1.8V, 1µA max, Zerø-Crossover RAIL-TO-RAIL I/O OPERATIONAL AMPLIFIER

FEATURES

- **ZERØ-CROSSOVER**
- **LOW POWER: 1µA (max)**
- **LOW OFFSET VOLTAGE: 750µV (max)**
- **LOW VOLTAGE SUPPLY: +1.8V to +5.5V**
- **LOW OFFSET DRIFT: 1.75µV/°C (max)**
- ***micro*SIZE PACKAGES:**
  - **SC70-5, SOT23-8, MSOP-8**

APPLICATIONS

- **BATTERY-POWERED INSTRUMENTS**
- **PORTABLE DEVICES**
- **MEDICAL INSTRUMENTS**
- **TEST EQUIPMENT**

DESCRIPTION

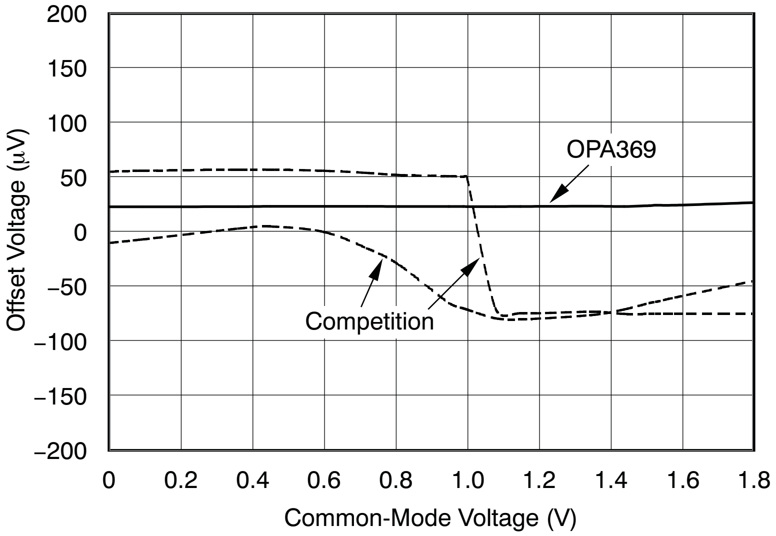
The OPA369 and OPA2369 are new low-power, low-voltage operational amplifiers from Texas Instruments designed especially for battery-powered applications.

The OPAx369 operates on a supply voltage as low as 1.8V and has true rail-to-rail operation that makes it useful for a wide range of applications. The *zero-crossover* feature resolves the problem of input crossover distortion that becomes very prominent in low voltage (< 3V), rail-to-rail input applications.

In addition to *micro*size packages and very low quiescent current (1µA, max) the OPAx369 features 12kHz bandwidth, low offset drift (1.75µV/°C, max), and low 0.1Hz to 10Hz noise (3.6µV$_{PP}$).

The OPA369 (single version, available Q4 2007) is offered in an SC70-5 package. The OPA2369 (dual version) comes in both MSOP-8 and SOT23-8 packages.

OFFSET VOLTAGE
vs COMMON-MODE VOLTAGE
(V_S = 1.8V)



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

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

ABSOLUTE MAXIMUM RATINGS[1]

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

		VALUE	UNIT
Supply Voltage, V_S = (V+) – (V–)		+7V	V
Single Input Terminals	Voltage[2]	–0.5 to (V+) + 0.5	V
	Current[2]	±10	mA
Output Short-Circuit[3]		Continuous	
Operating Temperature, T_A		–55 to +125	°C
Storage Temperature, T_A		–65 to +150	°C
Junction Temperature, T_J		+150	°C
ESD Ratings	Human Body Model (HBM)	4000	V
	Charged Device Model (CDM)	1000	V
	Machine Model (MM)	200	V

(1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.
(2) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5V beyond the supply rails should be current limited to 10mA or less.
(3) Short-circuit to $V_S/2$, one amplifier per package.

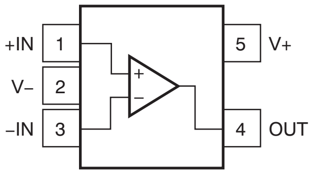
PACKAGE/ORDERING INFORMATION[1]

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
OPA369	SC70-5[2]	DCK	CJS
OPA2369	MSOP-8	DGK	OCCQ
	SOT23-8	DCN	OCBQ

(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.
(2) Available Q4, 2007.

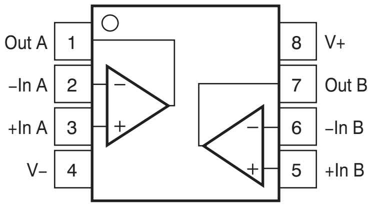
PIN CONFIGURATIONS

OPA369[1]
SC70-5
(TOP VIEW)



(1) Available Q4, 2007.

OPA2369
MSOP-8, SOT23-8
(TOP VIEW)



ELECTRICAL CHARACTERISTICS: V_S = +1.8V to +5.5V

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +85°C.
At T_A = +25°C, R_L = 100kΩ connected to V_S/2, unless otherwise noted.

			OPA369[1], OPA2369			
PARAMETER		**CONDITIONS**	**MIN**	**TYP**	**MAX**	**UNIT**
OFFSET VOLTAGE						
Input Offset Voltage	V_{OS}			250	750	µV
over Temperature					**1**	**mV**
Drift	**dV_{OS}/dT**			**0.4**	**1.75**	**µV/°C**
vs Power Supply	**PSRR**	**V_S = 1.8V to 5.5V**		**5**	**20**	**µV/V**
Channel Separation		**dc**		**0.1**		**µV/V**
		f = 1kHz		**120**		**dB**
INPUT VOLTAGE RANGE						
Common-Mode Voltage Range	V_{CM}		(V–)		(V+)	V
Common-Mode Rejection Ratio	CMRR	(V–) ≤ V_{CM} ≤ (V+)	100	114		dB
over Temperature		**(V–) ≤ V_{CM} ≤ (V+)**	**90**			**dB**
INPUT BIAS CURRENT						
Input Bias Current	I_B			10	50	pA
Input Offset Current	I_{OS}			10	50	pA
INPUT IMPEDANCE						
Differential				$10^{13} \parallel 3$		Ω ∥ pF
Common-Mode				$10^{13} \parallel 6$		Ω ∥ pF
NOISE						
Input Voltage Noise		f = 0.1Hz to 10Hz		3.6		μV_{PP}
Input Voltage Noise Density		f = 100Hz		160		nV/√Hz
		f = 1kHz		120		nV/√Hz
Current Noise Density		f = 1kHz		1		fA/√Hz
OPEN-LOOP GAIN						
Open-Loop Voltage Gain	A_{OL}	100mV ≤ V_O ≤ (V+)–100mV, R_L = 100kΩ	114	134		dB
Over Temperature		**100mV ≤ V_O ≤ (V+)–100mV, R_L = 100kΩ**	**100**			**dB**
		500mV ≤ V_O ≤ (V+)–500mV, R_L = 10kΩ	114	134		dB
Over Temperature		**500mV ≤ V_O ≤ (V+)–500mV, R_L = 10kΩ**	**90**			**dB**
OUTPUT						
Voltage Output Swing from Rail		**R_L = 100kΩ**			**10**	**mV**
		R_L = 10kΩ			**25**	**mV**
Short-Circuit Current	I_{SC}			10		mA
Capacitive Load Drive	C_{LOAD}		See Typical Characteristics			pF
FREQUENCY RESPONSE						
Gain-Bandwidth Product	GBW			12		kHz
Slew Rate	SR	G = +1		0.005		V/µs
Overload Recovery Time		V_{IN} × Gain > V_S		250		µs
POWER SUPPLY						
Specified Voltage	V_S		1.8		5.5	V
Quiescent Current (per channel amplifier)	I_Q	I_{OUT} = 0A		0.7	1	µA
Over Temperature					**1.25**	**µA**

(1) OPA369 specifications are preview. Available Q4, 2007.

ELECTRICAL CHARACTERISTICS: V_S = +1.8V to +5.5V (continued)

BOLDFACE limits apply over the specified temperature range, T_A = –40°C to +85°C.
At T_A = +25°C, R_L = 100kΩ connected to $V_S/2$, unless otherwise noted.

