



1 μ A, Rail-to-Rail I/O CMOS OPERATIONAL AMPLIFIERS

FEATURES

- **LOW SUPPLY CURRENT:** 1 μ A
- **GAIN-BANDWIDTH:** 70kHz
- **UNITY GAIN STABLE**
- **LOW INPUT BIAS CURRENT:** 10pA (max)
- **WIDE SUPPLY RANGE:** 1.8V to 5.5V
- **INPUT RANGE 200mV BEYOND RAILS**
- **OUTPUT SWINGS TO 150mV OF RAILS**
- **OUTPUT DRIVE CURRENT:** 8mA
- **OPEN-LOOP GAIN:** 90dB
- **MicroPACKAGES:** SC70, SOT23-5, SOT23-8

APPLICATIONS

- **BATTERY PACKS AND POWER SUPPLIES**
- **PORTABLE PHONES, PAGERS, AND CAMERAS**
- **SOLAR-POWERED SYSTEMS**
- **SMOKE, GAS, AND FIRE DETECTION SYSTEMS**
- **REMOTE SENSORS**
- **PCMCIA CARDS**
- **DRIVING A/D CONVERTERS**
- **MicroPOWER FILTERS**

OPAX349 RELATED PRODUCTS

FEATURES	PRODUCT
1 μ A, 5.5kHz, Rail-To-Rail	TLV240x
1 μ A, 5.5kHz, Rail-To-Rail	TLV224x
7 μ A, 160kHz, Rail-To-Rail, 2.7V to 16V Supply	TLV238x
7 μ A, 160kHz, Rail-To-Rail, Micro Power	TLV27Lx
20 μ A, 500kHz, Rail-To-Rail, 1.8V Micro Power	TLV276x
20 μ A, 350kHz, Rail-To-Rail, Micro Power	OPAx347
45 μ A, 1MHz, Rail-To-Rail, 2.1V to 5.5V Supply	OPAx348

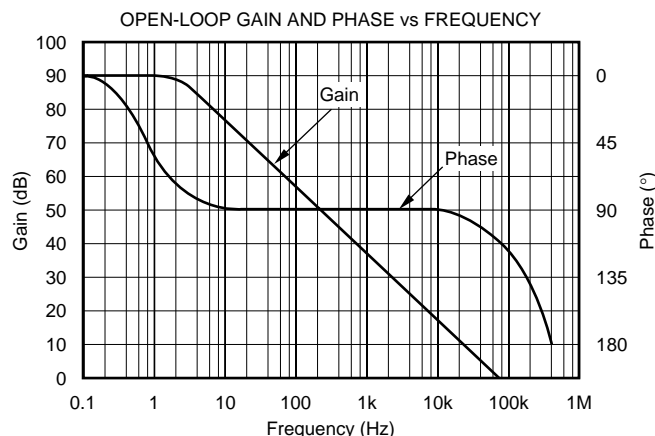
DESCRIPTION

The OPA349 and the OPA2349 are ultra-low power operational amplifiers that provide 70kHz bandwidth with only 1 μ A quiescent current. These rail-to-rail input and output amplifiers are specifically designed for battery-powered applications. The input common-mode voltage range extends 200mV beyond the power supply rails and the output swings to within 150mV of the rails, maintaining wide dynamic range. Unlike some micropower op amps, these parts are unity-gain stable and require no external compensation to achieve wide bandwidth. The OPA349 features a low input bias current that allows the use of large source and feedback resistors.

OPA349 can be operated with power supplies from 1.8V to 5.5V with little change in performance, ensuring continuing superior performance even in low battery situations.

OPA349 comes in the miniature SOT23-5, SC70, and SO-8 surface mount packages. OPA2349 dual is available in the SOT23-8, and SO-8 surface-mount packages. These tiny packages are ideal for use in high-density applications, such as PCMCIA cards, battery packs, and portable instruments.

The OPA349 is specified for -40°C to $+125^{\circ}\text{C}$. The OPA2349 is specified for -40°C to $+70^{\circ}\text{C}$.



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.

ABSOLUTE MAXIMUM RATINGS⁽¹⁾

Supply Voltage, V+ to V-	5.5V
Signal Input Terminals, Voltage ⁽²⁾	(V-) - 0.5V to (V+) + 0.5V
Current ⁽²⁾	10mA
Output Short Circuit ⁽³⁾	Continuous
Operating Temperature	-55°C to +125°C
Storage Temperature	-65°C to +150°C
Junction Temperature	150°C
Lead Temperature (soldering, 3s)	300°C

NOTES: (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 implied. (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 ground, one amplifier per package.



ELECTROSTATIC DISCHARGE SENSITIVITY

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.

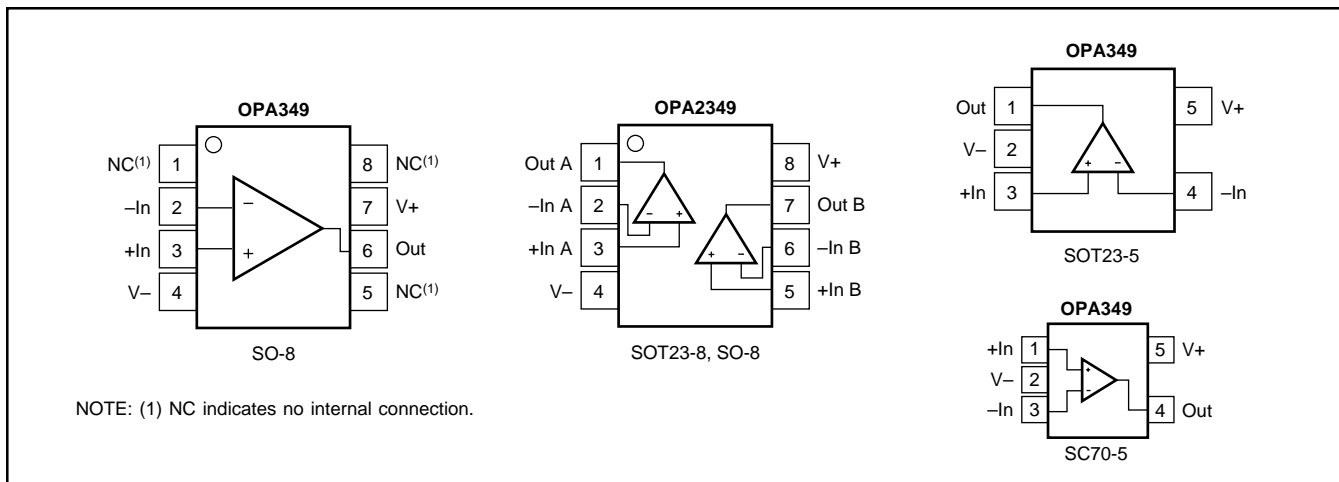
ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

PACKAGE/ORDERING INFORMATION

PRODUCT	PACKAGE	PACKAGE DESIGNATOR ⁽¹⁾	SPECIFIED TEMPERATURE RANGE	PACKAGE MARKING	ORDERING NUMBER ⁽²⁾	TRANSPORT MEDIA, QUANTITY
Single						
OPA349NA	SOT23-5	DBV	-40°C to +125°C	A49	OPA349NA/250	Tape and Reel, 250
"	"	"	"	"	OPA349NA/3K	Tape and Reel, 3000
OPA349UA	SO-8	D	-40°C to +125°C	OPA349UA	OPA349UA	Rails, 100
"	"	"	"	"	OPA349UA/2K5	Tape and Reel, 2500
OPA349SA	SC70-5	DCK	-40°C to +125°C	S49	OPA349SA/250	Tape and Reel, 250
"	"	"	"	"	OPA349SA/3K	Tape and Reel, 3000
Dual						
OPA2349EA	SOT23-8	DCN	-40°C to +70°C	C49	OPA2349EA/250	Tape and Reel, 250
"	"	"	"	"	OPA2349EA/3K	Tape and Reel, 3000
OPA2349UA	SO-8	D	-40°C to +70°C	OPA2349UA	OPA2349UA	Rails, 100
"	"	"	"	"	OPA2349UA/2K5	Tape and Reel, 2500

NOTE: (1) For the most current specifications and package information, refer to our web site at www.ti.com. (2) Models with a (/) are available only in Tape and Reel in the quantities indicated (e.g., /3K indicates 3000 devices per reel). Ordering 3000 pieces of "OPA2349EA/3K" will get a single 3000-piece Tape and Reel.

