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

FEATURES

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

APPLICATIONS

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

DESCRIPTION

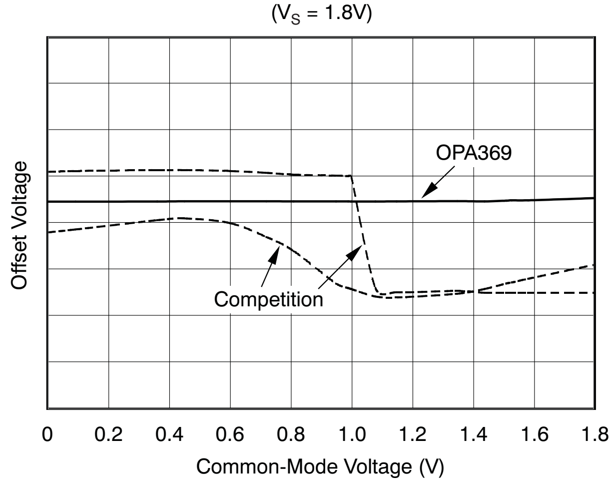
The OPA369 and OPA2369 are ultra-low-power, low-voltage operational amplifiers from Texas Instruments designed especially for battery-powered applications.

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 *zerø-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, the OPAx369 features 12kHz bandwidth, low offset drift (1.75µV/°C, max), and low noise 3.6µV_{PP} (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.

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



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

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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(1)

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

			VALUE	UNIT
Supply Voltage		V_S = (V+) – (V–)	+7	V
Single Input Terminals	Voltage(2)		(V–) –0.5 to (V+) + 0.5	V
	Current(2)		±10	mA
Output Short-Circuit(3)			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.

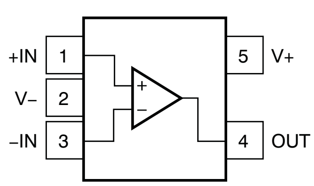
PACKAGE/ORDERING INFORMATION(1)

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

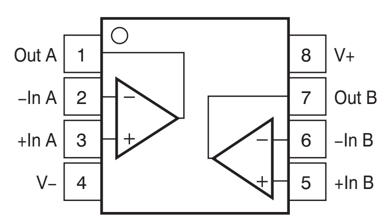
(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

PIN CONFIGURATIONS

OPA369
SC70-5
(TOP VIEW)



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, and R_L = 100kΩ connected to V_S/2, unless otherwise noted.

PARAMETER		CONDITIONS	OPA369, OPA2369 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		140		dB
		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
over Temperature				See Figure 16		**pA**
Input Offset Current	I_{OS}			10	50	pA
INPUT IMPEDANCE						
Differential				10^{13} || 3		Ω || pF
Common-Mode				10^{13} || 6		Ω || pF
NOISE						
Input Voltage Noise		f = 0.1Hz to 10Hz		3.6		μV_{PP}
Input Voltage Noise Density		f = 100Hz		220		nV/√Hz
		f = 1kHz		290		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 Figure 20		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

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, and R_L = 100kΩ connected to V_S/2, unless otherwise noted.

PARAMETER		CONDITIONS	OPA369, OPA2369 MIN	TYP	MAX	UNIT
POWER SUPPLY						
Specified Voltage	V_S		1.8		5.5	V
Quiescent Current	I_Q	I_{OUT} = 0A				
OPA369				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_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, and R_L = 100kΩ connected to V_S/2, unless otherwise noted.

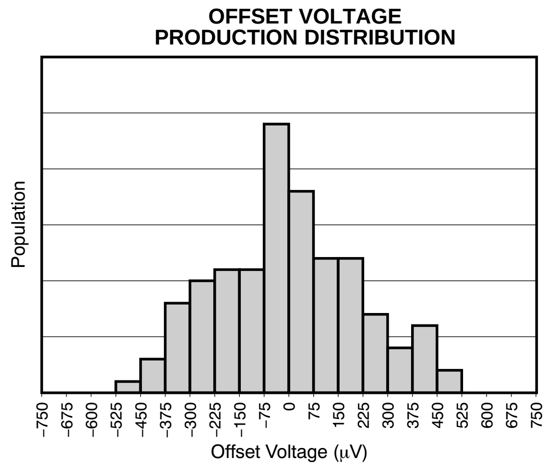


Figure 1.

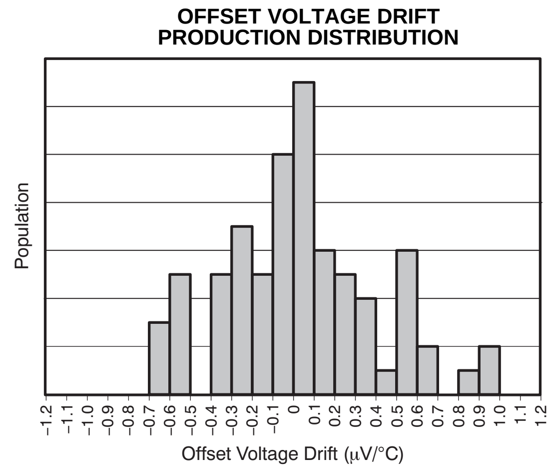


Figure 2.

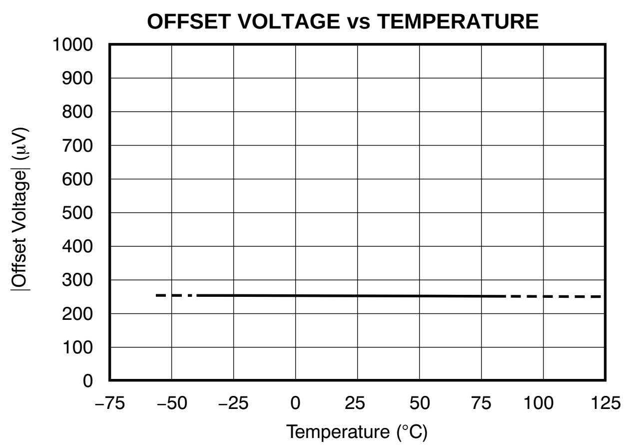


Figure 3.

