OPAx365 50-MHz, Zerø-Crossover, Low-Distortion, High-CMRR, RRI/O, Single-Supply Operational Amplifiers

1 Features

- Gain bandwidth: 50 MHz
- Zerø-crossover distortion topology:
  - Excellent THD+N: 0.0004%
  - CMRR: 100 dB (minimum)
  - Rail-to-rail input and output
    - Input 100 mV beyond supply rail
- Low noise: 4.5 nV/√Hz at 100 kHz
- Slew rate: 25 V/µs
- Fast settling: 0.3 µs to 0.01%
- Precision:
  - Low offset: 100 µV
  - Low input bias current: 0.2 pA
- 2.2-V to 5.5-V operation

2 Applications

- Signal conditioning
- Data acquisition
- Process control
- Active filters
- Test equipment
- Audio
- Wideband amplifiers

3 Description

The OPA365 and OPA2365 (OPAx365) zerø-crossover series, rail-to-rail, high-performance, CMOS operational amplifiers are optimized for very low voltage, single-supply applications. Rail-to-rail input or output, low-noise (4.5 nV/√Hz), and high-speed operation (50-MHz gain bandwidth) make these devices an excellent choice for driving sampling analog-to-digital converters (ADCs). Applications include audio, signal conditioning, and sensor amplification.

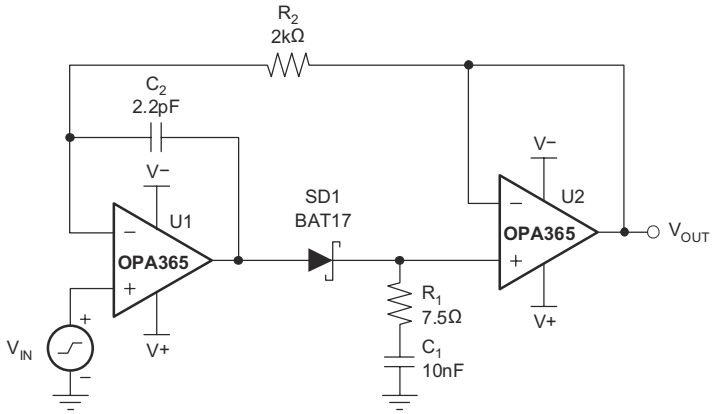
Special features include an excellent common-mode rejection ratio (CMRR), no input stage crossover distortion, high input impedance, and rail-to-rail input and output swing. The input common-mode range includes both the negative and positive supplies. The output voltage swing is within 10 mV of the rails.

The OPA365 (single version) is available in the micro-size SOT23-5 (SOT-5) and SOIC-8 packages. The OPA2365 (dual version) is offered in the SOIC-8 package. All versions are specified for operation from −40°C to +125°C. Single and dual versions have identical specifications for maximum design flexibility.

Device Information

PART NUMBER	CHANNEL COUNT	PACKAGE(1)
OPA365	Single	D (SOIC, 8)
		DBV (SOT-23, 5)
OPA2365	Dual	D (SOIC, 8)

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



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Fast-Settling Peak Detector

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4 Revision History

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

Changes from Revision F (April 2020) to Revision G (May 2023)	Page
• Updated the numbering format for tables, figures, and cross-references throughout the document	1
• Added new row for TLVx365 in *Device Comparison Table*	3

Changes from Revision E (August 2016) to Revision F (April 2020)	Page
• Added *Device Comparison Table*	3

Changes from Revision D (June 2009) to Revision E (August 2016)	Page
• Added *ESD Ratings* table, *Feature Description* section, *Device Functional Modes*, *Application and Implementation* section, *Power Supply Recommendations* section, *Layout* section, *Device and Documentation Support* section, and *Mechanical, Packaging, and Orderable Information* section	1
• Added current package designators to last paragraph of *Description* section	1

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5 Device Comparison Table

DEVICE	INPUT TYPE	OFFSET DRIFT, TYPICAL (µV/ºC)	MINIMUM GAIN STABLE	I_Q/CHANNEL, TYPICAL (mA)	GAIN BANDWIDTH (MHz)	SLEW RATE (V/µs)	VOLTAGE NOISE (nV/√Hz)
OPAx365	CMOS	1	1 V/V	4.6	50	25	4.5
TLVx365	CMOS	0.4	1 V/V	4.6	50	27	4.5
OPAx607	CMOS	0.3	6 V/V	0.9	50	24	3.8
OPAx837	Bipolar	0.4	1 V/V	0.6	50	105	4.7

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6 Pin Configuration and Functions

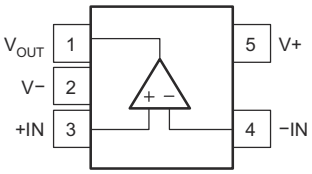
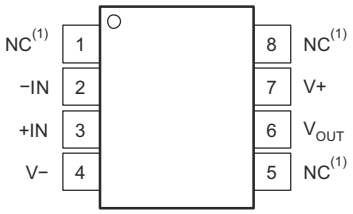


Figure 6-1. OPA365: DBV Package, 5-Pin SOT-23 (Top View)



(1) NC denotes no internal connection.

Figure 6-2. OPA365: D Package, 8-Pin SOIC (Top View)

Pin Functions: OPA365

PIN			TYPE	DESCRIPTION
NAME	SOIC	SOT		
–IN	2	4	Input	Negative (inverting) input
+IN	3	3	Input	Positive (noninverting) input
NC	1, 5, 8	—	—	No internal connection (can be left floating)
V–	4	2	—	Negative (lowest) power supply
V+	7	5	—	Positive (highest) power supply
V_{OUT}	6	1	Output	Output

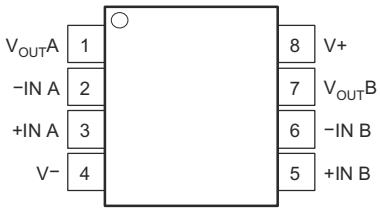


Figure 6-3. OPA2365: D Package, 8-Pin SOIC (Top View)

Pin Functions: OPA2365

PIN		TYPE	DESCRIPTION
NAME	NO.		
–IN A	2	Input	Negative (inverting) input signal, channel A
+IN A	3	Input	Positive (noninverting) input signal, channel A
–IN B	6	Input	Negative (inverting) input signal, channel B
+IN B	5	Input	Positive (noninverting) input signal, channel B
V–	4	—	Negative (lowest) power supply
V+	8	—	Positive (highest) power supply
V_{OUT}A	1	Output	Output, channel A
V_{OUT}B	7	Output	Output, channel B

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7 Specifications

7.1 Absolute Maximum Ratings

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

		MIN	MAX	UNIT
Voltage	Supply voltage		5.5	V
	Signal input terminals, voltage(2)	–0.5	0.5	V
Current	Signal input terminals, current(2)	–10	10	mA
	Output short-circuit(3)	Continuous		
Temperature	Operating, T_A	–40	150	°C
	Junction, T_J		150	°C
	Storage, T_{stg}	–65	150	°C

(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 terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5 V beyond the supply rails should 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(1)	±4000	V
		Charged-device model (CDM), per JEDEC specification JESD22-C101(2)	±1000	
		Machine model	±400	

(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
Power supply voltage, (V+) – (V–)	2.2		5.5	V
Specified temperature	−40		+125	°C
Operating temperature	−40		+150	°C

7.4 Thermal Information: OPA365

THERMAL METRIC(1)		OPA365		UNIT
		DBV (SOT-23)	D (SOIC)	
		5 PINS	8 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	206.9	140.1	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	69.4	89.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	34.2	80.6	°C/W
ψ_{JT}	Junction-to-top characterization parameter	1.8	28.7	°C/W
ψ_{JB}	Junction-to-board characterization parameter	33.9	80.1	°C/W
$R_{\theta JC(bot)}$	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.

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7.5 Thermal Information: OPA2365

THERMAL METRIC[1]		OPA2365 D (SOIC) 8 PINS	UNIT
$R_{\theta JA}$	Junction-to-ambient thermal resistance	115.5	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	60.1	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	56.9	°C/W
ψ_{JT}	Junction-to-top characterization parameter	9.5	°C/W
ψ_{JB}	Junction-to-board characterization parameter	56.3	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	N/A	°C/W

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

7.6 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				100	200	µV
dV_{OS}/dT	Input offset voltage versus drift		At T_A = −40°C to +125°C		1		µV/°C
PSRR	Input offset voltage versus power supply		V_S = 2.2 V to 5.5 V, at T_A = −40°C to +125°C		10		µV/V
	Channel separation, DC				0.2		µV/V
INPUT BIAS CURRENT							
I_B	Input bias current				±0.2	±10	pA
		Over temperature	At T_A = −40°C to +125°C	See *Section 7.7*			
I_{OS}	Input offset current				±0.2	±10	pA
NOISE							
e_n	Input voltage noise		f = 0.1 Hz to 10 Hz		5		μV_{PP}
e_n	Input voltage noise density		f = 100 kHz		4.5		$nV/\sqrt{Hz}$
i_n	Input current noise density		f = 10 kHz		4		$fA/\sqrt{Hz}$
INPUT VOLTAGE RANGE							
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, at T_A = −40°C to +125°C	100	120		dB
INPUT CAPACITANCE							
	Differential				6		pF
	Common-mode				2		pF
OPEN-LOOP GAIN							
A_{OL}	Open-loop voltage gain		R_L = 10 kΩ, 100 mV < V_O < (V+) – 100 mV, at T_A = −40°C to +125°C	100	120		dB
			R_L = 600 Ω, 200 mV < V_O < (V+) – 200 mV	100	120		
			R_L = 600 Ω, 200 mV < V_O < (V+) – 200 mV, at T_A = −40°C to +125°C	94			

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7.6 Electrical Characteristics (continued)

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
FREQUENCY RESPONSE							
GBW	Gain-bandwidth product		V_S = 5 V		50		MHz
SR	Slew rate		V_S = 5 V, G = 1		25		V/µs
t_S	Settling time	0.1%	V_S = 5 V, 4-V step, G = +1		200		ns
		0.01%	V_S = 5 V, 4-V step, G = +1		300		
	Overload recovery time		V_S = 5 V, V_{IN} × Gain > V_S		< 0.1		µs
THD+N	Total harmonic distortion + noise(1)		V_S = 5 V, R_L = 600 Ω, V_O = 4 V_{PP}, G = 1, f = 1 kHz		0.0004%		
OUTPUT							
	Voltage output swing from rail		R_L = 10 kΩ, V_S = 5.5 V, at T_A = −40°C to +125°C		10	20	mV
I_{SC}	Short-circuit current				±65		mA
C_L	Capacitive load drive				See *Section 7.7*		
	Open-loop output impedance		f = 1 MHz, I_O = 0 mA		30		Ω
POWER SUPPLY							
V_S	Specified voltage range			2.2		5.5	V
I_Q	Quiescent current per amplifier		I_O = 0 mA		4.6	5	mA
		Over temperature	At T_A = −40°C to +125°C			5	

(1) 3rd-order filter; bandwidth 80 kHz at −3 dB.

