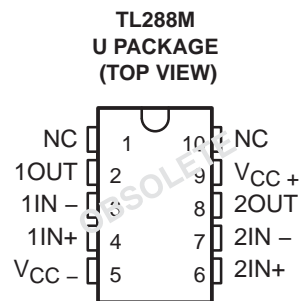
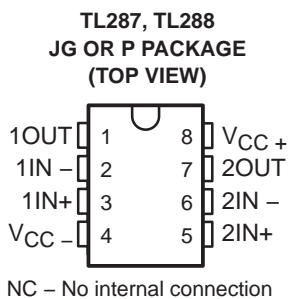
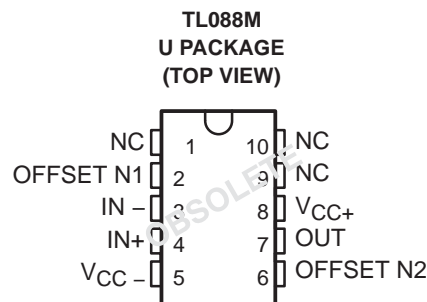
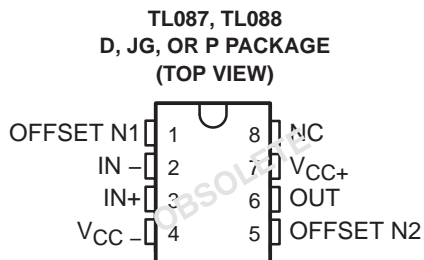


# TL087, TL088, TL287, TL288 JFET-INPUT OPERATIONAL AMPLIFIERS

The TL087, TL088, and TL287 are obsolete and are no longer supplied.

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- 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/ $\mu$ s Typ
- Low Total Harmonic Distortion 0.003% Typ



## description/ordering information

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.

## ORDERING INFORMATION

TA	TYPE	V <sub>IO</sub> MAX AT 25°C	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	Dual	1 mV	PDIP (P)	Tube of 50	TL288CP	TL288CP

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at [www.ti.com/sc/package](http://www.ti.com/sc/package).



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

PRODUCTION DATA information is 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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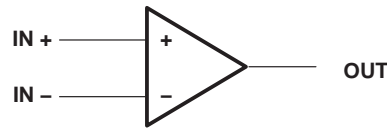
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# TL087, TL088, TL287, TL288 JFET-INPUT OPERATIONAL AMPLIFIERS

The TL087, TL088, and TL287 are obsolete and are no longer supplied.

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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)	$\pm 30$	$\pm 30$	$\pm 30$	V
Input voltage (see Notes 1 and 3)	$\pm 15$	$\pm 15$	$\pm 15$	V
Input current, $I_I$ (each Input)	$\pm 1$	$\pm 1$	$\pm 1$	mA
Output current, $I_O$ (each output)	$\pm 80$	$\pm 80$	$\pm 80$	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			
Maximum junction temperature, $T_J$		150	150	$^{\circ}\text{C}$
Package thermal impedance, $\theta_{JA}$ (see Notes 5 and 6)	P package	85	85	$^{\circ}\text{C}/\text{W}$
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds	JG or U package	300	300	$^{\circ}\text{C}$
Storage temperature range, $T_{Stg}$	-65 to 150	-65 to 150	-65 to 150	$^{\circ}\text{C}$

- 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.
5. Maximum power dissipation is a function of  $T_J(\text{max})$ ,  $\theta_{JA}$ , and  $T_A$ . The maximum allowable power dissipation at any allowable ambient temperature is  $PD = (T_J(\text{max}) - T_A)/\theta_{JA}$ . Operating at the absolute maximum  $T_J$  of  $150^{\circ}\text{C}$  can affect reliability.
6. The package thermal impedance is calculated in accordance with JESD 51-7.
7. 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.
8. Maximum power dissipation is a function of  $T_J(\text{max})$ ,  $\theta_{JA}$ , and  $T_A$ . The maximum allowable power dissipation at any allowable ambient temperature is  $PD = (T_J(\text{max}) - T_A)/\theta_{JA}$ . Operating at the absolute maximum  $T_J$  of  $150^{\circ}\text{C}$  can affect reliability.
9. The package thermal impedance is calculated in accordance with JESD 51-7.

DISSIPATION RATING TABLE

PACKAGE	$T_A \leq 25^{\circ}\text{C}$ POWER RATING	DERATING FACTOR ABOVE $T_A = 25^{\circ}\text{C}$	$T_A = 70^{\circ}\text{C}$ POWER RATING	$T_A = 85^{\circ}\text{C}$ POWER RATING	$T_A = 125^{\circ}\text{C}$ POWER RATING
JG	1050 mW	8.4 mW/ $^{\circ}\text{C}$	672 mW	546 mW	210 mW
U	675 mW	5.4 mW/ $^{\circ}\text{C}$	432 mW	351 mW	135 mW

The TL087, TL088, and TL287 are obsolete and are no longer supplied.

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**recommended operating conditions**

		C-SUFFIX		I-SUFFIX		M-SUFFIX		UNIT	
		MIN	MAX	MIN	MAX	MIN	MAX		
V <sub>CC</sub>	Supply voltage	±5	±5	±5	±5	±5	±15	V	
V <sub>IC</sub>	Common-mode input voltage	V <sub>CC±</sub> = ±5 V	-1	4	-1	4	-1	4	V
		V <sub>CC±</sub> = ±15 V	-11	11	-11	11	-11	11	
V <sub>I</sub>	Input voltage	V <sub>CC±</sub> = ±5 V	-1	4	-1	4	-1	4	V
		V <sub>CC±</sub> = ±15 V	-11	11	-11	11	-11	11	
T <sub>A</sub>	Operating free-air temperature	0	70	-40	85	-55	125	°C	

**operating characteristics V<sub>CC</sub> = ±15 V, T<sub>A</sub> = 25°C**

PARAMETER		TEST CONDITIONS		TL088M, TL288M			TL087I, TL087C TL088I, TL088C			UNIT
				MIN	TYP	MAX	MIN	TYP	MAX	
SR	Slew rate at unity gain	V <sub>I</sub> = 10 V, C <sub>L</sub> = 100 pF,	R <sub>L</sub> = 2 kΩ, A <sub>VD</sub> = 1		18		8	18	V/μs	
t <sub>r</sub>	Rise time	V <sub>I</sub> = 20 mV,	R <sub>L</sub> = 2 kΩ,		55		55		ns	
	Overshoot factor	C <sub>L</sub> = 100 pF,	A <sub>VD</sub> = 1		25		25		%	
V <sub>N</sub>	Equivalent input noise voltage	R <sub>S</sub> = 100 Ω,	f = 1 kHz		19		19		nV/√Hz	

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

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

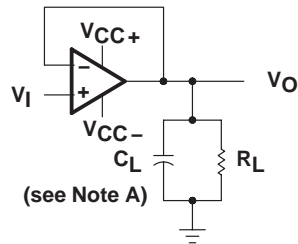
PARAMETER	TEST CONDITIONS†		TL088M		TL087I		TL087C		UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
$V_{IO}$ Input offset voltage	$R_S = 50\ \Omega$ , $V_O = 0$ $T_A = 25^\circ\text{C}$	TL087, TL287			0.1	0.5	0.1	0.5	mV
		TL088, TL288	0.1	3	0.1	1	0.1	1	
	$R_S = 50\ \Omega$ , $V_O = 0$ , $T_A = \text{full range}$	TL087, TL287 TL088, TL288			2	3	1.5	2.5	
$\alpha_{V_{IO}}$ 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		5	100	pA
	$T_A = \text{full range}$			25		3		2	nA
$I_{IB}$ Input bias current‡	$T_A = 25^\circ\text{C}$		30		30		30	200	pA
	$T_A = \text{full range}$			100		20		7	nA
$V_{ICR}$ Common-mode input voltage range	$T_A = 25^\circ\text{C}$		( $V_{CC-}$ ) + 4 to ( $V_{CC+}$ ) - 4		( $V_{CC-}$ ) + 4 to ( $V_{CC+}$ ) - 4		( $V_{CC-}$ ) + 4 to ( $V_{CC+}$ ) - 4		V
	$T_A = 25^\circ\text{C}$ , $R_L = 10\ \text{k}\Omega$		24	27	24	27	24	27	
$V_O(\text{PP})$ Maximum-peak-to-peak output voltage swing	$T_A = 25^\circ\text{C}$ , $R_L \geq 10\ \text{k}\Omega$		24		24		24		V
	$T_A = \text{full range}$ , $R_L \geq 2\ \text{k}\Omega$		20		20		20		
$A_{VD}$ Large-signal differential voltage amplification	$R_L \geq 2\ \text{k}\Omega$ , $T_A = 25^\circ\text{C}$		50	105	50	105	50	105	V/mV
	$R_L \geq 2\ \text{k}\Omega$ , $T_A = \text{full range}$		25		25		25		
$B_1$ Unity-gain bandwidth	$T_A = 25^\circ\text{C}$		3		3		3		MHz
	$T_A = 25^\circ\text{C}$		1012		1012		1012		$\Omega$
$r_i$ Input resistance	$T_A = 25^\circ\text{C}$		80	93	80	93	80	93	dB
	$R_S = 50\ \Omega$ , $V_O = 0\ \text{V}$ , $V_{IC} = V_{ICR}\ \text{min}$ , $T_A = 25^\circ\text{C}$								
CMRR Common-mode rejection ratio	$R_S = 50\ \Omega$ , $V_O = 0\ \text{V}$ , $V_{CC\pm} = \pm 9\ \text{V}$ to $\pm 15\ \text{V}$ , $T_A = 25^\circ\text{C}$		80	99	80	99	80	99	dB
kSVR Supply voltage rejection ratio ( $\Delta V_{CC} \pm \Delta V_{IO}$ )	No load, $T_A = 25^\circ\text{C}$		26	2.8	26	2.8	26	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  $-55^\circ\text{C}$  to  $125^\circ\text{C}$  for TL\_88M;  $-40^\circ\text{C}$  to  $85^\circ\text{C}$  for TL\_8\_I; and  $0^\circ\text{C}$  to  $70^\circ\text{C}$  for TL\_8\_C.

