

0.03- $\mu\text{V}/^\circ\text{C}$ Drift, Low-Noise, Rail-to-Rail Output, 36-V, Zero-Drift OPERATIONAL AMPLIFIERS

Check for Samples: [OPA188](#), [OPA2188](#), [OPA4188](#)

FEATURES

- **Low Offset Voltage:** 25 μV (max)
- **Zero-Drift:** 0.03 $\mu\text{V}/^\circ\text{C}$
- **Low Noise:** 8.8 $\text{nV}/\sqrt{\text{Hz}}$
0.1-Hz to 10-Hz Noise: 0.25 μV_{PP}
- **Excellent DC Precision:**
PSRR: 142 dB
CMRR: 146 dB
Open-Loop Gain: 136 dB
- **Gain Bandwidth:** 2 MHz
- **Quiescent Current:** 475 μA (max)
- **Wide Supply Range:** $\pm 2\text{ V}$ to $\pm 18\text{ V}$
- **Rail-to-Rail Output:**
Input Includes Negative Rail
- **RFI Filtered Inputs**
- **MicroSIZE Packages**

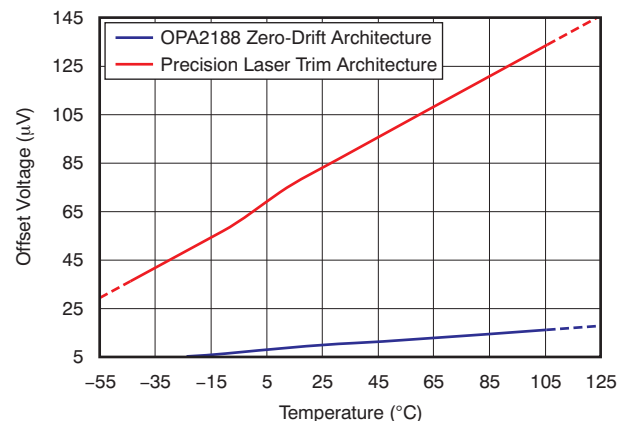
APPLICATIONS

- **Bridge Amplifiers**
- **Strain Gauges**
- **Test Equipment**
- **Transducer Applications**
- **Temperature Measurement**
- **Electronic Scales**
- **Medical Instrumentation**
- **Resister Thermal Detectors**
- **Precision Active Filters**

DESCRIPTION

The OPAx188 series operational amplifiers use TI proprietary auto-zeroing techniques to provide low offset voltage (25 μV , max), and near zero-drift over time and temperature. These miniature, high-precision, low quiescent current amplifiers offer high input impedance and rail-to-rail output swing within 15 mV of the rails. The input common-mode range includes the negative rail. Either single or dual supplies can be used in the range of +4.0 V to +36 V ($\pm 2\text{ V}$ to $\pm 18\text{ V}$).

The single version is available in the *MicroSIZE* SOT23-5, MSOP-8, and SO-8 packages; the dual is offered in MSOP-8 and SO-8 packages; the quad is offered in SO-14 and TSSOP-14 packages. All versions are specified for operation from -40°C to $+105^\circ\text{C}$.



Zero-Drift Amplifier Portfolio

VERSION	PRODUCT	OFFSET VOLTAGE (μV)	OFFSET VOLTAGE DRIFT ($\mu\text{V}/^\circ\text{C}$)	BANDWIDTH (MHz)
Single	OPA188 (4 V to 36 V)	25	0.085	2
Single	OPA333 (5 V)	10	0.05	0.35
	OPA378 (5 V)	50	0.25	0.9
	OPA735 (12 V)	5	0.05	1.6
Dual	OPA2188 (4 V to 36 V)	25	0.085	2
	OPA2333 (5 V)	10	0.05	0.35
	OPA2378 (5 V)	50	0.25	0.9
	OPA2735 (12 V)	5	0.05	1.6
Quad	OPA4188 (4 V to 36 V)	25	0.085	2
Quad	OPA4330 (5 V)	50	0.25	0.35



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This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE INFORMATION⁽¹⁾

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER	TRANSPORT MEDIA, QUANTITY
SINGLE						
OPA188 ⁽²⁾	SOT23-5	DBV	−40°C to +105°C	TBD	OPA188AIDBVT	Tape and Reel, 250
					OPA188AIDBVR	Tape and Reel, 3000
	SO-8	D	−40°C to +105°C	OPA188A	OPA188AID	Rails, 100
					OPA188AIDR	Tape and Reel, 2500
	MSOP-8	DGK	−40°C to +105°C	TBD	OPA188AIDGKT	Tape and Reel, 250
					OPA188AIDGKR	Tape and Reel, 2500
DUAL						
OPA2188	SO-8	D	−40°C to +105°C	2188	OPA2188AID	Rails, 100
					OPA2188AIDR	Tape and Reel, 2500
	MSOP-8	DGK	−40°C to +105°C	2188	OPA2188AIDGKT	Tape and Reel, 250
					OPA2188AIDGKR	Tape and Reel, 2500
QUAD						
OPA4188 ⁽²⁾	SO-14	D	−40°C to +105°C	OPA4188A	OPA4188AID	Rails, 90
					OPA4188AIDR	Tape and Reel, 2000
	TSSOP-14	PW	−40°C to +105°C	OPA4188A	OPA4188AIPW	Rails, 90
					OPA4188AIPWR	Tape and Reel, 2000

(1) For the most current package and ordering information, see the Package Option Addendum at the end of this document, or visit the device product folder at www.ti.com.

(2) Product preview device.

ABSOLUTE MAXIMUM RATINGS

		OPAx188	UNIT
Supply voltage		±20, 40 (single supply)	V
Signal input terminals	Voltage	(V–) – 0.5 to (V+) + 0.5	V
	Current ⁽¹⁾	±10	mA
Output short-circuit ⁽²⁾		Continuous	
Operating temperature		–55 to +125	°C
Storage temperature		–65 to +150	°C
Junction temperature		+150	°C
ESD ratings	Human body model (HBM)	1.5	kV
	Charged device model (CDM)	1	kV

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only and functional operation of the device at these or any other conditions beyond those specified is not implied.

(2) Short-circuit to ground, one amplifier per package.

ELECTRICAL CHARACTERISTICS: High-Voltage Operation

 $V_S = \pm 4\text{ V to } \pm 18\text{ V}$ ($V_S = +8\text{ V to } +36\text{ V}$)

Boldface limits apply over the specified temperature range, $T_A = -40^\circ\text{C to } +105^\circ\text{C}$.

At $T_A = +25^\circ\text{C}$, $R_L = 10\text{ k}\Omega$ connected to $V_S/2$, and $V_{\text{COM}} = V_{\text{OUT}} = V_S/2$, unless otherwise noted.

PARAMETER		CONDITIONS	OPA188, OPA2188, OPA4188			UNIT
			MIN	TYP	MAX	
OFFSET VOLTAGE						
V _{OS}	Input offset voltage		6	25		μV
dV _{OS} /dT	vs Temperature		0.03	0.085		μV/°C
PSRR	vs power supply	V _S = 4 V to 36 V, V _{CM} = V _S /2	0.075	0.3		μV/V
	vs temperature	V _S = 4 V to 36 V, V _{CM} = V _S /2		0.3		μV/V
	Long-term stability		See note ⁽¹⁾			μV
	Channel separation, dc		1			μV/V
INPUT BIAS CURRENT						
I _B	Input bias current	V _{CM} = V _S /2	±160	±850		pA
	over temperature	−40°C to +105°C		±4		nA
I _{OS}	Input offset current		±320	±1700		pA
	over temperature	−40°C to +105°C		±2		nA
NOISE						
e _n	Input voltage noise, f = 0.1 Hz to 10 Hz		0.25			μV _{PP}
e _n	Input voltage noise density, f = 1 kHz		8.8			nV/√Hz
i _n	Input current noise density, f = 1 kHz		7			fA/√Hz
INPUT VOLTAGE RANGE						
V _{CM}	Common-mode voltage range		V−	(V+) − 1.5		V
CMRR	Common-mode rejection ratio	(V−) < V _{CM} < (V+) − 1.5 V	120	134		dB
		(V−) + 0.5 V < V _{CM} < (V+) − 1.5 V, V _S = ±18 V	130	146		dB
	over temperature	(V−) + 0.5 V < V _{CM} < (V+) − 1.5 V, V _S = ±18 V	120	126		dB
INPUT IMPEDANCE						
	Differential			100/6		MΩ/pF
	Common-mode			6/9.5		10 ¹² Ω/pF
OPEN-LOOP GAIN						
A _{OL}	Open-loop voltage gain	(V−) + 500 mV < V _O < (V+) − 500 mV, R _L = 10 kΩ	130	136		dB
	Open-loop voltage gain	(V−) + 500 mV < V _O < (V+) − 500 mV, R _L = 10 kΩ	120	126		dB
FREQUENCY RESPONSE						
GBW	Gain-bandwidth product		2			MHz
SR	Slew rate	G = +1	0.8			V/μs
	Settling time, 0.1%	V _S = ±18 V, G = 1, 10-V step	20			μs
	Settling time, 0.01%	V _S = ±18 V, G = 1, 10-V step	27			μs
	Overload recovery time	V _{IN} × G = V _S	1			μs
THD+N	Total harmonic distortion + noise	1 kHz, G = 1, V _{OUT} = 1 Vrms	0.0001			%

(1) 1000-hour life test at $+125^\circ\text{C}$ demonstrated randomly distributed variation in the range of measurement limits—approximately $4\text{ }\mu\text{V}$.

