



SBOS099C − SEPTEMBER 2000 − REVISED JANUARY 2005

# High-Speed, Single-Supply, Rail-to-Rail OPERATIONAL AMPLIFIERS

## *Micro*Amplifier™ Series

## FEATURES

- RAIL-TO-RAIL INPUT
- RAIL-TO-RAIL OUTPUT (within 10mV)
- WIDE BANDWIDTH: 38MHz
- HIGH SLEW RATE: 22V/μs
- LOW NOISE: 5nV/√Hz
- LOW THD+NOISE: 0.0006%
- UNITY-GAIN STABLE
- *Micro*SIZE PACKAGES
- SINGLE, DUAL, AND QUAD

## APPLICATIONS

- CELL PHONE PA CONTROL LOOPS
- DRIVING A/D CONVERTERS
- VIDEO PROCESSING
- DATA ACQUISITION
- PROCESS CONTROL
- AUDIO PROCESSING
- COMMUNICATIONS
- ACTIVE FILTERS
- TEST EQUIPMENT

## DESCRIPTION

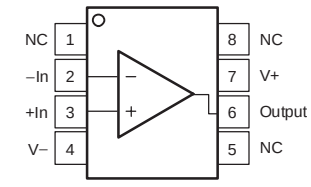
The OPA350 series rail-to-rail CMOS operational amplifiers are optimized for low voltage, single-supply operation. Rail-to-rail input/output, low noise (5nV/√Hz), and high speed operation (38MHz, 22V/μs) make them ideal for driving sampling Analog-to-Digital (A/D) converters. They are also well suited for cell phone PA control loops and video processing (75Ω drive capability) as well as audio and general purpose applications. Single, dual, and quad versions have identical specifications for maximum design flexibility.

The OPA350 series operates on a single supply as low as 2.5V with an input common-mode voltage range that extends 300mV below ground and 300mV above the positive supply. Output voltage swing is to within 10mV of the supply rails with a 10kΩ load. Dual and quad designs feature completely independent circuitry for lowest crosstalk and freedom from interaction.

The single (OPA350) and dual (OPA2350) come in the miniature MSOP-8 surface mount, SO-8 surface mount, and DIP-8 packages. The quad (OPA4350) packages are the space-saving SSOP-16 surface mount and SO-14 surface mount. All are specified from −40°C to +85°C and operate from −55°C to +150°C.

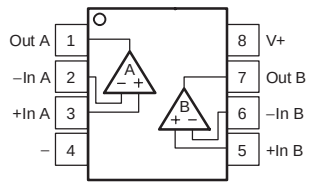
**SPICE model available at www.ti.com**

**OPA350**



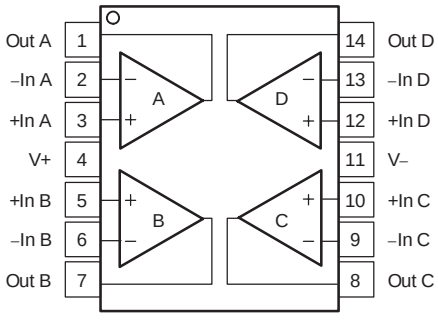

DIP−8, SO−8, MSOP−8

**OPA2350**



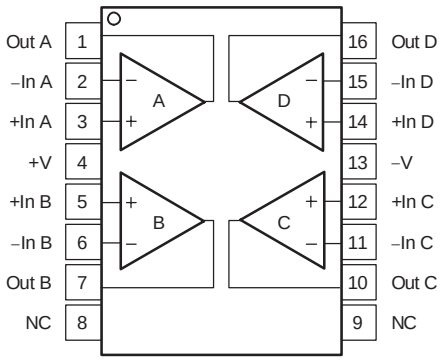

DIP−8, SO−8, MSOP−8

**OPA4350**




SO−14

**OPA4350**




SSOP−16

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## ABSOLUTE MAXIMUM RATINGS(1)

| | |
|---|---|
| Supply Voltage | 7.0V |
| Signal Input Terminals(2), Voltage | (V−) − 0.3V to (V+) + 0.3V |
| Current | 10mA |
| Open Short-Circuit Current(3) | Continuous |
| Operating Temperature Range | −55°C to +150°C |
| Storage Temperature Range | −55°C to +150°C |
| Junction Temperature | +150°C |
| Lead Temperature (soldering, 10s) | +300°C |

