1.1nV/√Hz Noise, Low Power, Precision Operational Amplifier in Small DFN-8 Package

FEATURES

- **LOW VOLTAGE NOISE: 1.1nV/√Hz at 1kHz**
- **INPUT VOLTAGE NOISE: 80nV$_{PP}$ (0.1Hz to 10Hz)**
- **THD+N: –136dB (G = 1, f = 1kHz)**
- **OFFSET VOLTAGE: 125μV (max)**
- **OFFSET VOLTAGE DRIFT: 0.35μV/°C (typ)**
- **LOW SUPPLY CURRENT: 3.6mA/Ch (typ)**
- **UNITY-GAIN STABLE**
- **GAIN BANDWIDTH PRODUCT: 80MHz (G = 100) 45MHz (G = 1)**
- **SLEW RATE: 27V/μs**
- **16-BIT SETTLING: 700ns**
- **WIDE SUPPLY RANGE: ±2.25V to ±18V, +4.5V to +36V**
- **RAIL-TO-RAIL OUTPUT**
- **OUTPUT CURRENT: 30mA**
- **DFN-8 (3mm × 3mm), MSOP-8, AND SO-8**

APPLICATIONS

- **PLL LOOP FILTER**
- **LOW-NOISE, LOW-POWER SIGNAL PROCESSING**
- **16-BIT ADC DRIVERS**
- **DAC OUTPUT AMPLIFIERS**
- **ACTIVE FILTERS**
- **LOW-NOISE INSTRUMENTATION AMPS**
- **ULTRASOUND AMPLIFIERS**
- **PROFESSIONAL AUDIO PREAMPLIFIERS**
- **LOW-NOISE FREQUENCY SYNTHESIZERS**
- **INFRARED DETECTOR AMPLIFIERS**
- **HYDROPHONE AMPLIFIERS**
- **GEOPHONE AMPLIFIERS**
- **MEDICAL**

DESCRIPTION

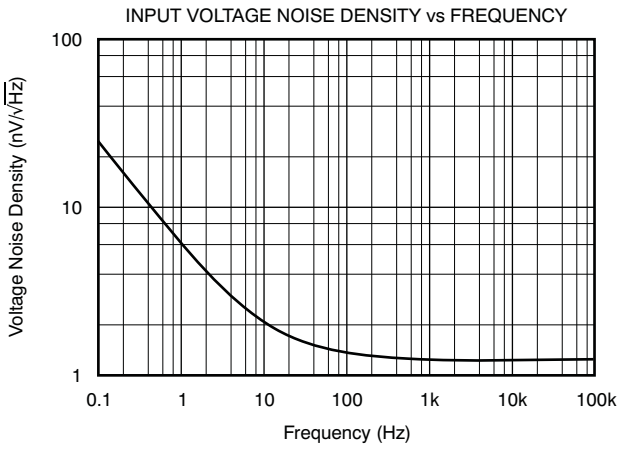
The OPA211 series of precision operational amplifiers achieves very low 1.1nV/√Hz noise density with a supply current of only 3.6mA. This series also offers rail-to-rail output swing, which maximizes dynamic range.

The extremely low voltage and low current noise, high speed, and wide output swing of the OPA211 series make these devices an excellent choice as a loop filter amplifier in PLL applications.

In precision data acquisition applications, the OPA211 series of op amps provides 700ns settling time to 16-bit accuracy throughout 10V output swings. This ac performance, combined with only 125μV of offset and 0.35μV/°C of drift over temperature, makes the OPA211 ideal for driving high-precision 16-bit analog-to-digital converters (ADCs) or buffering the output of high-resolution digital-to-analog converters (DACs).

The OPA211 series is specified over a wide dual-power supply range of ±2.25V to ±18V, or for single-supply operation from +4.5V to +36V.

The OPA211 is available in the small DFN-8 (3mm × 3mm), MSOP-8, and SO-8 packages. A dual version, the OPA2211, is available in the DFN-8 (3mm × 3mm) or an SO-8 PowerPAD™ package. This series of op amps is specified from T_A = –40°C to +125°C.



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.

ABSOLUTE MAXIMUM RATINGS(1)

Over operating free-air temperature range (unless otherwise noted).

		VALUE	UNIT
Supply Voltage	V_S = (V+) – (V–)	40	V
Input Voltage		(V–) – 0.5 to (V+) + 0.5	V
Input Current (Any pin except power-supply pins)		±10	mA
Output Short-Circuit(2)		Continuous	
Operating Temperature	(T_A)	–55 to +150	°C
Storage Temperature	(T_A)	–65 to +150	°C
Junction Temperature	(T_J)	200	°C
ESD Ratings	Human Body Model (HBM)	3000	V
	Charged Device Model (CDM)	1000	V

(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 supported.
(2) Short-circuit to V_S/2 (ground in symmetrical dual supply setups), one amplifier per package.

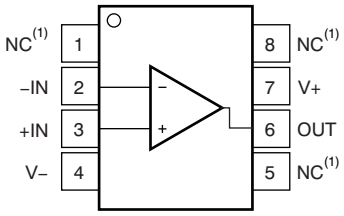
PACKAGE/ORDERING INFORMATION(1)

PRODUCT	PACKAGE-LEAD	SINGLE	SHUTDOWN	DUAL	PACKAGE DESIGNATOR	PACKAGE MARKING
Standard Grade						
OPA211AI	DFN-8 (3mm × 3mm)	✓	✓		DRG	OBDQ
	MSOP-8	✓	✓		DGK	OBCQ
	SO-8	✓			D	A TI OPA 211
OPA2211AI	DFN-8 (3mm × 3mm)(2)			✓	DRG	OBHQ
	SO-8 PowerPAD(2)			✓	DDA	A TI OPA 2211
High Grade						
OPA211I	DFN-8 (3mm × 3mm)	✓	✓		DRG	OBDQ
	MSOP-8	✓	✓		DGK	OBCQ
	SO-8	✓			D	TI OPA 211

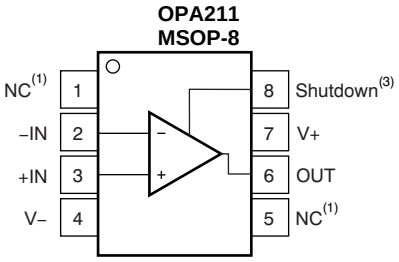
(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Product preview devices.

PIN CONFIGURATIONS

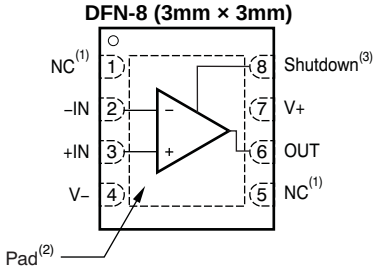
OPA211
SO-8



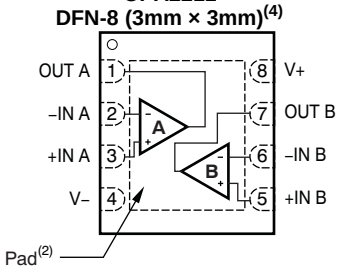
OPA211
MSOP-8



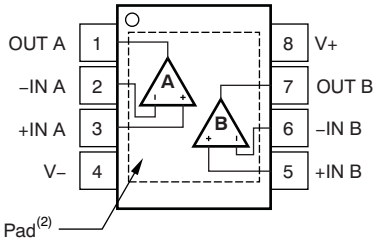
OPA211
DFN-8 (3mm × 3mm)



OPA2211
DFN-8 (3mm × 3mm)(4)



OPA2211
SO-8 PowerPAD(4)



(1) NC denotes no internal connection. Pin can be left floating or connected to any voltage between (V–) and (V+).

(2) Exposed thermal die pad on underside; connect thermal die pad to V–. Soldering the thermal pad improves heat dissipation and provides specified performance.

(3) Shutdown function:

- Device enabled: (V–) ≤ $V_{SHUTDOWN}$ ≤ (V+) – 3V
- Device disabled: $V_{SHUTDOWN}$ ≥ (V+) – 0.35V

(4) Product preview device.

ELECTRICAL CHARACTERISTICS: V_S = ±2.25V to ±18V

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, unless otherwise noted.

PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI MIN	TYP	MAX	High Grade OPA211I(1) MIN	TYP	MAX	UNIT
OFFSET VOLTAGE									
Input Offset Voltage	V_{OS}	V_S = ±15V		±30	±125		±20	±50	µV
Drift	**dV_{OS}/dT**			**0.35**	**1.5**		**0.15**	**0.85**	**µV/°C**
vs Power Supply	PSRR	V_S = ±2.25V to ±18V		0.1	1		0.1	0.5	µV/V
Over Temperature					**3**			**3**	**µV/V**
INPUT BIAS CURRENT									
Input Bias Current	I_B	V_{CM} = 0V		±60	±175		±50	±125	nA
Over Temperature					**±200**			**±200**	**nA**
Offset Current	I_{OS}	V_{CM} = 0V		±25	±100		±20	±75	nA
Over Temperature					**±150**			**±150**	**nA**
NOISE									
Input Voltage Noise	e_n	f = 0.1Hz to 10Hz		80			80		nV_{PP}
Input Voltage Noise Density		f = 10Hz		2			2		$nV/\sqrt{Hz}$
		f = 100Hz		1.4			1.4		$nV/\sqrt{Hz}$
		f = 1kHz		1.1			1.1		$nV/\sqrt{Hz}$
Input Current Noise Density	I_n	f = 10Hz		3.2			3.2		$pA/\sqrt{Hz}$
		f = 1kHz		1.7			1.7		$pA/\sqrt{Hz}$
INPUT VOLTAGE RANGE									
Common-Mode Voltage Range	V_{CM}	V_S ≥ ±5V	(V–) + 1.8		(V+) – 1.4	(V–) + 1.8		(V+) – 1.4	V
		V_S < ±5V	(V–) + 2		(V+) – 1.4	(V–) + 2		(V+) – 1.4	V
Common-Mode Rejection Ratio	**CMRR**	**V_S ≥ ±5V, (V–) + 2V ≤ V_{CM} ≤ (V+) – 2V**	**114**	**120**		**114**	**120**		**dB**
		V_S < ±5V, (V–) + 2V ≤ V_{CM} ≤ (V+) – 2V	**110**	**120**		**110**	**120**		**dB**
INPUT IMPEDANCE									
Differential				20k || 8			20k || 8		Ω || pF
Common-Mode				10^9 || 2			10^9 || 2		Ω || pF
OPEN-LOOP GAIN									
Open-Loop Voltage Gain	**A_{OL}**	**(V–) + 0.2V ≤ V_O ≤ (V+) – 0.2V, R_L = 10kΩ**	**114**	**130**		**114**	**130**		**dB**
	A_{OL}	(V–) + 0.6V ≤ V_O ≤ (V+) – 0.6V, R_L = 600Ω	110	114		110	114		dB
Over Temperature	**A_{OL}**	**(V–) + 0.6V ≤ V_O ≤ (V+) – 0.6V, I_O ≤ 15mA**	**110**			**110**			**dB**
	A_{OL}	**(V–) + 0.6V ≤ V_O ≤ (V+)–0.6V, 15mA < I_O ≤ 30mA**	**103**			**103**			**dB**
FREQUENCY RESPONSE									
Gain-Bandwidth Product	GBW	G = 100		80			80		MHz
		G = 1		45			45		MHz
Slew Rate	SR			27			27		V/µs
Settling Time, 0.01%	t_S	V_S = ±15V, G = –1, 10V Step, C_L = 100pF		400			400		ns
0.0015% (16-bit)		V_S = ±15V, G = –1, 10V Step, C_L = 100pF		700			700		ns
Overload Recovery Time		G = –10		500			500		ns
Total Harmonic Distortion + Noise	THD+N	G = +1, f = 1kHz, V_O = $3V_{RMS}$, R_L = 600Ω		0.000015			0.000015		%
				–136			–136		dB

(1) Shaded cells indicate different specifications from standard-grade version of device.

ELECTRICAL CHARACTERISTICS: V_S = ±2.25V to ±18V (continued)

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +125°C.
At T_A = +25°C, R_L = 10kΩ connected to midsupply, V_{CM} = V_{OUT} = midsupply, unless otherwise noted.

PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI			High Grade OPA211I[1]			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
OUTPUT									
Voltage Output	**V_{OUT}**	**R_L = 10kΩ, A_{OL} ≥ 114dB**	**(V–) + 0.2**		**(V+) – 0.2**	**(V–) + 0.2**		**(V+) – 0.2**	**V**
		R_L = 600Ω, A_{OL} ≥ 110dB	(V–) + 0.6		(V+) – 0.6	(V–) + 0.6		(V+) – 0.6	V
		I_O < 15mA, A_{OL} ≥ 110dB	**(V–) + 0.6**		**(V+) – 0.6**	**(V–) + 0.6**		**(V+) – 0.6**	**V**
Short-Circuit Current	I_{SC}			+30/–45			+30/–45		mA
Capacitive Load Drive	C_{LOAD}		See Typical Characteristics			See Typical Characteristics			pF
Open-Loop Output Impedance	Z_O	f = 1MHz		5			5		Ω
SHUTDOWN									
Shutdown Pin Input Voltage[2]		Device disabled (shutdown)	(V+) – 0.35			(V+) – 0.35			V
		Device enabled			(V+) – 3			(V+) – 3	V
Shutdown Pin Leakage Current				1			1		µA
Turn-On Time[3]				2			2		µs
Turn-Off Time[3]				3			3		µs
Shutdown Current		Shutdown (disabled)		1	20		1	20	µA
POWER SUPPLY									
Specified Voltage	V_S		±2.25		±18	±2.25		±18	V
Quiescent Current (per channel)	I_Q	I_{OUT} = 0A		3.6	4.5		3.6	4.5	mA
Over Temperature					**6**			**6**	**mA**
TEMPERATURE RANGE									
Specified Range		T_A	–40		+125	–40		+125	°C
Operating Range		T_A	–55		+150	–55		+150	°C
Thermal Resistance									
DFN (3mm × 3mm)	θ_{JA}	High-K board		65			65		°C/W
	θ_{JC}			57			57		°C/W
MSOP-8	θ_{JA}			200			200		°C/W
SO-8	θ_{JA}			150			150		°C/W
SO-8 PowerPAD	θ_{JA}	High-K board		52			52		°C/W
	θ_{JC}			43			43		°C/W

(2) When disabled, the output assumes a high-impedance state.
(3) See Typical Characteristic curves, Figure 39 through Figure 41.

TYPICAL CHARACTERISTICS

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

INPUT VOLTAGE NOISE DENSITY vs FREQUENCY

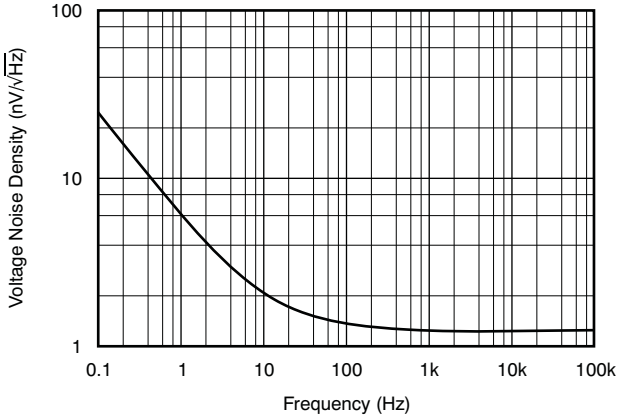


Figure 1.

INPUT CURRENT NOISE DENSITY vs FREQUENCY

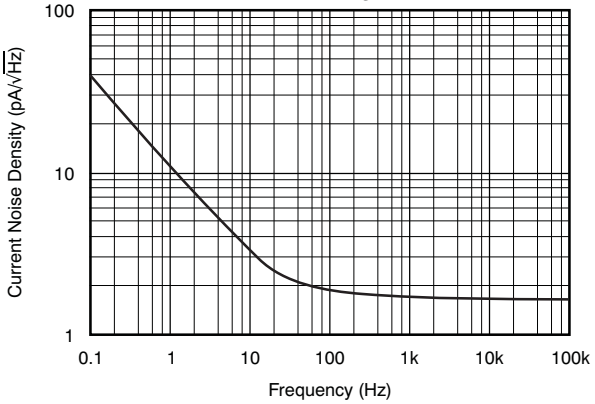


Figure 2.

THD+N RATIO vs FREQUENCY

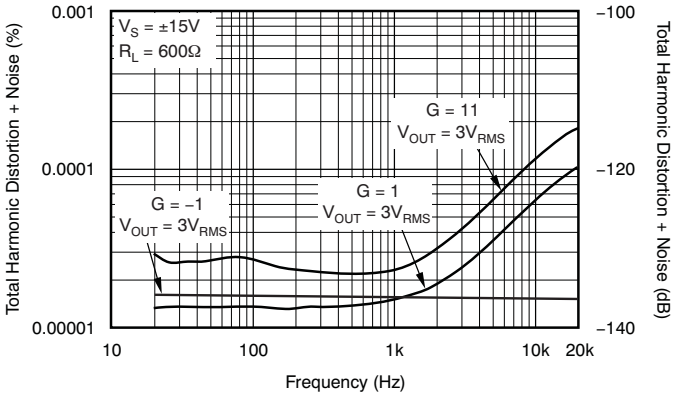


Figure 3.

THD+N RATIO vs OUTPUT VOLTAGE AMPLITUDE

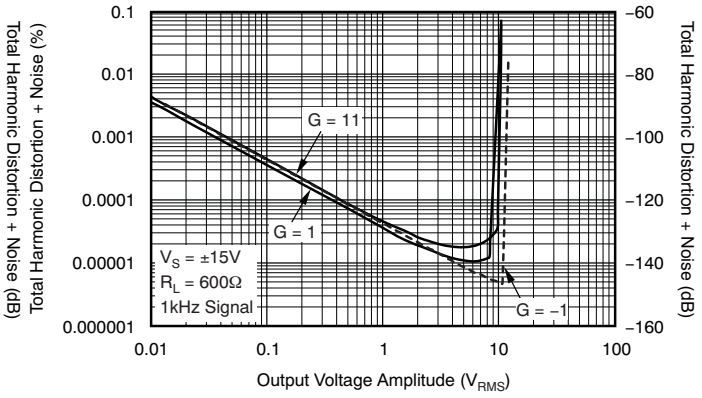


Figure 4.

0.1Hz TO 10Hz NOISE

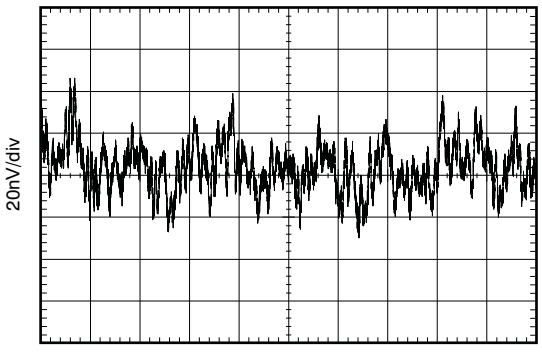


Figure 5.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

POWER-SUPPLY REJECTION RATIO vs FREQUENCY (Referred to Input)

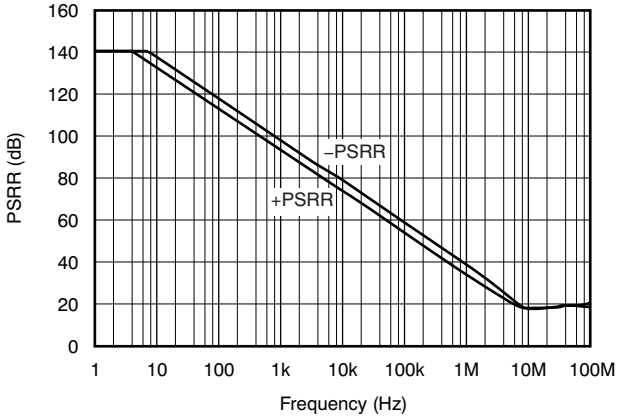


Figure 6.

COMMON-MODE REJECTION RATIO vs FREQUENCY

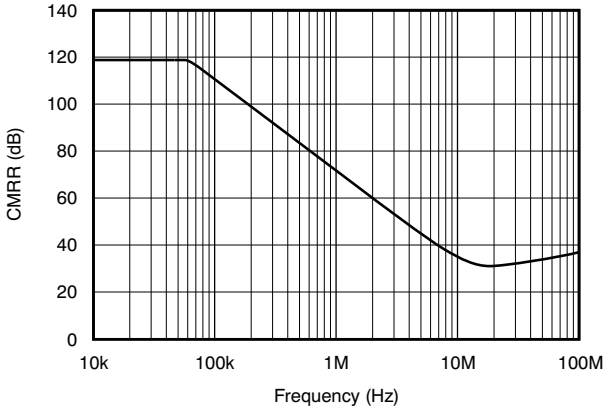


Figure 7.

OPEN-LOOP OUTPUT IMPEDANCE vs FREQUENCY

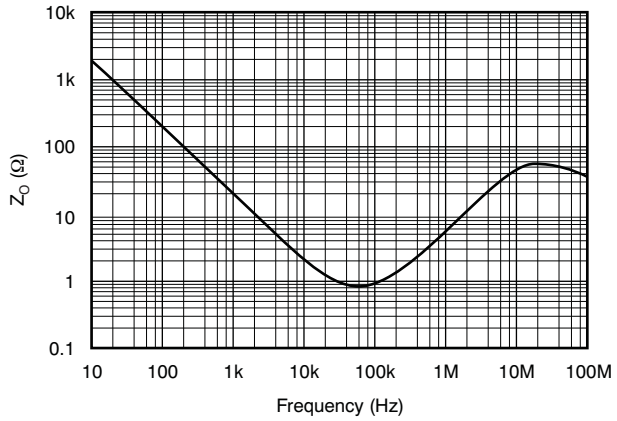


Figure 8.

GAIN AND PHASE vs FREQUENCY

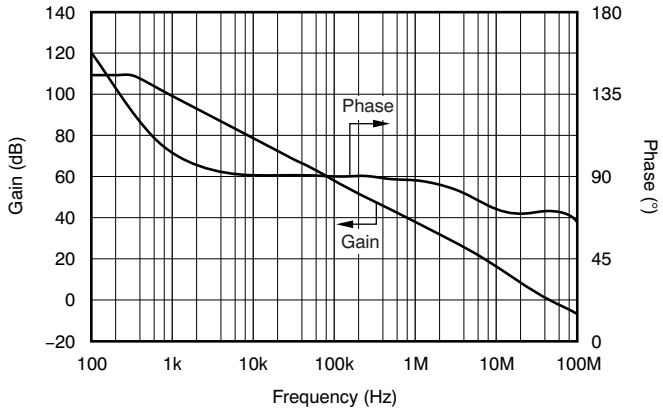


Figure 9.

OPEN-LOOP GAIN vs TEMPERATURE

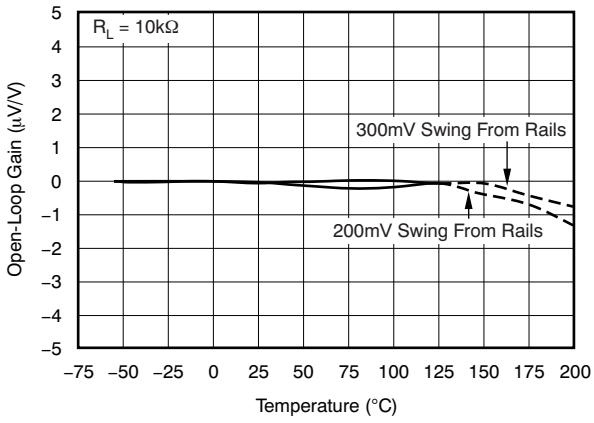


Figure 10.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

OFFSET VOLTAGE PRODUCTION DISTRIBUTION

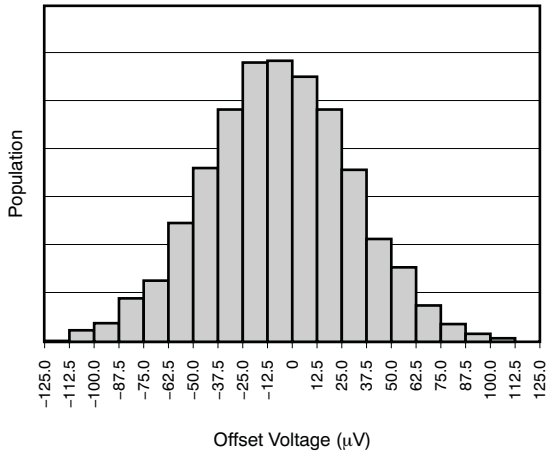


Figure 11.

OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION

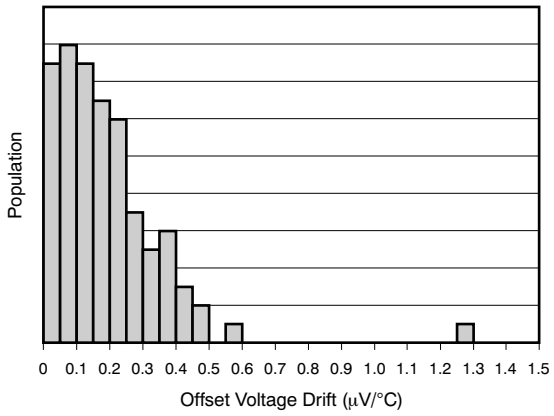


Figure 12.

I_B AND I_{OS} CURRENT vs TEMPERATURE

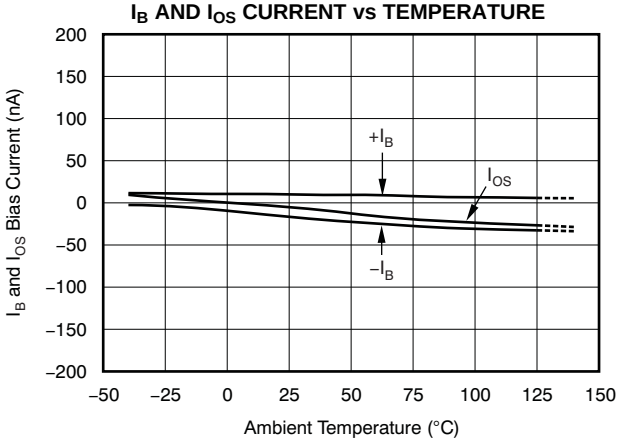


Figure 13.

OFFSET VOLTAGE vs COMMON-MODE VOLTAGE

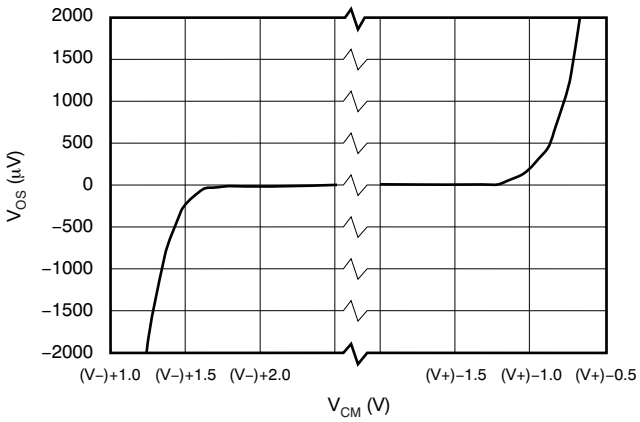


Figure 14.

V_{OS} WARMUP

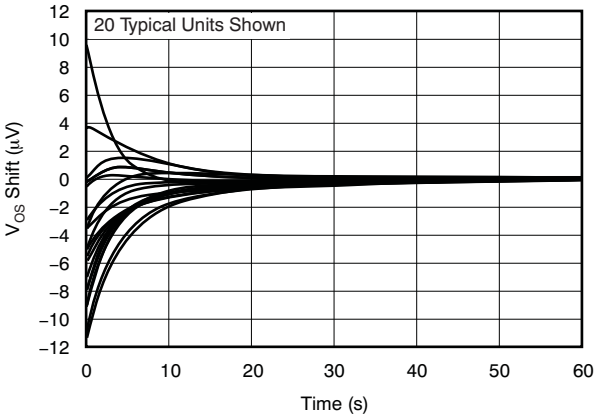


Figure 15.

INPUT OFFSET CURRENT vs SUPPLY VOLTAGE

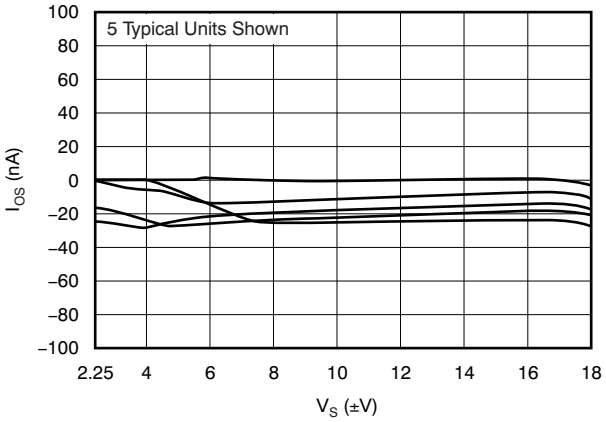


Figure 16.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

INPUT OFFSET CURRENT vs COMMON-MODE VOLTAGE

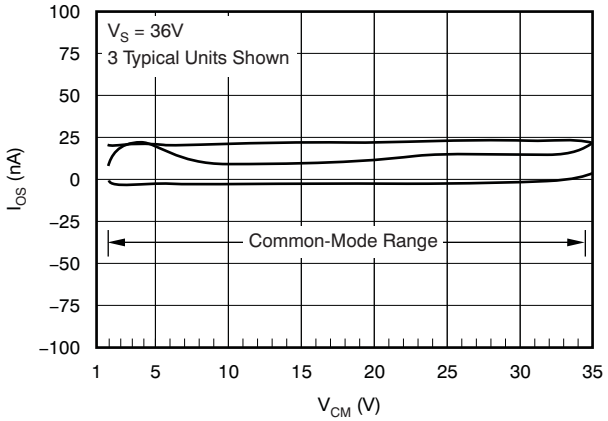


Figure 17.

INPUT BIAS CURRENT vs SUPPLY VOLTAGE

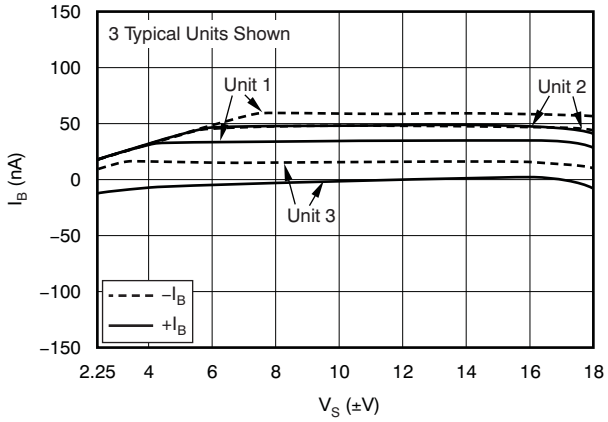


Figure 18.

INPUT BIAS CURRENT vs COMMON-MODE VOLTAGE

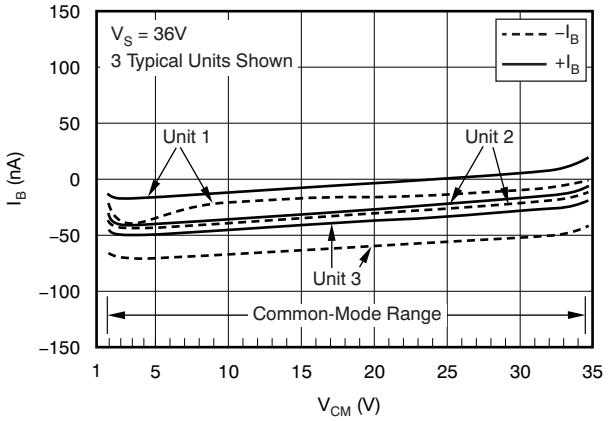


Figure 19.

QUIESCENT CURRENT vs TEMPERATURE

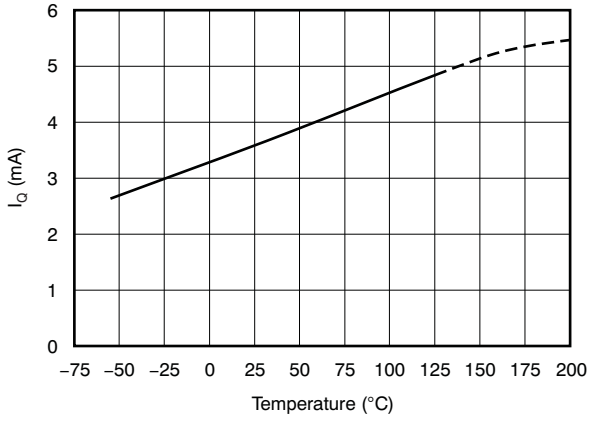


Figure 20.

QUIESCENT CURRENT vs SUPPLY VOLTAGE

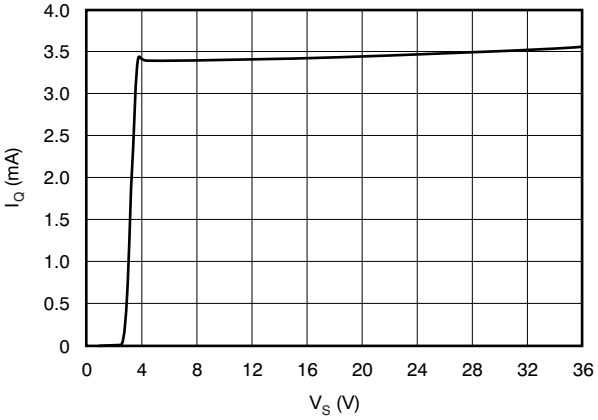


Figure 21.

NORMALIZED QUIESCENT CURRENT vs TIME

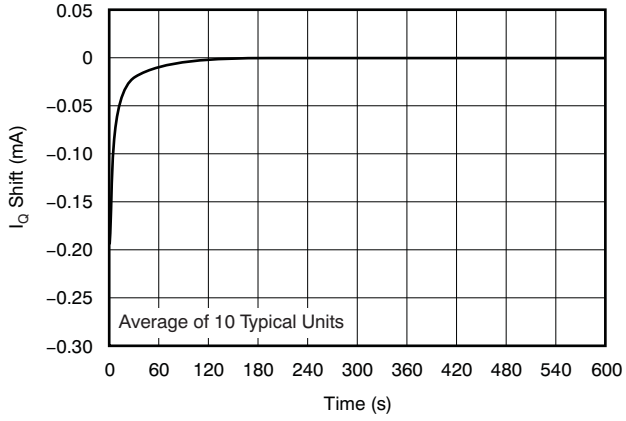


Figure 22.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

SHORT-CIRCUIT CURRENT vs TEMPERATURE

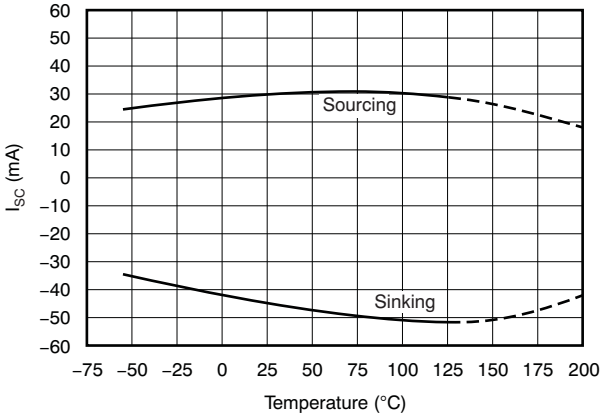


Figure 23.

SMALL-SIGNAL STEP RESPONSE (100mV)

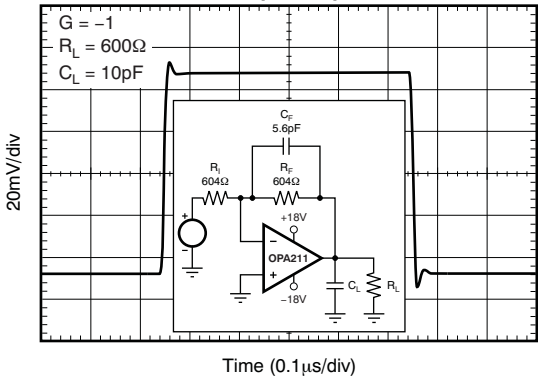


Figure 24.