ELECTRICAL CHARACTERISTICS: High-Voltage Operation (continued)

$V_S = \pm 4\text{ V to } \pm 18\text{ V}$ ($V_S = +8\text{ V to } +36\text{ V}$)

Boldface limits apply over the specified temperature range, $T_A = -40^\circ\text{C to } +105^\circ\text{C}$.

At $T_A = +25^\circ\text{C}$, $R_L = 10\text{ k}\Omega$ connected to $V_S/2$, and $V_{\text{COM}} = V_{\text{OUT}} = V_S/2$, unless otherwise noted.

PARAMETER		CONDITIONS	OPA188, OPA2188, OPA4188			UNIT
			MIN	TYP	MAX	
OUTPUT						
Voltage output swing from rail		No load		6	15	mV
		R _L = 10 kΩ		220	250	mV
Voltage output swing from rail		R _L = 10 kΩ		310	350	mV
I _{SC}	Short-circuit current			±18		mA
R _O	Open-loop output resistance	f = 1 MHz, I _O = 0		120		Ω
C _{LOAD}	Capacitive load drive			1		nF
POWER SUPPLY						
V _S	Operating voltage range		4 to 36 (±2 to ±18)			V
I _Q	Quiescent current (per amplifier)	V _S = ±4 V to V _S = ±18 V		415	475	μA
	over temperature	I _O = 0 mA			525	μA
TEMPERATURE RANGE						
Specified range				−40	+105	°C
Operating range				−40	+125	°C
Storage range				−65	+150	°C

ELECTRICAL CHARACTERISTICS: Low-Voltage Operation

 $V_S = \pm 2 \text{ V to } < \pm 4 \text{ V}$ ($V_S = +4 \text{ V to } < +8 \text{ V}$)

Boldface limits apply over the specified temperature range, $T_A = -40^\circ\text{C to } +105^\circ\text{C}$.

At $T_A = +25^\circ\text{C}$, $R_L = 10 \text{ k}\Omega$ connected to $V_S/2$, and $V_{\text{COM}} = V_{\text{OUT}} = V_S/2$, unless otherwise noted.

PARAMETER		CONDITIONS	OPA188, OPA2188, OPA4188			UNIT
			MIN	TYP	MAX	
OFFSET VOLTAGE						
V _{OS}	Input offset voltage			6	25	μV
dV _{OS} /dT	vs temperature			0.03	0.085	μV/°C
PSRR	vs power supply	V _S = 4 V to 36 V, V _{CM} = V _S /2		0.075	0.3	μV/V
	vs temperature	V _S = 4 V to 36 V, V _{CM} = V _S /2			0.3	μV/V
	Long-term stability			See Note ⁽¹⁾		μV
	Channel separation, dc			1		μV/V
INPUT BIAS CURRENT						
I _B	Input bias current	V _{CM} = V _S /2		±160	±850	pA
	over temperature	−40°C to +105°C			±4	nA
I _{OS}	Input offset current			±320	±1700	pA
	over temperature	−40°C to +105°C			±2	nA
NOISE						
e _n	Input voltage noise, f = 0.1 Hz to 10 Hz			0.25		μV _{PP}
	Input voltage noise density, f = 1 kHz			8.8		nV/√Hz
i _n	Input current noise density, f = 1 kHz			7		fA/√Hz
INPUT VOLTAGE RANGE						
V _{CM}	Common-mode voltage range			V−	(V+) − 1.5	V
CMRR	Common-mode rejection ratio	(V−) < V _{CM} < (V+) − 1.5 V		106	114	dB
		(V−) + 0.5 V < V _{CM} < (V+) − 1.5 V, V _S = ±2 V		114	120	dB
	over temperature	(V−) + 0.5 V < V _{CM} < (V+) − 1.5 V, V _S = ±2 V		110	120	dB
INPUT IMPEDANCE						
	Differential			100/6		MΩ/pF
	Common-mode			6/95		10 ¹² Ω/pF
OPEN-LOOP GAIN						
A _{OL}	Open-loop voltage gain	(V−) + 500 mV < V _O < (V+) − 500 mV, R _L = 5 kΩ, V _S = 5 V		110	120	dB
		(V−) + 500 mV < V _O < (V+) − 500 mV, R _L = 10 kΩ		120	130	dB
	Open-loop voltage gain	(V−) + 500 mV < V _O < (V+) − 500 mV, R _L = 10 kΩ		114	120	dB
FREQUENCY RESPONSE						
GBW	Gain-bandwidth product			2		MHz
SR	Slew rate	G = +1		0.8		V/μs
	Overload recovery time	V _{IN} × G = V _S		1		μs
THD+N	Total harmonic distortion + noise	1 kHz, G = 1, V _{OUT} = 1 Vrms		0.0001		%

(1) 1000-hour life test at $+125^\circ\text{C}$ demonstrated randomly distributed variation in the range of measurement limits—approximately $4 \mu\text{V}$.

ELECTRICAL CHARACTERISTICS: Low-Voltage Operation (continued)

$V_S = \pm 2\text{ V to } < \pm 4\text{ V}$ ($V_S = +4\text{ V to } < +8\text{ V}$)

Boldface limits apply over the specified temperature range, $T_A = -40^\circ\text{C to } +105^\circ\text{C}$.

At $T_A = +25^\circ\text{C}$, $R_L = 10\text{ k}\Omega$ connected to $V_S/2$, and $V_{\text{COM}} = V_{\text{OUT}} = V_S/2$, unless otherwise noted.

PARAMETER		CONDITIONS	OPA188, OPA2188, OPA4188			UNIT
			MIN	TYP	MAX	
OUTPUT						
Voltage output swing from rail	No load		6	15	mV	
	R _L = 10 kΩ		220	250	mV	
Voltage output swing from rail	R _L = 10 kΩ		310	350	mV	
I _{SC}	Short-circuit current		±18		mA	
R _O	Open-loop output resistance	f = 1 MHz, I _O = 0	120		Ω	
C _{LOAD}	Capacitive load drive		1		nF	
POWER SUPPLY						
V _S	Operating voltage range		4 to 36 (±2 to ±18)			V
I _Q	Quiescent current (per amplifier)	V _S = ±2 V to V _S = ±4 V	385	440	μA	
	over temperature	I _O = 0 mA		525	μA	
TEMPERATURE RANGE						
Specified range			−40	+105	°C	
Operating range			−40	+125	°C	
Storage range			−65	+150	°C	

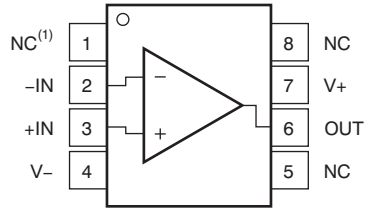
THERMAL INFORMATION: OPA2188

THERMAL METRIC ⁽¹⁾		OPA2188ID	OPA2188IDGK	UNITS
		D	DGK	
		8 PINS	8 PINS	
θ_{JA}	Junction-to-ambient thermal resistance	111.0	159.3	$^\circ\text{C/W}$
$\theta_{J\text{Ctop}}$	Junction-to-case (top) thermal resistance	54.9	37.4	
θ_{JB}	Junction-to-board thermal resistance	51.7	48.5	
ψ_{JT}	Junction-to-top characterization parameter	9.3	1.2	
ψ_{JB}	Junction-to-board characterization parameter	51.1	77.1	
$\theta_{J\text{Cbot}}$	Junction-to-case (bottom) thermal resistance	n/a	n/a	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, [SPRA953](#).

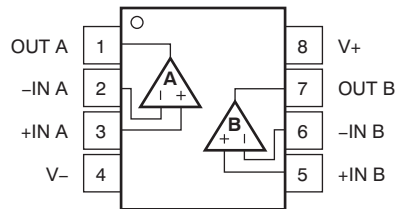
PIN CONFIGURATIONS

OPA188
D, DGK PACKAGES (SO-8, MSOP-8)
(TOP VIEW)

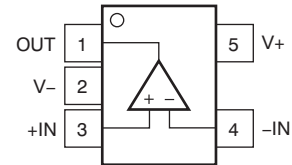


(1) NC = no connection.

