

# 1.8V, 700nA, Zero-Crossover RAIL-TO-RAIL I/O OPERATIONAL AMPLIFIER

## FEATURES

- **nanoPOWER:**
  - OPA369: 800nA
  - OPA2369: 700nA/ch.
- **LOW OFFSET VOLTAGE: 250 $\mu$ V**
  - ZERO-CROSSOVER
- **LOW OFFSET DRIFT: 0.4 $\mu$ V/°C**
- **DC PRECISION:**
  - CMRR: 114dB
  - PSRR: 106dB
  - AOL: 134dB
- **GAIN-BANDWIDTH PRODUCT: 12kHz**
- **SUPPLY VOLTAGE: 1.8V to 5.5V**
- **microSIZE PACKAGES:**
  - SC70-5, SOT23-5, MSOP-8

## DESCRIPTION

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

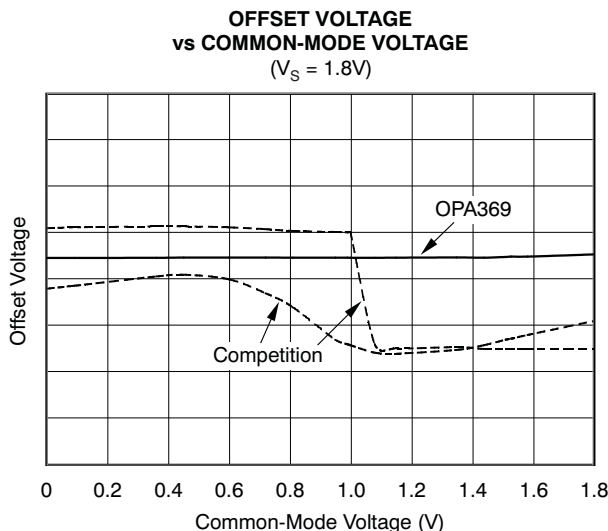
The OPAx369 operates on a supply voltage as low as 1.8V and has true rail-to-rail operation that makes it useful for a wide range of applications. The *zero-crossover* feature resolves the problem of input crossover distortion that becomes very prominent in low voltage (< 3V), rail-to-rail input applications.

In addition to *microsize* packages and very low quiescent current, the OPAx369 features 12kHz bandwidth, low offset drift (1.75 $\mu$ V/°C, max), and low noise 3.6 $\mu$ V<sub>PP</sub> (0.1Hz to 10Hz).

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

## APPLICATIONS

- BATTERY-POWERED INSTRUMENTS
- PORTABLE DEVICES
- MEDICAL INSTRUMENTS
- TEST EQUIPMENT
- LOW-POWER SENSOR SIGNAL CONDITIONING



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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<sup>(1)</sup>

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

			VALUE	UNIT
Supply Voltage $V_S = (V+) - (V-)$			+7	V
Single Input Terminals	Voltage <sup>(2)</sup>		$(V-) - 0.5$ to $(V+) + 0.5$	V
	Current <sup>(2)</sup>		$\pm 10$	mA
Output Short-Circuit <sup>(3)</sup>			Continuous	
Ambient Operating Temperature			–55 to +125	°C
Ambient Storage Temperature			–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

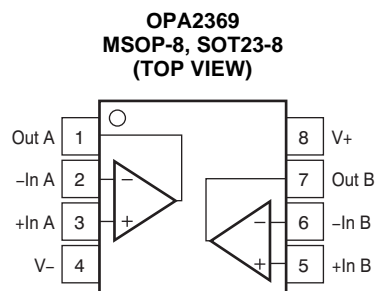
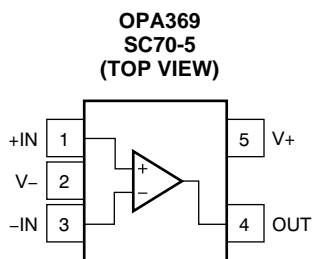
- (1) Stresses above these ratings may cause permanent damage. Exposure to absolute maximum conditions for extended periods may degrade device reliability. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those specified is not supported.
- (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<sup>(1)</sup>

PRODUCT	PACKAGE-LEAD	PACKAGE DESIGNATOR	PACKAGE MARKING
OPA369	SC70-5	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](http://www.ti.com).

## PIN CONFIGURATIONS



**ELECTRICAL CHARACTERISTICS:  $V_S = +1.8V$  to  $+5.5V$** 
**BOLDFACE** limits apply over the specified temperature range,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ .

At  $T_A = +25^{\circ}C$ , and  $R_L = 100k\Omega$  connected to  $V_S/2$ , unless otherwise noted.

PARAMETER	CONDITIONS	OPA369, OPA2369			UNIT
		MIN	TYP	MAX	
<b>OFFSET VOLTAGE</b>					
Input Offset Voltage $V_{OS}$			250	750	$\mu V$
<b>over Temperature</b>				<b>1</b>	<b>mV</b>
<b>Drift</b> $dV_{OS}/dT$			<b>0.4</b>	<b>1.75</b>	$\mu V/^{\circ}C$
<b>vs Power Supply</b> PSRR	$V_S = 1.8V$ to $5.5V$		<b>5</b>	<b>20</b>	$\mu V/V$
Channel Separation	dc		140		dB
	$f = 1kHz$		120		dB
<b>INPUT VOLTAGE RANGE</b>					
Common-Mode Voltage Range $V_{CM}$		(V–)		(V+)	V
Common-Mode Rejection Ratio CMRR	$(V-) \leq V_{CM} \leq (V+)$	100	114		dB
<b>over Temperature</b>	$(V-) \leq V_{CM} \leq (V+)$	<b>90</b>			<b>dB</b>
<b>INPUT BIAS CURRENT</b>					
Input Bias Current $I_B$			10	50	pA
<b>over Temperature</b>			See Figure 16		<b>pA</b>
Input Offset Current $I_{OS}$			10	50	pA
<b>INPUT IMPEDANCE</b>					
Differential			$10^{13} \parallel 3$		$\Omega \parallel pF$
Common-Mode			$10^{13} \parallel 6$		$\Omega \parallel pF$
<b>NOISE</b>					
Input Voltage Noise	$f = 0.1Hz$ to $10Hz$		3.6		$\mu V_{PP}$
Input Voltage Noise Density	$f = 100Hz$		220		$nV/\sqrt{Hz}$
	$f = 1kHz$		290		$nV/\sqrt{Hz}$
Current Noise Density	$f = 1kHz$		1		$fA/\sqrt{Hz}$
<b>OPEN-LOOP GAIN</b>					
Open-Loop Voltage Gain $A_{OL}$	$100mV \leq V_O \leq (V+) - 100mV$ , $R_L = 100k\Omega$	114	134		dB
<b>Over Temperature</b>	$100mV \leq V_O \leq (V+) - 100mV$ , $R_L = 100k\Omega$	<b>100</b>			<b>dB</b>
	$500mV \leq V_O \leq (V+) - 500mV$ , $R_L = 10k\Omega$	114	134		dB
<b>Over Temperature</b>	$500mV \leq V_O \leq (V+) - 500mV$ , $R_L = 10k\Omega$	<b>90</b>			<b>dB</b>
<b>OUTPUT</b>					
Voltage Output Swing from Rail	$R_L = 100k\Omega$ $R_L = 10k\Omega$			<b>10</b> <b>25</b>	<b>mV</b> <b>mV</b>
Short-Circuit Current $I_{SC}$			10		mA
Capacitive Load Drive $C_{LOAD}$			See Figure 20		pF
<b>FREQUENCY RESPONSE</b>					
Gain-Bandwidth Product GBW			12		kHz
Slew Rate SR	$G = +1$		0.005		V/ $\mu s$
Overload Recovery Time	$V_{IN} \times Gain > V_S$		250		$\mu s$

