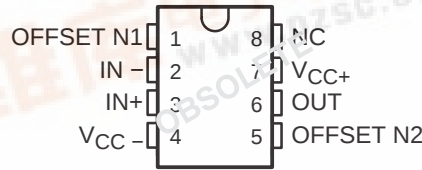


The TL087, TL088, and TL287 are obsolete and are no longer supplied.

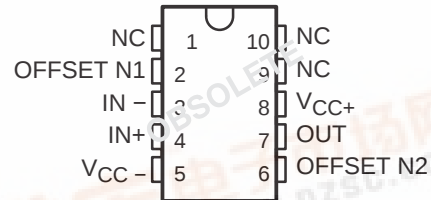
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- Low Input Offset Voltage . . . 0.5 mV Max
- Low Power Consumption
- Wide Common-Mode and Differential Voltage Ranges
- Low Input Bias and Offset Currents
- High Input Impedance . . . JFET-Input Stage
- Internal Frequency Compensation
- Latch-Up-Free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

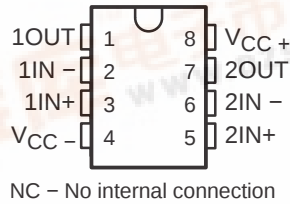
TL087, TL088
D, JG, OR P PACKAGE
(TOP VIEW)



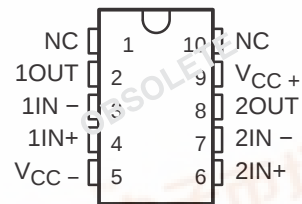
TL088M
U PACKAGE
(TOP VIEW)



TL287, TL288
JG OR P PACKAGE
(TOP VIEW)



TL288M
U PACKAGE
(TOP VIEW)



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.

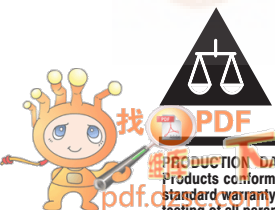
The C-suffix devices are characterized for operation from 0°C to 70°C, and the I-suffix devices are characterized for operation from –40°C to 85°C. The M-suffix devices are characterized for operation over the full military temperature range of –55°C to 125°C.

ORDERING INFORMATION

T _A	TYPE	V _{IO} 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.

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.



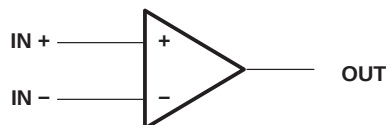
TL087, TL088, TL287, TL288

JFET-INPUT OPERATIONAL AMPLIFIERS

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

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			
Maximum junction temperature, T_J		150	150	$^{\circ}\text{C}$
Package thermal impedance, θ_{JA} (see Notes 5 and 6)	P package	85	85	$^{\circ}\text{C/W}$
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 $T_J(\text{max})$, θ_{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°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 $T_J(\text{max})$, θ_{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°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

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

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 _{CC}	Supply voltage	±5	±5	±5	±5	±5	±15	V
V _{IC}	Common-mode input voltage	V _{CC±} = ±5 V		-1	4	-1	4	V
		V _{CC±} = ±15 V		-11	11	-11	11	
V _I	Input voltage	V _{CC±} = ±5 V		-1	4	-1	4	V
		V _{CC±} = ±15 V		-11	11	-11	11	
T _A	Operating free-air temperature	0	70	-40	85	-55	125	°C

operating characteristics V_{CC} = ±15 V, T_A = 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 _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, C _L = 100 pF,	R _L = 2 kΩ, A _{VD} = 1		55			55		ns
	Overshoot factor				25			25		%
V _N	Equivalent input noise voltage	R _S = 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 TL288M		TL087I TL088I TL287I TL288I			TL087C TL088C TL287C TL288C			UNIT
					MIN	TYP	MAX	MIN	TYP	MAX	MIN	TYP	
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	1		0.1	1		
	R _S = 50 Ω, V _O = 0, T _A = full range	TL087, TL287						2			1.5		
		TL088, TL288						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	
I _{IB} Input bias current†	T _A = full range				25			3			2	nA	
	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 ≥ 10 kΩ		24			24			24			
		R _L ≥ 2 kΩ		20			20			20			
A _{V/D} Large-signal differential voltage amplification	R _L ≥ 2 kΩ, T _A = 25°C	V _O = ±10 V,		50	105		50	105		50	105	V/mV	
	R _L ≥ 2 kΩ, T _A = full range	V _O = ±10 V,		25			25			25			
		T _A = 25°C											
		T _A = 25°C											
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 (ΔV _{CC±} /ΔV _{IO})	R _S = 50 Ω, V _{CC±} = ±9 V to ±15 V, T _A = 25°C	V _O = 0 V,										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	

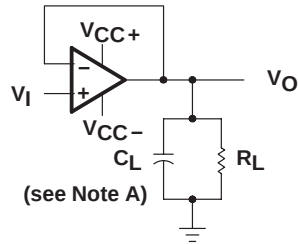
† All characteristics are measured under open-loop conditions with zero common-mode input voltage, unless otherwise specified. Full range for T_A is -55°C to 125°C for TL_88M; -40°C to 85°C for TL_8_I; and 0°C to 70°C for TL_8_C.

‡ Input bias currents of 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.

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

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PARAMETER MEASUREMENT INFORMATION



NOTE A: C_L includes fixture capacitance.

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

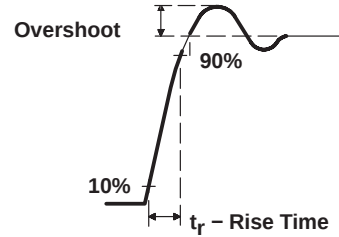


Figure 2. Rise Time and Overshoot Waveform

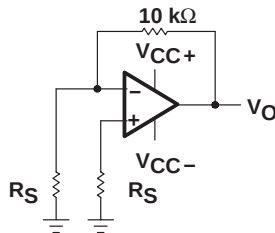
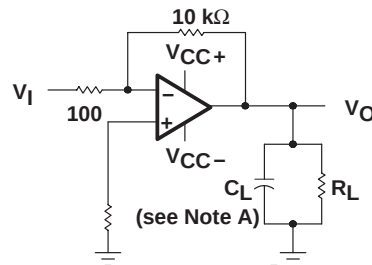


Figure 3. Noise Voltage Test Circuit



NOTE A: C_L includes fixture capacitance.

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

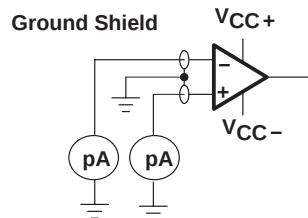


Figure 5. Input Bias and Offset Current Test Circuit

TL087, TL088, TL287, TL288

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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.

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

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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} 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