(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 0.3V 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(1)

| PRODUCT | PACKAGE-LEAD | PACKAGE DESIGNATOR | SPECIFIED TEMPERATURE RANGE | PACKAGE MARKING | ORDERING NUMBER | TRANSPORT MEDIA, QUANTITY |
|---|---|---|---|---|---|---|
| **SINGLE** | | | | | | |
| OPA350EA | MSOP-8 | DGK | −40°C to +85°C | C50 | OPA350EA/250 | Tape and Reel, 250 |
| | | | | | OPA350EA/2K5 | Tape and Reel, 2500 |
| OPA350UA | SO-8 | D | −40°C to +85°C | OPA350UA | OPA350UA | Rails |
| | | | | | OPA350UA/2K5 | Tape and Reel, 2500 |
| OPA350PA | DIP-8 | P | −40°C to +85°C | OPA350PA | OPA350PA | Rails |
| **DUAL** | | | | | | |
| OPA2350EA | MSOP-8 | DGK | −40°C to +85°C | D50 | OPA2350EA/250 | Tape and Reel, 250 |
| | | | | | OPA2350EA/2K5 | Tape and Reel, 2500 |
| OPA2350UA | SO-8 | D | −40°C to +85°C | OPA2350UA | OPA2350UA | Rails |
| | | | | | OPA2350UA/2K5 | Tape and Reel, 2500 |
| OPA2350PA | DIP-8 | P | −40°C to +85°C | OPA2350PA | OPA2350PA | Rails |
| **QUAD** | | | | | | |
| OPA4350EA | SSOP-16 | DBQ | −40°C to +85°C | OPA4350EA | OPA4350EA/250 | Tape and Reel, 250 |
| | | | | | OPA4350EA/2K5 | Tape and Reel, 2500 |
| OPA4350UA | SO-14 | D | −40°C to +85°C | OPA4350UA | OPA4350UA | Rails |
| | | | | | OPA4350UA/2K5 | Tape and Reel, 2500 |

(1) For the most current package and ordering information, see the Package Option Addendum located at the end of this data sheet.

## ELECTRICAL CHARACTERISTICS: $V_S$ = 2.7V to 5.5V

**Boldface** limits apply over the temperature range, **$T_A$ = −40°C to +85°C**. $V_S$ = 5V.

All specifications at $T_A$ = +25°C, $R_L$ = 1kΩ connected to $V_S$/2 and $V_{OUT}$ = $V_S$/2, unless otherwise noted.

| PARAMETER | | TEST CONDITIONS | OPA350, OPA2350, OPA4350 MIN | TYP(1) | MAX | UNIT |
|---|---|---|---|---|---|---|
| **OFFSET VOLTAGE** | | | | | | |
| Input Offset Voltage | $V_{OS}$ | $V_S$ = 5V | | ±150 | ±500 | µV |
| **$T_A$ = −40°C to +85°C** | | | | | **±1** | mV |
| vs Temperature | | **$T_A$ = −40°C to +85°C** | | **±4** | | µV/°C |
| vs Power-Supply Rejection Ratio | PSRR | $V_S$ = 2.7V to 5.5V, $V_{CM}$ = 0V | | 40 | 150 | µV/V |
| **$T_A$ = −40°C to +85°C** | | **$V_S$ = 2.7V to 5.5V, $V_{CM}$ = 0V** | | | **175** | µV/V |
| Channel Separation (dual, quad) | | dc | | 0.15 | | µV/V |
| **INPUT BIAS CURRENT** | | | | | | |
| Input Bias Current | $I_B$ | | | ±0.5 | ±10 | pA |
| vs Temperature | | | | See Typical Characteristics | | |
| Input Offset Current | $I_{OS}$ | | | ±0.5 | ±10 | pA |
| **NOISE** | | | | | | |
| Input Voltage Noise, f = 100Hz to 400kHz | | | | 4 | | µVrms |
| Input Voltage Noise Density, f = 10kHz | $e_n$ | | | 7 | | nV/√Hz |
| Input Current Noise Density, f = 100kHz | | | | 5 | | nV/√Hz |
| Current Noise Density, f = 10kHz | $i_n$ | | | 4 | | fA/√Hz |
| **INPUT VOLTAGE RANGE** | | | | | | |
| Common-Mode Voltage Range | $V_{CM}$ | **$T_A$ = −40°C to +85°C** | **−0.1** | | **(V+) + 0.1** | V |
| Common-Mode Rejection Ratio | CMRR | $V_S$ = 2.7V, −0.1V < $V_{CM}$ < 2.8V | 66 | 84 | | dB |
| | | $V_S$ = 5.5V, −0.1V < $V_{CM}$ < 5.6V | 74 | 90 | | dB |
| **$T_A$ = −40°C to +85°C** | | **$V_S$ = 5.5V, −0.1V < $V_{CM}$ < 5.6V** | **74** | | | dB |
| **INPUT IMPEDANCE** | | | | | | |
| Differential | | | | $10^{13}$ ‖ 2.5 | | Ω ‖ pF |
| Common-Mode | | | | $10^{13}$ ‖ 6.5 | | Ω ‖ pF |
| **OPEN-LOOP GAIN** | | | | | | |
| Open-Loop Voltage Gain | $A_{OL}$ | $R_L$ = 10kΩ, 50mV < $V_O$ < (V+) −50mV | 100 | 122 | | dB |
| **$T_A$ = −40°C to +85°C** | | **$R_L$ = 10kΩ, 50mV < $V_O$ < (V+) −50mV** | **100** | | | dB |
| | | $R_L$ = 1kΩ, 200mV < $V_O$ < (V+) −200mV | 100 | 120 | | dB |
| **$T_A$ = −40°C to +85°C** | | **$R_L$ = 1kΩ, 200mV < $V_O$ < (V+) −200mV** | **100** | | | dB |
| **FREQUENCY RESPONSE** | | $C_L$ = 100pF | | | | |
| Gain-Bandwidth Product | GBW | G = 1 | | 38 | | MHz |
| Slew Rate | SR | G = 1 | | 22 | | V/µs |
| Settling Time: 0.1% | | G = ±1, 2V Step | | 0.22 | | µs |
| 0.01% | | G = ±1, 2V Step | | 0.5 | | µs |
| Overload Recovery Time | | $V_{IN}$ • G = $V_S$ | | 0.1 | | µs |
| Total Harmonic Distortion + Noise | THD+N | $R_L$ = 600Ω, $V_O$ = 2.5$V_{PP}$(2), G = 1, f = 1kHz | | 0.0006 | | % |
| Differential Gain Error | | G = 2, $R_L$ = 600Ω, $V_O$ = 1.4V(3) | | 0.17 | | % |
| Differential Phase Error | | G = 2, $R_L$ = 600Ω, $V_O$ = 1.4V(3) | | 0.17 | | deg |