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

**BOLDFACE** limits apply over the specified temperature range,  $T_A = -40^{\circ}C$  to  $+85^{\circ}C$ .

At  $T_A = +25^{\circ}C$ , and  $R_L = 100k\Omega$  connected to  $V_S/2$ , unless otherwise noted.

PARAMETER	CONDITIONS	OPA369, OPA2369			UNIT
		MIN	TYP	MAX	
POWER SUPPLY					
Specified Voltage	V <sub>S</sub>	1.8		5.5	V
Quiescent Current	I <sub>Q</sub>				
OPA369	I <sub>OUT</sub> = 0A		0.8	1.2	μA
OPA2369 (per channel)			0.7	1	μA
Over Temperature					
OPA369				1.45	μA
OPA2369 (per channel)				1.25	μA
TEMPERATURE RANGE					
Specified Range	T <sub>A</sub>	−40		+85	°C
Operating Range	T <sub>A</sub>	−55		+125	°C
Thermal Resistance	θ <sub>JA</sub>				
SC70			250		°C/W
SOT23			223		°C/W
MSOP			252		°C/W

## TYPICAL CHARACTERISTICS

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ , and  $R_L = 100\text{k}\Omega$  connected to  $V_S/2$ , unless otherwise noted.

**OFFSET VOLTAGE  
PRODUCTION DISTRIBUTION**

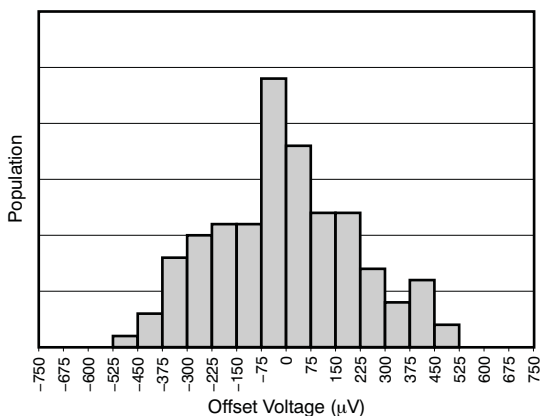


Figure 1.

**OFFSET VOLTAGE DRIFT  
PRODUCTION DISTRIBUTION**

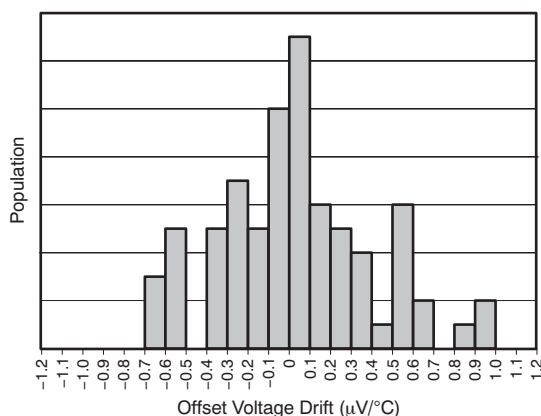


Figure 2.

**OFFSET VOLTAGE vs TEMPERATURE**

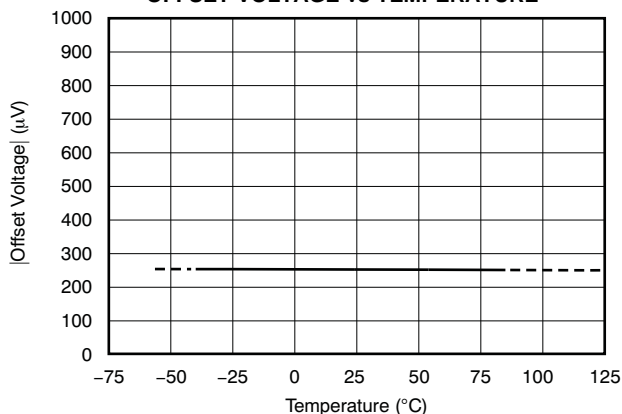


Figure 3.

**NORMALIZED OFFSET VOLTAGE  
vs COMMON-MODE VOLTAGE**

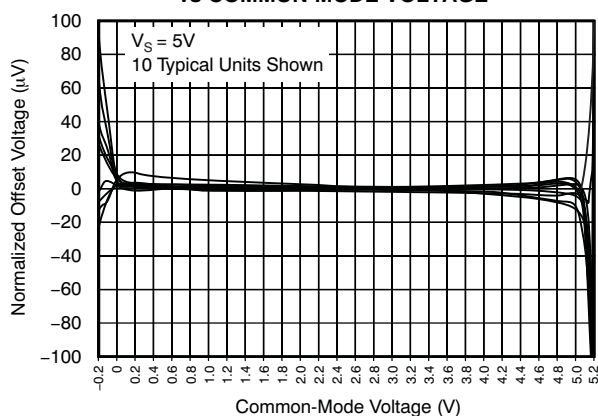


Figure 4.