PARAMETER		CONDITIONS	OPA369[1], OPA2369			UNIT
			MIN	TYP	MAX	
TEMPERATURE RANGE						
Specified Range		T_A	–40		+85	°C
Operating Range		T_A	–55		+125	°C
Thermal Resistance	θ_{JA}					
SC70				250		°C/W
SOT23				223		°C/W
MSOP				252		°C/W

TYPICAL CHARACTERISTICS

At T_A = +25°C, V_S = 5V, R_L = 100kΩ connected to V_S/2, unless otherwise noted.

OFFSET VOLTAGE PRODUCTION DISTRIBUTION

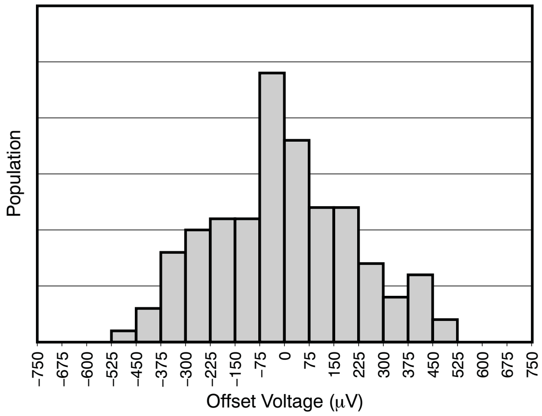


Figure 1.

OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION

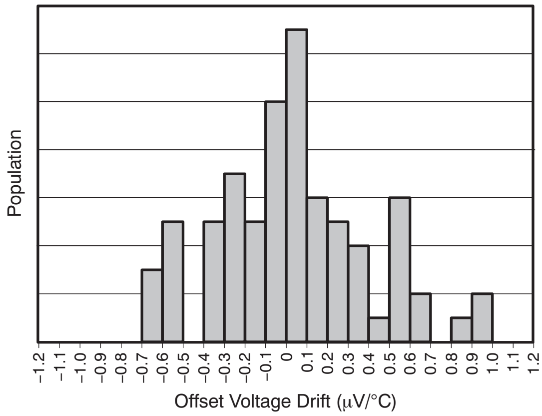


Figure 2.

OFFSET VOLTAGE vs TEMPERATURE

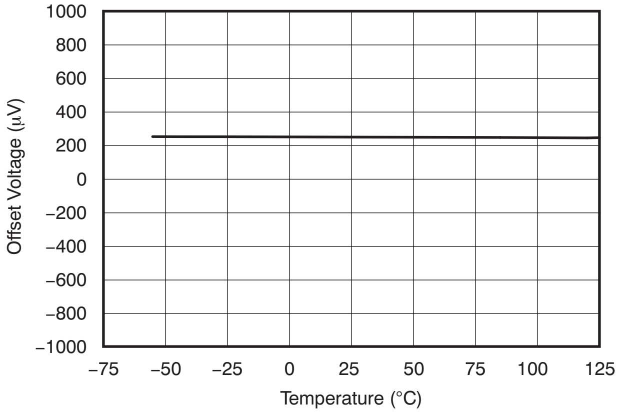


Figure 3.

NORMALIZED OFFSET VOLTAGE vs COMMON-MODE VOLTAGE

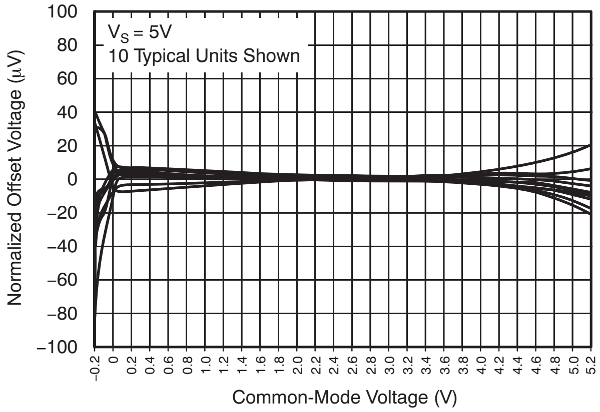


Figure 4.

0.1Hz to 10Hz NOISE

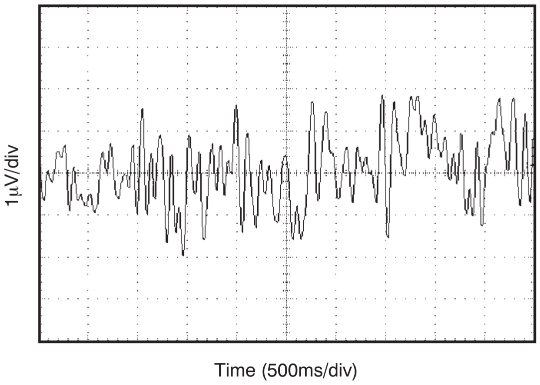


Figure 5.

INPUT-REFERRED VOLTAGE NOISE vs FREQUENCY

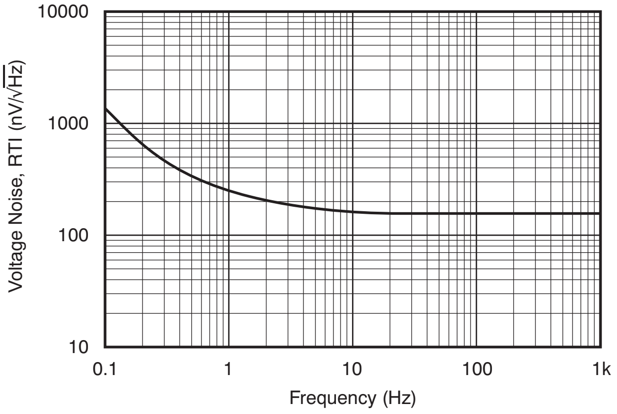


Figure 6.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = 5V, R_L = 100kΩ connected to $V_S/2$, unless otherwise noted.

OPEN-LOOP GAIN AND PHASE vs FREQUENCY

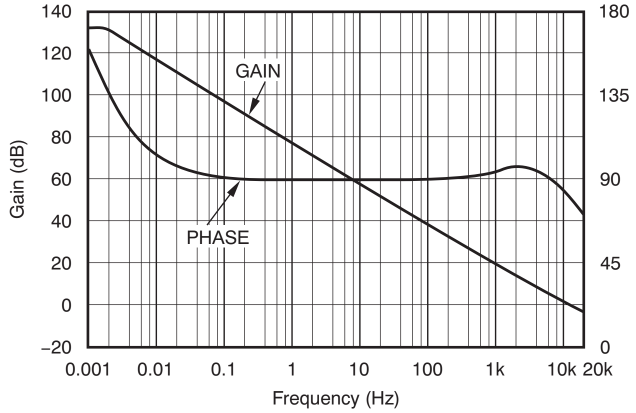


Figure 7.

POWER-SUPPLY REJECTION RATIO vs FREQUENCY

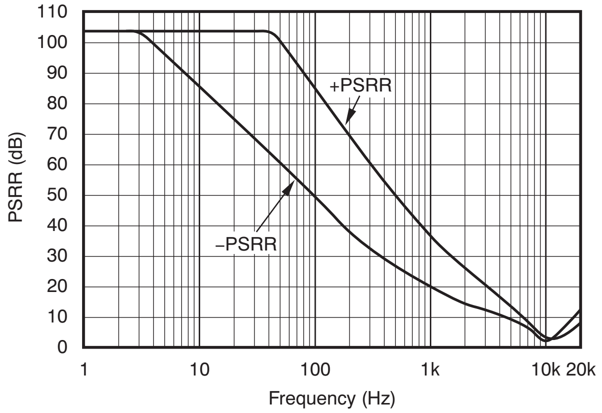


Figure 8.