(1) $V_S$ = +5V.
(2) $V_{OUT}$ = 0.25V to 2.75V.
(3) NTSC signal generator used. See Figure 6 for test circuit.
(4) Output voltage swings are measured between the output and power supply rails.
(5) See typical characteristic curve, *Output Voltage Swing vs Output Current*.

## ELECTRICAL CHARACTERISTICS: $V_S$ = 2.7V to 5.5V (continued)

**Boldface** limits apply over the temperature range, **$T_A$ = −40°C to +85°C**. $V_S$ = 5V.

All specifications at $T_A$ = +25°C, $R_L$ = 1kΩ connected to $V_S$/2 and $V_{OUT}$ = $V_S$/2, unless otherwise noted.

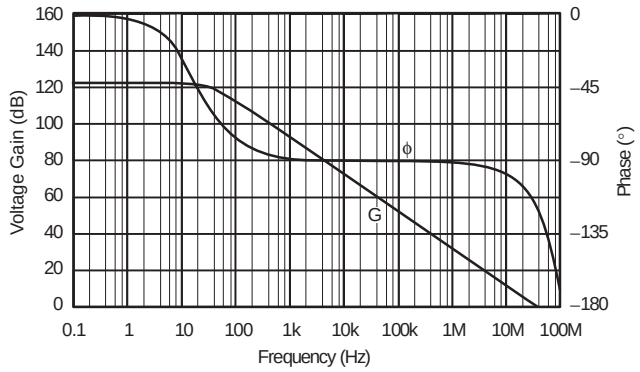
| PARAMETER | | TEST CONDITIONS | OPA350, OPA2350, OPA4350 MIN | TYP(1) | MAX | UNIT |
|---|---|---|---|---|---|---|
| **OUTPUT** | | | | | | |
| Voltage Output Swing from Rail(4) | $V_{OUT}$ | $R_L$ = 10kΩ, $A_{OL}$ ≥ 100dB | | 10 | 50 | mV |
| **$T_A$ = −40°C to +85°C** | | **$R_L$ = 10kΩ, $A_{OL}$ ≥ 100dB** | | | **50** | mV |
| | | $R_L$ = 1kΩ, $A_{OL}$ ≥ 100dB | | 25 | 200 | mV |
| **$T_A$ = −40°C to +85°C** | | **$R_L$ = 1kΩ, $A_{OL}$ ≥ 100dB** | | | **200** | mV |
| Output Current | $I_{OUT}$ | | | ±40(5) | | mA |
| Short-Circuit Current | $I_{SC}$ | | | ±80 | | mA |
| Capacitive Load Drive | $C_{LOAD}$ | | | See Typical Characteristics | | |
| **POWER SUPPLY** | | | | | | |
| Operating Voltage Range | $V_S$ | **$T_A$ = −40°C to +85°C** | **2.7** | | **5.5** | V |
| Minimum Operating Voltage | | | | 2.5 | | V |
| Quiescent Current (per amplifier) | $I_Q$ | $I_O$ = 0 | | 5.2 | 7.5 | mA |
| **$T_A$ = −40°C to +85°C** | | $I_O$ = 0 | | | **8.5** | mA |
| **TEMPERATURE RANGE** | | | | | | |
| Specified Range | | | −40 | | +85 | °C |
| Operating Range | | | −55 | | +150 | °C |
| Storage Range | | | −55 | | +150 | °C |
| Thermal Resistance | $\theta_{JA}$ | | | | | |
| MSOP-8 Surface Mount | | | | 150 | | °C/W |
| SO-8 Surface Mount | | | | 150 | | °C/W |
| DIP-8 | | | | 100 | | °C/W |
| SO-14 Surface Mount | | | | 100 | | °C/W |
| SSOP-16 Surface Mount | | | | 100 | | °C/W |