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

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TYPICAL CHARACTERISTICS†

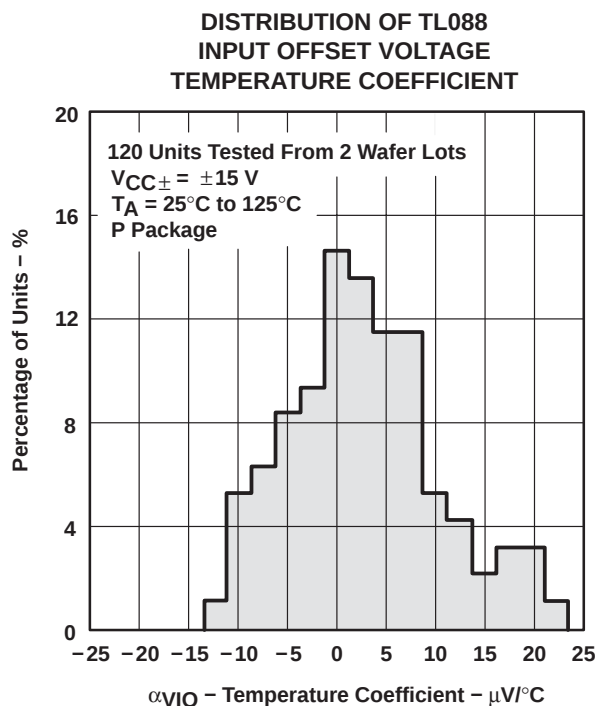


Figure 6

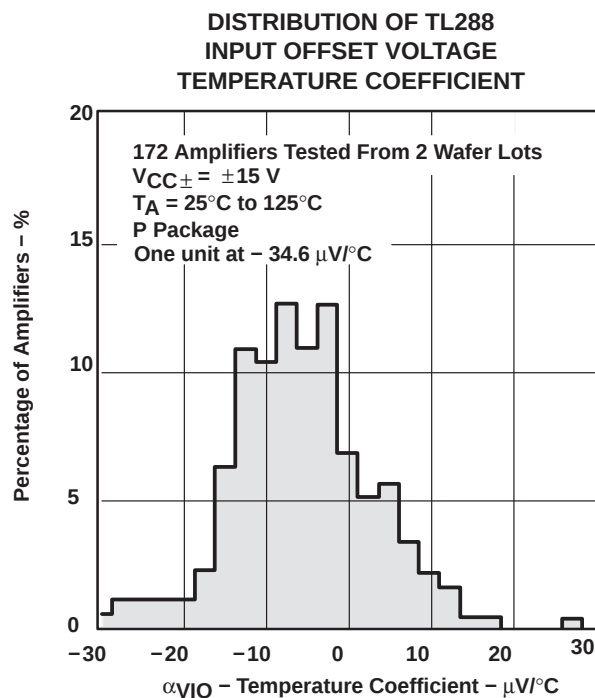


Figure 7

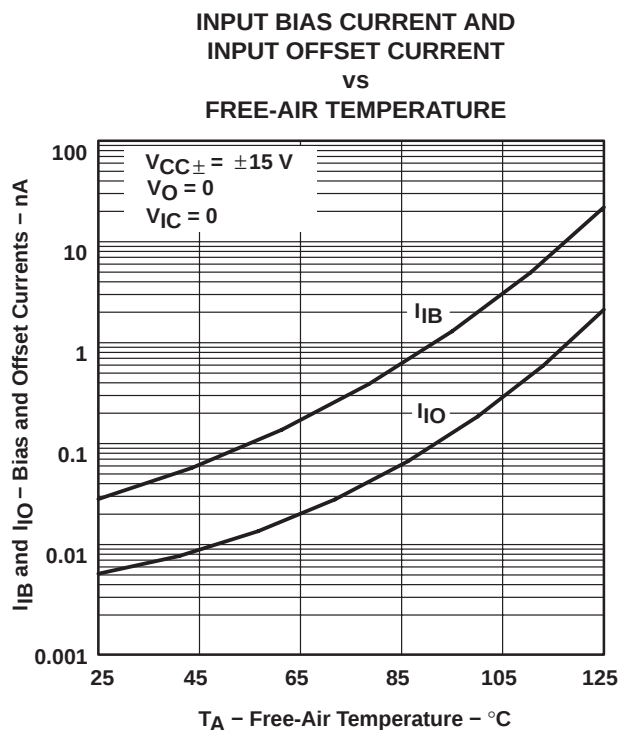


Figure 8

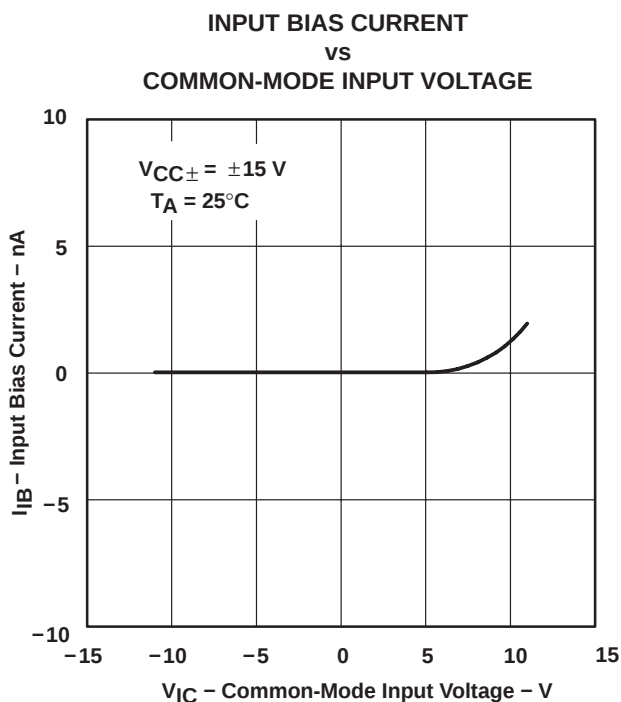


Figure 9

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

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

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TYPICAL CHARACTERISTICS†

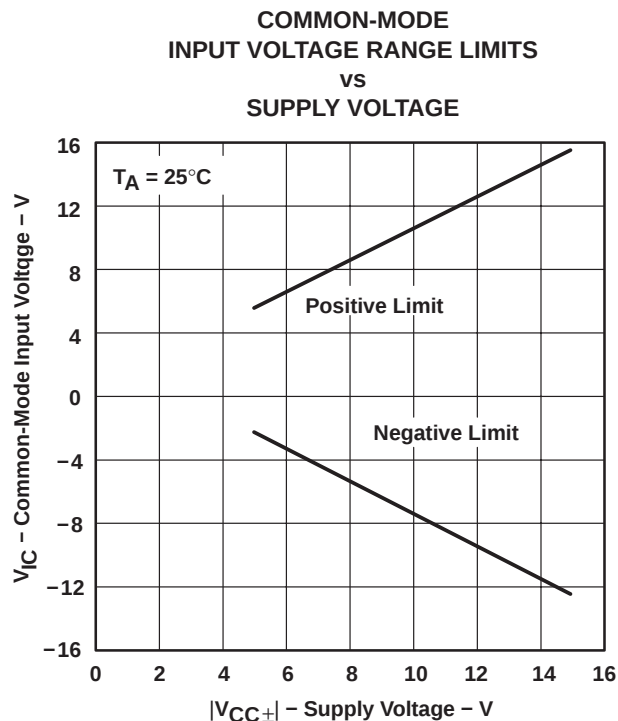


Figure 10

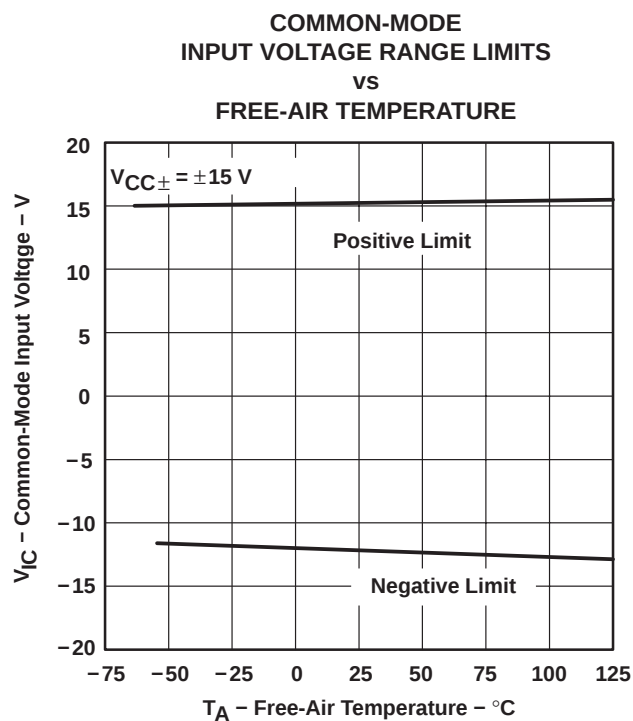