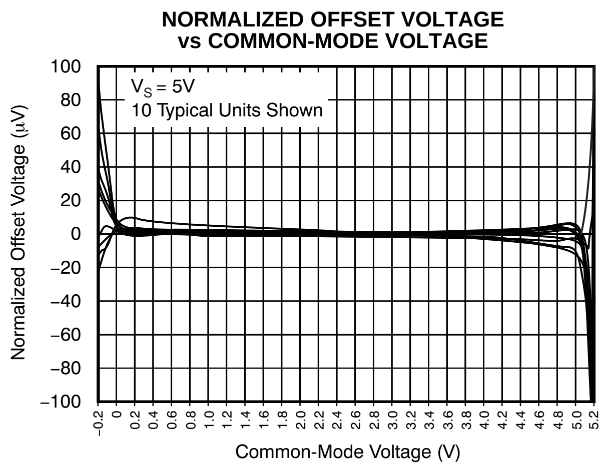


Figure 4.

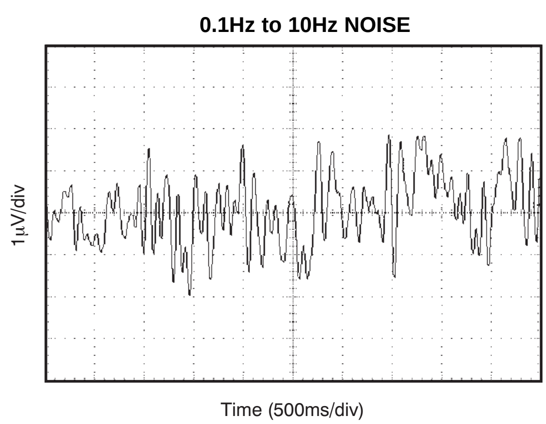


Figure 5.

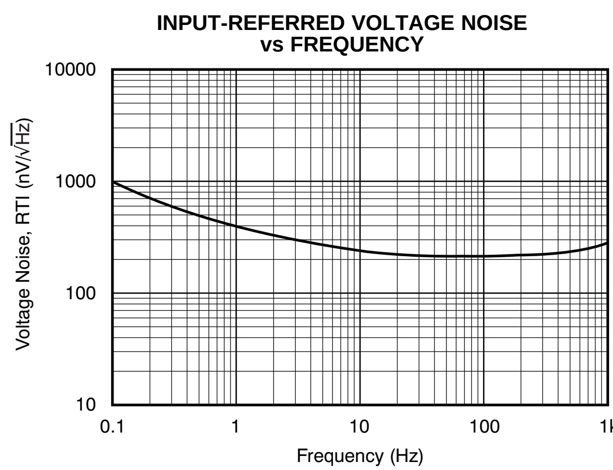


Figure 6.

TYPICAL CHARACTERISTICS (continued)

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

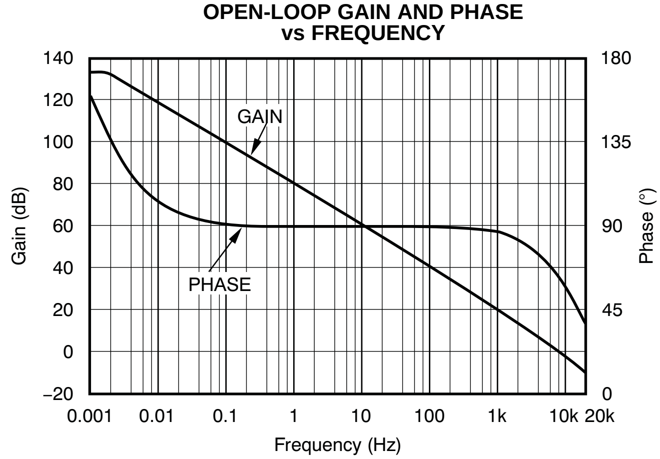


Figure 7.

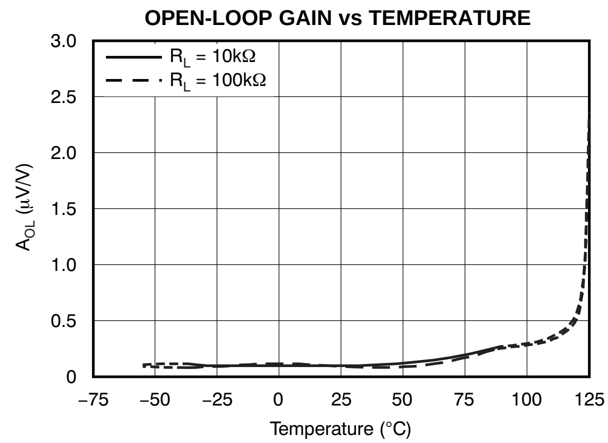


Figure 8.

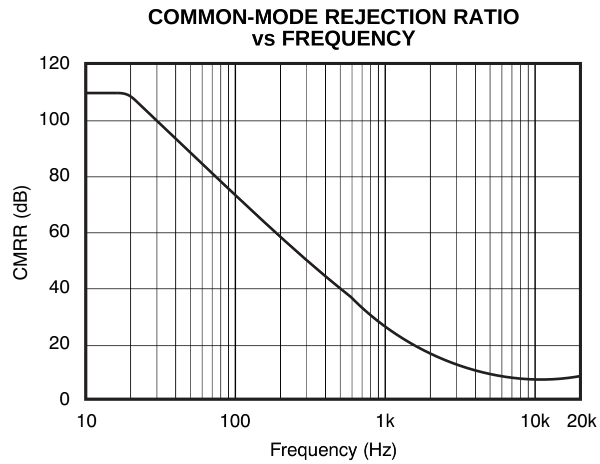


Figure 9.

