

## TLVx333 2- $\mu\text{V}$ $V_{OS}$ , 0.02- $\mu\text{V}/^\circ\text{C}$ , 17- $\mu\text{A}$ , CMOS Operational Amplifiers Zero-Drift Series

### 1 Features

- Unmatched Price Performance
- Low Offset Voltage: 2  $\mu\text{V}$
- Zero Drift: 0.02  $\mu\text{V}/^\circ\text{C}$
- Low Noise: 1.1  $\mu\text{V}_{PP}$ , 0.1 Hz to 10 Hz
- Quiescent Current: 17  $\mu\text{A}$
- Supply Voltage: 1.8 V to 5.5 V
- Rail-to-Rail Input/Output
- Internal EMI Filtering
- *microSize* Packages: SOT23, SC70

### 2 Applications

- Battery-Powered Instruments
- Temperature Measurements
- Transducer Applications
- Electronic Scales
- Medical Instrumentation
- Handheld Test Equipment
- Current Sense

### 3 Description

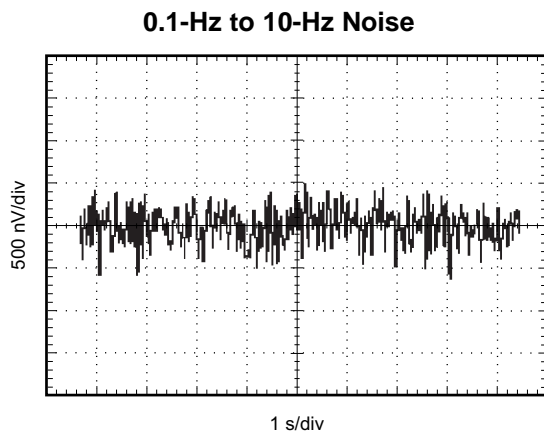
The TLVx333 series of CMOS operational amplifiers offer precision performance at a very competitive price. These devices are members of the *zero-drift* family of amplifiers that uses a proprietary auto-calibration technique to simultaneously provide low offset voltage (15  $\mu\text{V}$ , max) and near-zero drift over time and temperature at only 28  $\mu\text{A}$  (max) of quiescent current. The TLVx333 family features rail-to-rail input and output in addition to near-flat 1/f noise, making this amplifier ideal for many applications and much easier to design into a system. These devices are optimized for low-voltage operation as low as 1.8 V ( $\pm 0.9$  V) and up to 5.5 V ( $\pm 2.75$  V).

The TLV333 (single version) is available in the SC70-5, SOT23-5, and SOIC-8 packages. The TLV2333 (dual version) is offered in VSSOP-8 and SOIC-8 packages. The TLV4333 is offered in the standard SOIC-14 and TSSOP-14 packages. All versions are specified for operation from  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ .

#### Device Information<sup>(1)</sup>

PART NUMBER	PACKAGE	BODY SIZE (NOM)
TLV333	SOIC (8)	4.90 mm x 3.91 mm
	SOT-23 (5)	2.90 mm x 1.60 mm
	SC70 (5)	2.00 mm x 1.25 mm
TLV2333	SOIC (8)	4.90 mm x 3.91 mm
	VSSOP (8)	3.00 mm x 3.00 mm
TLV4333	SOIC (14)	8.65 mm x 3.91
	TSSOP (14)	5.00 mm x 4.40 mm

(1) For all available packages, see the orderable addendum at the end of the data sheet.



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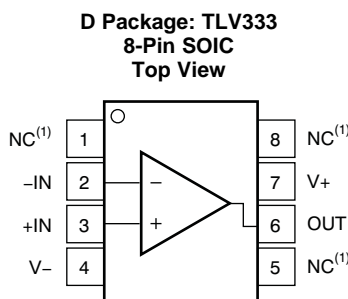
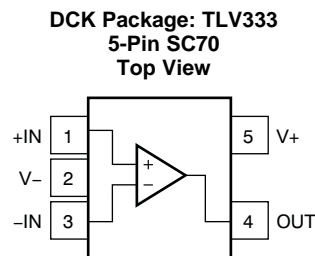
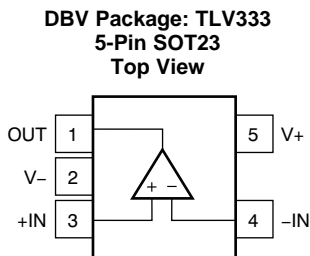
## 4 Revision History

DATE	REVISION	NOTES
December 2015	*	Initial release.

## 5 Device Comparison Table

DEVICE	NO. OF CHANNELS	PACKAGE-LEADS				
		SOIC	SOT23	SC70	VSSOP	TSSOP
TLV333	1	8	5	5	—	—
TLV2333	2	8	—	—	8	—
TLV4333	4	14	—	—	—	14

## 6 Pin Configuration and Functions

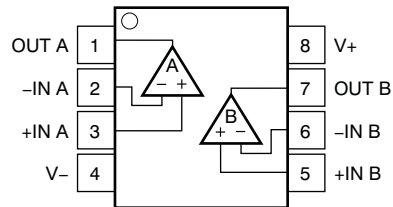


(1) NC denotes no internal connection.

### Pin Functions: TLV333

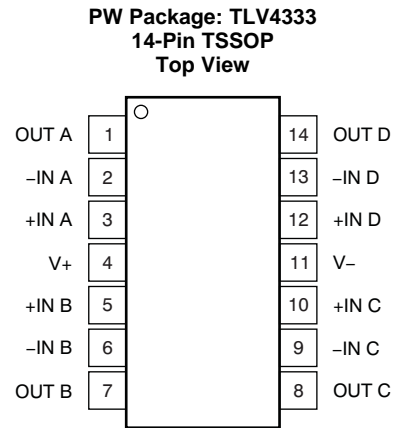
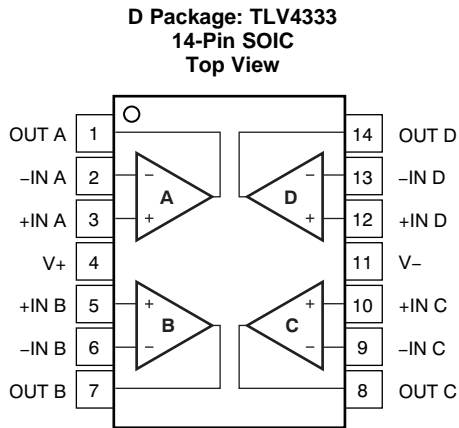
NAME	PIN			I/O	DESCRIPTION
	DBV (SOT23)	DCK (SC70)	D (SOIC)		
-IN	4	3	2	I	Inverting input
+IN	3	1	3	I	Noninverting input
NC	—	—	1, 5, 8	—	No internal connection (can be left floating)
OUT	1	4	6	O	Output
V-	2	2	4	—	Negative (lowest) power supply
V+	5	5	7	—	Positive (highest) power supply

**D Package: TLV2333**  
**8-Pin SOIC, VSSOP**  
**Top View**



**Pin Functions: TLV2333**

NAME	PIN		I/O	DESCRIPTION
	NO.	D (SOIC, VSSOP)		
-IN A	2		I	Inverting input, channel A
+IN A	3		I	Noninverting input, channel A
-IN B	6		I	Inverting input, channel B
+IN B	5		I	Noninverting input, channel B
OUT A	1		O	Output, channel A
OUT B	7		O	Output, channel B
V-	4		—	Negative (lowest) power supply
V+	8		—	Positive (highest) power supply


**Pin Functions: TLV4333**

NAME	PIN NO.		I/O	DESCRIPTION
	D (SOIC)	PW (TSSOP)		
-IN A	2	2	I	Inverting input, channel A
+IN A	3	3	I	Noninverting input, channel A
-IN B	6	6	I	Inverting input, channel B
+IN B	5	5	I	Noninverting input, channel B
-IN C	9	9	I	Inverting input, channel C
+IN C	10	10	I	Noninverting input, channel C
-IN D	13	13	I	Inverting input, channel D
+IN D	12	12	I	Noninverting input, channel D
OUT A	1	1	O	Output, channel A
OUT B	7	7	O	Output, channel B
OUT C	8	8	O	Output, channel C
OUT D	14	14	O	Output, channel D
V-	11	11	—	Negative (lowest) power supply
V+	4	4	—	Positive (highest) power supply

## 7 Specifications

### 7.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
Supply voltage	$V_S = (V+) - (V-)$	7		V
Signal input pins <sup>(2)</sup>	Voltage	(V-) -0.3	(V+) + 0.3	V
	Current	-10	10	mA
Output short-circuit <sup>(3)</sup>		Continuous		
Temperature	Operating	-40	150	°C
	Junction	150		
	Storage, $T_{stg}$	-65	150	

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.
- (2) Input pins are diode-clamped to the power-supply rails. Input signals that can swing more than 0.3 V beyond the supply rails must be current limited to 10 mA or less.
- (3) Short-circuit to ground, one amplifier per package.

### 7.2 ESD Ratings

		VALUE	UNIT
$V_{(ESD)}$ Electrostatic discharge	Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>	±4000	V
	Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup>	±1000	

- (1) JEDEC document JEP155 states that 500-V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250-V CDM allows safe manufacturing with a standard ESD control process.