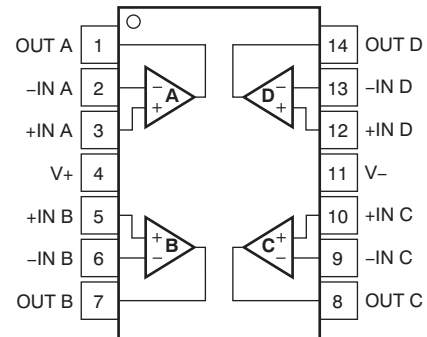
OPA2188
D, DGK PACKAGES (SO-8, MSOP-8)
(TOP VIEW)



OPA188
DBV PACKAGE (SOT23-5)
(TOP VIEW)



OPA4188
D, PW PACKAGES (SO-14, TSSOP-14)
(TOP VIEW)



TYPICAL CHARACTERISTICS

Table 1. Characteristic Performance Measurements

DESCRIPTION	FIGURE
Offset Voltage Production Distribution	Figure 1
Offset Voltage Drift Distribution	Figure 2
Offset Voltage vs Temperature	Figure 3
Offset Voltage vs Common-Mode Voltage	Figure 4, Figure 5
Offset Voltage vs Power Supply	Figure 6
I_B and I_{OS} vs Common-Mode Voltage	Figure 7
Input Bias Current vs Temperature	Figure 8
Output Voltage Swing vs Output Current (Maximum Supply)	Figure 9
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PSRR vs Temperature	Figure 13
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Maximum Output Voltage vs Frequency	Figure 36
Channel Separation vs Frequency	Figure 37
EMIRR IN+ vs Frequency	Figure 38

TYPICAL CHARACTERISTICS

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

OFFSET VOLTAGE PRODUCTION DISTRIBUTION

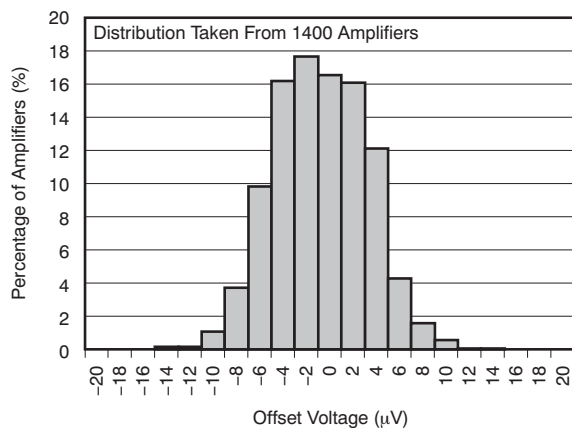


Figure 1.

OFFSET VOLTAGE DRIFT DISTRIBUTION

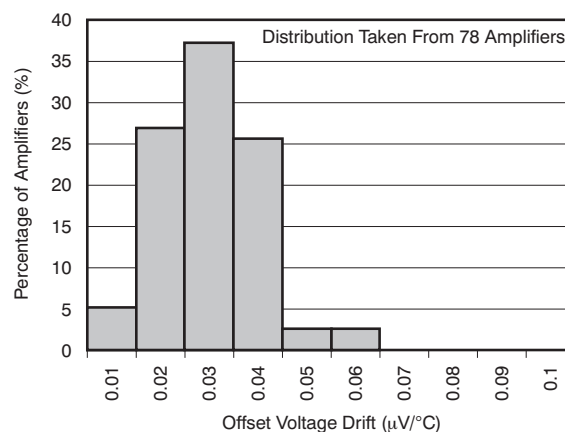


Figure 2.

OFFSET VOLTAGE vs TEMPERATURE

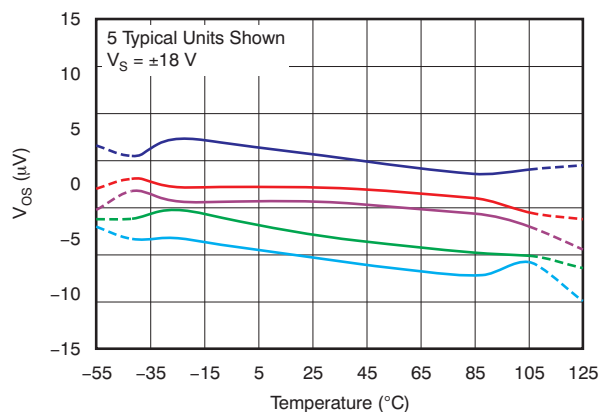


Figure 3.

OFFSET VOLTAGE vs COMMON-MODE VOLTAGE

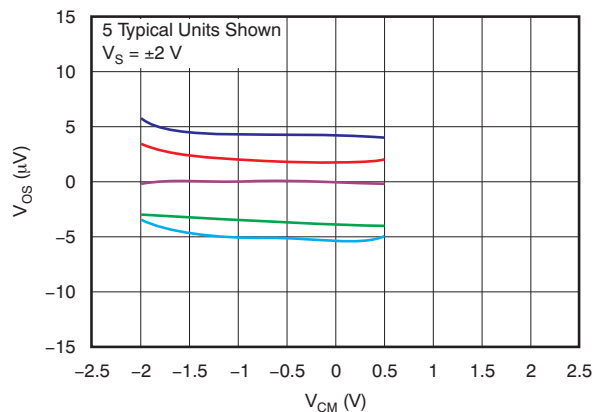


Figure 4.

OFFSET VOLTAGE vs COMMON-MODE VOLTAGE

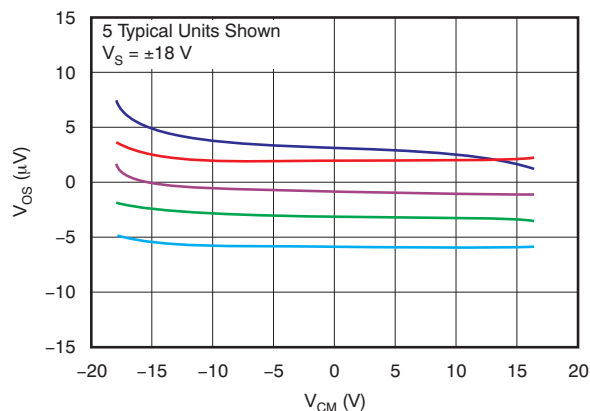


Figure 5.

OFFSET VOLTAGE vs POWER SUPPLY

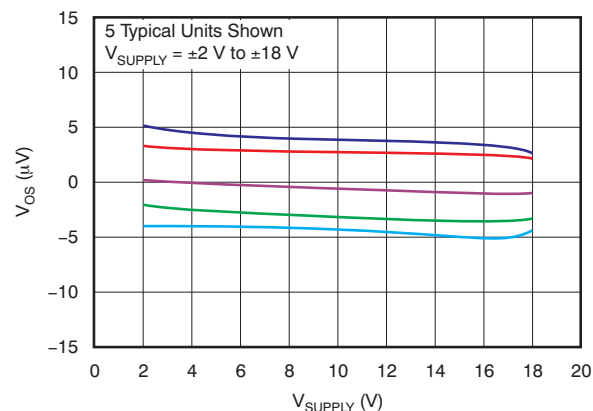


Figure 6.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

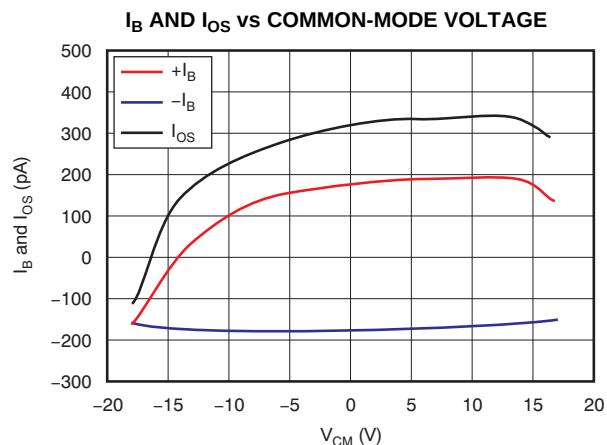


Figure 7.

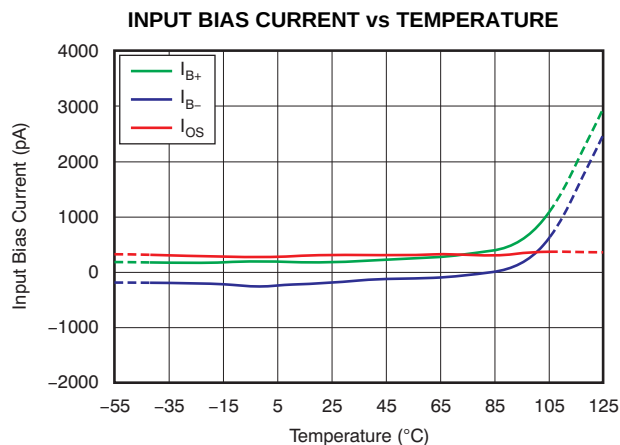


Figure 8.

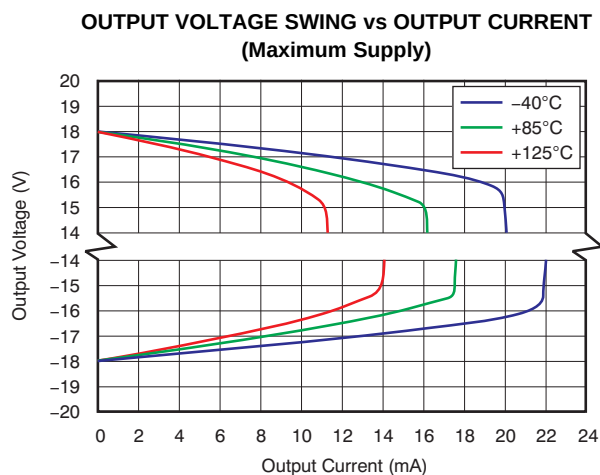


Figure 9.