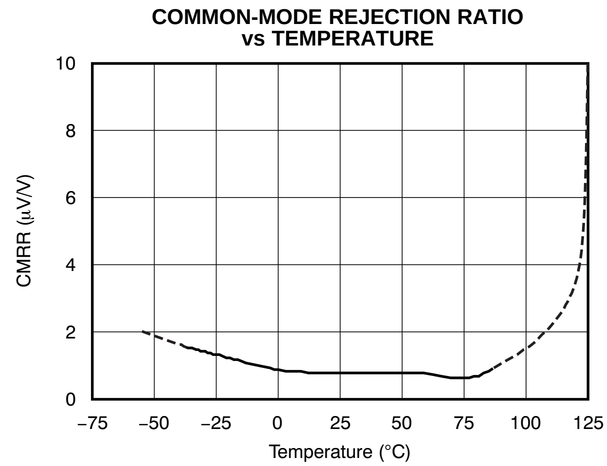


Figure 10.

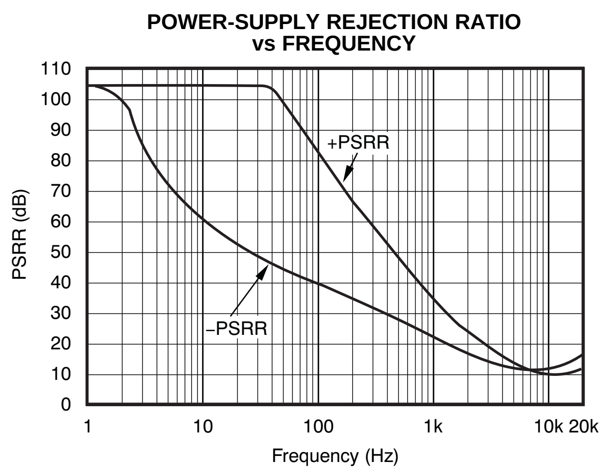


Figure 11.

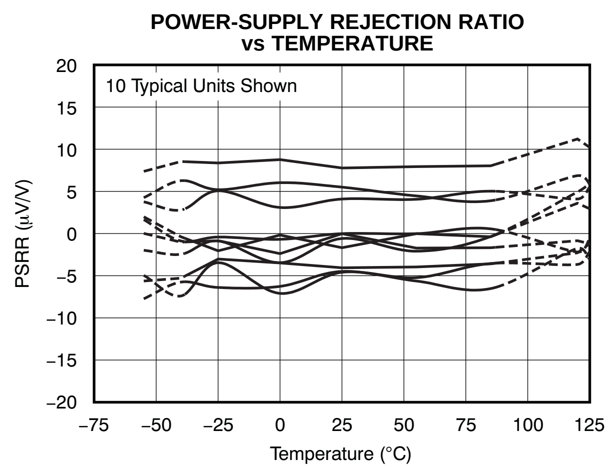


Figure 12.

TYPICAL CHARACTERISTICS (continued)

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

OUTPUT VOLTAGE vs OUTPUT CURRENT

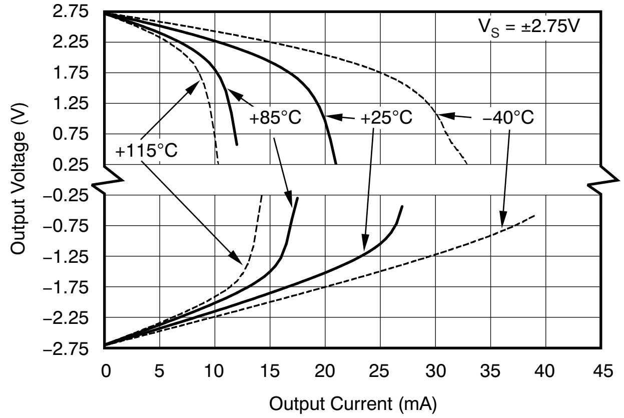


Figure 13.

OUTPUT VOLTAGE SWING-FROM-RAIL vs TEMPERATURE

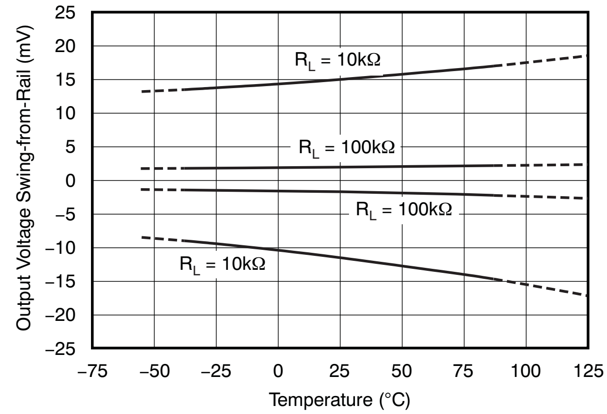


Figure 14.

MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

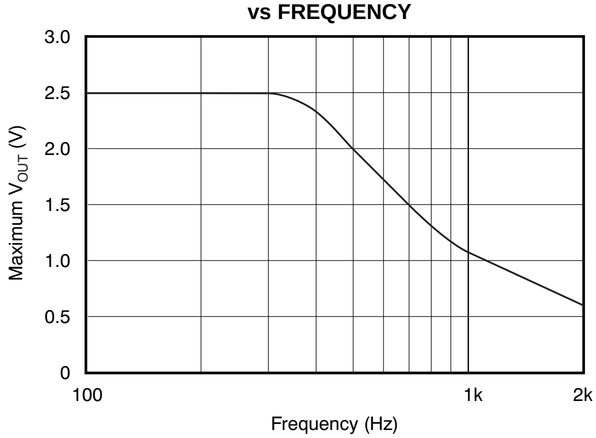


Figure 15.