Figure 11

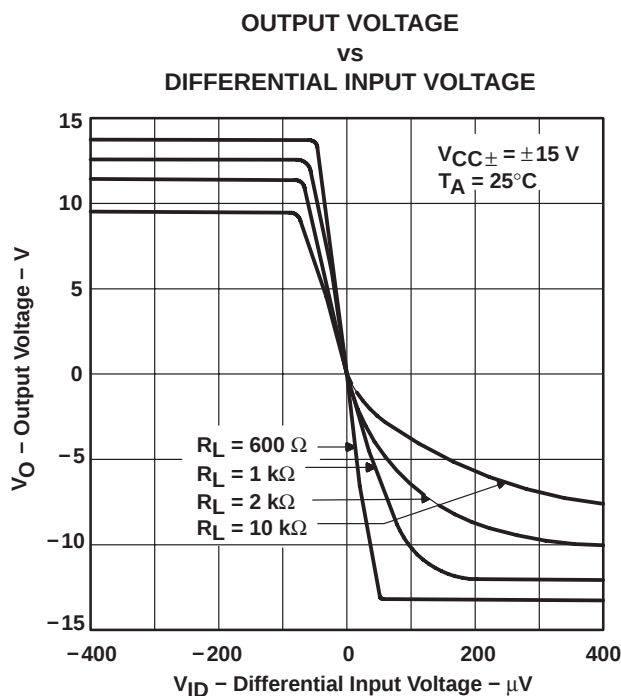


Figure 12

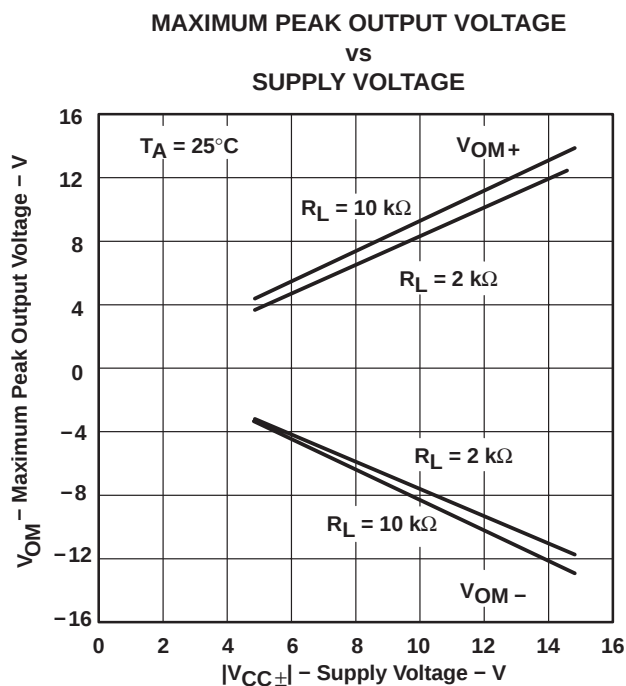


Figure 13

† 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†

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE

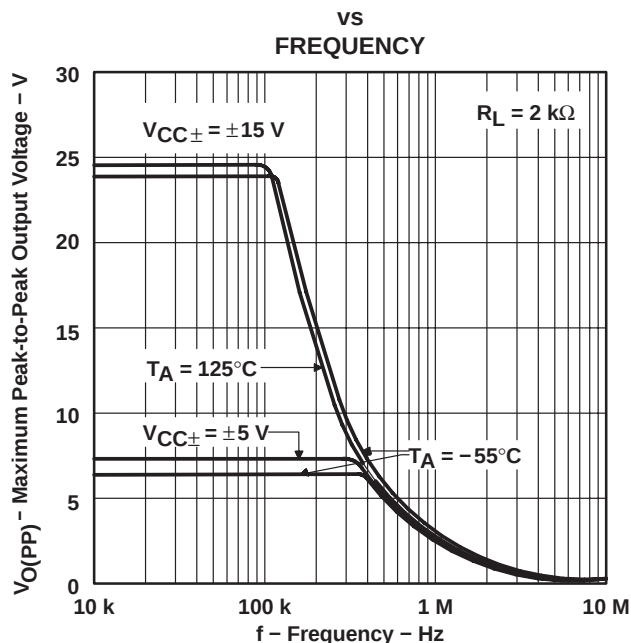


Figure 14

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE

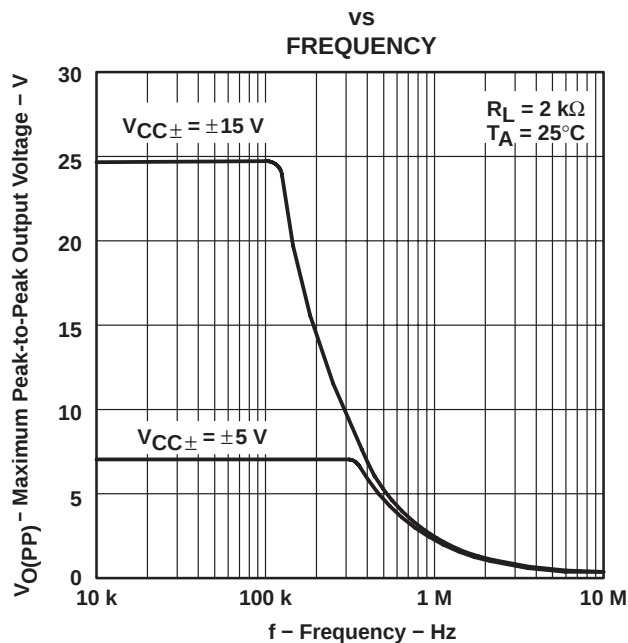


Figure 15

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE

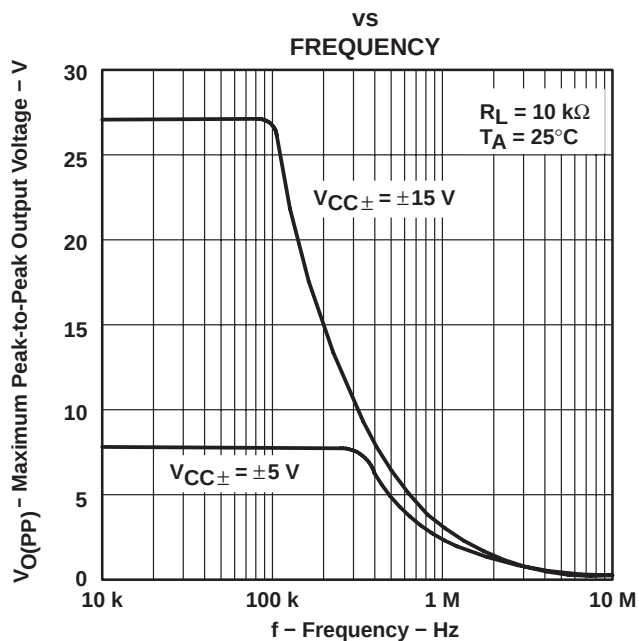


Figure 16

MAXIMUM PEAK OUTPUT VOLTAGE

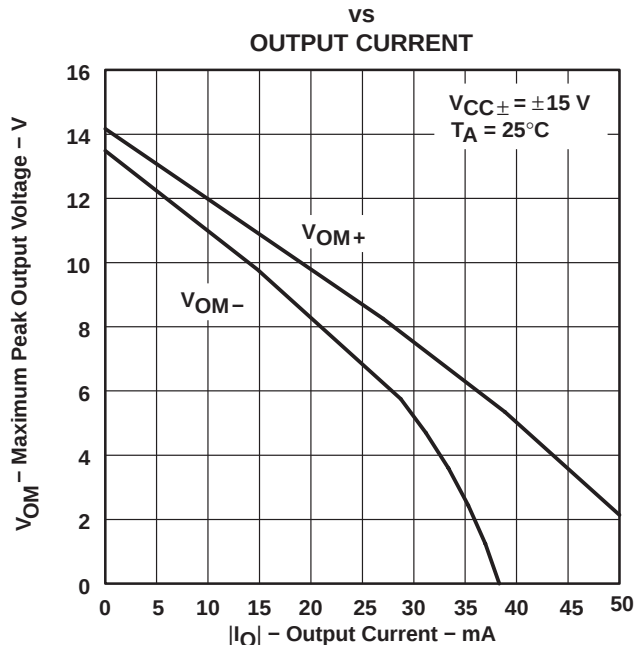


Figure 17