(1) $V_S$ = +5V.
(2) $V_{OUT}$ = 0.25V to 2.75V.
(3) NTSC signal generator used. See Figure 6 for test circuit.
(4) Output voltage swings are measured between the output and power supply rails.
(5) See typical characteristic curve, *Output Voltage Swing vs Output Current*.

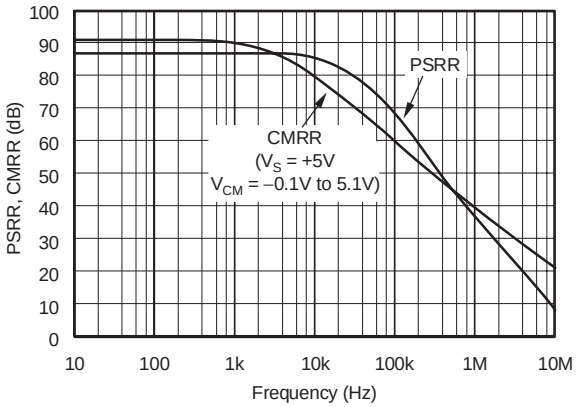
## TYPICAL CHARACTERISTICS

All specifications at $T_A$ = +25°C, $V_S$ = +5V, and $R_L$ = 1kΩ connected to $V_S$/2, unless otherwise noted.