COMMON-MODE REJECTION RATIO vs FREQUENCY

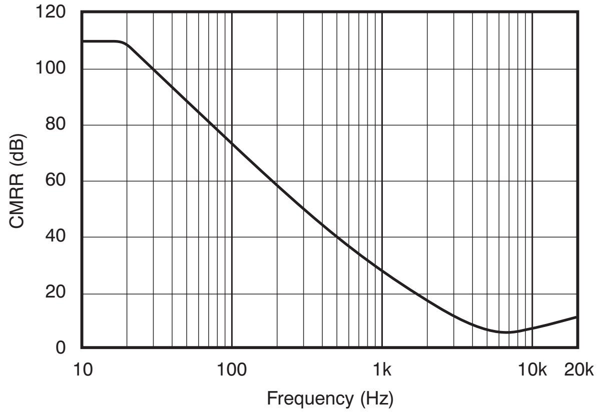


Figure 9.

CHANNEL SEPARATION vs FREQUENCY

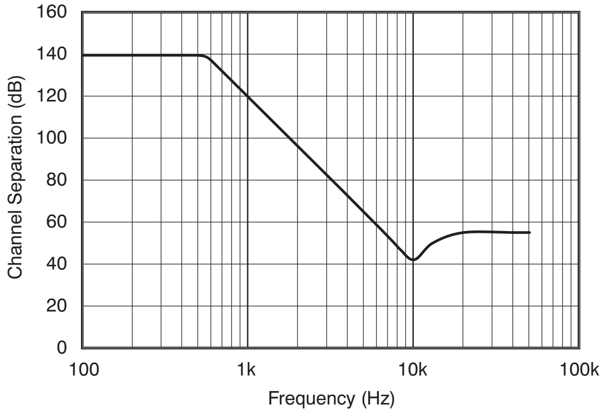


Figure 10.

COMMON-MODE REJECTION RATIO vs TEMPERATURE

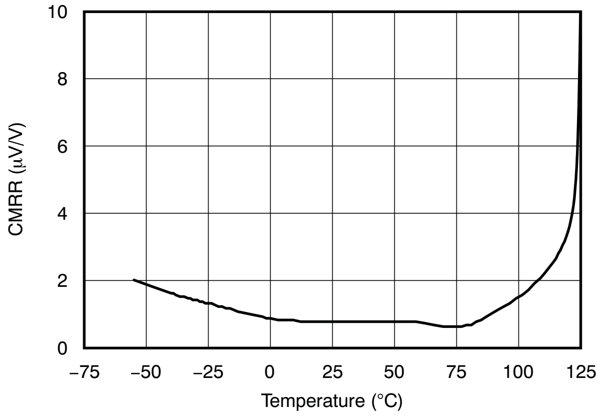


Figure 11.

POWER-SUPPLY REJECTION RATIO vs TEMPERATURE

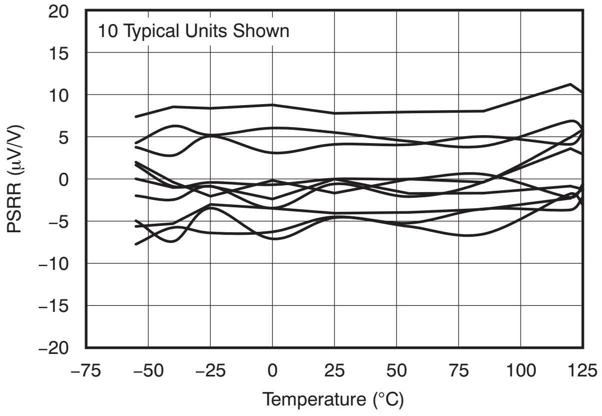


Figure 12.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = 5V, R_L = 100kΩ connected to V_S/2, unless otherwise noted.

OPEN-LOOP GAIN vs TEMPERATURE

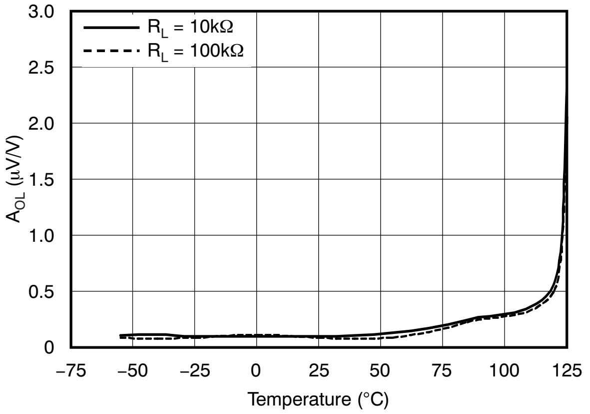


Figure 13.

OUTPUT VOLTAGE SWING-FROM-RAIL vs TEMPERATURE

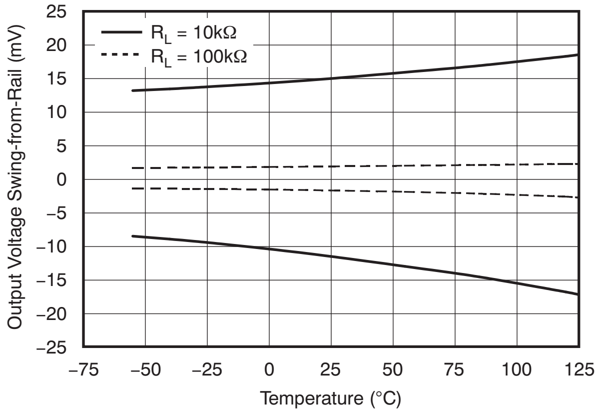


Figure 14.

INPUT BIAS CURRENT vs TEMPERATURE

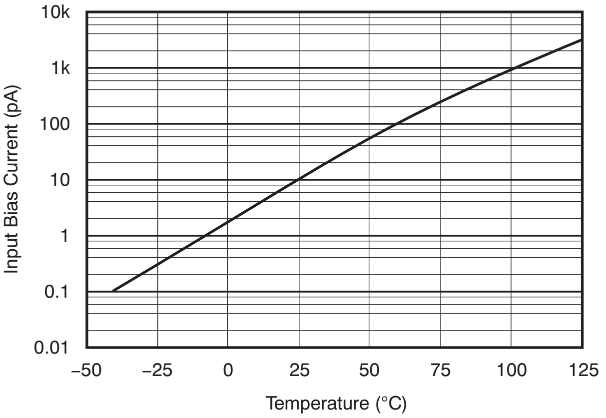


Figure 15.

OUTPUT VOLTAGE vs OUTPUT CURRENT

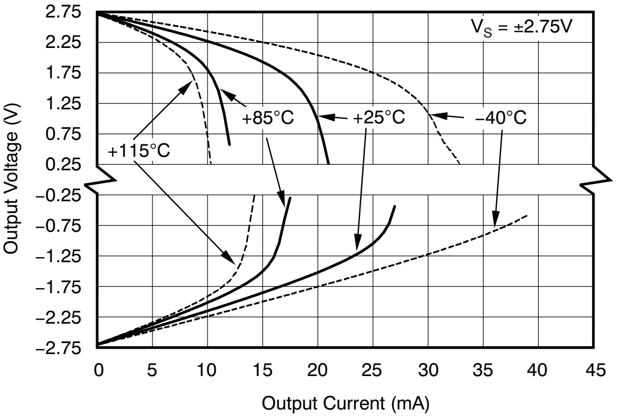


Figure 16.

QUIESCENT CURRENT vs TEMPERATURE

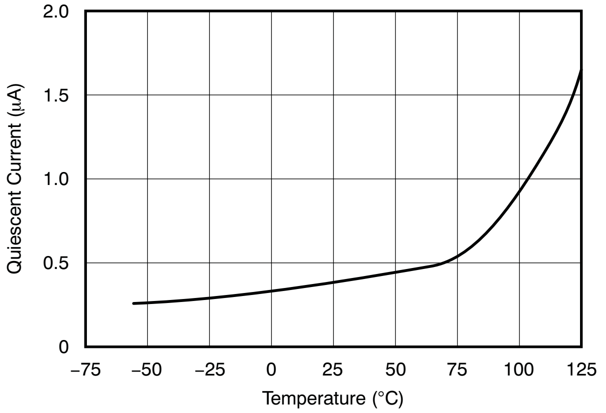


Figure 17.

MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

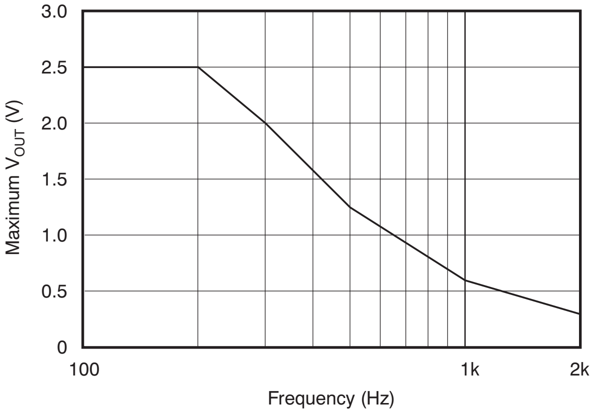


Figure 18.

TYPICAL CHARACTERISTICS (continued)

At T_A = +25°C, V_S = 5V, R_L = 100kΩ connected to $V_S/2$, unless otherwise noted.

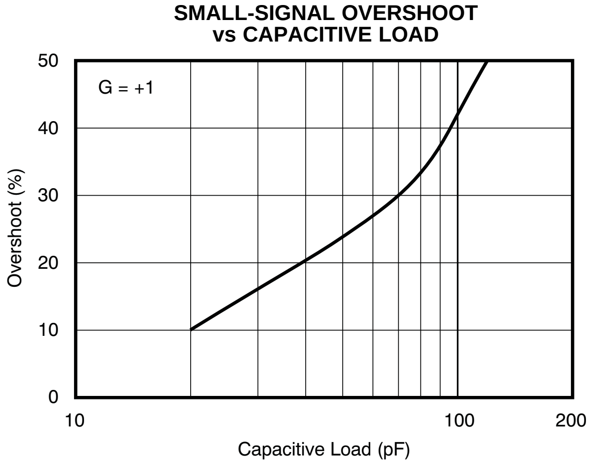


Figure 19.

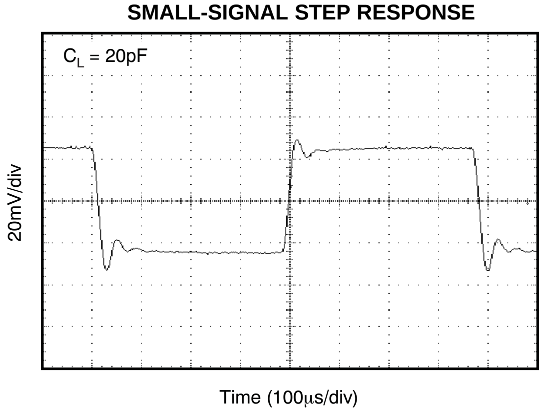


Figure 20.

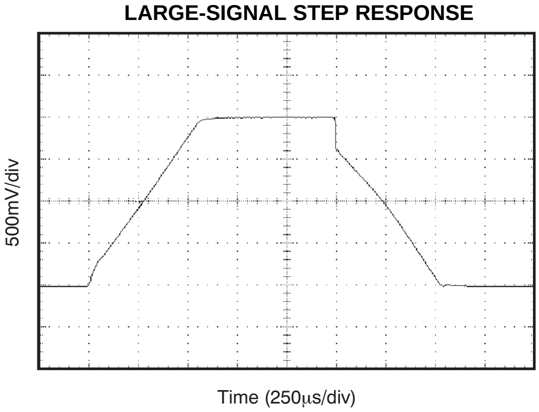


Figure 21.

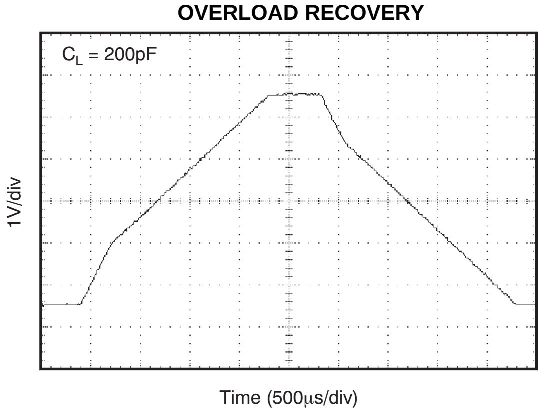


Figure 22.

APPLICATION INFORMATION

The OPA369 family of operational amplifiers minimizes power consumption and operates on supply voltages as low as 1.8V. Power-supply rejection ratio (PSRR), common-mode rejection ratio (CMRR), and open-loop gain (A_{OL}) typical values are in the range of 100dB or better.

When designing for ultralow power, choose system components carefully. To minimize current consumption, select large-value resistors. However, note that large resistors will react with stray capacitance in the circuit and the input capacitance of the operational amplifier. These parasitic RC combinations can affect the stability of the overall system. A feedback capacitor may be required to assure stability and limit overshoot or gain peaking.

Good layout practice and use of a 0.1μF bypass capacitor placed closely across the supply pins are mandatory.

OPERATING VOLTAGE

OPA369 series op amps are fully specified and tested from +1.8V to +5.5V. Parameters that vary significantly with supply voltage are shown in the Typical Characteristic curves.

INPUT COMMON-MODE VOLTAGE RANGE

The OPA369 family is designed to eliminate the input offset transition region typically present in most rail-to-rail complementary stage operational amplifiers, which allows the OPA369 family of amplifiers to provide superior common-mode performance over the entire input range.

The input common-mode voltage range of the OPA369 family typically extends to each supply rail. CMRR is specified from the negative rail to the positive rail. See Figure 4 the *Normalized Offset Voltage vs Common-Mode Voltage*.

PROTECTING INPUTS FROM OVER-VOLTAGE

Input currents are typically 10pA. However, large inputs (greater than 500mV beyond the supply rails) can cause excessive current to flow in or out of the input pins. Therefore, in addition to keeping the input voltage between the supply rails, it is also important to limit the input current to less than 10mA. This limiting is easily accomplished with an input resistor, as shown in Figure 23.

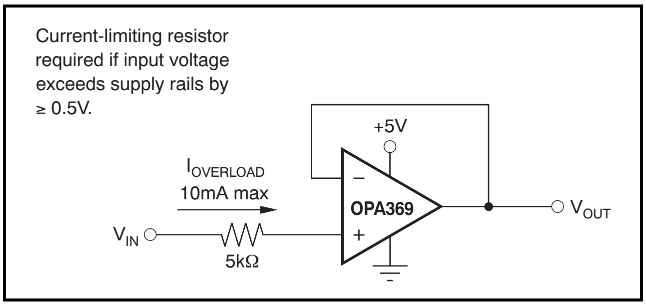


Figure 23. Input Current Protection for Voltages Exceeding the Supply Voltage

NOISE

Although micropower amplifiers frequently have high wideband noise, the OPA369 series offers excellent noise performance. The OPA369 has only $2.8\mu V_{PP}$ of 0.1Hz to 10Hz noise, and $80nV/\sqrt{Hz}$ of wideband noise. Resistors should be chosen carefully, because they can become the dominant source of noise.

CAPACITIVE LOAD AND STABILITY

Follower configurations with load capacitance in excess of approximately 50pF can produce extra overshoot and ringing in the output signal (see Figure 19). Increasing the gain enhances the ability of the amplifier to drive greater capacitive loads. In unity-gain configurations, capacitive load drive can be improved by inserting a small (10Ω to 20Ω) resistor, R_S, in series with the output, as shown in Figure 24. This resistor significantly reduces ringing while maintaining dc performance for purely capacitive loads. However, if there is a resistive load in parallel with the capacitive load, a voltage divider is created, introducing a dc error at the output and slightly reducing the output swing. The error introduced is proportional to the ratio R_S/R_L, and is generally negligible.

