SLOS082A – D2484, MARCH 1979 – REVISED JANUARY 1993

- **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/μs 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.

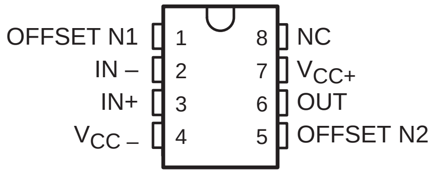
The C-suffix devices are characterized for operation from 0°C to 70°C, and the I-suffix devices are characterized for operation from –40°C to 85°C. The M-suffix devices are characterized for operation over the full military temperature range of –55°C to 125°C.

AVAILABLE OPTIONS

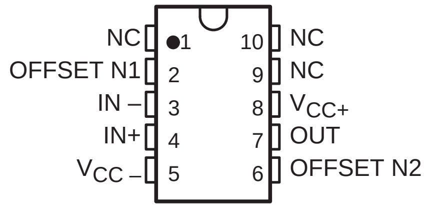
T_A	TYPE	V_{IO} max AT 25°C	PACKAGE			
			SMALL OUTLINE (D)	CERAMIC DIP (JG)	PLASTIC DIP (P)	FLAT (U)
0°C to 70°C	Single	0.5 mV 1 mV	TL087CD TL088CD	TL087CJG TL088CJG	TL087CP TL088CP	
	Dual	0.5 mV 1 mV	TL287CD TL288CD	TL287CJG TL288CJG	TL287CP TL288CP	
–40°C to 85°C	Single	0.5 mV 1 mV	TL087ID TL088ID	TL087IJG TL088IJG	TL087IP TL088IP	
	Dual	0.5 mV 1 mV	TL287ID TL288ID	TL287IJG TL288IJG	TL287IP TL288IP	
–55°C to 125°C	Single	1 mV		TL088MJG		TL088MU
	Dual	1 mV		TL288MJG		TL288MU

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

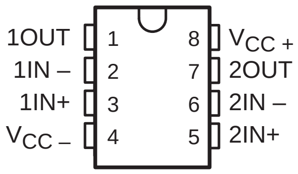
TL087, TL088
D, JG, OR P PACKAGE
(TOP VIEW)



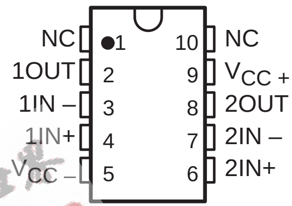
TL088M
U PACKAGE
(TOP VIEW)



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

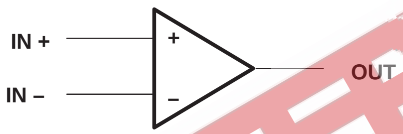


TL288M
U PACKAGE
(TOP VIEW)



NC – No internal connection

symbol (each amplifier)



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 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	$T_A \le 25°C$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25°C$	$T_A = 70°C$ POWER RATING	$T_A = 85°C$ POWER RATING	$T_A = 125°C$ 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
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

		C-SUFFIX			I-SUFFIX			M-SUFFIX			UNIT
		MIN	NOM	MAX	MIN	NOM	MAX	MIN	NOM	MAX	
Supply voltage, V_{CC}		±5		±5	±5		±5	±5		±15	V
Common-mode input voltage, V_{IC}	$V_{CC\pm} = \pm5$ V	–1		4	–1		4	–1		4	V
	$V_{CC\pm} = \pm15$ V	–11		11	–11		11	–11		11	V
Input voltage, V_I	$V_{CC\pm} = \pm5$ V	–1		4	–1		4	–1		4	V
	$V_{CC\pm} = \pm15$ V	–11		11	–11		11	–11		11	V
Operating free-air temperature, T_A		0		70	–40		85	–55		125	°C

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

PARAMETER		TEST CONDITIONS†		TL088M, TL288M MIN	TL088M, TL288M TYP	TL088M, TL288M MAX	TL087I, TL088I, TL287I, TL288I MIN	TL087I, TL088I, TL287I, TL288I TYP	TL087I, TL088I, TL287I, TL288I MAX	TL087C, TL088C, TL287C, TL288C MIN	TL087C, TL088C, TL287C, TL288C TYP	TL087C, TL088C, TL287C, TL288C MAX	UNIT
V_{IO}	Input offset voltage	R_S = 50 Ω, V_O = 0, T_A = 25°C	TL087, TL287					0.1	0.5		0.1	0.5	mV
			TL088, TL288		0.1	3		0.1	1		0.1	1	
		R_S = 50 Ω, V_O = 0, T_A = full range	TL087, TL287						2			1.5	
			TL088, TL288			6			3			2.5	
α_{VIO}	Temperature coefficient of input offset voltage	R_S = 50 Ω,	T_A = 25°C to MAX		10			8			8		μV/°C
I_{IO}	Input offset current	T_A = 25°C			5			5	100		5	100	pA
		T_A = full range				25			3			2	nA
I_{IB}	Input bias current‡	T_A = 25°C			30			30	200		30	200	pA
		T_A = full range				100			20			7	nA
V_{ICR}	Common-mode input voltage range	T_A = 25°C		$V_{CC-}+4$ to $V_{CC+}-4$			$V_{CC-}+4$ to $V_{CC+}-4$			$V_{CC-}+4$ to $V_{CC+}-4$			V
$V_{O(PP)}$	Maximum-peak-to-peak output voltage swing	T_A = 25°C,	R_L = 10 kΩ	24	27		24	27		24	27		V
		T_A = full range	$R_L \ge$ 10 kΩ	24			24			24			
			$R_L \ge$ 2 kΩ	20			20			20			
A_{VD}	Large-signal differential voltage amplification	$R_L \ge$ 2 kΩ, T_A = 25°C	V_O = ±10 V,	50	105		50	105		50	105		V/mV
		$R_L \ge$ 2 kΩ, T_A = full range	V_O = ±10 V,	25			25			25			
B_1	Unity-gain bandwidth	T_A = 25°C			3			3			3		MHz
r_i	Input resistance	T_A = 25°C			10^{12}			10^{12}			10^{12}		Ω
CMRR	Common–mode rejection ratio	R_S = 50 Ω, $V_{IC} = V_{ICR}$ min, T_A = 25°C	V_O = 0 V,	80	93		80	93		80	93		dB
k_{SVR}	Supply voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	R_S = 50 Ω, $V_{CC\pm}$ = ±9 V to ±15 V, T_A = 25°C	V_O = 0 V,	80	99		80	99		80	99		dB
I_{CC}	Supply current (per amplifier)	No load, T_A = 25°C	V_O = 0 V,		26	2.8		2.6	2.8		2.6	2.8	mA

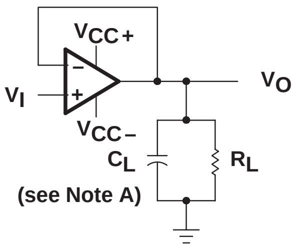
† All characteristics are measured under open–loop conditions with zero common-mode input voltage unless otherwise specified. Full range for T_A is –55°C to 125°C for TL_88M; –40°C to 85°C for TL_8_I; and 0°C to 70°C for TL_8_C.

‡ 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.

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

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

PARAMETER MEASUREMENT INFORMATION



NOTE A: C_L includes fixture capacitance.

Figure 1. Slew Rate, Rise/Fall Time, and Overshoot Test Circuit

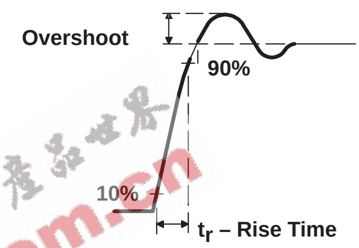


Figure 2. Rise Time and Overshoot Waveform

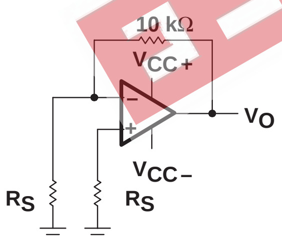
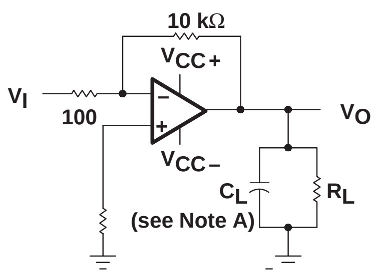


Figure 3. Noise Voltage Test Circuit



NOTE A: C_L includes fixture capacitance.