INPUT BIAS CURRENT vs TEMPERATURE

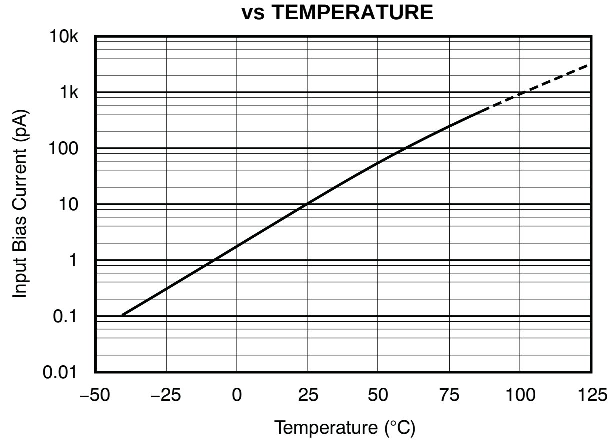


Figure 16.

QUIESCENT CURRENT vs TEMPERATURE

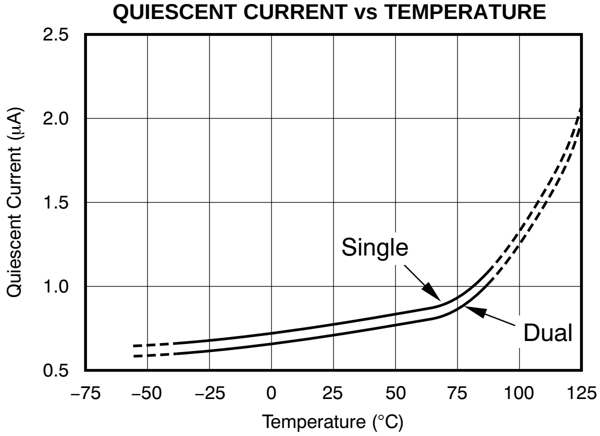


Figure 17.

OPEN-LOOP OUTPUT IMPEDANCE vs FREQUENCY

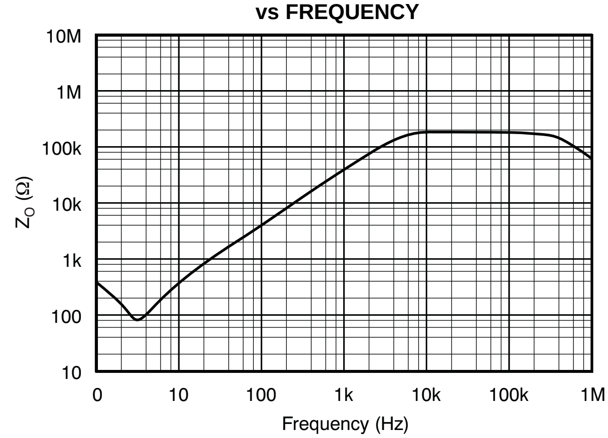


Figure 18.

TYPICAL CHARACTERISTICS (continued)

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

CHANNEL SEPARATION vs FREQUENCY

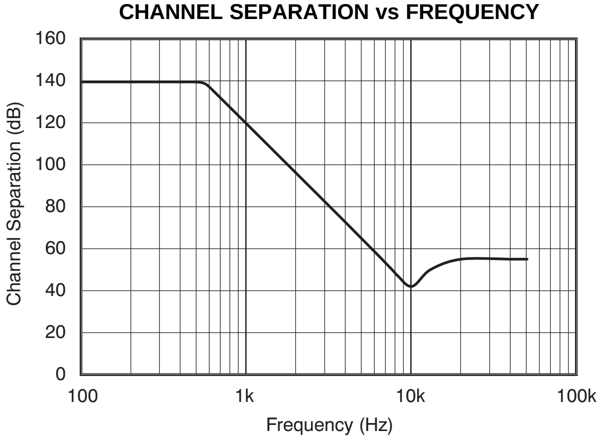


Figure 19.

SMALL-SIGNAL OVERSHOOT vs CAPACITIVE LOAD

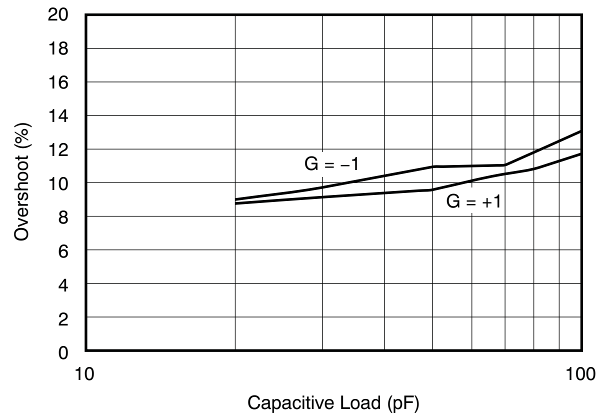


Figure 20.

SMALL-SIGNAL STEP RESPONSE

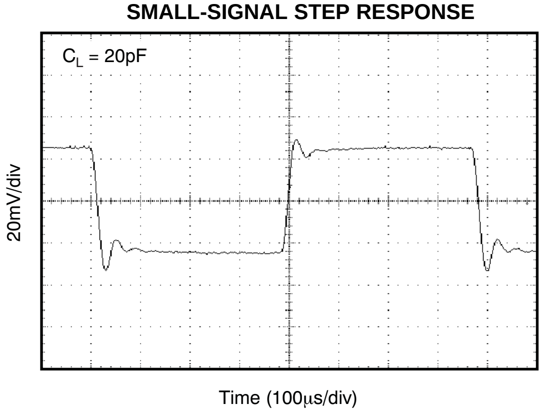


Figure 21.