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7.7 Typical Characteristics

at T_A = 25°C, V_S = 5 V, and C_L = 0 pF (unless otherwise noted)

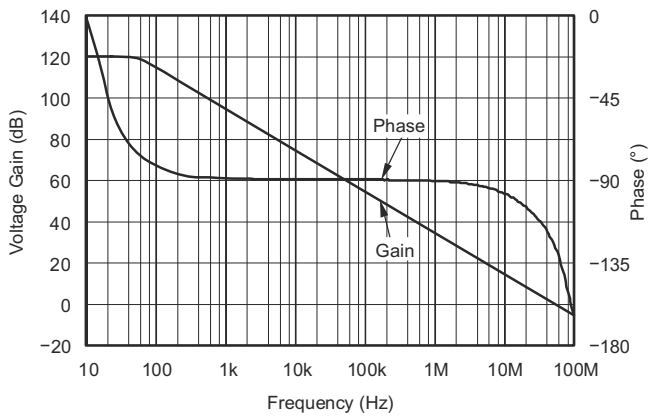


Figure 7-1. Open-Loop Gain and Phase vs Frequency

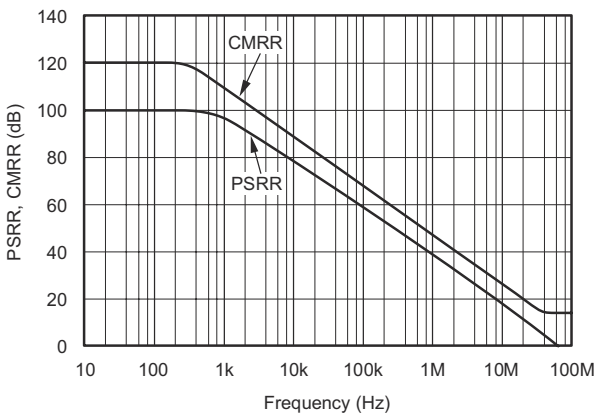


Figure 7-2. Power-Supply and Common-Mode Rejection Ratio vs Frequency

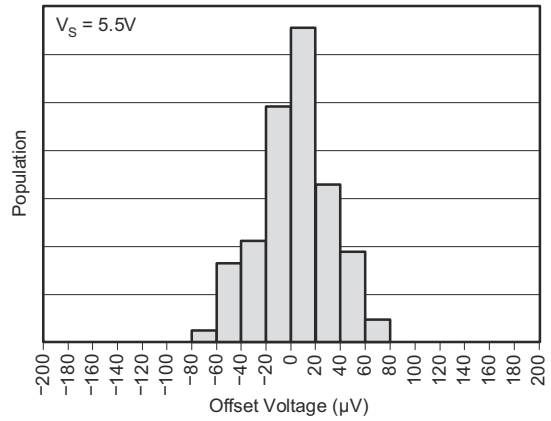


Figure 7-3. Offset Voltage Production Distribution

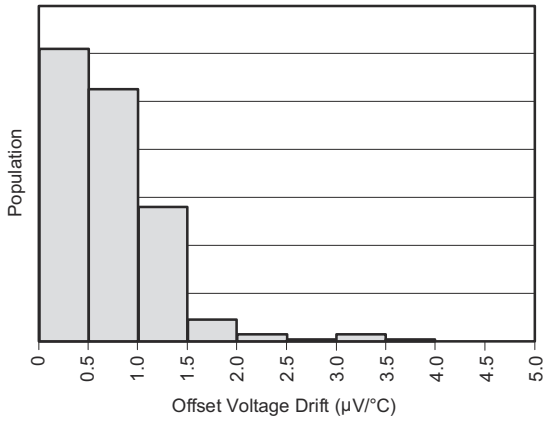


Figure 7-4. Offset Voltage Drift Production Distribution

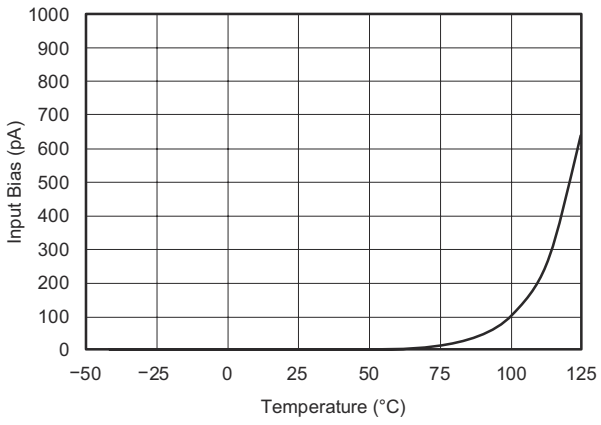


Figure 7-5. Input Bias Current vs Temperature

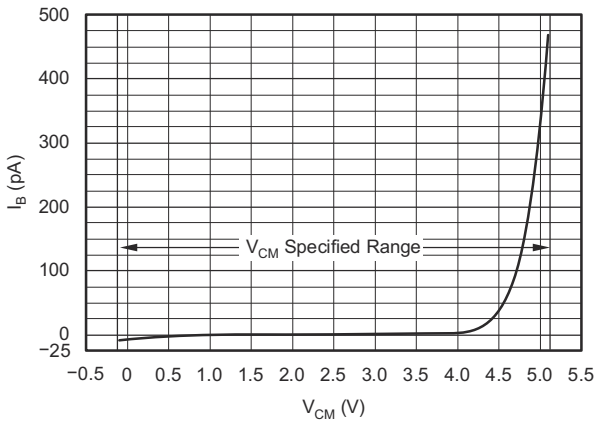


Figure 7-6. Input Bias Current vs Common-Mode Voltage

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7.7 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, and C_L = 0 pF (unless otherwise noted)

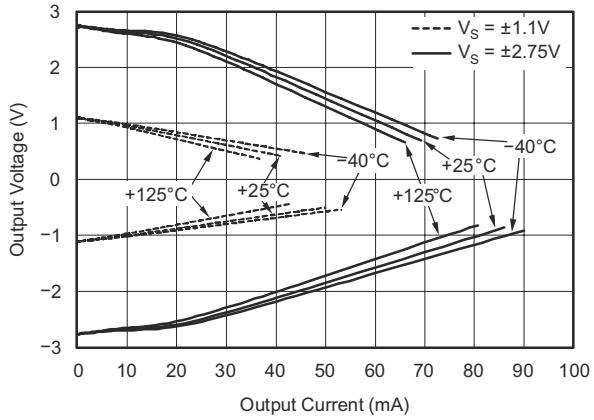


Figure 7-7. OPA365 Output Voltage vs Output Current

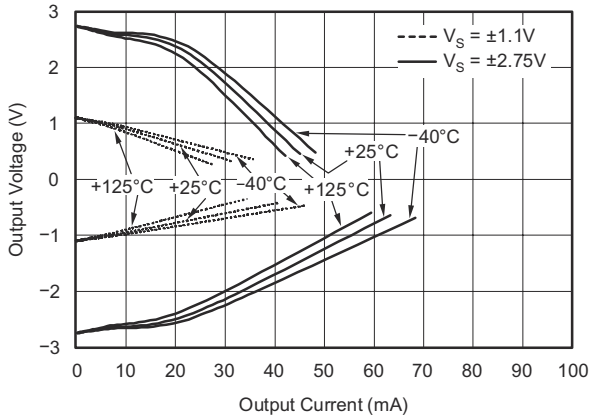


Figure 7-8. OPA2365 Output Voltage vs Output Current

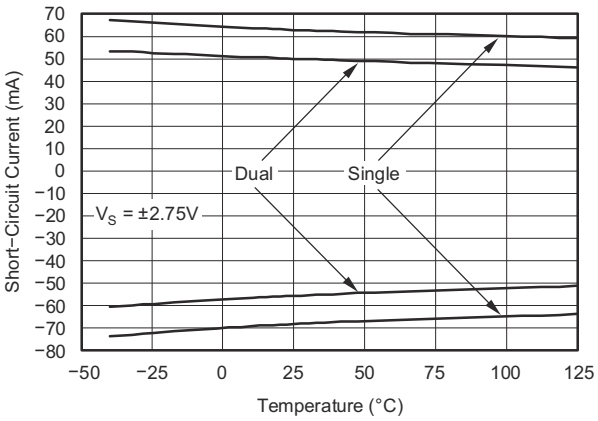


Figure 7-9. Short-Circuit Current vs Temperature

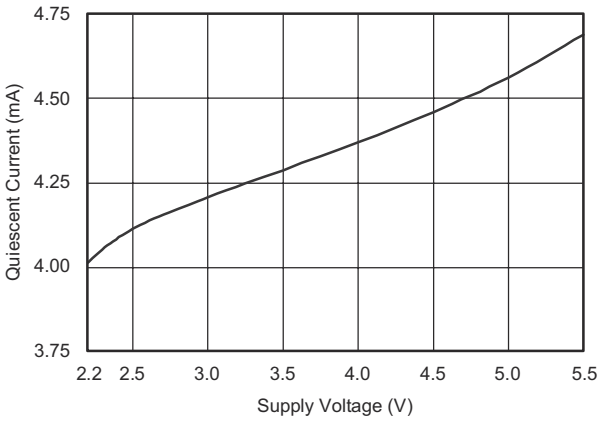


Figure 7-10. Quiescent Current vs Supply Voltage

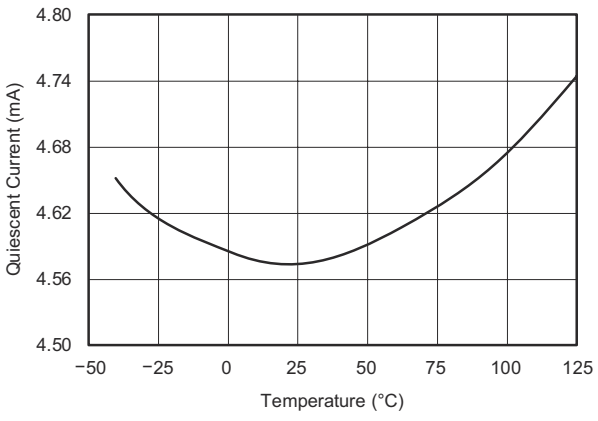


Figure 7-11. Quiescent Current vs Temperature

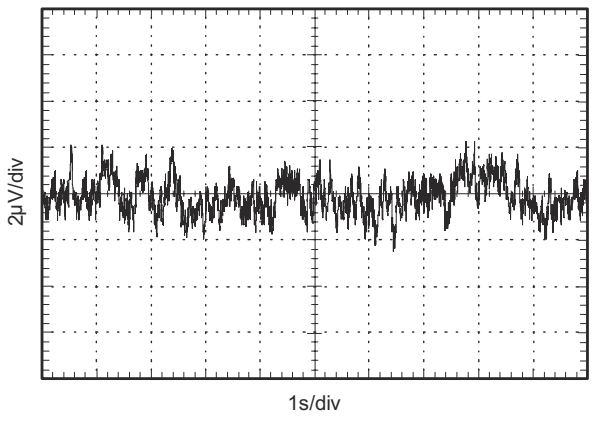


Figure 7-12. 0.1-Hz to 10-Hz Input Voltage Noise

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7.7 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, and C_L = 0 pF (unless otherwise noted)