PIN CONFIGURATIONS



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

Boldface limits apply over the specified temperature range, $T_A = -40^{\circ}C$ to $+125^{\circ}C$

At $T_A = +25^{\circ}C$, $R_L = 1M\Omega$ connected to $V_S/2$, unless otherwise noted.

PARAMETER	CONDITION	OPA349NA, UA, SA			UNITS
		MIN	TYP	MAX	
OFFSET VOLTAGE Input Offset Voltage Over Temperature Drift vs Power Supply Over Temperature	V_{OS} dV_{OS}/dT $PSRR$ $V_S = 5V, V_{CM} = 2.5V$ $V_S = 1.8V$ to $5.5V, V_{CM} = (V-) + 0.3V$		± 2 ± 2 ± 15 350	± 10 ± 13 1000 3000	mV mV $\mu V/^{\circ}C$ $\mu V/V$ $\mu V/V$
INPUT VOLTAGE RANGE Common-Mode Voltage Range Common-Mode Rejection Ratio Over Temperature Over Temperature	V_{CM} $CMRR$ $V_S = +5V, -0.2V < V_{CM} < 3.5V$ $V_S = +5V, -0.2V < V_{CM} < 5.2V$	$(V-) - 0.2$ 52 50 48 46	72 60	$(V+) + 0.2$ 	V dB dB dB dB
INPUT BIAS CURRENT Input Bias Current Input Offset Current	I_B I_{OS}		± 0.5 ± 1	± 10 ± 10	pA pA
INPUT IMPEDANCE Differential Common-Mode			$10^{13} \parallel 2$ $10^{13} \parallel 4$		$\Omega \parallel pF$ $\Omega \parallel pF$
NOISE Input Voltage Noise, $f = 0.1Hz$ to $10Hz$ Input Voltage Noise Density, $f = 1kHz$ Current Noise Density, $f = 1kHz$	e_n i_n		8 300 4		$\mu Vp-p$ nV/ \sqrt{Hz} fA/ \sqrt{Hz}
OPEN-LOOP GAIN Open-Loop Voltage Gain Over Temperature Open-Loop Voltage Gain Over Temperature	A_{OL} A_{OL} $R_L = 1M\Omega, V_S = +5.5V, +0.05V < V_O < +5.45V$ $R_L = 10k\Omega, V_S = +5.5V, +0.15V < V_O < +5.35V$	74 72 74 60	90 90		dB dB dB dB
OUTPUT Voltage Output Swing from Rail Over Temperature Over Temperature Output Current Short-Circuit Current Capacitive Load Drive	C_{LOAD} I_{SC}	$R_L = 1M\Omega, V_S = +5.5V, A_{OL} > 74dB$ $R_L = 10k\Omega, V_S = +5.5V, A_{OL} > 74dB$	 ± 8 ± 10	50 50 150 150	mV mV mV mV mA mA
FREQUENCY RESPONSE Gain-Bandwidth Product Slew Rate Settling Time, 0.1% 0.01% Overload Recovery Time	GBW SR t_s t_s	$C_L = 10pF$ $G = +1$ $V_S = +5V, G = +1$ $V_S = 5V, 1V$ Step $V_S = 5V, 1V$ Step $V_{IN} \cdot \text{Gain} = V_S$	70 0.02 65 80 5		kHz V/ μs μs μs μs
POWER SUPPLY Specified Voltage Range Quiescent Current (per amplifier) Over Temperature	I_Q	$I_Q = 0$	1.8 1	5.5 2 2.5	V μA μA
TEMPERATURE RANGE Specified Range Storage Range Thermal Resistance SOT23-5 Surface Mount SO-8 Surface Mount SC70-5 Surface Mount	θ_{JA}		-40 -65	+125 +150	$^{\circ}C$ $^{\circ}C$ $^{\circ}C/W$ $^{\circ}C/W$ $^{\circ}C/W$ $^{\circ}C/W$

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

Boldface limits apply over the specified temperature range, $T_A = -40^{\circ}C$ to $+70^{\circ}C$

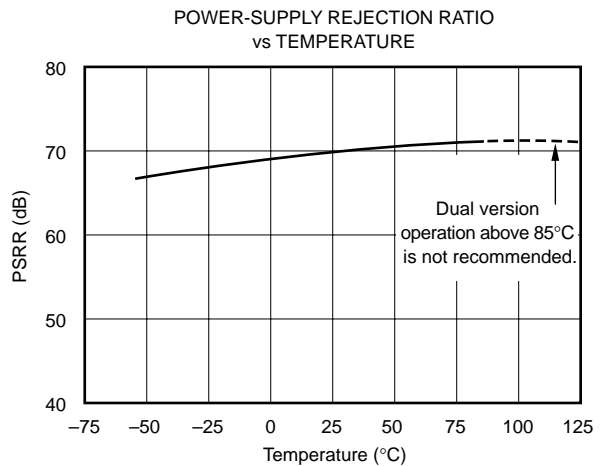
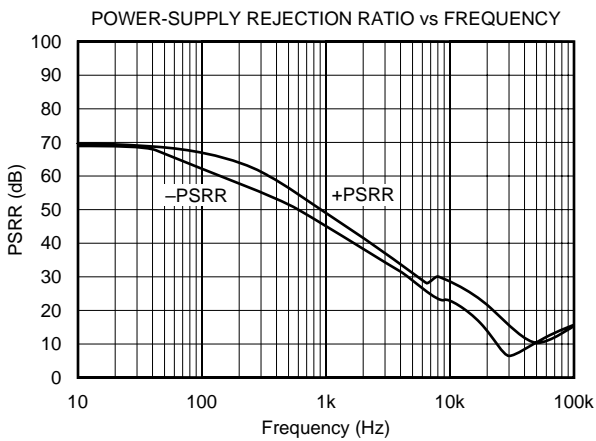
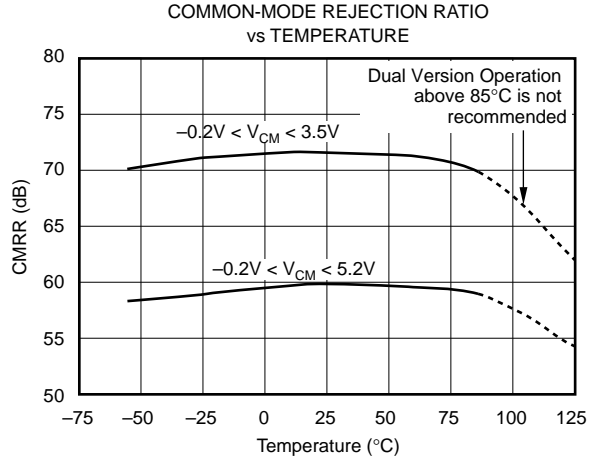
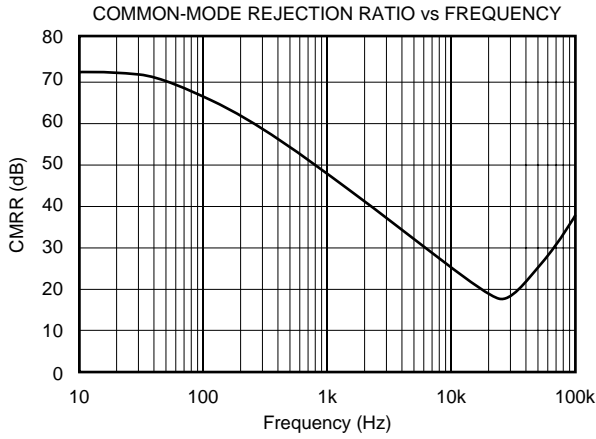
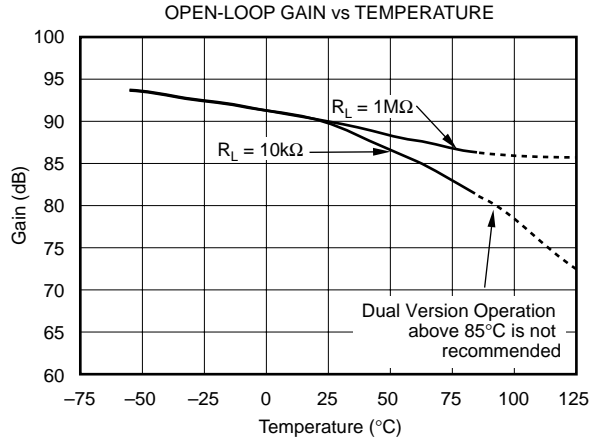
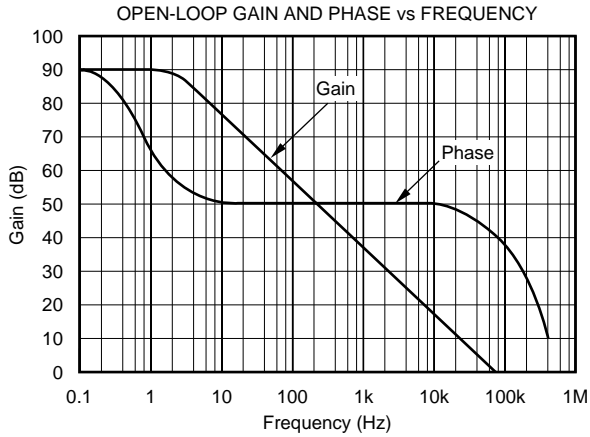
At $T_A = +25^{\circ}C$, $R_L = 1M\Omega$ connected to $V_S/2$, unless otherwise noted.