LARGE-SIGNAL STEP RESPONSE

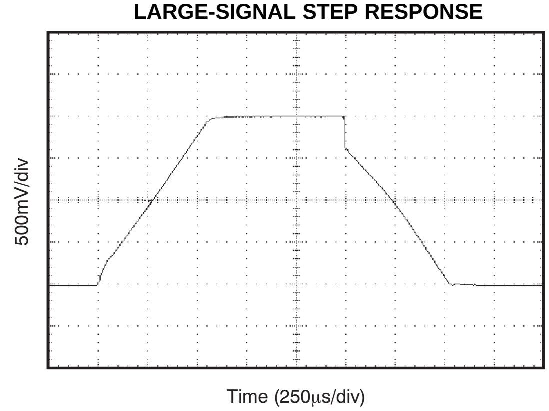


Figure 22.

OVERLOAD RECOVERY

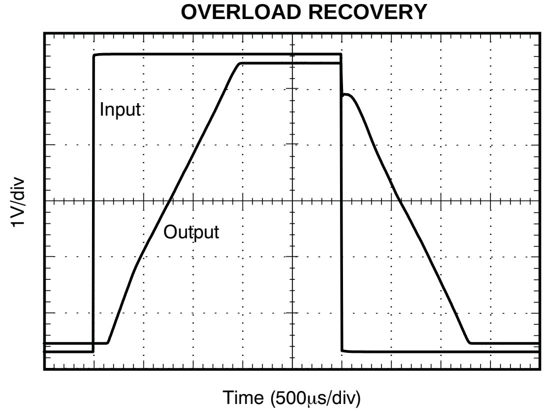


Figure 23.

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 (±0.9V to ±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.

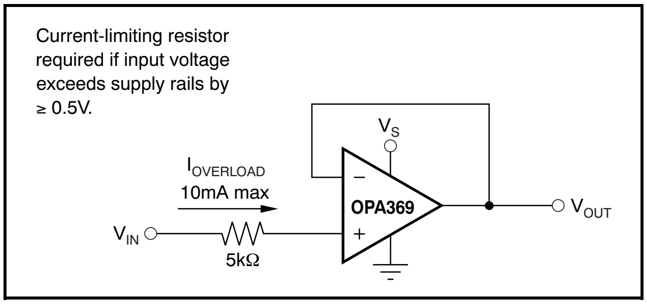


Figure 24. Input Current Protection for Voltages Exceeding the Supply Voltage

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:

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

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:

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

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:

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

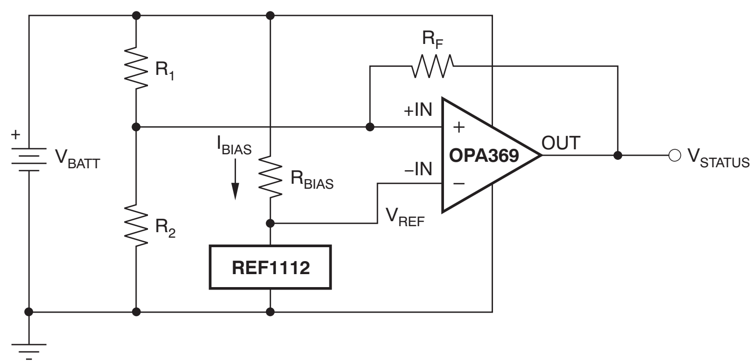


Figure 25. Battery Monitor

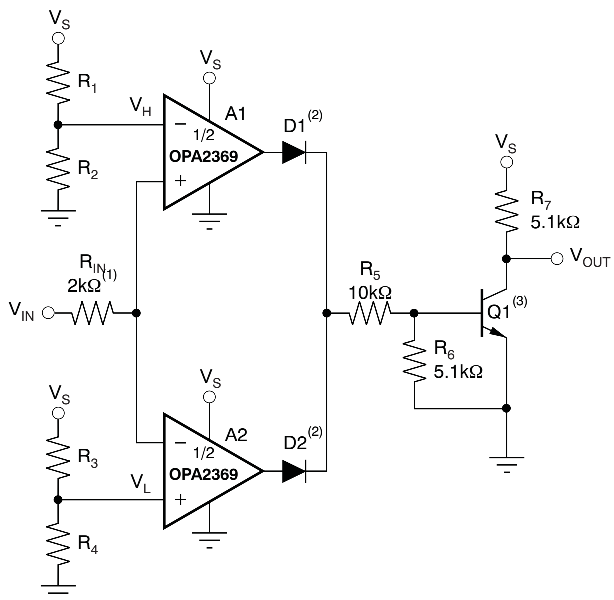
WINDOW COMPARATOR

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:

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

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



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 26. OPA2369 as a Window Comparator

ADDITIONAL APPLICATION EXAMPLES

Figure 27 through Figure 29 illustrate additional application examples.