† 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†

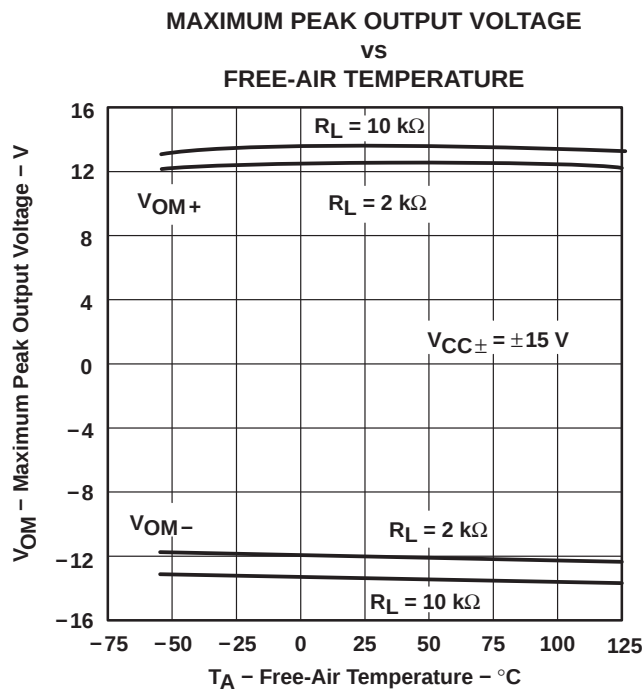


Figure 18

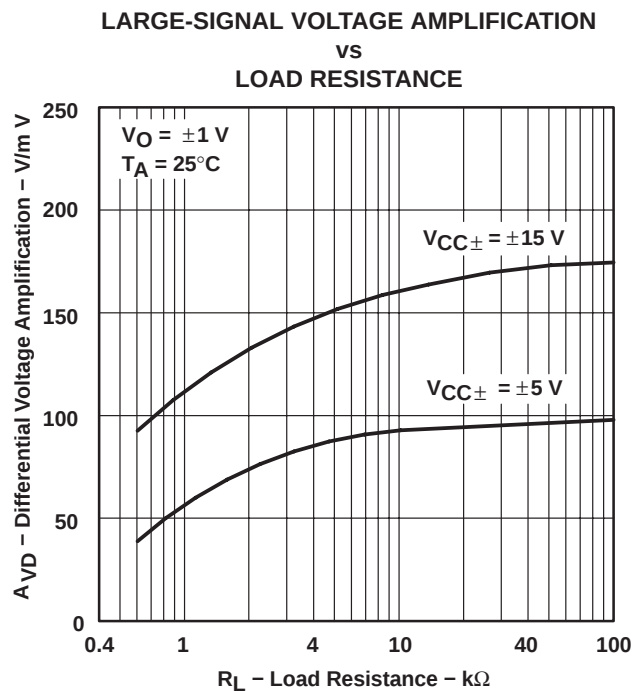


Figure 19

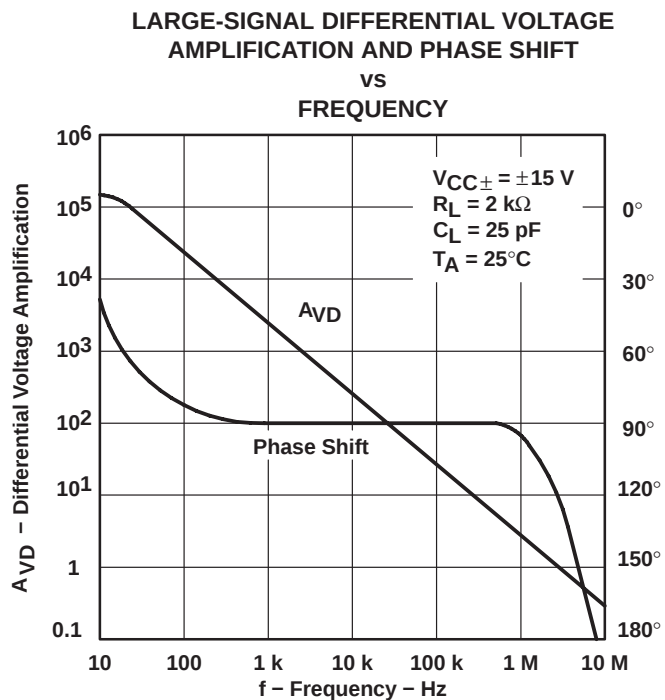


Figure 20

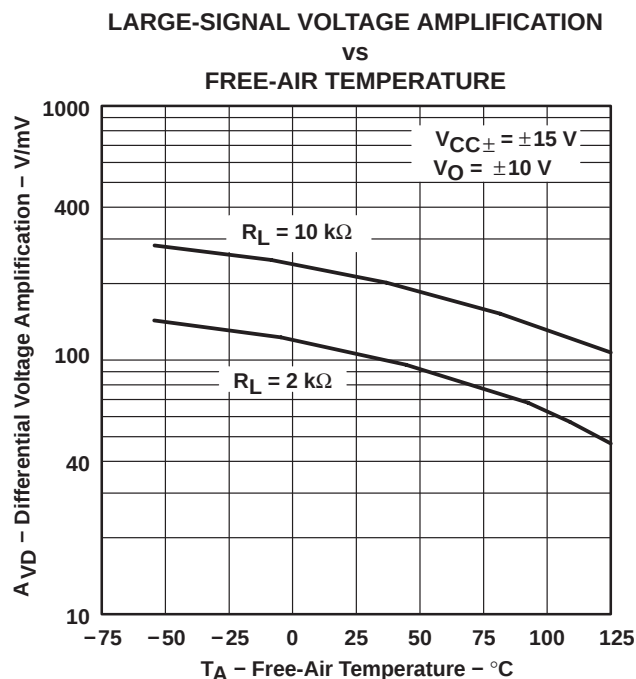


Figure 21

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

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

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TYPICAL CHARACTERISTICS†

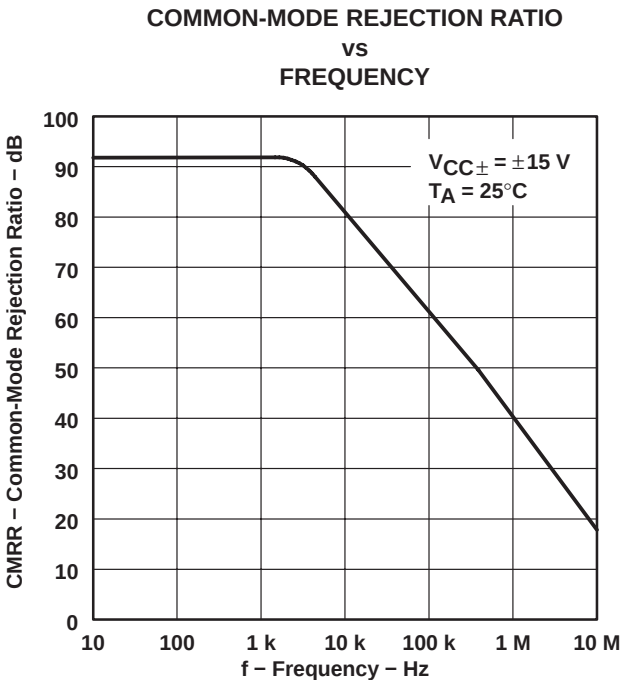


Figure 22

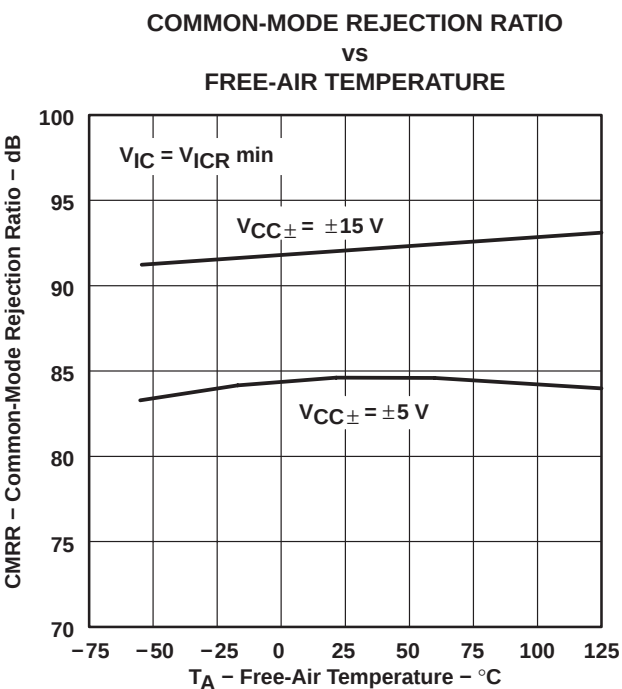


Figure 23

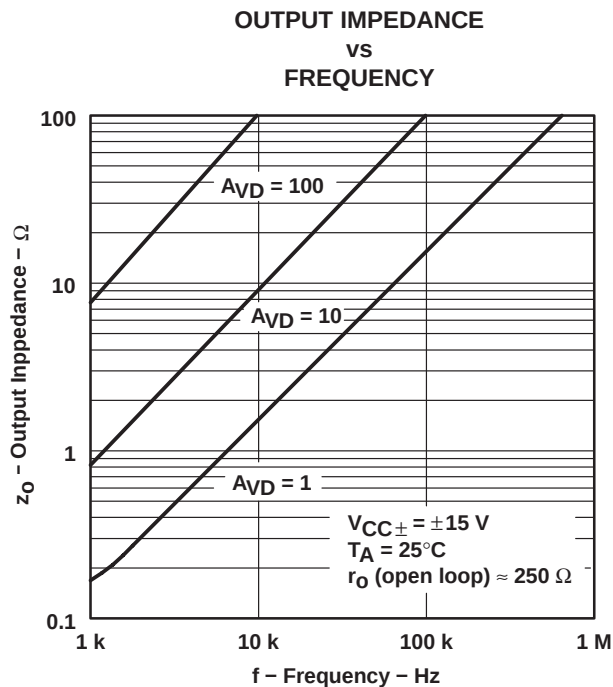


Figure 24