SMALL-SIGNAL STEP RESPONSE (100mV)

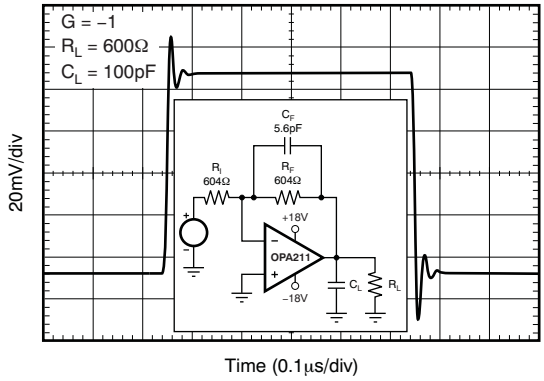


Figure 25.

SMALL-SIGNAL STEP RESPONSE (100mV)

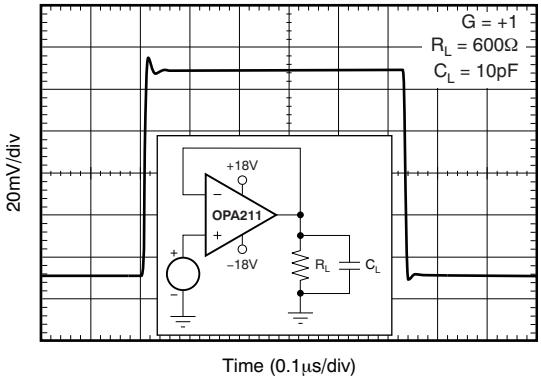


Figure 26.

SMALL-SIGNAL STEP RESPONSE (100mV)

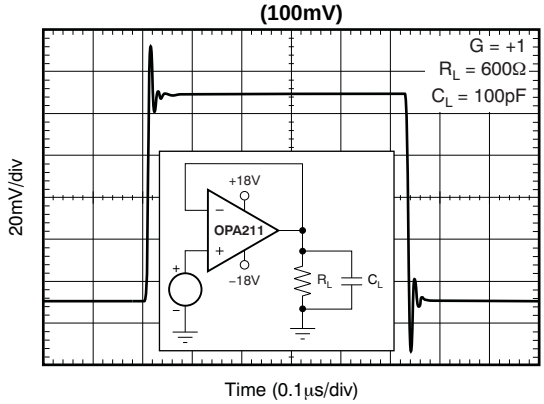


Figure 27.

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

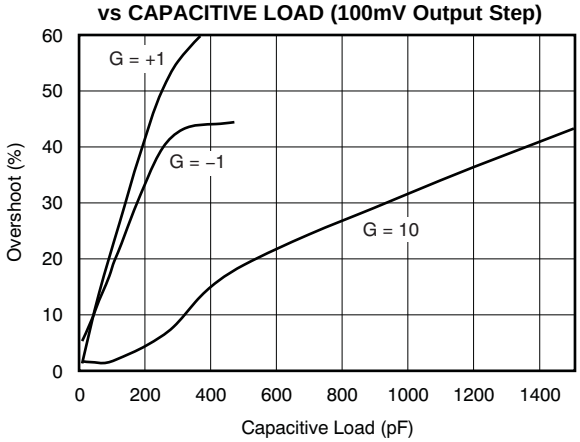


Figure 28.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

LARGE-SIGNAL STEP RESPONSE

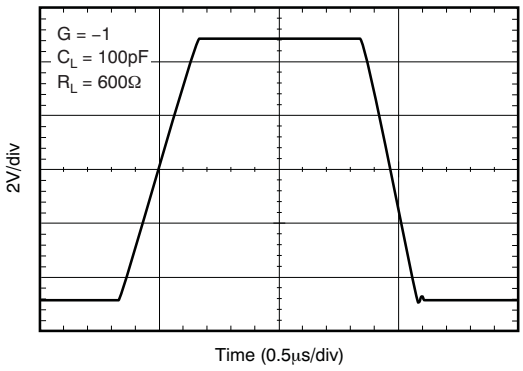


Figure 29.

LARGE-SIGNAL STEP RESPONSE

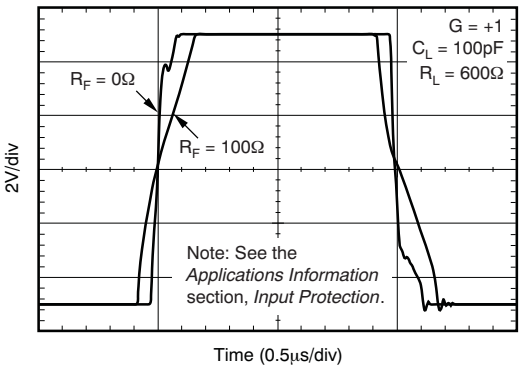


Figure 30.

LARGE-SIGNAL POSITIVE SETTLING TIME ($10V_{PP}$, C_L = 100pF)

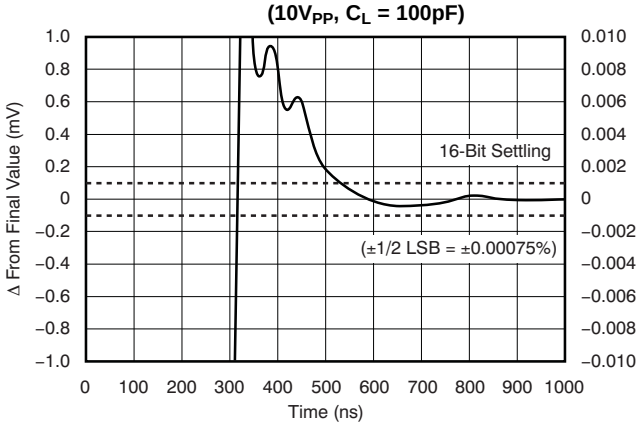


Figure 31.

LARGE-SIGNAL POSITIVE SETTLING TIME ($10V_{PP}$, C_L = 10pF)

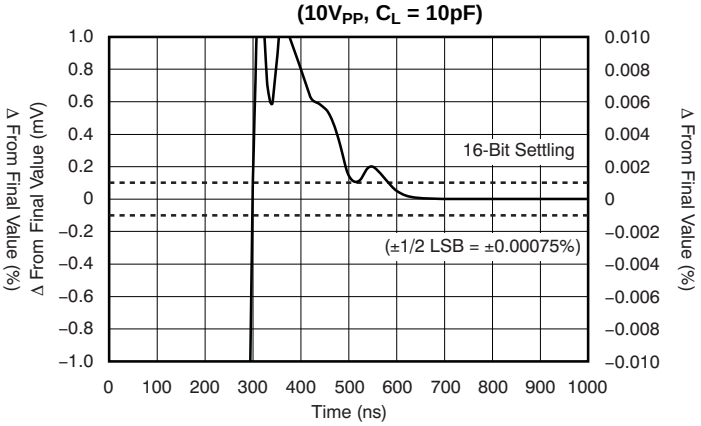


Figure 32.

LARGE-SIGNAL NEGATIVE SETTLING TIME ($10V_{PP}$, C_L = 100pF)

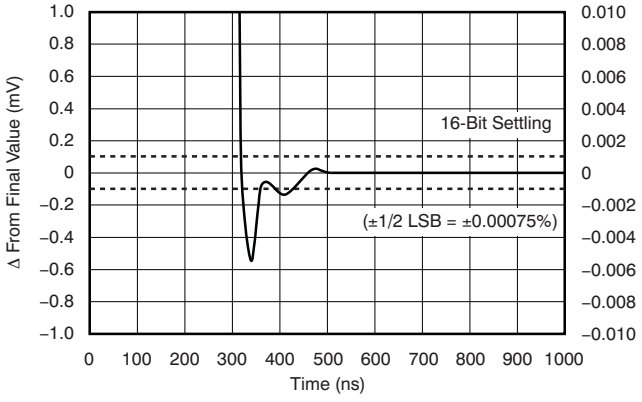


Figure 33.

LARGE-SIGNAL NEGATIVE SETTLING TIME ($10V_{PP}$, C_L = 10pF)

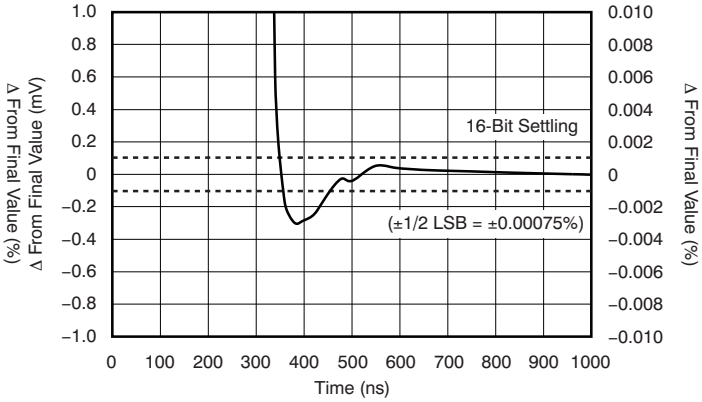


Figure 34.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

NEGATIVE OVERLOAD RECOVERY

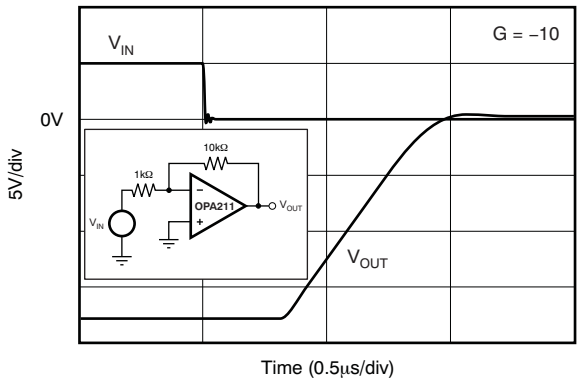


Figure 35.

POSITIVE OVERLOAD RECOVERY

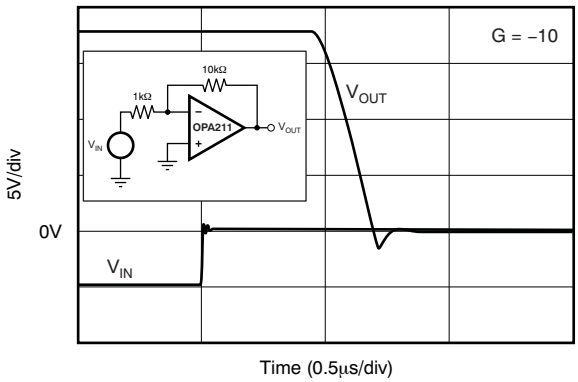


Figure 36.

OUTPUT VOLTAGE vs OUTPUT CURRENT

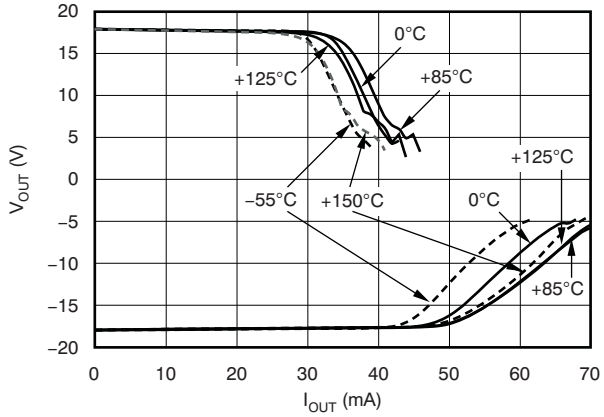


Figure 37.

NO PHASE REVERSAL

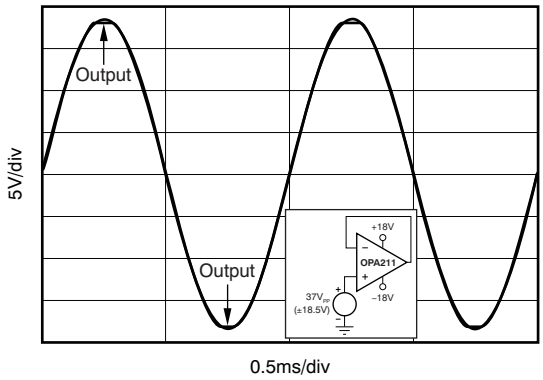


Figure 38.

