OPA2333P 1.8-V, *micro*Power, Zero-Drift Operational Amplifier

1 Features

- Low Offset Voltage: 10 μV (Maximum)
- Zero Drift: 0.05 μV/°C (Maximum)
- Specified Start-Up Time: 500 μs (Maximum)
- 0.01-Hz to 10-Hz Noise: 1.1 μV_{PP}
- Quiescent Current: 17 μA
- Single-Supply Operation
- Supply Voltage: 1.8 V to 5.5 V
- Rail-to-Rail Input/Output
- *micro*Size Package: 2-mm × 2-mm WSON

2 Applications

- Smartphones
- Wearables
- Fitness and Healthcare Products
- Electronic Scales
- Medical Instrumentation
- Battery-Powered Instruments
- Handheld Test Equipment
- Circuit Breakers

3 Description

The OPA2333P is a CMOS operational amplifier that uses a proprietary auto-calibration technique to simultaneously provide very low offset voltage (10 μV, maximum) and near-zero drift over time and temperature. This miniature, high-precision, low quiescent current amplifier offers high-impedance inputs that have a common-mode range 100 mV beyond the rails, and rail-to-rail output that swings within 50 mV of the rails. Single or dual supplies as low as 1.8 V (±0.9 V) and up to 5.5 V (±2.75 V) can be used. This device is optimized for low-voltage, single-supply operation.

The OPA2333P also features a specified maximum start-up time. Specified start-up time ensures high-precision performance after 500 μs of powering the amplifier, allowing for reliable use in dynamic supply operation.

The OPA2333P offers excellent CMRR without the crossover associated with traditional complementary input stages. This design results in superior performance for driving analog-to-digital converters (ADCs) without degradation of differential linearity.

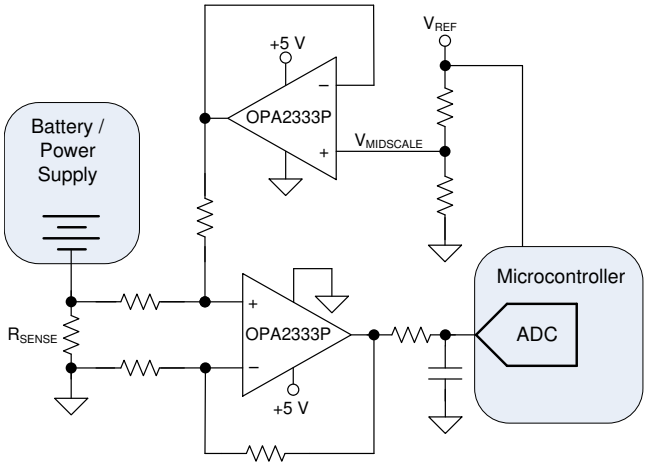
The OPA2333P is available in a 2-mm × 2-mm 8-pin WSON package and is specified for operation from –40°C to 125°C.

Device Information(1)

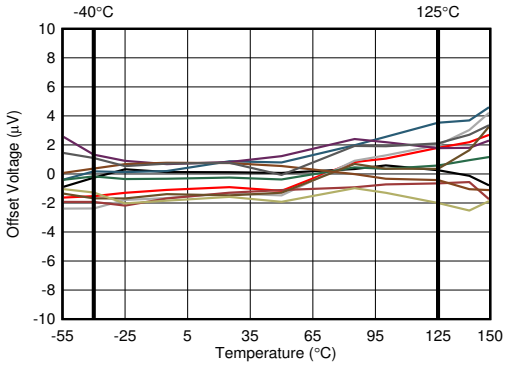
PART NUMBER	PACKAGE	BODY SIZE (NOM)
OPA2333P	WSON (8)	2.00 mm × 2.00 mm

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

Bidirectional, Low-Side Current Shunt Amplifier



Offset Voltage vs Temperature



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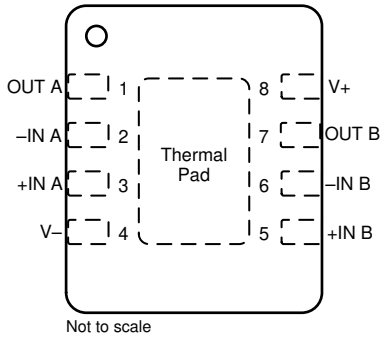
4 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (November 2017) to Revision A	Page
• Deleted "CMOS" from title and changed wording	1
• Added new paragraph 2 to *Description*	1
• Changed graphics on page 1	1
• Changed "DFN" to "DSG" Package	3
• Changed footnote reference for Common-mode and "0.5" V to "0.3" V in footnote 2	4
• Changed "10 mA" to "1 mA" in Abs Max footnotes 2 and 3	4
• Changed "-40" to "-55" in *Abs Max* MIN for T_A	4
• Changed "5" to "±5" in PSRR row of *Electrical Characteristics*	5
• Deleted "±400" from second row of I_B in *Electrical Characteristics*	5
• Changed "100" Hz to "10" Hz in i_N row of *Electrical Characteristics*	5
• Deleted second row for AOL in *Electrical Characteristics*	5
• Deleted "C_L = 100 pF" from Phase margin and Gain-bandwidth product rows of *Electrical Characteristics*	5
• Deleted "RL = 2 kohm" rows	5
• Deleted from OUTPUT subsection of *Electrical Characteristics*	5
• Deleted "±" from "5" in TYP column of ISC row in *Electrical Characteristics*	5
• Changed "Turnon" to "Start-up" in OUTPUT subsection of *Electrical Characteristics*	5
• Added "Quiescent Current Production Distribution" graph	6
• Changed "DFN" to "WSON"; "SON" to "DFN" in *WSON Package*	13
• Deleted "Single-Supply, Very Low Power, ECG Circuit" graphic	18
• Deleted "THS4281 Very Low-Power, High-Speed, Rail-to-Rail Input and Output Voltage-Feedback Operational Amplifier" from *Development Support*	21

5 Pin Configuration and Functions

DSG Package
8-Pin WSON With Exposed Thermal Pad
Top View



Not to scale

Pin Functions

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

6 Specifications

6.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)(1)

			MIN	MAX	UNIT
Supply voltage, V_S = (V+) - (V-)	Single-supply			7	V
	Dual-supply			±3.5	
Signal input pins	Voltage	Common-mode(2)	(V–) – 0.3	(V+) + 0.3	
		Differential(3)		±0.5	
	Current			±10	mA
Output short current(4)			Continuous		
Temperature	Operating, T_A		–55	150	°C
	Junction, T_J			150	
	Storage, T_{stg}		–65	150	

(1) Stresses beyond those listed under *Absolute Maximum Rating* 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 terminals 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 1 mA or less.
(3) Input terminals are anti-parallel diode-clamped to each other. Input signals that can cause differential voltages of swing more than ±0.5 V must be current-limited to 1 mA or less.
(4) Short-circuit to ground, one amplifier per package.

6.2 ESD Ratings

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

6.3 Recommended Operating Conditions

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

			MIN	NOM	MAX	UNIT
V_S	Supply voltage, [(V+) – (V–)]	Single supply	1.8		5.5	V
		Dual supply	±0.9		±2.75	
	Specified temperature		–40		125	°C

6.4 Thermal Information: OPA2333P

THERMAL METRIC(1)		OPA2333P DSG (WSON) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	74.5	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	93.5	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	41.1	°C/W
Ψ_{JT}	Junction-to-top characterization parameter	4.3	°C/W
Ψ_{JB}	Junction-to-board characterization parameter	41.2	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	15.7	°C/W