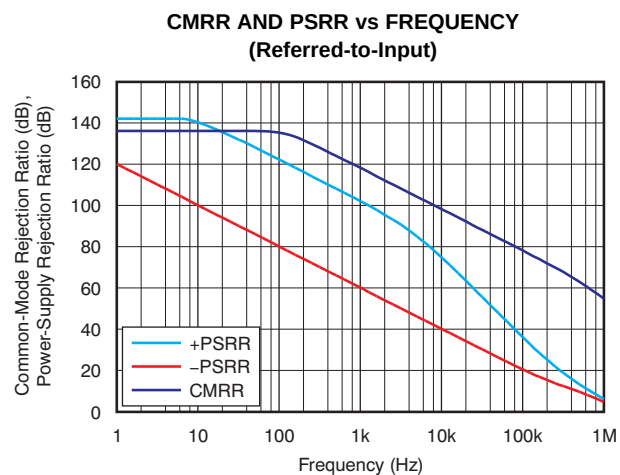


Figure 10.

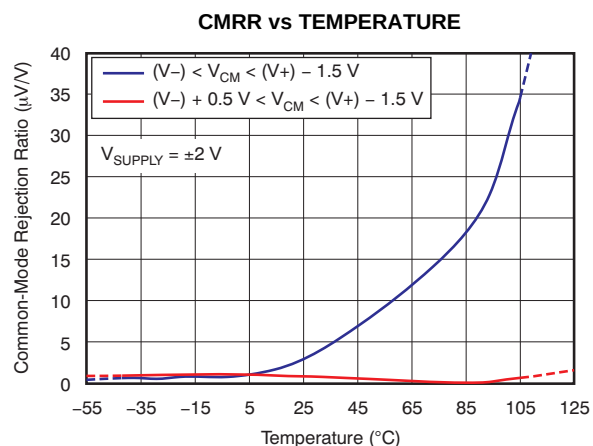


Figure 11.

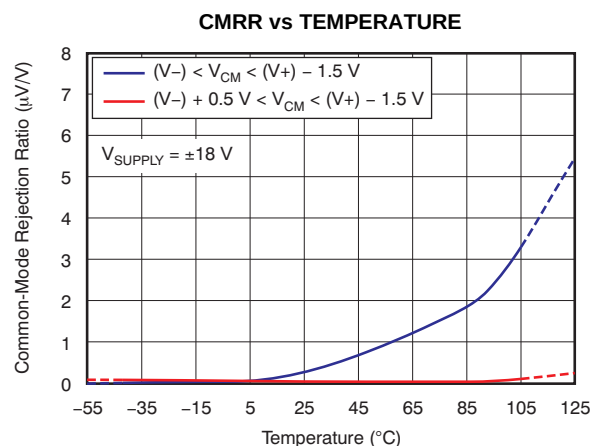


Figure 12.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

PSRR vs TEMPERATURE

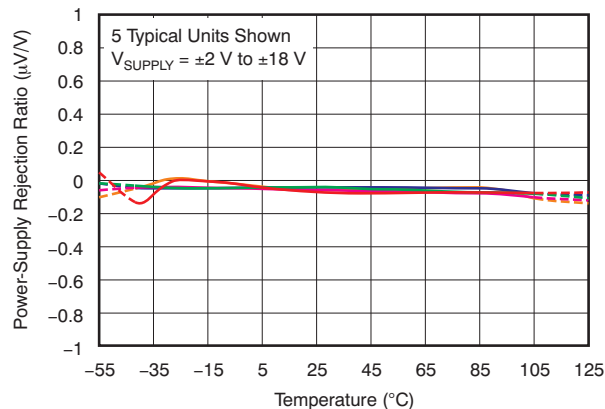


Figure 13.

0.1-Hz TO 10-Hz NOISE

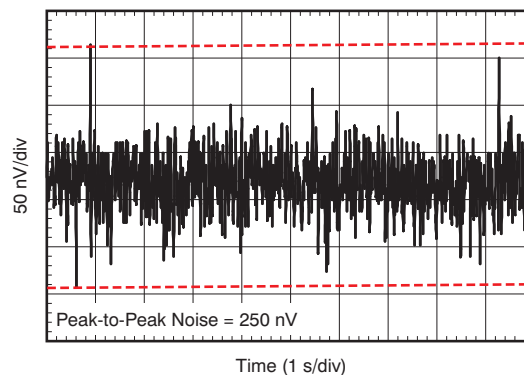


Figure 14.

INPUT VOLTAGE NOISE SPECTRAL DENSITY vs FREQUENCY

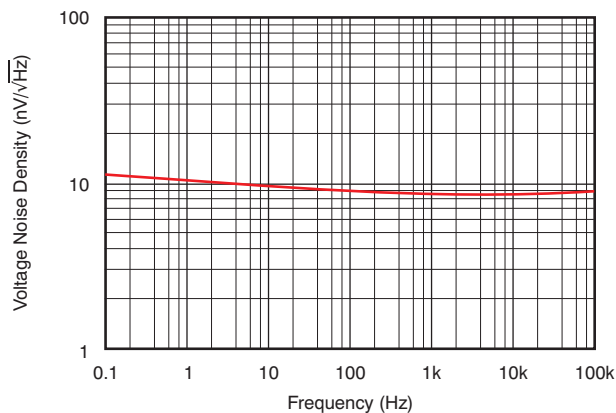


Figure 15.

THD+N RATIO vs FREQUENCY

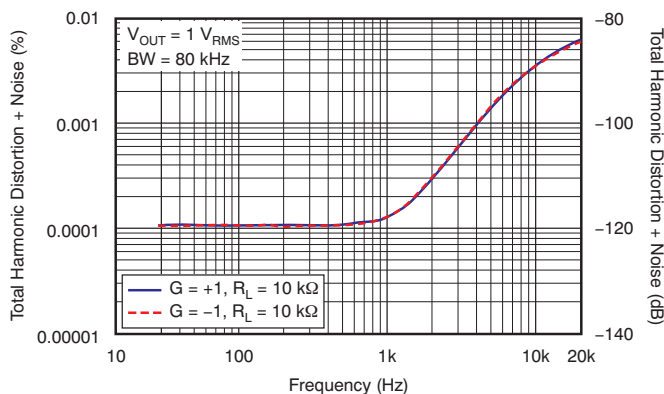


Figure 16.

THD+N vs OUTPUT AMPLITUDE

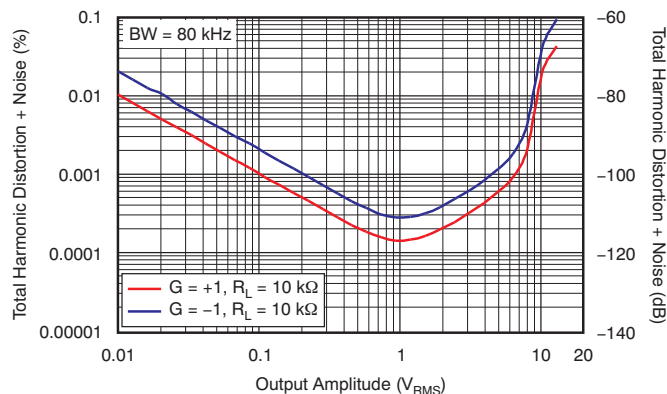


Figure 17.

QUIESCENT CURRENT vs SUPPLY VOLTAGE

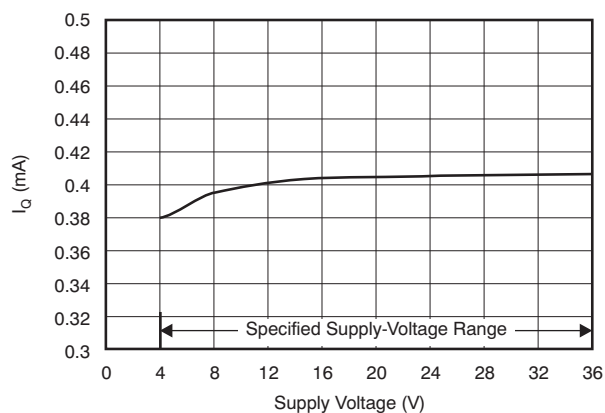


Figure 18.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

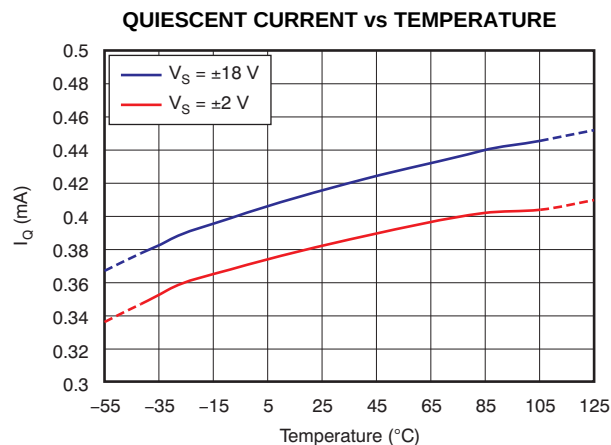


Figure 19.