TURN-OFF TRANSIENT

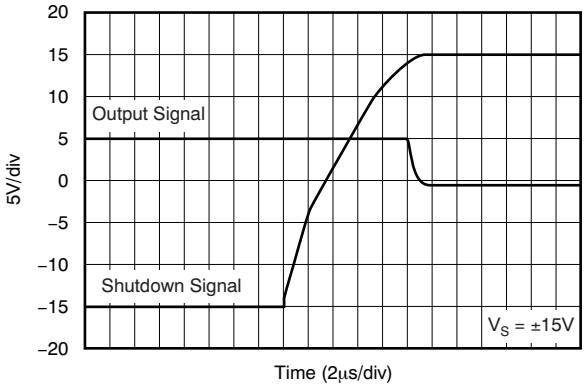


Figure 39.

TURN-ON TRANSIENT

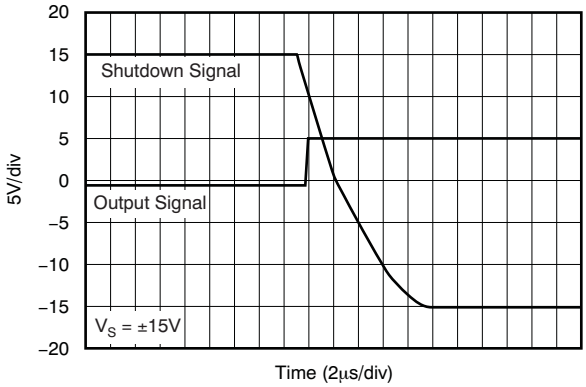


Figure 40.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = ±18V, and R_L = 10kΩ, unless otherwise noted.

TURN-ON/TURN-OFF TRANSIENT

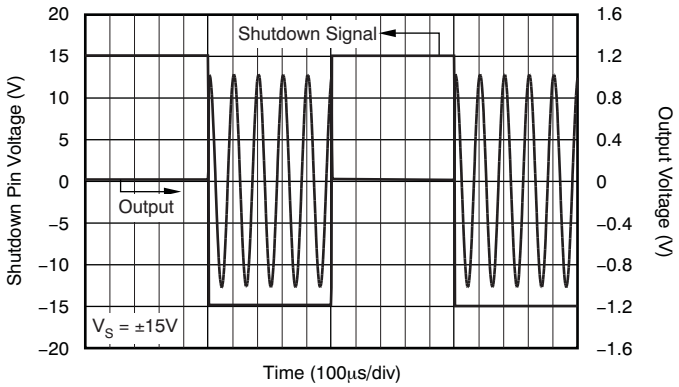


Figure 41.

APPLICATION INFORMATION

The OPA211 and OPA2211 are unity-gain stable, precision op amps with very low noise. Applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases, 0.1µF capacitors are adequate. Figure 42 shows a simplified schematic of the OPA211. This die uses a SiGe bipolar process and contains 180 transistors.

OPERATING VOLTAGE

OPA211 series op amps operate from ±2.25V to ±18V supplies while maintaining excellent performance. The OPA211 series can operate with as little as +4.5V between the supplies and with up to +36V between the supplies. However, some applications do not require equal positive and negative output voltage swing. With the OPA211 series, power-supply voltages do not need to be equal. For example, the positive supply could be set to +25V with the negative supply at –5V or vice-versa.

The common-mode voltage must be maintained within the specified range. In addition, key parameters are assured over the specified temperature range, T_A = –40°C to +125°C. Parameters that vary significantly with operating voltage or temperature are shown in the Typical Characteristics.

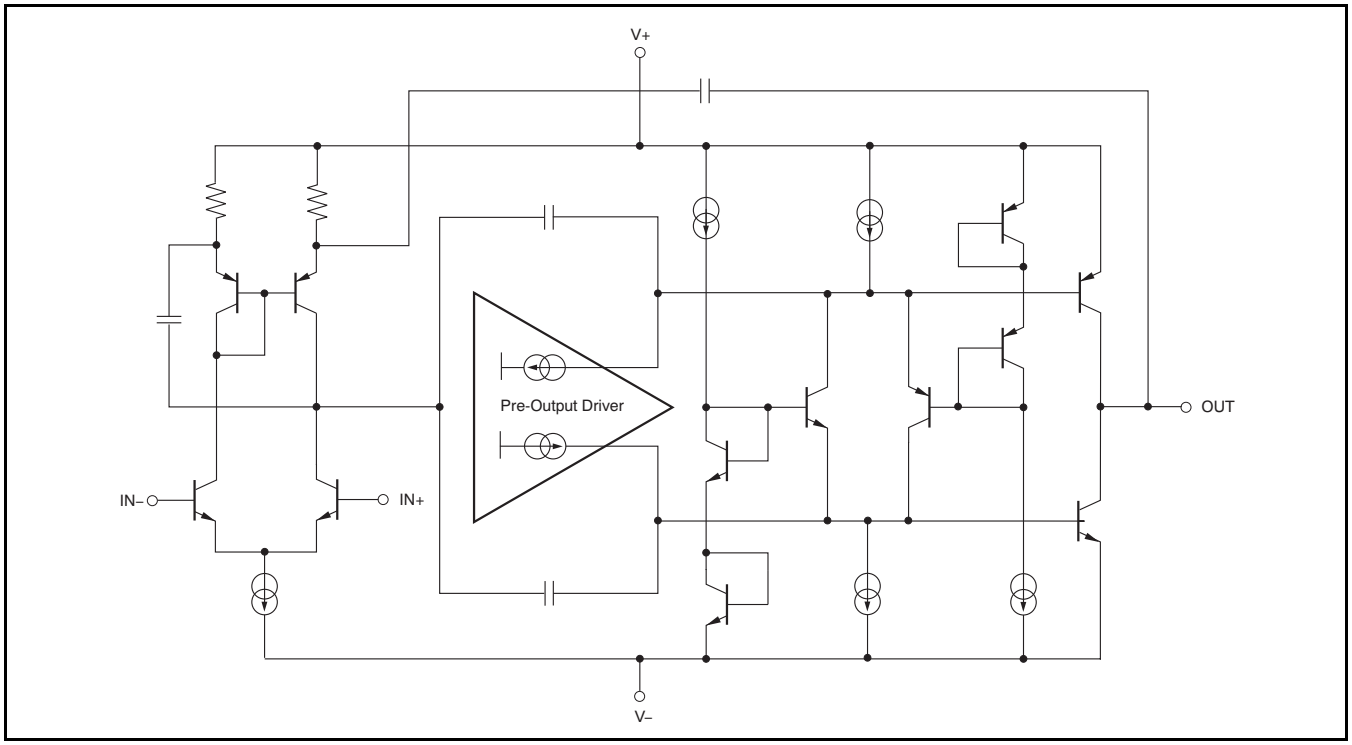


Figure 42. OPA211 Simplified Schematic

INPUT PROTECTION

The input terminals of the OPA211 are protected from excessive differential voltage with back-to-back diodes, as shown in Figure 43. In most circuit applications, the input protection circuitry has no consequence. However, in low-gain or G = 1 circuits, fast ramping input signals can forward bias these diodes because the output of the amplifier cannot respond rapidly enough to the input ramp. This effect is illustrated in Figure 30 of the Typical Characteristics. If the input signal is fast enough to create this forward bias condition, the input signal current must be limited to 10mA or less. If the input signal current is not inherently limited, an input series resistor can be used to limit the signal input current. This input series resistor degrades the low-noise performance of the OPA211, and is discussed in the *Noise Performance* section of this data sheet. Figure 43 shows an example implementing a current-limiting feedback resistor.

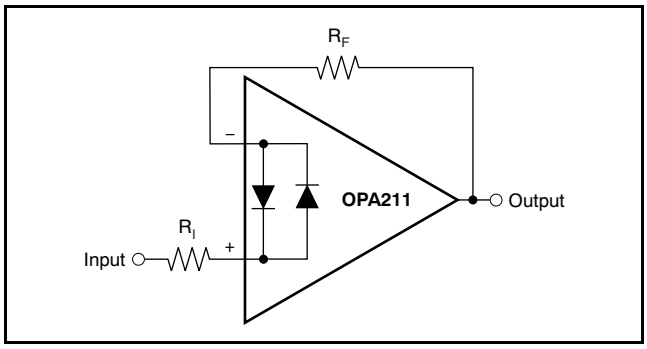


Figure 43. Pulsed Operation

NOISE PERFORMANCE

Figure 44 shows total circuit noise for varying source impedances with the op amp in a unity-gain configuration (no feedback resistor network, and therefore no additional noise contributions). Two different op amps are shown with total circuit noise calculated. The OPA211 has very low voltage noise, making it ideal for low source impedances (less than 2kΩ). A similar precision op amp, the OPA227, has somewhat higher voltage noise but lower current noise. It provides excellent noise performance at moderate source impedance (10kΩ to 100kΩ). Above 100kΩ, a FET-input op amp such as the OPA132 (very low current noise) may provide improved performance. The equation in Figure 44 is shown for the calculation of the total circuit noise. Note that e_n = voltage noise, I_n = current noise, R_S = source impedance, k = Boltzmann's constant = 1.38×10^{-23} J/K, and T is temperature in K.

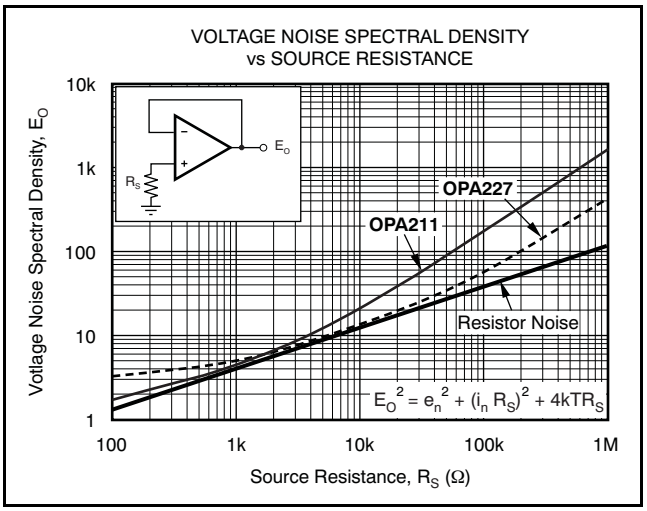


Figure 44. Noise Performance of the OPA211 and OPA227 in Unity-Gain Buffer Configuration

BASIC NOISE CALCULATIONS

Design of low-noise op amp circuits requires careful consideration of a variety of possible noise contributors: noise from the signal source, noise generated in the op amp, and noise from the feedback network resistors. The total noise of the circuit is the root-sum-square combination of all noise components.

The resistive portion of the source impedance produces thermal noise proportional to the square root of the resistance. This function is plotted in Figure 44. The source impedance is usually fixed; consequently, select the op amp and the feedback resistors to minimize the respective contributions to the total noise.

Figure 44 depicts total noise for varying source impedances with the op amp in a unity-gain configuration (no feedback resistor network, and therefore no additional noise contributions). The operational amplifier itself contributes both a voltage noise component and a current noise component. The voltage noise is commonly modeled as a time-varying component of the offset voltage. The current noise is modeled as the time-varying component of the input bias current and reacts with the source resistance to create a voltage component of noise. Therefore, the lowest noise op amp for a given application depends on the source impedance. For low source impedance, current noise is negligible and voltage noise generally dominates. For high source impedance, current noise may dominate.

Figure 45 illustrates both inverting and noninverting op amp circuit configurations with gain. In circuit configurations with gain, the feedback network resistors also contribute noise. The current noise of the op amp reacts with the feedback resistors to create additional noise components. The feedback resistor values can generally be chosen to make these noise sources negligible. The equations for total noise are shown for both configurations.

TOTAL HARMONIC DISTORTION MEASUREMENTS

OPA211 series op amps have excellent distortion characteristics. THD + Noise is below 0.0001% (G = +1, V_O = $3V_{RMS}$) throughout the audio frequency range, 20Hz to 20kHz, with a 600Ω load.

The distortion produced by OPA211 series op amps is below the measurement limit of many commercially available distortion analyzers. However, a special test circuit illustrated in Figure 46 can be used to extend the measurement capabilities.