PARAMETER	CONDITION	OPA2349EA, UA			UNITS
		MIN	TYP	MAX	
OFFSET VOLTAGE Input Offset Voltage Over Temperature Drift vs Power Supply Over Temperature Channel Separation, dc	V_{OS} dV_{OS}/dT PSRR $R_L = 100k\Omega$ $f = 1kHz$	$V_S = 5V, V_{CM} = 2.5V$ $V_S = 1.8V$ to $5.5V, V_{CM} = (V-) + 0.3V$	± 2 ± 2 ± 15 350 10 66 ⁽¹⁾	± 10 ± 13 1000 3000	mV mV $\mu V/^{\circ}C$ $\mu V/V$ $\mu V/V$ dB
INPUT VOLTAGE RANGE Common-Mode Voltage Range Common-Mode Rejection Ratio Over Temperature Over Temperature	V_{CM} CMRR	$V_S = +5V, -0.2V < V_{CM} < 3.5V$ $V_S = +5V, -0.2V < V_{CM} < 5.2V$	$(V-) - 0.2$ 52 50 48 46	$(V+) + 0.2$ 	V dB dB dB dB
INPUT BIAS CURRENT Input Bias Current Input Offset Current	I_B I_{OS}		± 0.5 ± 1	± 10 ± 10	pA pA
INPUT IMPEDANCE Differential Common-Mode			$10^{13} \parallel 2$ $10^{13} \parallel 4$		$\Omega \parallel pF$ $\Omega \parallel pF$
NOISE Input Voltage Noise, $f = 0.1Hz$ to $10Hz$ Input Voltage Noise Density, $f = 1kHz$ Current Noise Density, $f = 1kHz$	e_n i_n		8 300 4		$\mu Vp-p$ nV/\sqrt{Hz} fA/\sqrt{Hz}
OPEN-LOOP GAIN Open-Loop Voltage Gain Over Temperature Open-Loop Voltage Gain Over Temperature	A_{OL} A_{OL}	$R_L = 1M\Omega, V_S = +5.5V, +0.3V < V_O < +5.2V$ $R_L = 10k\Omega, V_S = +5.5V, +0.35V < V_O < +5.15V$	74 72 74 60	90 90	dB dB dB dB
OUTPUT Voltage Output Swing from Rail Over Temperature Over Temperature Output Current Short-Circuit Current	I_{SC}	$R_L = 1M\Omega, V_S = +5.5V, A_{OL} > 74dB$ $R_L = 10k\Omega, V_S = +5.5V, A_{OL} > 74dB$	 ± 8 ± 10	150 300 300 350 350	mV mV mV mV mA mA
FREQUENCY RESPONSE Gain-Bandwidth Product Slew Rate Settling Time, 0.1% 0.01% Overload Recovery Time	GBW SR t_s	$C_L = 10pF$ $G = +1$ $V_S = +5V, G = +1$ $V_S = 5V, 1V$ Step $V_S = 5V, 1V$ Step $V_{IN} \cdot Gain = V_S$	70 0.02 65 80 5		kHz V/ μs μs μs μs
POWER SUPPLY Specified Voltage Range Quiescent Current (per amplifier) Over Temperature	V_S I_Q	$I_O = 0$	1.8 1	5.5 2 10	V μA μA
TEMPERATURE RANGE Specified Range Operating Range Storage Range Thermal Resistance SOT23-8 Surface Mount SO-8 Surface Mount	θ_{JA}		-40 -40 -65 200 150	+70 +85 +150	$^{\circ}C$ $^{\circ}C$ $^{\circ}C$ $^{\circ}C/W$ $^{\circ}C/W$ $^{\circ}C/W$

NOTE: (1) Refer to "Typical Characteristics" Curves.