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

6.5 Electrical Characteristics

At T_A = 25°C, R_L= 10 kΩ connected to V_S / 2, V_{CM} = V_S / 2, and V_{OUT} = V_S / 2 (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
OFFSET VOLTAGE							
V_{OS}	Input offset voltage	V_S = 5 V			±2	±10	µV
dV_{OS}/dT	Input offset voltage drift	V_S = 5 V	T_A = –40°C to +125°C		0.02	±0.05	µV/°C
PSRR	Power-supply rejection ratio	1.8 V ≤ V_S ≤ 5.5 V	T_A = –40°C to +125°C		1	±5	µV/V
	Channel separation, dc				0.1		µV/V
INPUT BIAS CURRENT							
I_B	Input bias current				±70	±200	pA
		T_A = –40°C to +125°C			±150		pA
I_{OS}	Input offset current				±140	±400	pA
NOISE							
E_N	Input voltage noise	f = 0.1 Hz to 10 Hz, peak-to-peak			1.1		μV_{PP}
		f = 0.1 Hz to 10 Hz, RMS			0.2		μV_{RMS}
e_N	Input voltage noise density	f = 10 Hz			55		$nV/\sqrt{Hz}$
		f = 1 kHz			55		$nV/\sqrt{Hz}$
i_N	Input current noise density	f = 10 Hz			100		$fA/\sqrt{Hz}$
INPUT VOLTAGE							
V_{CM}	Common-mode voltage range			(V–) – 0.1		(V+) + 0.1	V
CMRR	Common-mode rejection ratio	(V–) – 0.1 V ≤ V_{CM} ≤ (V+) + 0.1 V, V_S = 5.5 V		106	130		dB
INPUT IMPEDANCE							
Z_{ID}	Differential				10^{13} || 2		Ω || pF
Z_{ICM}	Common-mode				10^{13} || 4		Ω || pF
OPEN-LOOP GAIN							
A_{OL}	Open-loop voltage gain	T_A = –40°C to +125°C	(V–) + 100 mV ≤ V_O ≤ (V+) – 100 mV, R_L = 10 kΩ	106	130		dB
FREQUENCY RESPONSE							
φ_m	Phase margin	V_O = 10 mV_{PP}			65		Degrees
GBW	Gain-bandwidth product	V_O = 10 mV_{PP}			350		kHz
SR	Slew rate	V_O = 4-V step	G = 1		0.16		V/µs
OUTPUT							
	Output voltage swing				30	50	mV
		T_A = –40°C to +125°C				70	mV
I_{SC}	Short-circuit current				±5		mA
C_L	Capactive load drive				See *Typical Characteristics*		
Z_O	Open-loop output impedance	f = 350 kHz, I_O = 0 mA			2		kΩ
	Start-up time	V_S = 5 V			100	500	µs
POWER SUPPLY							
V_S	Specified voltage			1.8		5.5	V
I_Q	Quiescent current (per amplifier)	I_O = 0 A			17	25	µA
			T_A = –40°C to +125°C			28	
TEMPERATURE RANGE							
T_A	Specified range			–40		125	°C
T_A	Operating range			–55		150	°C

6.6 Typical Characteristics

Table 1. List of Typical Characteristics

TITLE	FIGURE
Offset Voltage Production Distribution	Figure 1
Offset Voltage Drift Production Distribution	Figure 2
Quiescent Current Production Distribution	Figure 3
Open-Loop Gain vs Frequency	Figure 4
Common-Mode Rejection Ratio vs Frequency	Figure 5
Power-Supply Rejection Ratio vs Frequency	Figure 6
Output Voltage Swing vs Output Current	Figure 7
Input Bias Current vs Common-Mode Voltage	Figure 8
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Large-Signal Step Response	Figure 11
Small-Signal Step Response	Figure 12
Positive Overvoltage Recovery	Figure 13
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Settling Time vs Closed-Loop Gain	Figure 15
Small-Signal Overshoot vs Load Capacitance	Figure 16
0.1-Hz to 10-Hz Noise	Figure 17
Current and Voltage Noise Spectral Density vs Frequency	Figure 18

At T_A = 25°C, V_S = 5 V, and C_L = 0 pF, unless otherwise noted.

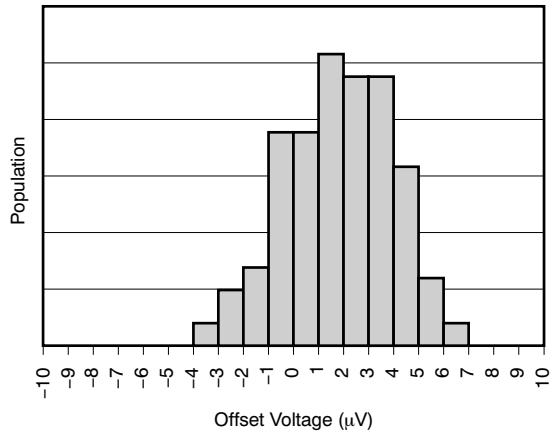


Figure 1. Offset Voltage Production Distribution

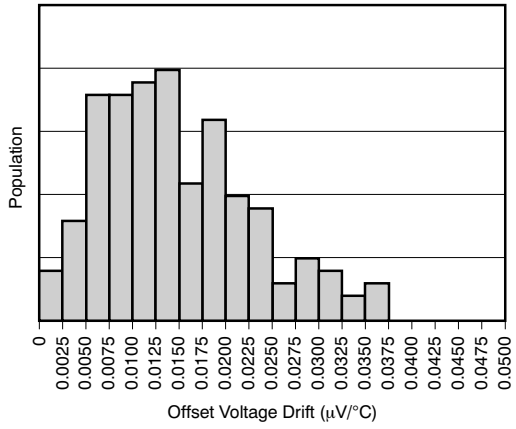


Figure 2. Offset Voltage Drift Production Distribution

At T_A = 25°C, V_S = 5 V, and C_L = 0 pF, unless otherwise noted.