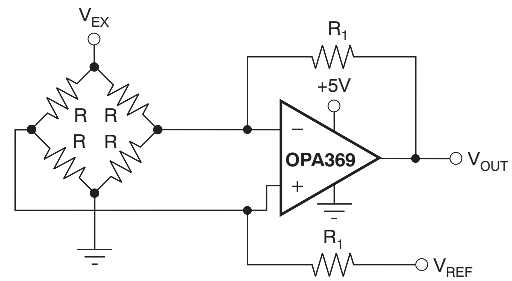


Figure 27. Single Op Amp Bridge Amplifier

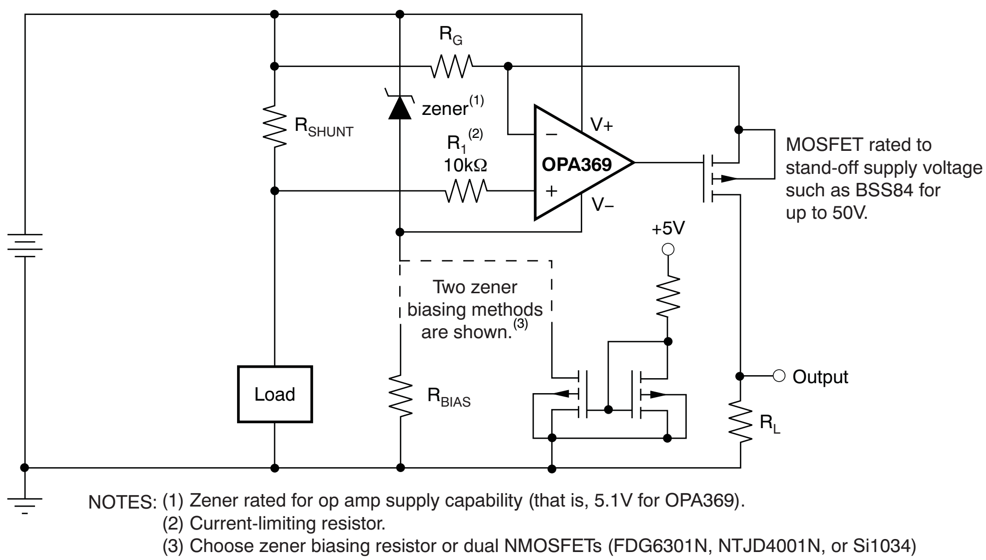
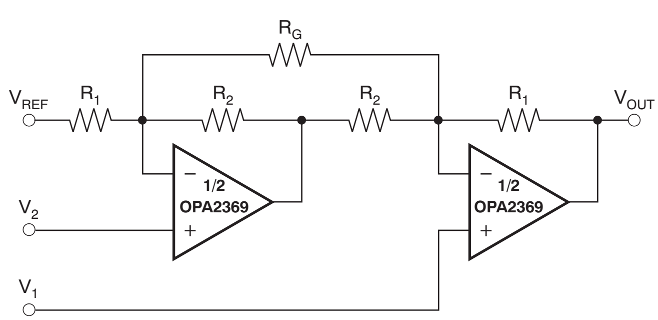


Figure 28. High-Side Current Monitor



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

Figure 29. Two Op Amp Instrumentation Amplifier

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	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

[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)

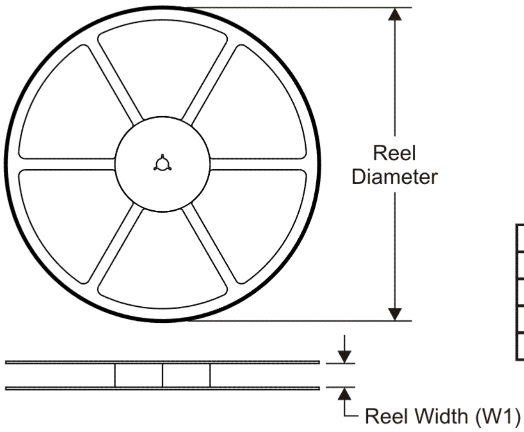
[3] MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

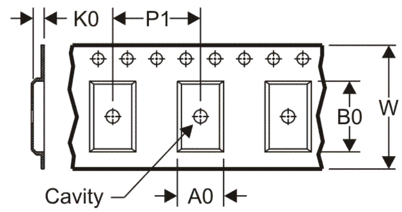
In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

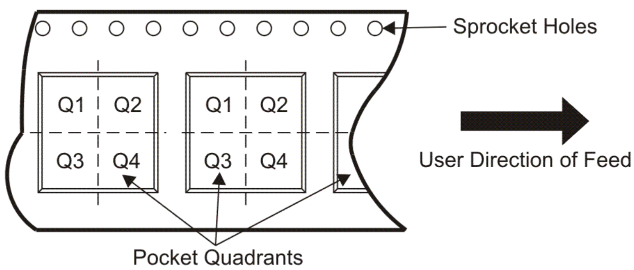


TAPE DIMENSIONS



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

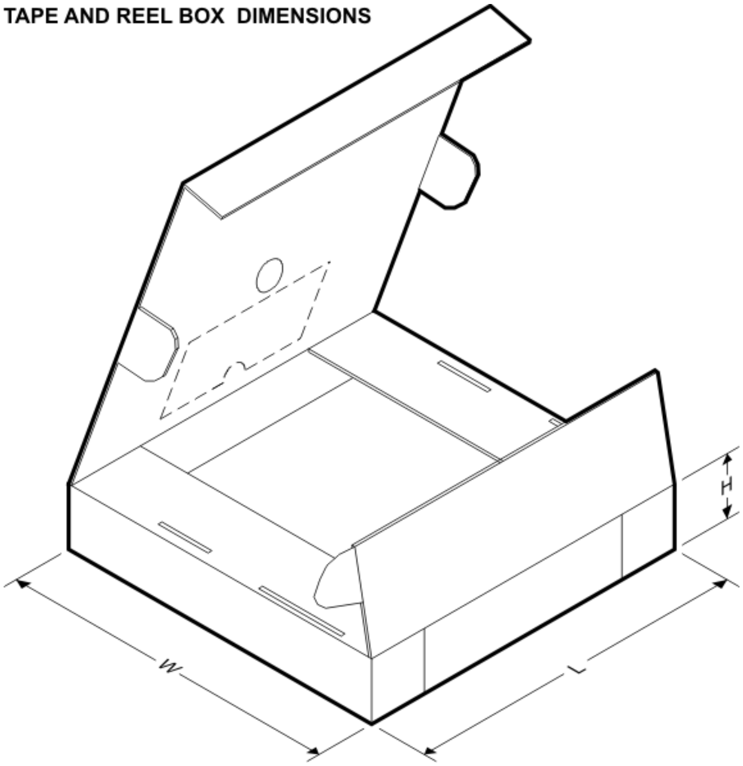
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
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