‡ Input bias currents of an 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.



PARAMETER MEASUREMENT INFORMATION



NOTE A:  $C_L$  includes fixture capacitance.

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

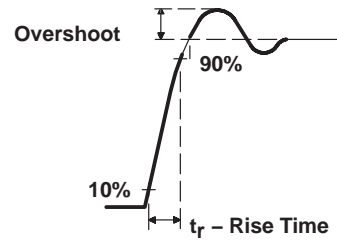


Figure 2. Rise Time and Overshoot Waveform

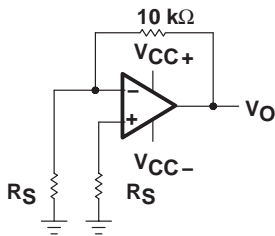
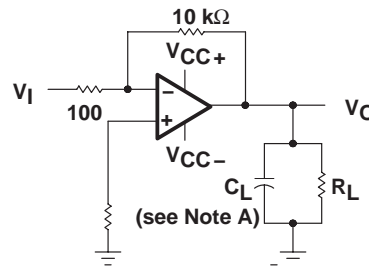


Figure 3. Noise Voltage Test Circuit



NOTE A:  $C_L$  includes fixture capacitance.

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

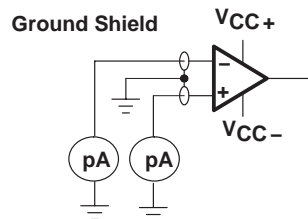


Figure 5. Input Bias and Offset Current Test Circuit

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

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## 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 then is 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 then are subtracted algebraically to determine the bias current of the device.



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**TYPICAL CHARACTERISTICS**

**table of graphs**

		<b>FIGURE</b>	
$\alpha_{V_{IO}}$	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
$\phi_m$	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