### 7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

		MIN	NOM	MAX	UNIT
$V_S$	Supply voltage	1.8		5.5	V
Specified temperature range		-40		125	°C

## 7.4 Thermal Information: TLV333

THERMAL METRIC <sup>(1)</sup>		TLV333			UNIT
		D (SOIC)	DBV (SOT23)	DCK (SC70)	
		8 PINS	5 PINS	5 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	140.1	220.8	298.4	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	89.8	97.5	65.4	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	80.6	61.7	97.1	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	28.7	7.6	0.8	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	80.1	61.1	95.5	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	n/a	n/a	n/a	°C/W

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

## 7.5 Thermal Information: TLV2333

THERMAL METRIC <sup>(1)</sup>		TLV2333		UNIT
		D (SOIC)	DGK (VSSOP)	
		8 PINS	8 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	124.0	180.3	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	73.7	48.1	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	64.4	100.9	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	18.0	2.4	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	63.9	99.3	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	n/a	n/a	°C/W

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

## 7.6 Thermal Information: TLV4333

THERMAL METRIC <sup>(1)</sup>		TLV4333		UNIT
		D (SOIC)	PW (TSSOP)	
		14 PINS	14 PINS	
R <sub>θJA</sub>	Junction-to-ambient thermal resistance	83.8	120.8	°C/W
R <sub>θJC(top)</sub>	Junction-to-case (top) thermal resistance	70.7	34.3	°C/W
R <sub>θJB</sub>	Junction-to-board thermal resistance	59.5	62.8	°C/W
Ψ <sub>JT</sub>	Junction-to-top characterization parameter	11.6	1.0	°C/W
Ψ <sub>JB</sub>	Junction-to-board characterization parameter	37.7	56.5	°C/W
R <sub>θJC(bot)</sub>	Junction-to-case (bottom) thermal resistance	n/a	n/a	°C/W

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

## 7.7 Electrical Characteristics: $V_S = 1.8\text{ V to }5.5\text{ V}$

 at  $T_A = 25^\circ\text{C}$ ,  $R_L = 10\text{ k}\Omega$  connected to mid-supply, and  $V_{CM} = V_{OUT} = \text{mid-supply}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>OFFSET VOLTAGE</b>						
$V_{OS}$	Input offset voltage <sup>(1)</sup>	$V_S = 5\text{ V}$		2	15	$\mu\text{V}$
$dV_{OS}/dT$	$V_{OS}$ vs temperature	$T_A = -40^\circ\text{C to }+125^\circ\text{C}$		0.02		$\mu\text{V}/^\circ\text{C}$
PSRR	$V_{OS}$ vs power supply	$V_S = 1.8\text{ V to }5.5\text{ V}$		1	8	$\mu\text{V/V}$
	Long-term stability <sup>(2)</sup>			1 <sup>(2)</sup>		$\mu\text{V}$
	Channel separation, dc			0.1		$\mu\text{V/V}$
<b>INPUT BIAS CURRENT</b>						
$I_B$	Input bias current			$\pm 70$		$\text{pA}$
	Input bias current over temperature	$T_A = -40^\circ\text{C to }+125^\circ\text{C}$		$\pm 150$		$\text{pA}$
$I_{OS}$	Input offset current			$\pm 140$		$\text{pA}$
<b>NOISE</b>						
$e_n$	Input voltage noise density	$f = 1\text{ kHz}$		55		$\text{nV}/\sqrt{\text{Hz}}$
	Input voltage noise	$f = 0.01\text{ Hz to }1\text{ Hz}$		0.3		$\mu\text{V}_{PP}$
		$f = 0.1\text{ Hz to }10\text{ Hz}$		1.1		
$i_n$	Input current noise	$f = 10\text{ Hz}$		100		$\text{fA}/\sqrt{\text{Hz}}$
<b>INPUT VOLTAGE RANGE</b>						
$V_{CM}$	Common-mode voltage range		$(V-) - 0.1$		$(V+) + 0.1$	$\text{V}$
CMRR	Common-mode rejection ratio	$(V-) - 0.1\text{ V} < V_{CM} < (V+) + 0.1\text{ V}$	102	115		$\text{dB}$
<b>INPUT CAPACITANCE</b>						
	Differential			2		$\text{pF}$
	Common-mode			4		
<b>OPEN-LOOP GAIN</b>						
$A_{OL}$	Open-loop voltage gain	$(V-) + 0.1\text{ V} < V_O < (V+) - 0.1\text{ V}$	102	130		$\text{dB}$
<b>FREQUENCY RESPONSE</b>						
GBW	Gain-bandwidth product	$C_L = 100\text{ pF}$		350		$\text{kHz}$
SR	Slew rate	$G = 1$		0.16		$\text{V}/\mu\text{s}$
<b>OUTPUT</b>						
	Voltage output swing from rail	$T_A = -40^\circ\text{C to }+125^\circ\text{C}$		30	70	$\text{mV}$
$I_{SC}$	Short-circuit current			$\pm 5$		$\text{mA}$
$C_L$	Capacitive load drive		See <a href="#">Typical Characteristics</a>			
$Z_O$	Open-loop output impedance	$f = 350\text{ kHz}, I_O = 0\text{ mA}$		2		$\text{k}\Omega$
<b>POWER SUPPLY</b>						
$V_S$	Specified voltage range		1.8		5.5	$\text{V}$
$I_Q$	Quiescent current per amplifier	$I_O = 0\text{ mA}, T_A = -40^\circ\text{C to }+125^\circ\text{C}$		17	28	$\mu\text{A}$
	Turn-on time	$V_S = 5\text{ V}$		100		$\mu\text{s}$
<b>TEMPERATURE RANGE</b>						
	Specified range		-40		125	$^\circ\text{C}$
	Operating range		-40		150	$^\circ\text{C}$
	Storage range		-65		150	$^\circ\text{C}$

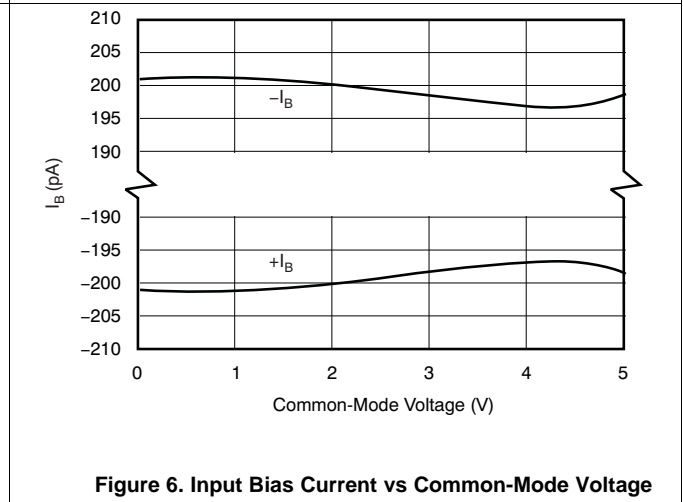
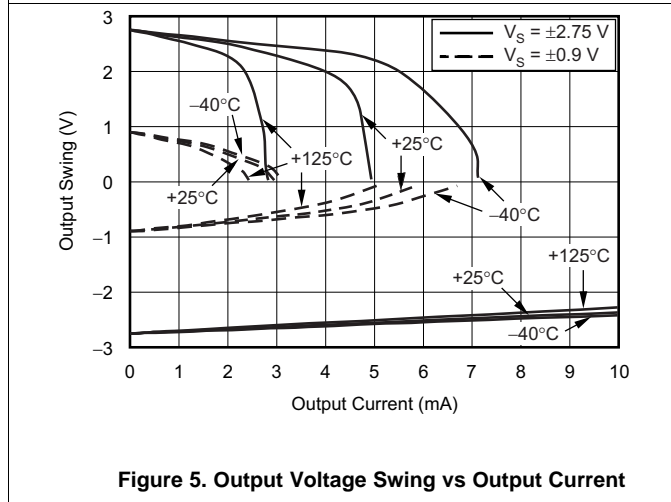
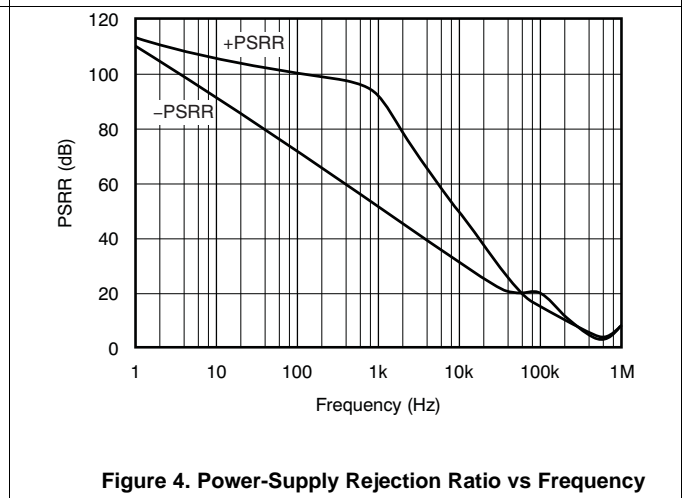
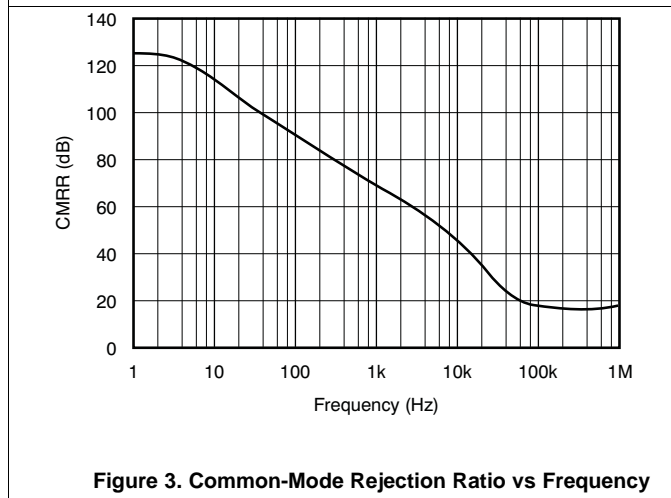
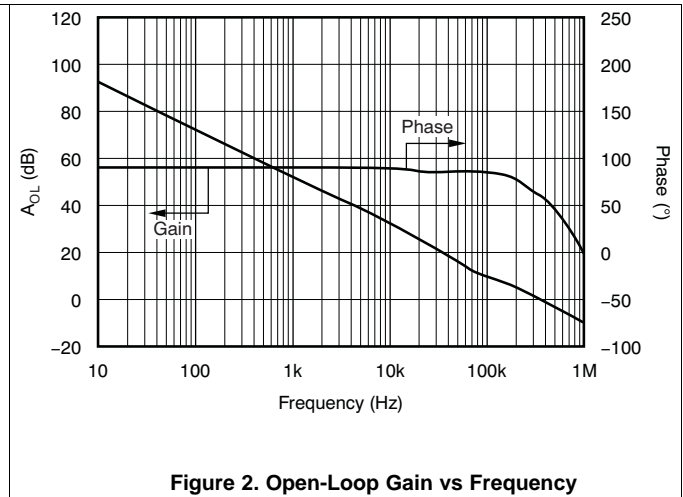
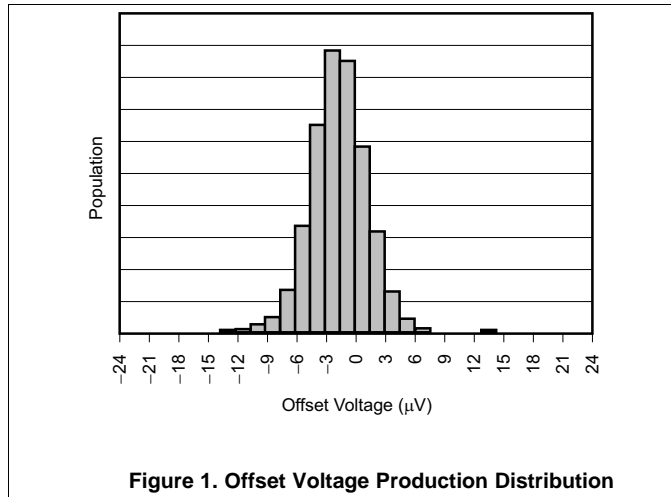
 (1) Specified by design and characterization. Amplifiers are 100% production screened at  $25^\circ\text{C}$  to reduce defective units.