**0.1Hz to 10Hz NOISE**

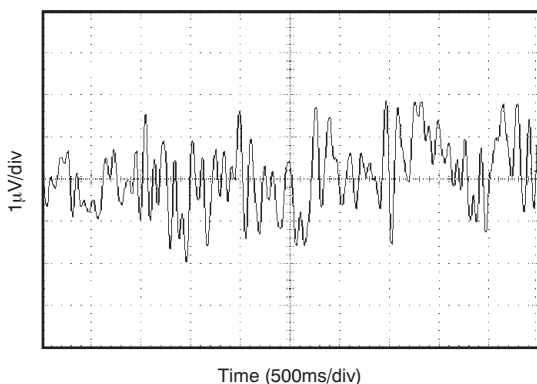


Figure 5.

**INPUT-REFERRED VOLTAGE NOISE  
vs FREQUENCY**

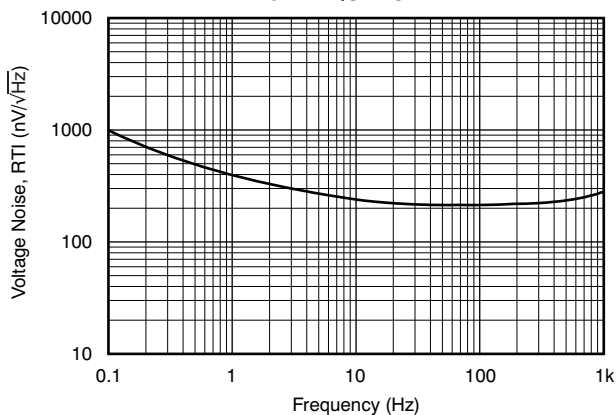


Figure 6.

## TYPICAL CHARACTERISTICS (continued)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ , and  $R_L = 100\text{k}\Omega$  connected to  $V_S/2$ , unless otherwise noted.

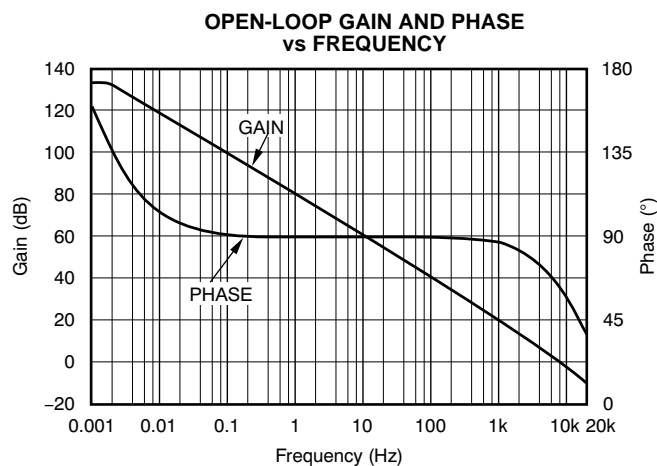


Figure 7.

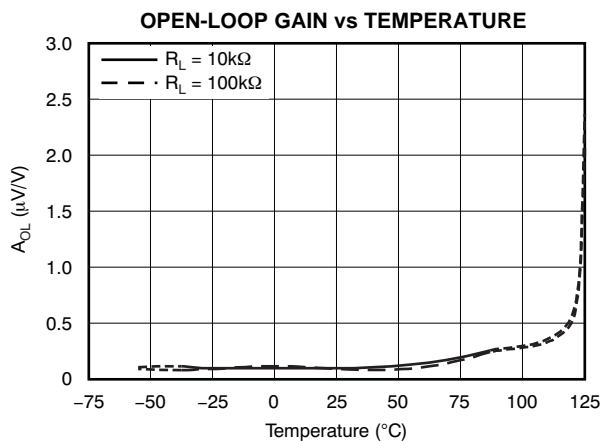


Figure 8.

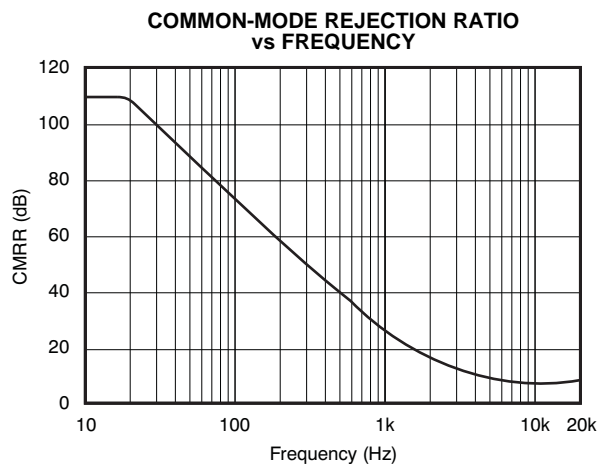


Figure 9.

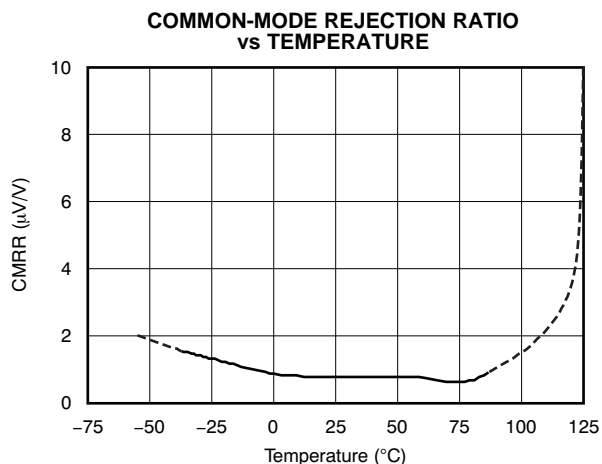


Figure 10.

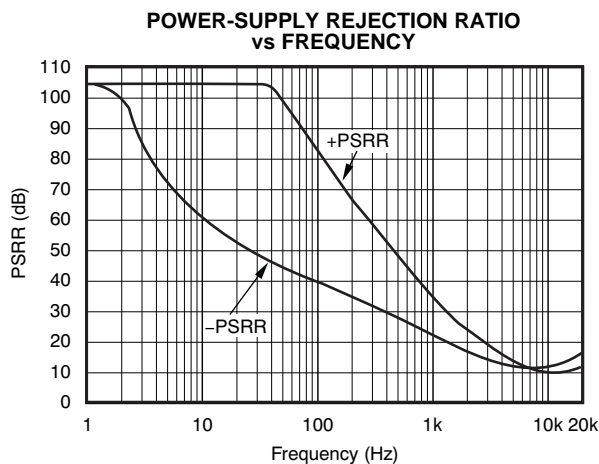


Figure 11.