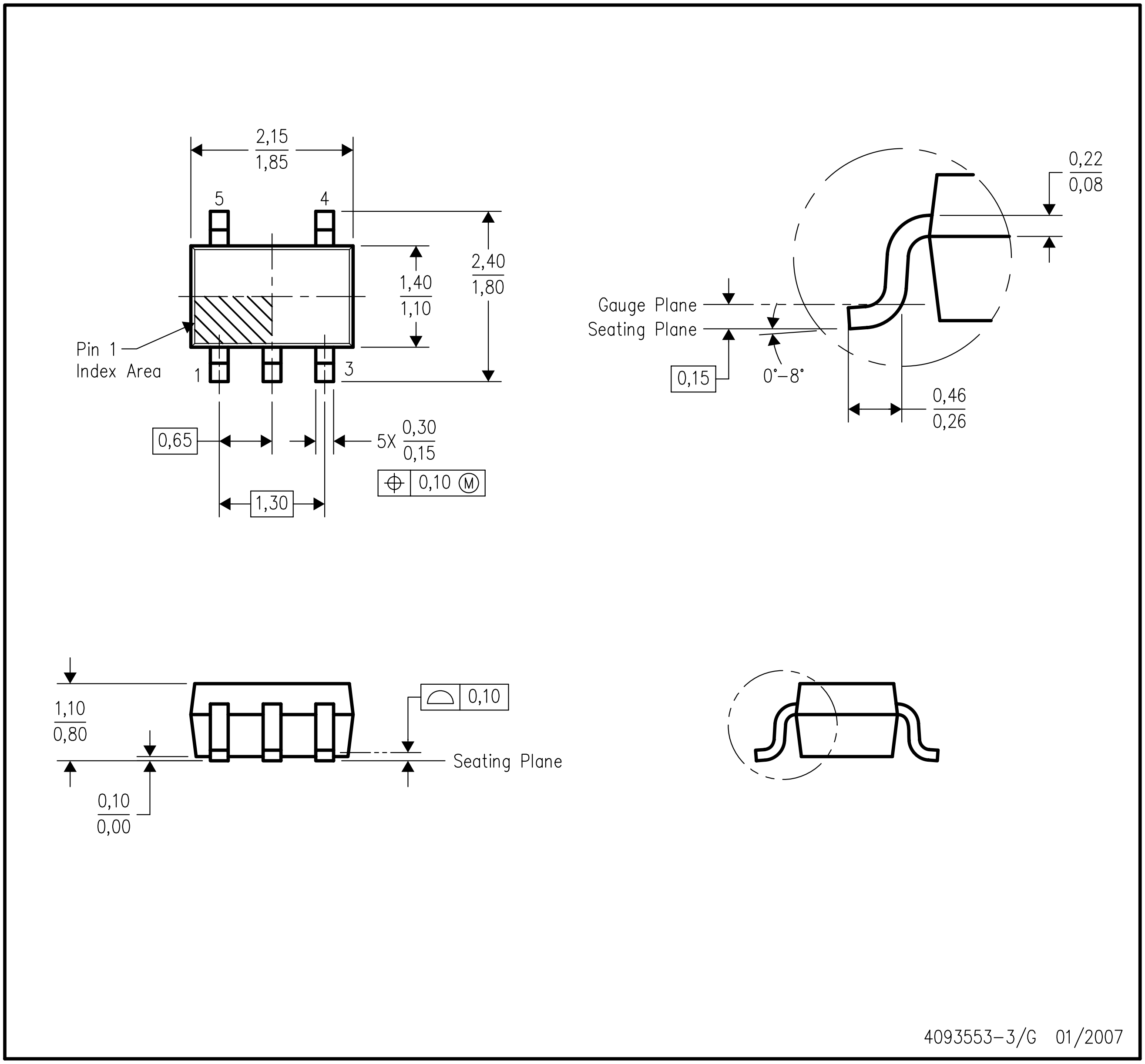
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

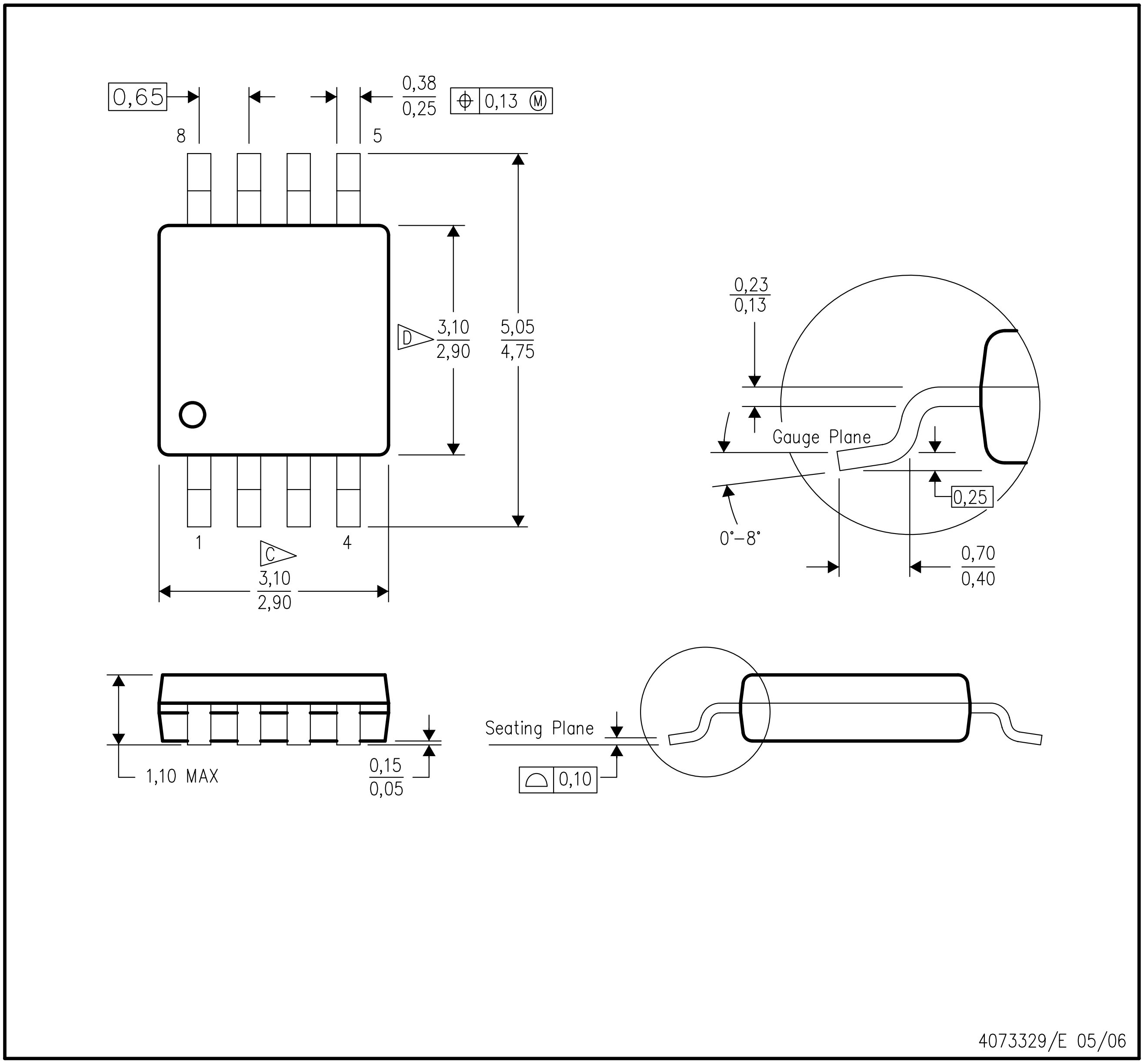
Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
OPA2369AIDCNR	SOT-23	DCN	8	3000	195.0	200.0	45.0
OPA2369AIDCNT	SOT-23	DCN	8	250	195.0	200.0	45.0
OPA2369AIDGKR	MSOP	DGK	8	2500	346.0	346.0	29.0
OPA2369AIDGKT	MSOP	DGK	8	250	190.5	212.7	31.8
OPA369AIDCKR	SC70	DCK	5	3000	195.0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