 (2) 300-hour life test at  $150^\circ\text{C}$  demonstrated randomly distributed variation of approximately  $1\text{ }\mu\text{V}$ .



## 7.8 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $C_L = 0\text{ pF}$ ,  $R_L = 10\text{ k}\Omega$  connected to mid-supply,  $V_{CM} = V_{OUT} = \text{mid-supply}$  (unless otherwise noted)



### Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $C_L = 0\text{ pF}$ ,  $R_L = 10\text{ k}\Omega$  connected to mid-supply,  $V_{CM} = V_{OUT} = \text{mid-supply}$  (unless otherwise noted)

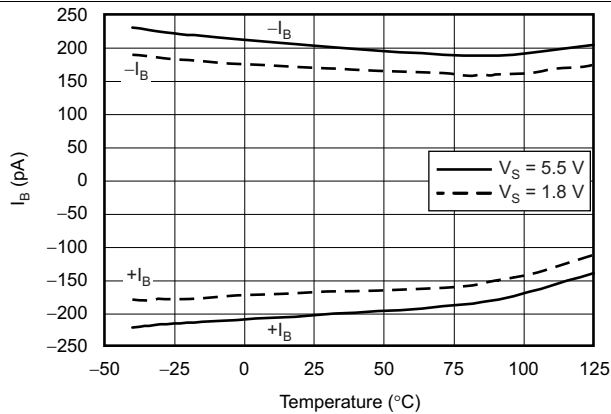


Figure 7. Input Bias Current vs Temperature

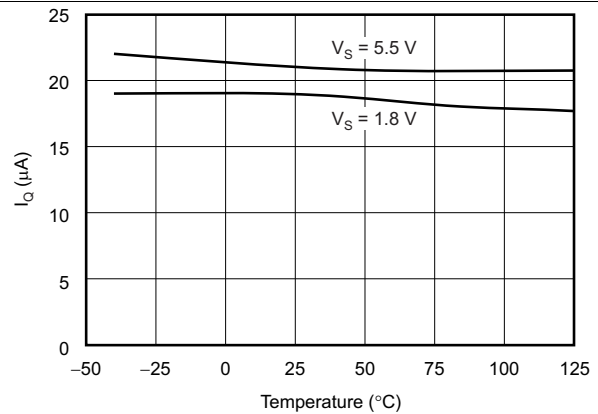


Figure 8. Quiescent Current vs Temperature

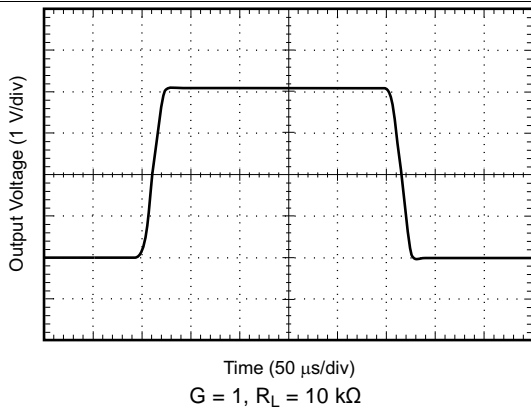


Figure 9. Large-Signal Step Response

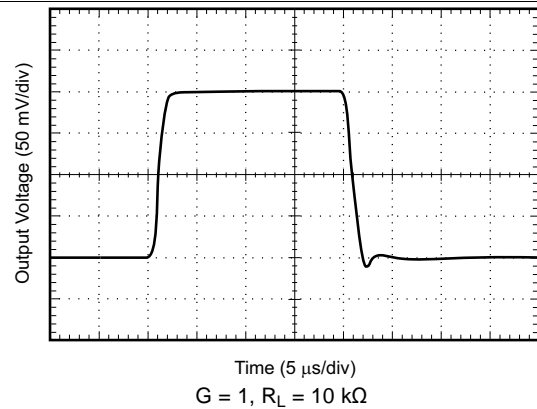


Figure 10. Small-Signal Step Response

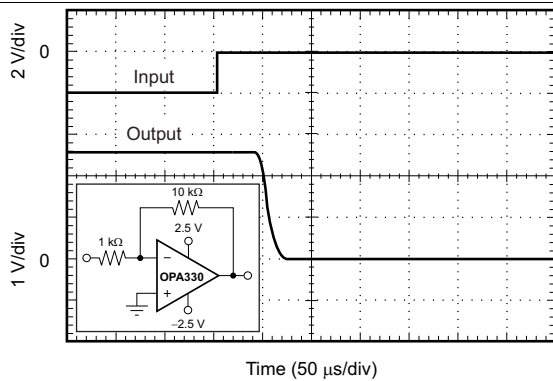


Figure 11. Positive Overvoltage Recovery

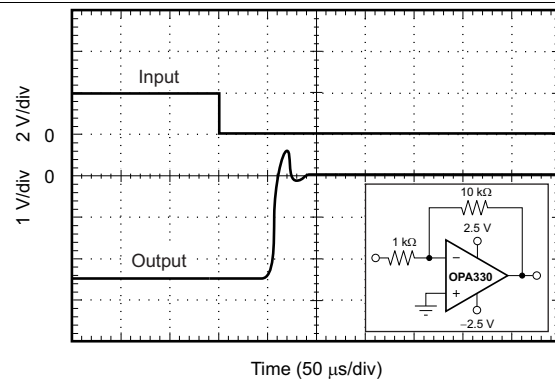


Figure 12. Negative Overvoltage Recovery

Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $C_L = 0\text{ pF}$ ,  $R_L = 10\text{ k}\Omega$  connected to mid-supply,  $V_{CM} = V_{OUT} = \text{mid-supply}$  (unless otherwise noted)