Figure 4. Unity-Gain Brandwidth and Phase Margin Test Circuit

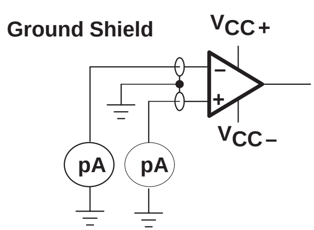


Figure 5. Input Bias and Offset Current Test Circuit

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.

TYPICAL CHARACTERISTICS

table of graphs

			FIGURE
α_{VIO}	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} vs Temperature	9 8
V_I	Common-mode input voltage range limits	vs V_{CC} vs Temperature	10 11
V_{ID}	Differential input voltage	vs Output voltage	12
V_{OM}	Maximum peak output voltage swing	vs V_{CC} vs Output current vs Frequency vs Temperature	13 17 14, 15, 16 18
A_{VD}	Differential voltage amplification	vs R_L vs Frequency vs Temperature	19 20 21
z_o	Output impedance	vs Frequency	24
CMRR	Common-mode rejection ratio	vs Frequency vs Temperature	22 23
k_{SVR}	Supply-voltage rejection ratio	vs Temperature	25
I_{OS}	Short-circuit output current	vs V_{CC} vs Time vs Temperature	26 27 28
I_{CC}	Supply current	vs V_{CC} vs Temperature	29 30
SR	Slew rate	vs R_L vs Temperature	31 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} vs Temperature	36 37
ϕ_m	Phase margin	vs V_{CC} vs C_L vs Temperature	38 39 40
	Phase shift	vs Frequency	20
	Pulse response	Small-signal Large-signal	41 42