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

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## TYPICAL CHARACTERISTICS†

**DISTRIBUTION OF TL088  
INPUT OFFSET VOLTAGE  
TEMPERATURE COEFFICIENT**

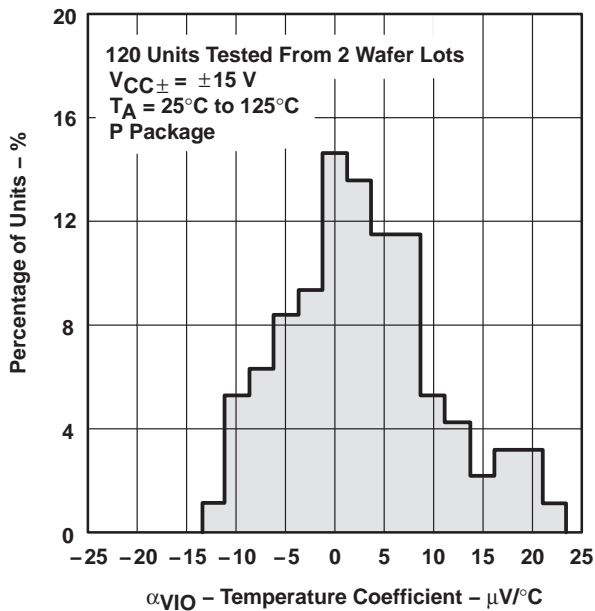


Figure 6

**DISTRIBUTION OF TL288  
INPUT OFFSET VOLTAGE  
TEMPERATURE COEFFICIENT**

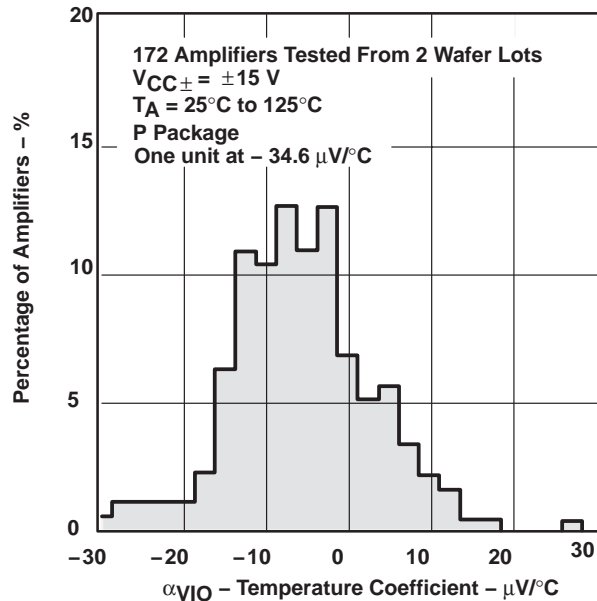


Figure 7

**INPUT BIAS CURRENT AND  
INPUT OFFSET CURRENT  
VS  
FREE-AIR TEMPERATURE**

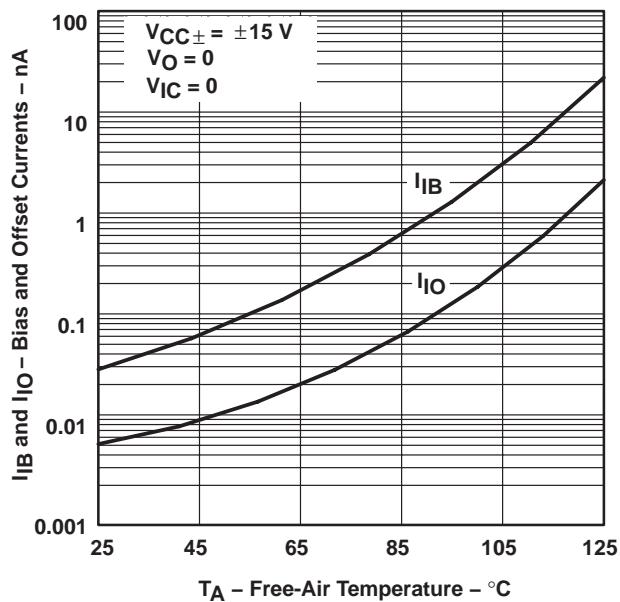


Figure 8

**INPUT BIAS CURRENT  
VS  
COMMON-MODE INPUT VOLTAGE**

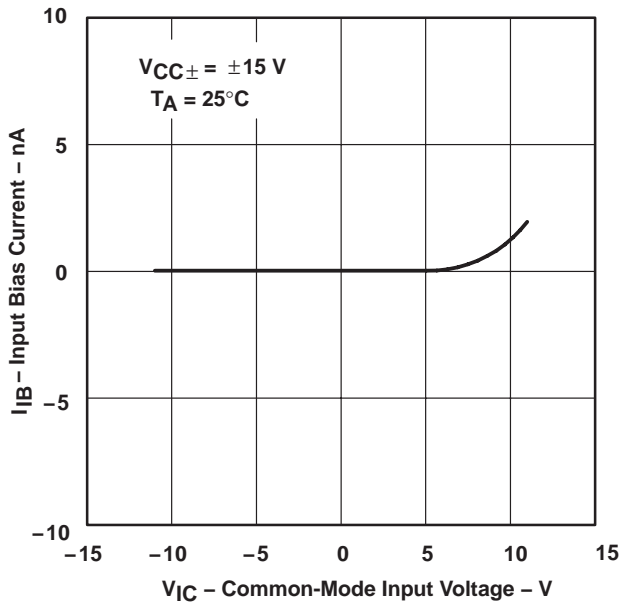
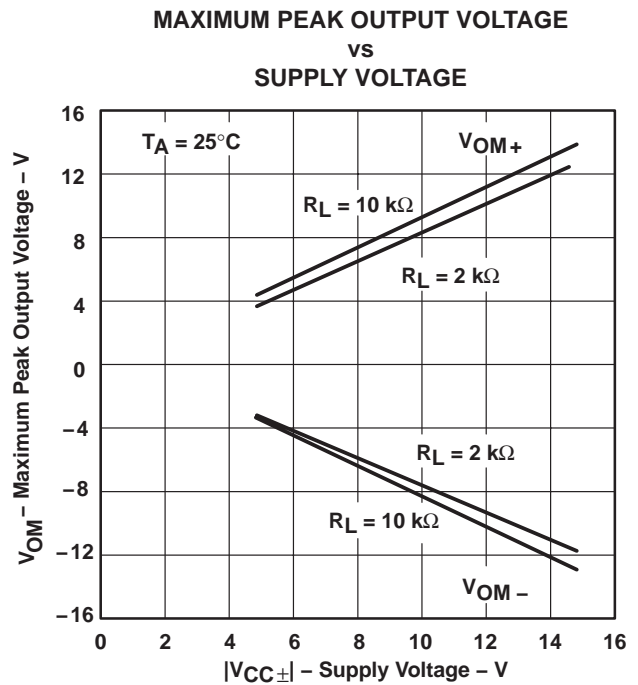
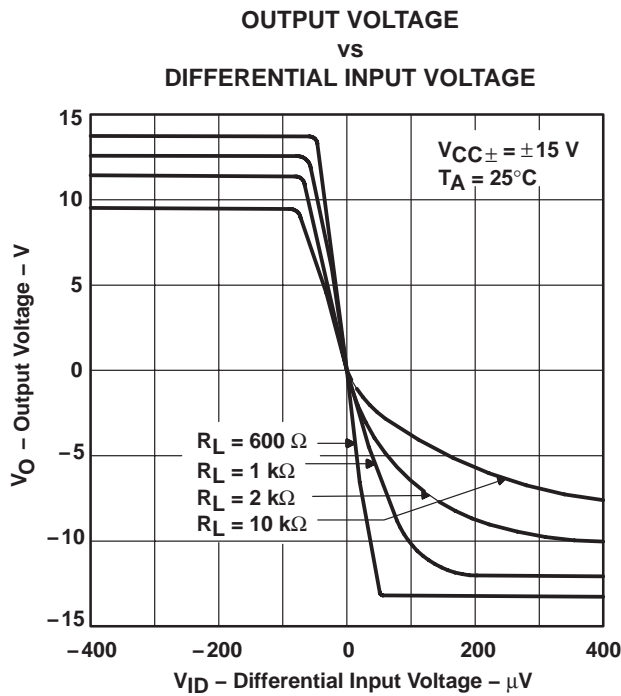
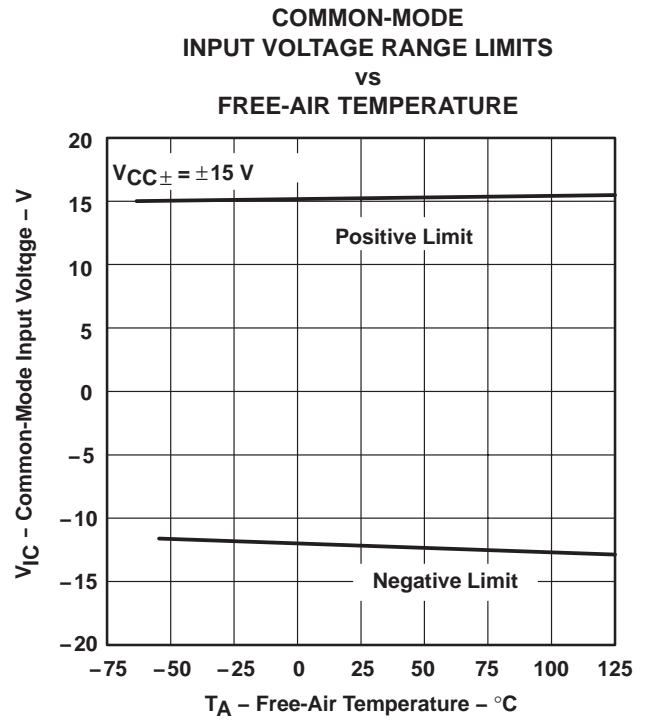
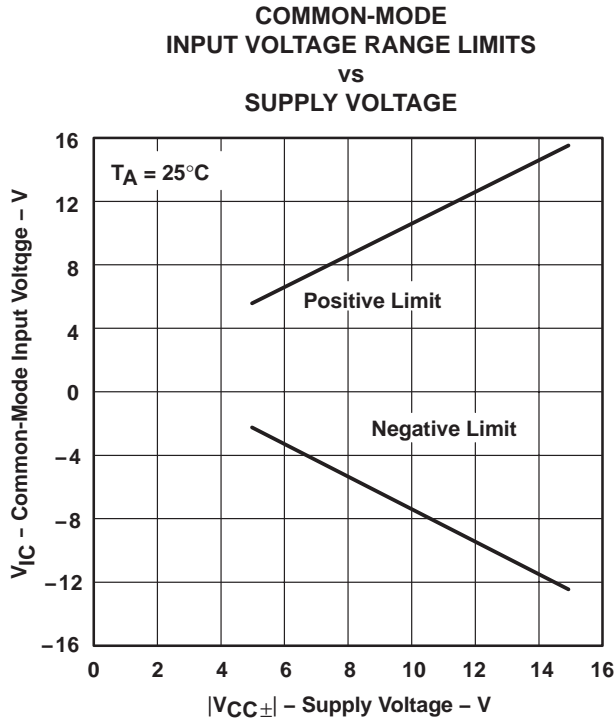