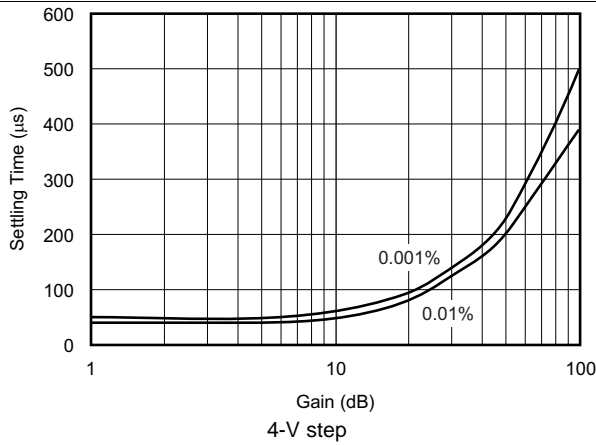


Figure 13. Settling Time vs Closed-Loop Gain

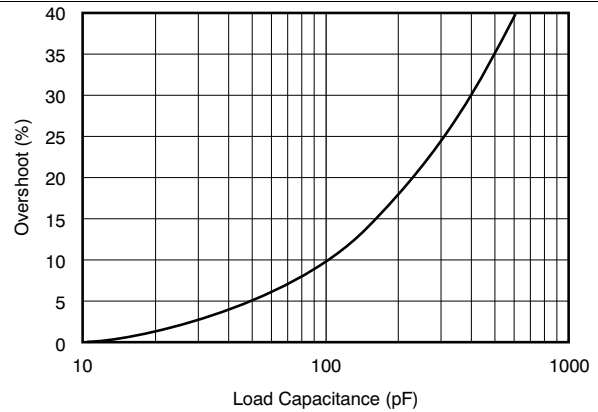


Figure 14. Small-Signal Overshoot vs Load Capacitance

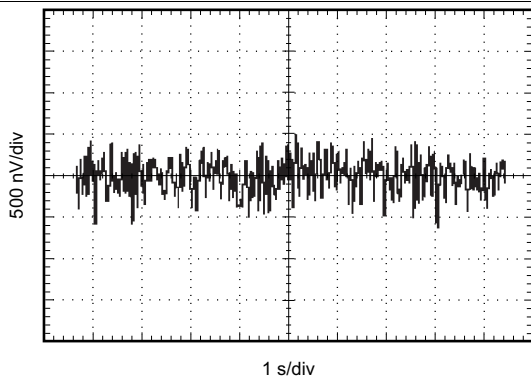


Figure 15. 0.1-Hz to 10-Hz Noise

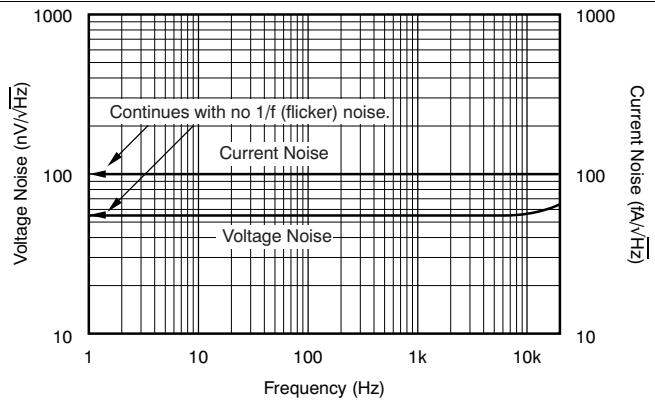


Figure 16. Current and Voltage Noise Spectral Density vs Frequency

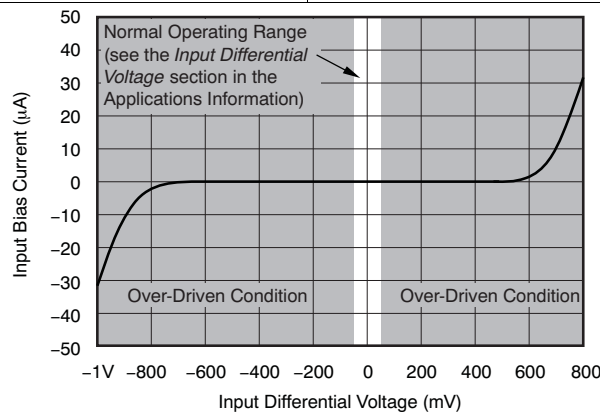


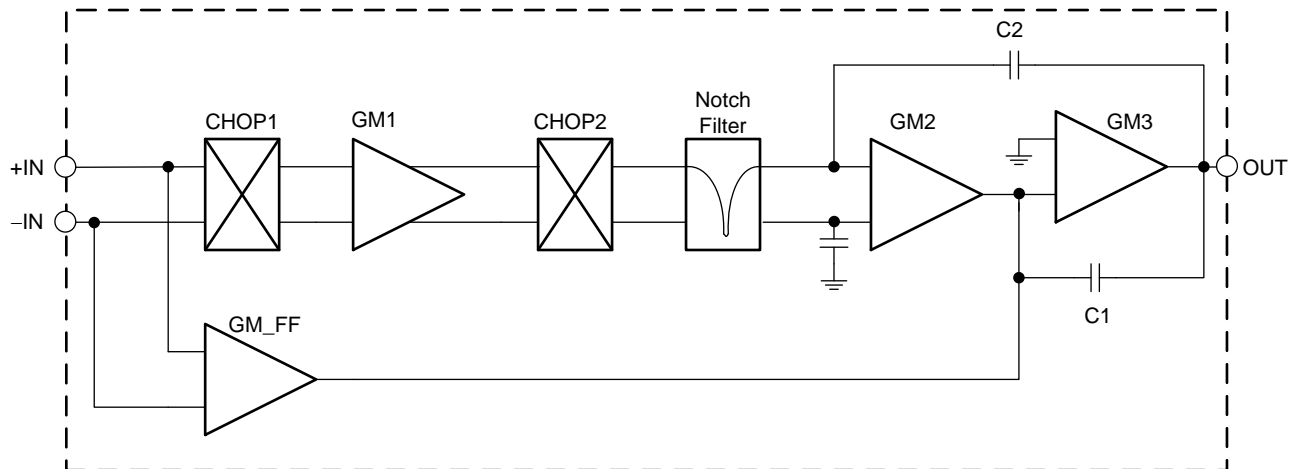
Figure 17. Input Bias Current vs Input Differential Voltage

## 8 Detailed Description

### 8.1 Overview

The TLVx333 series of low-cost operational amplifiers are unity-gain stable and free from unexpected output phase reversal. These devices use a proprietary auto-calibration technique to provide low offset voltage and very low drift over time and temperature. The TLVx333 family also offers rail-to-rail input and output and near-flat 1/f noise. These features make this series of op amps ideal for many applications and much easier to design into a wide variety of systems.

### 8.2 Functional Block Diagram



### 8.3 Feature Description

The TLV333, TLV2333, and TLV4333 are unity-gain stable, precision operational amplifiers free from unexpected output phase reversal. The use of proprietary zero-drift circuitry gives the benefit of low input offset voltage over time and temperature, as well as lowering the 1/f noise component. As a result of the high PSRR, these devices work well in applications that run directly from battery power without regulation. The TLV333 family is optimized for low-voltage, single-supply operation. These miniature, high-precision, low quiescent current amplifiers offer high-impedance inputs that have a common-mode range 100 mV beyond the supplies and a rail-to-rail output that swings within 100 mV of the supplies under normal test conditions. The TLV333 series are precision amplifiers for cost-sensitive applications.

#### 8.3.1 Operating Voltage

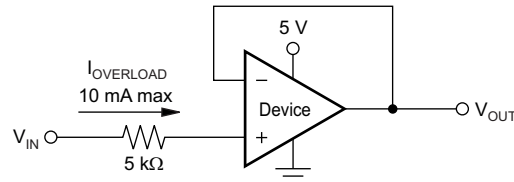
The TLV333 series op amps can be used with single or dual supplies from an operating range of  $V_S = 1.8\text{ V}$  ( $\pm 0.9\text{ V}$ ) up to  $5.5\text{ V}$  ( $\pm 2.75\text{ V}$ ). Supply voltages greater than  $7\text{ V}$  can permanently damage the device; see the [Absolute Maximum Ratings](#) table. Key parameters that vary over the supply voltage or temperature range are listed in the [Typical Characteristics](#) section.

## Feature Description (continued)

### 8.3.2 Input Voltage

The TLV333, TLV2333, and TLV4333 input common-mode voltage range extends 0.1 V beyond the supply rails. The TLV333 is designed to cover the full range without the troublesome transition region found in some other rail-to-rail amplifiers.

Typically, input bias current is approximately 200 pA; however, input voltages that exceed the power supplies can cause excessive current to flow into or out of the input pins. Momentary voltages greater than the power supply can be tolerated if the input current is limited to 10 mA. This limitation is easily accomplished with an input resistor, as shown in Figure 18.



NOTE: A current-limiting resistor required if the input voltage exceeds the supply rails by  $\geq 0.3$  V.

Figure 18. Input Current Protection

### 8.3.3 Internal Offset Correction

The TLV333, TLV2333, and TLV4333 op amps use an auto-calibration technique with a time-continuous, 125-kHz op amp in the signal path. This amplifier is zero-corrected every 8  $\mu$ s using a proprietary technique. Upon power-up, the amplifier requires approximately 100  $\mu$ s to achieve specified  $V_{OS}$  accuracy. This design has no aliasing or flicker noise.

### 8.3.4 Achieving Output Swing to the Op Amp Negative Rail

Some applications require output voltage swings from 0 V to a positive full-scale voltage (such as 2.5 V) with excellent accuracy. With most single-supply op amps, problems arise when the output signal approaches 0 V, near the lower output swing limit of a single-supply op amp. A good single-supply op amp can swing close to single-supply ground, but does not reach ground. The output of the TLV333, TLV2333, and TLV4333 can be made to swing to ground, or slightly below, on a single-supply power source. This swing to ground requires the use of another resistor and an additional, more negative, power supply than the op amp negative supply. Connect a pull-down resistor between the output and the additional negative supply to pull the output down below the value that the output can otherwise achieve, as shown in Figure 19.

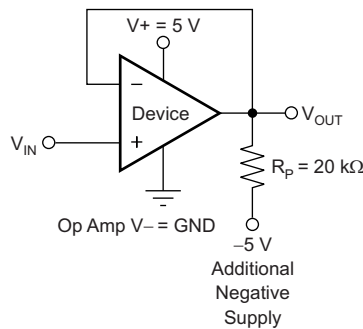


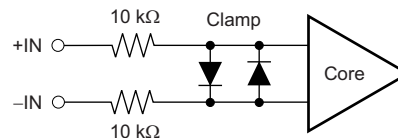
Figure 19. For  $V_{OUT}$  Range to Ground

## Feature Description (continued)

The TLV333, TLV2333, and TLV4333 have an output stage that allows the output voltage to be pulled to its negative supply rail, or slightly below, using the technique previously described. This technique only works with some types of output stages. The TLV333, TLV2333, and TLV4333 are characterized to perform with this technique; the recommended resistor value is approximately 20 k $\Omega$ . Note that this configuration increases the current consumption by several hundreds of microamps. Accuracy is excellent down to 0 V and as low as –2 mV. Limiting and nonlinearity occur below –2 mV, but excellent accuracy returns when the output is again driven above –2 mV. Lowering the resistance of the pull-down resistor allows the op amp to swing even further below the negative rail. Resistances as low as 10 k $\Omega$  can be used to achieve excellent accuracy down to –10 mV.

### 8.3.5 Input Differential Voltage

The typical input bias current of the TLV333 during normal operation is approximately 200 pA. In overdriven conditions, the bias current can increase significantly (see [Figure 17](#)). The most common cause of an overdriven condition occurs when the op amp is outside of the linear range of operation. When the output of the op amp is driven to one of the supply rails, the feedback loop requirements cannot be satisfied and a differential input voltage develops across the input pins. This differential input voltage results in activation of parasitic diodes inside the front-end input chopping switches that combine with 10-k $\Omega$  electromagnetic interference (EMI) filter resistors to create the equivalent circuit shown in [Figure 20](#). Notice that the input bias current remains within specification within the linear region.