TYPICAL CHARACTERISTICS†

DISTRIBUTION OF TL088
INPUT OFFSET VOLTAGE
TEMPERATURE COEFFICIENT

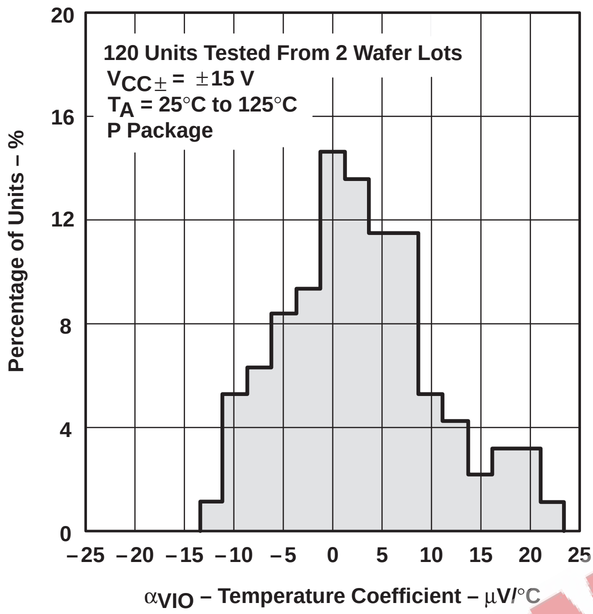


Figure 6

DISTRIBUTION OF TL288
INPUT OFFSET VOLTAGE
TEMPERATURE COEFFICIENT

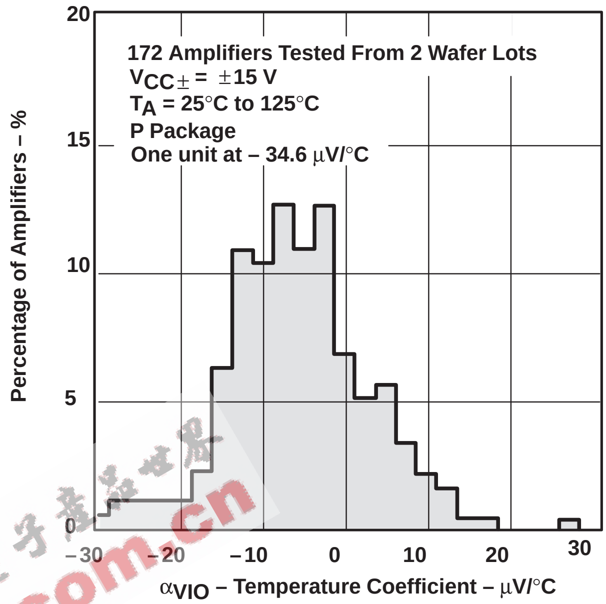


Figure 7

INPUT BIAS CURRENT AND
INPUT OFFSET CURRENT
vs
FREE-AIR TEMPERATURE

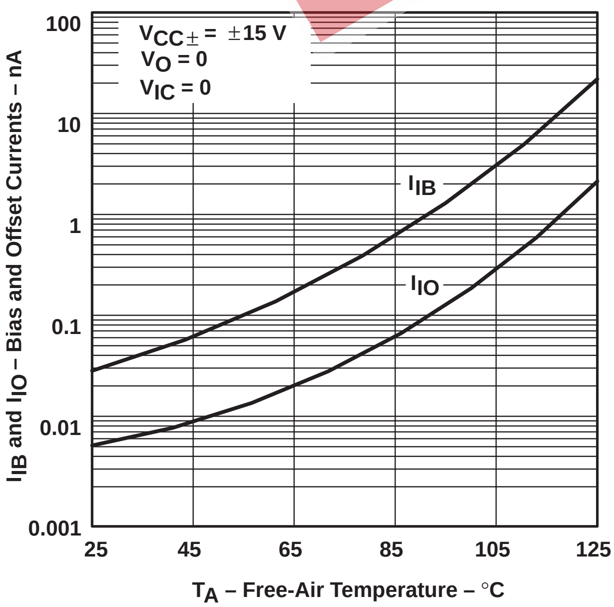


Figure 8

INPUT BIAS CURRENT
vs
COMMON-MODE INPUT VOLTAGE

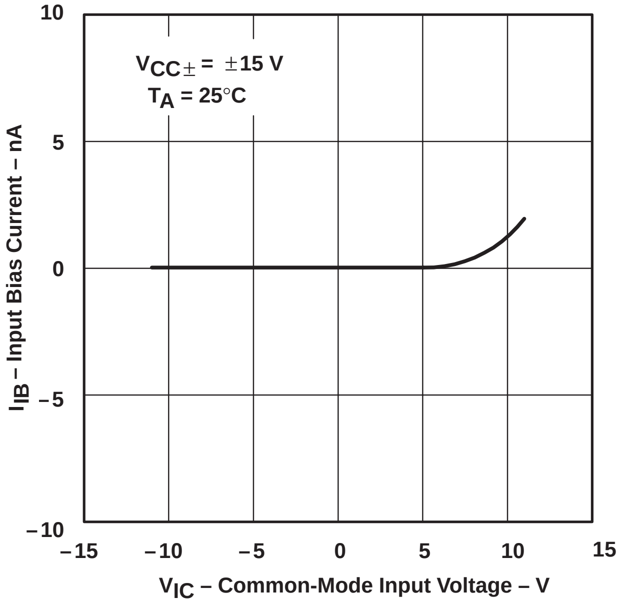


Figure 9

† 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

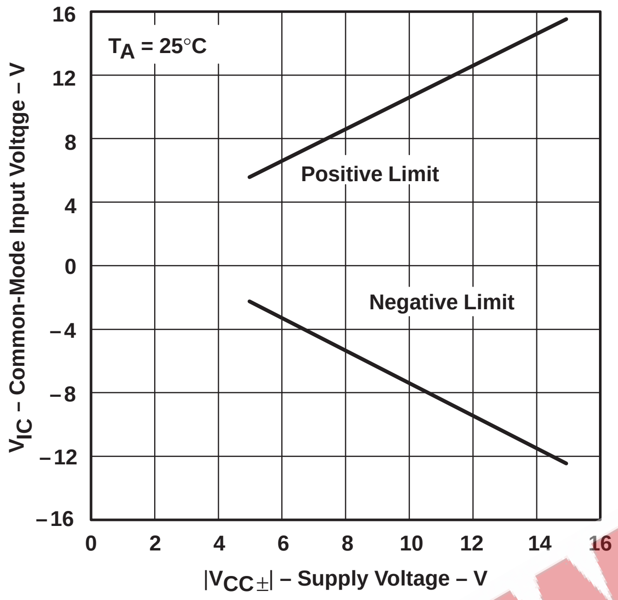


Figure 10

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

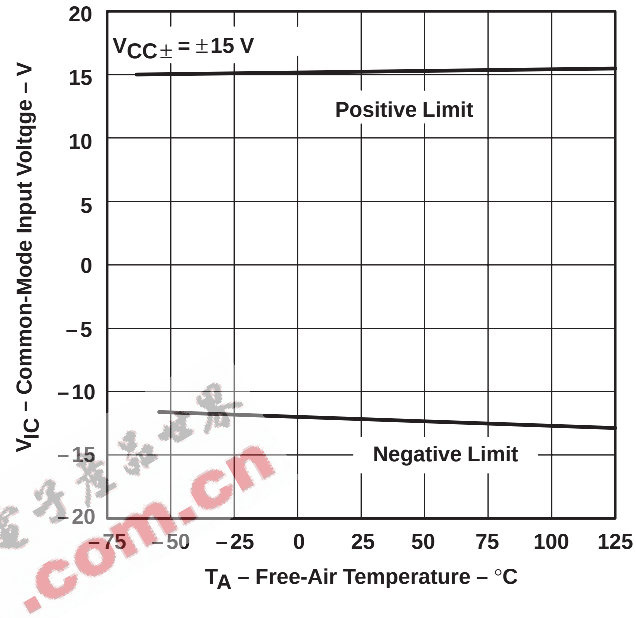


Figure 11

OUTPUT VOLTAGE
vs
DIFFERENTIAL INPUT VOLTAGE

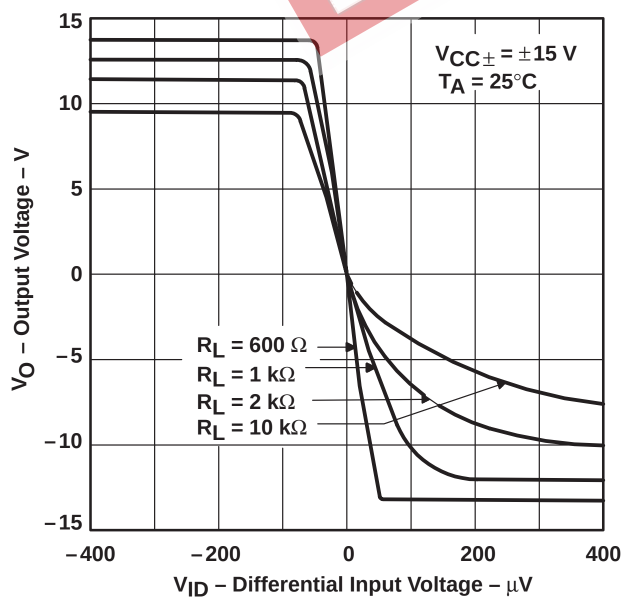