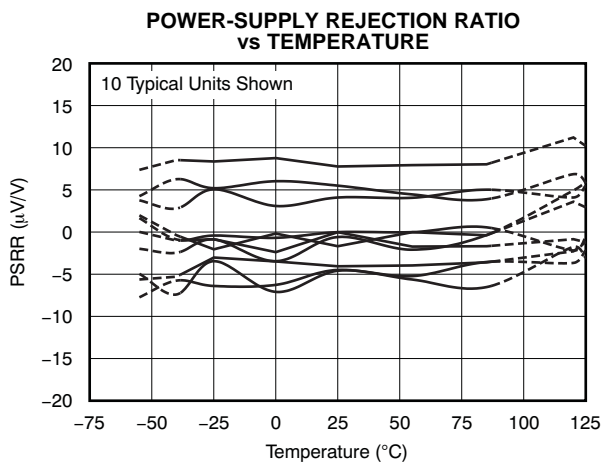


Figure 12.

## TYPICAL CHARACTERISTICS (continued)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ , and  $R_L = 100\text{k}\Omega$  connected to  $V_S/2$ , unless otherwise noted.

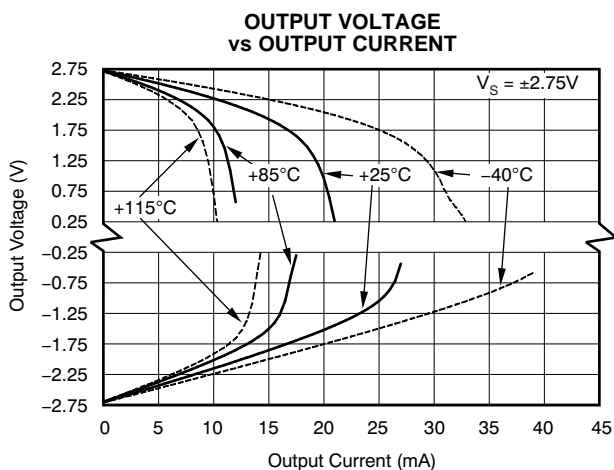


Figure 13.

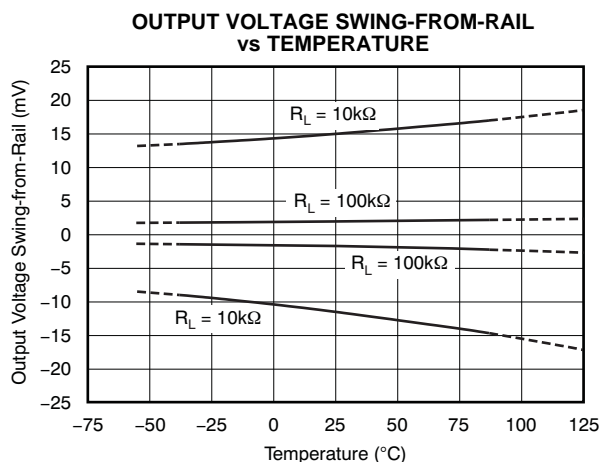


Figure 14.

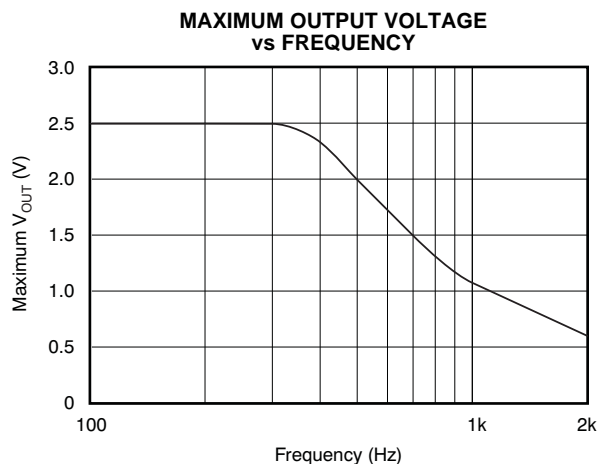


Figure 15.

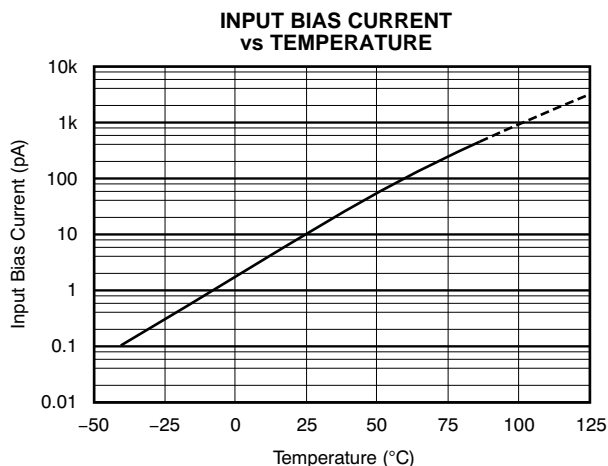


Figure 16.

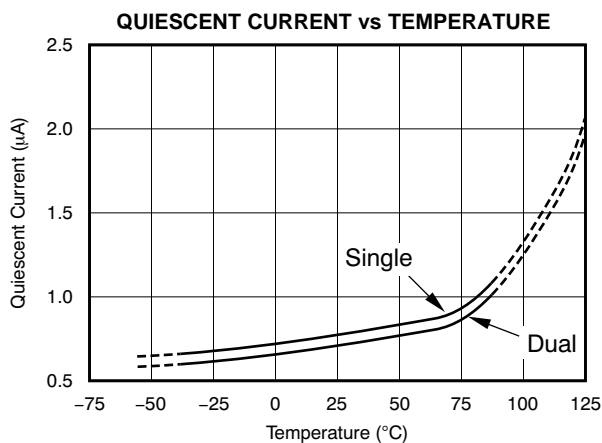


Figure 17.