**Figure 20. Equivalent Input Circuit**

### 8.3.6 EMI Susceptibility and Input Filtering

Operational amplifiers vary in their susceptibility to EMI. If conducted EMI enters the operational amplifier, the dc offset observed at the amplifier output may shift from its nominal value when EMI is present. This shift is a result of signal rectification associated with the internal semiconductor junctions. Although all operational amplifier pin functions can be affected by EMI, the input pins are likely to be the most susceptible. The TLV333 operational amplifier family incorporates an internal input low-pass filter that reduces the amplifier response to EMI. Both common-mode and differential mode filtering are provided by the input filter. The filter is designed for a cutoff frequency of approximately 8 MHz (–3 dB), with a roll-off of 20 dB per decade.

## 8.4 Device Functional Modes

The TLV333 devices have a single functional mode. These devices are powered on as long as the power-supply voltage is between 1.8 V ( $\pm 0.9$  V) and 5.5 V ( $\pm 2.75$  V).

## 9 Application and Implementation

### NOTE

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 9.1 System Examples

Figure 21 shows the basic configuration for a bridge amplifier.

A low-side current shunt monitor is shown in Figure 22.

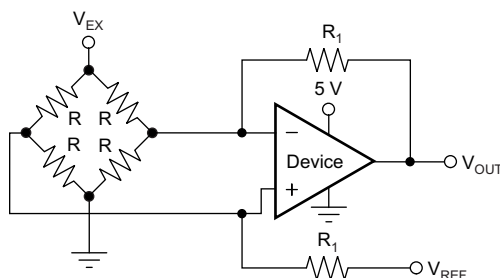
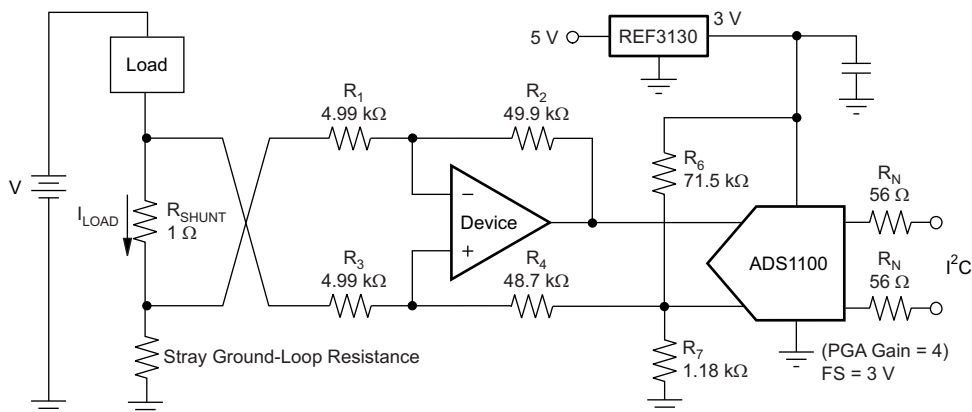


Figure 21. Single Op Amp Bridge Amplifier



NOTE: 1% resistors provide adequate common-mode rejection at small ground-loop errors.

Figure 22. Low-Side Current Monitor

$R_N$  are operational resistors used to isolate the ADS1100 from the noise of the digital I<sup>2</sup>C bus. Because the ADS1100 is a 16-bit converter, a precise reference is essential for maximum accuracy. If absolute accuracy is not required, and the 5-V power supply is sufficiently stable, the REF3130 can be omitted.

Figure 23 shows the TLV333 in a typical thermistor circuit.

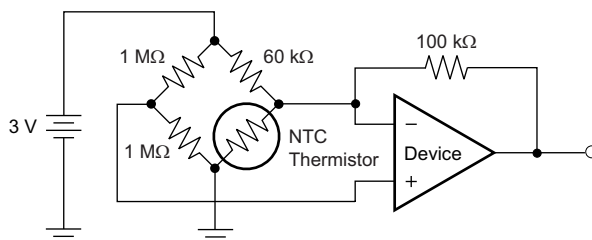


Figure 23. Thermistor Measurement

## 10 Power Supply Recommendations

The TLV333 is specified for operation from 1.8 V to 5.5 V ( $\pm 0.9$  V to  $\pm 2.75$  V); many specifications apply from  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . The [Typical Characteristics](#) section presents parameters that can exhibit significant variance with regard to operating voltage or temperature.

### CAUTION

Supply voltages larger than 7 V can permanently damage the device (see the [Absolute Maximum Ratings](#) table).

Place 0.1- $\mu\text{F}$  bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high-impedance power supplies. For more detailed information on bypass capacitor placement, see the [Layout](#) section.

## 11 Layout

### 11.1 Layout Guidelines

#### 11.1.1 General Layout Guidelines

Attention to good layout practice is always recommended. Keep traces short and, when possible, use a printed circuit board (PCB) ground plane with surface-mount components placed as close to the device pins as possible. Place a 0.1- $\mu\text{F}$  capacitor closely across the supply pins. Apply these guidelines throughout the analog circuit to improve performance and to provide benefits such as reducing the electromagnetic interference (EMI) susceptibility.

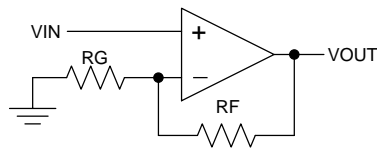
For lowest offset voltage and precision performance, circuit layout and mechanical conditions must be optimized. Avoid temperature gradients that create thermoelectric (Seebeck) effects in the thermocouple junctions formed from connecting dissimilar conductors. These thermally-generated potentials can be made to cancel by assuring they are equal on both input terminals. Other layout and design considerations include:

- Use low thermoelectric-coefficient conditions (avoid dissimilar metals).
- Thermally isolate components from power supplies or other heat sources.
- Shield op amp and input circuitry from air currents, such as cooling fans.

Following these guidelines reduces the likelihood of junctions being at different temperatures, which can cause thermoelectric voltages of 0.1  $\mu\text{V}/^{\circ}\text{C}$  or higher, depending on materials used.



## 11.2 Layout Example



(Schematic Representation)

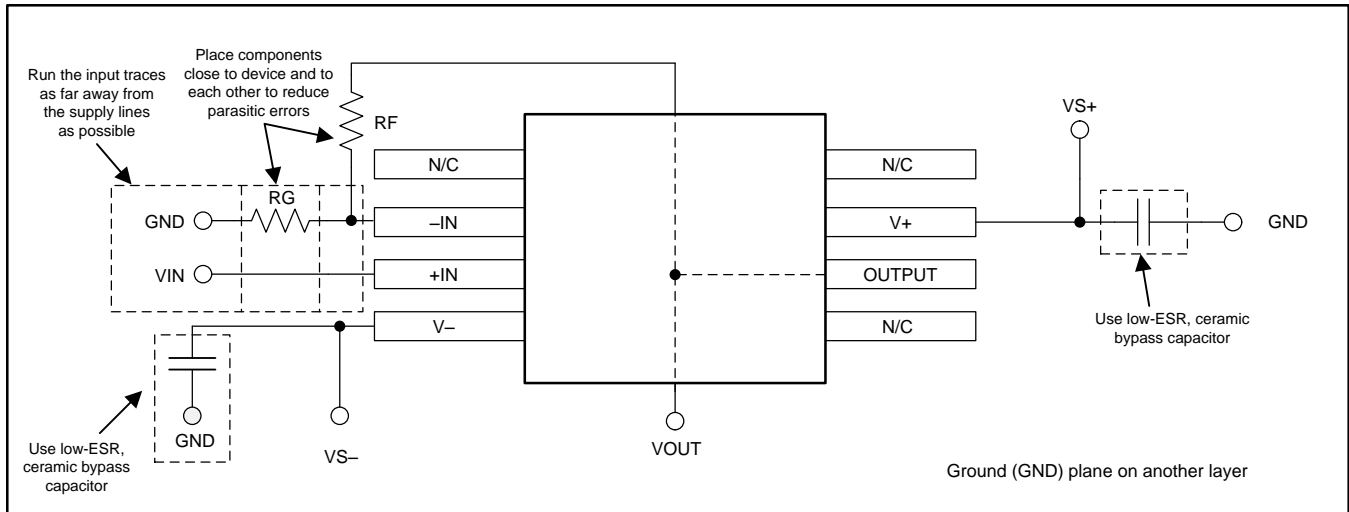


Figure 24. Layout Example

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Development Support

For development support on this product, see the following:

- High-Side V-I Converter, 0 V to 2 V to 0 mA to 100 mA, 1% Full-Scale Error, [TIPD102](#)
- Low-Level V-to-I Converter Reference Design, 0-V to 5-V Input to 0-μA to 5-μA Output, [TIPD107](#)
- 18-Bit, 1-MSPS, Serial Interface, microPower, Truly-Differential Input, SAR ADC, [ADS8881](#)
- Very Low-Power, High-Speed, Rail-To-Rail Input/Output, Voltage Feedback Operational Amplifier, [THS4281](#)
- Data Acquisition Optimized for Lowest Distortion, Lowest Noise, 18-bit, 1-MSPS Reference Design, [TIPD115](#)
- Self-Calibrating, 16-Bit Analog-to-Digital Converter, [ADS1100](#)
- 20-ppm/Degrees C Max, 100-μA, SOT23-3 Series Voltage Reference, [REF3130](#)

### 12.2 Documentation Support

#### 12.2.1 Related Documentation

For related documentation, see the following:

- QFN/SON PCB Attachment, [SLUA271](#)
- Quad Flatpack No-Lead Logic Packages, [SCBA017](#)

### 12.3 Related Links

[Table 1](#) lists quick access links. Categories include technical documents, support and community resources, tools and software, and quick access to sample or buy.

**Table 1. Related Links**

PARTS	PRODUCT FOLDER	SAMPLE & BUY	TECHNICAL DOCUMENTS	TOOLS & SOFTWARE	SUPPORT & COMMUNITY
TLV333	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>
TLV2333	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>
TLV4333	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>	<a href="#">Click here</a>

### 12.4 Community Resources

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At [e2e.ti.com](#), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

### 12.5 Trademarks

E2E is a trademark of Texas Instruments. All other trademarks are the property of their respective owners.