Figure 12

MAXIMUM PEAK OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

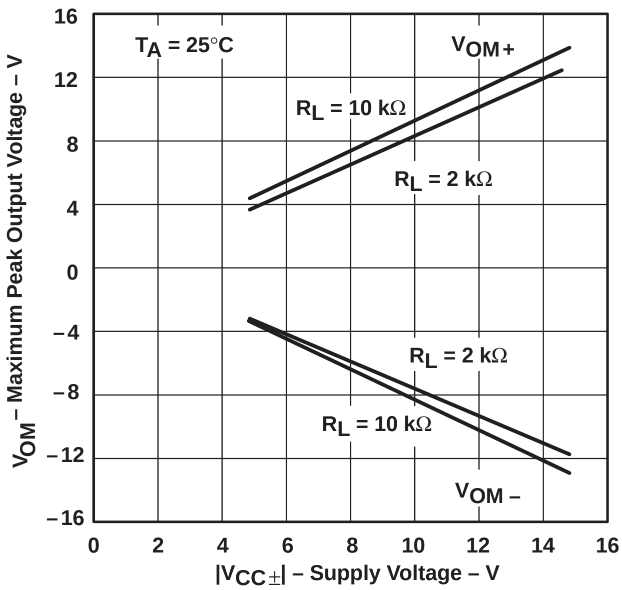


Figure 13

† 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

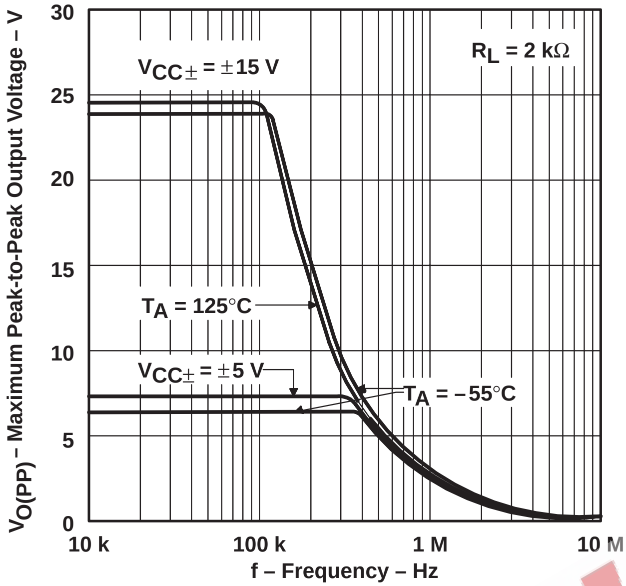


Figure 14

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE vs FREQUENCY

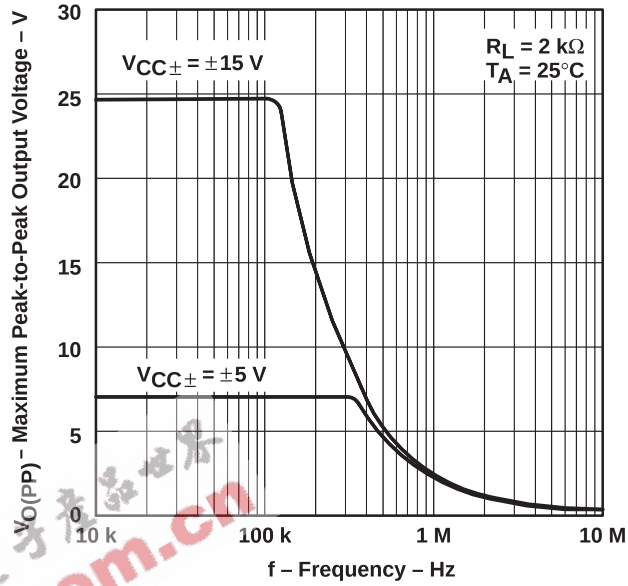


Figure 15

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE vs FREQUENCY

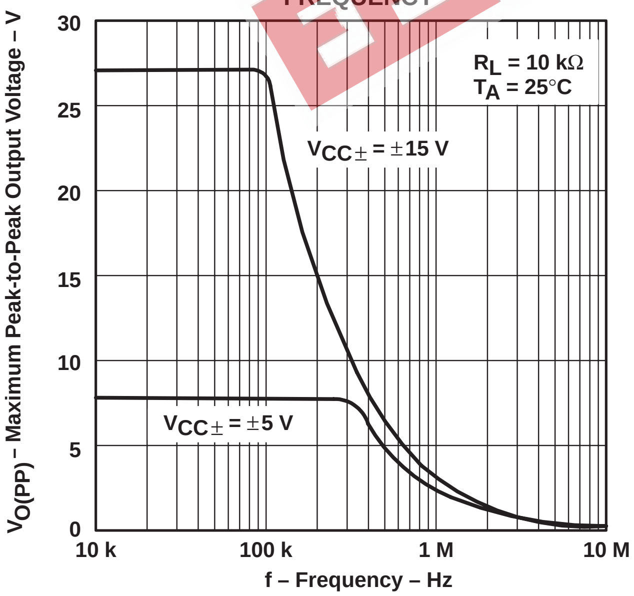


Figure 16

MAXIMUM PEAK OUTPUT VOLTAGE vs OUTPUT CURRENT

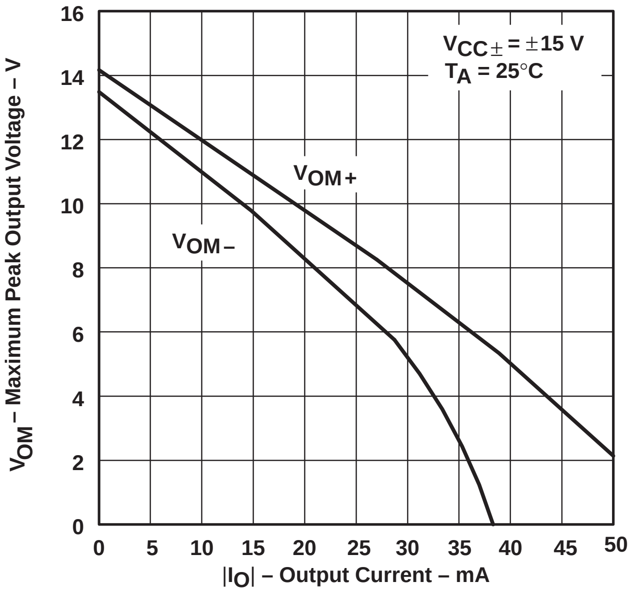


Figure 17

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

TYPICAL CHARACTERISTICS†

MAXIMUM PEAK OUTPUT VOLTAGE vs FREE-AIR TEMPERATURE

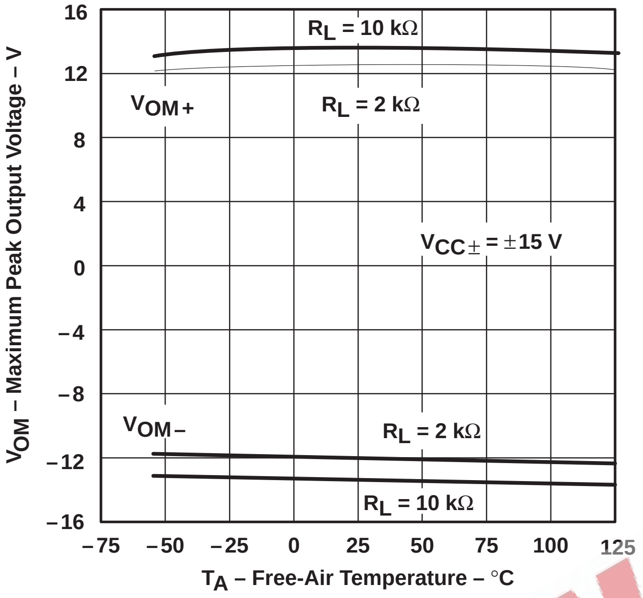