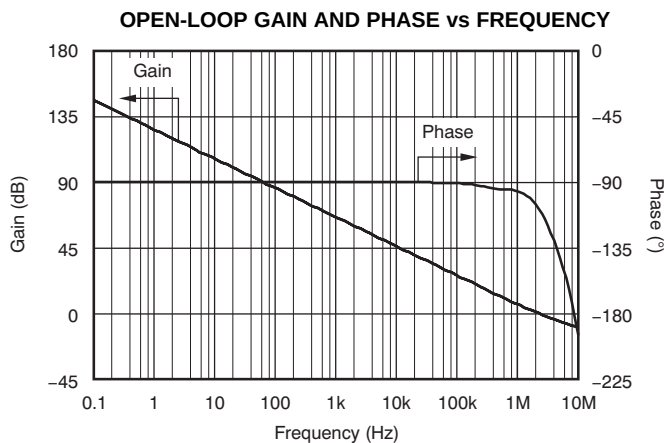


Figure 20.

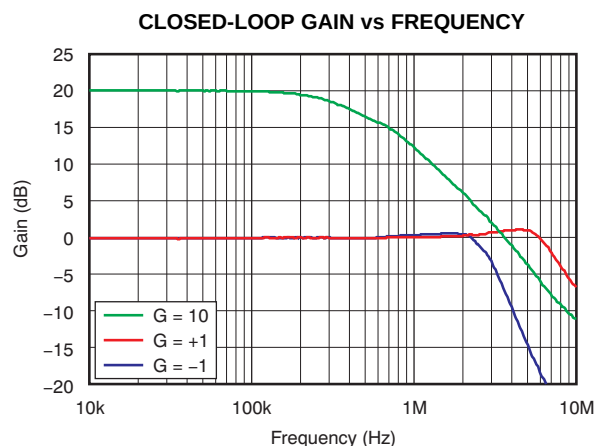


Figure 21.

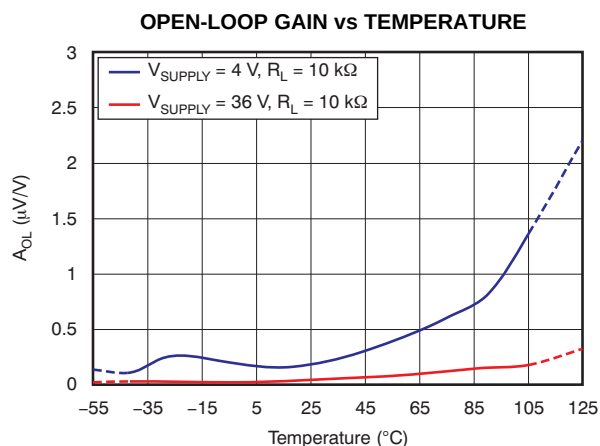


Figure 22.

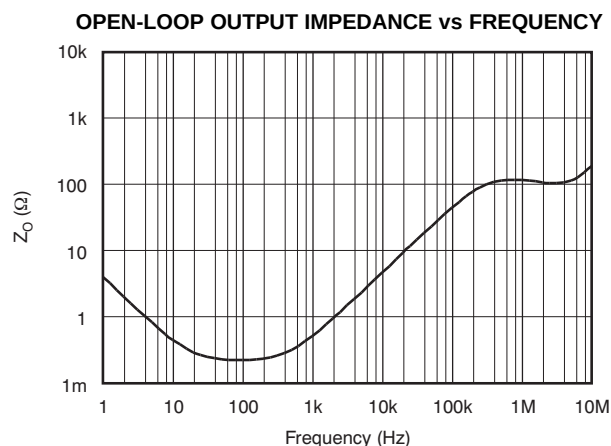


Figure 23.

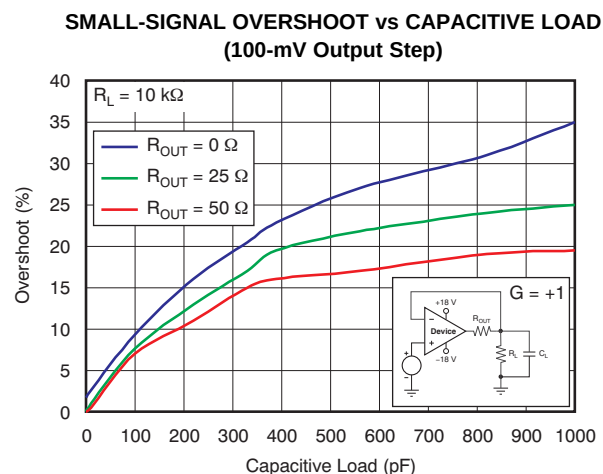


Figure 24.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

SMALL-SIGNAL OVERSHOOT vs CAPACITIVE LOAD (100-mV Output Step)

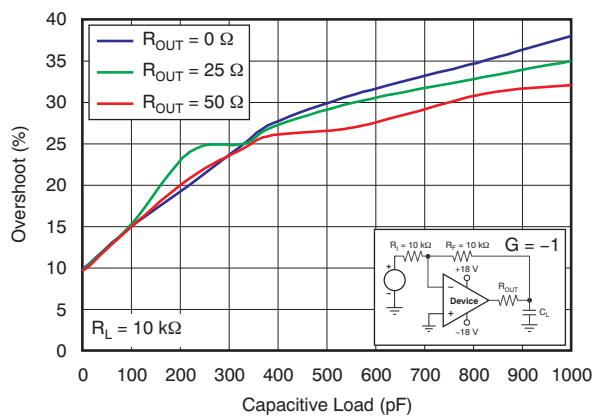


Figure 25.

NO PHASE REVERSAL

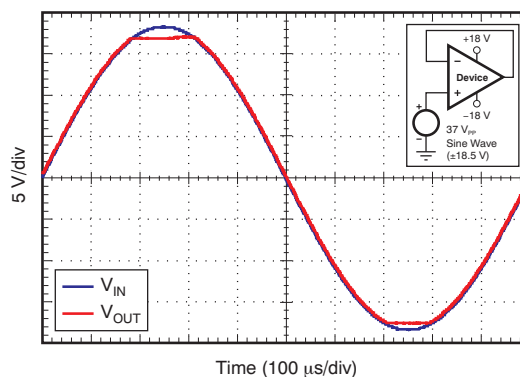


Figure 26.

POSITIVE OVERLOAD RECOVERY

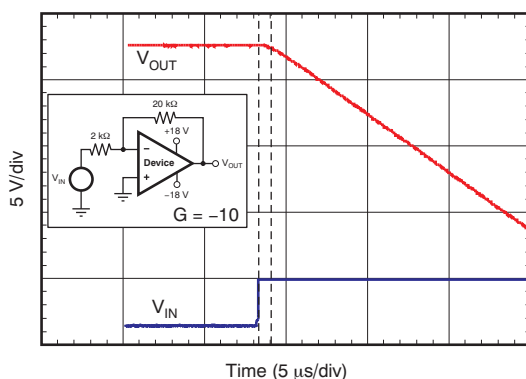


Figure 27.

NEGATIVE OVERLOAD RECOVERY

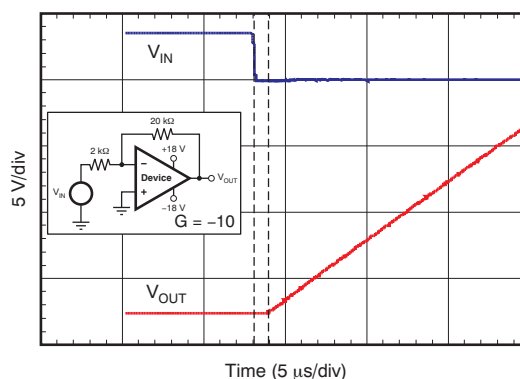


Figure 28.

SMALL-SIGNAL STEP RESPONSE (100 mV)

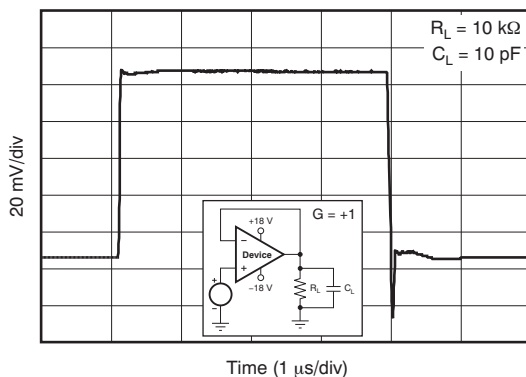


Figure 29.