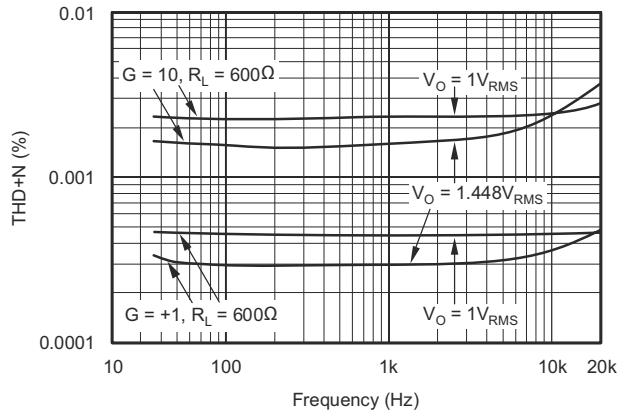


Figure 7-13. Total Harmonic Distortion + Noise vs Frequency

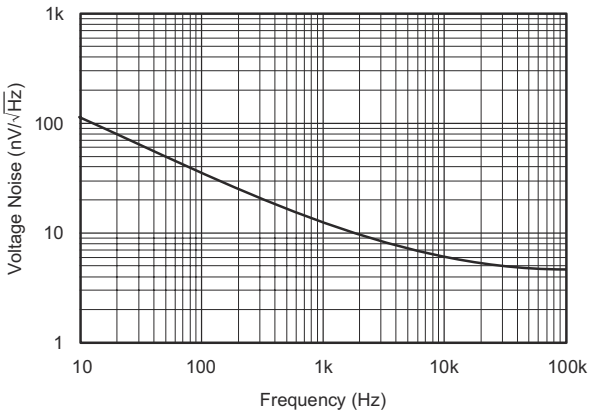


Figure 7-14. Input Voltage Noise Spectral Density

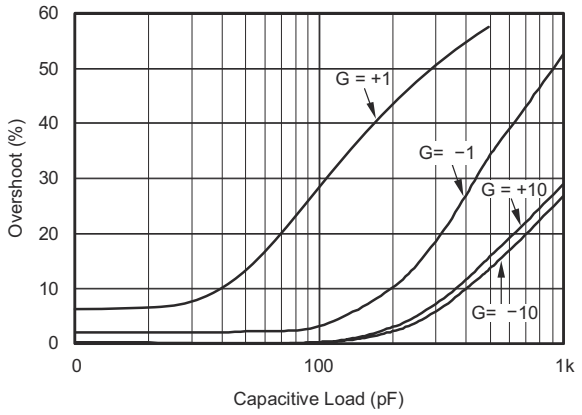


Figure 7-15. Overshoot vs Capacitive Load

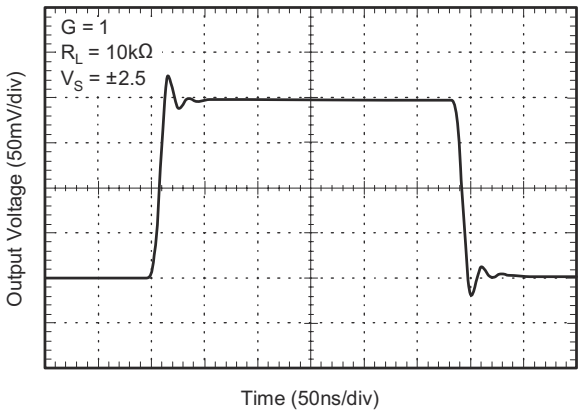


Figure 7-16. Small-Signal Step Response

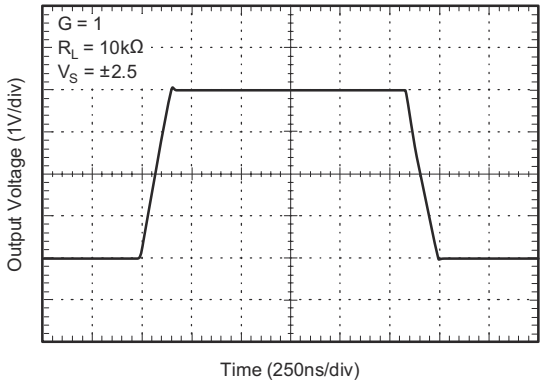


Figure 7-17. Large-Signal Step Response

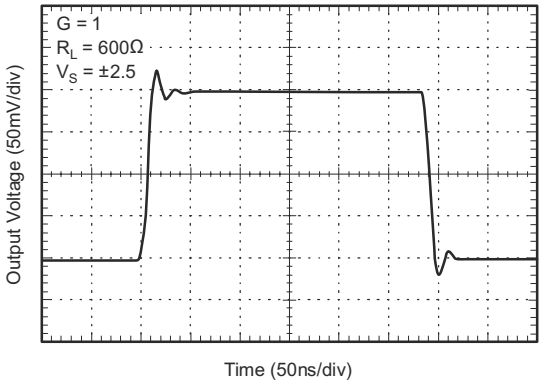


Figure 7-18. Small-Signal Step Response

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7.7 Typical Characteristics (continued)

at T_A = 25°C, V_S = 5 V, and C_L = 0 pF (unless otherwise noted)

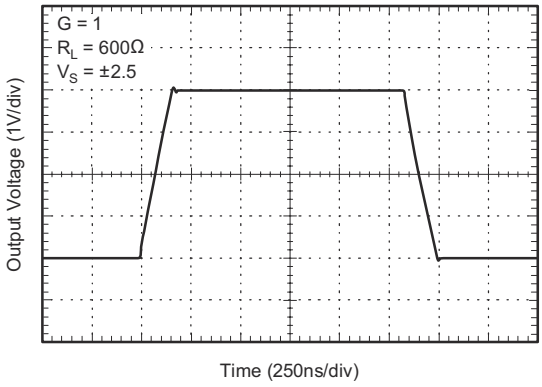


Figure 7-19. Large-Signal Step Response

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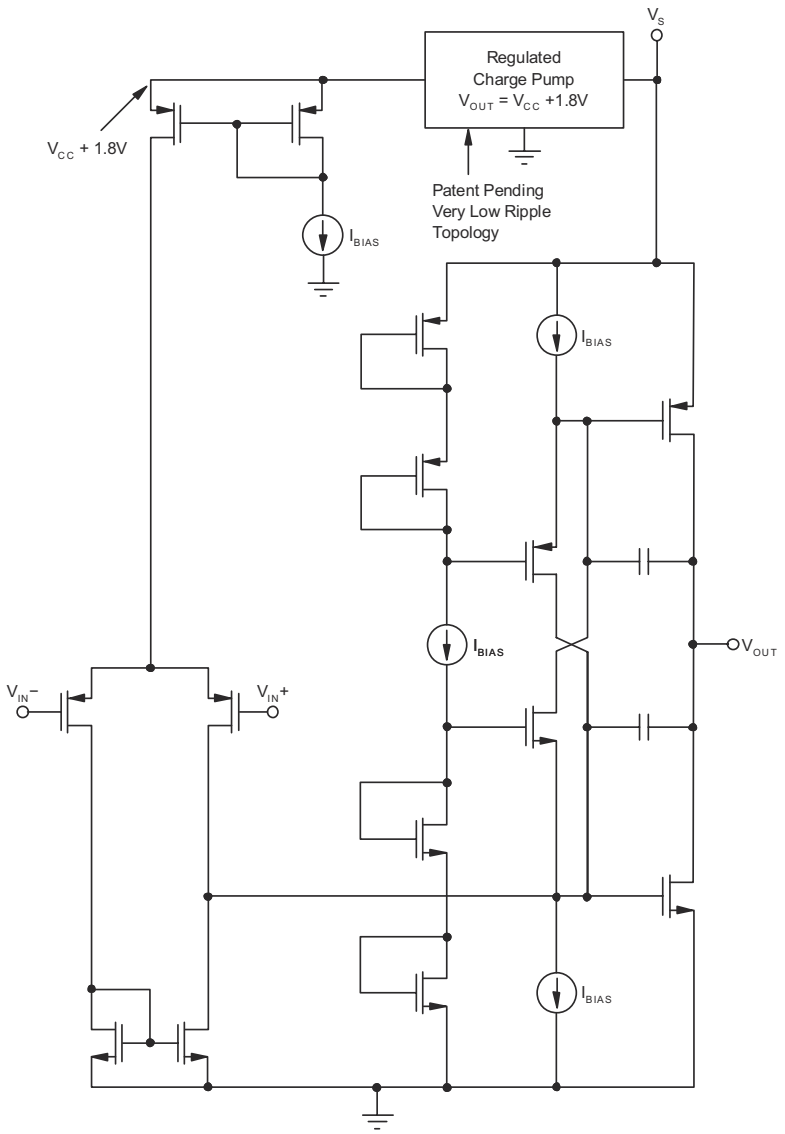
8 Detailed Description

8.1 Overview

The OPAx365 series of operational amplifiers feature rail-to-rail, high performance that make these devices an excellent choice for driving ADCs. Other typical applications include signal conditioning, cell phone power amplifier control loops, audio, and sensor amplification. The OPAx365 is a wideband amplifier that can be operated with either a single supply or dual supplies.

Furthermore, the OPA365 amplifier parameters are fully specified from 2.2 V to 5.5 V. Many of the specifications apply from −40°C to +125°C. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in *Section 7.7*.

8.2 Functional Block Diagram



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8.3 Feature Description

8.3.1 Rail-to-Rail Input

The OPAx365 product family features true rail-to-rail input operation, with supply voltages as low as ±1.1 V (2.2 V). A unique zerø-crossover input topology eliminates the input offset transition region typical of many rail-to-rail, complementary stage operational amplifiers. This topology also allows the OPAx365 to provide excdellent common-mode performance over the entire input range, which extends 100 mV beyond both power-supply rails, as shown in Figure 8-1. When driving ADCs, the highly linear V_{CM} range of the OPAx365 makes sure that the op amp or ADC system linearity performance is not compromised.

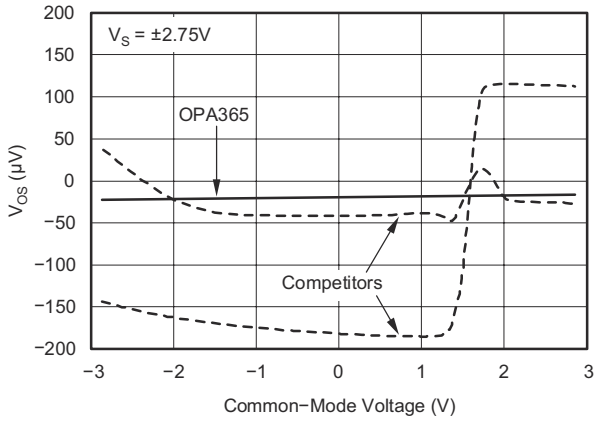


Figure 8-1. OPA365 Linear Offset Over the Entire Common-Mode Range

For a simplified schematic illustrating the rail-to-rail input circuitry, see *Section 8.2*.

8.3.2 Input and ESD Protection

The OPAx365 devices incorporate internal electrostatic discharge (ESD) protection circuits on all pins. In the case of input and output pins, this protection primarily consists of current steering diodes connected between the input and power-supply pins. These ESD protection diodes also provide in-circuit, input overdrive protection, provided that the current is limited to 10 mA, as stated in *Section 7.1*. Figure 8-2 shows how a series input resistor can be added to the driven input to limit the input current. The added resistor contributes thermal noise at the amplifier input and the value must be kept to the minimum in noise-sensitive applications.