Figure 18

LARGE-SIGNAL VOLTAGE AMPLIFICATION vs LOAD RESISTANCE

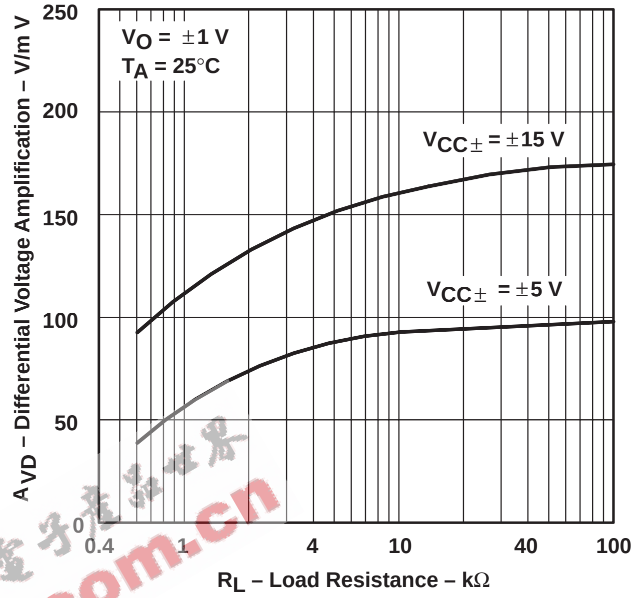


Figure 19

LARGE-SIGNAL DIFFERENTIAL VOLTAGE AMPLIFICATION AND PHASE SHIFT vs FREQUENCY

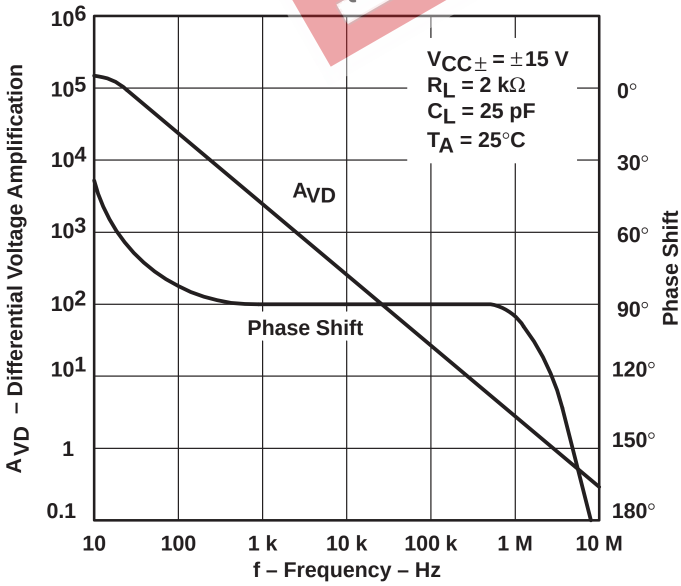


Figure 20

LARGE-SIGNAL VOLTAGE AMPLIFICATION vs FREE-AIR TEMPERATURE

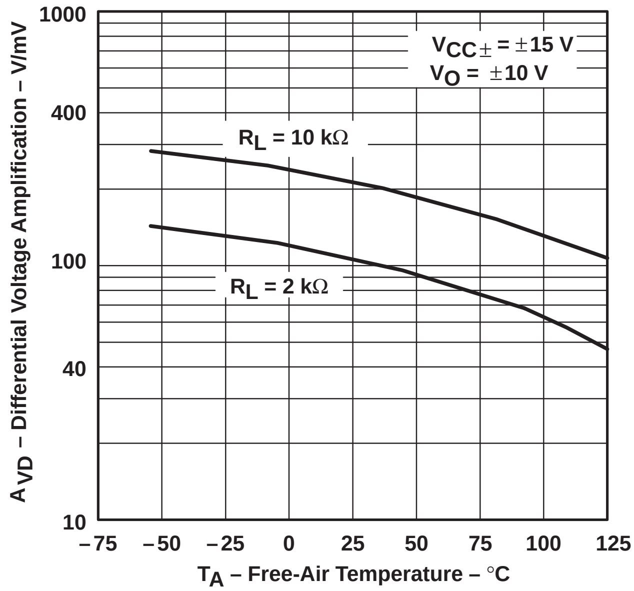


Figure 21

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

TYPICAL CHARACTERISTICS†

COMMON-MODE REJECTION RATIO vs FREQUENCY

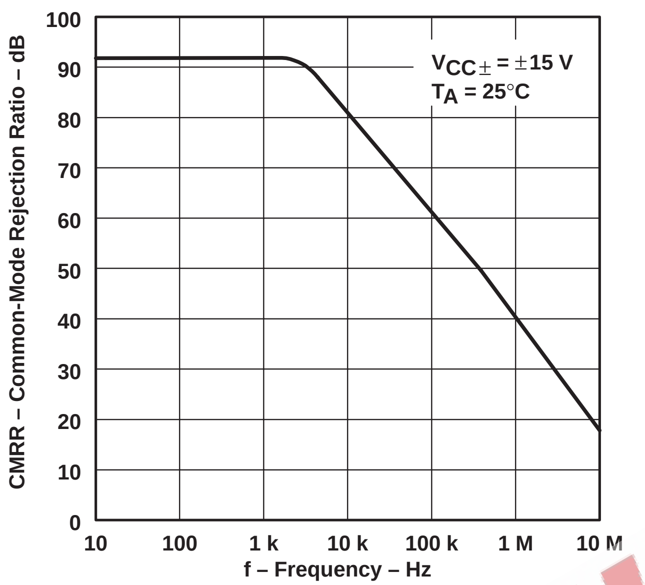


Figure 22

COMMON-MODE REJECTION RATIO vs FREE-AIR TEMPERATURE

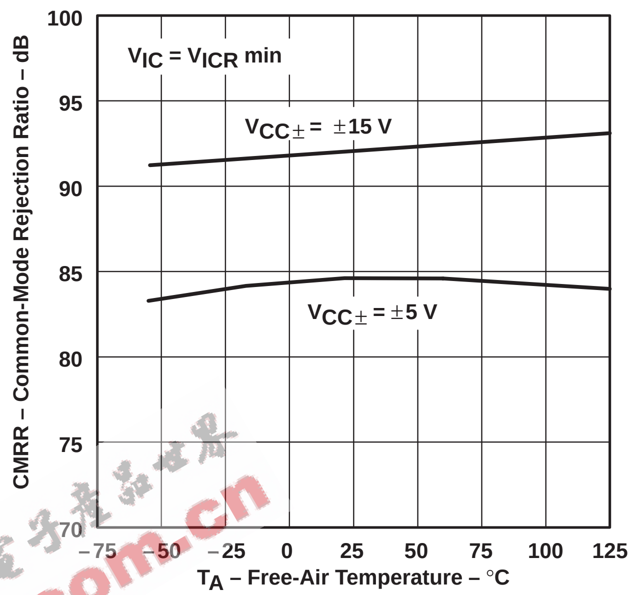


Figure 23

OUTPUT IMPEDANCE vs FREQUENCY

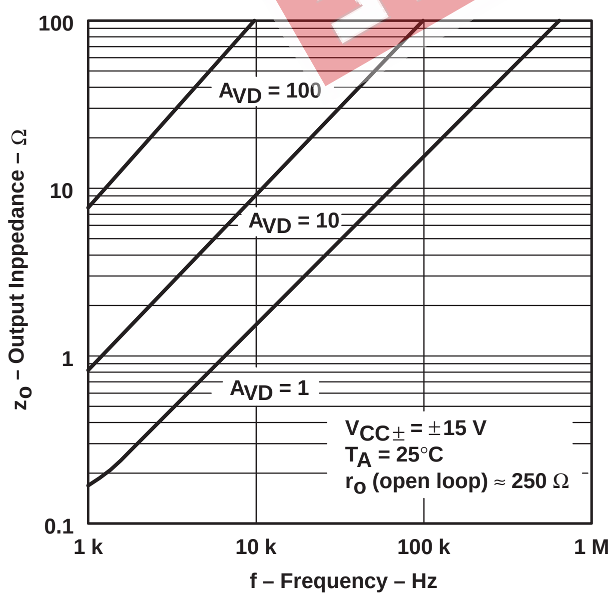


Figure 24

SUPPLY-VOLTAGE REJECTION RATIO vs FREE-AIR TEMPERATURE