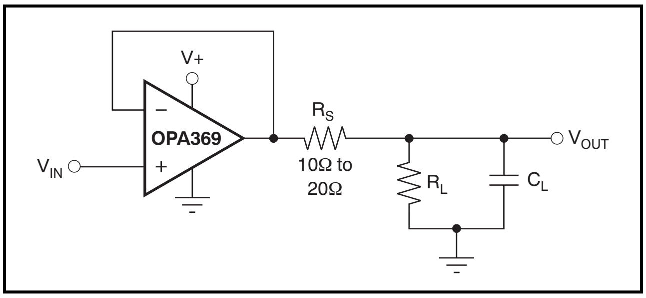


Figure 24. Series Resistor in Unity-Gain Buffer Configuration Improves Capacitive Load Drive

In unity-gain inverter configuration, phase margin can be reduced by the reaction between the capacitance at the op amp input and the gain setting resistors. Best performance is achieved by using smaller valued resistors. However, when larger valued resistors cannot be avoided, a small (4pF to 6pF) capacitor, C_{FB}, can be inserted in the feedback, as shown in Figure 25. This configuration significantly reduces overshoot by compensating the effect of capacitance, C_{IN}, which includes the amplifier input capacitance and printed circuit board (PCB) parasitic capacitance.

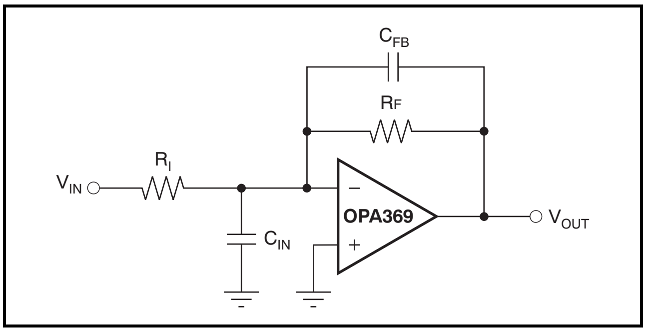


Figure 25. Improving Stability for Large R_F and R_{IN}

BATTERY MONITORING

The low operating voltage and quiescent current of the OPA369 series make it an excellent choice for battery monitoring applications, as shown in Figure 26. In this circuit, V_{STATUS} is high as long as the battery voltage remains above 2V. A low-power reference is used to set the trip point. Resistor values are selected as follows:

1. Selecting R_F: Select R_F such that the current through R_F is approximately 1000x larger than the maximum bias current over temperature:

$$R_F = \frac{V_{REF}}{1000(I_{BMAX})} = \frac{1.2V}{1000(50pA)} = 24M\Omega \approx 20M\Omega \qquad (1)$$

2. Choose the hysteresis voltage, V_{HYST}. For battery-monitoring applications, 50mV is adequate.
3. Calculate R_1 as follows:

$$R_1 = R_F\left[\frac{V_{HYST}}{V_{BATT}}\right] = 20M\Omega\left[\frac{50mV}{2.4V}\right] = 420k\Omega \qquad (2)$$

4. Select a threshold voltage for V_{IN} rising (V_{THRS}) = 2.0V
5. Calculate R_2 as follows:

$$R_2 = \frac{1}{\left[\left(\frac{V_{THRS}}{V_{BATT}}\right) - \frac{1}{R_1} - \frac{1}{R_1}\right]} = \frac{1}{\left[\left(\frac{2V}{1.2V \times 420k\Omega}\right) - \frac{1}{420k\Omega} - \frac{1}{20M\Omega}\right]} = 650k\Omega \qquad (3)$$

6. Calculate R_{BIAS}: The minimum supply voltage for this circuit is 1.8V. The REF1112 has a current requirement of 1.2μA (max). Providing the REF1112 with 2μA of supply current assures proper operation. Therefore:

$$R_{BIAS} = \frac{V_{BATTMIN}}{I_{BIAS}} = \frac{1.8V}{2\mu A} = 0.9M\Omega \qquad (4)$$

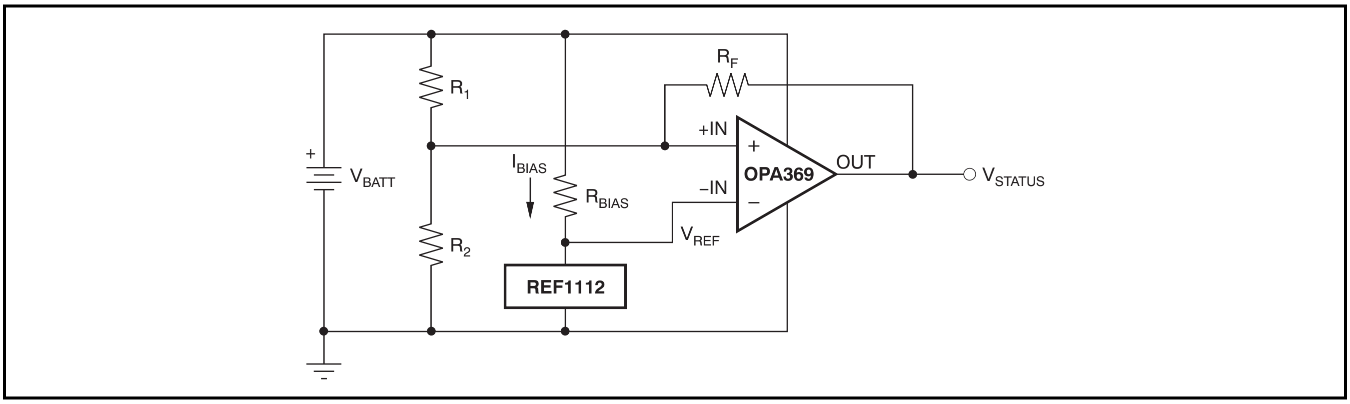


Figure 26. Battery Monitor

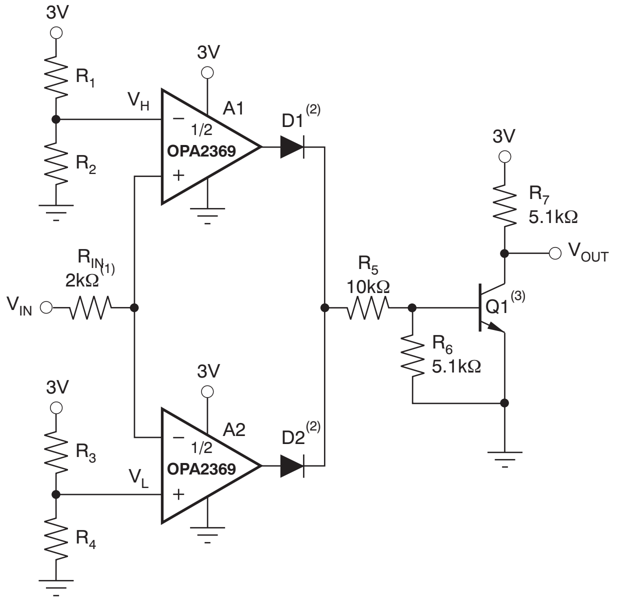
WINDOW COMPARATOR

Figure 27 shows the OPA2369 used as a window comparator. The threshold limits are set by V_H and V_L, with $V_H > V_L$. When $V_{IN} < V_H$, the output of A1 is low. When $V_{IN} > V_L$, the output of A2 is low. Therefore, both op amp outputs are at 0V as long as V_{IN} is between V_H and V_L. This configuration results in no current flowing through either diode, Q1 in cutoff, with the base voltage at 0V, and V_{OUT} forced high.

If V_{IN} falls below V_L, the output of A2 is high, current flows through D2, and V_{OUT} is low. Likewise, if V_{IN} rises above V_H, the output of A1 is high, current flows through D1, and V_{OUT} is low. The window comparator threshold voltages are set as follows:

$$V_H = \frac{R_2}{R_1 + R_2} \tag{5}$$

$$V_L = \frac{R_4}{R_3 + R_4} \tag{6}$$



NOTES: (1) R_{IN} protects A1 and A2 from possible excess current flow.
(2) IN4446 or equivalent diodes.
(3) 2N2222 or equivalent NPN transistor.

Figure 27. OPA2369 as a Window Comparator

ADDITIONAL APPLICATION EXAMPLES

Figure 28 through Figure 32 illustrate additional application examples.