SMALL-SIGNAL STEP RESPONSE (100 mV)

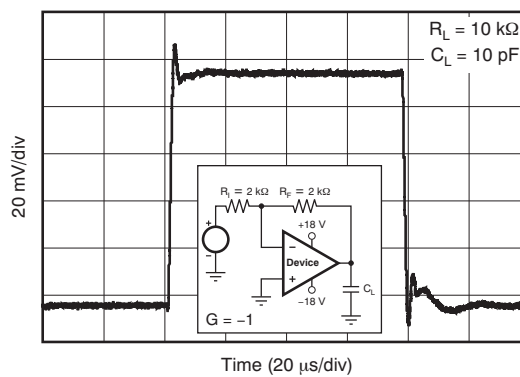


Figure 30.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

LARGE-SIGNAL STEP RESPONSE

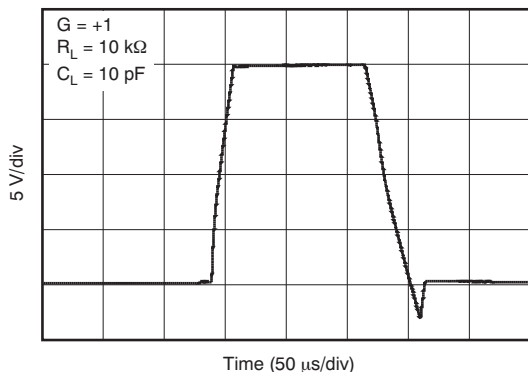


Figure 31.

LARGE-SIGNAL STEP RESPONSE

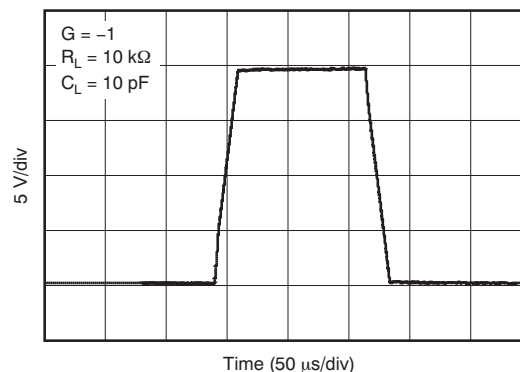


Figure 32.

LARGE-SIGNAL SETTLING TIME
(10-V Positive Step)

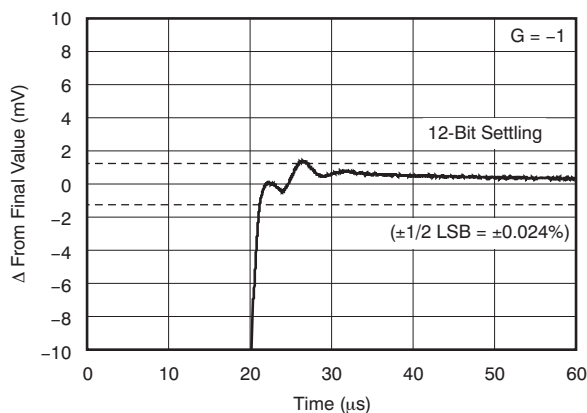


Figure 33.

LARGE-SIGNAL SETTLING TIME
(10-V Negative Step)

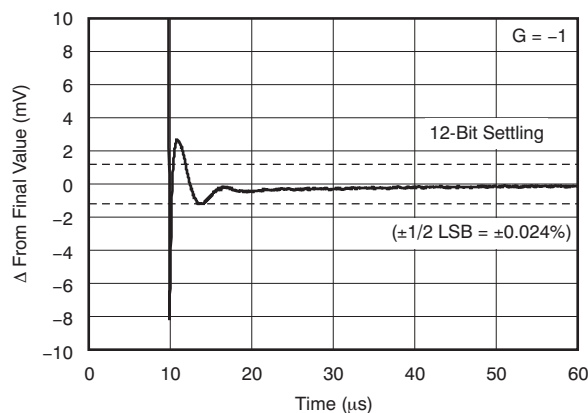


Figure 34.

SHORT-CIRCUIT CURRENT vs TEMPERATURE

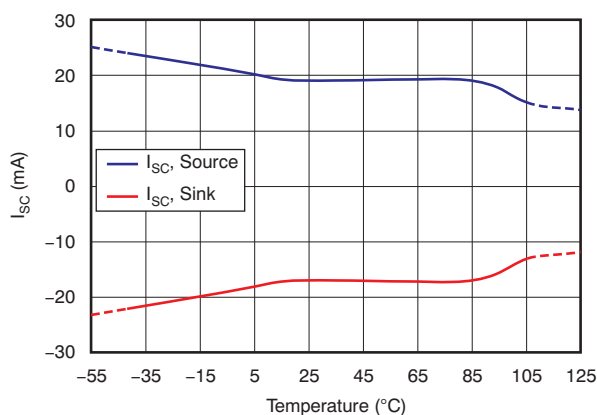


Figure 35.

MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

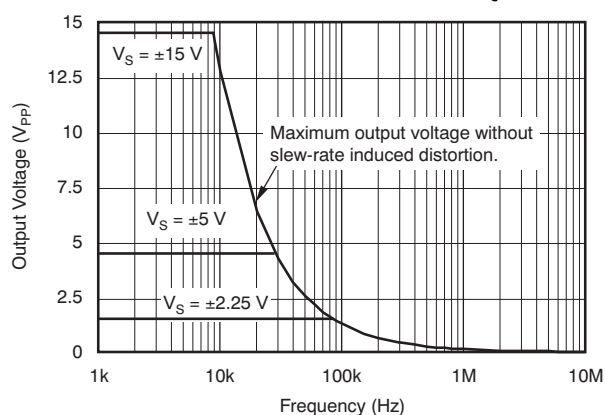


Figure 36.

TYPICAL CHARACTERISTICS (continued)

$V_S = \pm 18\text{ V}$, $V_{CM} = V_S/2$, $R_{LOAD} = 10\text{ k}\Omega$ connected to $V_S/2$, and $C_L = 100\text{ pF}$, unless otherwise noted.

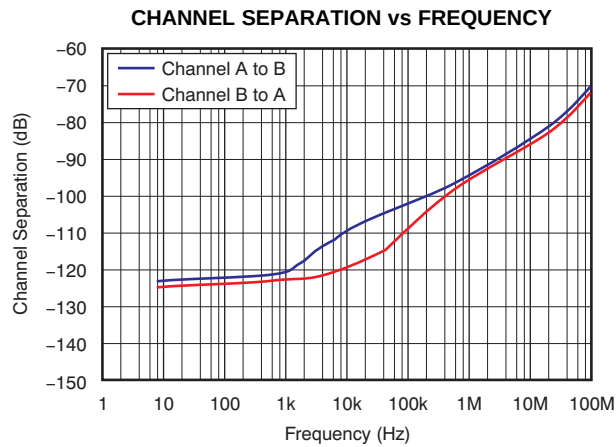


Figure 37.

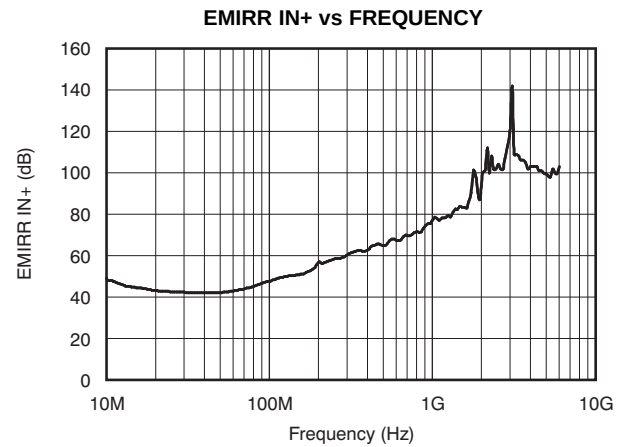


Figure 38.

APPLICATION INFORMATION

The OPAx188 family of operational amplifiers combine precision offset and drift with excellent overall performance, making them ideal for many precision applications. The precision offset drift of only $0.085 \mu\text{V}/^\circ\text{C}$ provides stability over the entire temperature range. In addition, the device offers excellent overall performance with high CMRR, PSRR, and A_{OL} . As with all amplifiers, applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases, $0.1\text{-}\mu\text{F}$ capacitors are adequate.

OPERATING CHARACTERISTICS

The OPAx188 family of amplifiers is specified for operation from 4 V to 36 V ($\pm 2 \text{ V}$ to $\pm 18 \text{ V}$). Many of the specifications apply from -40°C to $+105^\circ\text{C}$. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in the [Typical Characteristics](#).

EMI REJECTION

The OPAx188 uses integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI interference from sources such as wireless communications and densely populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the OPAx188 benefits from these design improvements. Texas Instruments has developed the ability to accurately measure and quantify the immunity of an operational amplifier over a broad frequency spectrum extending from 10 MHz to 6 GHz . [Figure 39](#) shows the results of this testing on the OPAx188. Detailed information can also be found in the [Application Report EMI Rejection Ratio of Operational Amplifiers \(SBOA128\)](#), available for download from the TI website.