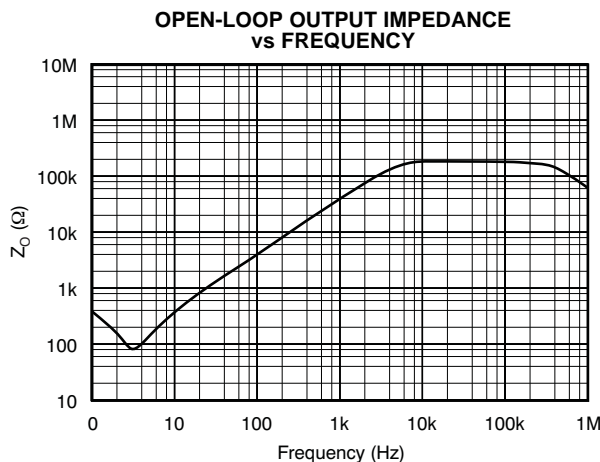


Figure 18.

## TYPICAL CHARACTERISTICS (continued)

At  $T_A = +25^\circ\text{C}$ ,  $V_S = 5\text{V}$ , and  $R_L = 100\text{k}\Omega$  connected to  $V_S/2$ , unless otherwise noted.

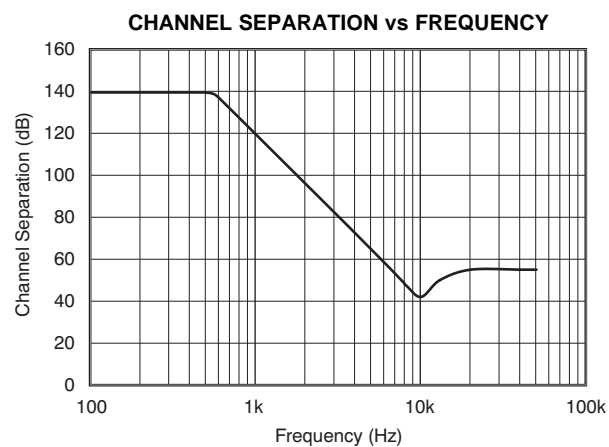


Figure 19.

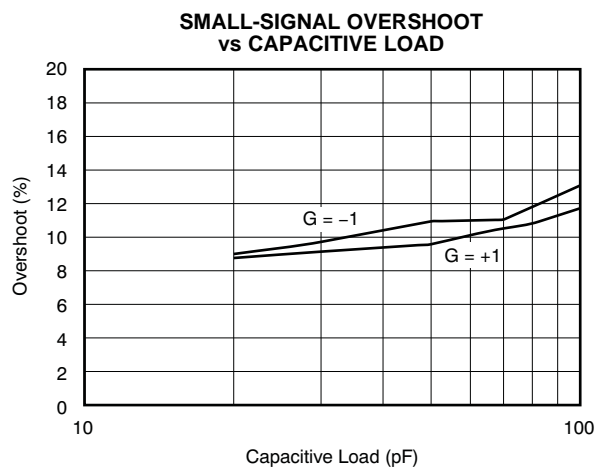
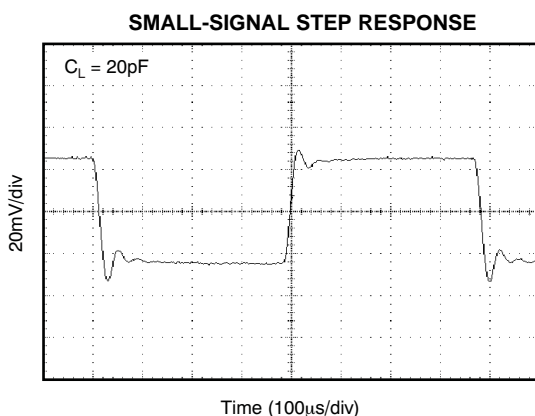
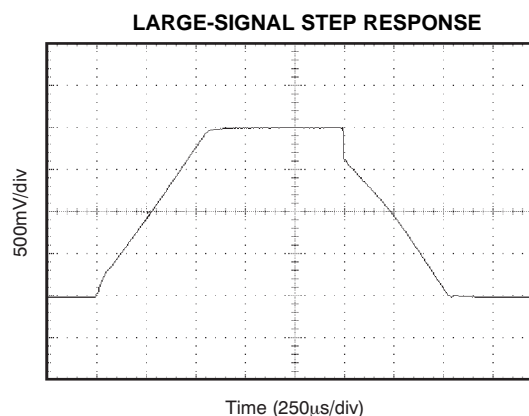


Figure 20.



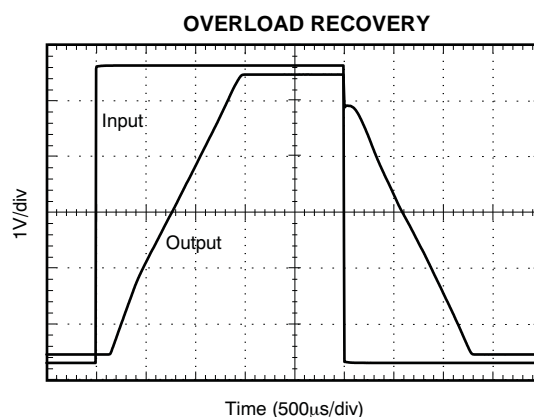
Time (100µs/div)

Figure 21.



Time (250µs/div)

Figure 22.



Time (500µs/div)

Figure 23.



## 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. Any 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 mandates the use of a 0.1μF bypass capacitor placed closely across the supply pins.

### OPERATING VOLTAGE

OPA369 series op amps are fully specified and tested from +1.8V to +5.5V ( $\pm 0.9V$  to  $\pm 2.75V$ ). Parameters that vary significantly with supply voltage are shown in the [Typical Characteristic](#) curves.

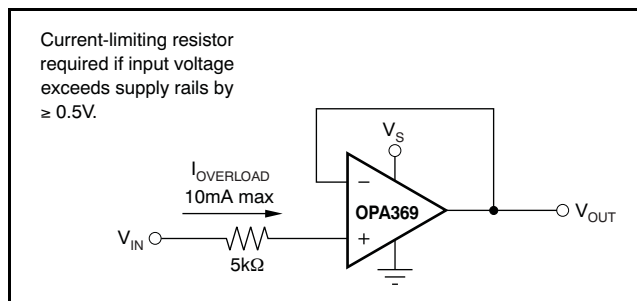
### INPUT COMMON-MODE VOLTAGE RANGE

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](#), *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 24](#).