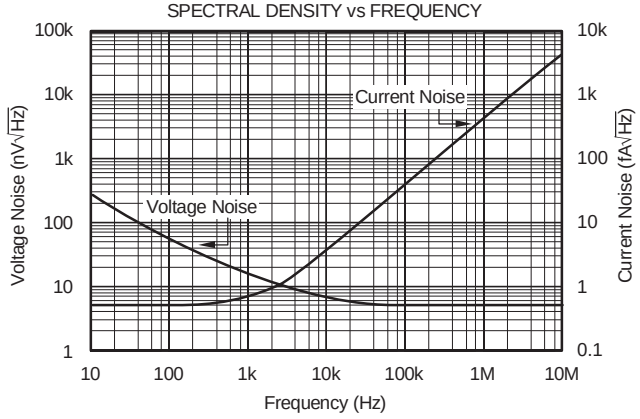
OPEN-LOOP GAIN/PHASE vs FREQUENCY



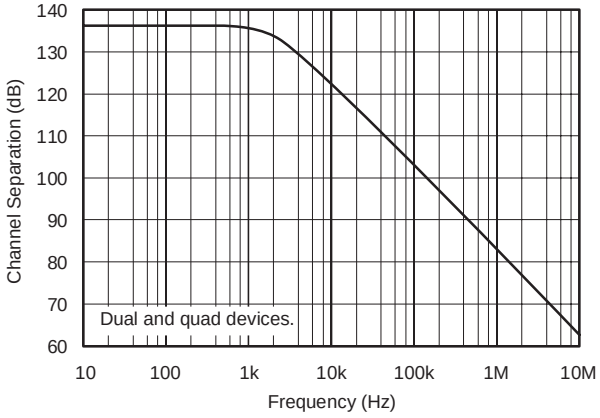

POWER SUPPLY AND COMMON-MODE REJECTION RATIO vs FREQUENCY



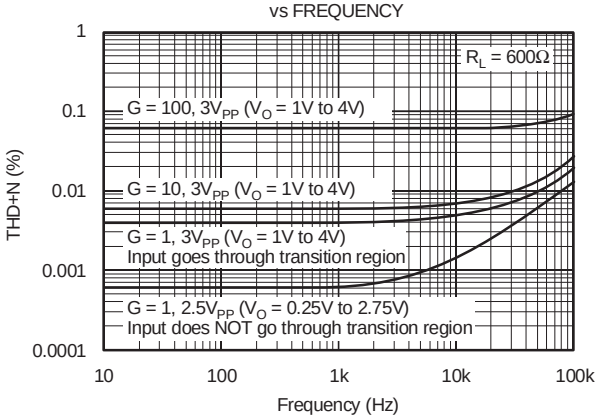

INPUT VOLTAGE AND CURRENT NOISE SPECTRAL DENSITY vs FREQUENCY



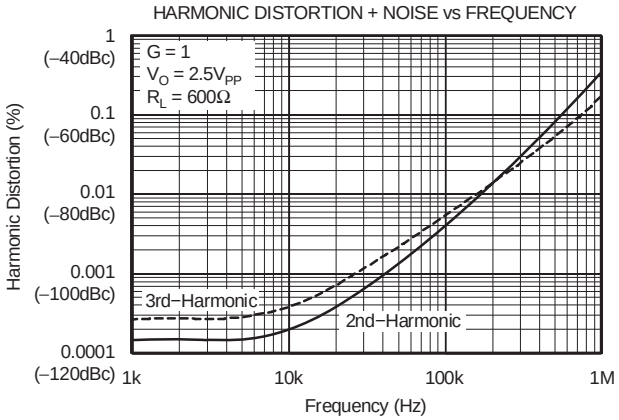

CHANNEL SEPARATION vs FREQUENCY




TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY



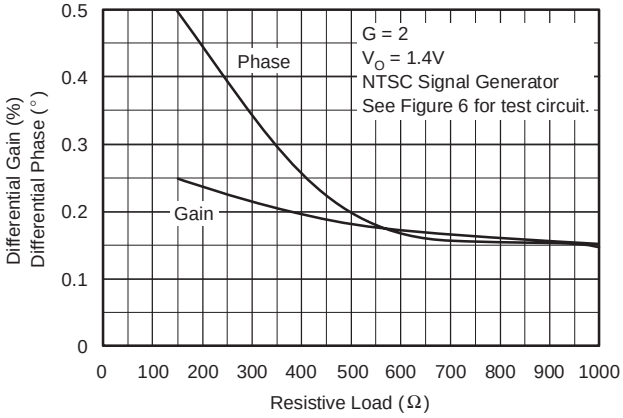

HARMONIC DISTORTION + NOISE vs FREQUENCY



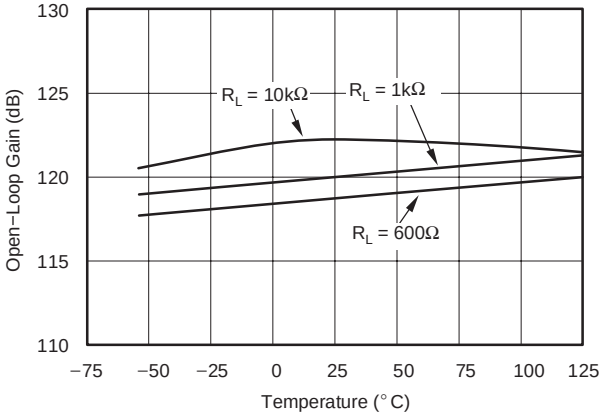
## TYPICAL CHARACTERISTICS (continued)

All specifications at $T_A$ = +25°C, $V_S$ = +5V, and $R_L$ = 1kΩ connected to $V_S$/2, unless otherwise noted.

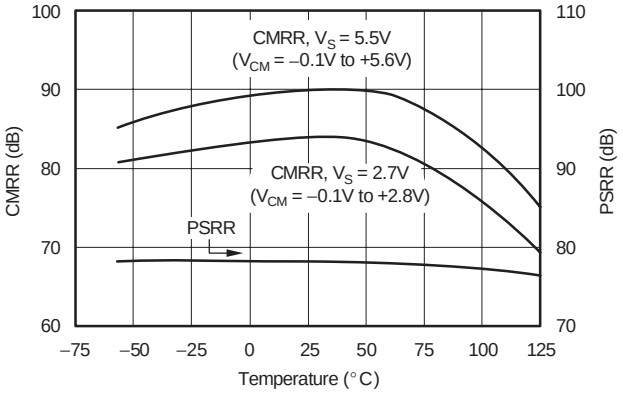
DIFFERENTIAL GAIN/PHASE vs RESISTIVE LOAD