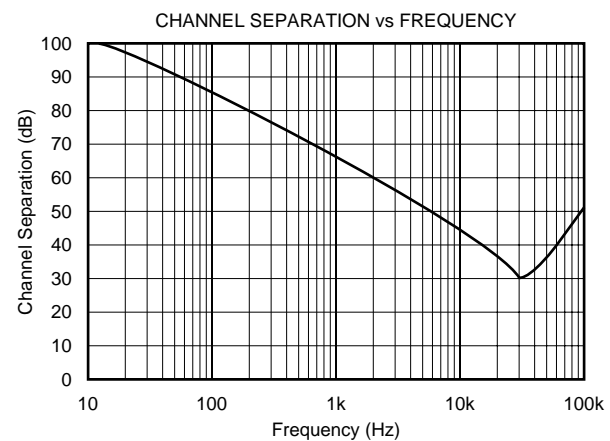
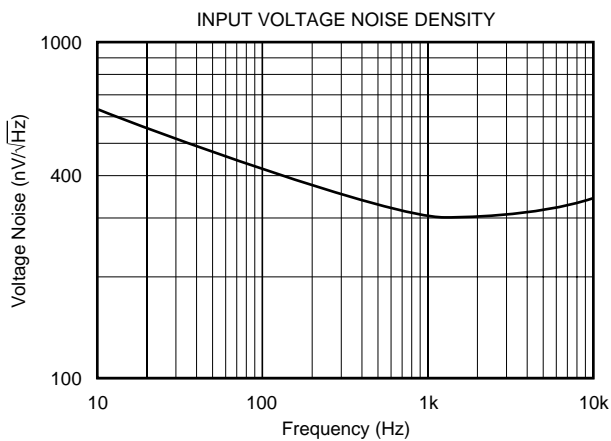
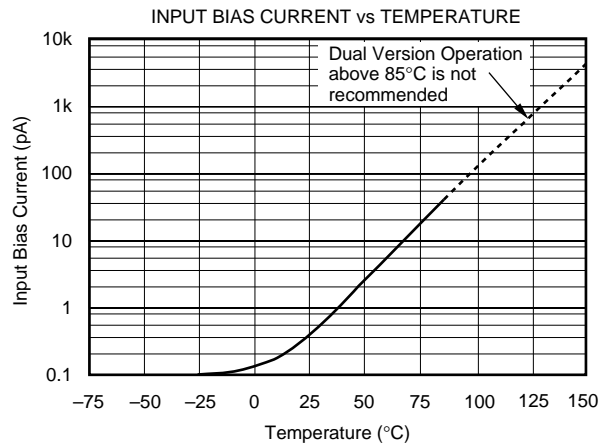
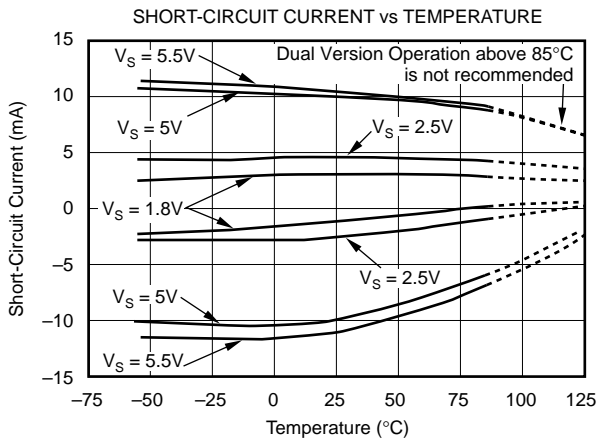
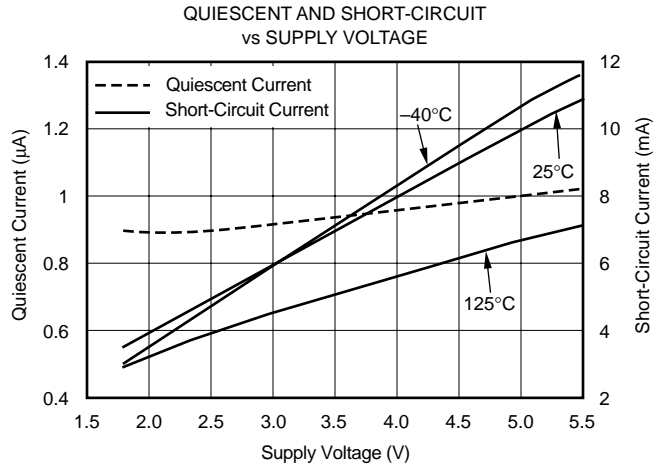
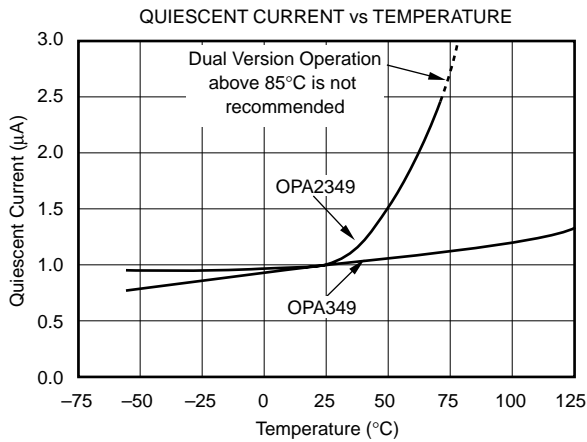
TYPICAL CHARACTERISTICS

At $T_A = +25^\circ\text{C}$, $V_S = +5\text{V}$, $R_L = 1\text{M}\Omega$ connected to $V_S/2$, unless otherwise noted.



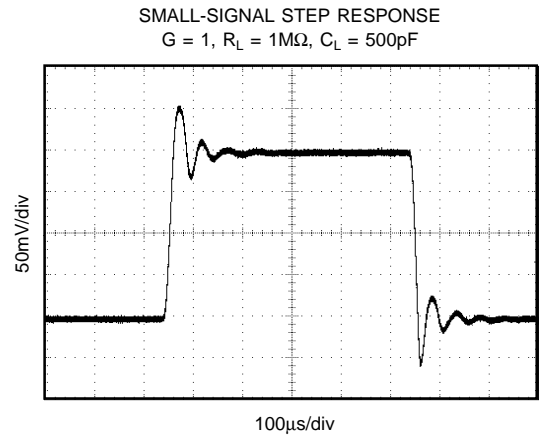
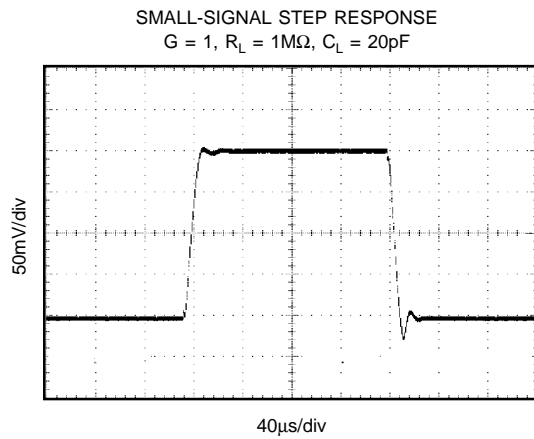
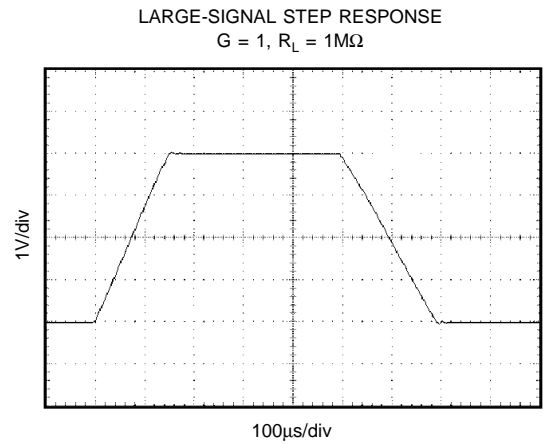
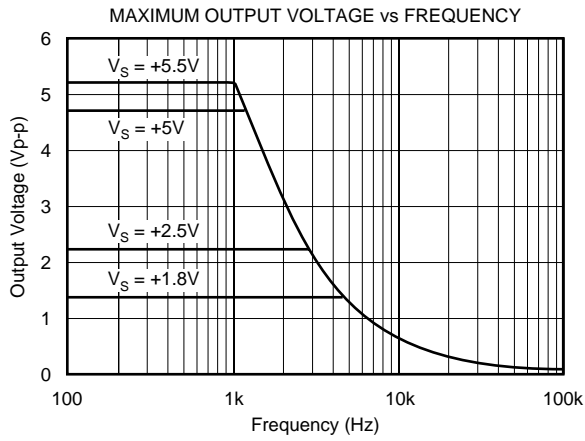
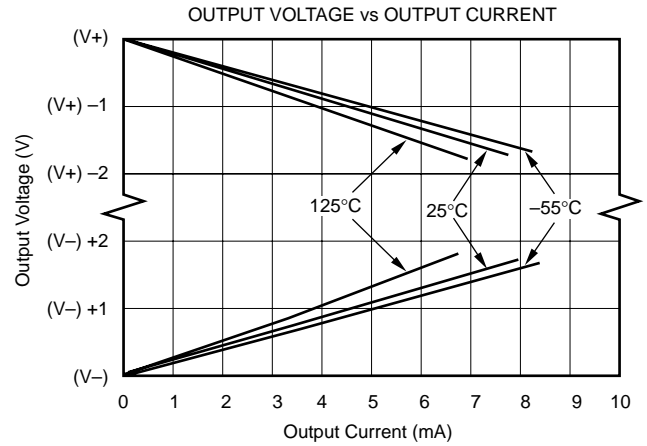
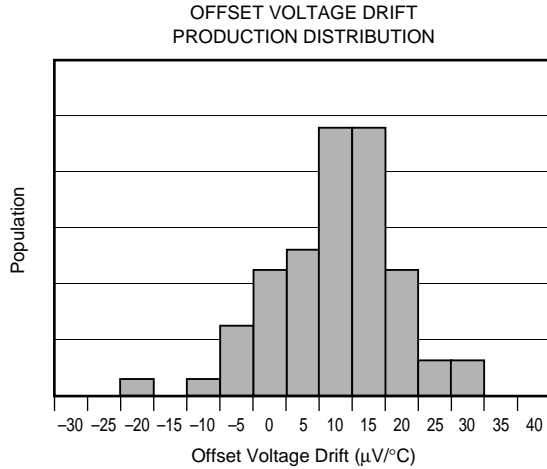
TYPICAL CHARACTERISTICS (Cont.)