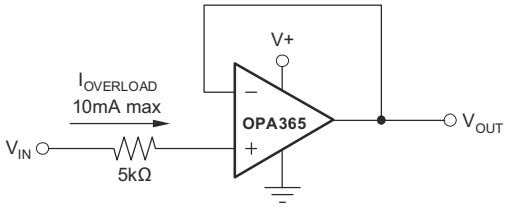


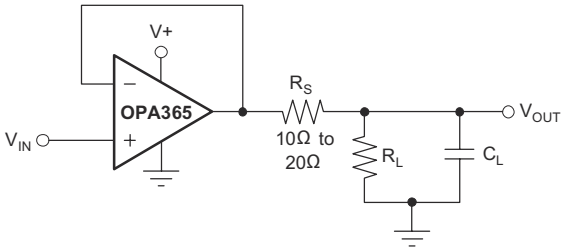
Figure 8-2. Input Current Protection

8.3.3 Capacitive Loads

The OPAx365 can be used in applications where driving a capacitive load is required. As with all op amps, there can be specific instances where the OPAx365 become unstable, leading to oscillation. The particular op-amp circuit configuration, layout, gain, and output loading are some of the factors to consider when establishing whether an amplifier will be stable in operation. An op amp in the unity-gain (+1 – V/V) buffer configuration and driving a capacitive load exhibits a greater tendency to be unstable than an amplifier operated at a higher noise gain. The capacitive load, in conjunction with the op amp output resistance, creates a pole within the feedback loop that degrades the phase margin. The degradation of the phase margin increases as the capacitive loading increases.

When operating in the unity-gain configuration, the OPAx365 remain stable with a pure capacitive load up to approximately 1 nF. The equivalent series resistance (ESR) of some very large capacitors (C_L > 1 µF) is sufficient to alter the phase characteristics in the feedback loop such that the amplifier remains stable. Increasing the amplifier closed-loop gain allows the amplifier to drive increasingly larger capacitance. This increased capability is evident when observing the overshoot response of the amplifier at higher voltage gains; see also Figure 7-15.

Figure 8-3 shows one technique to increase the capacitive load drive capability of the amplifier operating in unity gain is to insert a small resistor, typically 10 Ω to 20 Ω, in series with the output. This resistor significantly reduces the overshoot and ringing associated with large capacitive loads. A possible problem with this technique is that a voltage divider is created with the added series resistor and any resistor connected in parallel with the capacitive load. The voltage divider introduces a gain error at the output that reduces the output swing. The error contributed by the voltage divider is sometimes insignificant. For instance, with a load resistance, R_L = 10 kΩ, and R_S = 20 Ω, the gain error is only about 0.2%. However, when R_L is decreased to 600 Ω, which the OPAx365 are able to drive, the error increases to 7.5%.



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Figure 8-3. Improving Capacitive Load Drive

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8.3.4 Achieving an Output Level of Zero Volts (0 V)

Certain single-supply applications require the op amp output to swing from 0 V to a positive full-scale voltage and have high accuracy. An example is an op amp employed to drive a single-supply ADC having an input range from 0 V to 5 V. Rail-to-rail output amplifiers with very light output loading can achieve an output level within millivolts of 0 V (or $+V_S$ at the high end), but not 0 V. Furthermore, the deviation from 0 V only becomes greater as the load current required increases. This increased deviation is a result of limitations of the CMOS output stage.

When a pulldown resistor is connected from the amplifier output to a negative voltage source, the OPAx365 can achieve an output level of 0 V, and even a few millivolts below 0 V. Below this limit, nonlinearity and limiting conditions become evident. Figure 8-4 illustrates a circuit using this technique.

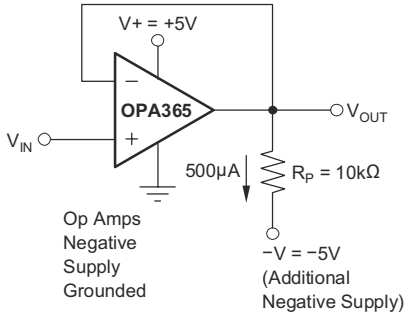
A pulldown current of approximately 500 µA is required when the OPAx365 is connected as a unity-gain buffer. A practical termination voltage (V_{NEG}) is −5 V, but other convenient negative voltages also can be used. Pulldown resistor R_L is calculated from $R_L = [(V_O - V_{NEG}) / (500\ \mu A)]$.

Using a minimum output voltage (V_O) of 0 V, $R_L = [0\ V - (-5\ V)] / (500\ \mu A)] = 10\ k\Omega$. Keep in mind that lower termination voltages result in smaller pulldown resistors that load the output during positive output voltage excursions.

Note

This technique does not work with all op amps; apply only to op amps such as the OPAx365 that have been specifically designed to operate in this manner. Also, operating the OPAx365 output at 0 V changes the output-stage operating conditions, resulting in somewhat lower open-loop gain and bandwidth.

Keep these precautions in mind when driving a capacitive load because these conditions can affect circuit transient response and stability.

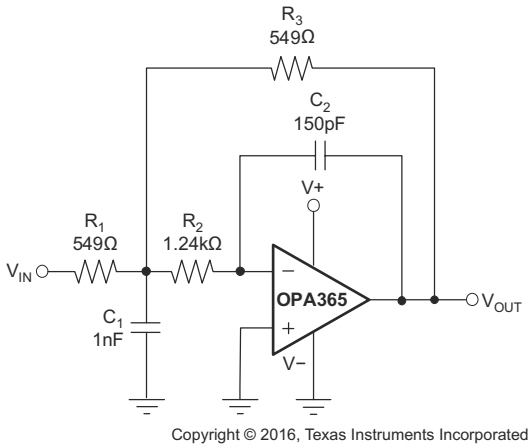


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Figure 8-4. Swing-to-Ground

8.3.5 Active Filtering

The OPAx365 are an excellent choice for active filter applications requiring a wide bandwidth, fast slew rate, low-noise, single-supply operational amplifier. Figure 8-5 shows a 500-kHz, second-order, low-pass filter using the multiple-feedback (MFB) topology. The components have been selected to provide a maximally-flat Butterworth response. Beyond the cutoff frequency, rolloff is −40 dB/dec. The Butterworth response is great for applications requiring predictable gain characteristics such as the antialiasing filter used ahead of an ADC.



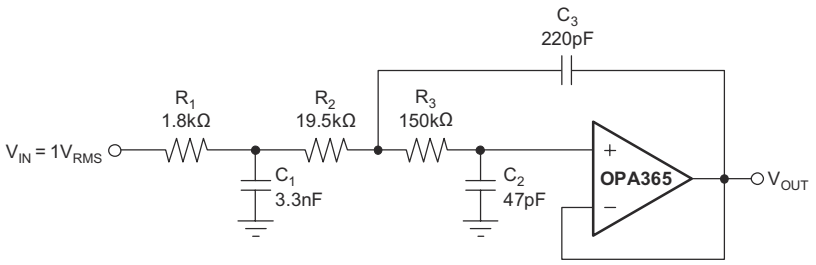
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Figure 8-5. Second-Order Butterworth, 500-kHz Low-Pass Filter

One point to observe when considering the MFB filter is that the output is inverted, relative to the input. If this inversion is not required, or not desired, a noninverting output can be achieved through one of these options:

- Add an inverting amplifier.
- Add an additional second-order MFB stage.
- Use a noninverting filter topology such as Sallen-Key.

The Sallen-Key topology is shown in Figure 8-6.



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Figure 8-6. Configured as a Three-Pole, 20-kHz, Sallen-Key Filter

8.4 Device Functional Modes

The OPA365 family has a single functional mode and are operational when the power-supply voltage is greater than 2.2 V (±1.1 V). The maximum power supply voltage for the OPA365 family is 5.5 V (±2.75 V).

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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, as well as validating and testing their design implementation to confirm system functionality.

9.1 Application Information

9.1.1 Basic Amplifier Configurations

As with other single-supply op amps, the OPAx365 can be operated with either a single supply or dual supplies. Figure 9-1 shows a typical dual-supply connection, which is accompanied by a single-supply connection. The OPAx365 are configured as a basic inverting amplifier with a gain of −10 V/V. The dual-supply connection has an output voltage centered on zero, while the single-supply connection has an output centered on the common-mode voltage V_{CM}. For the circuit shown, this voltage is 1.5 V, but can be any value within the common-mode input voltage range. The OPAx365 V_{CM} range extends 100 mV beyond the power-supply rails.

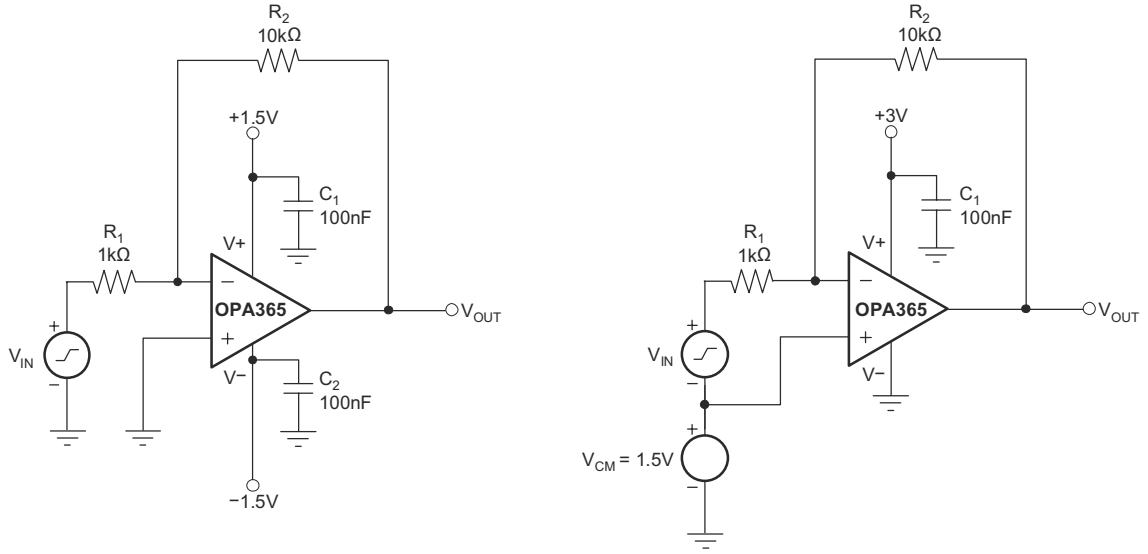


Figure 9-1. Basic Circuit Connections

Figure 9-2 shows a single-supply, electret microphone application where V_{CM} is provided by a resistive divider. The divider also provides the bias voltage for the electret element.