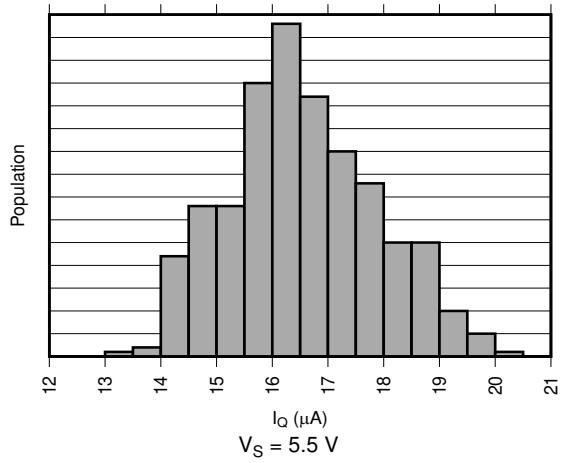


Figure 3. Quiescent Current Production Distribution

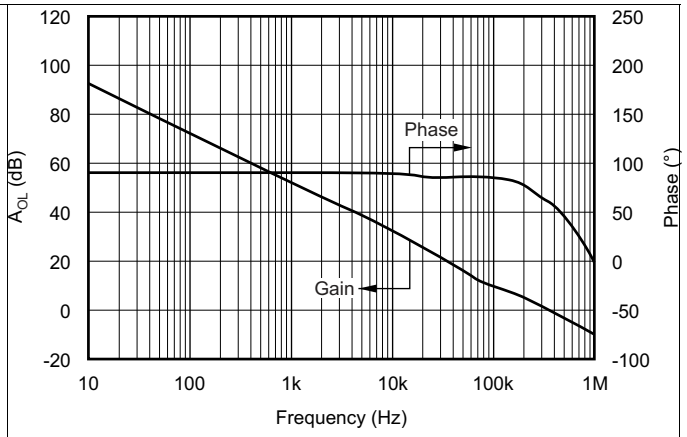


Figure 4. Open-Loop Gain and Phase vs Frequency

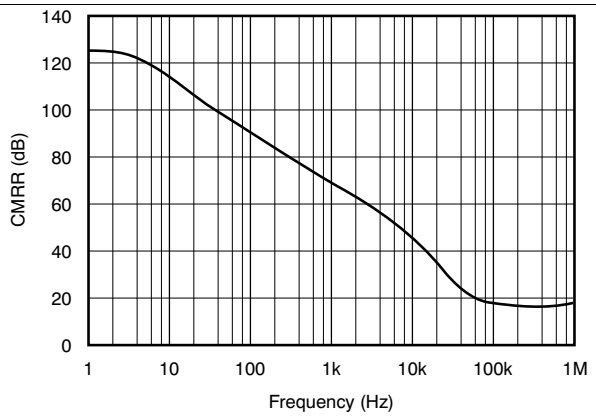


Figure 5. Common-Mode Rejection Ratio vs Frequency

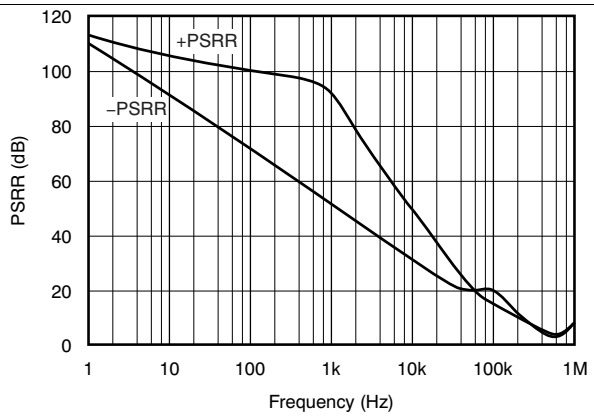


Figure 6. Power-Supply Rejection Ratio vs Frequency

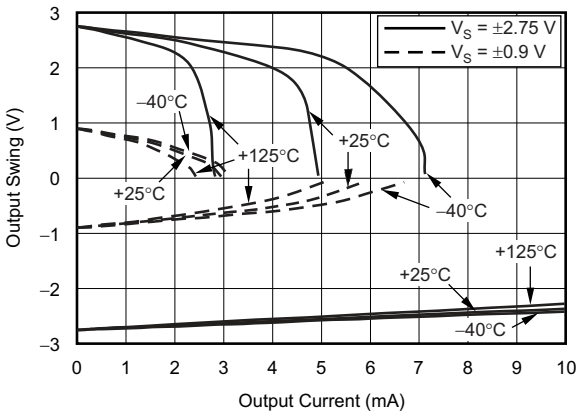


Figure 7. Output Voltage Swing vs Output Current

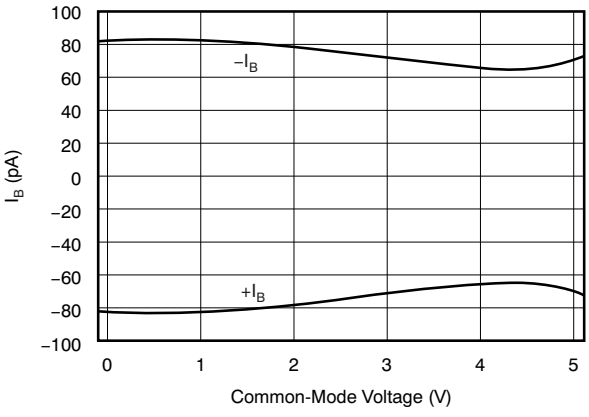


Figure 8. Input Bias Current vs Common-Mode Voltage

At T_A = 25°C, V_S = 5 V, and C_L = 0 pF, unless otherwise noted.

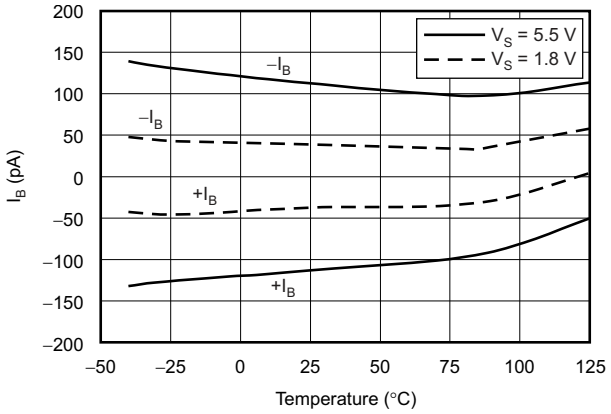


Figure 9. Input Bias Current vs Temperature

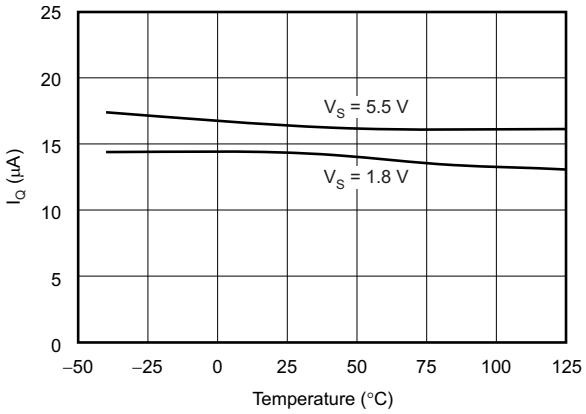


Figure 10. Quiescent Current vs Temperature

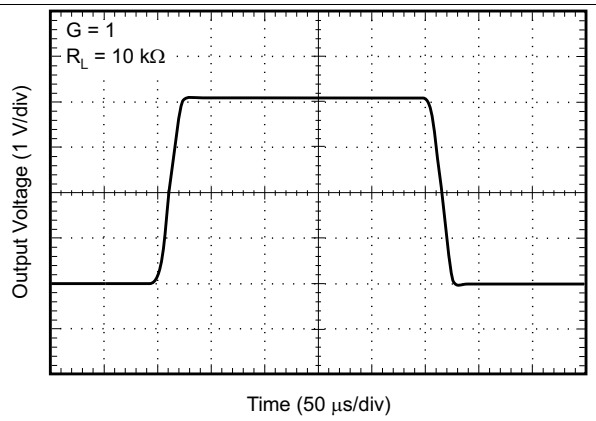


Figure 11. Large-Signal Step Response

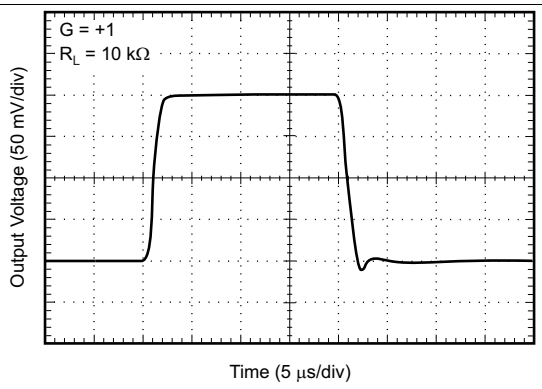


Figure 12. Small-Signal Step Response

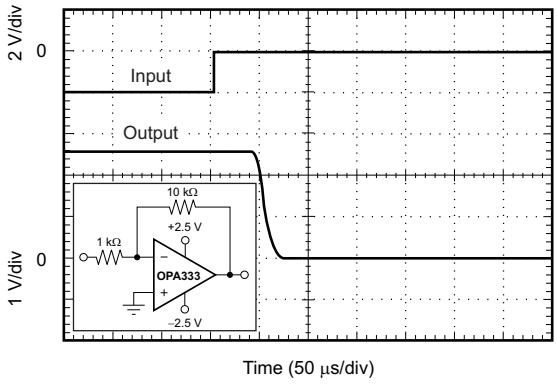


Figure 13. Positive Overvoltage Recovery

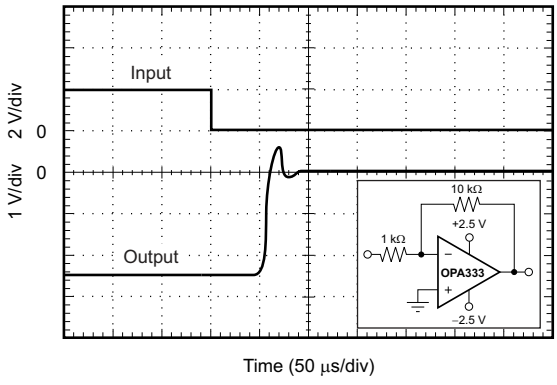


Figure 14. Negative Overvoltage Recovery

At T_A = 25°C, V_S = 5 V, and C_L = 0 pF, unless otherwise noted.