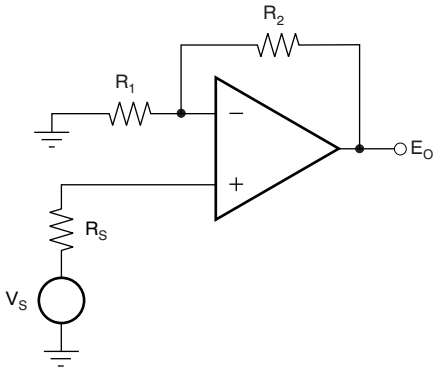
Op amp distortion can be considered an internal error source that can be referred to the input. Figure 46 shows a circuit that causes the op amp distortion to be 101 times greater than that normally produced by the op amp. The addition of R_3 to the otherwise standard noninverting amplifier configuration alters the feedback factor or noise gain of the circuit. The closed-loop gain is unchanged, but the feedback available for error correction is reduced by a factor of 101, thus extending the resolution by 101. Note that the input signal and load applied to the op amp are the same as with conventional feedback without R_3. The value of R_3 should be kept small to minimize its effect on the distortion measurements.

Validity of this technique can be verified by duplicating measurements at high gain and/or high frequency where the distortion is within the measurement capability of the test equipment. Measurements for this data sheet were made with an Audio Precision System Two distortion/noise analyzer, which greatly simplifies such repetitive measurements. The measurement technique can, however, be performed with manual distortion measurement instruments.

SHUTDOWN

The shutdown (enable) function of the OPA211 is referenced to the positive supply voltage of the operational amplifier. A valid high disables the op amp. A valid high is defined as (V+) – 0.35V of the positive supply applied to the shutdown pin. A valid low is defined as (V+) – 3V below the positive supply pin. For example, with V_{CC} at ±15V, the device is enabled at or below 12V. The device is disabled at or above 14.65V. If dual or split power supplies are used, care should be taken to ensure the valid high or valid low input signals are properly referred to the positive supply voltage. This pin must be connected to a valid high or low voltage or driven, and not left open-circuit. The enable and disable times are provided in the Typical Characteristics section (see Figure 39 through Figure 41). When disabled, the output assumes a high-impedance state.

Noise in Noninverting Gain Configuration



Noise at the output:

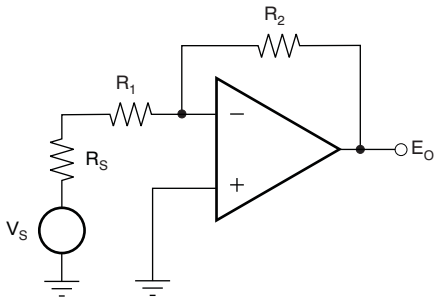
$$E_O^2 = \left(1 + \frac{R_2}{R_1}\right)^2 e_n^2 + e_1^2 + e_2^2 + (i_n R_2)^2 + e_S^2 + (i_n R_S)^2 \left(1 + \frac{R_2}{R_1}\right)^2$$

Where $e_S = \sqrt{4kTR_S} \times \left(1 + \frac{R_2}{R_1}\right)$ = thermal noise of R_S

$e_1 = \sqrt{4kTR_1} \times \left(\frac{R_2}{R_1}\right)$ = thermal noise of R_1

$e_2 = \sqrt{4kTR_2}$ = thermal noise of R_2

Noise in Inverting Gain Configuration



Noise at the output:

$$E_O^2 = \left(1 + \frac{R_2}{R_1 + R_S}\right)^2 e_n^2 + e_1^2 + e_2^2 + (i_n R_2)^2 + e_S^2$$

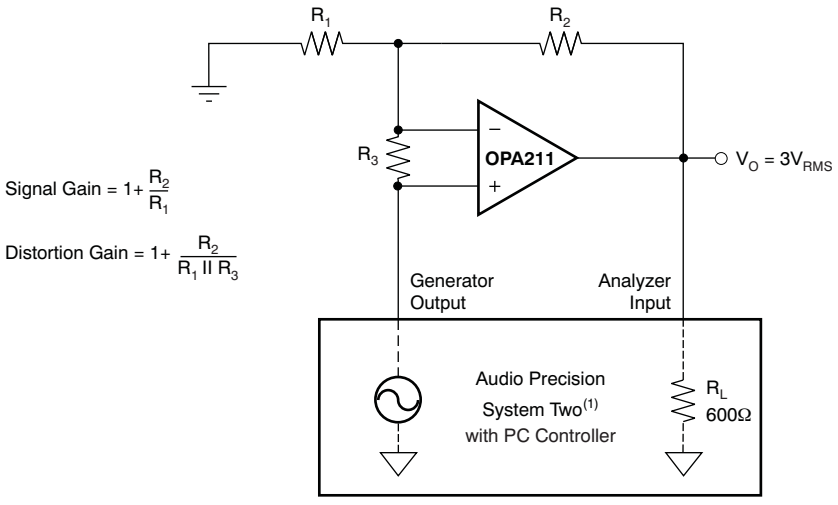
Where $e_S = \sqrt{4kTR_S} \times \left(\frac{R_2}{R_1 + R_S}\right)$ = thermal noise of R_S

$e_1 = \sqrt{4kTR_1} \times \left(\frac{R_2}{R_1 + R_S}\right)$ = thermal noise of R_1

$e_2 = \sqrt{4kTR_2}$ = thermal noise of R_2

For the OPA211 series op amps at 1kHz, $e_n = 1.1nV/\sqrt{Hz}$ and $i_n = 1.7pA/\sqrt{Hz}$.

Figure 45. Noise Calculation in Gain Configurations



SIG. GAIN	DIST. GAIN	R_1	R_2	R_3
1	101	∞	1kΩ	10Ω
11	101	100Ω	1kΩ	11Ω

NOTE: (1) Measurement BW = 80kHz.

Figure 46. Distortion Test Circuit

ELECTRICAL OVERSTRESS

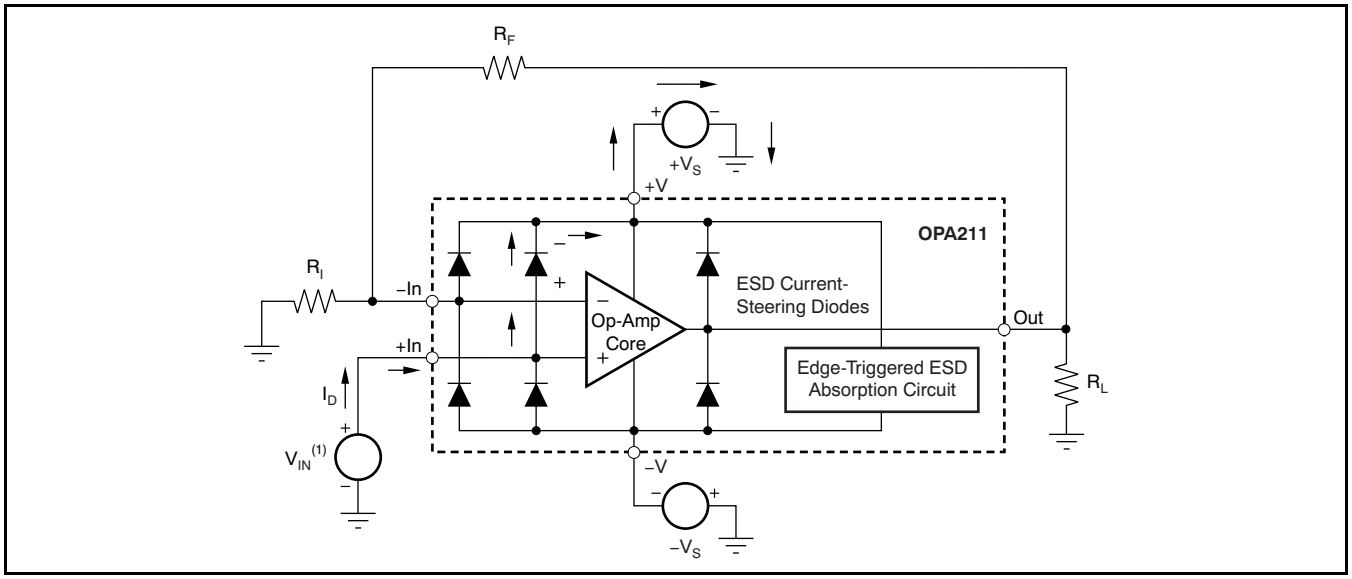
Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress. These questions tend to focus on the device inputs, but may involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined 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.

It is helpful to have a good understanding of this basic ESD circuitry and its relevance to an electrical overstress event. Figure 47 illustrates the ESD circuits contained in the OPA211 (indicated by the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where they meet at an absorption device internal to the operational amplifier. This protection circuitry is intended to remain inactive during normal circuit operation.

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 an ESD voltage develops across two or more of the amplifier device pins, current flows through one or more of the steering diodes. Depending on the path that the current takes, the absorption device may activate. The absorption device has a trigger, or threshold voltage, that is above the normal operating voltage of the OPA211 but below the device breakdown voltage level. Once this threshold is exceeded, the absorption device quickly activates and clamps the voltage across the supply rails to a safe level.

When the operational amplifier connects into a circuit such as that illustrated in Figure 47, 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 steering diode paths and rarely involves the absorption device.



(1) $V_{IN} = +V_S + 500mV$.

Figure 47. Equivalent Internal ESD Circuitry and Its Relation to a Typical Circuit Application

Figure 47 depicts a specific example where the input voltage, V_{IN}, exceeds the positive supply voltage ($+V_S$) by 500mV or more. Much of what happens in the circuit depends on the supply characteristics. If $+V_S$ can sink the current, one of the upper input steering diodes conducts and directs current to $+V_S$. Excessively high current levels can flow with increasingly higher V_{IN}. As a result, the datasheet specifications recommend that applications limit the input current to 10mA.

If the supply is not capable of sinking the current, V_{IN} may begin sourcing current to the operational amplifier, and then take over as the source of positive supply voltage. The danger in this case is that the voltage can rise to levels that exceed the operational amplifier absolute maximum ratings. In extreme but rare cases, the absorption device triggers on while $+V_S$ and $-V_S$ are applied. If this event happens, a direct current path is established between the $+V_S$ and $-V_S$ supplies. The power dissipation of the absorption device is quickly exceeded, and the extreme internal heating destroys the operational amplifier.

Another common question involves what happens to the amplifier if an input signal is applied to the input while the power supplies $+V_S$ and/or $-V_S$ are at 0V. Again, it depends on the supply characteristic while at 0V, or at a level below the input signal amplitude. If the supplies appear as high impedance, then the operational amplifier supply current may be supplied by the input source via the current steering diodes. This state is not a normal bias condition; the amplifier most likely will not operate normally. If the supplies are low impedance, then the current through the steering diodes can become quite high. The current level depends on the ability of the input source to deliver current, and any resistance in the input path.

DFN PACKAGE

The OPA211 is offered in an DFN-8 package (also known as SON). The DFN package is a QFN package with lead contacts on only two sides of the bottom of the package. This leadless package maximizes board space and enhances thermal and electrical characteristics through an exposed pad.

DFN packages are physically small, and have a smaller routing area, improved thermal performance, and improved electrical parasitics. Additionally, the absence of external leads eliminates bent-lead issues.

The DFN package can be easily mounted using standard printed circuit board (PCB) assembly techniques. See Application Note *QFN/SON PCB Attachment* (SLUA271) and Application Report *Quad Flatpack No-Lead Logic Packages* (SCBA017), both available for download at www.ti.com.

The exposed leadframe die pad on the bottom of the package must be connected to V–. Soldering the thermal pad improves heat dissipation and enables specified device performance.

DFN LAYOUT GUIDELINES

The exposed leadframe die pad on the DFN package should be soldered to a thermal pad on the PCB. A mechanical drawing showing an example layout is attached at the end of this data sheet. Refinements to this layout may be necessary based on assembly process requirements. Mechanical drawings located at the end of this data sheet list the physical dimensions for the package and pad. The five holes in the landing pattern are optional, and are intended for use with thermal vias that connect the leadframe die pad to the heatsink area on the PCB.

Soldering the exposed pad significantly improves board-level reliability during temperature cycling, key push, package shear, and similar board-level tests. Even with applications that have low-power dissipation, the exposed pad must be soldered to the PCB to provide structural integrity and long-term reliability.