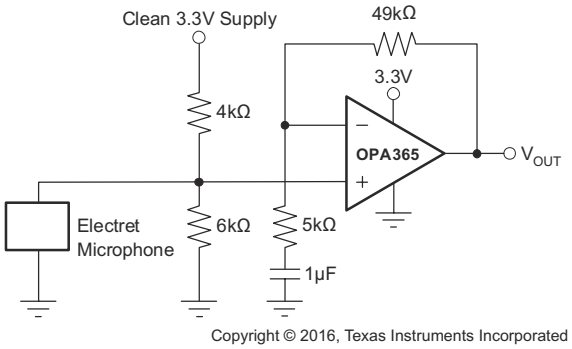
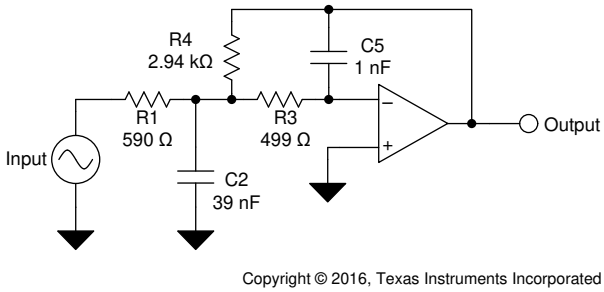


Figure 9-2. Microphone Preamplifier

9.2 Typical Application

Low-pass filters are commonly employed in signal processing applications to reduce noise and prevent aliasing. The OPAx365 are designed to construct high-speed, high-precision active filters. Figure 9-3 illustrates a second-order low-pass filter commonly encountered in signal processing applications.



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Figure 9-3. Second-Order Low-Pass Filter

9.2.1 Design Requirements

Use the following parameters for this design example:

- Gain = 5 V/V (inverting gain)
- Low-pass cutoff frequency = 25 kHz
- Second-order Chebyshev filter response with 3-dB gain peaking in the passband

9.2.2 Detailed Design Procedure

The infinite-gain multiple-feedback circuit for a low-pass network function is shown in Figure 9-3. Use Equation 1 to calculate the voltage transfer function.

$$\frac{\text{Output}}{\text{Input}}(s) = \frac{-1/R_1R_3C_2C_5}{s^2 + (s/C_2)(1/R_1 + 1/R_3 + 1/R_4) + 1/R_3R_4C_2C_5} \quad (1)$$

This circuit produces a signal inversion. For this circuit, the gain at dc and the low-pass cutoff frequency are calculated using Equation 2.

$$\text{Gain} = \frac{R_4}{R_1}$$
$$f_C = \frac{1}{2\pi}\sqrt{(1/R_3R_4C_2C_5)} \quad (2)$$

Software tools are readily available to simplify filter design. The filter design tool is a simple, powerful, and easy-to-use active filter design program. The filter design tool allows the user to create optimized filter designs using a selection of TI operational amplifiers and passive components from TI's vendor partners.

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9.2.3 Application Curve

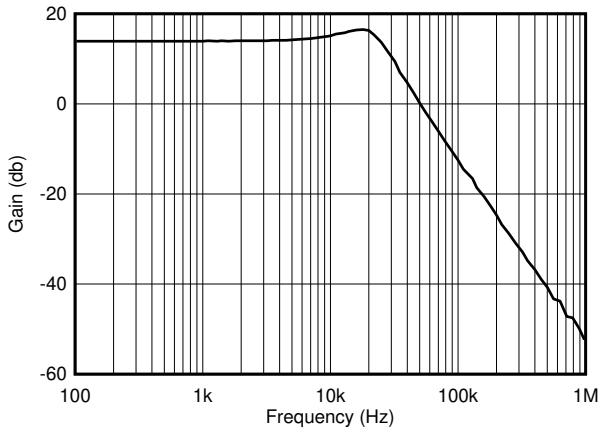


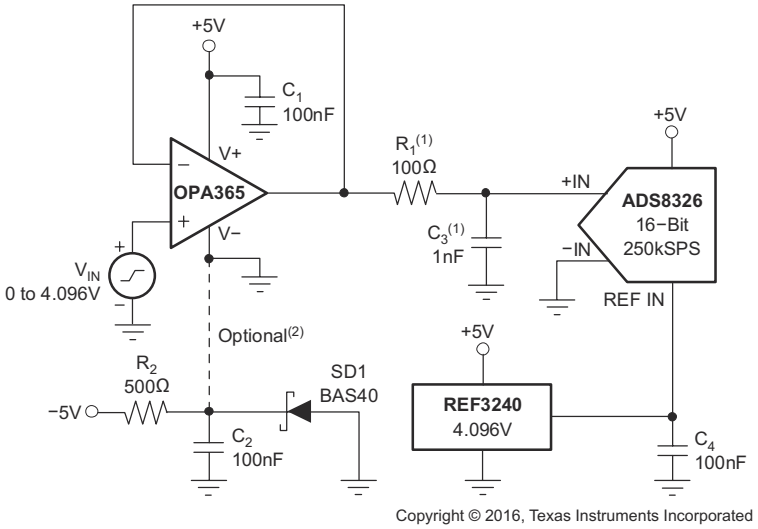
Figure 9-4. OPA365 Second-Order 25 kHz, Chebyshev, Low-Pass Filter

9.3 System Examples

9.3.1 Driving an Analog-to-Digital Converter

Very wide common-mode input range, rail-to-rail input and output voltage capability, and high speed make the OPAx365 excellent drivers for modern ADCs. Also, because the OPAx365 are free of the input offset transition characteristics inherent to some rail-to-rail CMOS op amps, these devices provide low THD and excellent linearity throughout the input voltage swing range.

Figure 9-5 shows the OPA365 driving an ADS8326, 16-bit, 250-kSPS converter. The amplifier is connected as a unity-gain, noninverting buffer and has an output swing to 0 V, making these devices directly compatible with the ADC minus full-scale input level. The 0-V level is achieved by powering the OPA365 V− pin with a small negative voltage established by the diode forward voltage drop. A small, signal-switching diode or Schottky diode provides a negative supply voltage of −0.3 V to −0.7 V. The supply rail-to-rail is equal to V+, plus the small negative voltage.



(1) Suggested value; can require adjustment based on specific application.

(2) Single-supply applications lose a small number of ADC codes near ground due to op amp output swing limitations. If a negative power supply is available, this simple circuit creates a −0.3-V supply to allow output swing to true ground potential.

Figure 9-5. Driving the ADS8326

One method to drive an ADC that negates the need for an output swing down to 0 V uses a slightly compressed ADC full-scale input range (FSR). For example, Figure 9-6 shows that the 16-bit ADS8361 has a maximum FSR of 0 V to 5 V when powered by a 5-V supply and V_{REF} of 2.5 V. The idea is to match the ADC input range with the op-amp full-linear output-swing range; for example, an output range of 0.1 V to 4.9 V. The reference output from the ADS8361 ADC is divided down from 2.5 V to 2.4 V using a resistive divider. The ADC FSR then becomes 4.8 V_{PP} centered on a common-mode voltage of 2.5 V. Current from the ADS8361 reference pin is limited to approximately ±10 µA. Here, 5 µA is used to bias the divider. The resistors must be precise to maintain the ADC gain accuracy. An additional benefit of this method is the elimination of the negative supply voltage; these devices require no additional power-supply current.

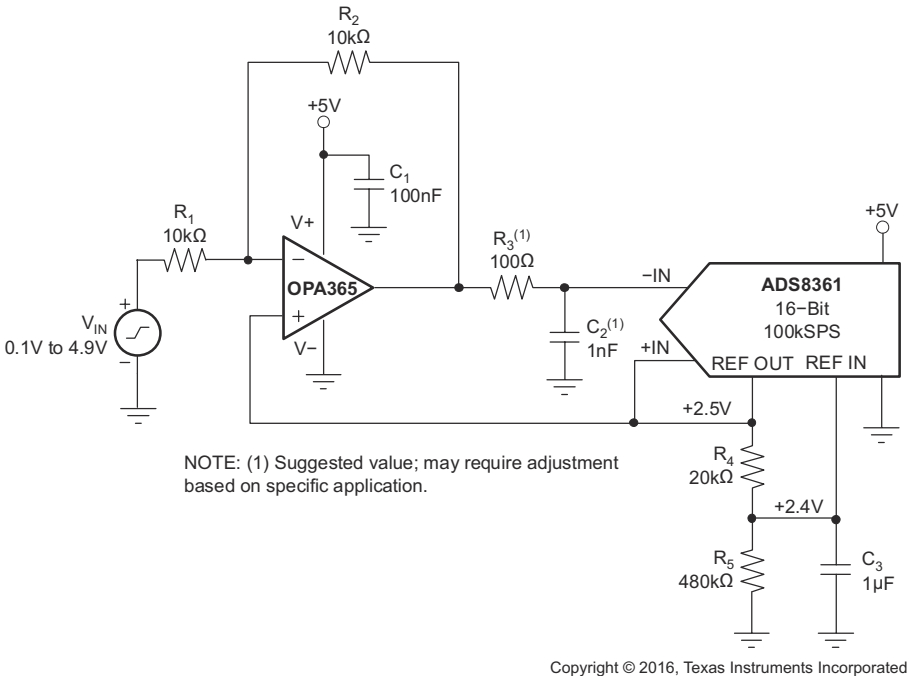


Figure 9-6. Driving the ADS8361

A resistor-capacitor (RC) network, consisting of R_1 and C_1, is included between the op amp and the ADS8361. The RC network not only provides a high-frequency filter function, but more importantly serves as a charge reservoir used for charging the converter internal hold capacitance. This capability maintains the op-amp output linearity as the ADC input characteristics change throughout the conversion cycle. Depending on the particular application and ADC, some optimization of the R_1 and C_1 values can be required for best transient performance.