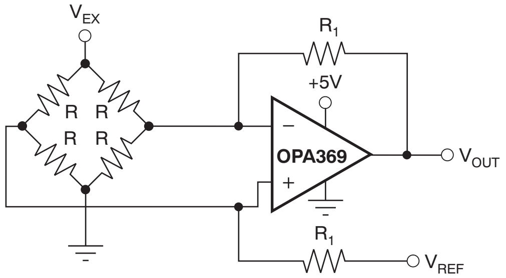


Figure 28. Single Op Amp Bridge Amplifier

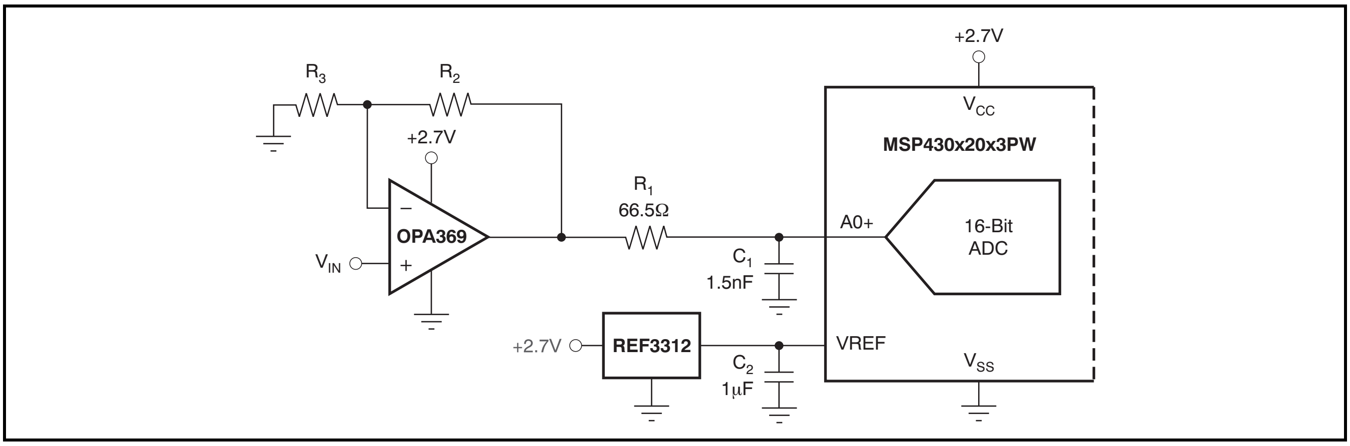
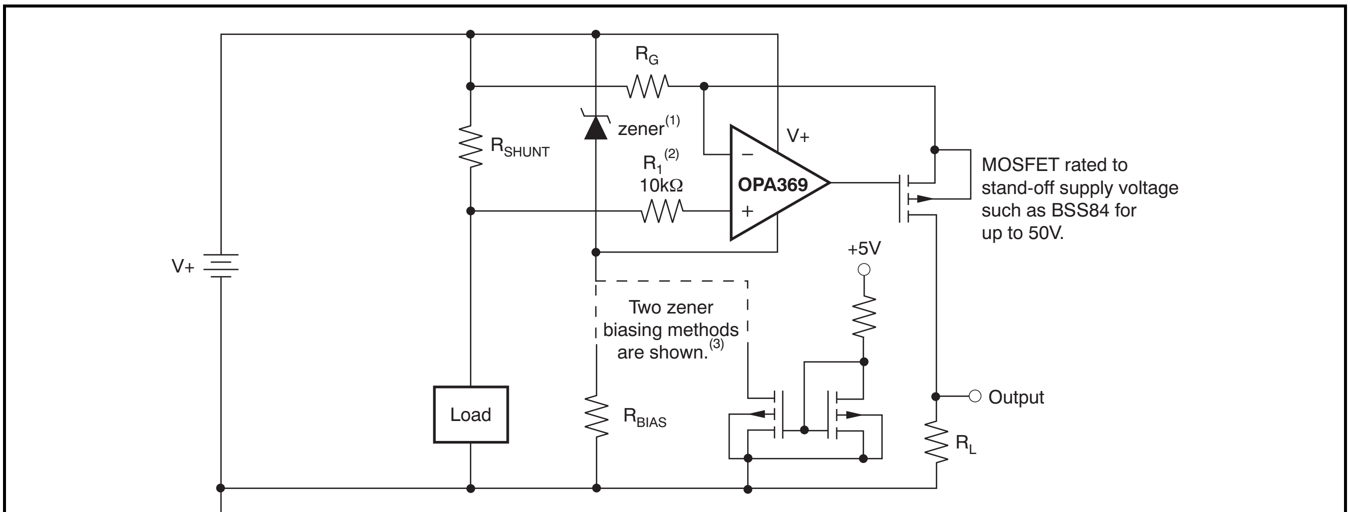
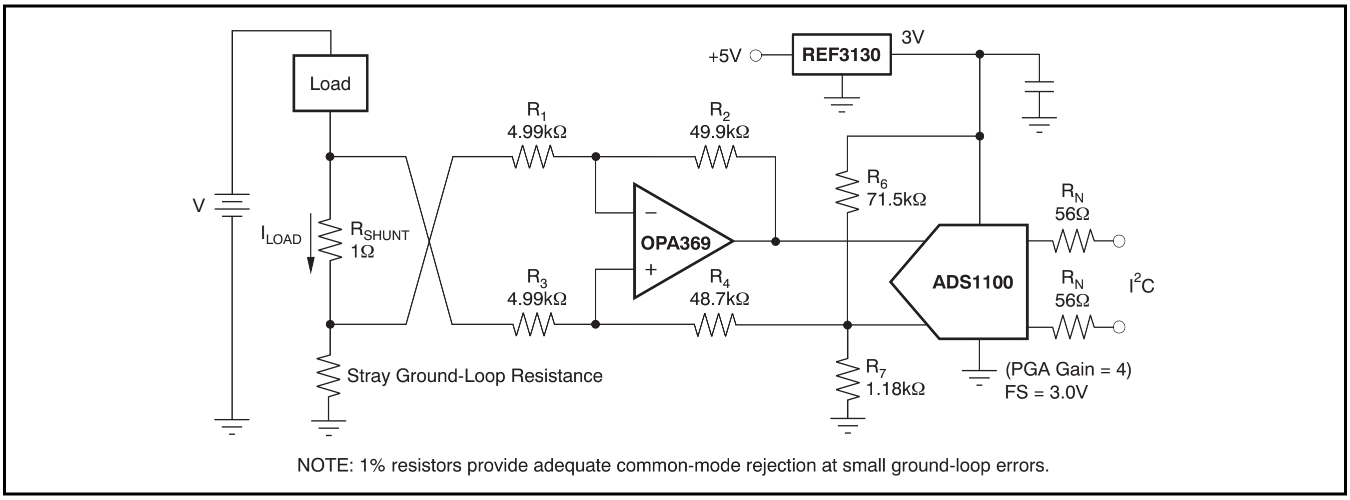


Figure 29. Unipolar Signal Chain Configuration



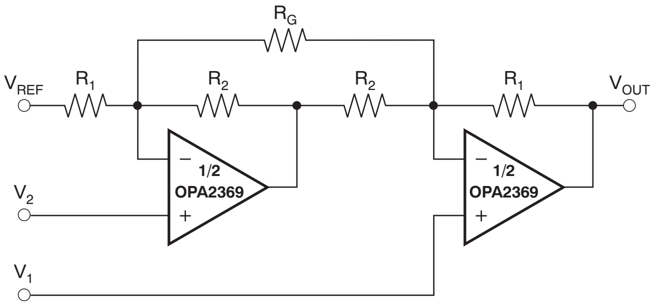
NOTES: (1) Zener rated for op amp supply capability (that is, 5.1V for OPA369).
(2) Current-limiting resistor.
(3) Choose zener biasing resistor or dual NMOSFETs (FDG6301N, NTJD4001N, or Si1034)

Figure 30. High-Side Current Monitor



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

Figure 31. Low-Side Current Monitor



$$V_{OUT} = (V_1 - V_2)\left(1 + \frac{R_1}{R_2} + \frac{2R_1}{R_G}\right) + V_{REF}$$