Figure 9

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



TYPICAL CHARACTERISTICS†



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

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## TYPICAL CHARACTERISTICS†

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE  
vs  
FREQUENCY

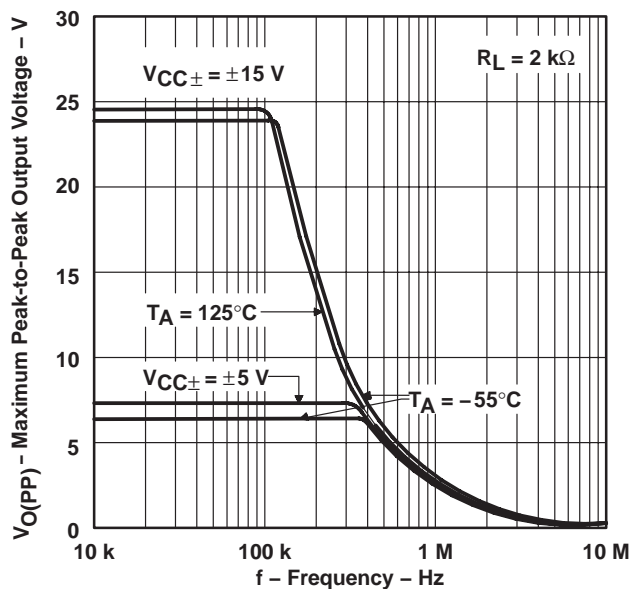


Figure 14

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE  
vs  
FREQUENCY

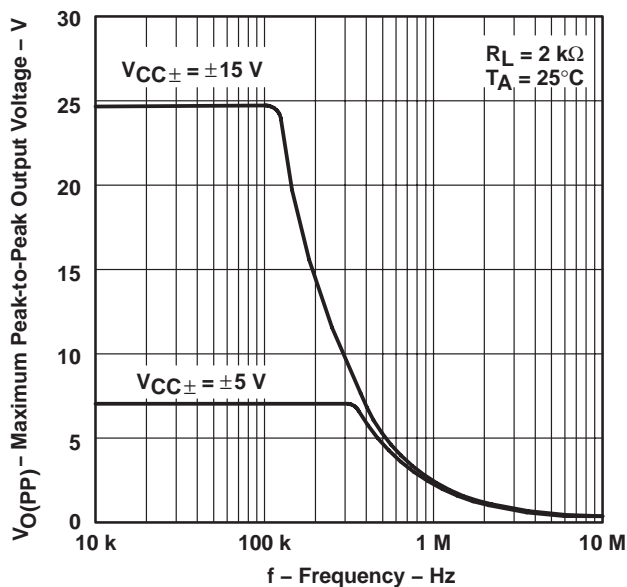


Figure 15

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE  
vs  
FREQUENCY

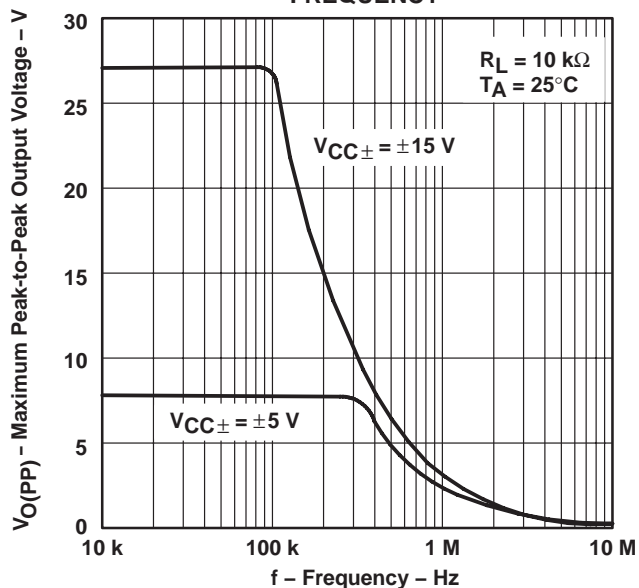


Figure 16

MAXIMUM PEAK OUTPUT VOLTAGE  
vs  
OUTPUT CURRENT

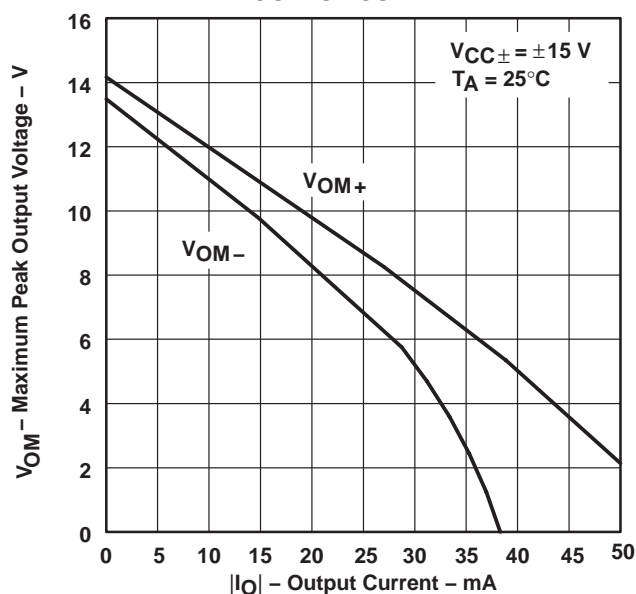