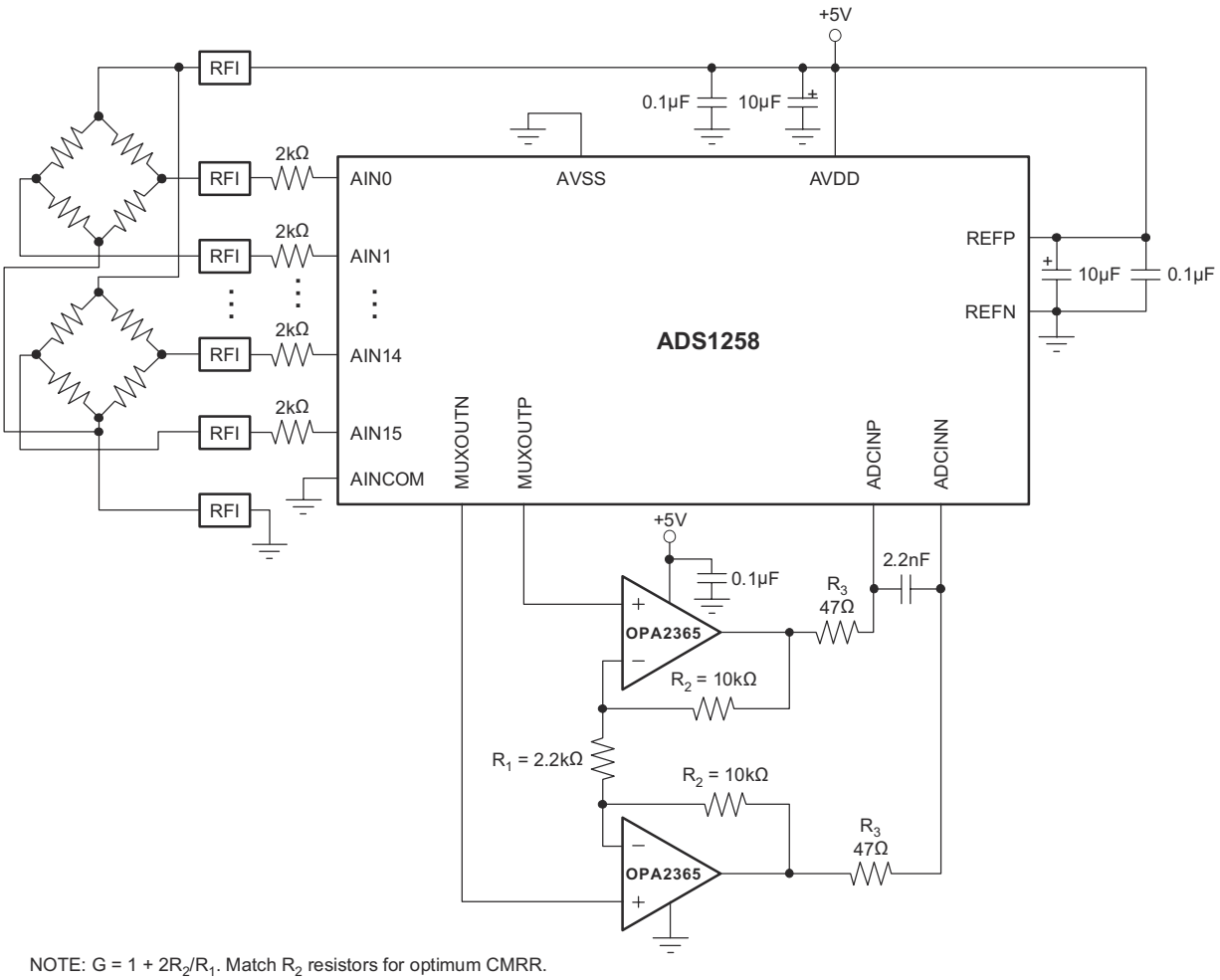
Figure 9-7 illustrates the OPA2365 dual op amp providing signal conditioning within an ADS1258 bridge sensor circuit. The OPA2365 is connected as a differential-in and differential-out amplifier after the ADS1258 16:1 multiplexer. The voltage gain for this stage is approximately 10 V/V. Driving the ADS1258 internal ADC in differential mode, rather than in a single-ended mode, exploits the full linearity performance capability of the converter. For best common-mode rejection, the two R_2 resistors must be closely matched.

Note that in Figure 9-7, the amplifiers, bridges, ADS1258, and internal reference are powered by the same single 5-V supply. This ratiometric connection helps cancel excitation voltage drift effects and noise. For best performance, the 5-V supply must be as free as possible from noise and transients.

When the ADS1258 data rate is set to maximum and the chop feature is enabled, this circuit yields 12 bits of noise-free resolution with a 50-mV full-scale input.

The chop feature is used to reduce the ADS1258 offset and offset drift to very low levels. A 2.2-nF capacitor is required across the ADC inputs to bypass the sampling currents. The 47-Ω resistors provide isolation for the OPA2365 outputs from the relatively large, 2.2-nF capacitive load.

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NOTE: G = 1 + $2R_2/R_1$. Match R_2 resistors for optimum CMRR.

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Figure 9-7. Conditioning Input Signals to the ADS1258 on a Single Supply

9.4 Power Supply Recommendations

The OPAx365 family is specified for operation from 2.2 V to 5.5 V (±1.1 V to ±2.75 V); many specifications apply from –40°C to 125°C. Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in *Section 7.7*.

9.5 Layout

9.5.1 Layout Guidelines

For best operational performance of the device, use good PCB layout practices, including:

- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and operational amplifier. Bypass capacitors are used to reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1-µF ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from V+ to ground is applicable for single-supply applications.
  - The OPAx365 are capable of high-output current (in excess of 65 mA). Applications with low-impedance loads or capacitive loads with fast transient signals demand large currents from the power supplies. Larger bypass capacitors such as 1-µF solid tantalum capacitors can improve dynamic performance in these applications.

- Separate grounding for analog and digital portions of circuitry is one of the simplest and most-effective methods of noise suppression. One or more layers on multilayer PCBs are usually devoted to ground planes. A ground plane helps distribute heat and reduces EMI noise pickup. Make sure to physically separate digital and analog grounds paying attention to the flow of the ground current.
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better as opposed to in parallel with the noisy trace.
- Place the external components as close to the device as possible. As Figure 9-8 shows, keep RF and RG close to the inverting input to minimize parasitic capacitance.
- Keep the length of input traces as short as possible. Always remember that the input traces are the most sensitive part of the circuit.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.
- For best performance, clean the PCB following board assembly.
- Any precision integrated circuit can experience performance shifts due to moisture ingress into the plastic package. Following any aqueous PCB cleaning process, bake the PCB assembly to remove moisture introduced into the device packaging during the cleaning process. A low-temperature, post-cleaning bake at 85°C for 30 minutes is sufficient for most circumstances.

9.5.2 Layout Example

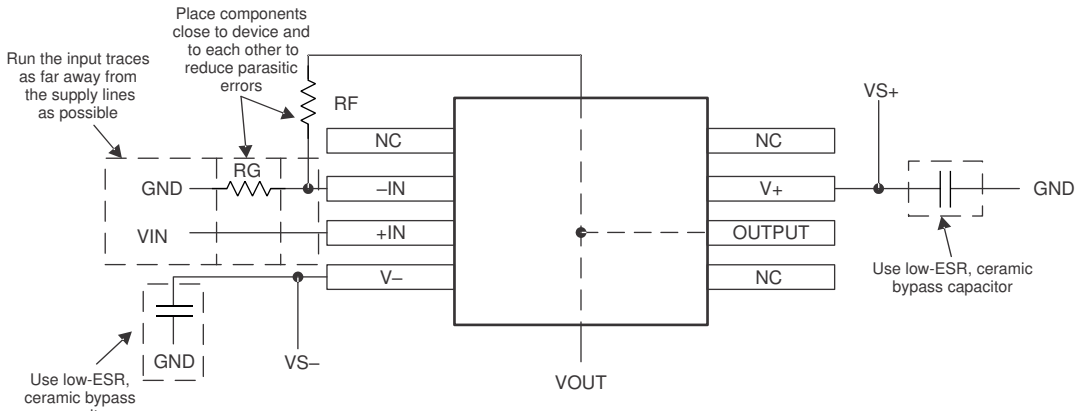


Figure 9-8. Layout Recommendation

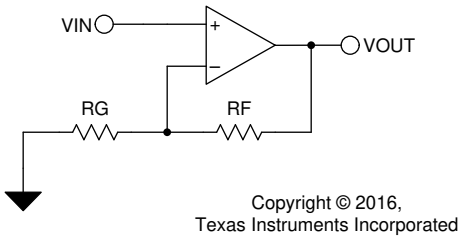


Figure 9-9. Schematic Representation

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10 Device and Documentation Support

10.1 Device Support

10.1.1 Development Support

10.1.1.1 PSpice® for TI

PSpice® for TI is a design and simulation environment that helps evaluate performance of analog circuits. Create subsystem designs and prototype solutions before committing to layout and fabrication, reducing development cost and time to market.

10.1.1.2 TINA-TI™ Simulation Software (Free Download)

TINA-TI™ simulation software is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI simulation software is a free, fully-functional version of the TINA™ software, preloaded with a library of macromodels, in addition to a range of both passive and active models. TINA-TI simulation software provides all the conventional dc, transient, and frequency domain analysis of SPICE, as well as additional design capabilities.

Available as a free download from the Design tools and simulation web page, TINA-TI simulation software offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

Note

These files require that either the TINA software or TINA-TI software be installed. Download the free TINA-TI simulation software from the TINA-TI™ software folder.

10.1.1.3 DIP-Adapter-EVM

Speed up your op amp prototyping and testing with the DIP-Adapter-EVM, which provides a fast, easy and inexpensive way to interface with small, surface-mount devices. Connect any supported op amp using the included Samtec terminal strips or wire them directly to existing circuits. The DIP-Adapter-EVM kit supports the following industry-standard packages: D or U (SOIC-8), PW (TSSOP-8), DGK (VSSOP-8), DBV (SOT-23-6, SOT-23-5 and SOT-23-3), DCK (SC70-6 and SC70-5), and DRL (SOT563-6).

10.1.1.4 DIYAMP-EVM

The DIYAMP-EVM is a unique evaluation module (EVM) that provides real-world amplifier circuits, enabling the user to quickly evaluate design concepts and verify simulations. This EVM is available in three industry-standard packages (SC70, SOT23, and SOIC) and 12 popular amplifier configurations, including amplifiers, filters, stability compensation, and comparator configurations for both single and dual supplies.

10.1.1.5 TI Reference Designs

TI reference designs are analog solutions created by TI's precision analog applications experts. TI reference designs offer the theory of operation, component selection, simulation, complete PCB schematic and layout, bill of materials, and measured performance of many useful circuits. TI reference designs are available online at https://www.ti.com/reference-designs.

10.1.1.6 Filter Design Tool

The filter design tool is a simple, powerful, and easy-to-use active filter design program. The filter design tool allows the user to create optimized filter designs using a selection of TI operational amplifiers and passive components from TI's vendor partners.

Available as a web-based tool from the Design tools and simulation web page, the filter design tool allows the user to design, optimize, and simulate complete multistage active filter solutions within minutes.

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10.2 Documentation Support

10.2.1 Related Documentation

The following documents are relevant to using the OPAx365, and recommended for reference. All are available for download at www.ti.com unless otherwise noted.

- Texas Instruments, *FilterPro™ MFB and Sallen-Key Low-Pass Filter Design Program User Guide*
- Texas Instruments, *Low Power Input and Reference Driver Circuit for ADS8318 and ADS8319* application report
- Texas Instruments, *Op Amp Performance Analysis* application bulletin
- Texas Instruments, *Single-Supply Operation of Operational Amplifiers* application bulletin
- Texas Instruments, *The Best of Baker's Best – Amplifiers eBook*

10.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on ti.com. Click on *Subscribe to updates* 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.

10.4 Support Resources

TI E2E™ support forums are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is 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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PSpice® is a registered trademark of Cadence Design Systems, Inc.
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10.6 Electrostatic Discharge Caution



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

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

10.7 Glossary

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

11 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.

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PACKAGING INFORMATION

Orderable part number	Status (1)	Material type (2)	Package | Pins	Package qty | Carrier	RoHS (3)	Lead finish/ Ball material (4)	MSL rating/ Peak reflow (5)	Op temp (°C)	Part marking (6)
OPA2365AID	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA2365AID.A	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA2365AIDG4	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA2365AIDR	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA2365AIDR.A	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA2365AIDRG4	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O2365A
OPA365AID	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A
OPA365AID.A	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A
OPA365AIDBVR	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	NIPDAU | SN	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDBVR.A	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDBVRG4	Active	Production	SOT-23 (DBV) | 5	3000 | LARGE T&R	Yes	SN	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDBVT	Active	Production	SOT-23 (DBV) | 5	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDBVT.A	Active	Production	SOT-23 (DBV) | 5	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDBVTG4	Active	Production	SOT-23 (DBV) | 5	250 | SMALL T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	OAVQ
OPA365AIDG4	Active	Production	SOIC (D) | 8	75 | TUBE	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A
OPA365AIDR	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A
OPA365AIDR.A	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A
OPA365AIDRG4	Active	Production	SOIC (D) | 8	2500 | LARGE T&R	Yes	NIPDAU	Level-1-260C-UNLIM	-40 to 125	O365A

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts 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.