At $T_A = +25^\circ\text{C}$, $V_S = +5\text{V}$, $R_L = 1\text{M}\Omega$ connected to $V_S/2$, unless otherwise noted.



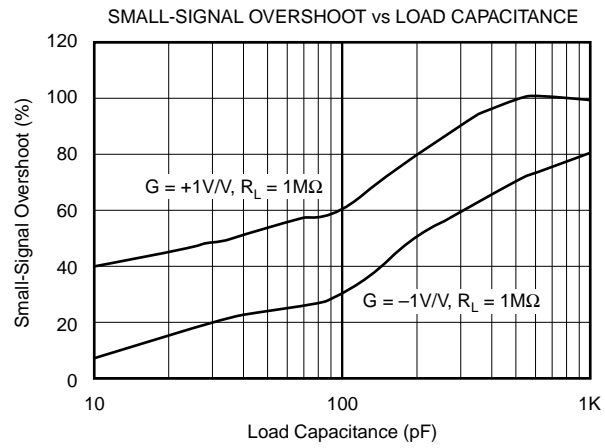
TYPICAL CHARACTERISTICS (Cont.)

At $T_A = +25^\circ\text{C}$, $V_S = +5\text{V}$, $R_L = 1\text{M}\Omega$ connected to $V_S/2$, unless otherwise noted.



TYPICAL CHARACTERISTICS (Cont.)

At $T_A = +25^\circ\text{C}$, $V_S = +5\text{V}$, $R_L = 1\text{M}\Omega$ connected to $V_S/2$, unless otherwise noted.



APPLICATIONS INFORMATION

OPA349 series op amps are unity gain stable and can operate on a single supply, making them highly versatile and easy to use. Power supply pins should be bypassed with 0.01 μ F ceramic capacitors.

OPA349 series op amps are fully specified and tested from +1.8V to +5.5V. Parameters that vary significantly with operating voltages or temperature are shown in the Typical Characteristics Curves.

The ultra low quiescent current of the OPA349 requires careful applications circuit techniques to achieve low overall current consumption. Figure 1 shows an ac-coupled amplifier

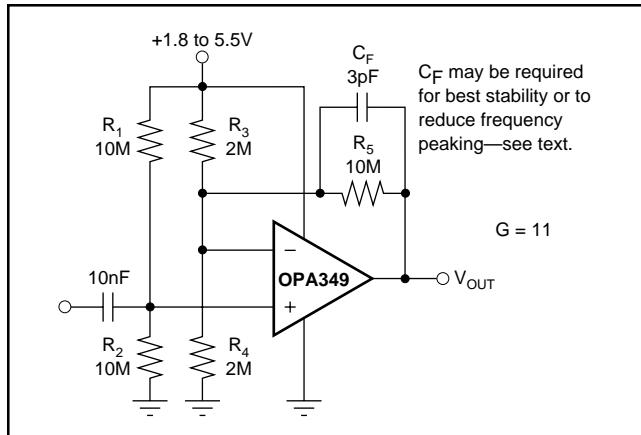


FIGURE 1. AC-Coupled Amplifier.

biased with a voltage divider. Resistor values must be very large to minimize current. The large feedback resistor value reacts with input capacitance and stray capacitance to produce a pole in the feedback network. A feedback capacitor may be required to assure stability and limit overshoot or gain peaking. Check circuit performance carefully to assure that biasing and feedback techniques meet your signal and quiescent current requirements.

RAIL-TO-RAIL INPUT

The input common-mode voltage range of the OPA349 series extends 200mV beyond the supply rails. This is achieved with a complementary input stage—an N-channel input differential pair in parallel with a P-channel differential pair (as shown in Figure 2). The N-channel pair is active for input voltages close to the positive rail, typically $(V+) - 1.3V$ to 200mV above the positive supply, while the P-channel pair is on for inputs from 200mV below the negative supply to approximately $(V+) - 1.3V$. There is a small transition region, typically $(V+) - 1.5V$ to $(V+) - 1.1V$, in which both pairs are on. This 400mV transition region can vary 300mV with process variation. Thus, the transition region (both stages on) can range from $(V+) - 1.8V$ to $(V+) - 1.4V$ on the low end, up to $(V+) - 1.2V$ to $(V+) - 0.8V$ on the high end. Within the 400mV transition region PSRR, CMRR, offset voltage, offset drift, and THD may be degraded compared to operation outside this region. For more information on designing with rail-to-rail input op amps, see Figure 3 “Design Optimization with Rail-to-Rail Input Op Amps.”