Figure 32. Two Op Amp Instrumentation Amplifier

PACKAGE OPTION ADDENDUM

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
OPA2369AIDCNR	ACTIVE	SOT-23	DCN	8	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDCNRG4	ACTIVE	SOT-23	DCN	8	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDCNT	ACTIVE	SOT-23	DCN	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDCNTG4	ACTIVE	SOT-23	DCN	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDGKR	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDGKRG4	ACTIVE	MSOP	DGK	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDGKT	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA2369AIDGKTG4	ACTIVE	MSOP	DGK	8	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA369AIDCKR	PREVIEW	SC70	DCK	5	3000	TBD	Call TI	Call TI
OPA369AIDCKT	PREVIEW	SC70	DCK	5	250	TBD	Call TI	Call TI

[1] The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

[2] Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

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

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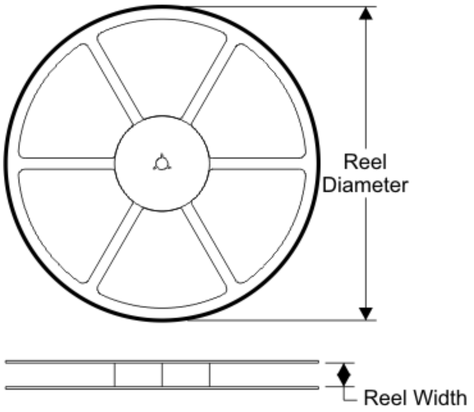
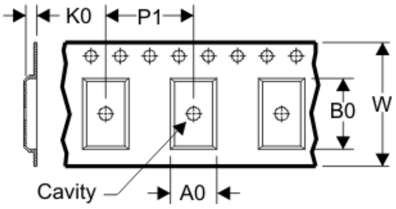
TAPE AND REEL BOX INFORMATION

REEL DIMENSIONS

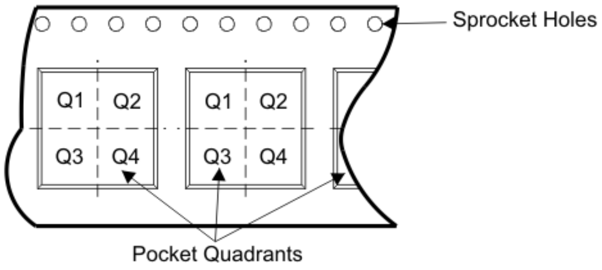


TAPE DIMENSIONS



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

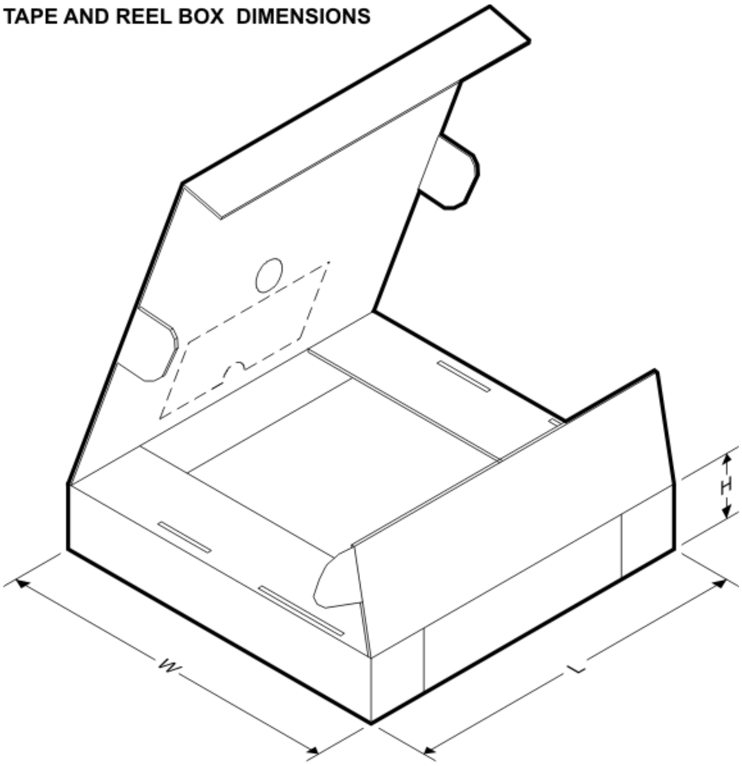
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



Device	Package	Pins	Site	Reel Diameter (mm)	Reel Width (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
OPA2369AIDCNR	DCN	8	SITE 48	179	8	3.2	3.2	1.4	4	8	Q3
OPA2369AIDCNT	DCN	8	SITE 48	179	8	3.2	3.2	1.4	4	8	Q3