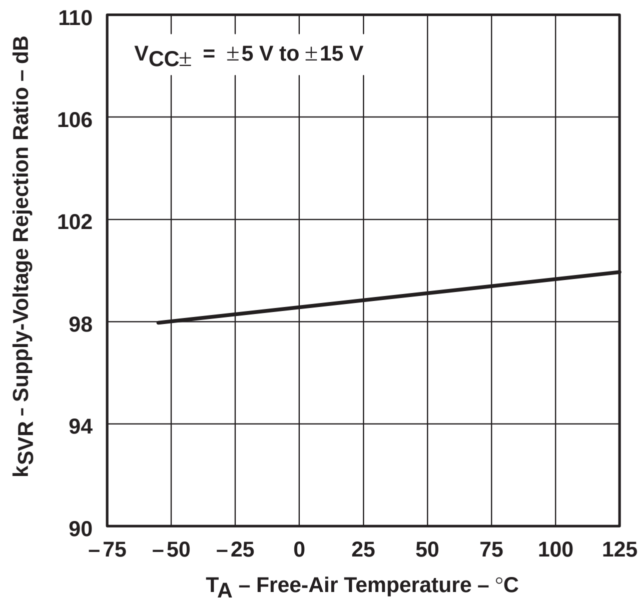


Figure 25

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

TYPICAL CHARACTERISTICS†

SHORT-CIRCUIT OUTPUT CURRENT
vs
SUPPLY VOLTAGE

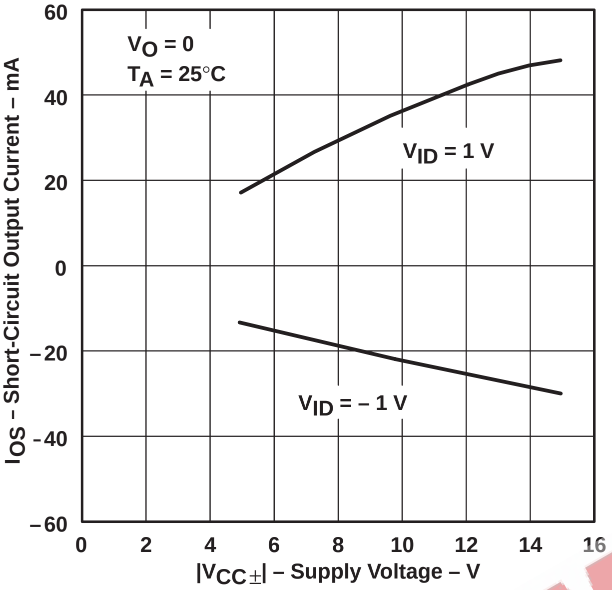


Figure 26

SHORT-CIRCUIT OUTPUT CURRENT
vs
TIME

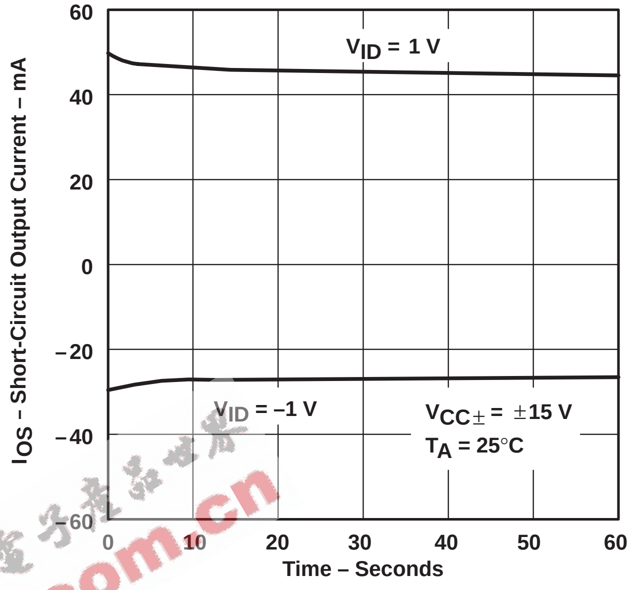


Figure 27

SHORT-CIRCUIT OUTPUT CURRENT
vs
FREE-AIR TEMPERATURE

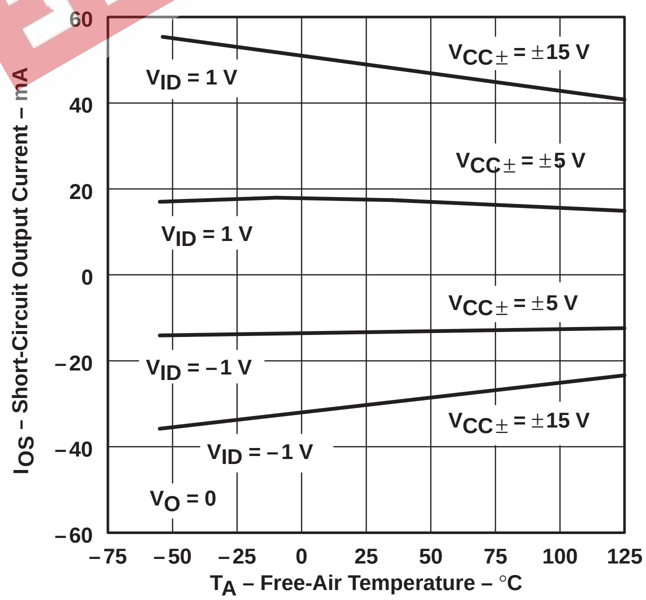


Figure 28

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

TYPICAL CHARACTERISTICS†

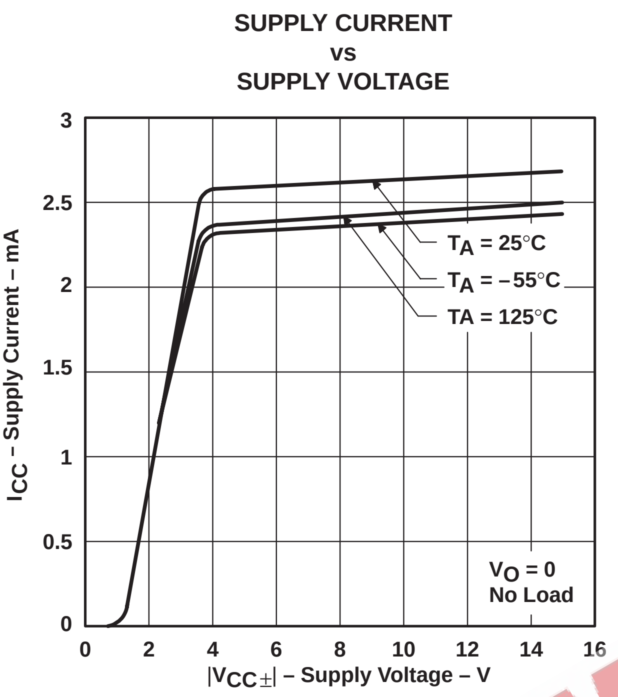


Figure 29

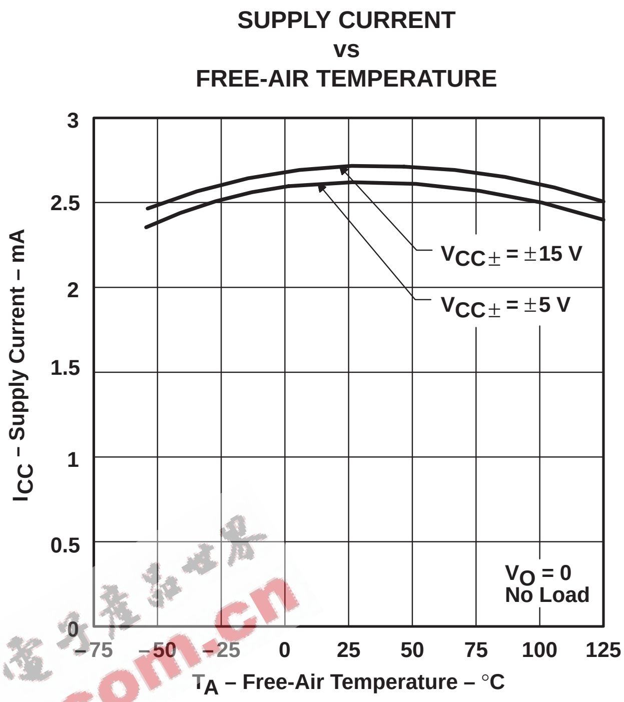
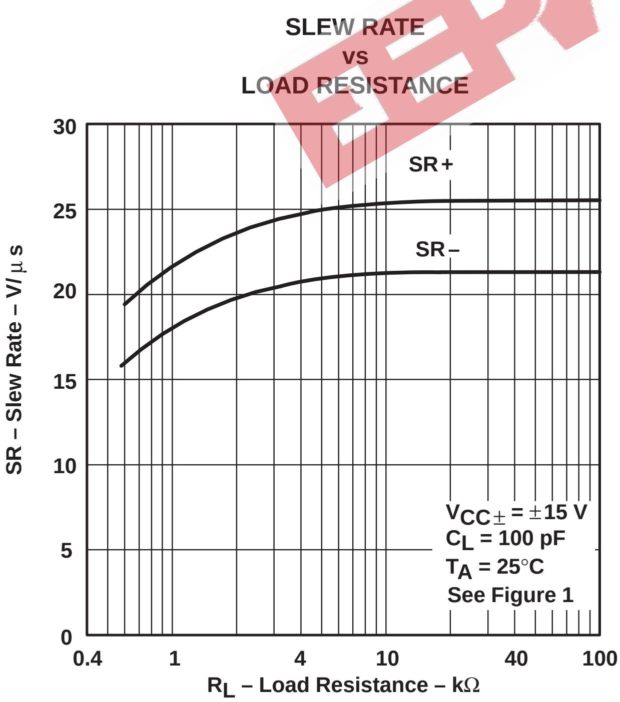


Figure 30



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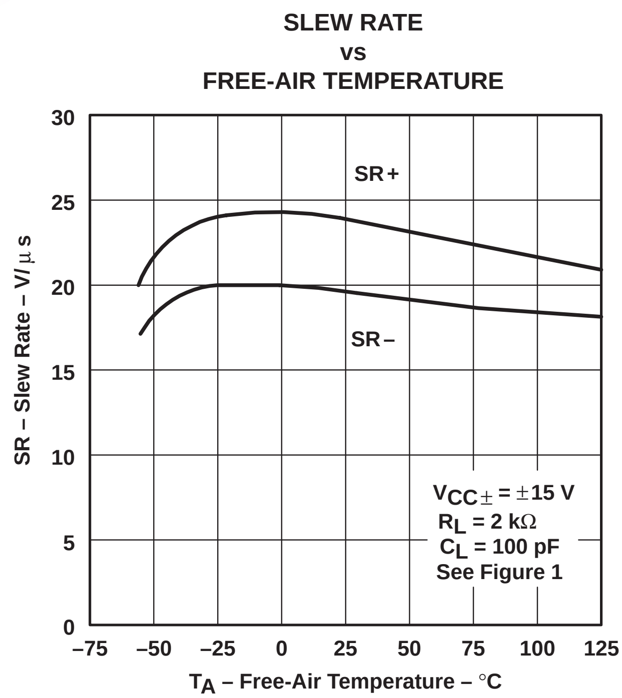