Figure 17

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

**TYPICAL CHARACTERISTICS†**

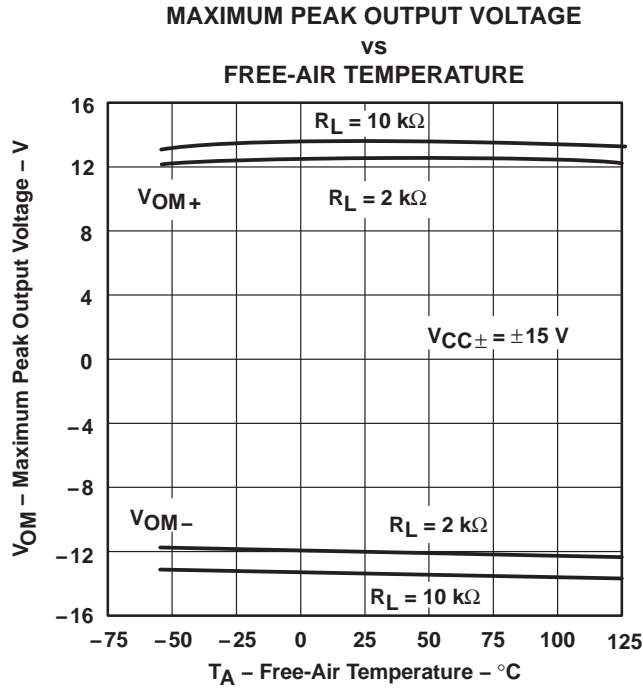


Figure 18

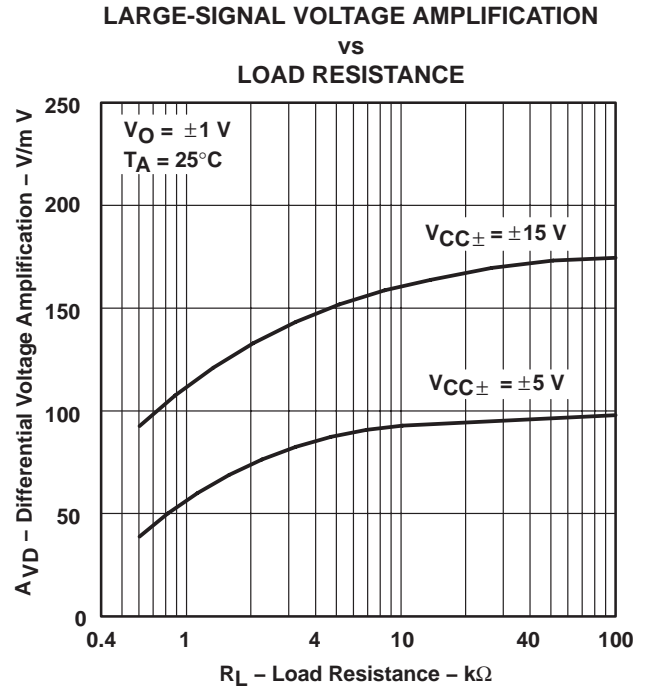


Figure 19

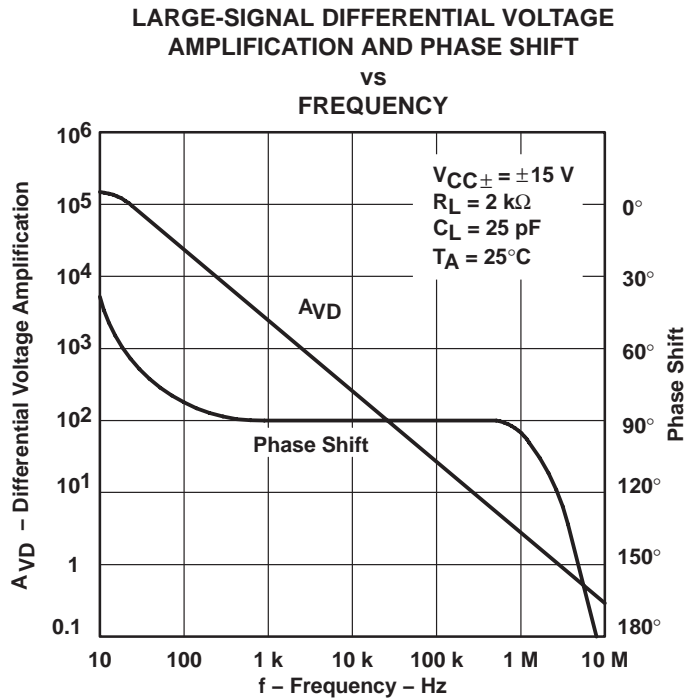


Figure 20

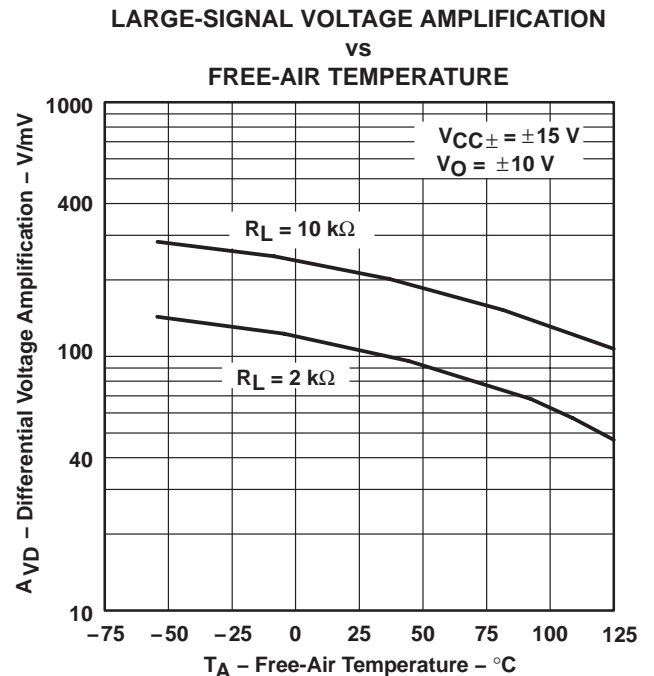


Figure 21

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

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## TYPICAL CHARACTERISTICS†

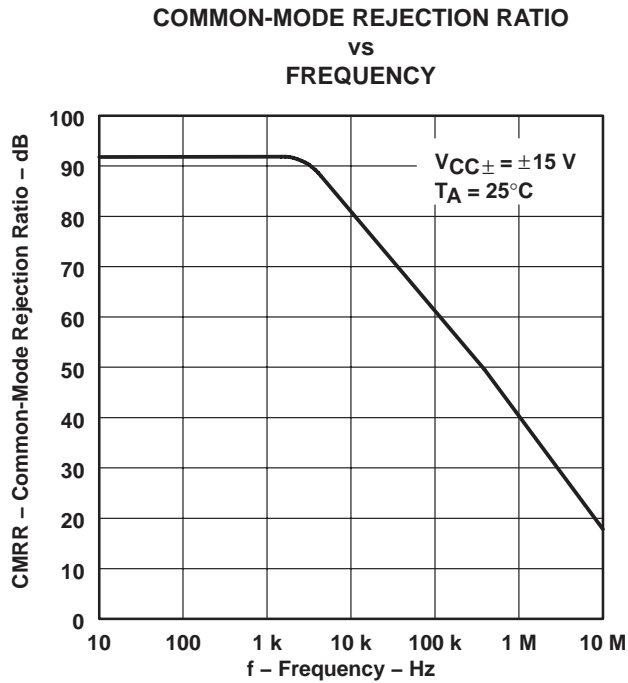


Figure 22

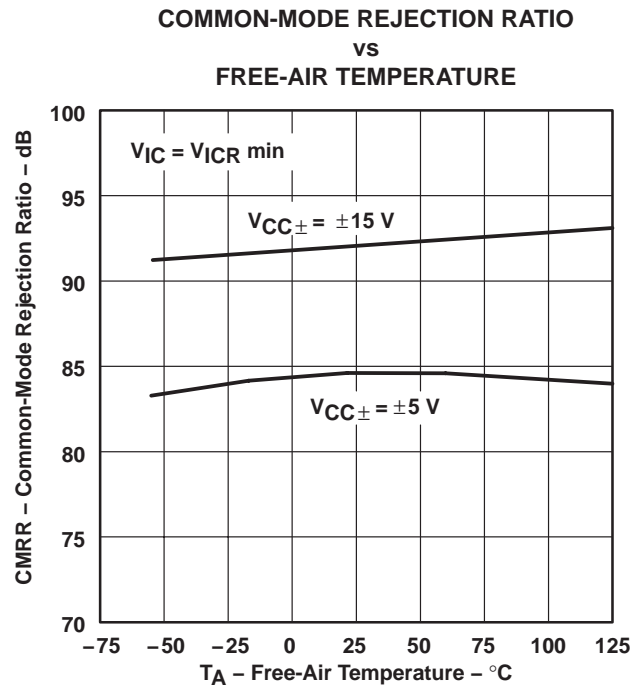


Figure 23

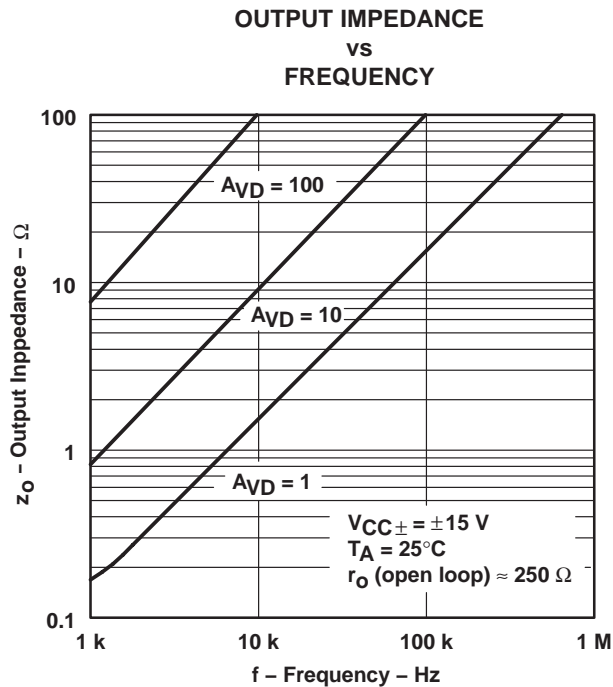


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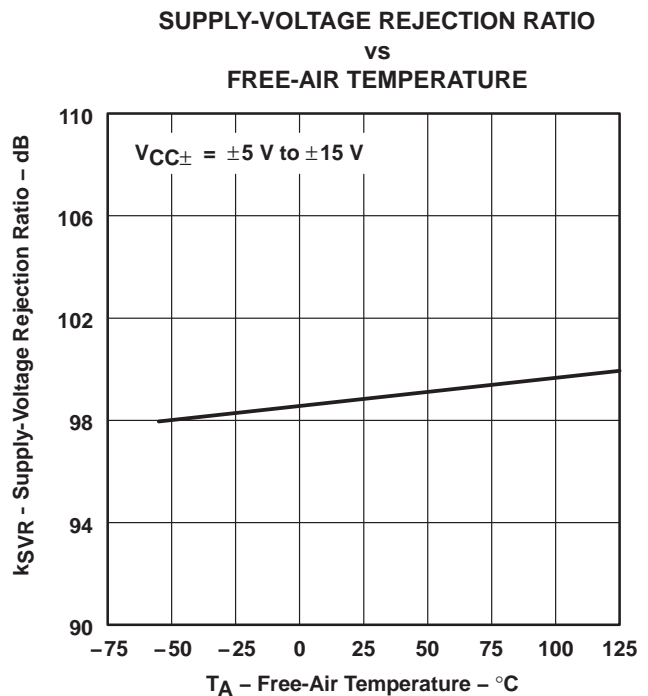