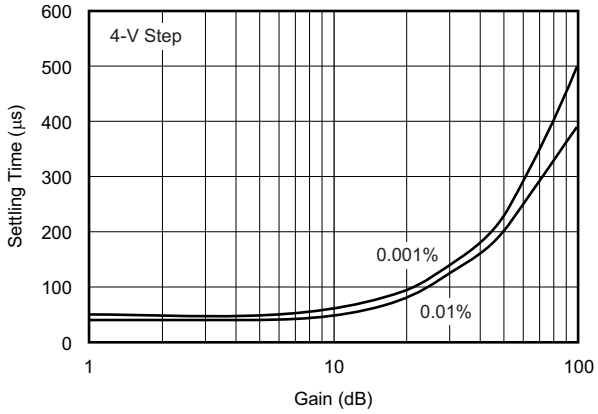


Figure 15. Settling Time vs Closed-Loop Gain

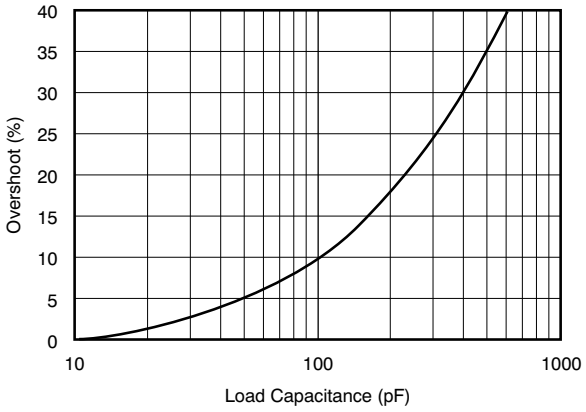


Figure 16. Small-Signal Overshoot vs Load Capacitance

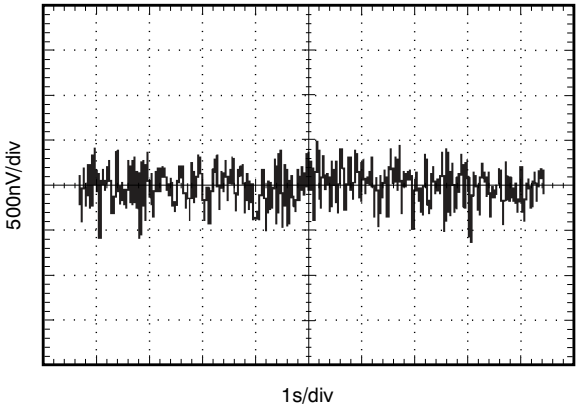


Figure 17. 0.1-Hz to 10-Hz Noise

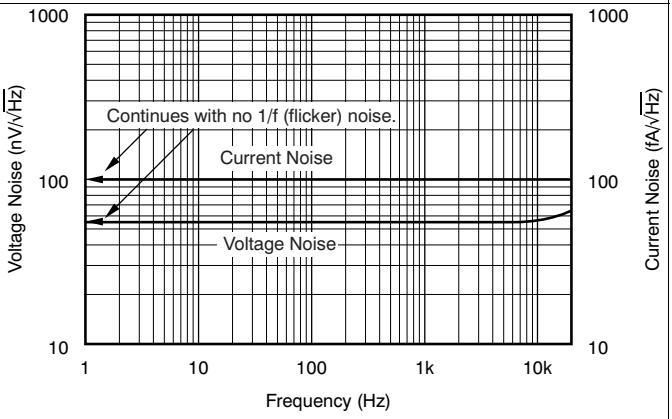


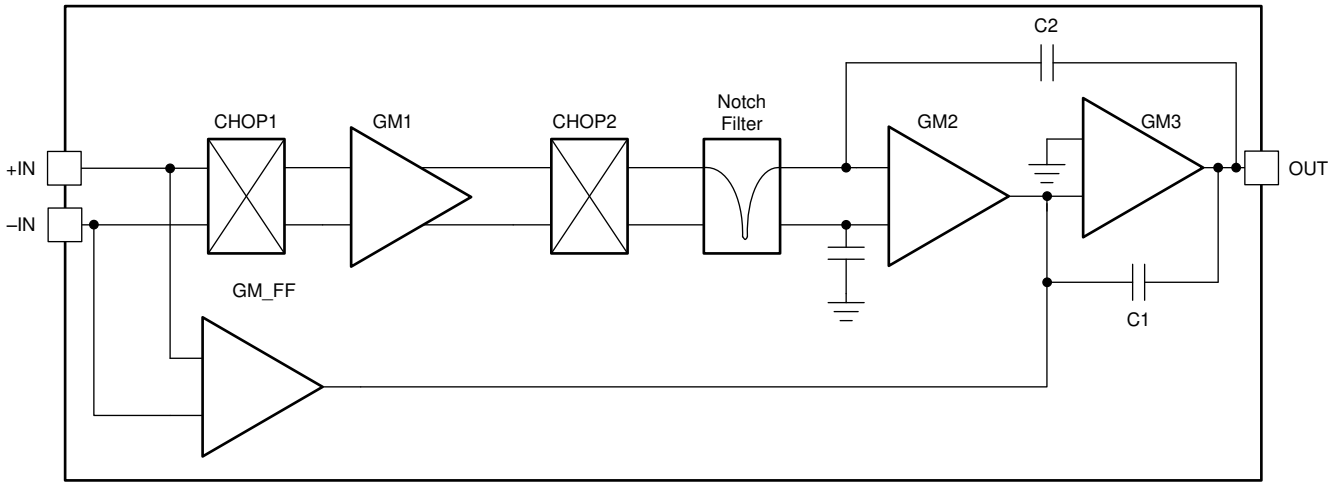
Figure 18. Current and Voltage Noise Spectral Density vs Frequency

7 Detailed Description

7.1 Overview

The OPA2333P is a Zero-Drift, low-power, rail-to-rail input and output operational amplifier. The device operates from 1.8 V to 5.5 V, is unity-gain stable, and is suitable for a wide range of general-purpose applications. The Zero-Drift architecture provides ultra-low offset voltage and near-zero offset voltage drift.

7.2 Functional Block Diagram



7.3 Feature Description

The OPA2333P is unity-gain stable and free from unexpected output phase reversal. This device uses a proprietary auto-calibration technique to provide low offset voltage and very low drift over time and temperature. For lowest offset voltage and precision performance, optimize circuit layout and mechanical conditions. Avoid temperature gradients that create thermoelectric (Seebeck) effects in the thermocouple junctions formed from connecting dissimilar conductors. Cancel these thermally-generated potentials 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 operational amplifier 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 μV/°C or higher, depending on materials used.

7.3.1 Operating Voltage

The OPA2333P operational amplifier operates over a power-supply range of 1.8 V to 5.5 V (±0.9 V to ±2.75 V). Parameters that vary over supply voltage or temperature are shown in the *Typical Characteristics* section.

CAUTION

Supply voltages higher than +7 V (absolute maximum) can permanently damage the device.

Feature Description (continued)

7.3.2 Input Voltage

The OPA2333P input common-mode voltage range extends 0.1 V beyond the supply rails. The OPA2333P 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 70 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 19.

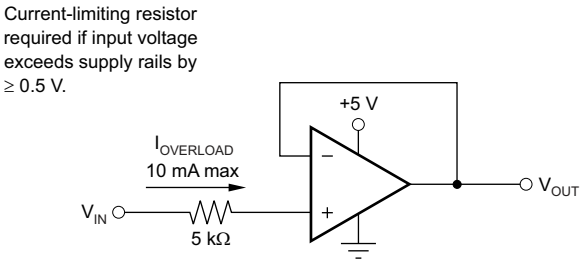


Figure 19. Input Current Protection

7.3.3 Internal Offset Correction

The OPA2333P operational amplifier uses an auto-calibration technique with a time-continuous 350-kHz operational amplifier in the signal path. This amplifier is zero-corrected every 8 μs using a proprietary technique. Upon power up, the amplifier requires approximately 100 μs to achieve specified V_{OS} accuracy. This design has no aliasing or flicker noise.

7.3.4 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 operational amplifiers, problems arise when the output signal approaches 0 V, near the lower output swing limit of a single-supply operational amplifier. A good, single-supply operational amplifier may swing close to single-supply ground, but does not reach ground. The output of the OPA2333P can be made to swing to, or slightly below, ground on a single-supply power source. This swing is achieved with the use of the use of another resistor and an additional, more negative power supply than the operational amplifier negative supply. A pulldown resistor can be connected between the output and the additional negative supply to pull the output down below the value that the output would otherwise achieve, as shown in Figure 20.

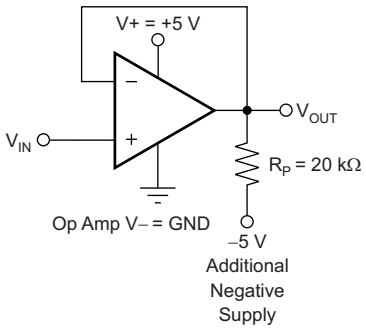


Figure 20. V_{OUT} Range to Ground

Feature Description (continued)

The OPA2333P has an output stage that allows the output voltage to be pulled to the negative supply rail, or slightly below, using the technique previously described. This technique only works with some types of output stages. The OPA2333P is characterized to perform with this technique; the recommended resistor value is approximately 20 kΩ.

NOTE

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 after the output is again driven above –2 mV. Lowering the resistance of the pulldown resistor allows the operational amplifier to swing even further below the negative rail. Resistances as low as 10 kΩ can be used to achieve excellent accuracy down to –10 mV.

7.3.5 Specified Start-Up Performance

The OPA2333P has a dedicated start-up circuit that ensures a fast, repeatable startup for all supply conditions. The OPA2333P is specified to have a maximum start-up time that is production-tested as illustrated in the configuration shown in Figure 21. Start-up time is defined as the time from when the power supply reaches the minimum specified voltage to the time the output has settled to within 20 mV of the nominal value. See Figure 22.

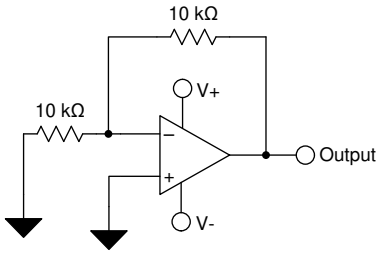


Figure 21. OPA2333P Equivalent Start-Up Test Configuration

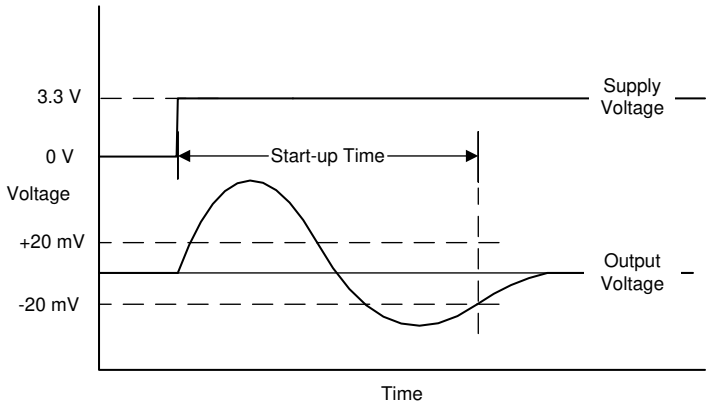


Figure 22. OPA2333P Start-Up Timing

Feature Description (continued)

7.3.6 WSON Package

The OPA2333P is offered in an WSON-8 package (also known as *DFN*). The WSON 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.