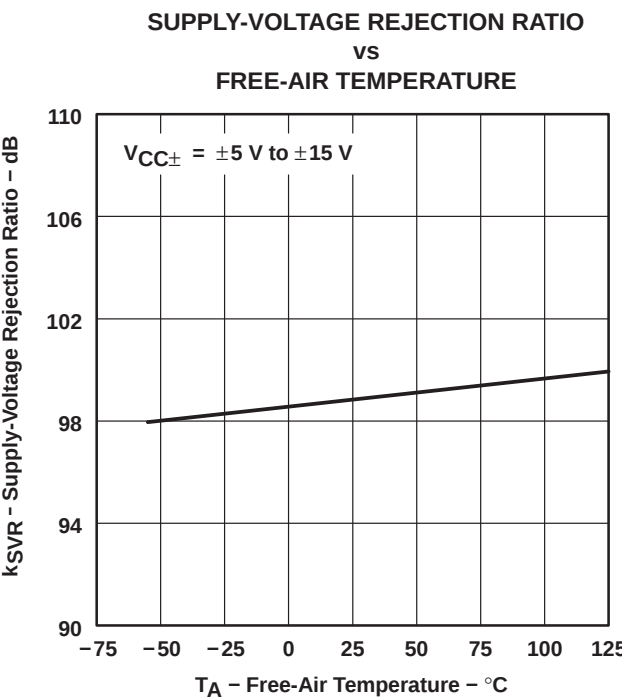


Figure 25

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

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

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TYPICAL CHARACTERISTICS†

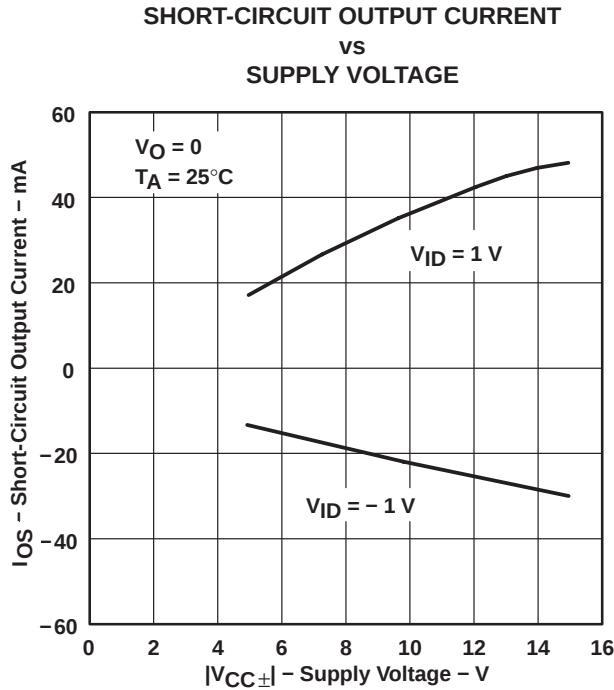


Figure 26

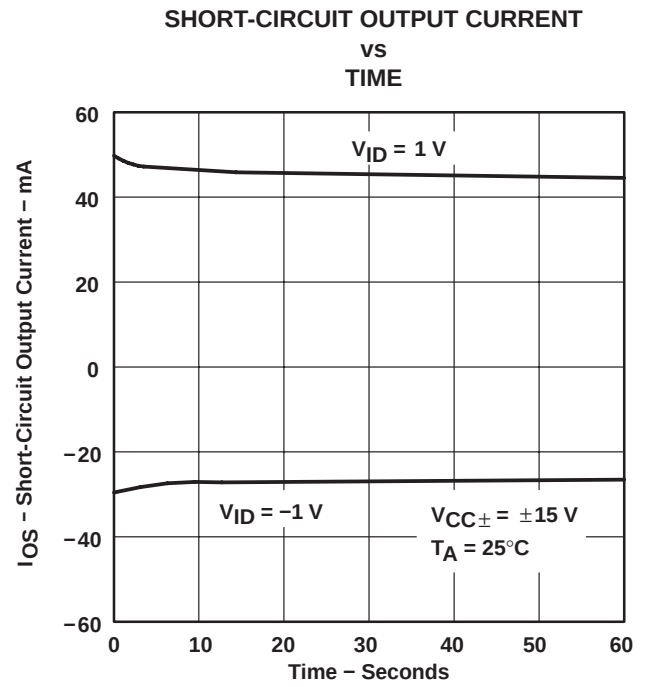


Figure 27

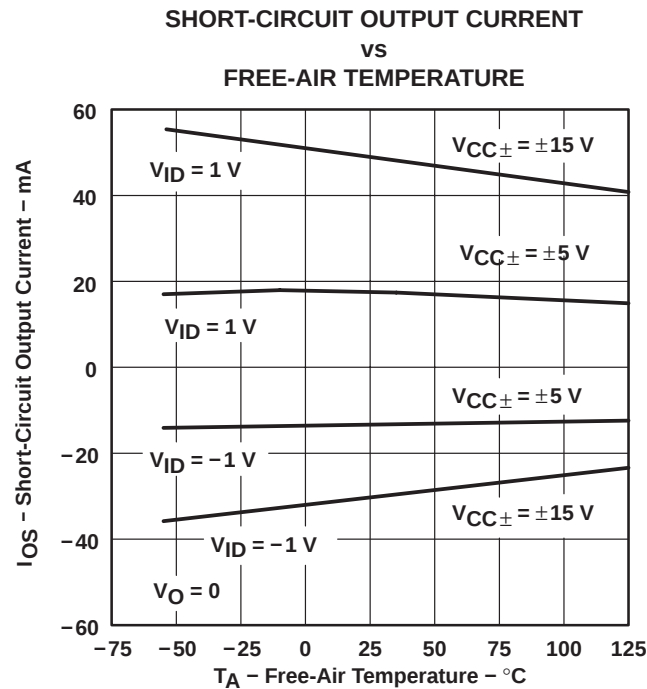


Figure 28

† 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†

SUPPLY CURRENT
VS
SUPPLY VOLTAGE

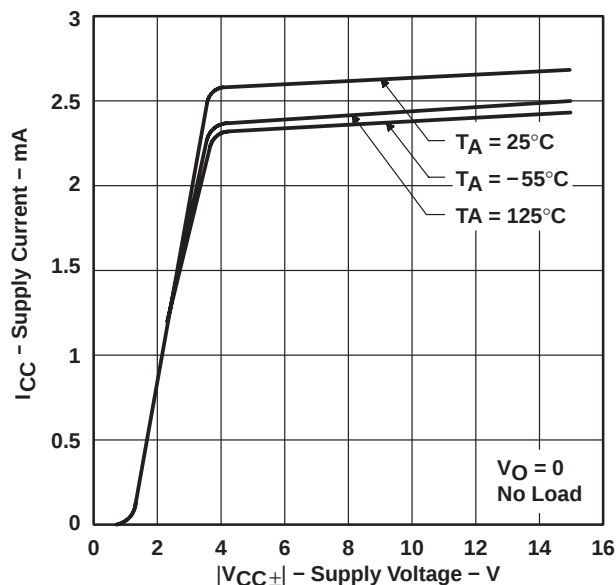


Figure 29

SUPPLY CURRENT
VS
FREE-AIR TEMPERATURE

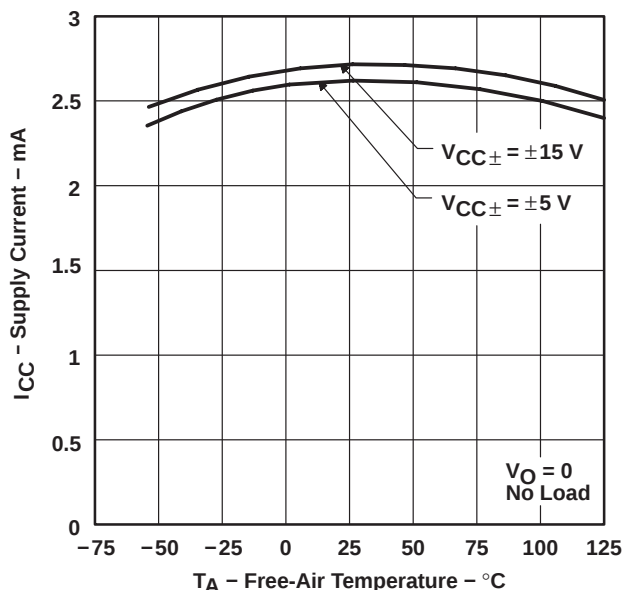