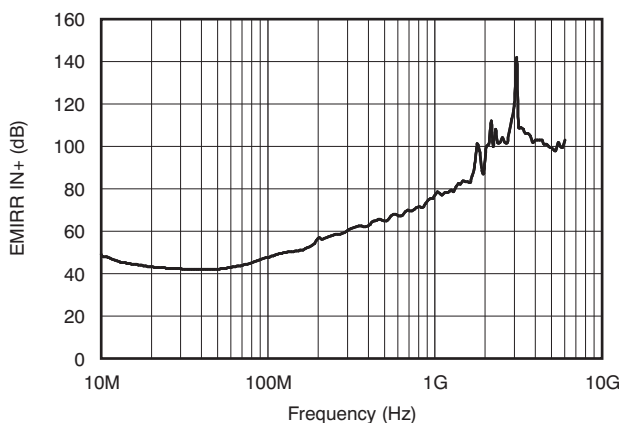


Figure 39. OPAx188 EMIRR Testing

GENERAL LAYOUT GUIDELINES

For best operational performance of the device, good printed circuit board (PCB) layout practices are recommended. Low-loss, 0.1- μ F bypass capacitors should be connected between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable to single-supply applications.

PHASE-REVERSAL PROTECTION

The OPAx188 family has an internal phase-reversal protection. Many op amps exhibit a phase reversal when the input is driven beyond its linear common-mode range. This condition is most often encountered in noninverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The input of the OPAx188 prevents phase reversal with excessive common-mode voltage. Instead, the output limits into the appropriate rail. This performance is shown in Figure 40.

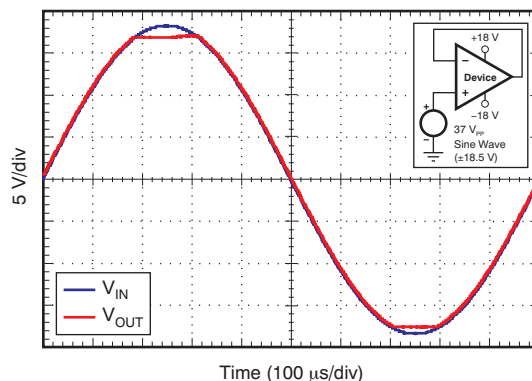


Figure 40. No Phase Reversal

CAPACITIVE LOAD AND STABILITY

The dynamic characteristics of the OPAx188 have been optimized for a range of common operating conditions. The combination of low closed-loop gain and high capacitive loads decreases the phase margin of the amplifier and can lead to gain peaking or oscillations. As a result, heavier capacitive loads must be isolated from the output. The simplest way to achieve this isolation is to add a small resistor (for example, R_{OUT} equal to 50 Ω) in series with the output. Figure 41 and Figure 42 illustrate graphs of small-signal overshoot versus capacitive load for several values of R_{OUT} . Also, refer to the [Applications Report, Feedback Plots Define Op Amp AC Performance \(SBOA015\)](#), available for download from the TI website, for details of analysis techniques and application circuits.

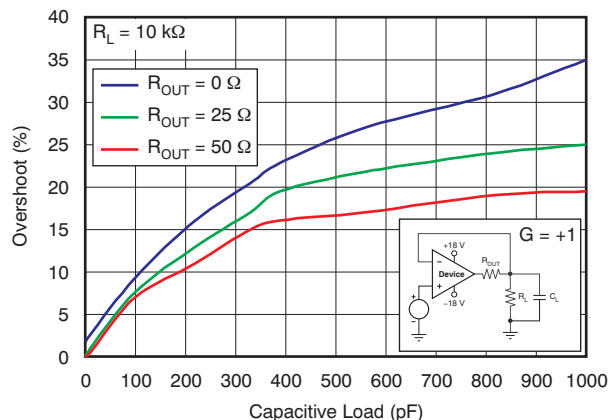


Figure 41. Small-Signal Overshoot versus Capacitive Load (100-mV Output Step)

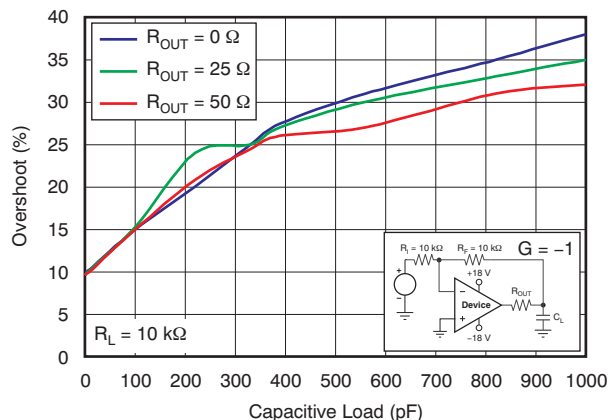


Figure 42. Small-Signal Overshoot versus Capacitive Load (100-mV Output Step)

ELECTRICAL OVERSTRESS

Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress. These questions tend to focus on the device inputs, but may involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined by the voltage breakdown characteristics of the particular semiconductor fabrication process and specific circuits connected to the pin. Additionally, internal electrostatic discharge (ESD) protection is built into these circuits to protect them from accidental ESD events both before and during product assembly.

These ESD protection diodes also provide in-circuit, input overdrive protection, as long as the current is limited to 10 mA as stated in the [Absolute Maximum Ratings](#). Figure 43 shows how a series input resistor may be added to the driven input to limit the input current. The added resistor contributes thermal noise at the amplifier input and its value should be kept to a minimum in noise-sensitive applications.

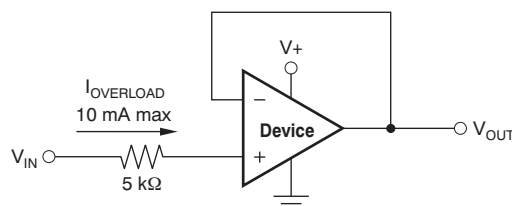


Figure 43. Input Current Protection

An ESD event produces a short duration, high-voltage pulse that is transformed into a short duration, high-current pulse as it discharges through a semiconductor device. The ESD protection circuits are designed to provide a current path around the operational amplifier core to prevent it from being damaged. The energy absorbed by the protection circuitry is then dissipated as heat.

When the operational amplifier connects into a circuit, the ESD protection components are intended to remain inactive and not become involved in the application circuit operation. However, circumstances may arise where an applied voltage exceeds the operating voltage range of a given pin. Should this condition occur, there is a risk that some of the internal ESD protection circuits may be biased on, and conduct current. Any such current flow occurs through ESD cells and rarely involves the absorption device.

If there is an uncertainty about the ability of the supply to absorb this current, external zener diodes may be added to the supply pins. The zener voltage must be selected such that the diode does not turn on during normal operation.

However, its zener voltage should be low enough so that the zener diode conducts if the supply pin begins to rise above the safe operating supply voltage level.

APPLICATION EXAMPLES

The application examples of [Figure 44](#) and [Figure 45](#) highlight only a few of the circuits where the OPAx188 family of devices can be used.

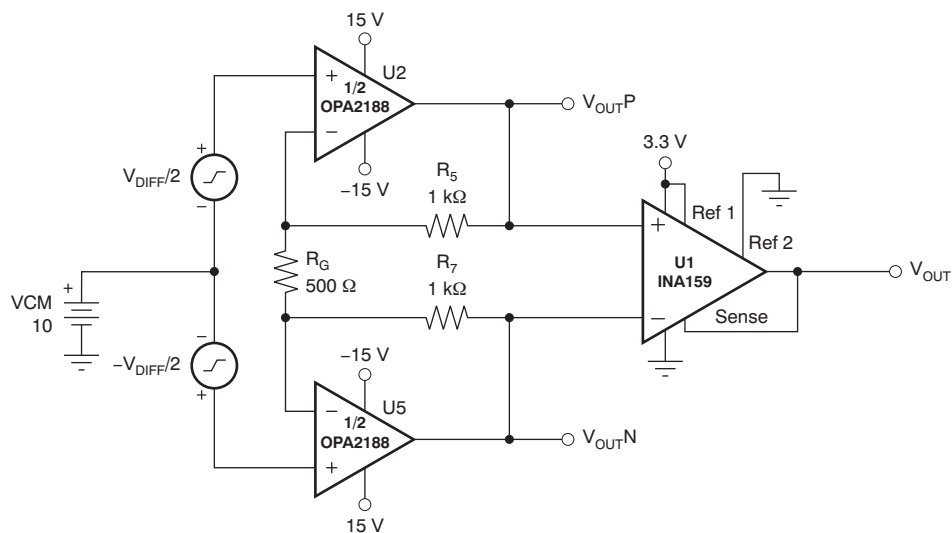
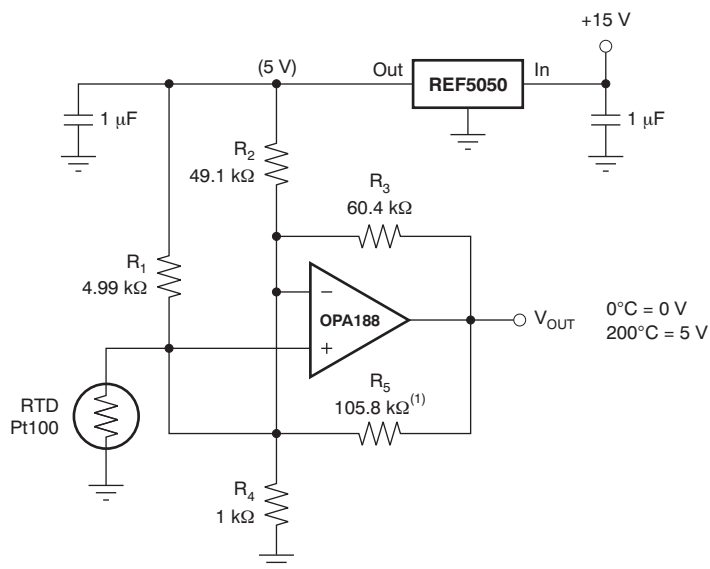


Figure 44. Discrete INA + Attenuation for ADC with 3.3-V Supply



(1) R_5 provides positive-varying excitation to linearize output.