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
OPA211AID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDRGR	ACTIVE	SON	DRG	8	1000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDRGRG4	ACTIVE	SON	DRG	8	1000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDRGT	ACTIVE	SON	DRG	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211AIDRGTG4	ACTIVE	SON	DRG	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA211ID	PREVIEW	SOIC	D	8		TBD	Call TI	Call TI
OPA211IDGKR	PREVIEW	MSOP	DGK	8		TBD	Call TI	Call TI
OPA211IDGKT	PREVIEW	MSOP	DGK	8		TBD	Call TI	Call TI
OPA211IDR	PREVIEW	SOIC	D	8		TBD	Call TI	Call TI
OPA211IDRGR	PREVIEW	SON	DRG	8		TBD	Call TI	Call TI
OPA211IDRGT	PREVIEW	SON	DRG	8		TBD	Call TI	Call TI
OPA2211AIDDA	PREVIEW	SO Power PAD	DDA	8	75	TBD	Call TI	Call TI
OPA2211AIDDAR	PREVIEW	SO Power PAD	DDA	8	2500	TBD	Call TI	Call TI
OPA2211AIDRGR	PREVIEW	SON	DRG	8	1000	TBD	Call TI	Call TI
OPA2211AIDRGT	PREVIEW	SON	DRG	8	250	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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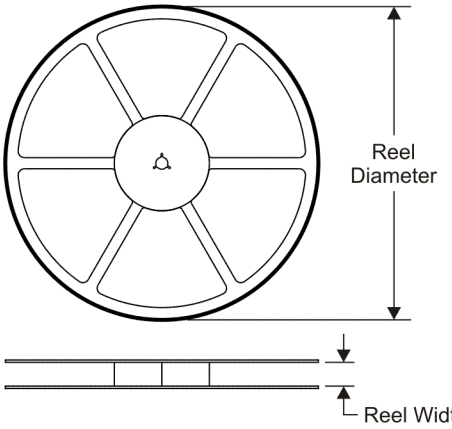
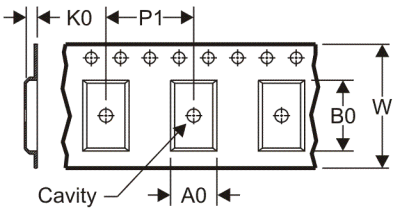
TAPE AND REEL INFORMATION

REEL DIMENSIONS

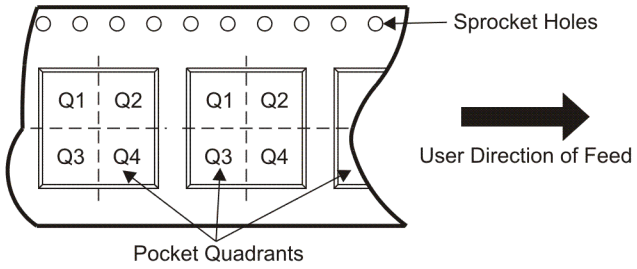


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

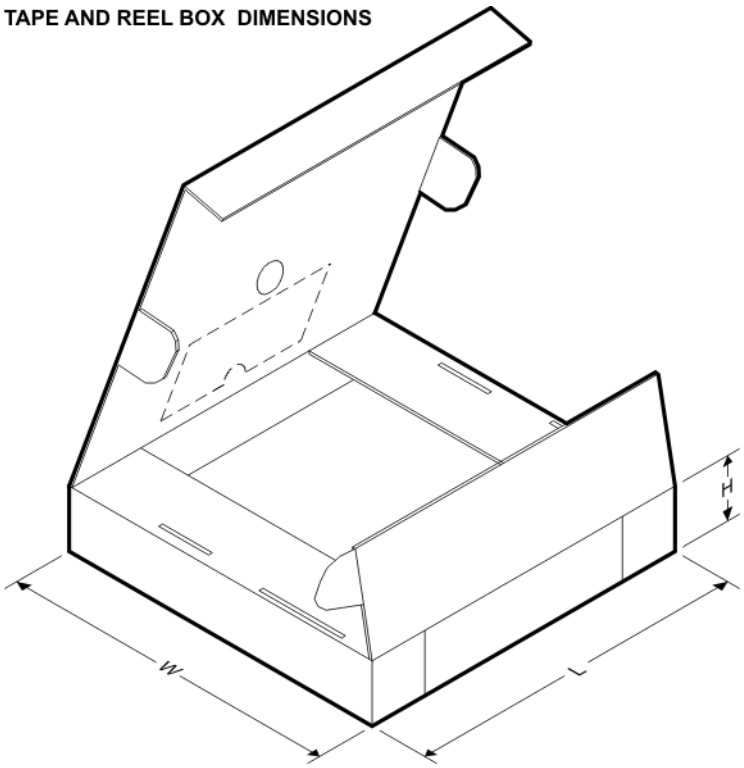
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
OPA211AIDGKR	MSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA211AIDGKT	MSOP	DGK	8	250	180.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA211AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
OPA211AIDRGR	SON	DRG	8	1000	330.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2
OPA211AIDRGT	SON	DRG	8	250	180.0	12.4	3.3	3.3	1.1	8.0	12.0	Q2

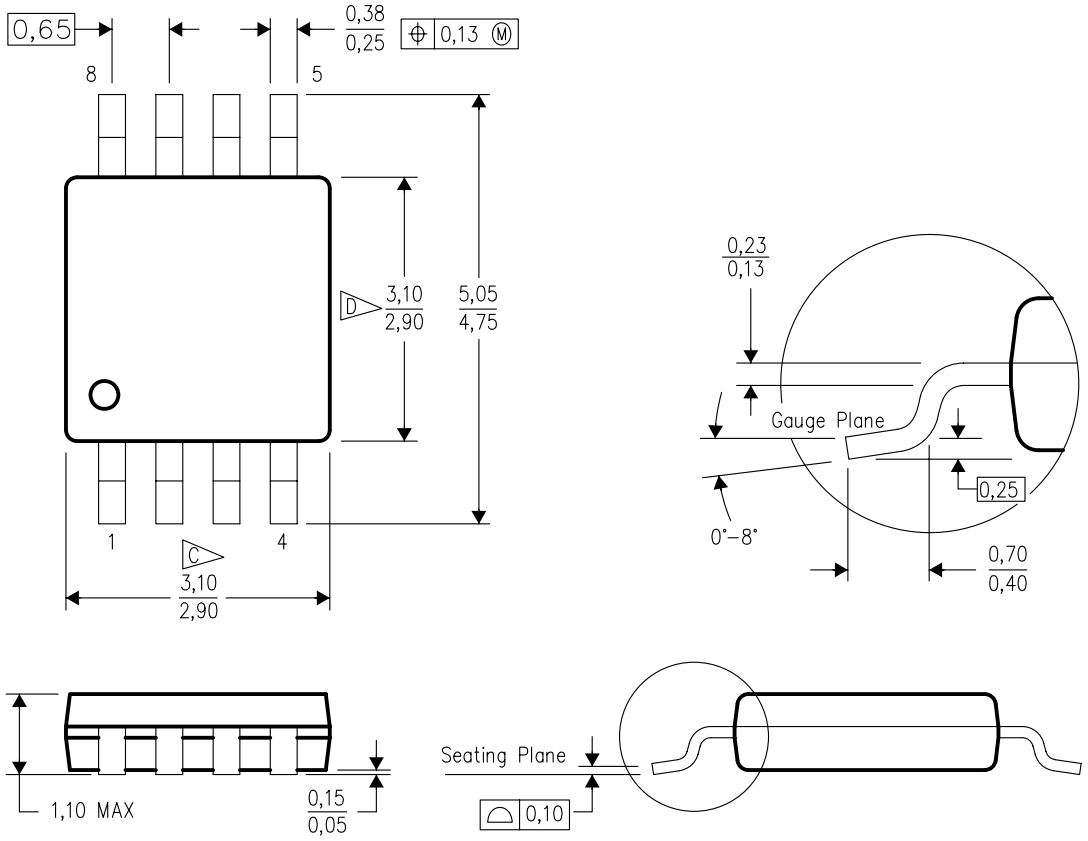
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA211AIDGKR	MSOP	DGK	8	2500	346.0	346.0	29.0
OPA211AIDGKT	MSOP	DGK	8	250	190.5	212.7	31.8
OPA211AIDR	SOIC	D	8	2500	346.0	346.0	29.0
OPA211AIDRGR	SON	DRG	8	1000	346.0	346.0	29.0
OPA211AIDRGT	SON	DRG	8	250	190.5	212.7	31.8

DGK (S–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



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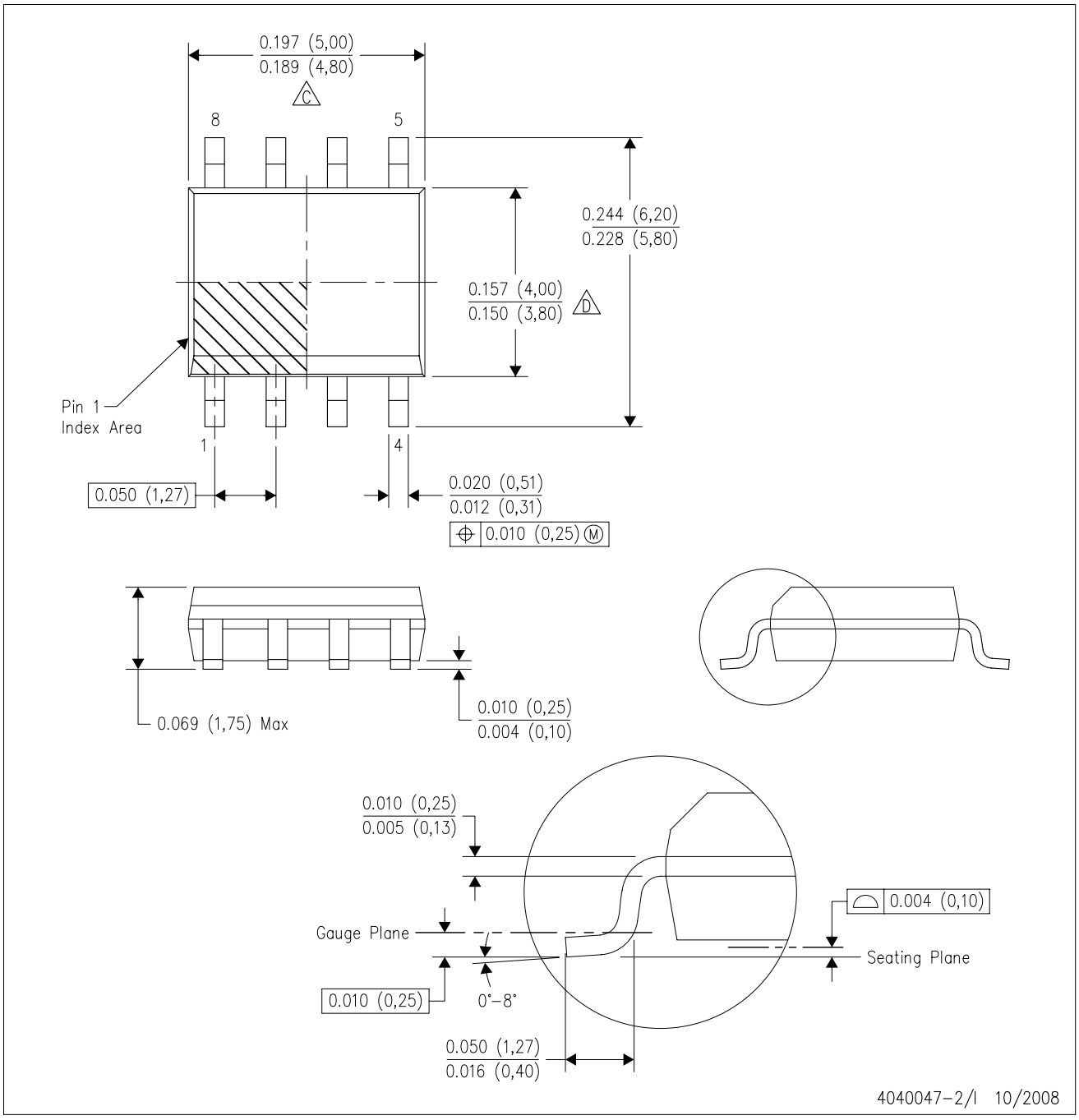
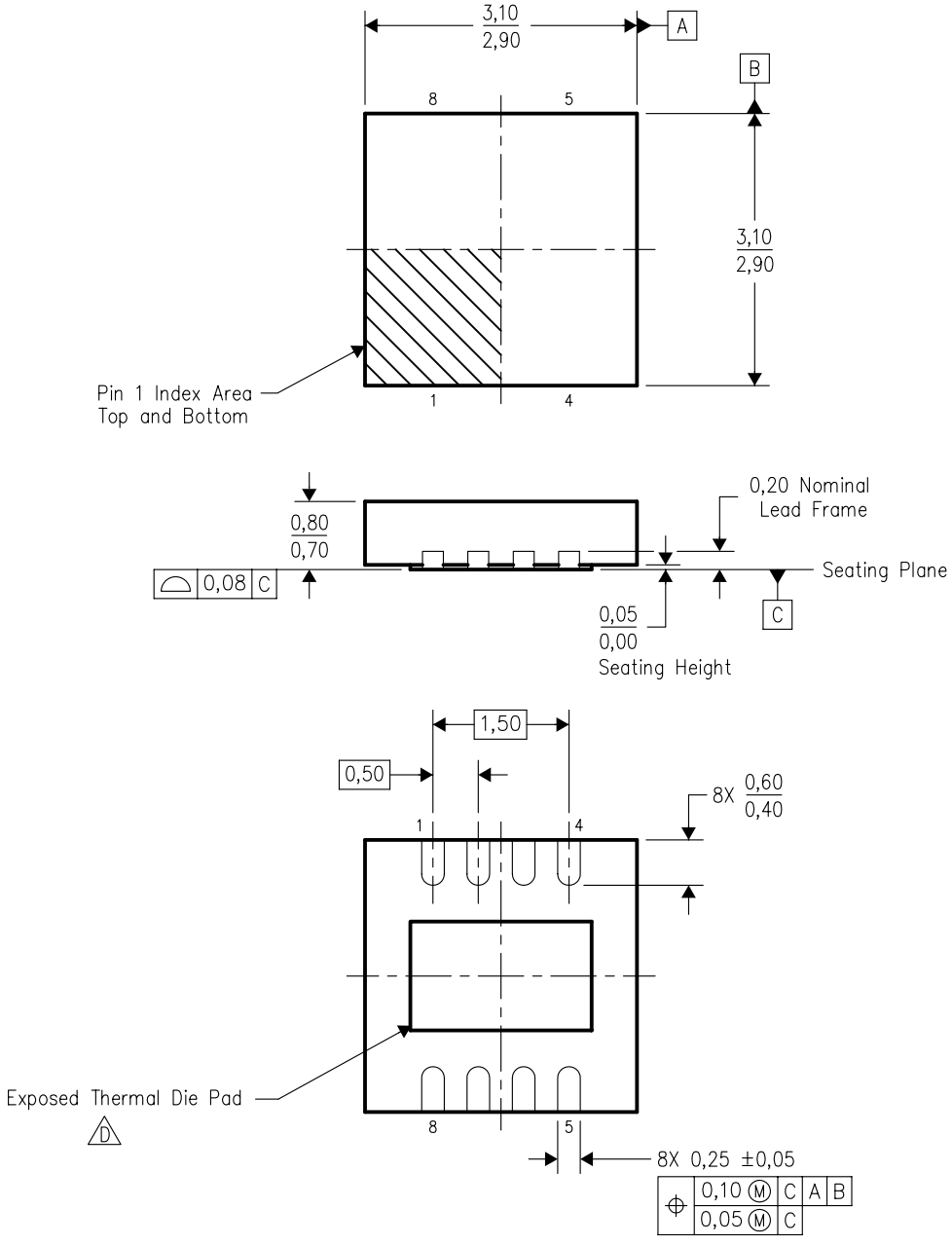
NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
D. Body width does not include interlead flash. Interlead 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 PACKAGE



