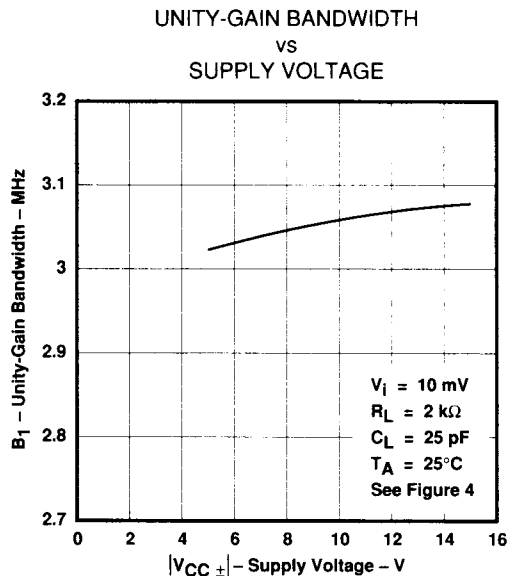


FIGURE 36

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS†

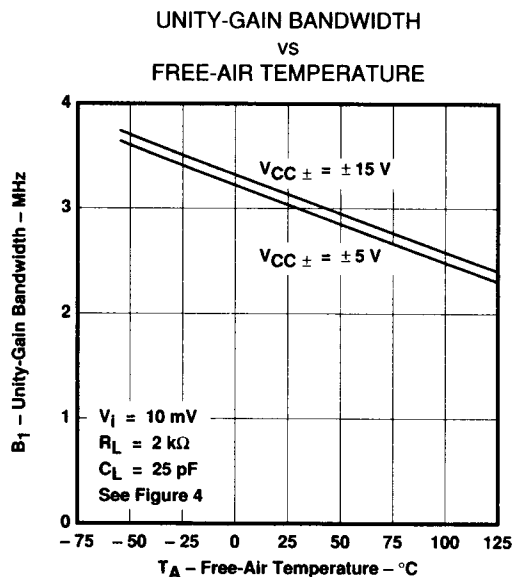


FIGURE 37

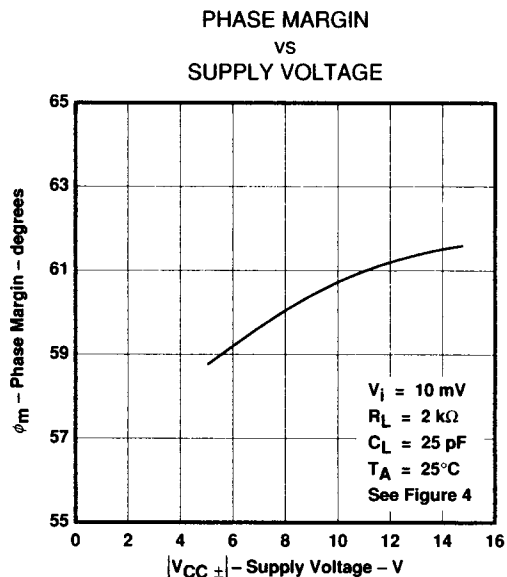


FIGURE 38

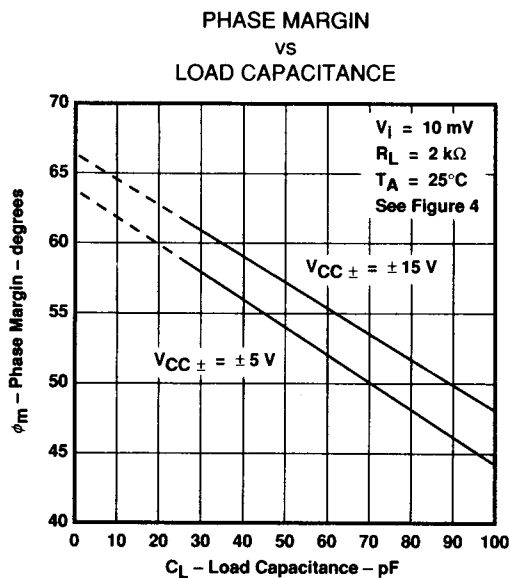


FIGURE 39

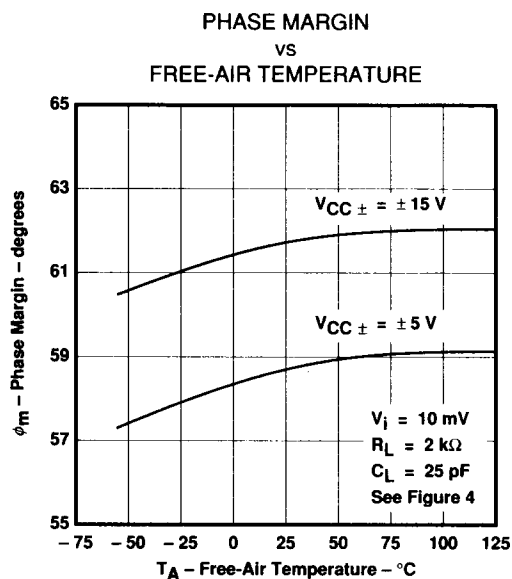


FIGURE 40

†Data at high and low temperatures are applicable within the rated operating free-air temperature ranges of the various devices.

TYPICAL CHARACTERISTICS

VOLTAGE-FOLLOWER
SMALL-SIGNAL
PULSE RESPONSE

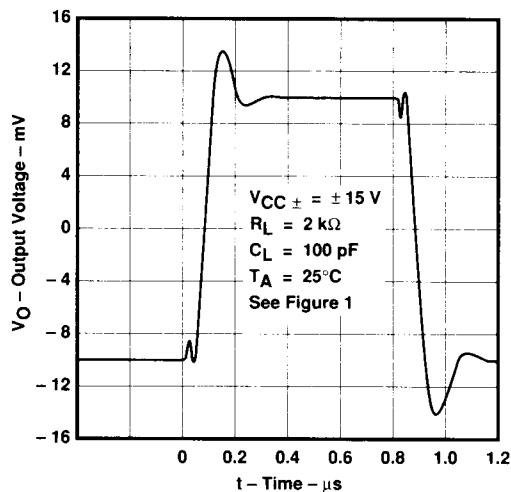


FIGURE 41

VOLTAGE-FOLLOWER
LARGE-SIGNAL
PULSE RESPONSE

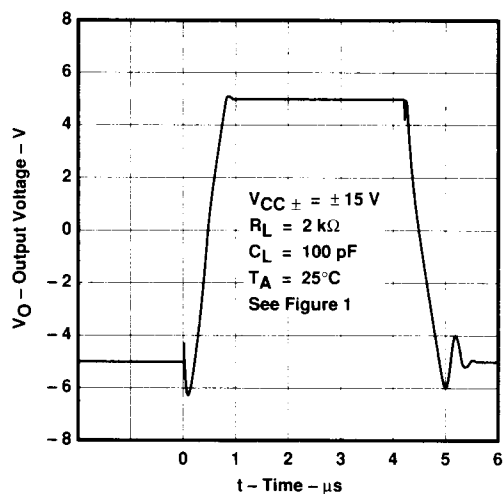


FIGURE 42

TYPICAL APPLICATION DATA

output characteristics

All operating characteristics are specified with 100-pF load capacitance. These amplifiers will drive higher capacitive loads; however, as the load capacitance increases, the resulting response pole occurs at lower frequencies, thereby causing ringing, peaking, or even oscillation. The value of the load capacitance at which oscillation occurs varies with production lots. If an application appears to be sensitive to oscillation due to load capacitance, adding a small resistance in series with the load should alleviate the problem. Capacitive loads of 1000 pF and larger may be driven if enough resistance is added in series with the output (see Figure 43).