### 12.6 Electrostatic Discharge Caution



These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

## 12.7 Glossary




[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 13 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TLV2333ID	PREVIEW	SOIC	D	8	75	TBD	Call TI	Call TI	-40 to 125		
TLV2333IDGKR	ACTIVE	VSSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-1-260C-UNLIM	-40 to 125	12Z6	
TLV2333IDGKT	ACTIVE	VSSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAUAG	Level-1-260C-UNLIM	-40 to 125	12Z6	
TLV2333IDR	PREVIEW	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	TLV233	
TLV333ID	PREVIEW	SOIC	D	8	75	TBD	Call TI	Call TI	-40 to 125		
TLV333IDBVR	PREVIEW	SOT-23	DBV	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	12YD	
TLV333IDBVT	PREVIEW	SOT-23	DBV	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	12YD	
TLV333IDR	PREVIEW	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	-40 to 125	TLV333	
TLV4333IPWR	ACTIVE	TSSOP	PW	14	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	-40 to 125	TLV4333	

(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.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

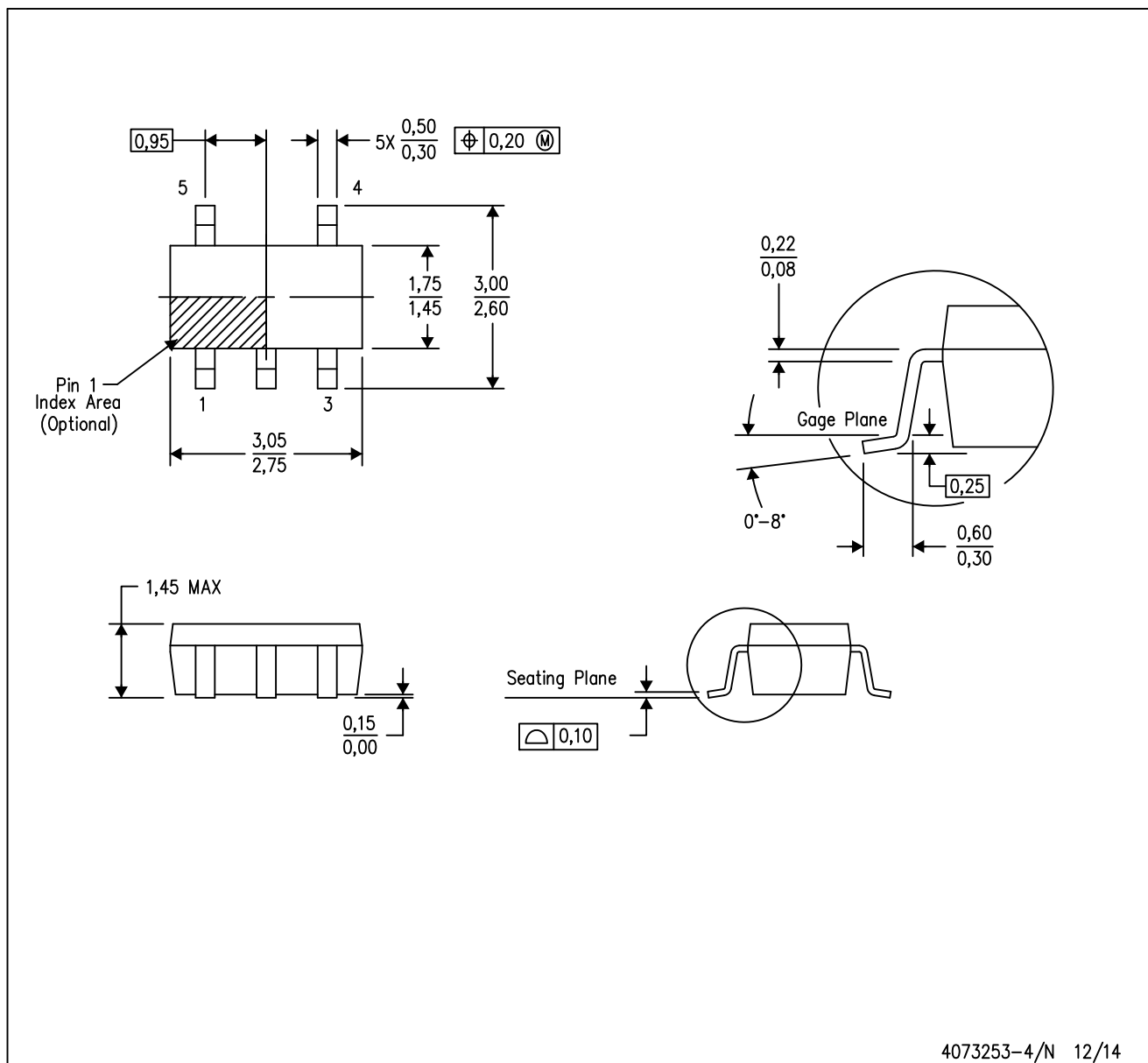
(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE



- 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. Mold flash and protrusion shall not exceed 0.15 per side.
  - D. Falls within JEDEC MO-178 Variation AA.

DBV (R-PDSO-G5)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
  - D. Publication IPC-7351 is recommended for alternate designs.
  - 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. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.

DCK (R-PDSO-G5)

PLASTIC SMALL-OUTLINE PACKAGE

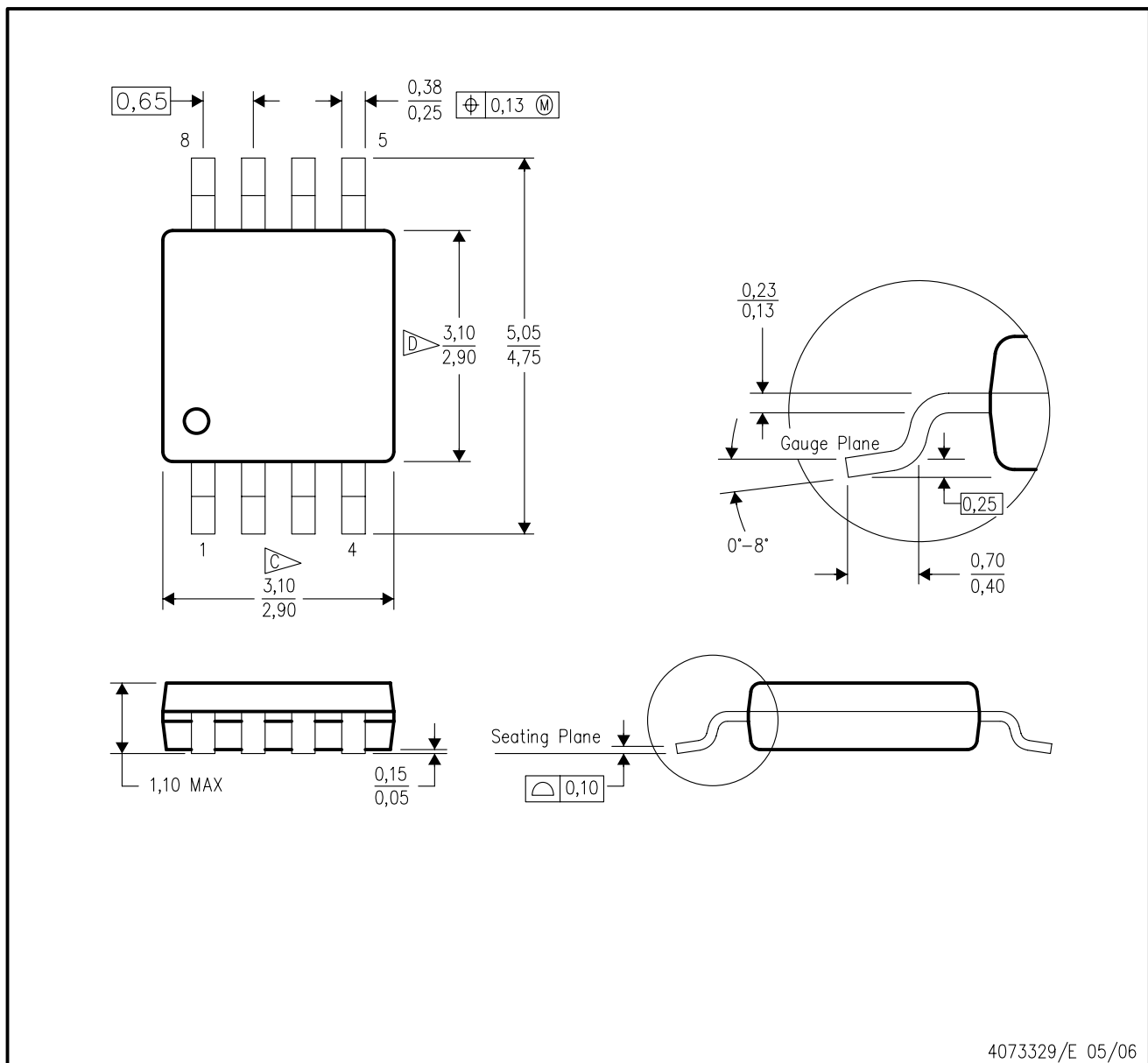


- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
  - D. Falls within JEDEC MO-203 variation AA.