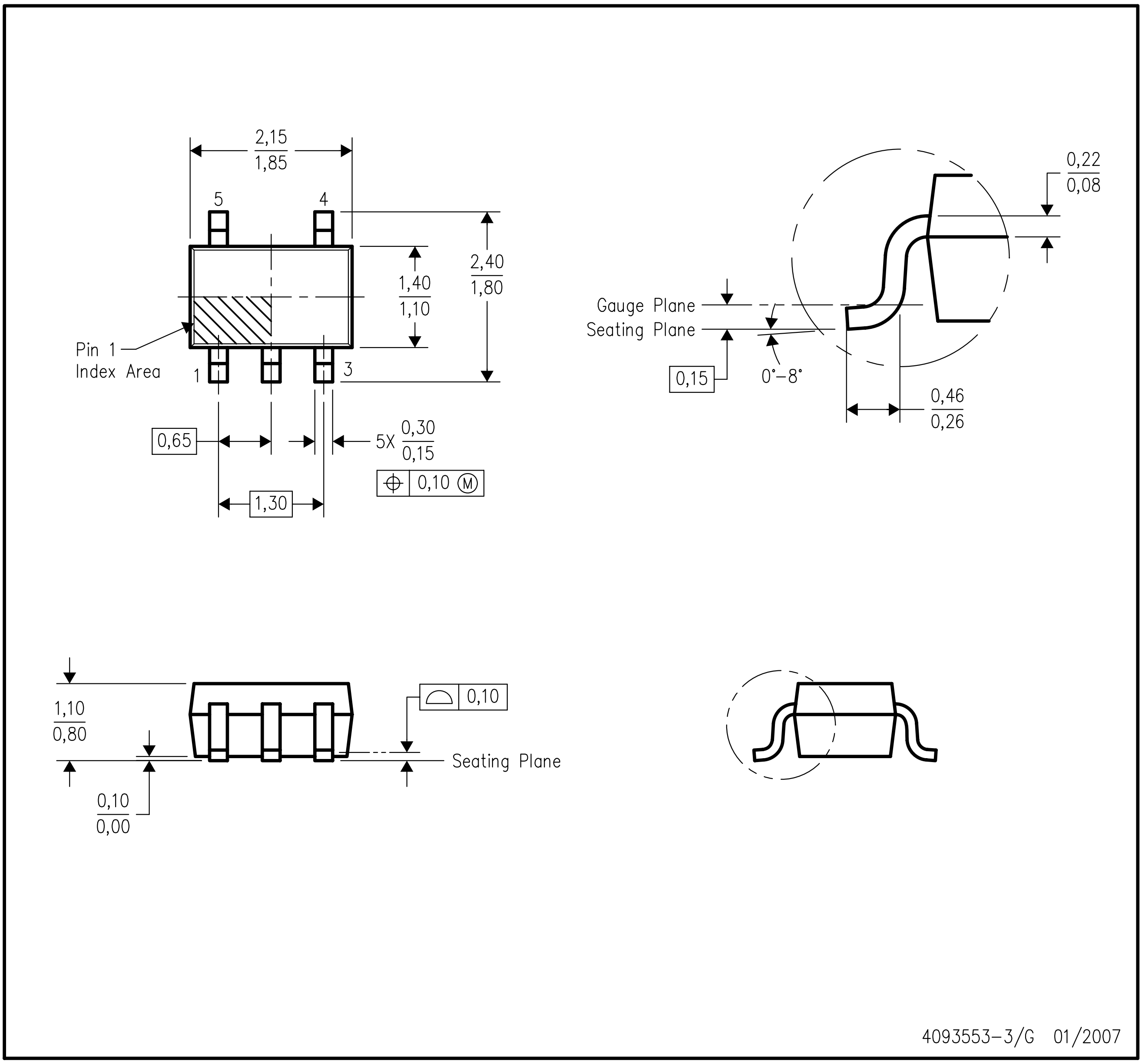
PACKAGE MATERIALS INFORMATION

TAPE AND REEL BOX DIMENSIONS



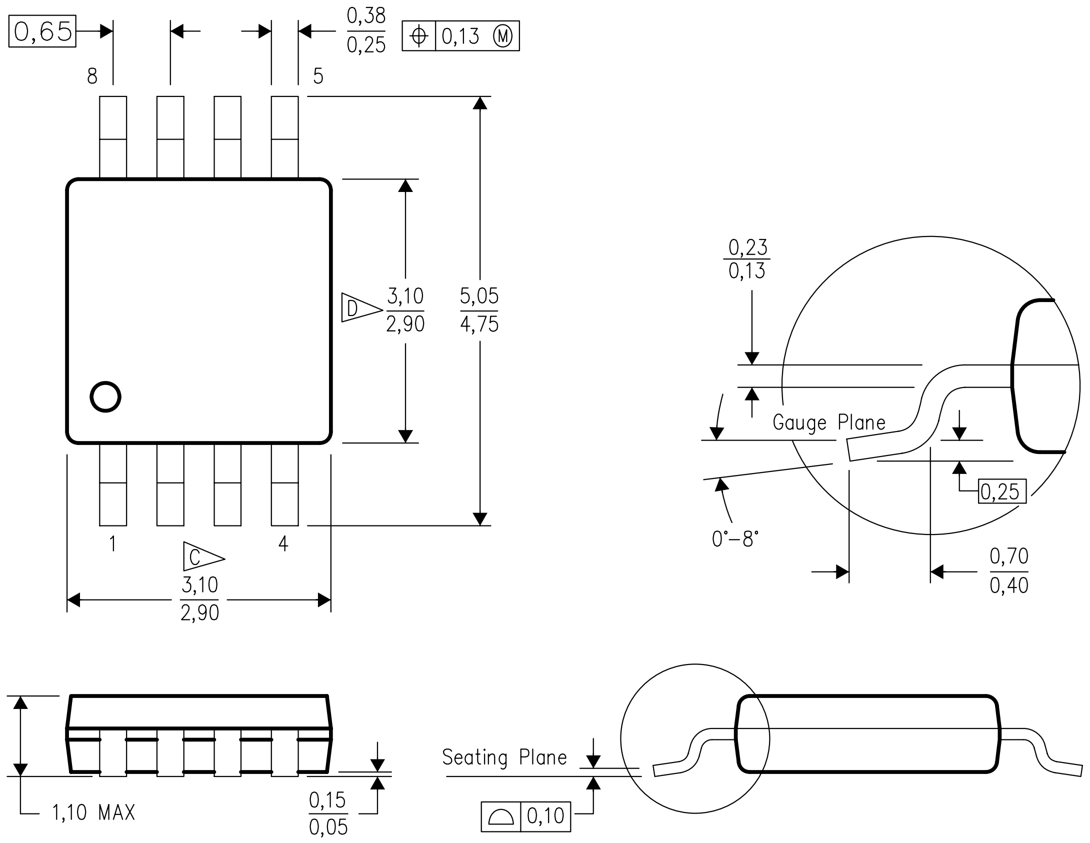
Device	Package	Pins	Site	Length (mm)	Width (mm)	Height (mm)
OPA2369AIDCNR	DCN	8	SITE 48	195.0	200.0	45.0
OPA2369AIDCNT	DCN	8	SITE 48	195.0	200.0	45.0

DCK (R-PDSO-G5) PLASTIC SMALL-OUTLINE PACKAGE



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

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



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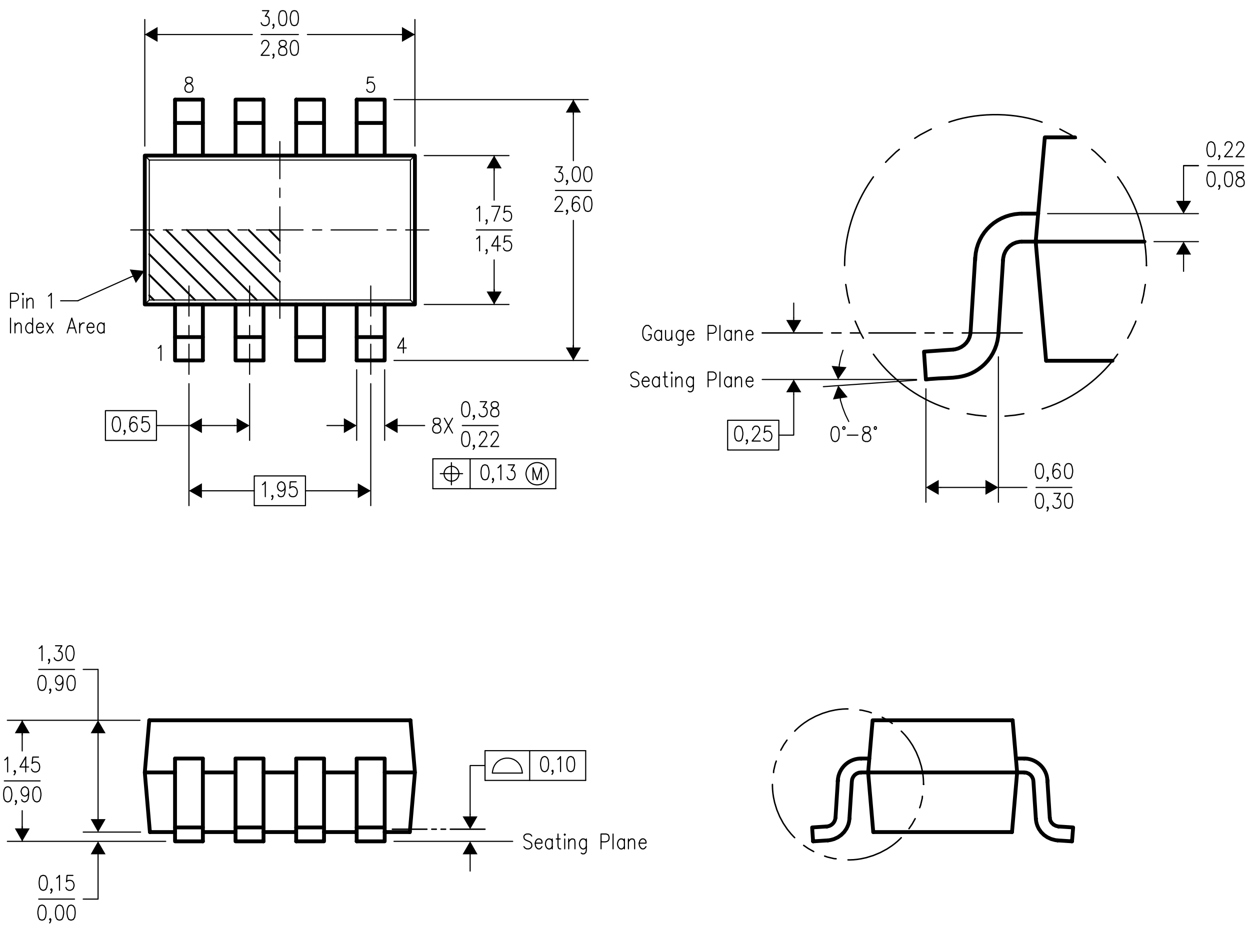
NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C▷ Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 per end.
- D▷ Body width does not include interlead flash.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

DCN (R-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE (DIE DOWN)



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NOTES:
- A. All linear dimensions are in millimeters.
- B. This drawing is subject to change without notice.
- C. Package outline exclusive of mold flash, metal burr & dambar protrusion/intrusion.
- D. Package outline inclusive of solder plating.
- E. A visual index feature must be located within the Pin 1 index area.
- F. Falls within JEDEC MO–178 Variation BA.

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