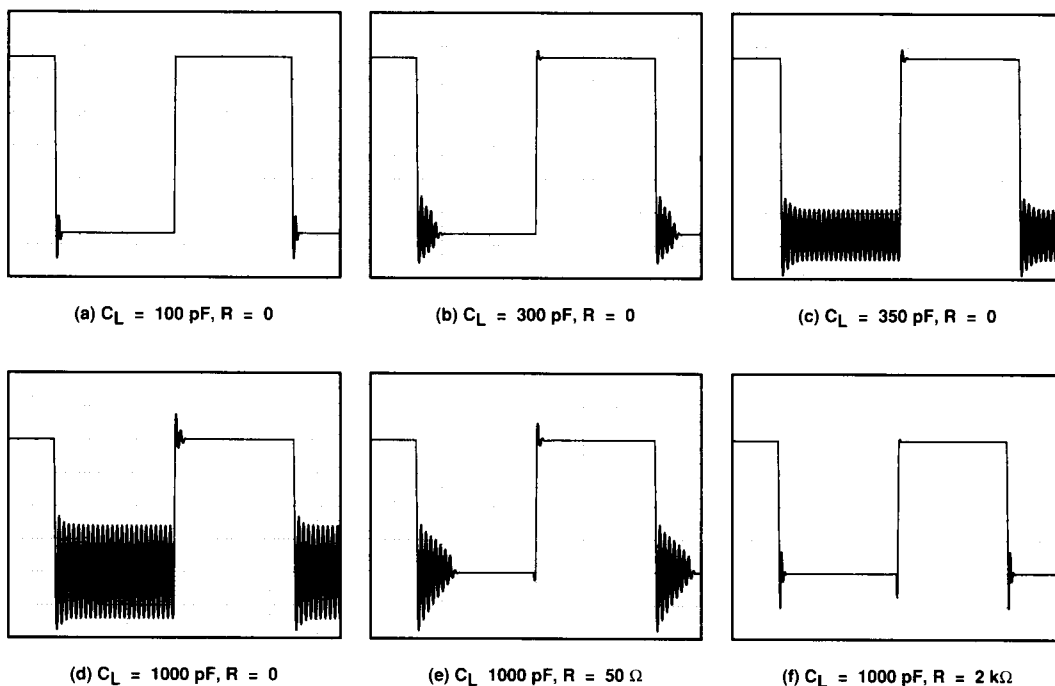
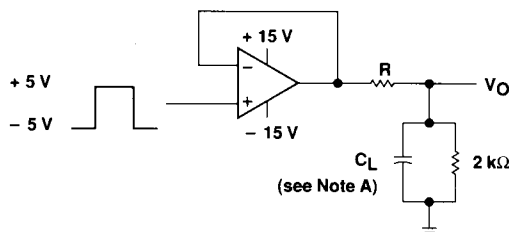


FIGURE 43. EFFECT OF CAPACITIVE LOADS



NOTE A: C_L includes fixture capacitance.

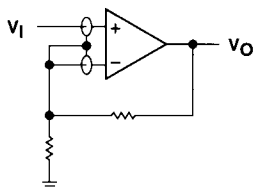
FIGURE 44. TEST CIRCUIT FOR OUTPUT CHARACTERISTICS

TYPICAL APPLICATION DATA

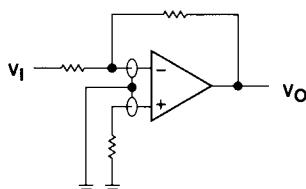
input characteristics

These amplifiers are specified with a minimum and a maximum input voltage that, if exceeded at either input, could cause the device to malfunction.

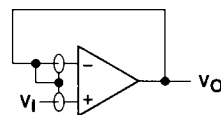
Because of the extremely high input impedance and resulting low bias current requirements, these amplifiers are well suited for low-level signal processing; however, leakage currents on printed circuit boards and sockets can easily exceed bias current requirements and cause degradation in system performance. It is good practice to include guard rings around inputs (see Figure 45). These guards should be driven from a low-impedance source at the same voltage level as the common-mode input.



(a) NONINVERTING AMPLIFIER



(b) INVERTING AMPLIFIER



(c) UNITY-GAIN AMPLIFIER

FIGURE 45. USE OF GUARD RINGS

noise performance

The noise specifications in op amp circuits are greatly dependent on the current in the first-stage differential amplifier. The low input bias current requirements of these amplifiers result in a very low current noise. This feature makes the devices especially favorable over bipolar devices when using values of circuit impedance greater than 50 k Ω .