Figure 32

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

TYPICAL CHARACTERISTICS†

OVERSHOOT FACTOR vs LOAD CAPACITANCE

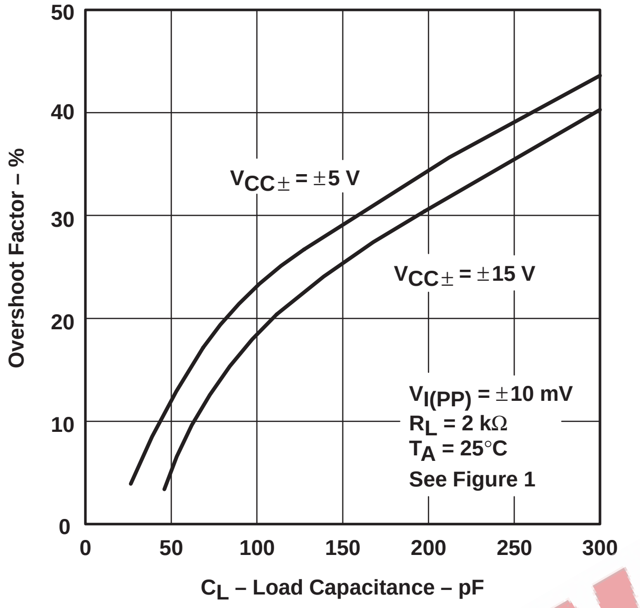


Figure 33

EQUIVALENT INPUT NOISE VOLTAGE vs FREQUENCY

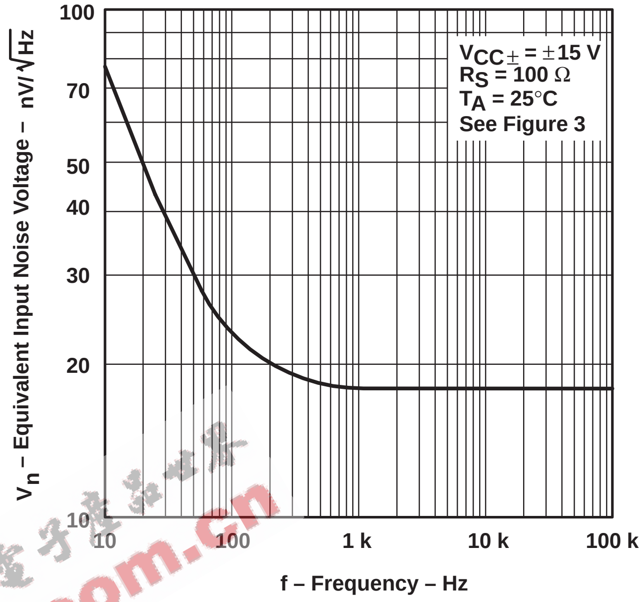


Figure 34

TOTAL HARMONIC DISTORTION vs FREQUENCY

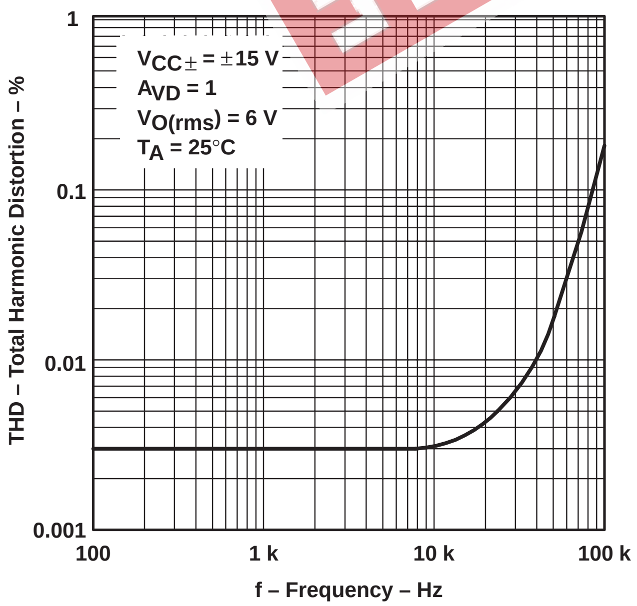


Figure 35

UNITY-GAIN BANDWIDTH vs SUPPLY VOLTAGE

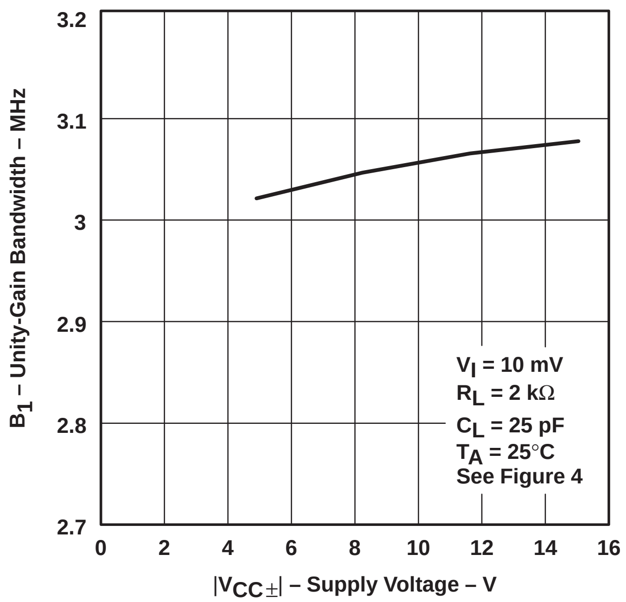


Figure 36

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

TYPICAL CHARACTERISTICS†

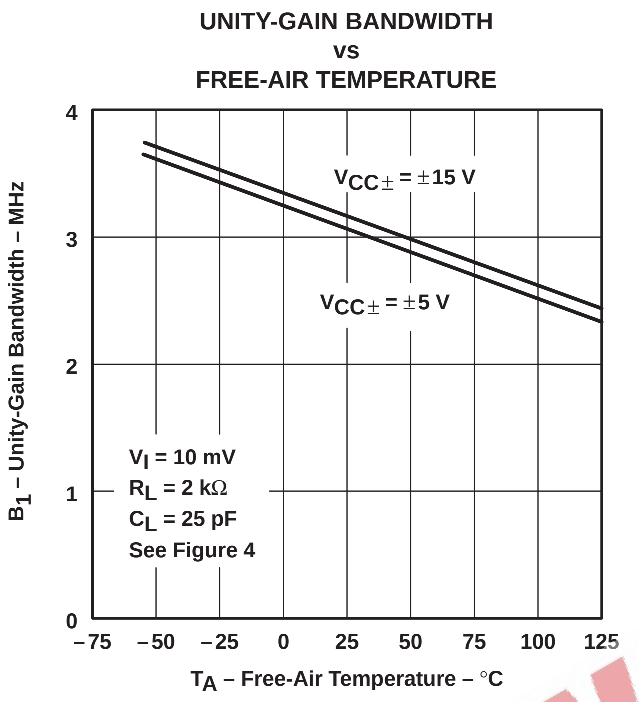


Figure 37

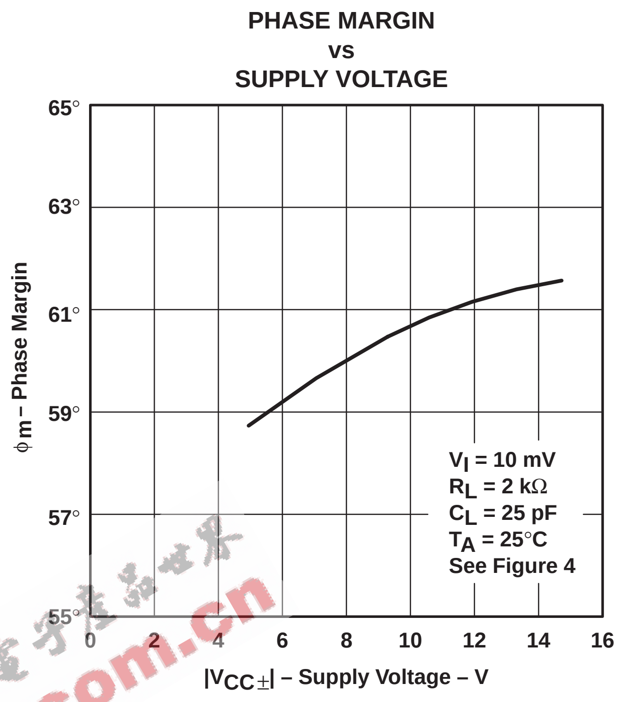


Figure 38

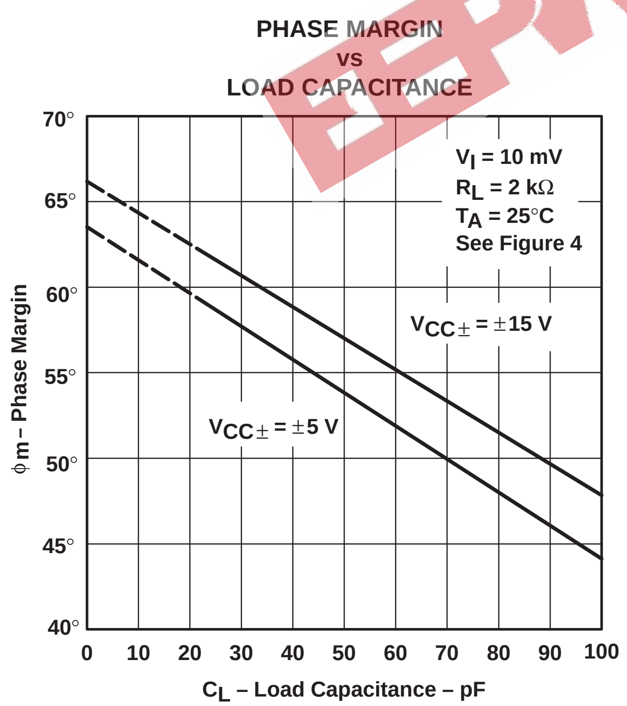


Figure 39

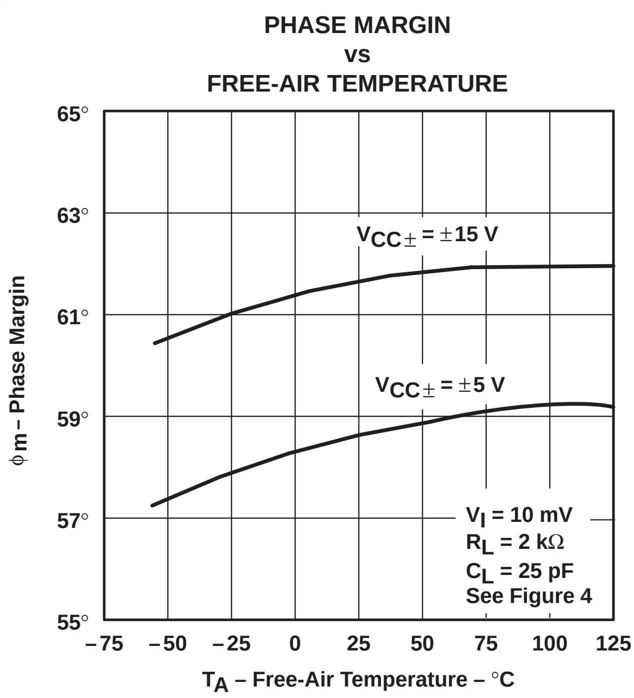


Figure 40

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

TYPICAL CHARACTERISTICS

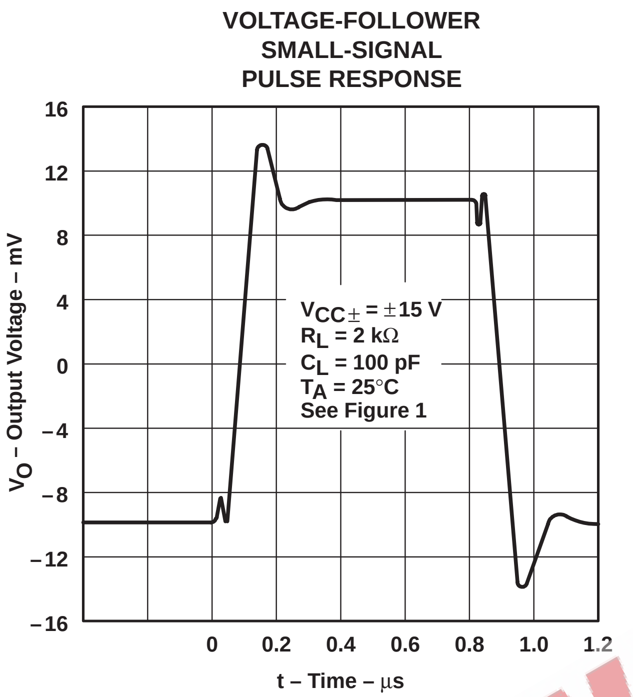


Figure 41

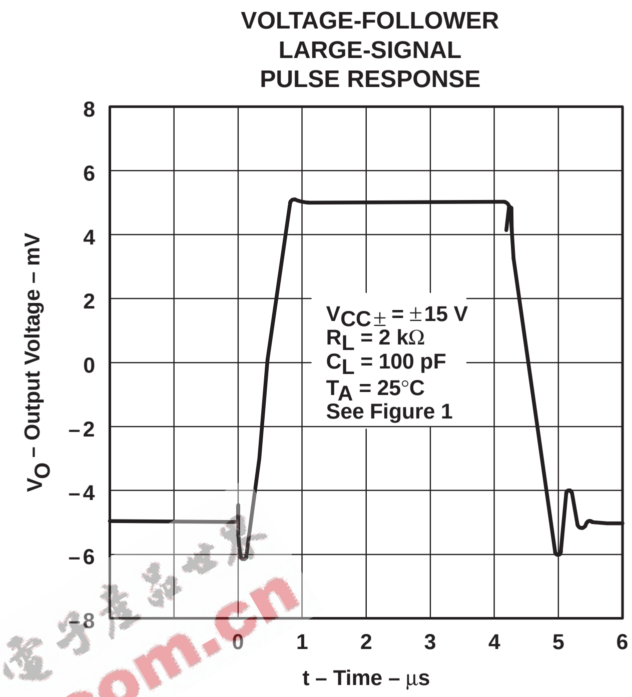
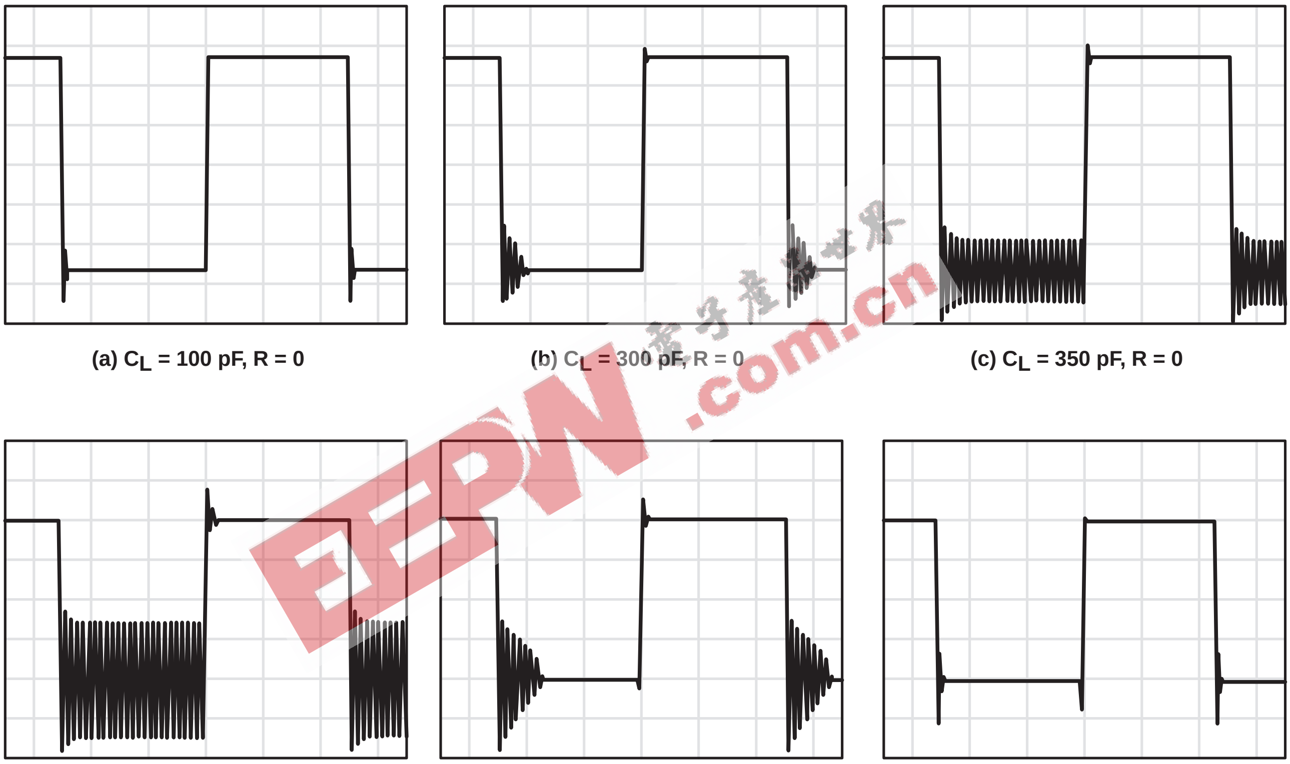


Figure 42

TYPICAL APPLICATION DATA