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

The WSON package can be easily mounted using standard PCB assembly techniques. See application reports *QFN/SON PCB Attachment* and *Quad Flatpack No-Lead Logic Packages*, both available for download at www.ti.com.

NOTE

The exposed leadframe die pad on the bottom of the package should be connected to V– or left unconnected.

7.4 Device Functional Modes

The OPA2333P device has a single functional mode. The device is powered on as long as the power supply voltage is between 1.8 V (±0.9 V) and 5.5 V (±2.75 V).

8 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.

8.1 Application Information

The OPA2333P is a unity-gain stable, precision operational amplifier with very low offset voltage drift; these devices are also free from output phase reversal. Applications with noisy or high-impedance power supplies require decoupling capacitors close to the device power-supply pins. In most cases, 0.1-μF capacitors are adequate.

8.2 Typical Application

8.2.1 Bidirectional Current-Sensing

This single-supply, low-side, bidirectional current-sensing solution detects load currents from –1 A to 1 A. The single-ended output spans from 110 mV to 3.19 V. This design uses the OPA2333P because of its low offset voltage and rail-to-rail input and output. One of the amplifiers is configured as a difference amplifier and the other provides the reference voltage.

Figure 23 shows the solution.

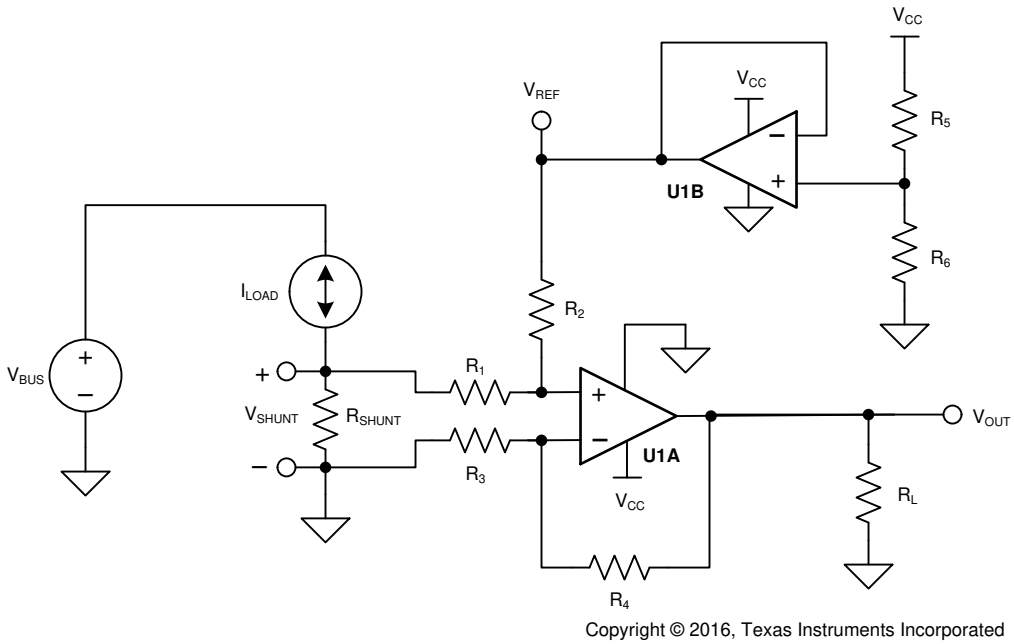


Figure 23. Bidirectional Current-Sensing Schematic

Typical Application (continued)

8.2.1.1 Design Requirements

This solution has the following requirements:

- Supply voltage: 3.3 V
- Input: –1 A to 1 A
- Output: 1.65 V ±1.54 V (110 mV to 3.19 V)

8.2.1.2 Detailed Design Procedure

The load current, I_{LOAD}, flows through the shunt resistor (R_{SHUNT}) to develop the shunt voltage, V_{SHUNT}. The shunt voltage is then amplified by the difference amplifier, which consists of U1A and R_1 through R_4. The gain of the difference amplifier is set by the ratio of R_4 to R_3. To minimize errors, set $R_2 = R_4$ and $R_1 = R_3$. The reference voltage, V_{REF}, is supplied by buffering a resistor divider using U1B. The transfer function is given by Equation 1.

$$V_{OUT} = V_{SHUNT} \times Gain_{Diff\_Amp} + V_{REF}$$

where

- $V_{SHUNT} = I_{LOAD} \times R_{SHUNT}$
- $Gain_{Diff\_Amp} = \frac{R_4}{R_3}$
- $V_{REF} = V_{CC} \times \left(\frac{R_6}{R_5 + R_6} \right)$

(1)

There are two types of errors in this design: offset and gain. Gain errors are introduced by the tolerance of the shunt resistor and the ratios of R_4 to R_3 and, similarly, R_2 to R_1. Offset errors are introduced by the voltage divider (R_5 and R_6) and how closely the ratio of R_4/R_3 matches R_2/R_1. The latter value impacts the CMRR of the difference amplifier, which ultimately translates to an offset error.

Because this is a low-side measurement, the value of V_{SHUNT} is the ground potential for the system load. Therefore, it is important to place a maximum value on V_{SHUNT}. In this design, the maximum value for V_{SHUNT} is set to 100 mV. Equation 2 calculates the maximum value of the shunt resistor given a maximum shunt voltage of 100 mV and maximum load current of 1 A.

$$R_{SHUNT(Max)} = \frac{V_{SHUNT(Max)}}{I_{LOAD(Max)}} = \frac{100\ mV}{1\ A} = 100\ m\Omega \quad (2)$$

The tolerance of R_{SHUNT} is directly proportional to cost. For this design, a shunt resistor with a tolerance of 0.5% was selected. If greater accuracy is required, select a 0.1% resistor or better.

The load current is bidirectional; therefore, the shunt voltage range is –100 mV to 100 mV. This voltage is divided down by R_1 and R_2 before reaching the operational amplifier, U1A. Take care to ensure that the voltage present at the noninverting node of U1A is within the common-mode range of the device. Therefore, it is important to use an operational amplifier, such as the OPA2333P, that has a common-mode range that extends below the negative supply voltage. Finally, to minimize offset error, note that the OPA2333P has a typical offset voltage of ±2 µV (±10 µV maximum).

Given a symmetric load current of –1 A to 1 A, the voltage divider resistors (R_5 and R_6) must be equal. To be consistent with the shunt resistor, a tolerance of 0.5% was selected. To minimize power consumption, 10-kΩ resistors were used.

To set the gain of the difference amplifier, the common-mode range and output swing of the OPA2333P must be considered. Equation 3 and Equation 4 depict the typical common-mode range and maximum output swing, respectively, of the OPA2333P given a 3.3-V supply.

$$-100\ mV < V_{CM} < 3.4\ V \quad (3)$$

$$100\ mV < V_{OUT} < 3.2\ V \quad (4)$$

The gain of the difference amplifier can now be calculated as shown in Equation 5.

$$Gain_{Diff\_Amp} = \frac{V_{OUT\_Max} - V_{OUT\_Min}}{R_{SHUNT} \times (I_{MAX} - I_{MIN})} = \frac{3.2\ V - 100\ mV}{100\ m\Omega \times [1\ A - (-1A)]} = 15.5\ \frac{V}{V} \quad (5)$$

Typical Application (continued)

The resistor value selected for R_1 and R_3 was 1 kΩ. 15.4 kΩ was selected for R_2 and R_4 because it is the nearest standard value. Therefore, the ideal gain of the difference amplifier is 15.4 V/V.

The gain error of the circuit primarily depends on R_1 through R_4. As a result of this dependence, 0.1% resistors were selected. This configuration reduces the likelihood that the design requires a two-point calibration. A simple one-point calibration, if desired, removes the offset errors introduced by the 0.5% resistors.