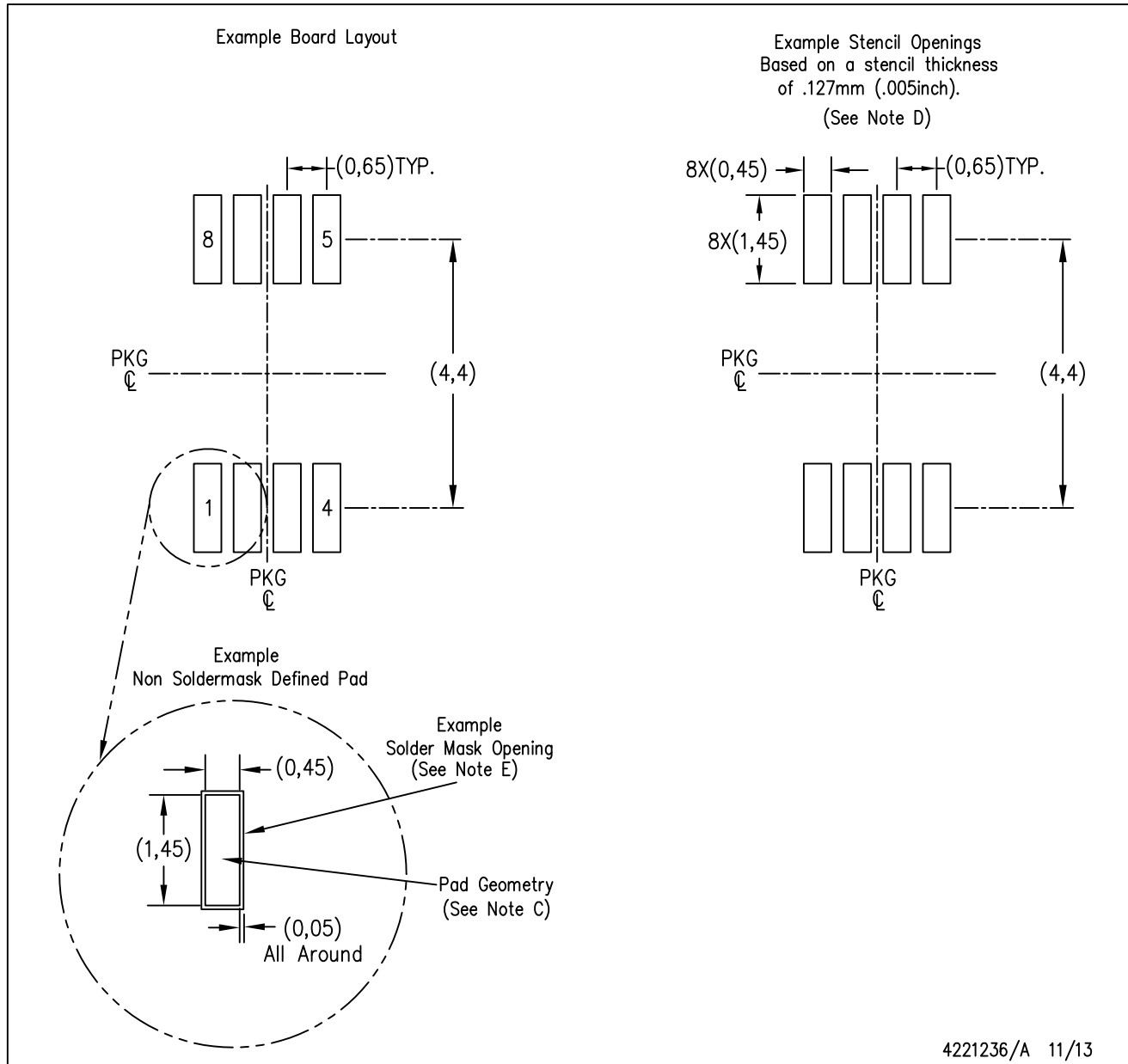


DGK (S-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE



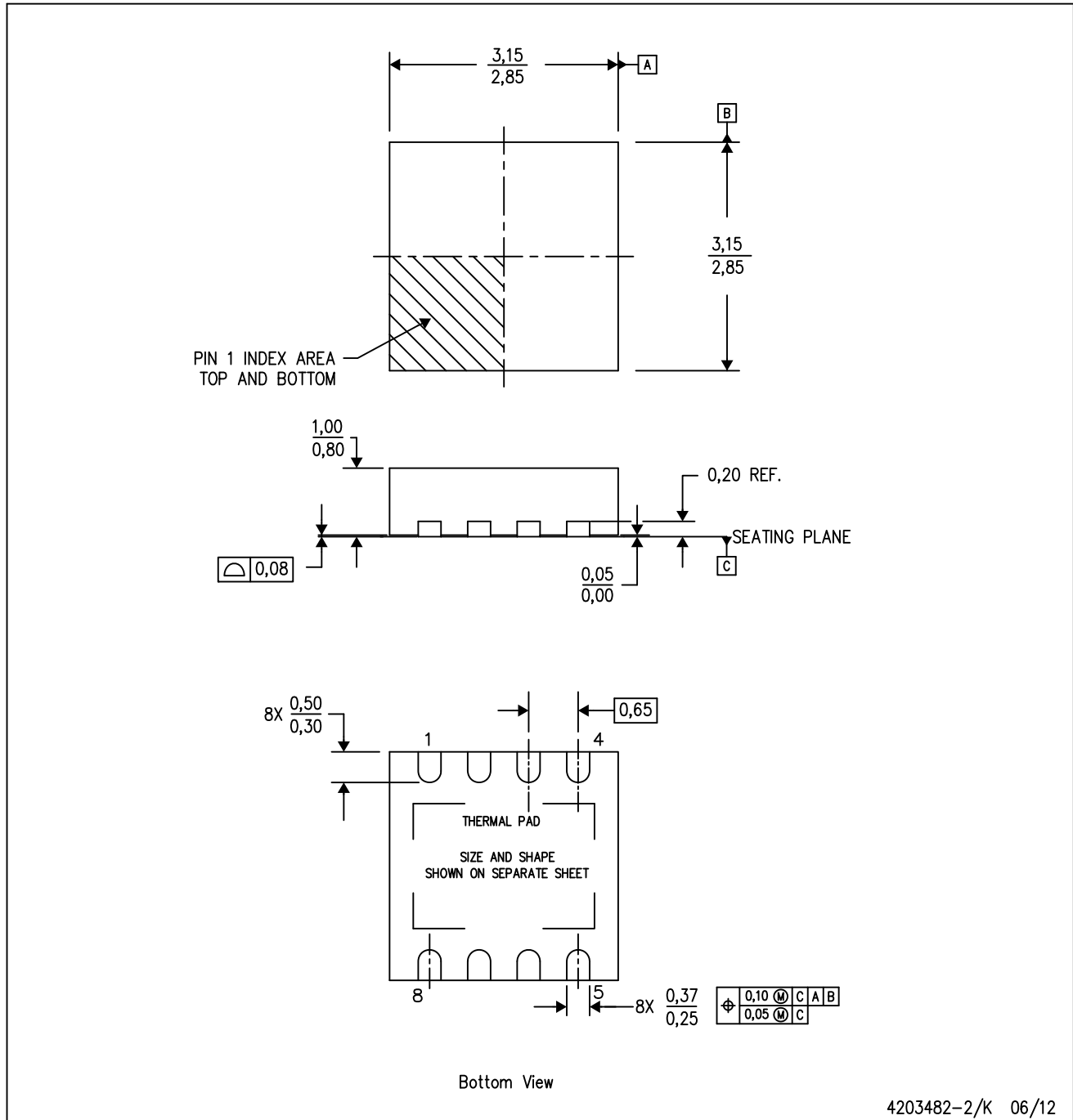
- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
  - D. Body width does not include interlead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



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. 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 other stencil recommendations.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DRB (S-PVSON-N8)

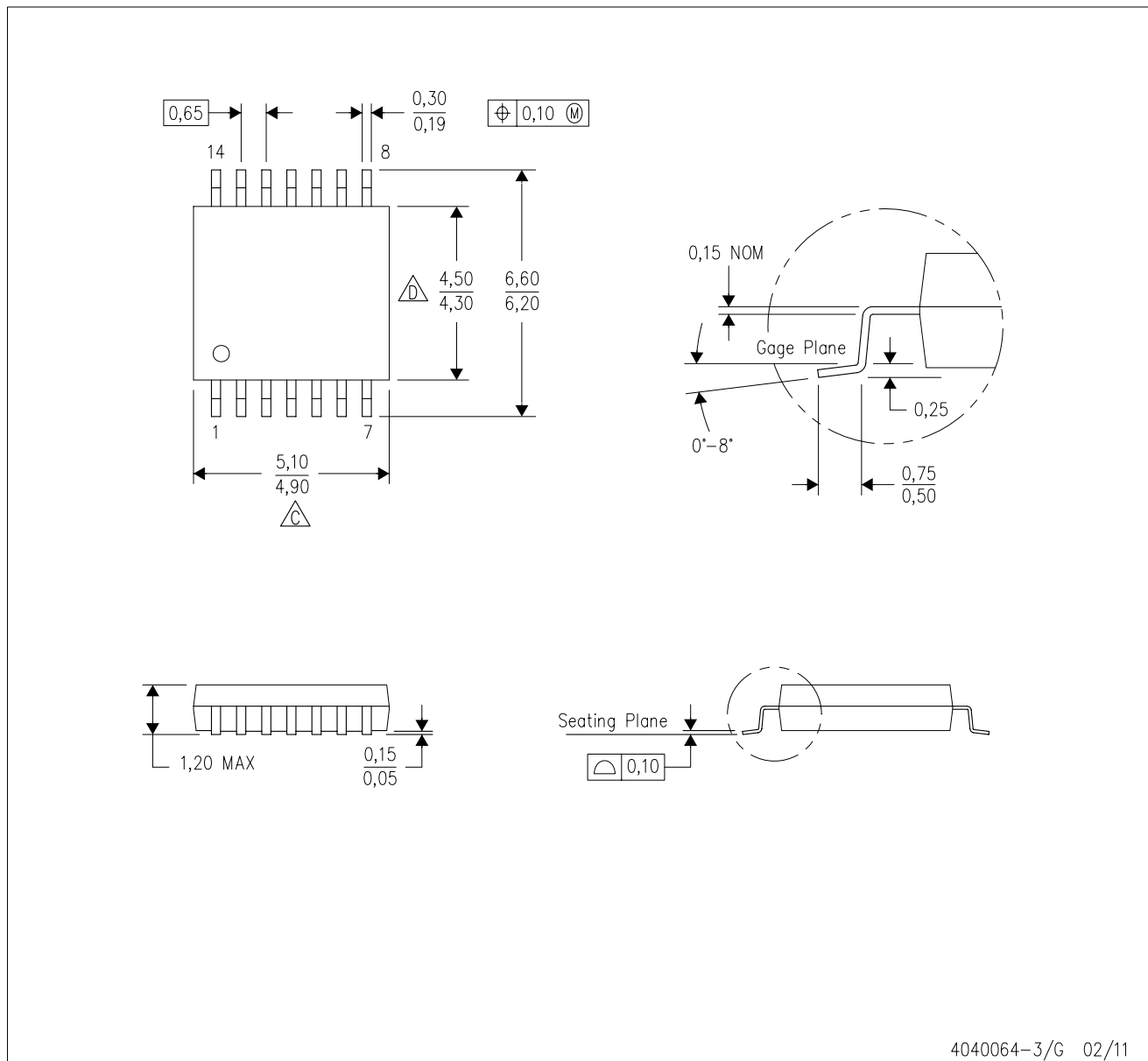
PLASTIC SMALL OUTLINE NO-LEAD



- NOTES:
- All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - This drawing is subject to change without notice.
  - Small Outline No-Lead (SON) package configuration.
  - The package thermal pad must be soldered to the board for thermal and mechanical performance.
  - See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.