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



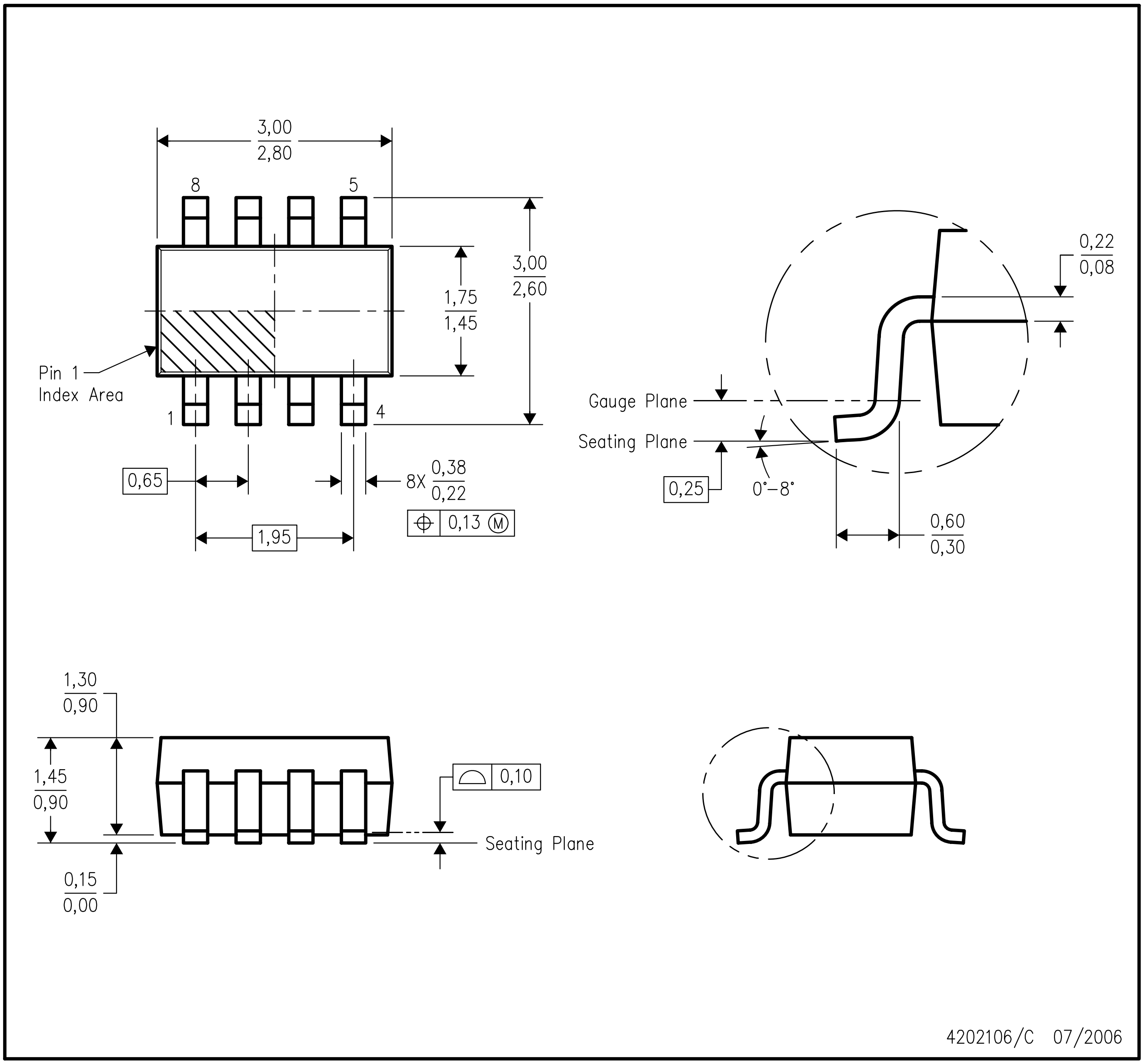
NOTES: A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion. Mold flash and protrusion shall not exceed 0.15 per side.
D. Falls within JEDEC MO-203 variation AA.

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



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

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 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.