output characteristics

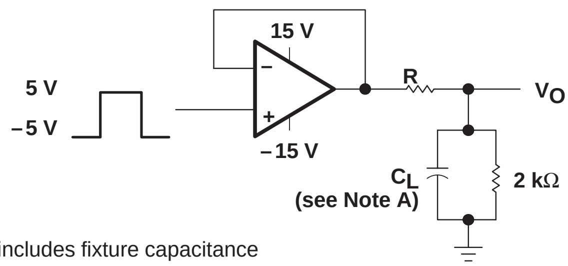
All operating characteristics are specified with 100-pF load capacitance. These amplifiers will drive higher capacitive loads; however, as the load capacitance increases, the resulting response pole occurs at lower frequencies, thereby causing ringing, peaking, or even oscillation. The value of the load 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).



(a) C_L = 100 pF, R = 0 — (b) C_L = 300 pF, R = 0 — (c) C_L = 350 pF, R = 0

(d) C_L = 1000 pF, R = 0 — (e) C_L = 1000 pF, R = 50 Ω — (f) C_L = 1000 pF, R = 2 kΩ

Figure 43. Effect of Capacitive Loads



NOTE A: C_L includes fixture capacitance

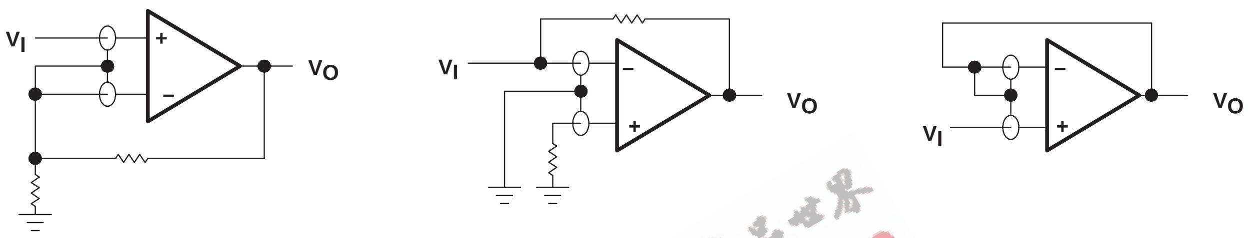
Figure 44. Test Circuit for Output Characteristics

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 diflferential amplifier. The low input bias current requirments 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 kΩ.

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