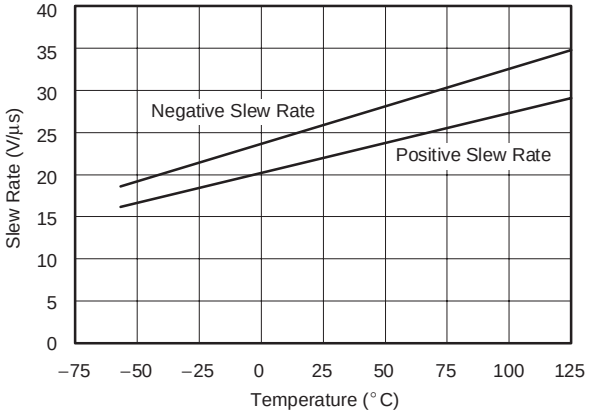

OPEN−LOOP GAIN vs TEMPERATURE



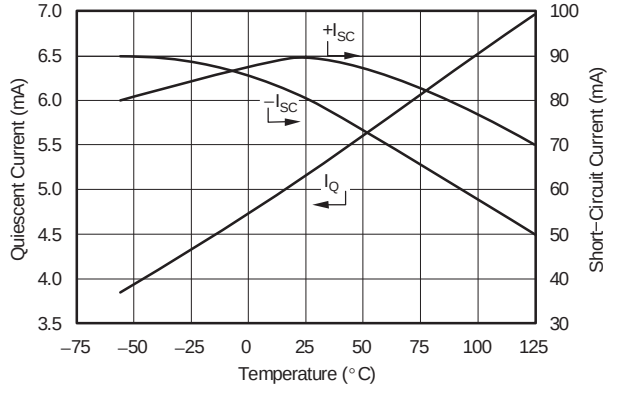

COMMON−MODE AND POWER−SUPPLY REJECTION RATIO vs TEMPERATURE



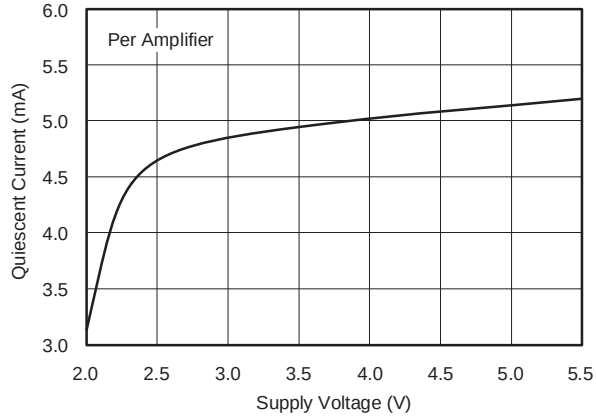

SLEW RATE vs TEMPERATURE




QUIESCENT CURRENT AND SHORT−CIRCUIT CURRENT vs TEMPERATURE



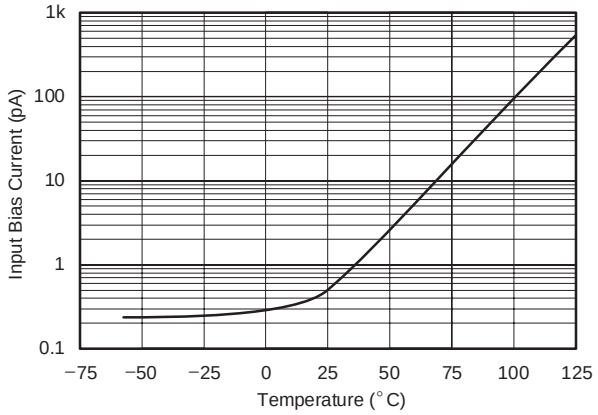

QUIESCENT CURRENT vs SUPPLY VOLTAGE



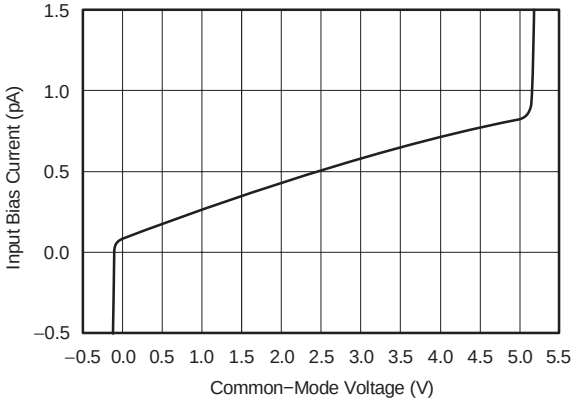
## TYPICAL CHARACTERISTICS (continued)

All specifications at $T_A$ = +25°C, $V_S$ = +5V, and $R_L$ = 1kΩ connected to $V_S$/2, unless otherwise noted.