Figure 25

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

TYPICAL CHARACTERISTICS†

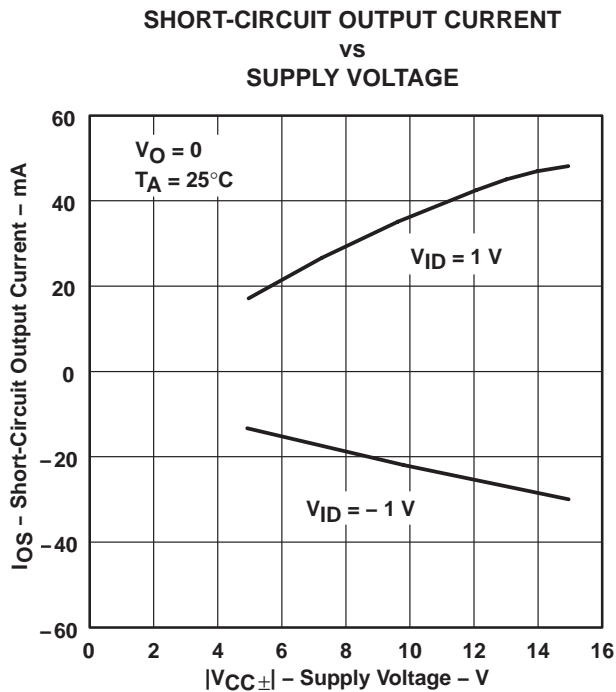


Figure 26

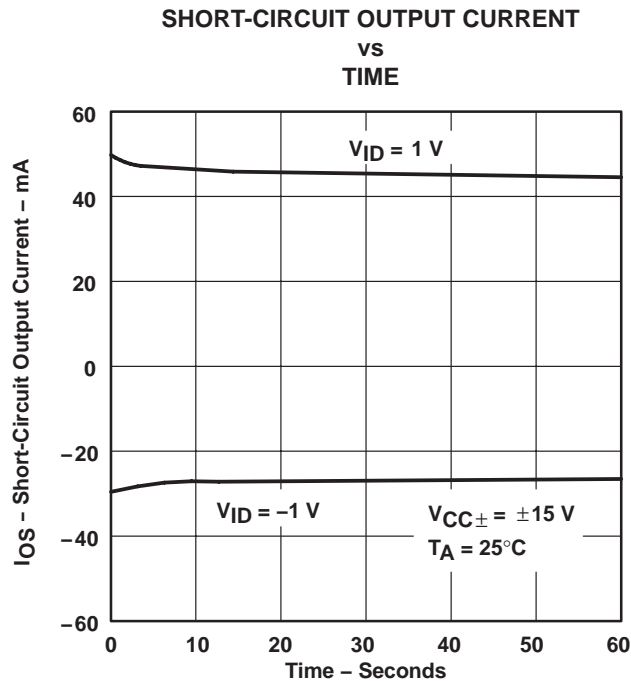


Figure 27

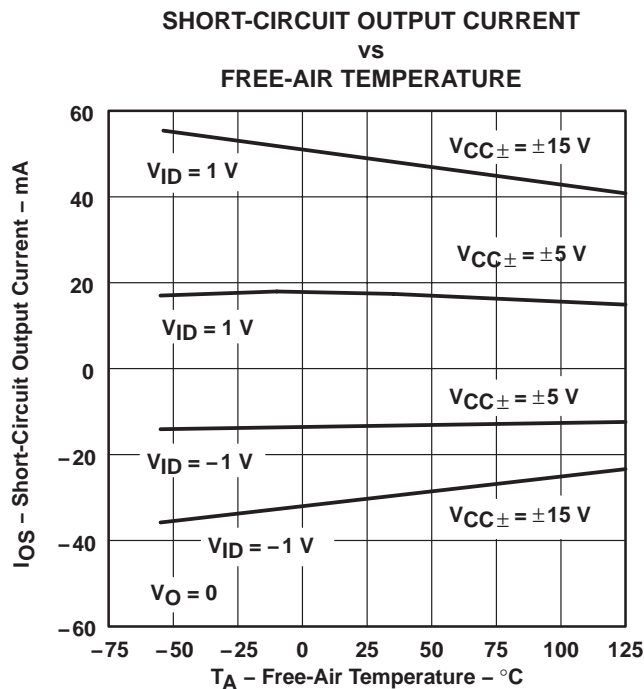


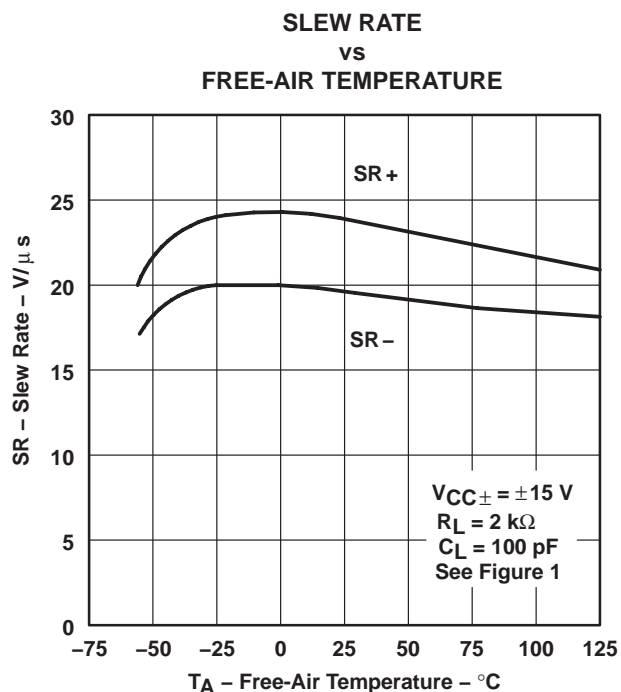
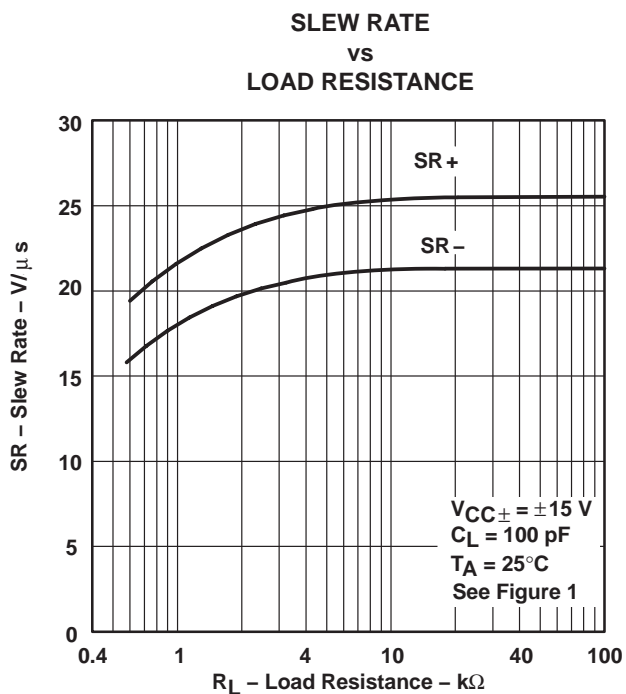
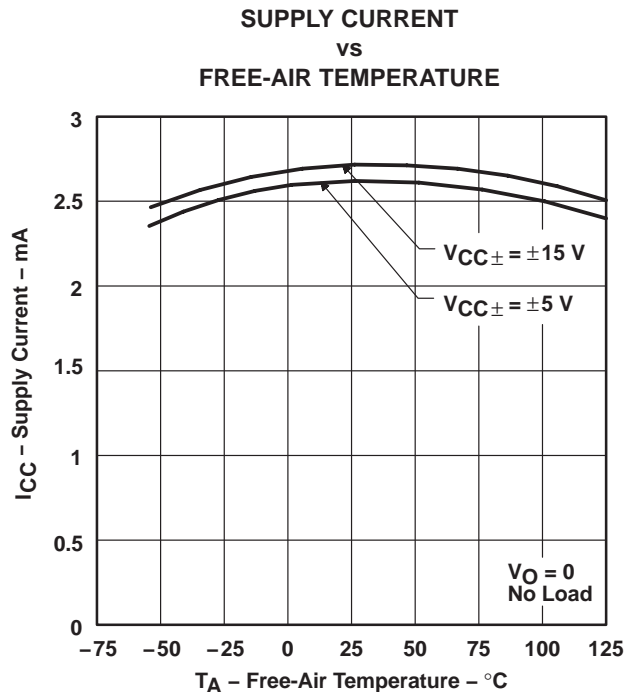
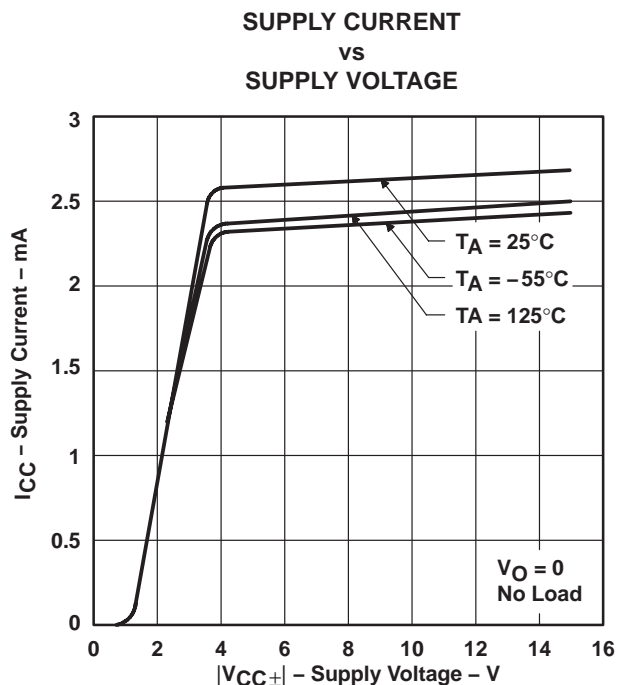
Figure 28

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

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

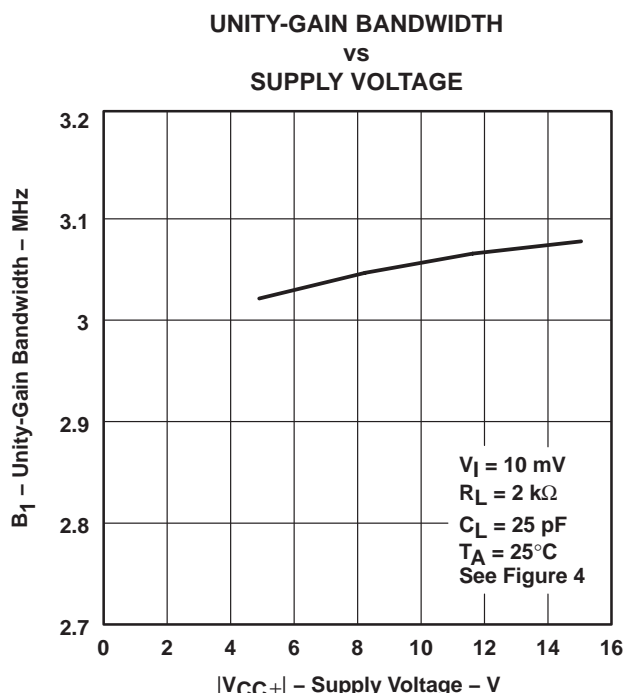
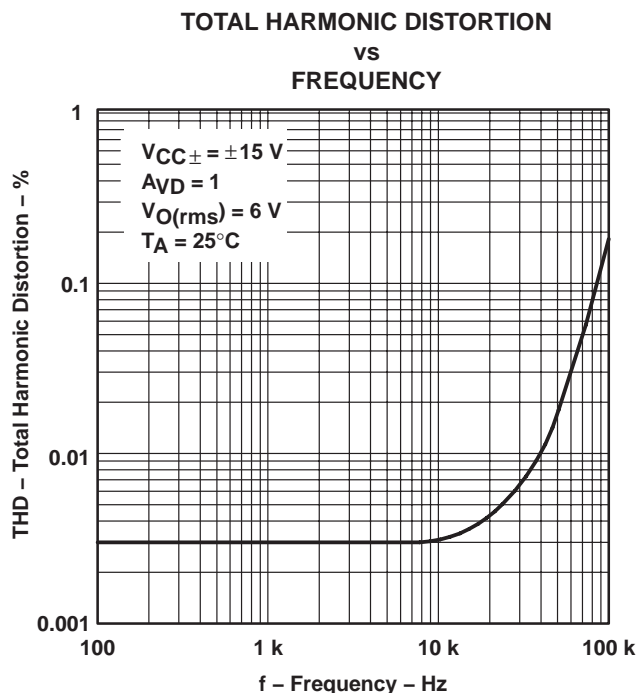
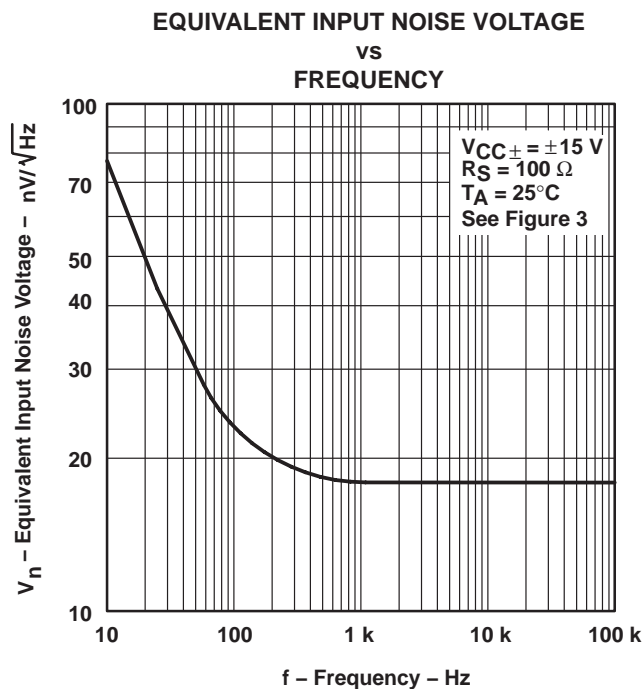
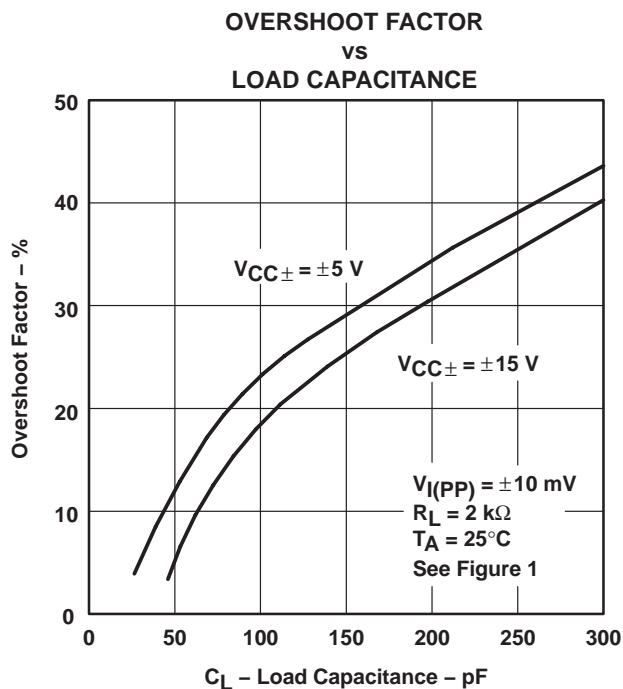
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## TYPICAL CHARACTERISTICS†



† 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.