Figure 30

SLEW RATE
VS
LOAD RESISTANCE

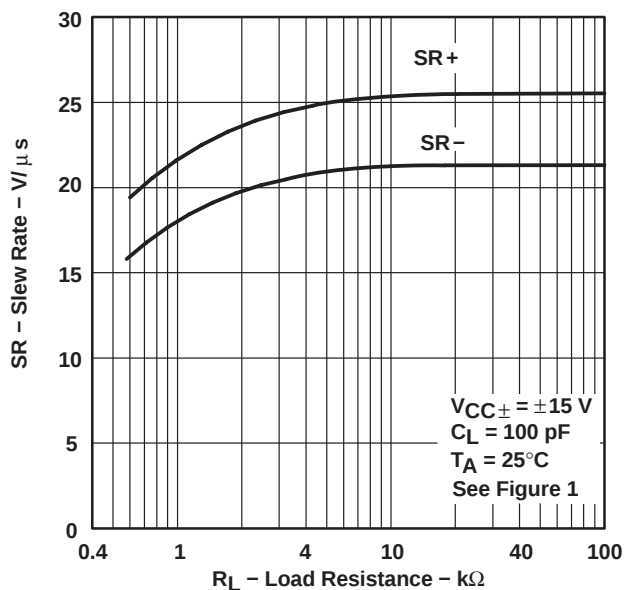


Figure 31

SLEW RATE
VS
FREE-AIR TEMPERATURE

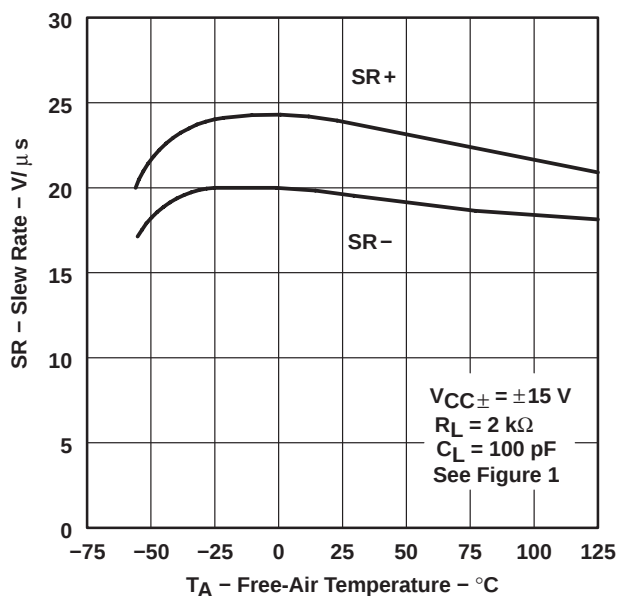


Figure 32

† 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†

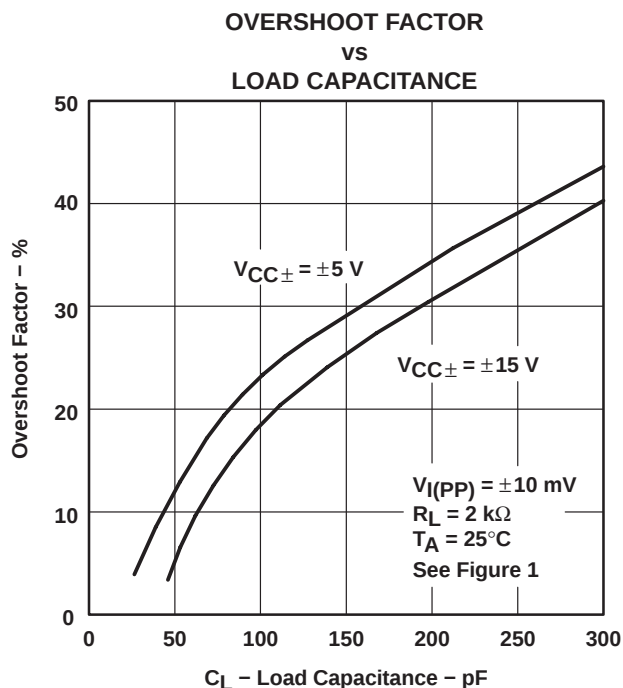


Figure 33

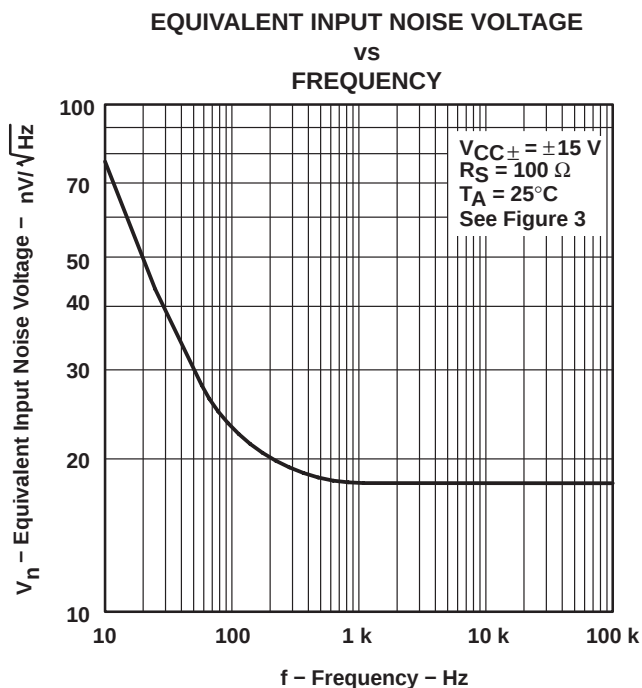


Figure 34

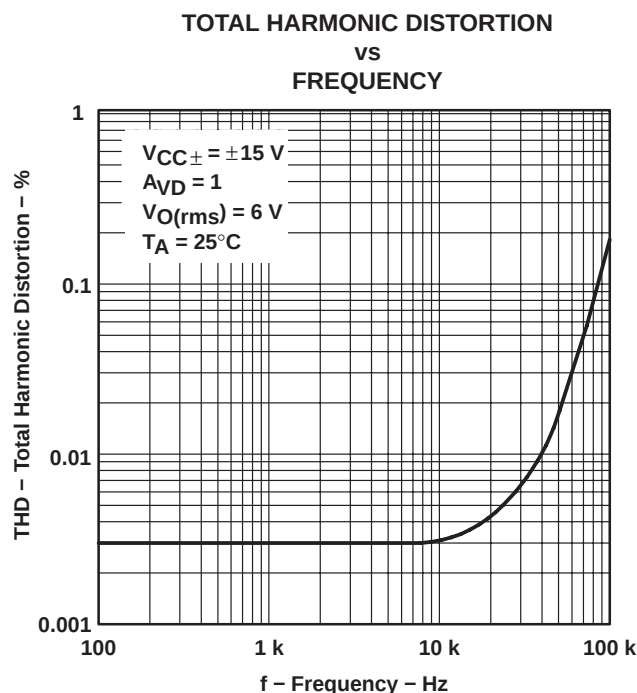


Figure 35

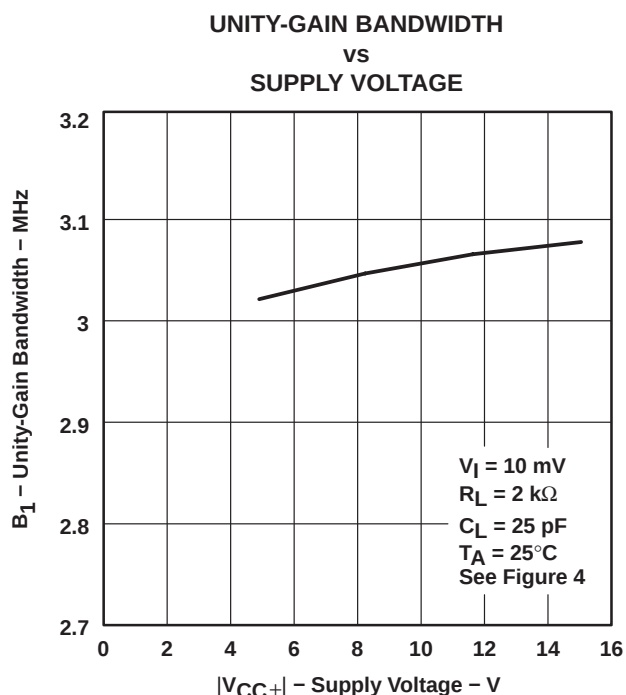


Figure 36

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

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