(5) MSL rating/Peak reflow: The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) Part marking: There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

OTHER QUALIFIED VERSIONS OF OPA2365, OPA365 :

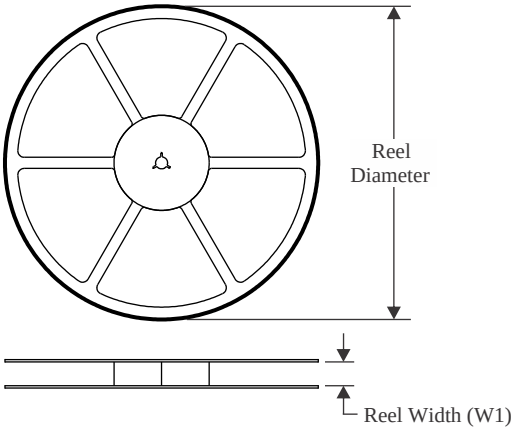
- Automotive : OPA2365-Q1, OPA365-Q1
- Enhanced Product : OPA365-EP

NOTE: Qualified Version Definitions:

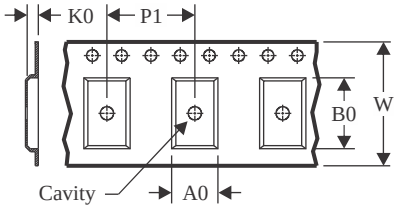
- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects
- Enhanced Product - Supports Defense, Aerospace and Medical Applications

TAPE AND REEL INFORMATION

REEL DIMENSIONS

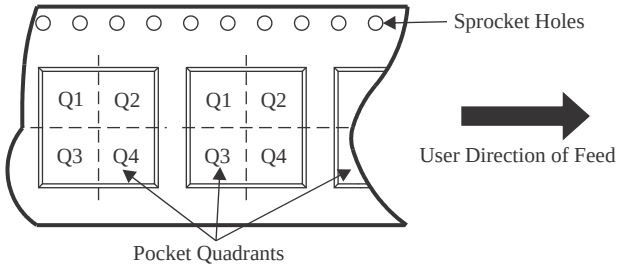


TAPE DIMENSIONS



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

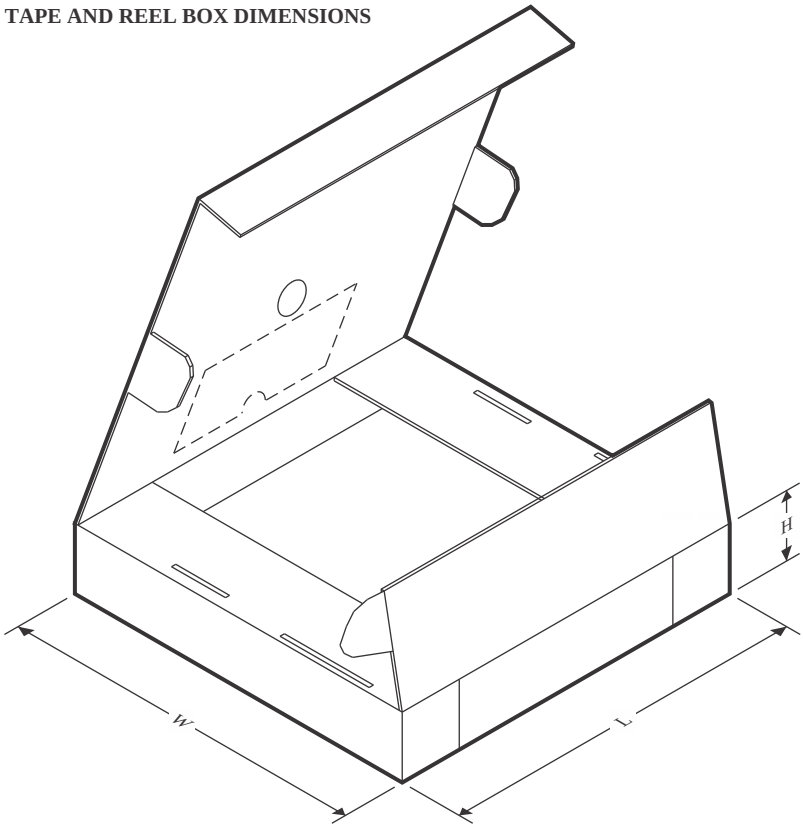
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
OPA2365AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1
OPA365AIDBVR	SOT-23	DBV	5	3000	178.0	9.0	3.3	3.2	1.4	4.0	8.0	Q3
OPA365AIDBVT	SOT-23	DBV	5	250	178.0	9.0	3.3	3.2	1.4	4.0	8.0	Q3
OPA365AIDR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

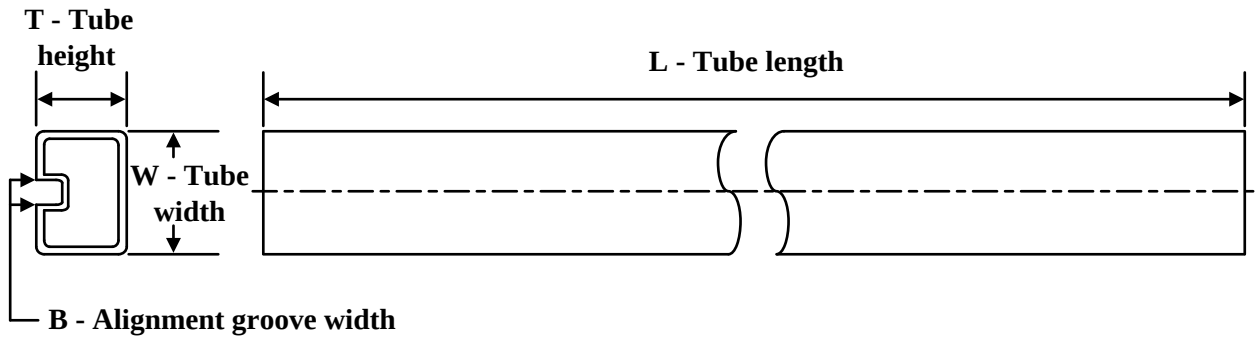
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

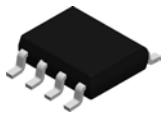
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2365AIDR	SOIC	D	8	2500	353.0	353.0	32.0
OPA365AIDBVR	SOT-23	DBV	5	3000	180.0	180.0	18.0
OPA365AIDBVT	SOT-23	DBV	5	250	180.0	180.0	18.0
OPA365AIDR	SOIC	D	8	2500	353.0	353.0	32.0

TUBE



*All dimensions are nominal

Device	Package Name	Package Type	Pins	SPQ	L (mm)	W (mm)	T (µm)	B (mm)
OPA2365AID	D	SOIC	8	75	506.6	8	3940	4.32
OPA2365AID.A	D	SOIC	8	75	506.6	8	3940	4.32
OPA2365AIDG4	D	SOIC	8	75	506.6	8	3940	4.32
OPA365AID	D	SOIC	8	75	506.6	8	3940	4.32
OPA365AID.A	D	SOIC	8	75	506.6	8	3940	4.32
OPA365AIDG4	D	SOIC	8	75	506.6	8	3940	4.32

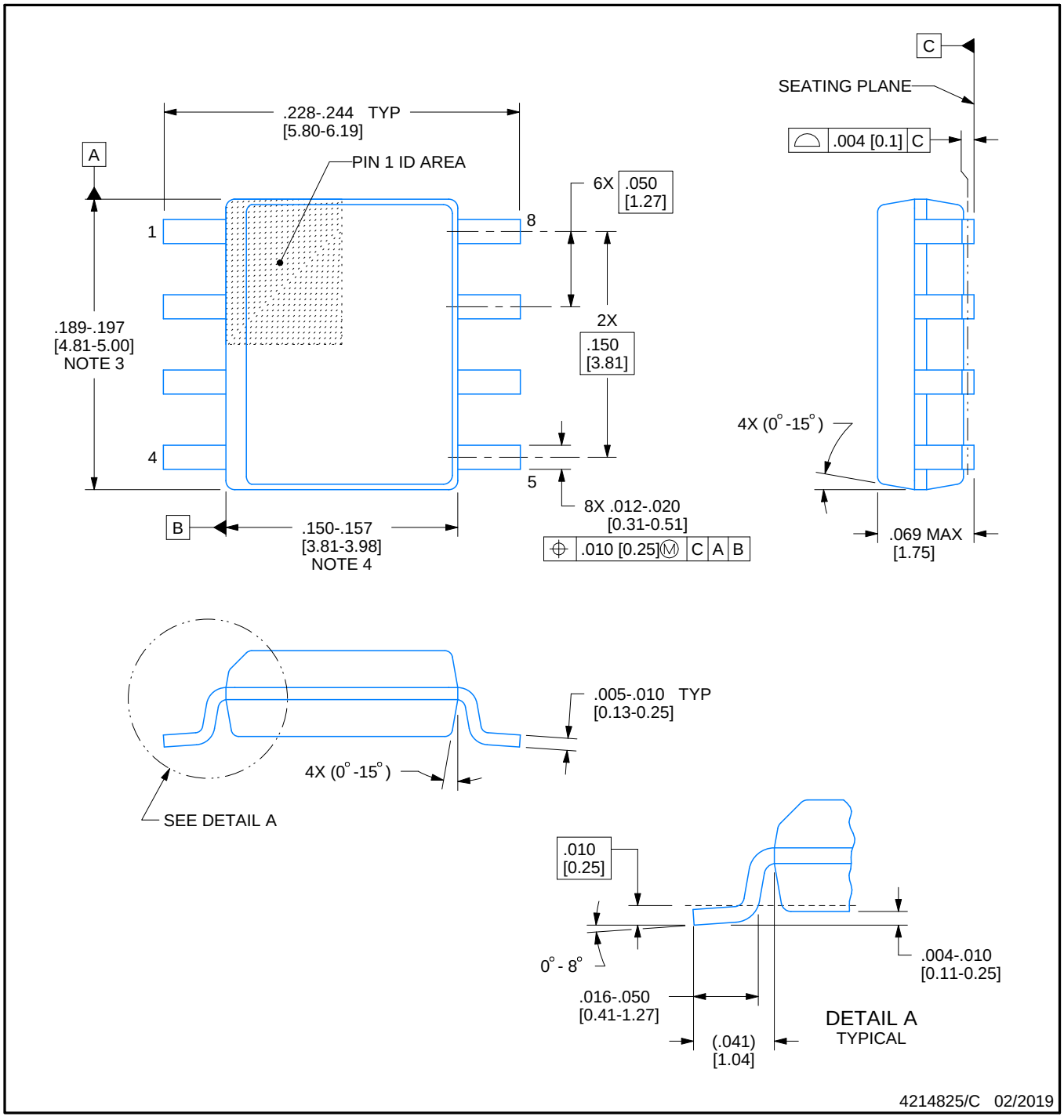


PACKAGE OUTLINE

D0008A

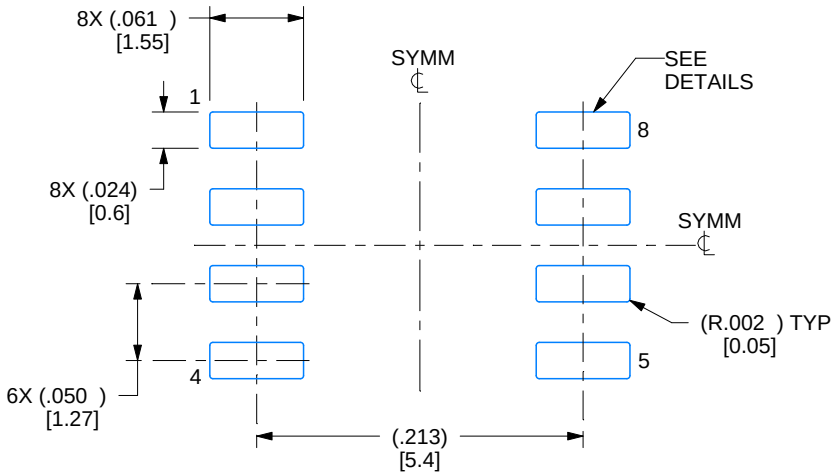
SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