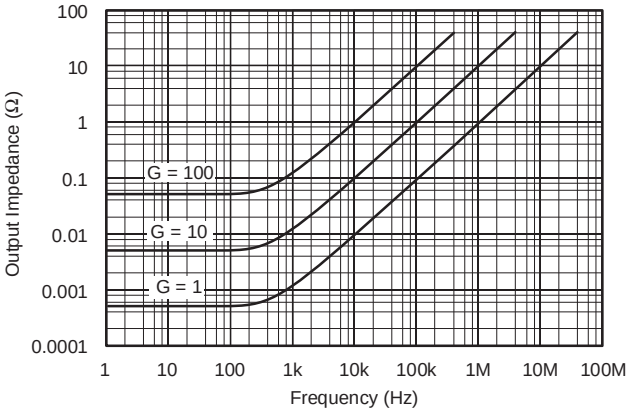
INPUT BIAS CURRENT vs TEMPERATURE



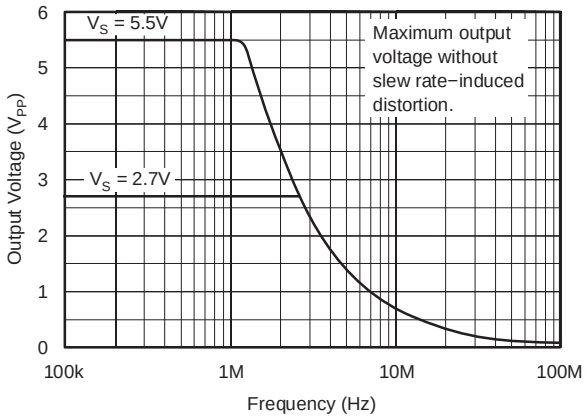

INPUT BIAS CURRENT
vs INPUT COMMON−MODE VOLTAGE



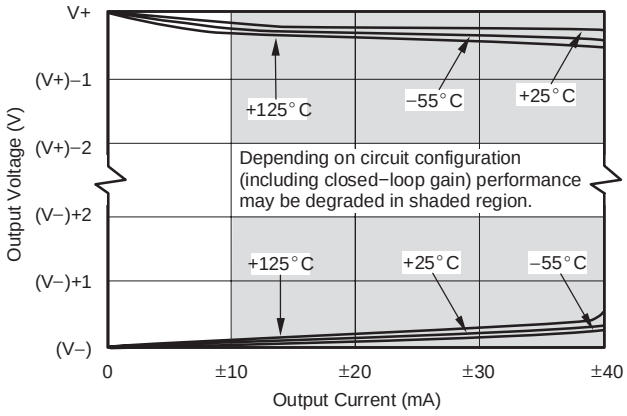

CLOSED−LOOP OUTPUT IMPEDANCE vs FREQUENCY



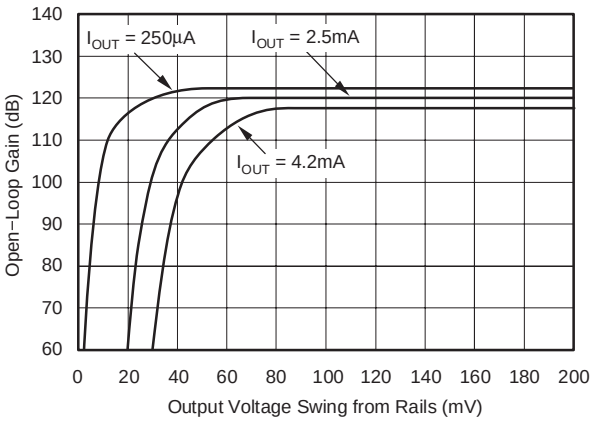

MAXIMUM OUTPUT VOLTAGE vs FREQUENCY




OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



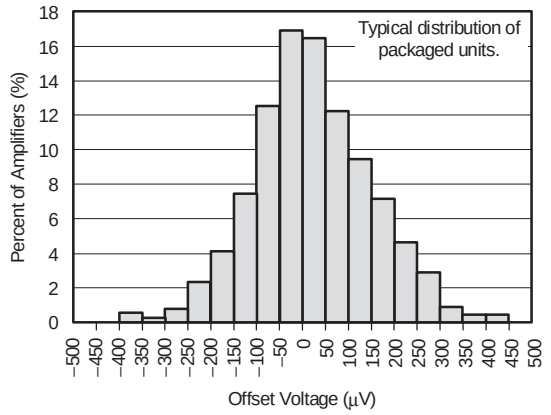

OPEN−LOOP GAIN vs OUTPUT VOLTAGE SWING



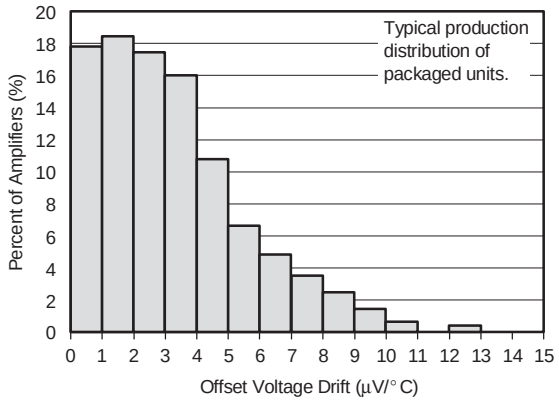
## TYPICAL CHARACTERISTICS (continued)

All specifications at $T_A$ = +25°C, $V_S$ = +5V, and $R_L$ = 1kΩ connected to $V_S$/2, unless otherwise noted.