8.2.1.3 Application Curve

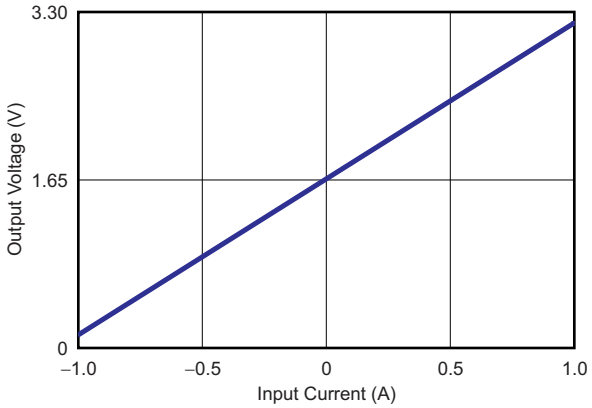


Figure 24. Bidirectional Current-Sensing Circuit Performance: Output Voltage vs Input Current

8.2.2 High-Side Voltage-to-Current (V-I) Converter

The circuit shown in Figure 25 is a high-side voltage-to-current (V-I) converter. It translates to an input voltage of 0 V to 2 V and output current of 0 mA to 100 mA. Figure 26 shows the measured transfer function for this circuit. The low offset voltage and offset drift of the OPA2333P facilitate excellent dc accuracy for the circuit.

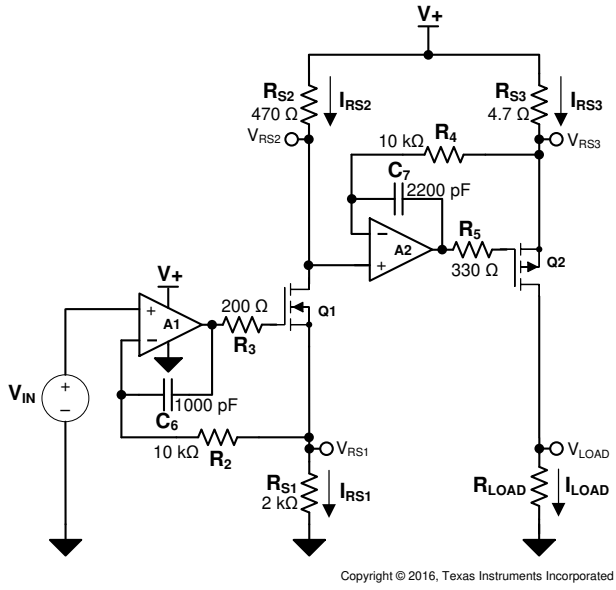


Figure 25. High-Side Voltage-to-Current (V-I) Converter

Typical Application (continued)

8.2.2.1 Design Requirements

The design requirements are as follows:

- Supply Voltage: 5 V DC
- Input: 0 V to 2 V DC
- Output: 0 mA to 100 mA DC

8.2.2.2 Detailed Design Procedure

The V-I transfer function of the circuit is based on the relationship between the input voltage, V_{IN}, and the three current sensing resistors, R_{S1}, R_{S2}, and R_{S3}. The relationship between V_{IN} and R_{S1} determines the current that flows through the first stage of the design. The current gain from the first stage to the second stage is based on the relationship between R_{S2} and R_{S3}.

For a successful design, pay close attention to the dc characteristics of the operational amplifier chosen for the application. To meet the performance goals, this application benefits from an operational amplifier with low offset voltage, low temperature drift, and rail-to-rail output. The OPA2333P CMOS operational amplifier is a high-precision, 2-uV offset, 0.02-μV/°C drift amplifier optimized for low-voltage, single-supply operation with an output swing to within 50 mV of the positive rail. The OPA2333P family uses chopping techniques to provide low initial offset voltage and near-zero drift over time and temperature. Low offset voltage and low drift reduce the offset error in the system, making these devices appropriate for precise dc control. The rail-to-rail output stage of the OPA2333P ensures that the output swing of the operational amplifier is able to fully control the gate of the MOSFET devices within the supply rails.

A detailed error analysis, design procedure, and additional measured results are given in TIPD102.

8.2.2.3 Application Curve

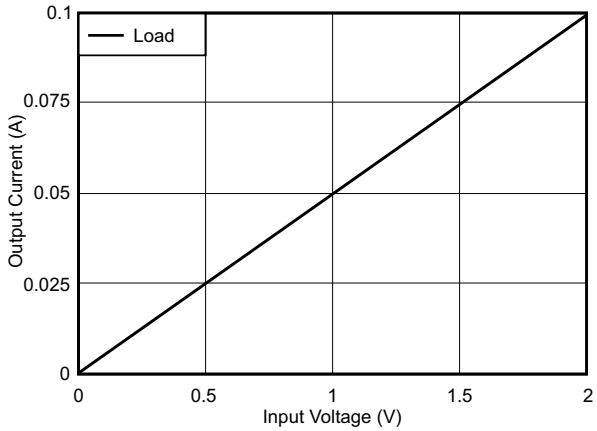
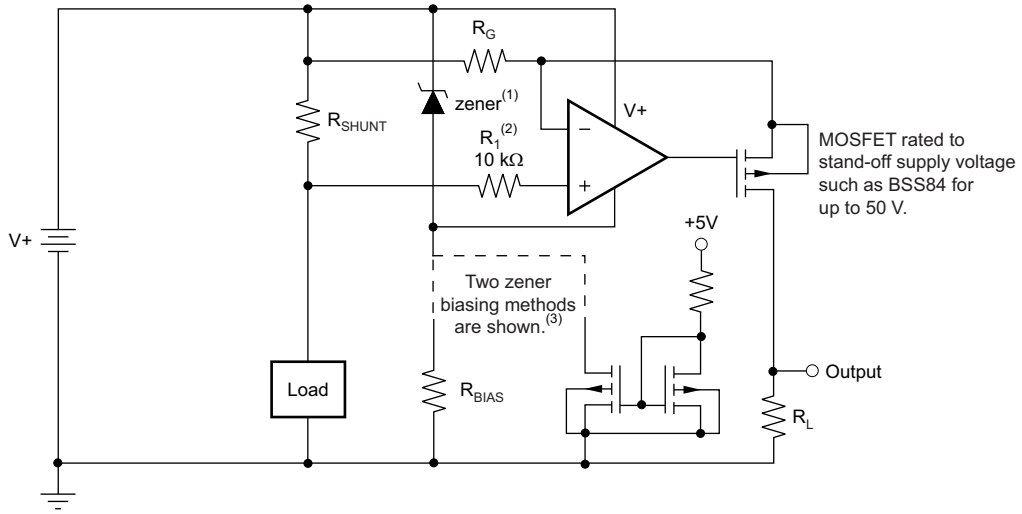


Figure 26. Measured Transfer Function for High-Side V-I Converter

Typical Application (continued)

8.2.3 Other Applications

Additional application ideas are shown in Figure 27 and Figure 28.



(1) Zener rated for op amp supply capability (that is, 5.1 V for OPA2333P).

(2) Current-limiting resistor.

(3) Choose zener biasing resistor or dual N-MOSFETs (FDG6301N, NTJD4001N, or Si1034).

Figure 27. High-Side Current Monitor

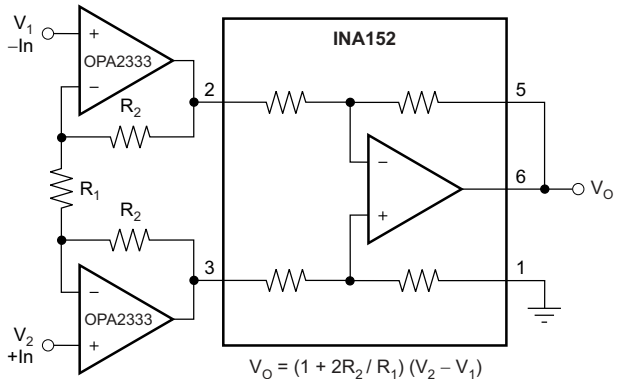


Figure 28. Precision Instrumentation Amplifier

9 Power Supply Recommendations

The OPA2333P is specified for operation from 1.8 V to 5.5 V (±0.9 V to ±2.75 V); many specifications apply from –40°C to 125°C. The *Typical Characteristics* 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 *Absolute Maximum Ratings*).

TI recommends placing 0.1-μF 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, refer to the *Layout* section.

10 Layout

10.1 Layout Guidelines

10.1.1 General Layout Guidelines

Pay attention to good layout practices. Keep traces short and when possible and 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-μF capacitor closely across the supply pins. Apply these guidelines throughout the analog circuit to improve performance and provide benefits, such as reducing the electromagnetic interference (EMI) susceptibility.

Operational amplifiers vary in susceptibility to radio frequency interference (RFI). RFI can generally be identified as a variation in offset voltage or DC signal levels with changes in the interfering RF signal. The OPA2333P is specifically designed to minimize susceptibility to RFI and demonstrates remarkably low sensitivity compared to previous generation devices. Strong RF fields may still cause varying offset levels.

10.1.2 WSON (DFN) Layout Guidelines

Solder the exposed leadframe die pad on the WSON package 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.