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

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## TYPICAL CHARACTERISTICS†

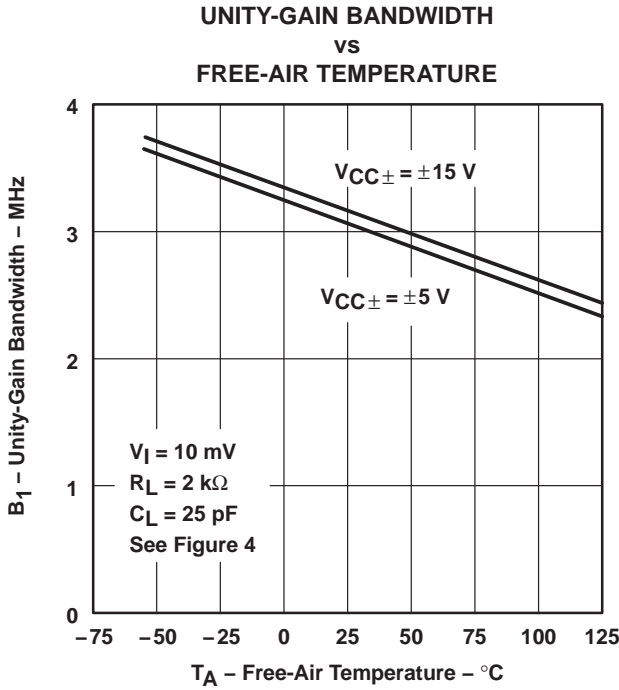


Figure 37

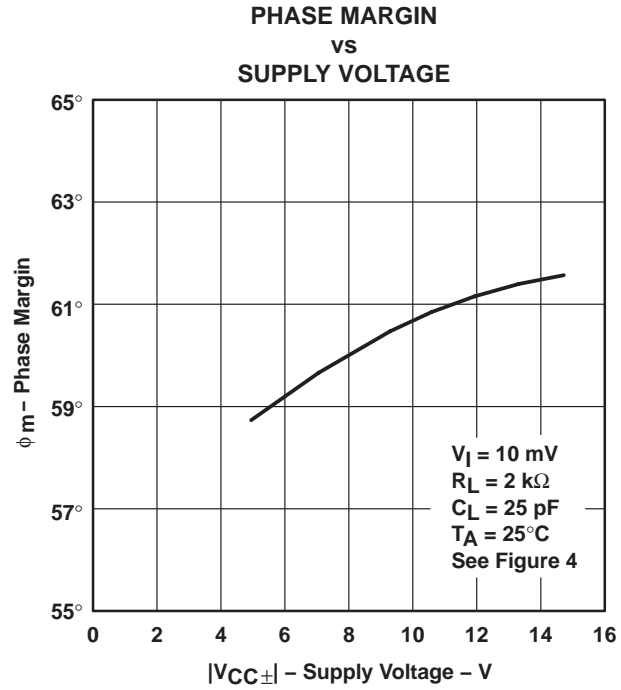


Figure 38

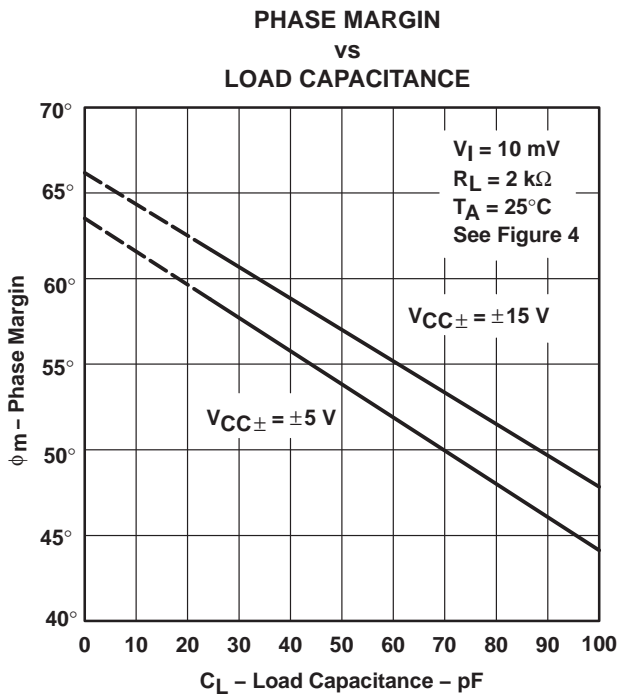


Figure 39

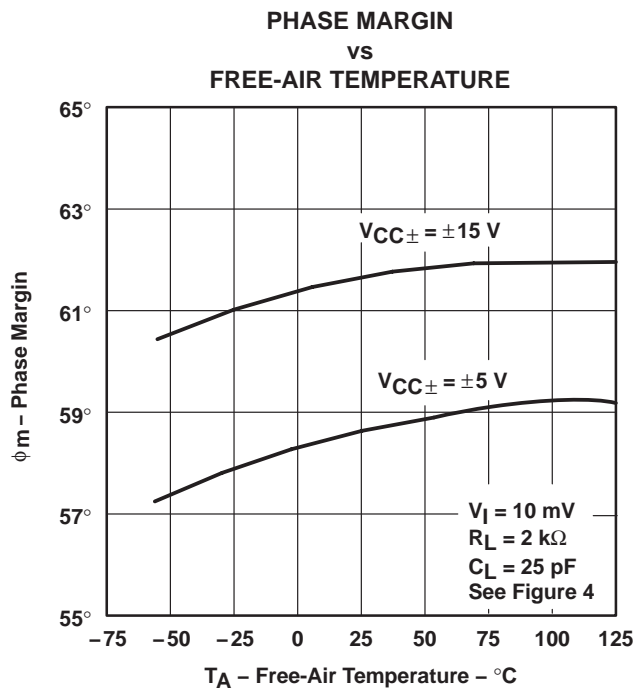


Figure 40

† 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

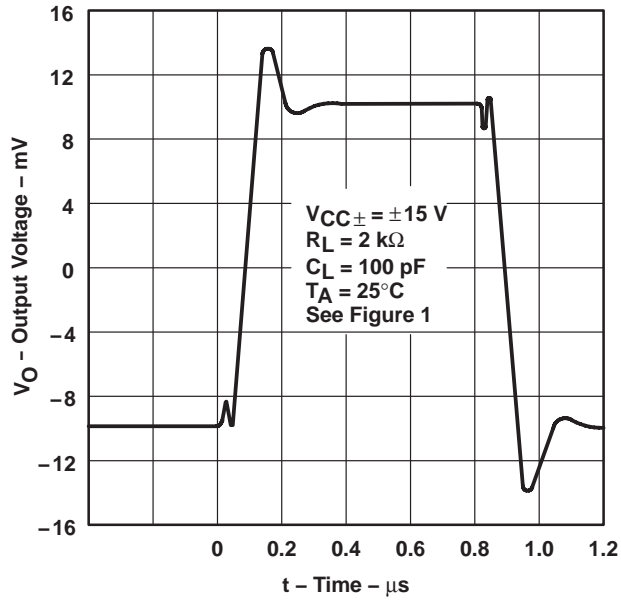


Figure 41

VOLTAGE-FOLLOWER  
LARGE-SIGNAL  
PULSE RESPONSE

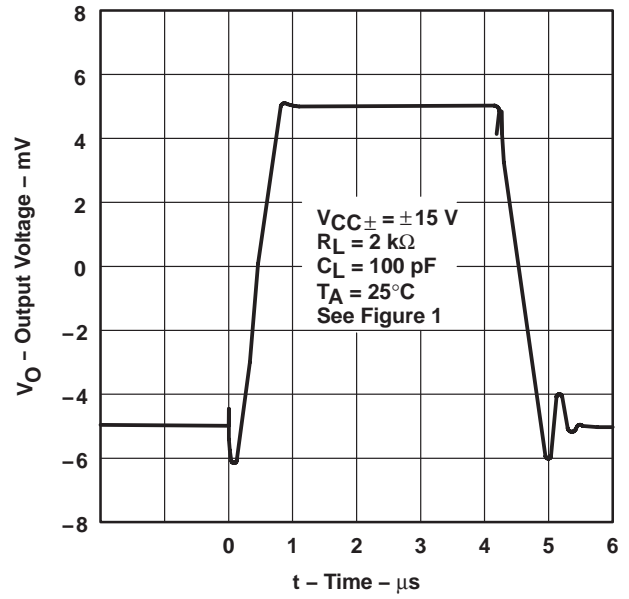


Figure 42

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

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## 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, 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).