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TYPICAL CHARACTERISTICS†

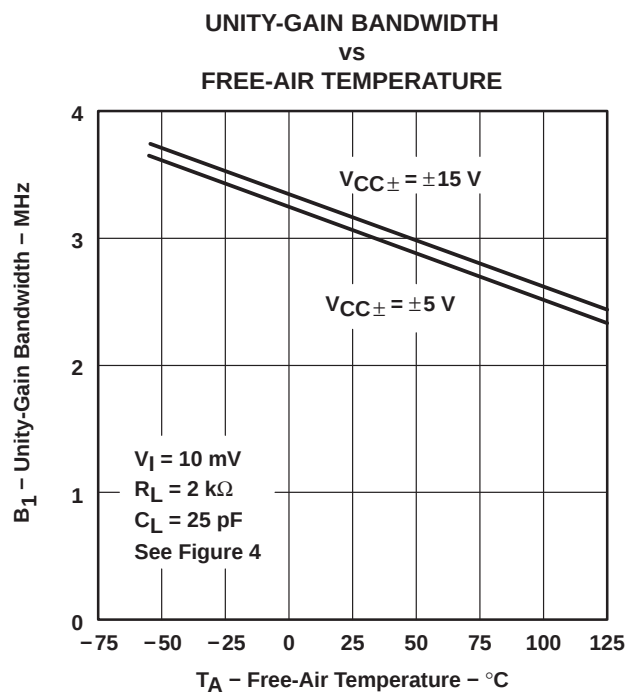


Figure 37

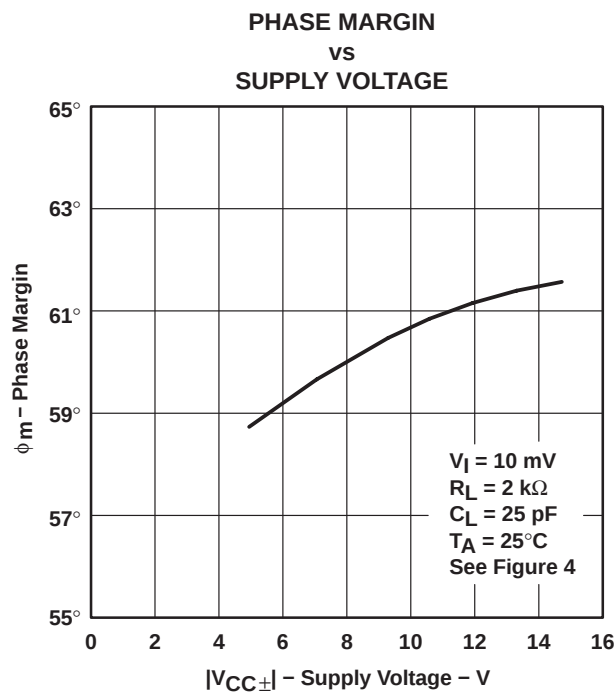


Figure 38

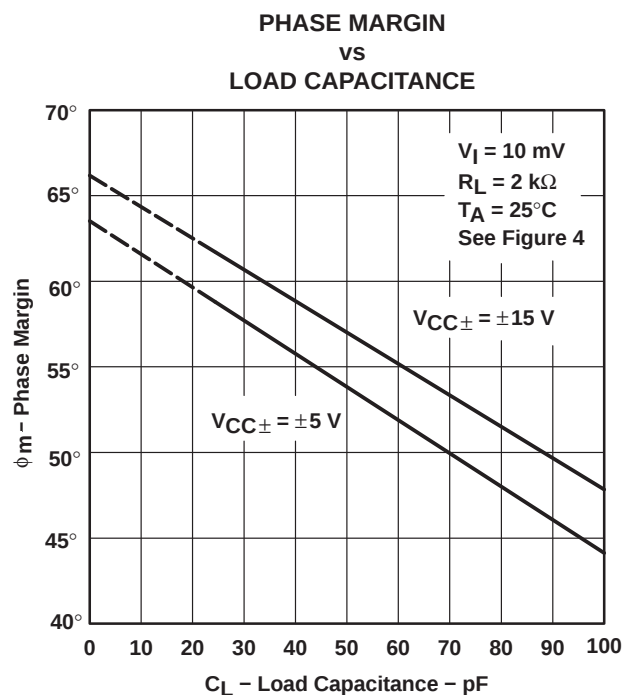


Figure 39

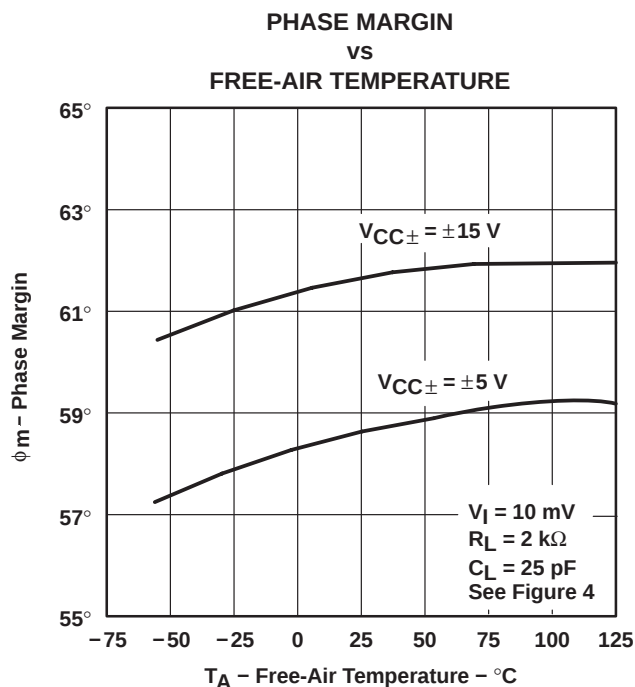


Figure 40

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

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

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TYPICAL CHARACTERISTICS

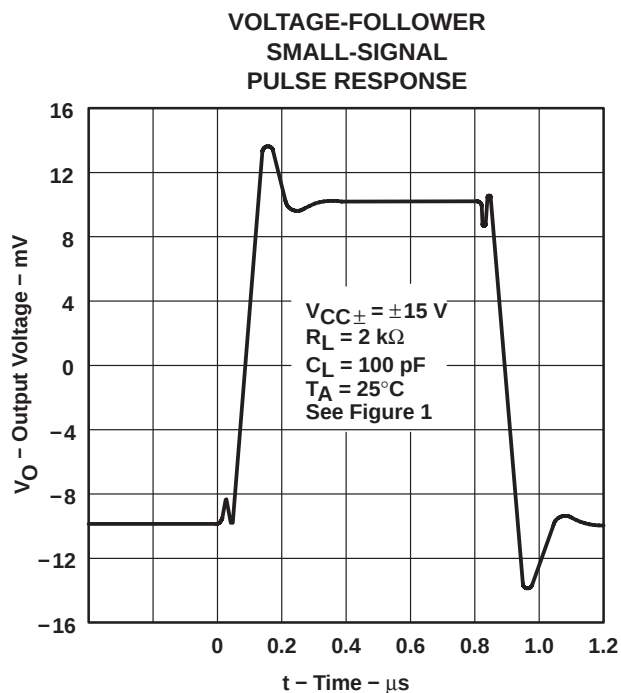


Figure 41

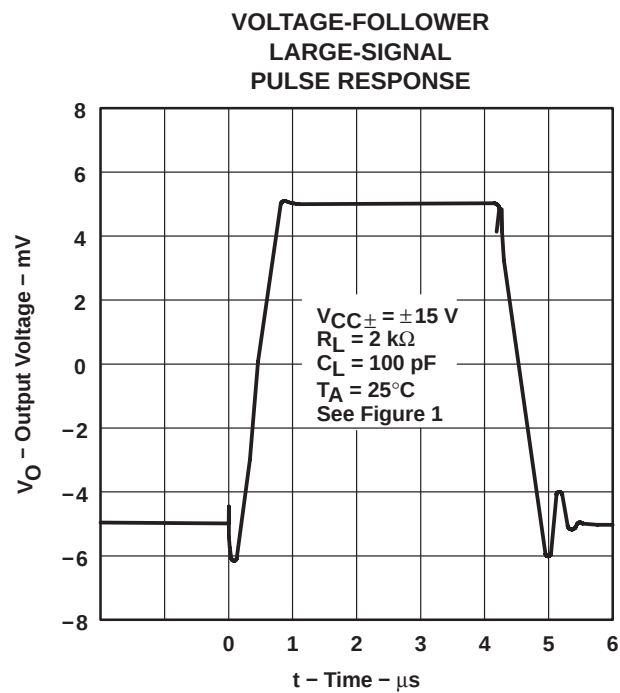


Figure 42

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).