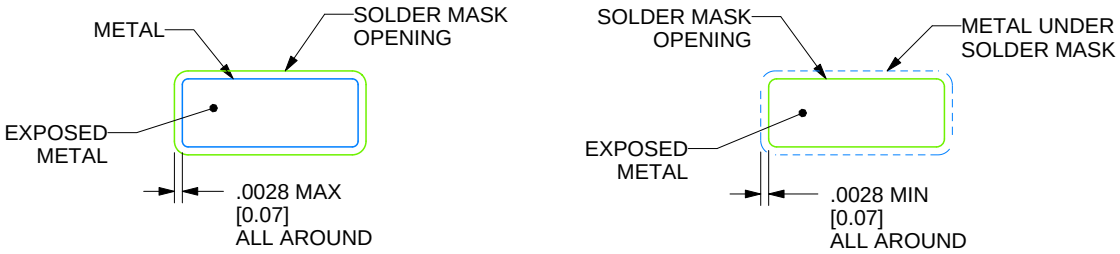


NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

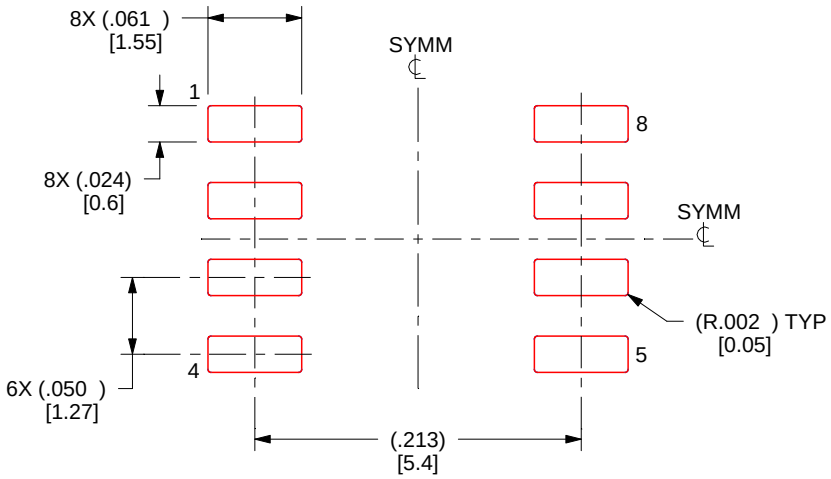
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

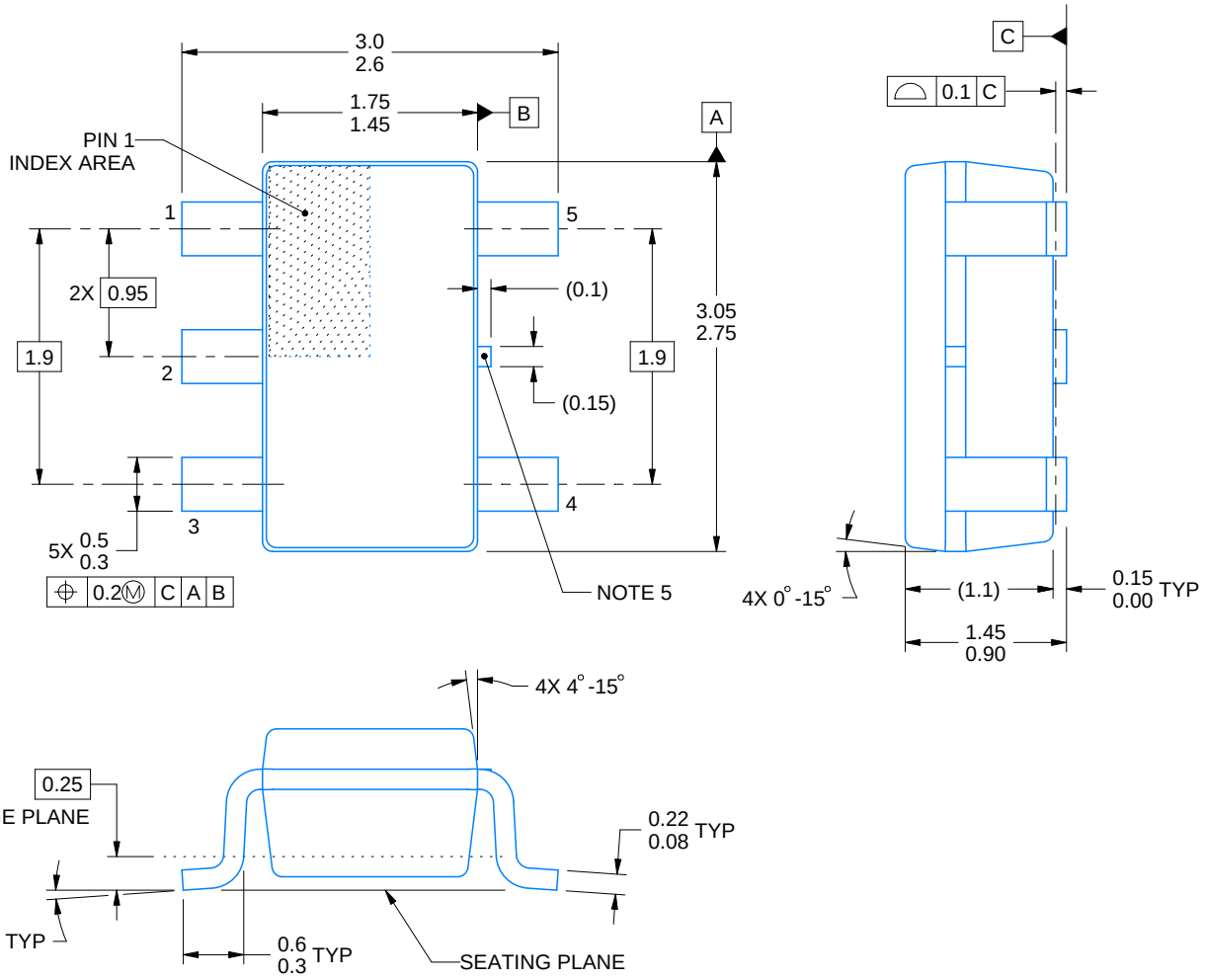
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

PACKAGE OUTLINE

DBV0005A

SOT-23 - 1.45 mm max height

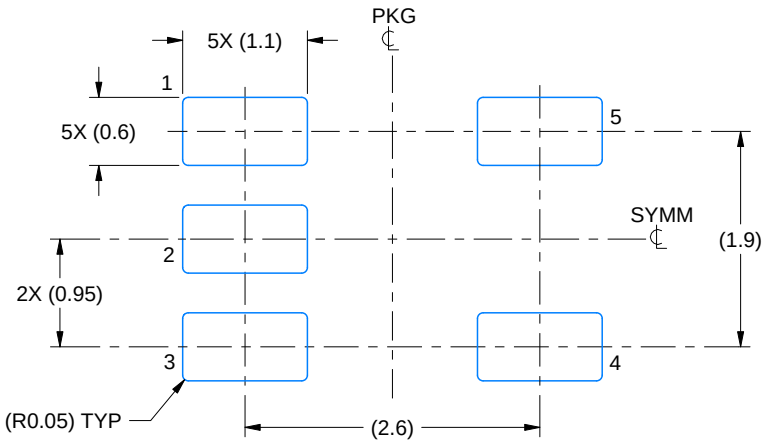
SMALL OUTLINE TRANSISTOR



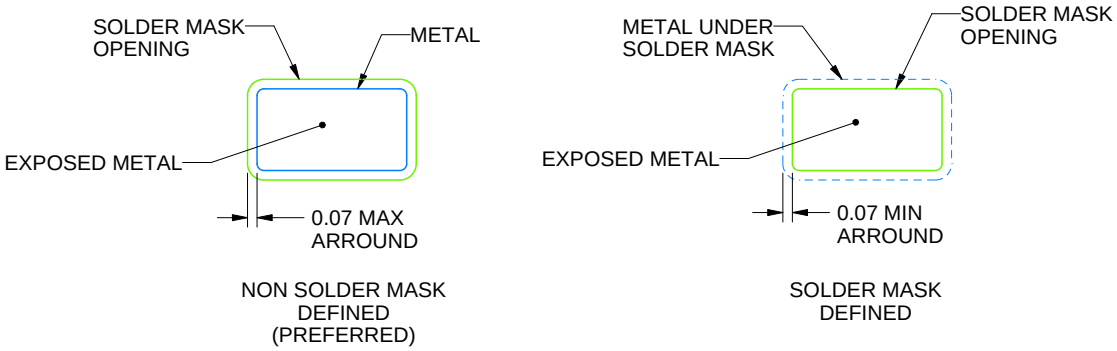
4214839/K 08/2024

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. Refernce JEDEC MO-178.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:15X

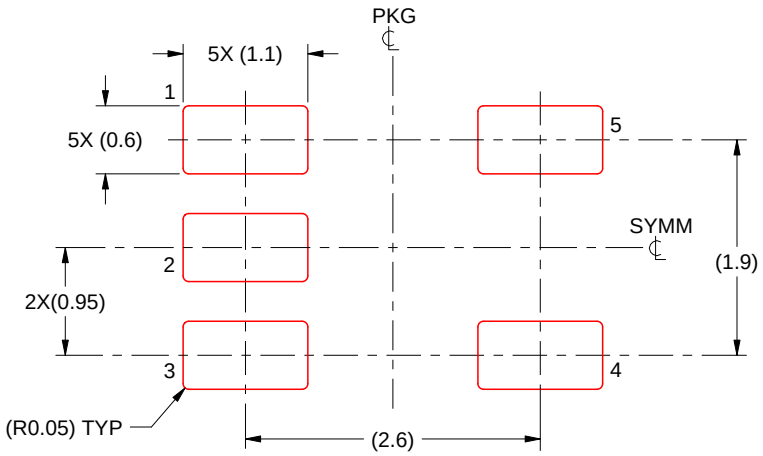


SOLDER MASK DETAILS

4214839/K 08/2024

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:15X

4214839/K 08/2024

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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