Figure 45. RTD Amplifier with Linearization

PACKAGING INFORMATION

Orderable Device	Status ⁽¹⁾	Package Type	Package Drawing	Pins	Package Qty	Eco Plan ⁽²⁾	Lead/ Ball Finish	MSL Peak Temp ⁽³⁾	Samples (Requires Login)
OPA2188AID	PREVIEW	SOIC	D	8		TBD	Call TI	Call TI	
OPA2188AIDGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
OPA2188AIDGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	
OPA2188AIDR	PREVIEW	SOIC	D	8		TBD	Call TI	Call TI	

⁽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)

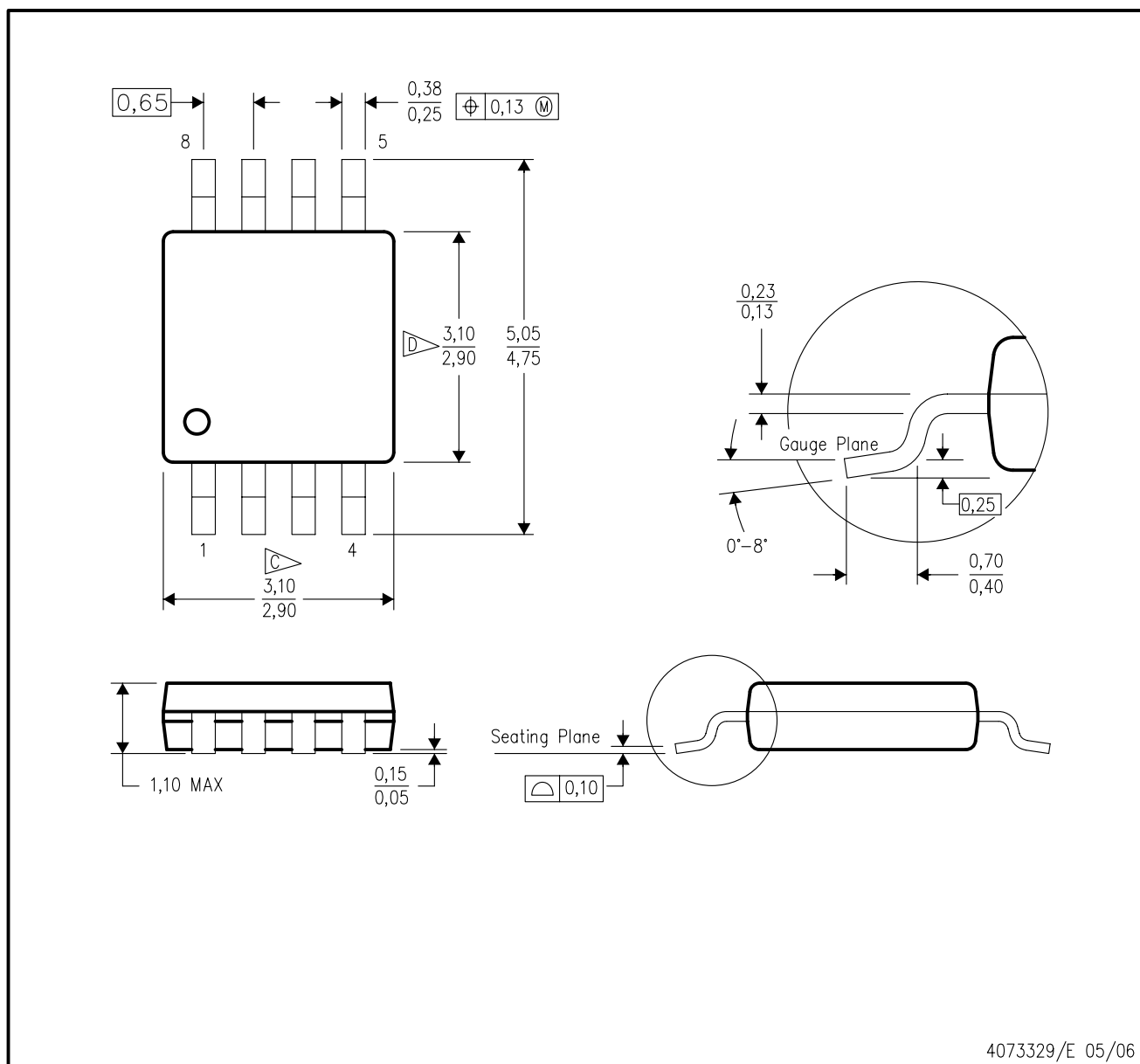
⁽³⁾ MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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DGK (S-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE

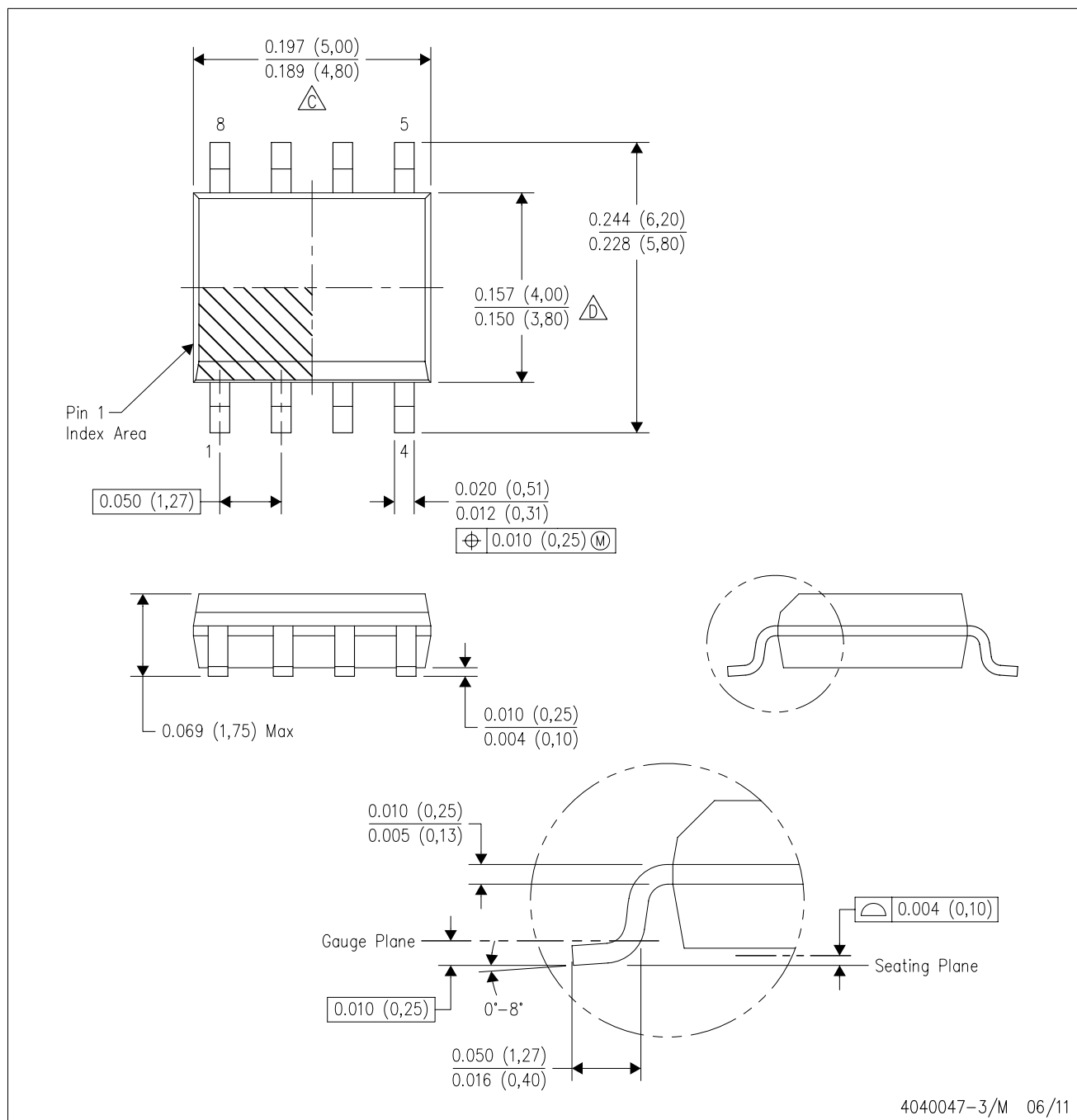


NOTES:

- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed 0.50 per side.
- E. Falls within JEDEC MO-187 variation AA, except interlead flash.

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - $\triangle C$ Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
 - $\triangle D$ Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
 - E. Reference JEDEC MS-012 variation AA.

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