**Figure 24. Input Current Protection for Voltages Exceeding the Supply Voltage**

## 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 25. 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:

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

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

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

4. Select a threshold voltage for  $V_{IN}$  rising ( $V_{THRS}$ ) = 2.0V

5. Calculate  $R_2$  as follows:

$$\begin{aligned} R_2 &= \frac{1}{\left[ \left( \frac{V_{THRS}}{V_{REF} \times R_1} \right) - \frac{1}{R_1} - \frac{1}{R_F} \right]} \\ &= \frac{1}{\left[ \left( \frac{2V}{1.2V \times 420k\Omega} \right) - \frac{1}{420k\Omega} - \frac{1}{20M\Omega} \right]} \\ &= 650k\Omega \end{aligned} \quad (3)$$

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:

$$R_{BIAS} = \frac{(V_{BATTMIN} - V_{REF})}{I_{BIAS}} = \frac{(1.8V - 1.2V)}{2\mu A} = 0.3M\Omega \quad (4)$$

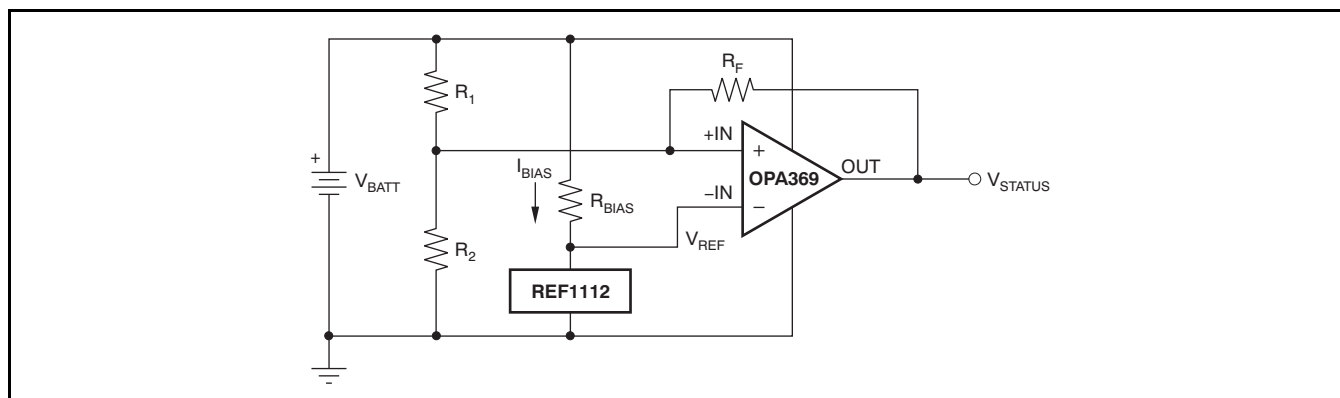


Figure 25. Battery Monitor

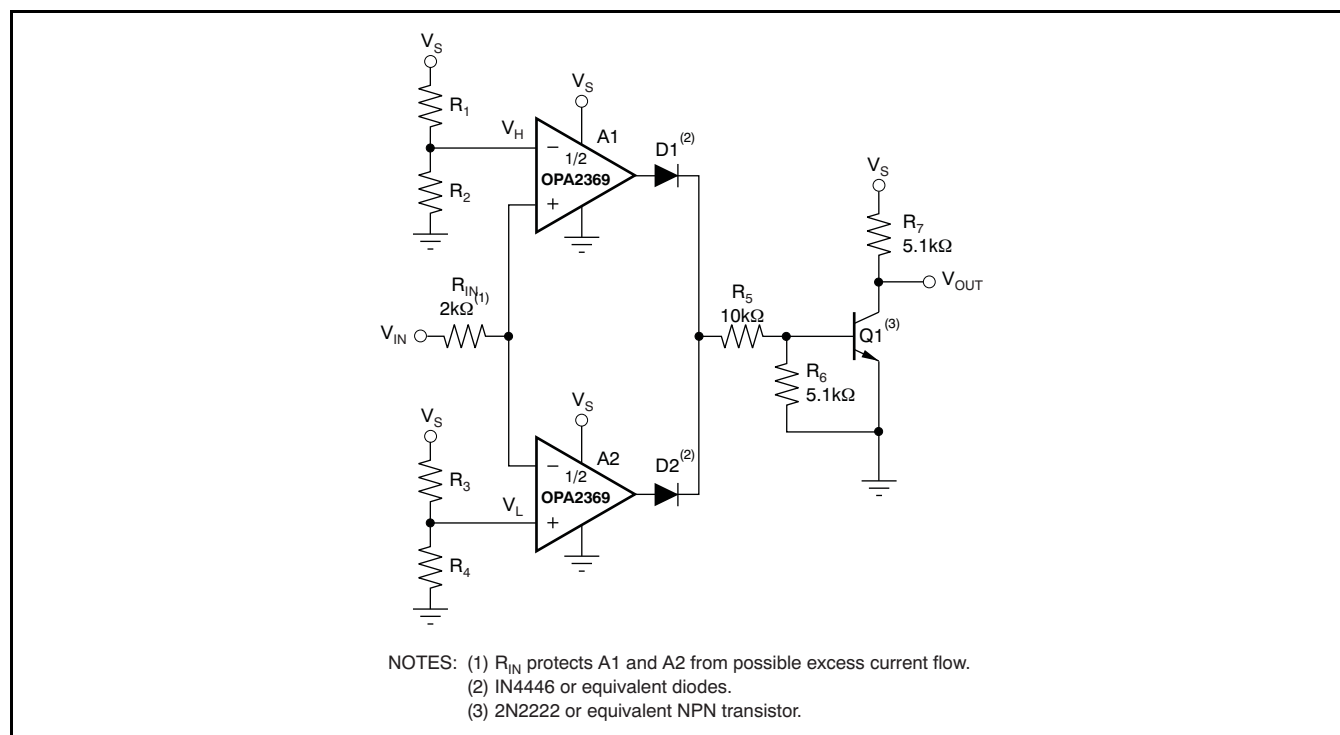
## WINDOW COMPARATOR

Figure 26 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 architecture 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:

$$V_H = \frac{R_2}{R_1 + R_2} \times V_S \quad (5)$$

$$V_L = \frac{R_4}{R_3 + R_4} \times V_S \quad (6)$$



**Figure 26. OPA2369 as a Window Comparator**

## ADDITIONAL APPLICATION EXAMPLES

Figure 27 through Figure 29 illustrate additional application examples.