NOTES:
A. All linear dimensions are in inches (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 .006 (0,15) per end.
D. Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
E. Reference JEDEC MS–012 variation AA.

DRG (S–PDSO–N8) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. SON (Small Outline No–Lead) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
E. JEDEC MO–229 package registration pending.

THERMAL PAD MECHANICAL DATA

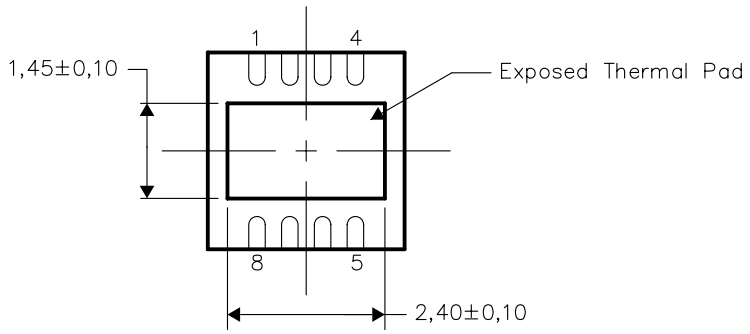
DRG (S–PDSO–N8)

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No–Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

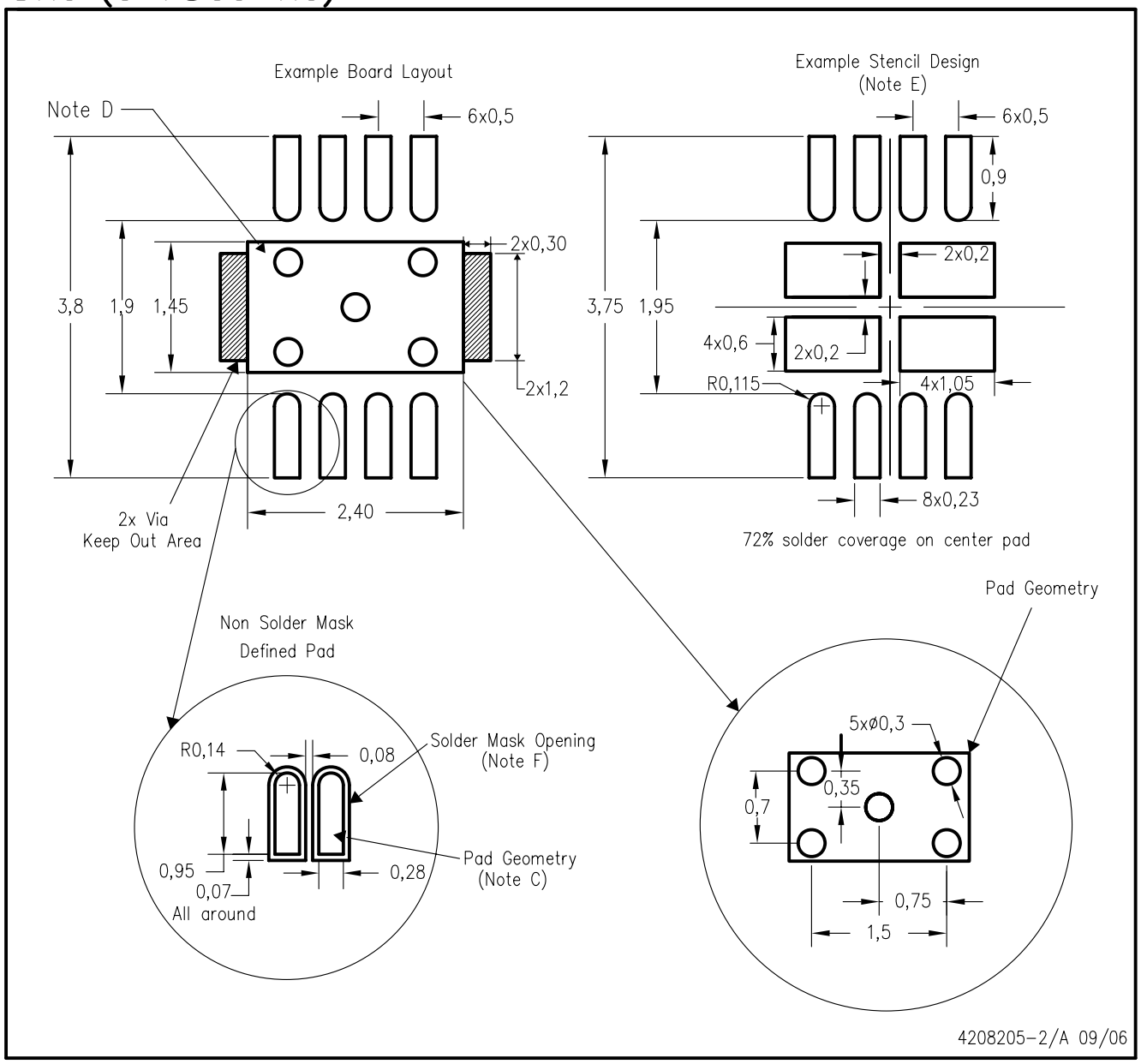


Bottom View

NOTE: All linear dimensions are in millimeters

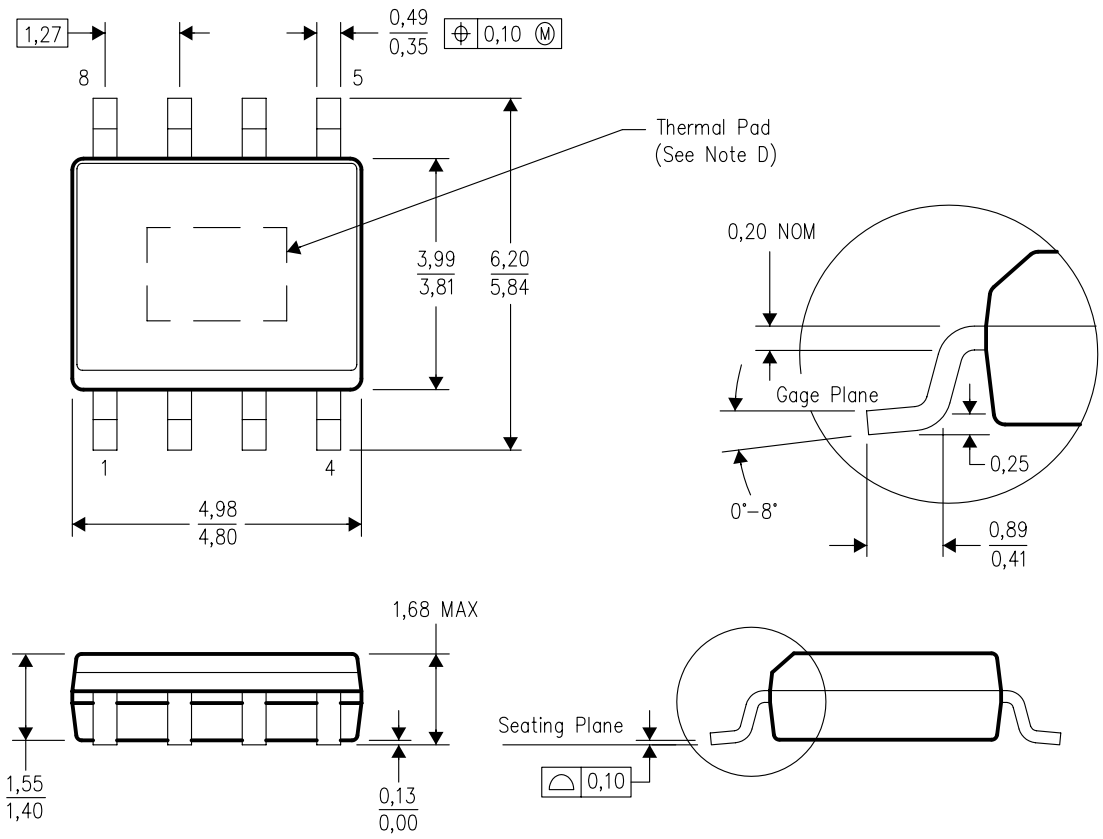
Exposed Thermal Pad Dimensions

DRG (S–PDSO–N8)



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–SM–782 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SCBA017, SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http://www.ti.com>.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

DDA (R–PDSO–G8) PowerPAD™ PLASTIC SMALL–OUTLINE PACKAGE



4202561/D 04/04

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at www.ti.com <http://www.ti.com>.

PowerPAD is a trademark of Texas Instruments.

THERMAL PAD MECHANICAL DATA

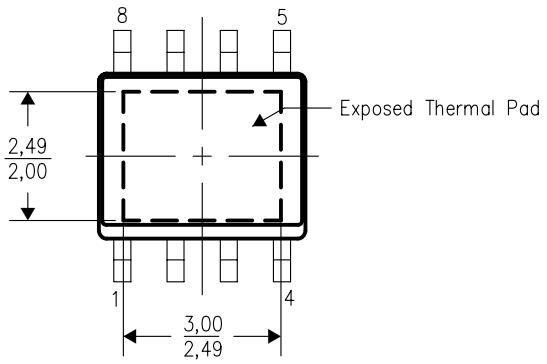
DDA (R–PDSO–G8)

THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.



Top View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265