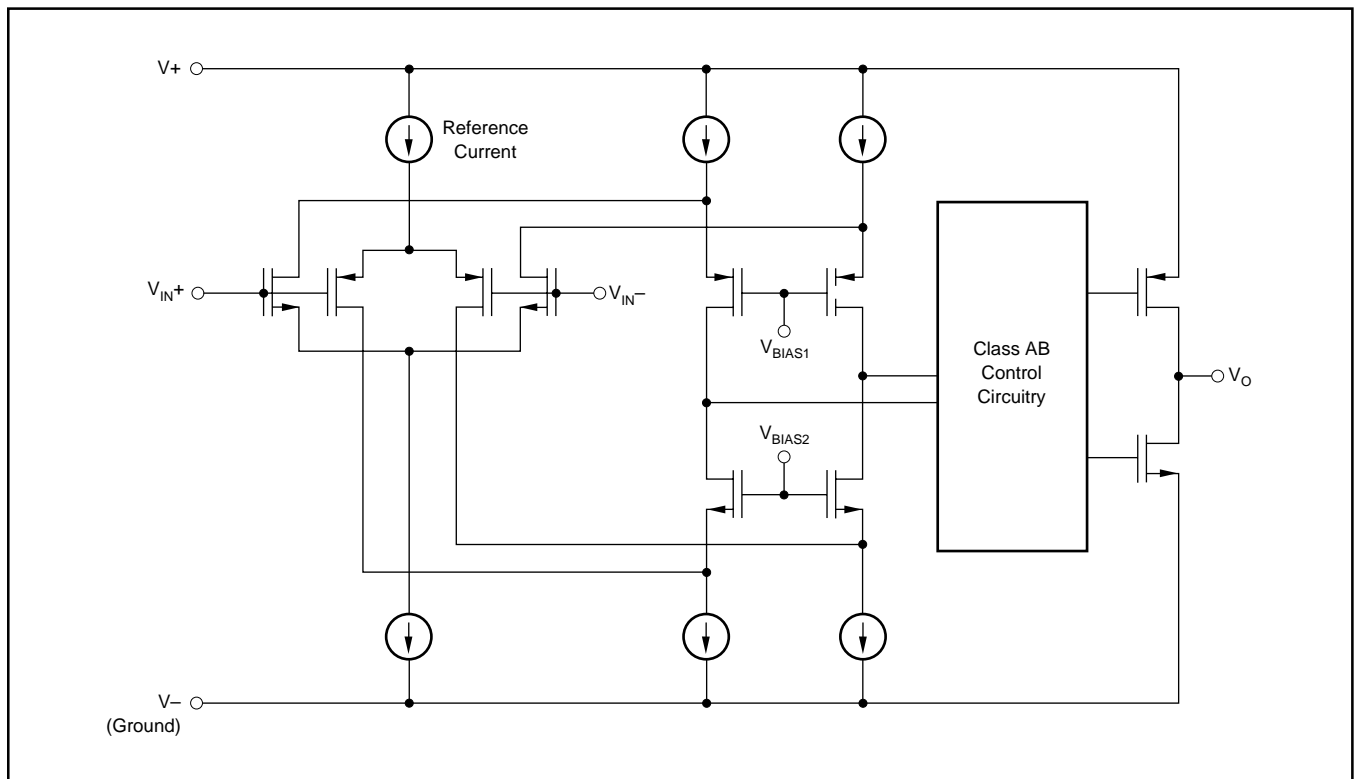


FIGURE 2. Simplified Schematic.

DESIGN OPTIMIZATION WITH RAIL-TO-RAIL INPUT OP AMPS

In most applications, operation is within the range of only one differential pair. However, some applications can subject the amplifier to a common-mode signal in the transition region. Under this condition, the inherent mismatch between the two differential pairs may lead to degradation of the CMRR and THD. The unity-gain buffer configuration is the most problematic—it will traverse through the transition region if a sufficiently

wide input swing is required. A design option would be to configure the op amp as a unity-gain inverter as shown below and hold the noninverting input at a set common-mode voltage outside the transition region. This can be accomplished with a voltage divider from the supply. The voltage divider should be designed such that the biasing point for the noninverting input is outside the transition region.



FIGURE 3. Design Optimization.

COMMON-MODE REJECTION

The CMRR for the OPA349 is specified in two ways so the best match for a given application may be used. First, the CMRR of the device in the common-mode range below the transition region ($V_{CM} < (V+) - 1.5V$) is given. This specification is the best indicator of the capability of the device when the application requires use of one of the differential input pairs. Second, the CMRR at $V_S = 5V$ over the entire common-mode range is specified.

OUTPUT DRIVEN TO $V-$ RAIL (DUAL VERSION ONLY)

Loads that connect to single-supply ground (or the $V-$ supply pin) can cause the OPA2349 (dual version) to oscillate if the output voltage is driven into the negative rail (Figure 4a).

Similarly, loads that can cause current to flow out of the output pin when the output voltage is near $V-$ can cause oscillations. The op amp will recover to normal operation a few microseconds after the output is driven positively out of the rail.

Some op amp applications can produce this condition even without a load connected to $V-$. The integrator in Figure 4b shows an example. Assume that the output ramps negatively, and saturates near $0V$. Any negative-going step at V_{IN} will produce a positive output current pulse through R_1 and C_1 . This may incite the oscillation. Diode, D_1 , prevents the input step from pulling output current when the output is saturated at the rail, thus preventing the oscillation.

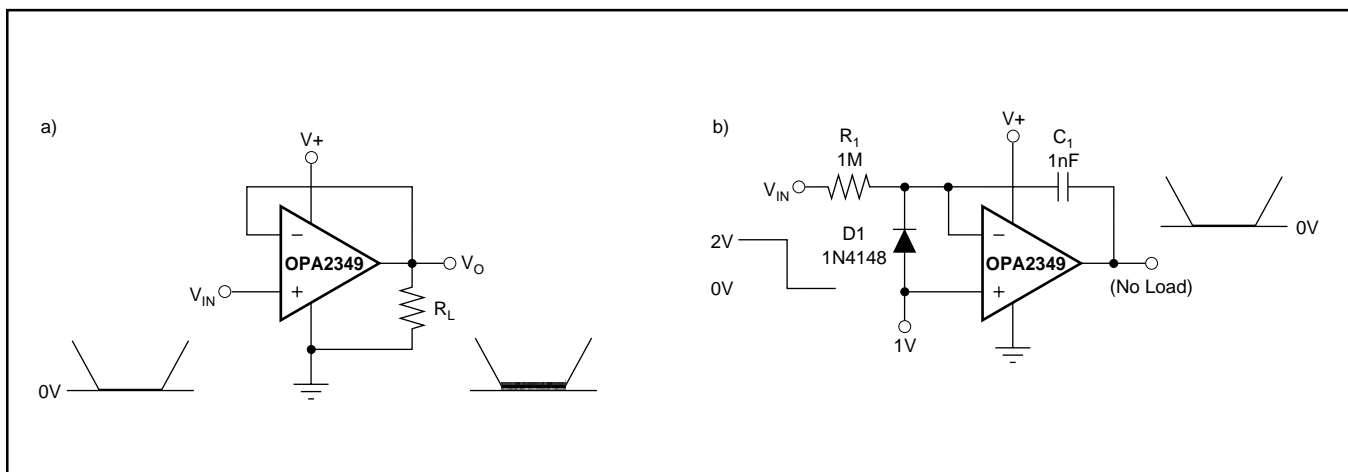
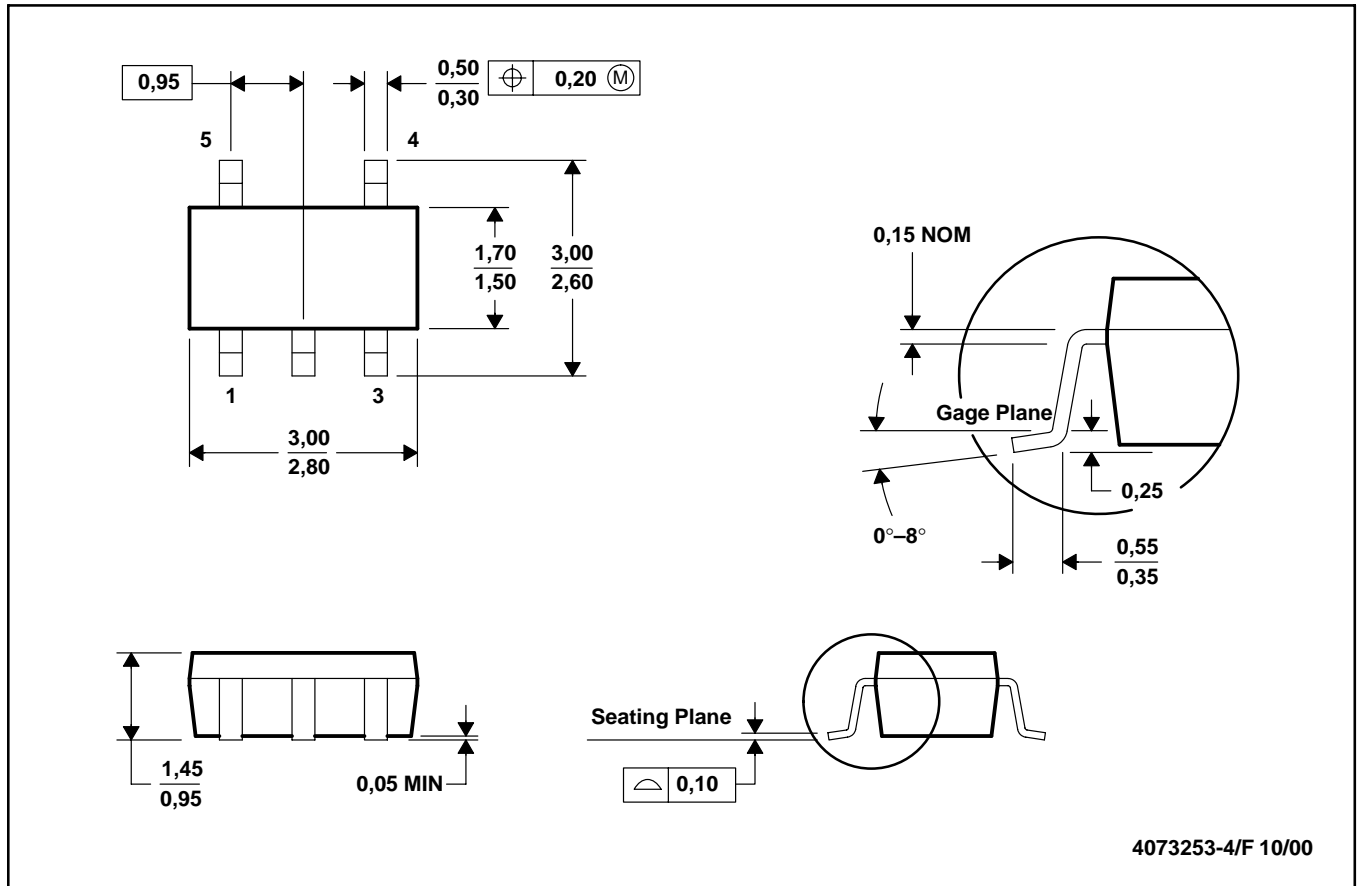