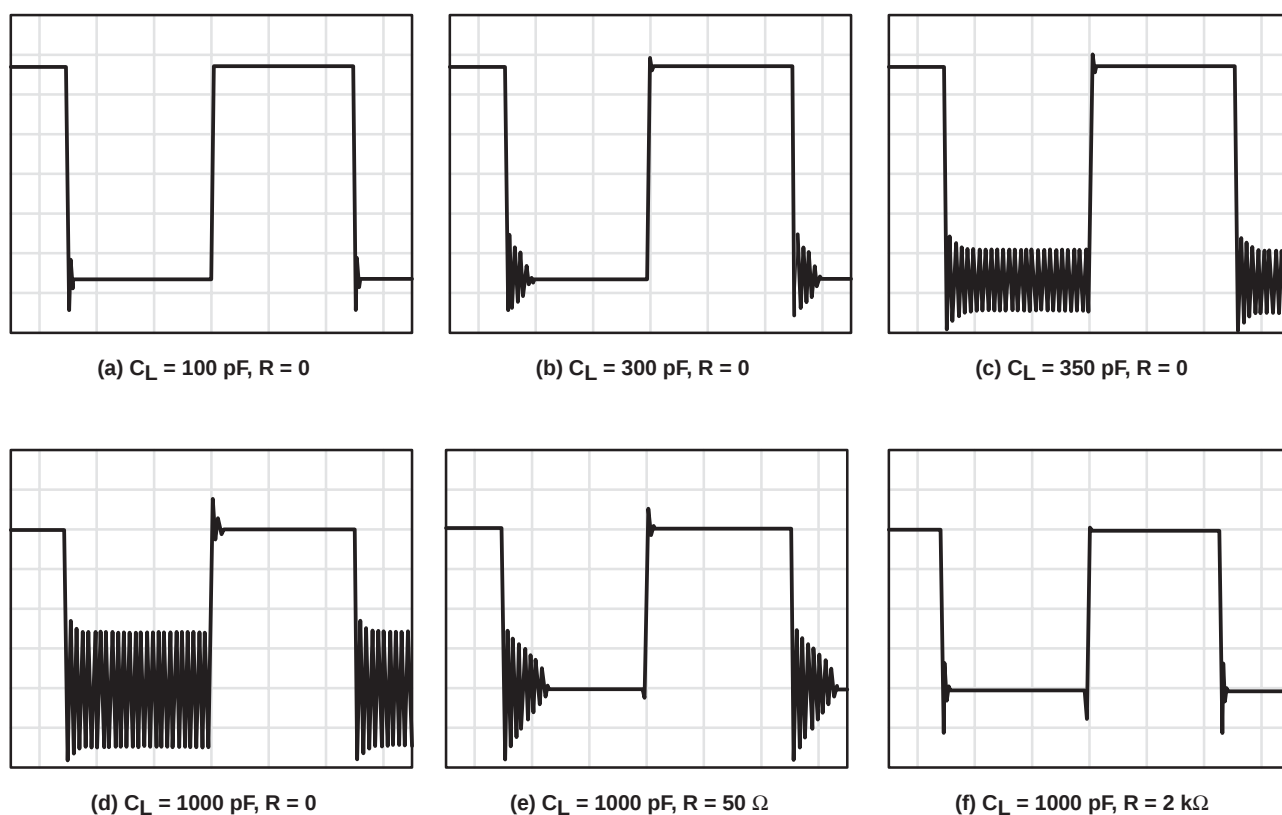


Figure 43. Effect of Capacitive Loads

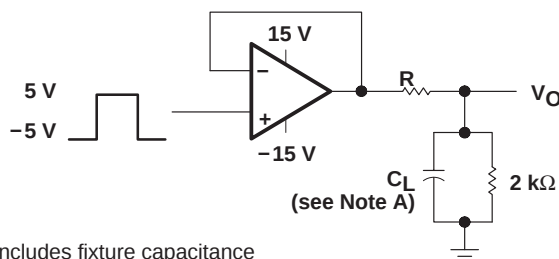


Figure 44. Test Circuit for Output Characteristics

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

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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.

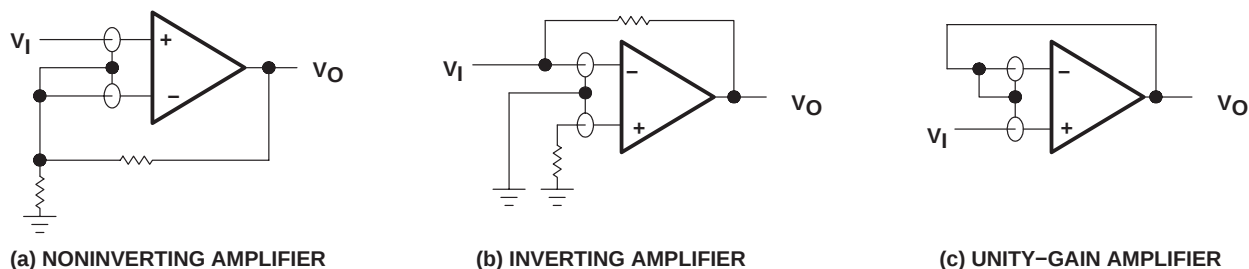


Figure 45. Use of Guard Rings

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 k Ω .

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/Ball Finish	MSL Peak Temp ⁽³⁾
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

⁽¹⁾ 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.

⁽²⁾ 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)

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

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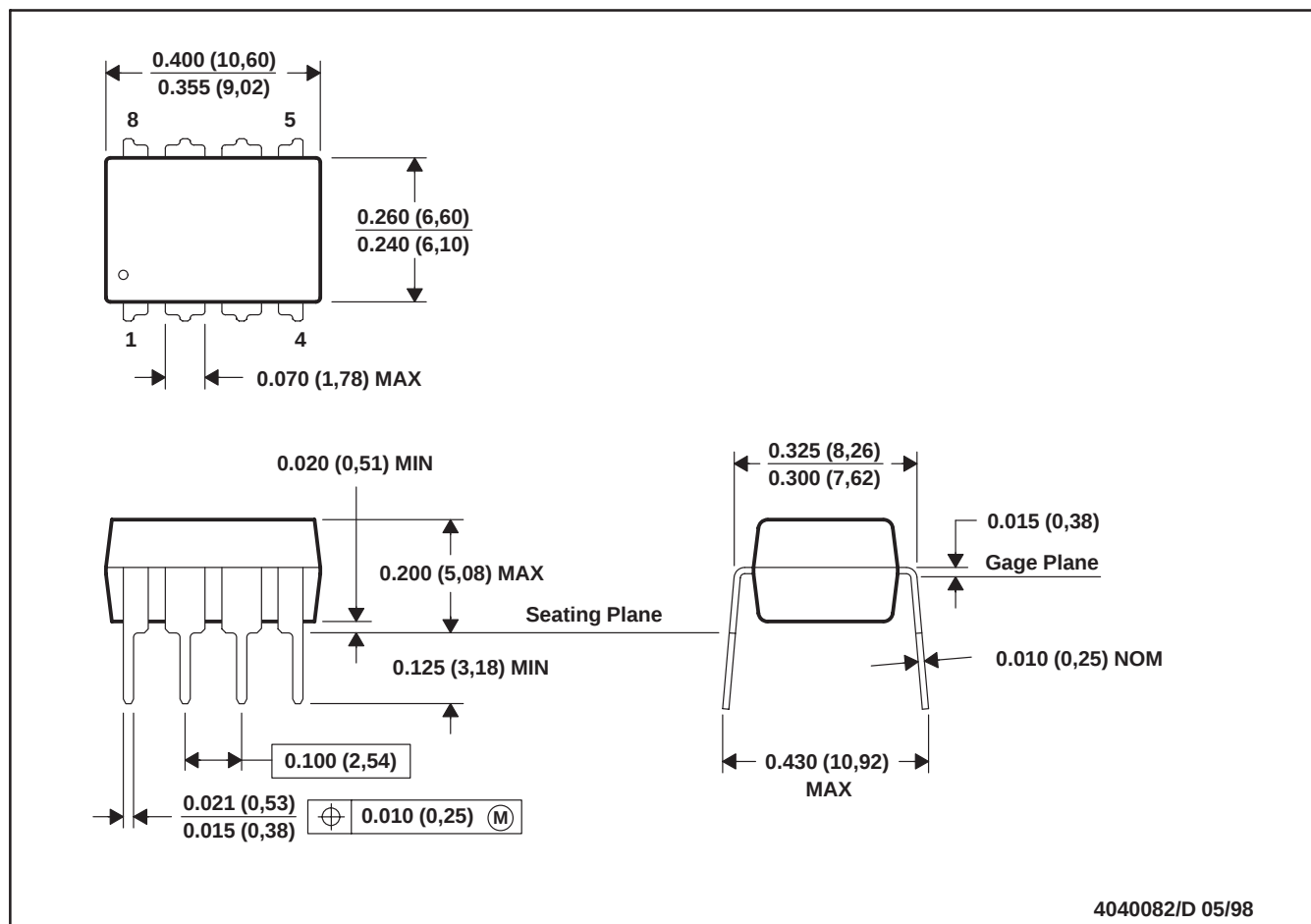
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MECHANICAL DATA

MPDI001A – JANUARY 1995 – REVISED JUNE 1999

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

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