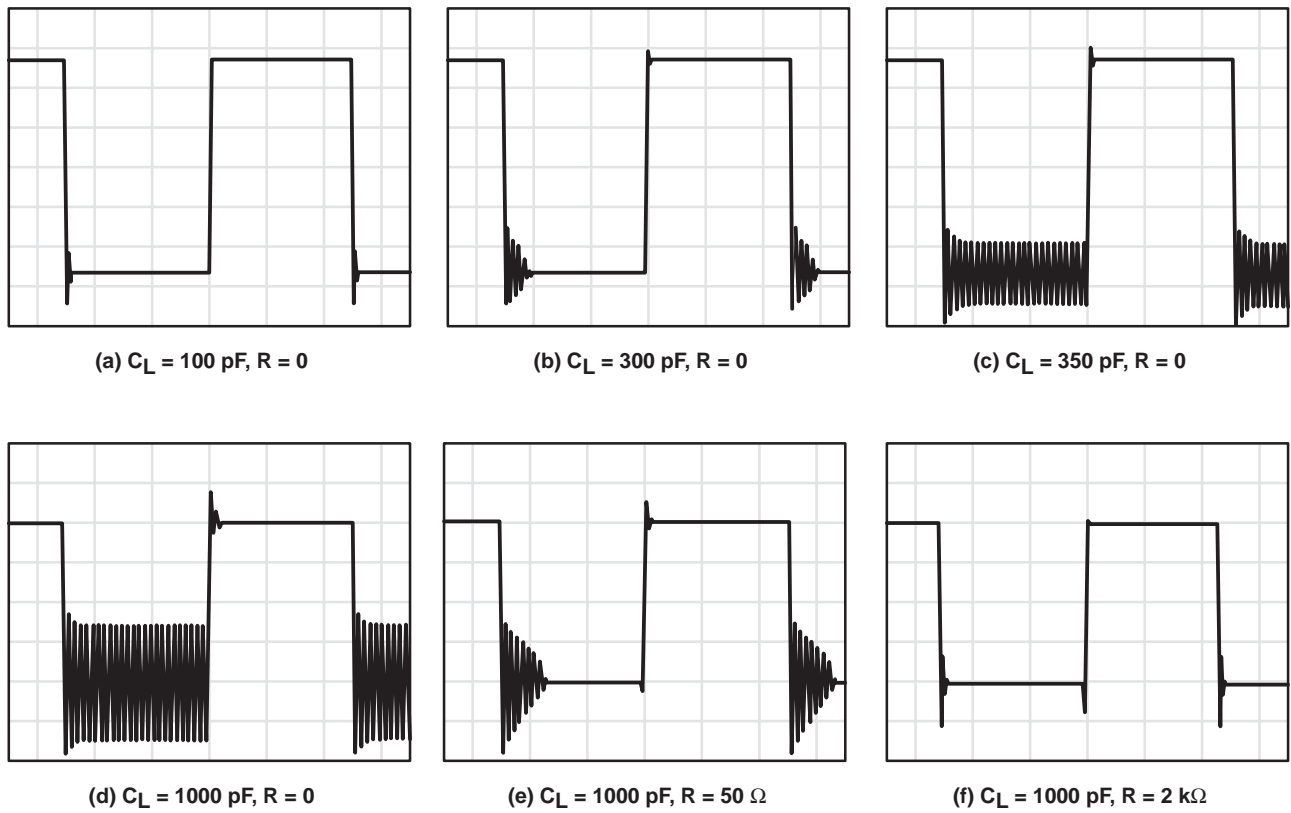
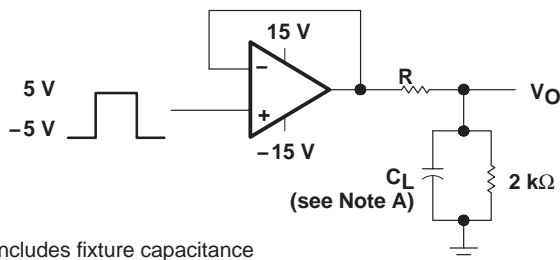


Figure 43. Effect of Capacitive Loads



NOTE A:  $C_L$  includes fixture capacitance

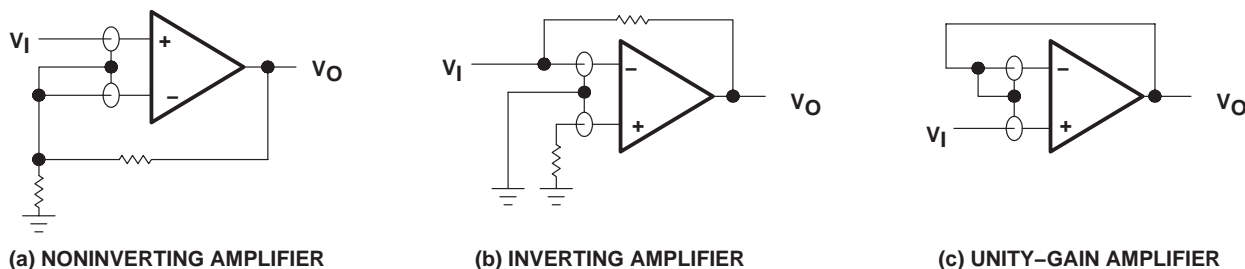
Figure 44. Test Circuit for Output Characteristics

**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 easily can 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.



**Figure 45. Use of Guard Rings**

**noise performance**

The noise specifications in operational amplifier 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 kΩ.

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
TL087CP	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
TL288CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
TL288CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type

<sup>(1)</sup> The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

<sup>(2)</sup> Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

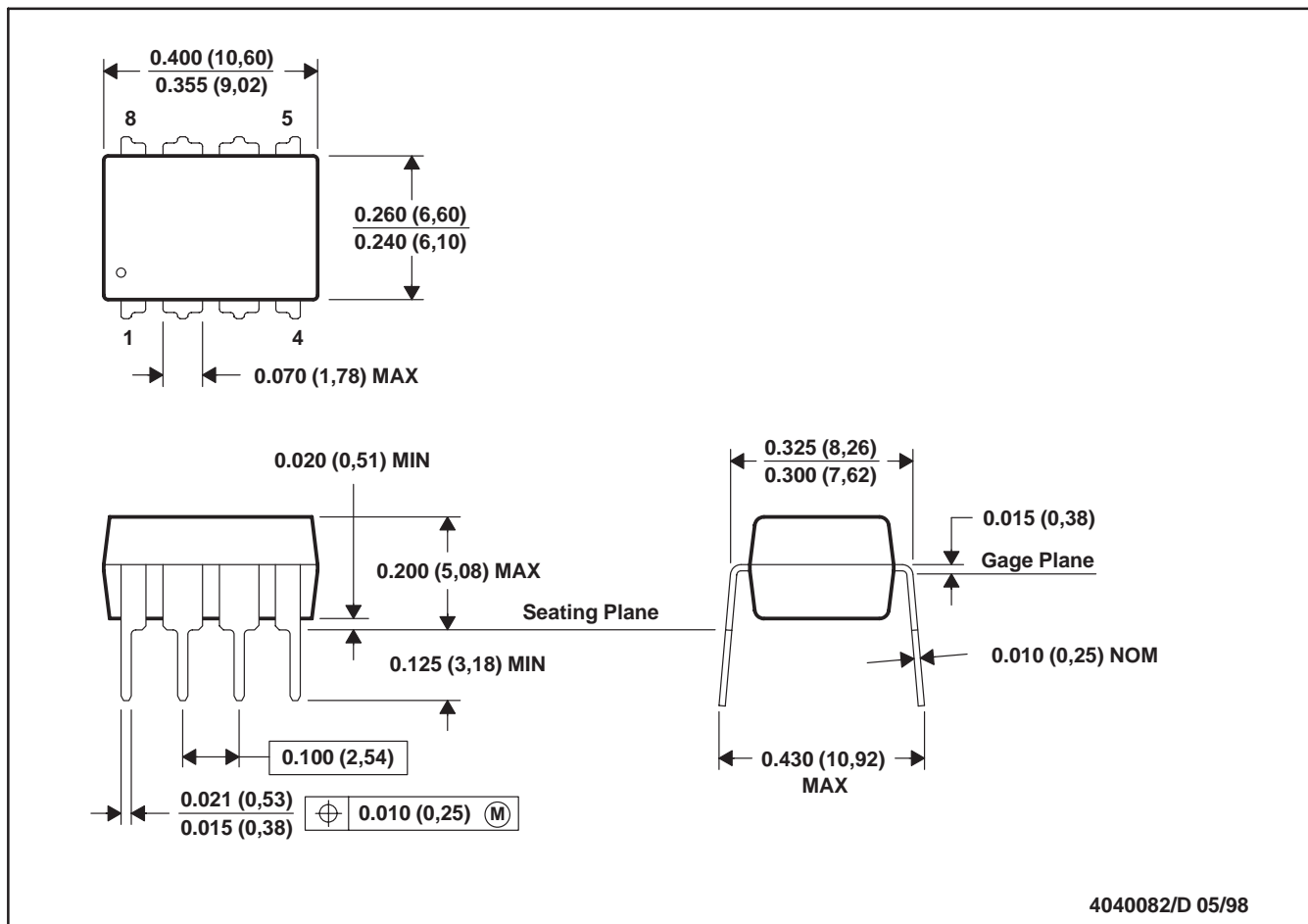
<sup>(3)</sup> MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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P (R-PDIP-T8)

PLASTIC DUAL-IN-LINE



- NOTES: A. All linear dimensions are in inches (millimeters).  
 B. This drawing is subject to change without notice.  
 C. Falls within JEDEC MS-001

For the latest package information, go to [http://www.ti.com/sc/docs/package/pkg\\_info.htm](http://www.ti.com/sc/docs/package/pkg_info.htm)



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DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>	Broadband	<a href="http://www.ti.com/broadband">www.ti.com/broadband</a>
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Logic	<a href="http://logic.ti.com">logic.ti.com</a>	Military	<a href="http://www.ti.com/military">www.ti.com/military</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>	Optical Networking	<a href="http://www.ti.com/opticalnetwork">www.ti.com/opticalnetwork</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>	Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
		Telephony	<a href="http://www.ti.com/telephony">www.ti.com/telephony</a>
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