FIGURE 4. Output Driven to Negative Rail (Dual Version Only).

DBV (R-PDSO-G5)

PLASTIC SMALL-OUTLINE

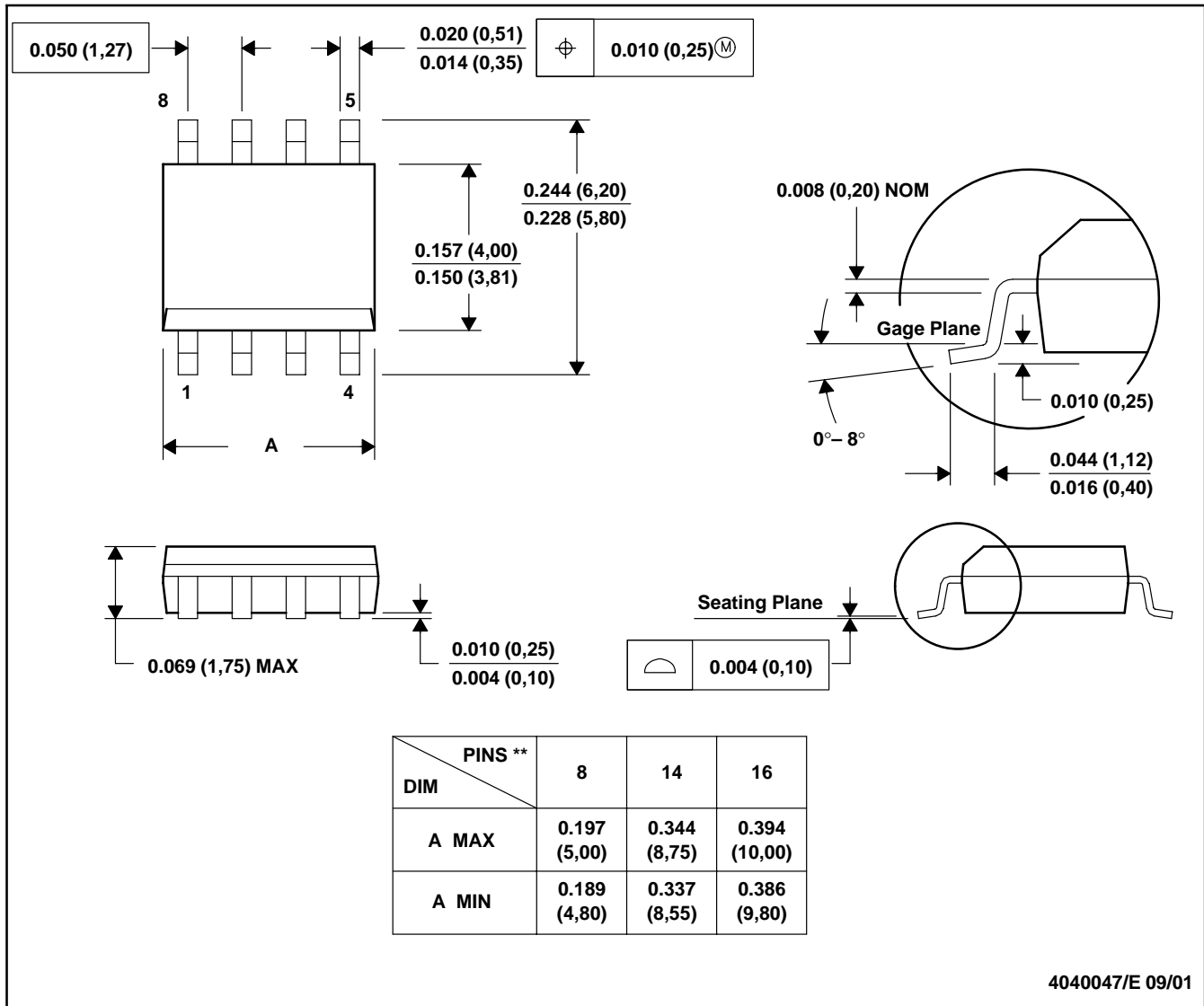


- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion.
 - D. Falls within JEDEC MO-178

D (R-PDSO-G**)