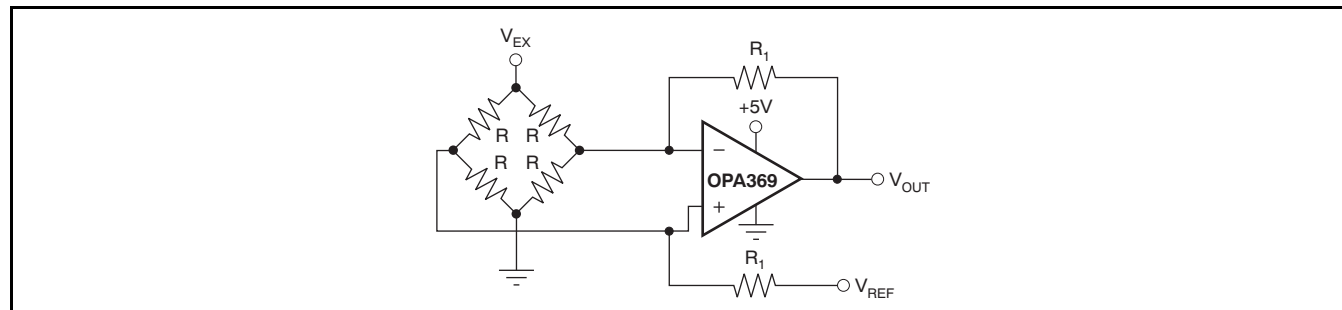


Figure 27. Single Op Amp Bridge Amplifier

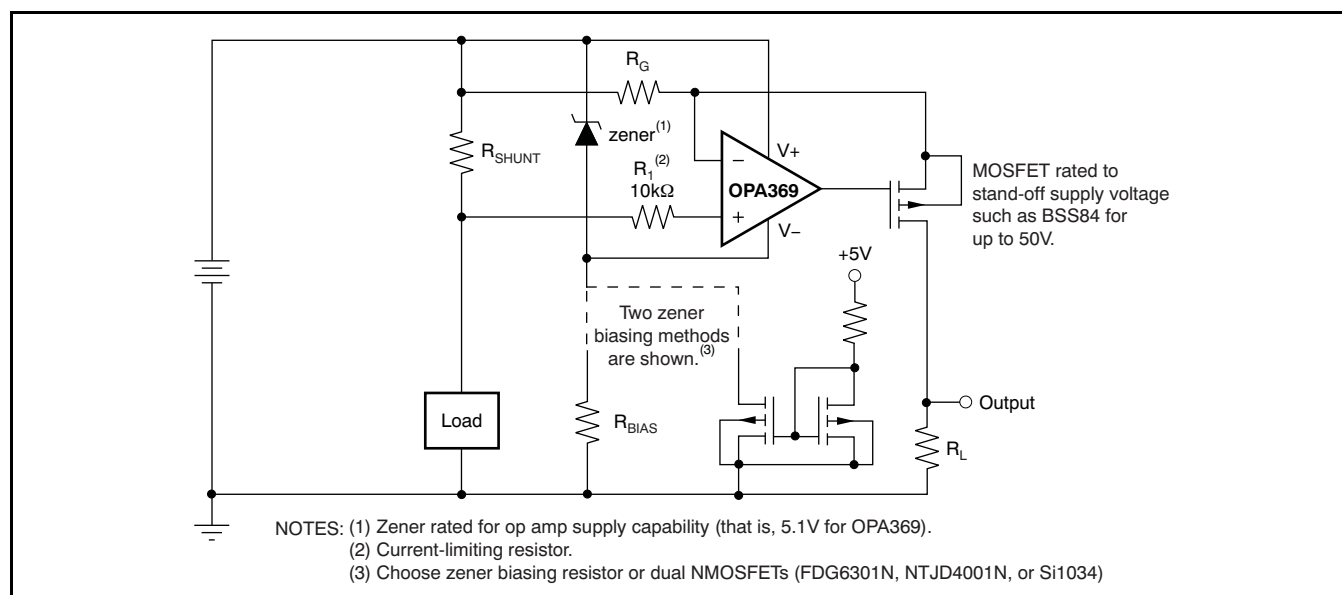


Figure 28. High-Side Current Monitor

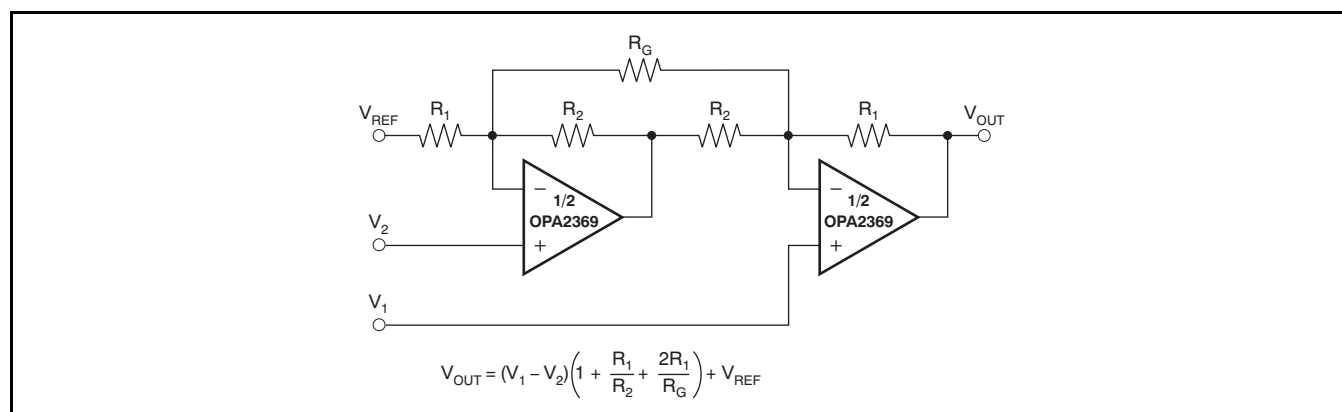


Figure 29. Two Op Amp Instrumentation Amplifier

**PACKAGING INFORMATION**

Orderable Device	Status <sup>(1)</sup>	Package Type	Package Drawing	Pins	Package Qty	Eco Plan <sup>(2)</sup>	Lead/Ball Finish	MSL Peak Temp <sup>(3)</sup>
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	ACTIVE	SC70	DCK	5	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR
OPA369AIDCKT	ACTIVE	SC70	DCK	5	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR

<sup>(1)</sup> 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.