PW (R-PDSO-G14)

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. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0,15 each side.
  - D. Body width does not include interlead flash. Interlead flash shall not exceed 0,25 each side.
  - E. Falls within JEDEC MO-153

PW (R-PDSO-G14)

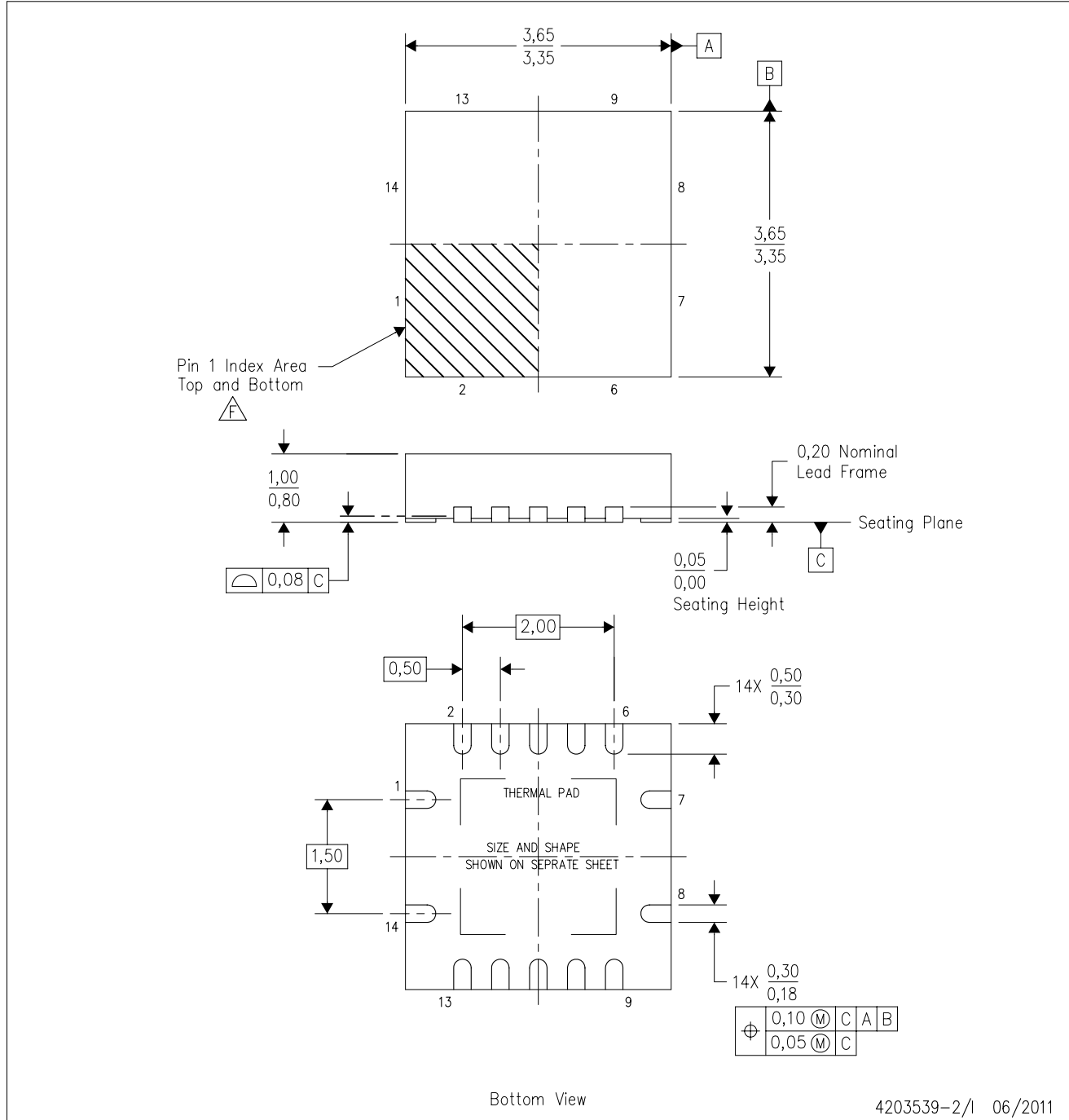
PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - 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 other stencil recommendations.
  - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

RGY (S-PVQFN-N14)

PLASTIC QUAD FLATPACK NO-LEAD



4203539-2/1 06/2011

- NOTES:
- All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M-1994.
  - This drawing is subject to change without notice.
  - QFN (Quad Flatpack No-Lead) package configuration.
  - The package thermal pad must be soldered to the board for thermal and mechanical performance.
  - See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
  - △ Pin 1 identifiers are located on both top and bottom of the package and within the zone indicated. The Pin 1 identifiers are either a molded, marked, or metal feature.
  - Package complies to JEDEC MO-241 variation BA.

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.
  - 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.
  - 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.

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



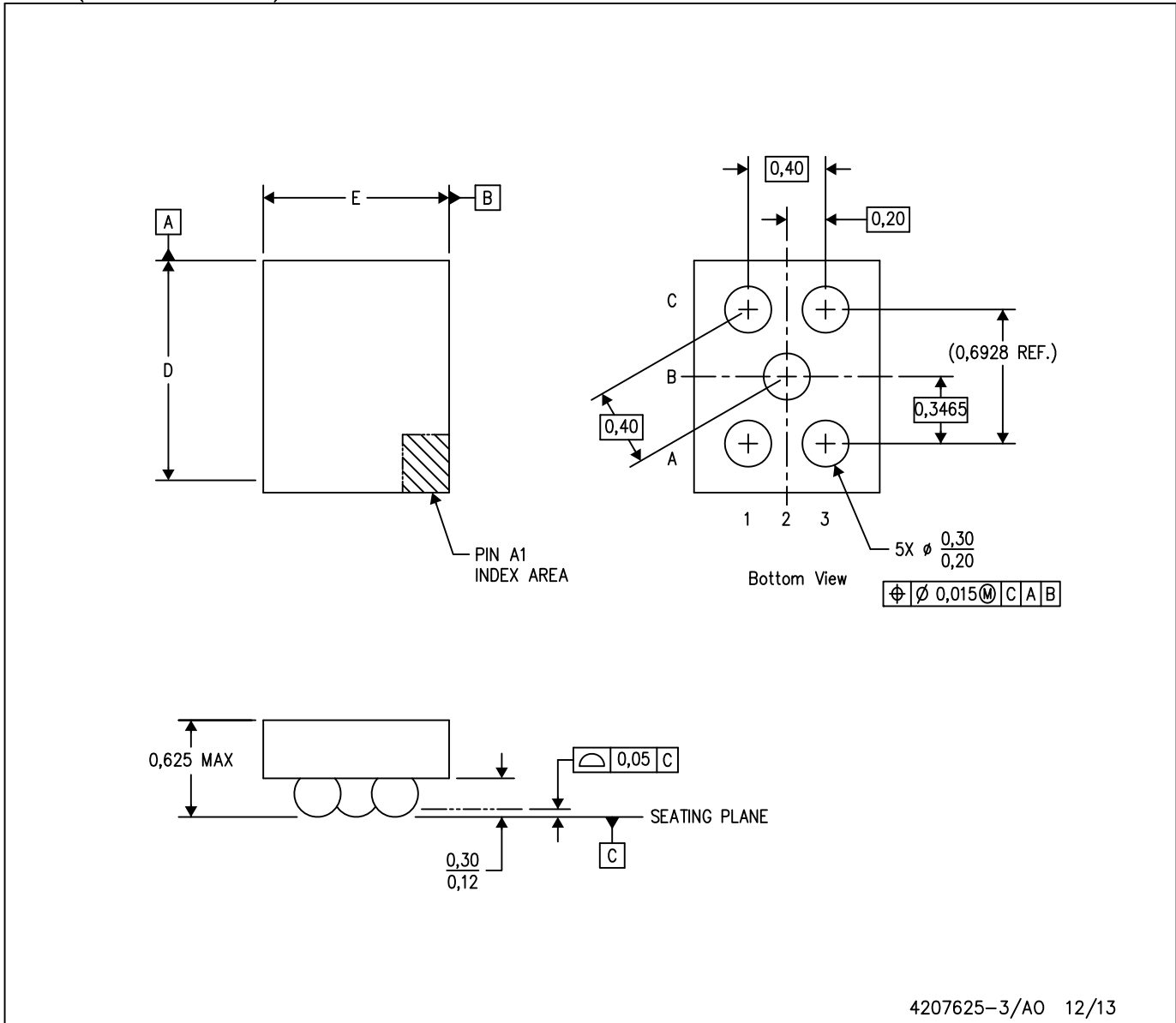
- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.



# MECHANICAL DATA

YFF (S-XBGA-N5)

DIE-SIZE BALL GRID ARRAY



- 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. NanoFree™ package configuration.

NanoFree is a trademark of Texas Instruments.

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In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
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