PLASTIC SMALL-OUTLINE PACKAGE

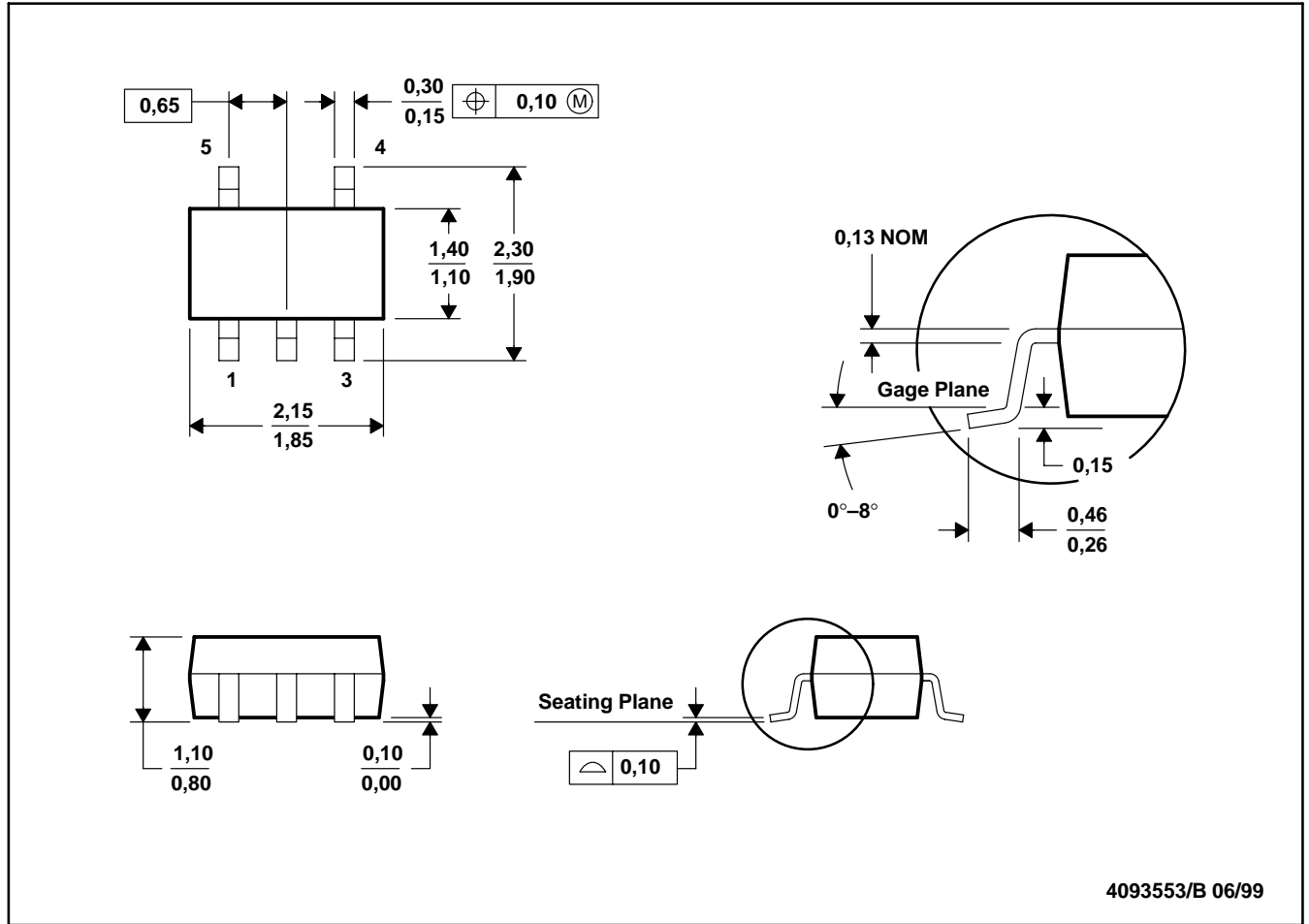
8 PINS SHOWN



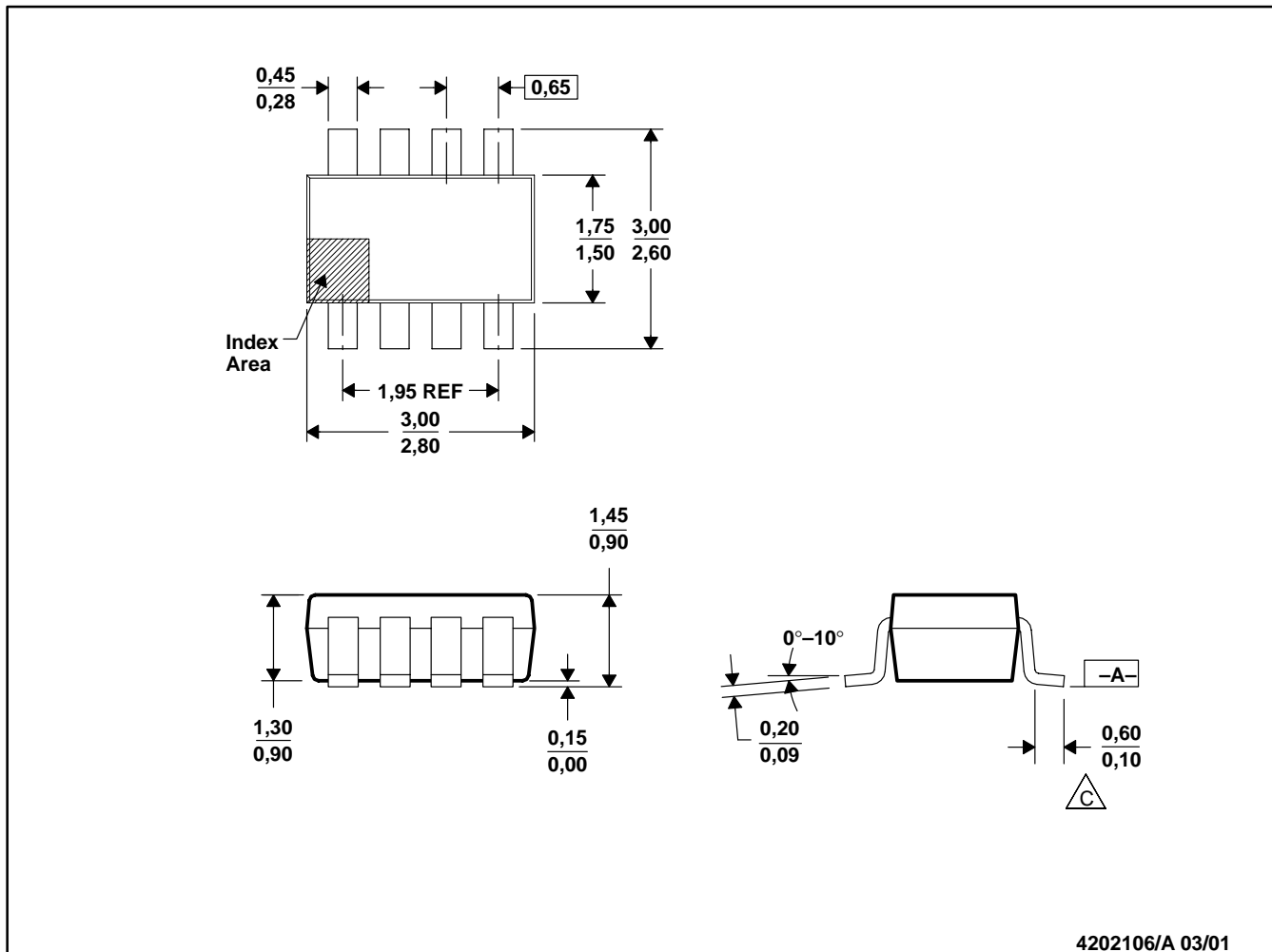
- NOTES:
- A. All linear dimensions are in inches (millimeters).
 - B. This drawing is subject to change without notice.
 - C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
 - D. Falls within JEDEC MS-012

DCK (R-PDSO-G5)

PLASTIC SMALL-OUTLINE



- 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.
 D. Falls within JEDEC MO-203



4202106/A 03/01

- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Foot length measured reference to flat foot surface parallel to Datum A.
 - D. Package outline exclusive of mold flash, metal burr and dambar protrusion/intrusion.
 - E. Package outline inclusive of solder plating.
 - F. A visual index feature must be located within the cross-hatched area.

PACKAGING INFORMATION

ORDERABLE DEVICE	STATUS(1)	PACKAGE TYPE	PACKAGE DRAWING	PINS	PACKAGE QTY
OPA2349EA/250	ACTIVE	SSOP	DCN	8	250
OPA2349EA/3K	ACTIVE	SSOP	DCN	8	3000
OPA2349UA	ACTIVE	SOIC	D	8	100
OPA2349UA/2K5	ACTIVE	SOIC	D	8	2500
OPA349NA/250	ACTIVE	SOP	DBV	5	250
OPA349NA/3K	ACTIVE	SOP	DBV	5	3000
OPA349SA/250	ACTIVE	SOP	DCK	5	250
OPA349SA/3K	ACTIVE	SOP	DCK	5	3000
OPA349UA	ACTIVE	SOIC	D	8	100
OPA349UA/2K5	ACTIVE	SOIC	D	8	2500

(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.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		Applications	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
DSP	dsp.ti.com	Broadband	www.ti.com/broadband
Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
		Video & Imaging	www.ti.com/video
		Wireless	www.ti.com/wireless

Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265

Copyright © 2003, Texas Instruments Incorporated