<sup>(2)</sup> 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)

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

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**TAPE AND REEL INFORMATION**



\*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
OPA2369AIDCNR	SOT-23	DCN	8	3000	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
OPA2369AIDCNT	SOT-23	DCN	8	250	179.0	8.4	3.2	3.2	1.4	4.0	8.0	Q3
OPA2369AIDGKR	MSOP	DGK	8	2500	330.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA2369AIDGKT	MSOP	DGK	8	250	180.0	12.4	5.3	3.4	1.4	8.0	12.0	Q1
OPA369AIDCKR	SC70	DCK	5	3000	179.0	8.4	2.2	2.5	1.2	4.0	8.0	Q3
OPA369AIDCKT	SC70	DCK	5	250	179.0	8.4	2.2	2.5	1.2	4.0	8.0	Q3

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2369AIDCNR	SOT-23	DCN	8	3000	195.0	200.0	45.0
OPA2369AIDCNT	SOT-23	DCN	8	250	195.0	200.0	45.0
OPA2369AIDGKR	MSOP	DGK	8	2500	346.0	346.0	29.0
OPA2369AIDGKT	MSOP	DGK	8	250	190.5	212.7	31.8
OPA369AIDCKR	SC70	DCK	5	3000	195.0	200.0	45.0
OPA369AIDCKT	SC70	DCK	5	250	195.0	200.0	45.0

## DCK (R-PDSO-G5)

## PLASTIC SMALL-OUTLINE PACKAGE



4093553-3/G 01/2007

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



DGK (S-PDSO-G8)

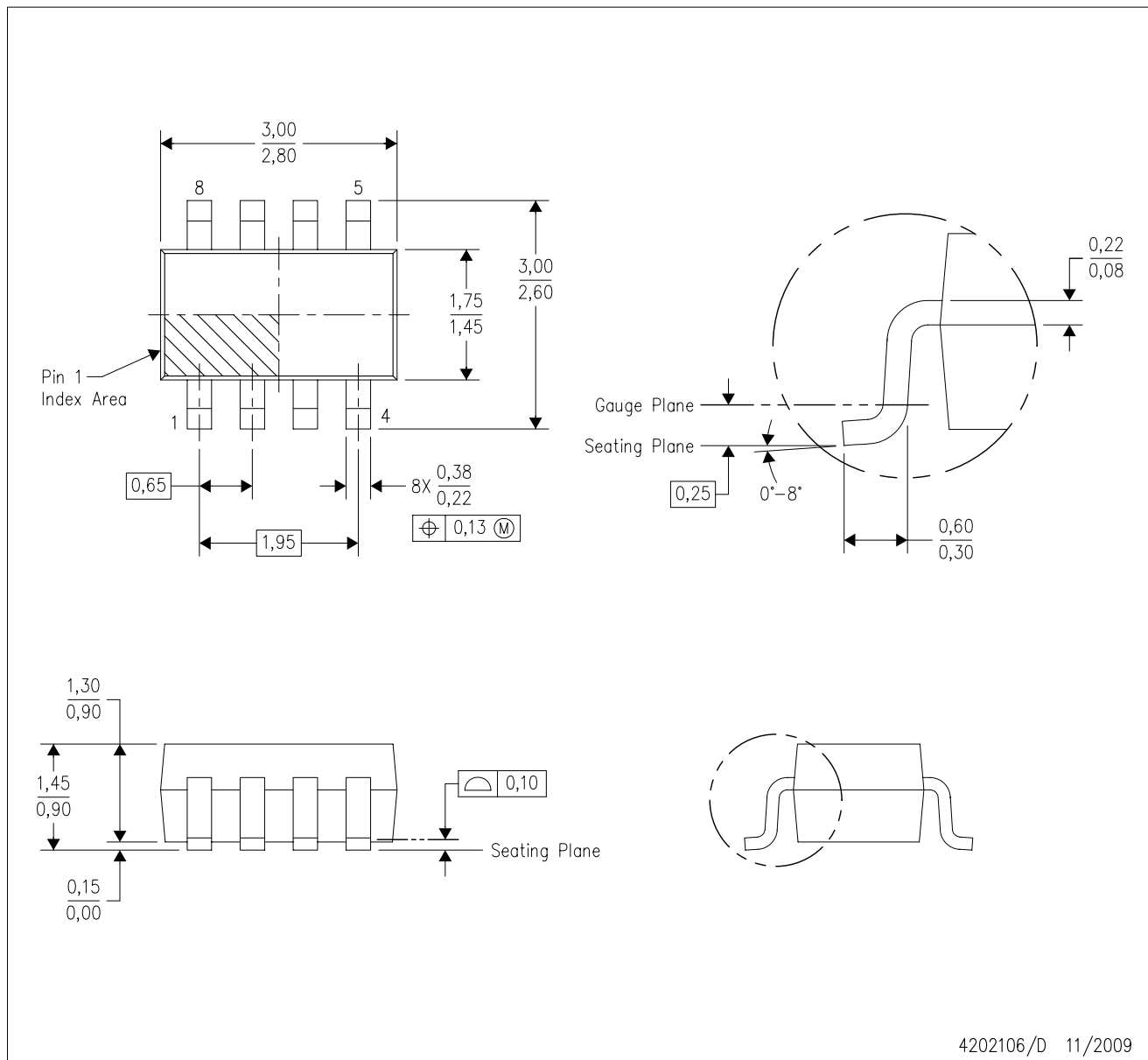
PLASTIC SMALL-OUTLINE PACKAGE



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

DCN (R-PDSO-G8)

PLASTIC SMALL-OUTLINE PACKAGE (DIE DOWN)



- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Package outline exclusive of 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.
  - G. Body dimensions do not include flash or protrusion. Mold flash and protrusion shall not exceed 0.25 per side.

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