10.2 Layout Example

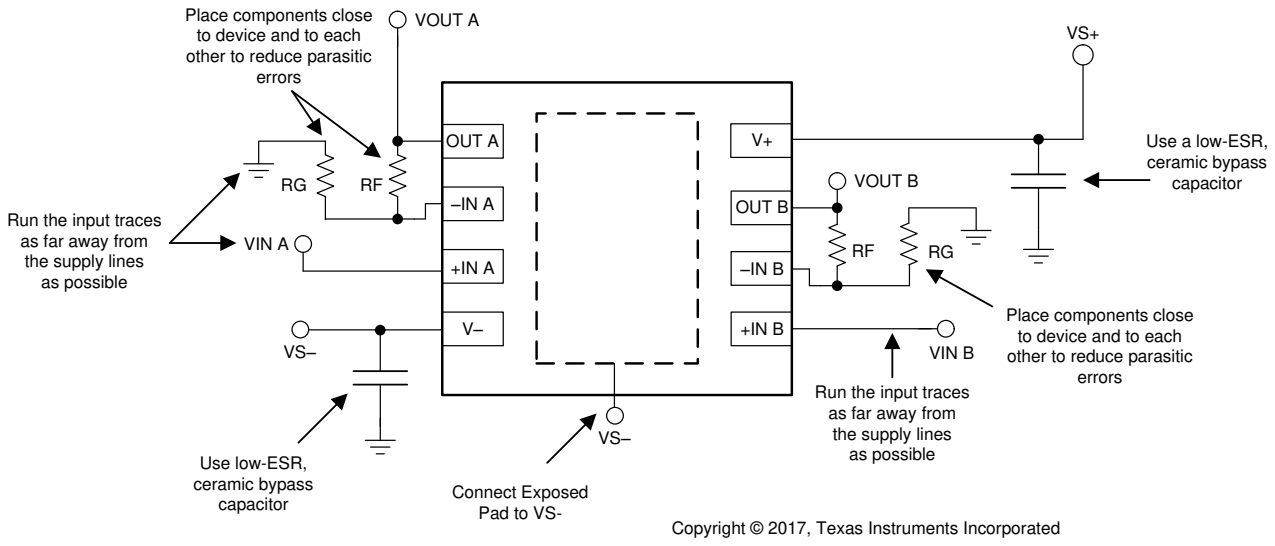


Figure 29. Layout Example

11 Device and Documentation Support

11.1 Device Support

11.1.1 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*
- *Low-Level V-to-I Converter Reference Design, 0-V to 5-V Input to 0-µA to 5-µA Output*
- *ADS8881x 18-Bit, 1-MSPS, Serial Interface, microPower, Miniature, True-Differential Input, SAR Analog-to-Digital Converter*
- *Data Acquisition Optimized for Lowest Distortion, Lowest Noise, 18-bit, 1-MSPS Reference Design*
- *ADS1100 Self-Calibrating, 16-Bit Analog-to-Digital Converter*
- *REF31xx 15ppm/°C Maximum, 100-µA, SOT-23 Series Voltage Reference*
- *INA326, INA327 Precision, Low Drift, CMOS Instrumentation Amplifier*

11.2 Documentation Support

11.2.1 Related Documentation

For related documentation, see the following:

- *QFN/SON PCB Attachment*
- *Zero-drift Amplifiers: Features and Benefits*

11.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. In the upper right corner, click on *Alert me* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

11.4 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.

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

11.5 Trademarks

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11.6 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.

11.7 Glossary

SLYZ022 — *TI Glossary*.

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

12 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 finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
OPA2333PIDSGR	ACTIVE	WSON	DSG	8	3000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	-40 to 125	1GFY	Samples
OPA2333PIDSGT	ACTIVE	WSON	DSG	8	250	RoHS & Green	NIPDAU	Level-1-260C-UNLIM	-40 to 125	1GFY	Samples

(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) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".
RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.
Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

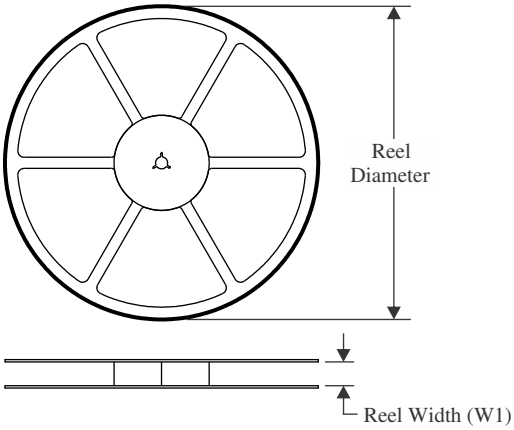
(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(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.

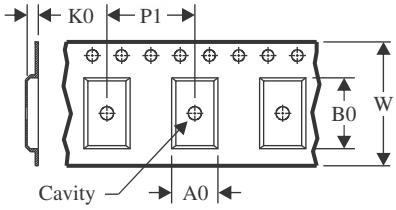
(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

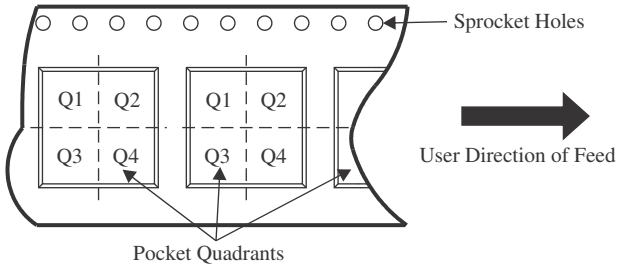


TAPE DIMENSIONS



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

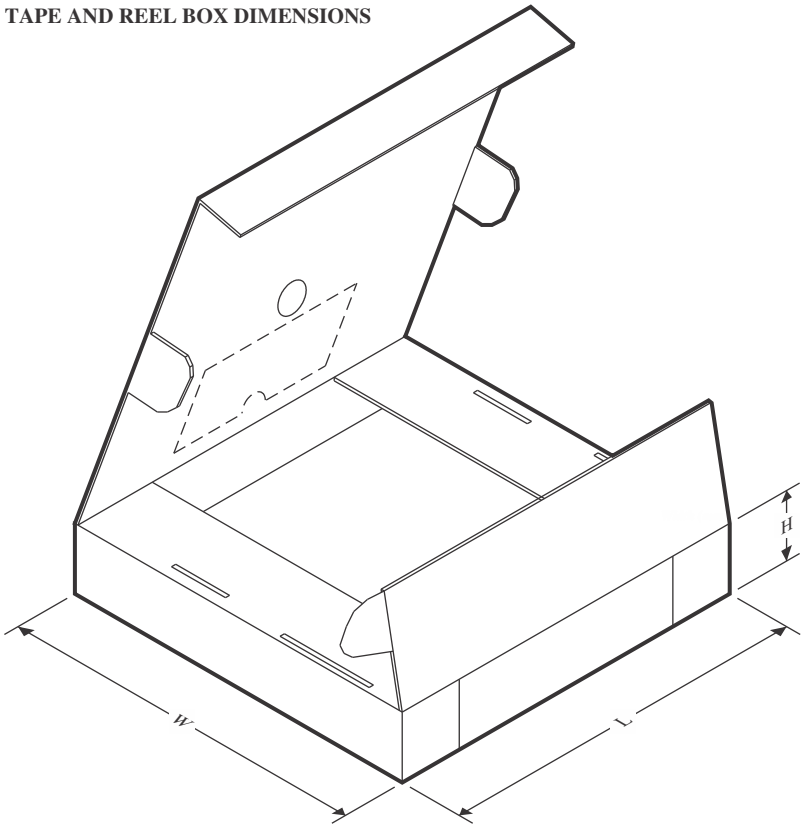
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
OPA2333PIDSGR	WSON	DSG	8	3000	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2
OPA2333PIDSGT	WSON	DSG	8	250	180.0	8.4	2.3	2.3	1.15	4.0	8.0	Q2

TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2333PIDSGR	WSON	DSG	8	3000	210.0	185.0	35.0
OPA2333PIDSGT	WSON	DSG	8	250	210.0	185.0	35.0

GENERIC PACKAGE VIEW

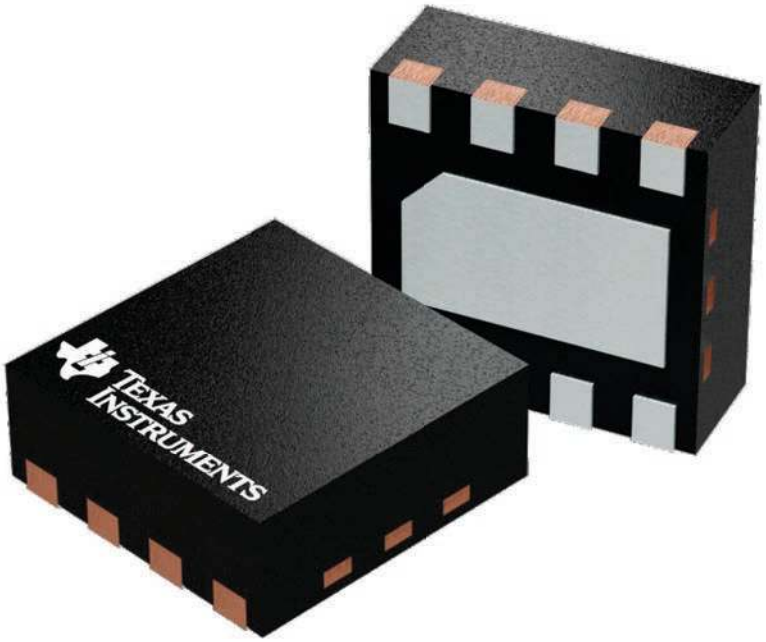
DSG 8

WSON - 0.8 mm max height

2 x 2, 0.5 mm pitch

PLASTIC SMALL OUTLINE - NO LEAD

This image is a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.



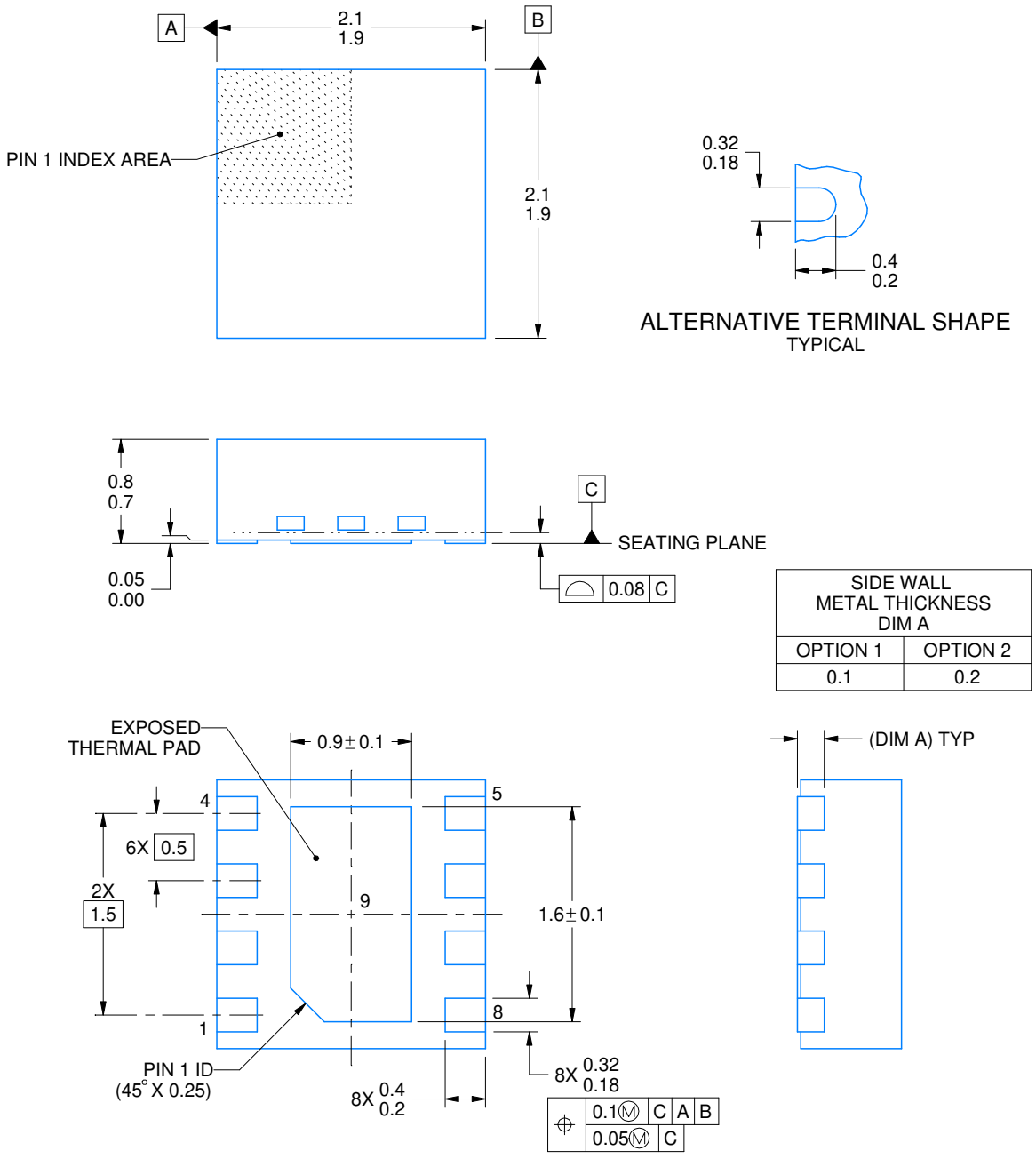
4224783/A

PACKAGE OUTLINE

DSG0008A

WSON - 0.8 mm max height

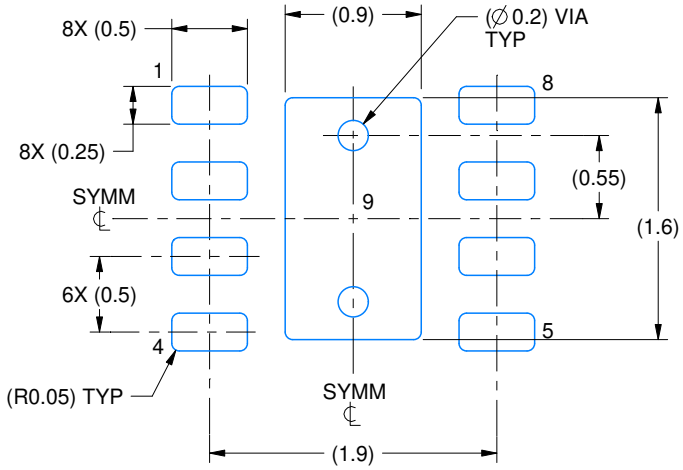
PLASTIC SMALL OUTLINE - NO LEAD



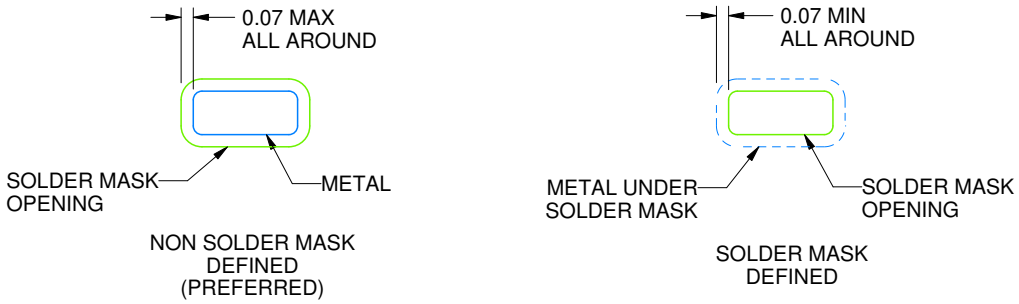
4218900/E 08/2022

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.



LAND PATTERN EXAMPLE
SCALE:20X



SOLDER MASK DETAILS

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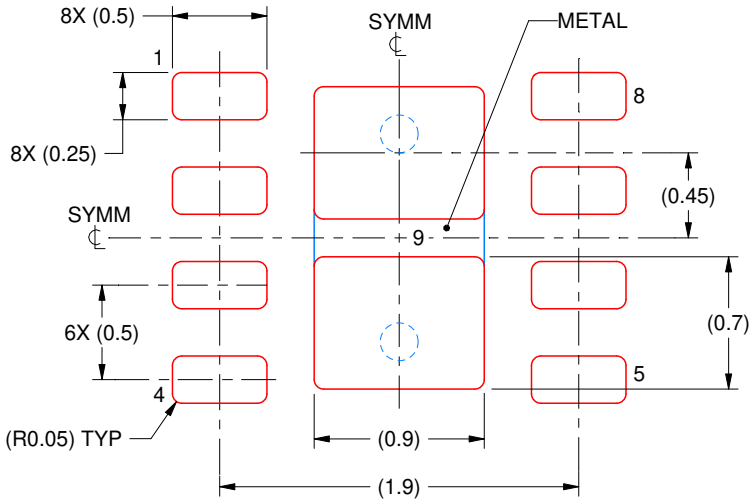
NOTES: (continued)

4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 (www.ti.com/lit/slua271).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD 9:
87% PRINTED SOLDER COVERAGE BY AREA UNDER PACKAGE
SCALE:25X

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NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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