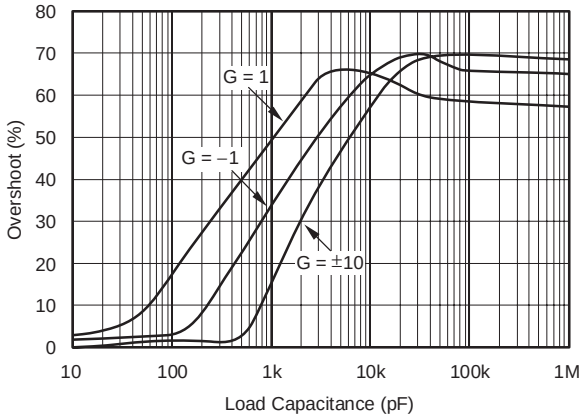
OFFSET VOLTAGE
PRODUCTION DISTRIBUTION



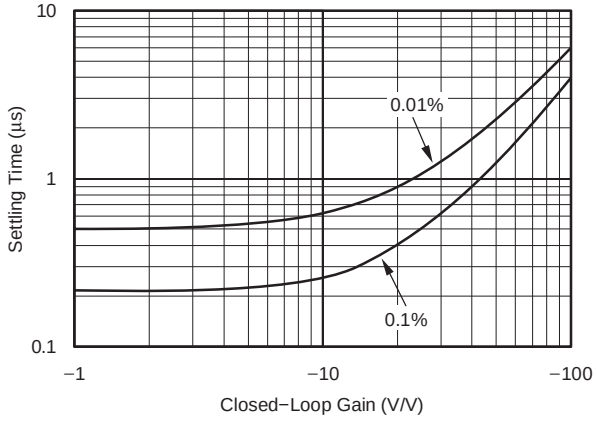

OFFSET VOLTAGE DRIFT
PRODUCTION DISTRIBUTION



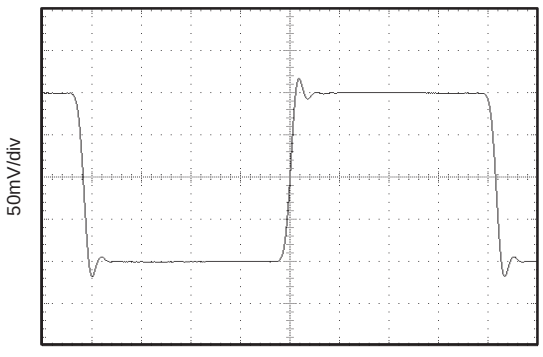

SMALL−SIGNAL OVERSHOOT vs LOAD CAPACITANCE



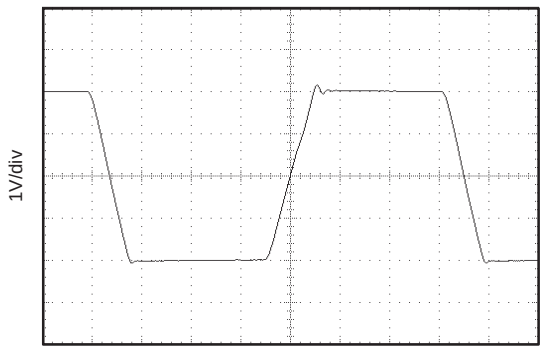

SETTLING TIME vs CLOSED−LOOP GAIN




SMALL−SIGNAL STEP RESPONSE
$C_L$ = 100pF




LARGE−SIGNAL STEP RESPONSE
$C_L$ = 100pF



# APPLICATIONS INFORMATION

OPA350 series op amps are fabricated on a state-of-the-art 0.6 micron CMOS process. They are unity-gain stable and suitable for a wide range of general-purpose applications. Rail-to-rail input/output make them ideal for driving sampling A/D converters. They are also well-suited for controlling the output power in cell phones. These applications often require high speed and low noise. In addition, the OPA350 series offers a low-cost solution for general-purpose and consumer video applications (75Ω drive capability).

Excellent ac performance makes the OPA350 series well-suited for audio applications. Their bandwidth, slew rate, low noise (5nV/√Hz), low THD (0.0006%), and small package options are ideal for these applications. The class AB output stage is capable of driving 600Ω loads connected to any point between V+ and ground.

Rail-to-rail input and output swing significantly increases dynamic range, especially in low voltage supply applications. Figure 1 shows the input and output waveforms for the OPA350 in unity-gain configuration. Operation is from a single +5V supply with a 1kΩ load connected to $V_S/2$. The input is a $5V_{PP}$ sinusoid. Output voltage swing is approximately $4.95V_{PP}$.

Power supply pins should be bypassed with 0.01µF ceramic capacitors.

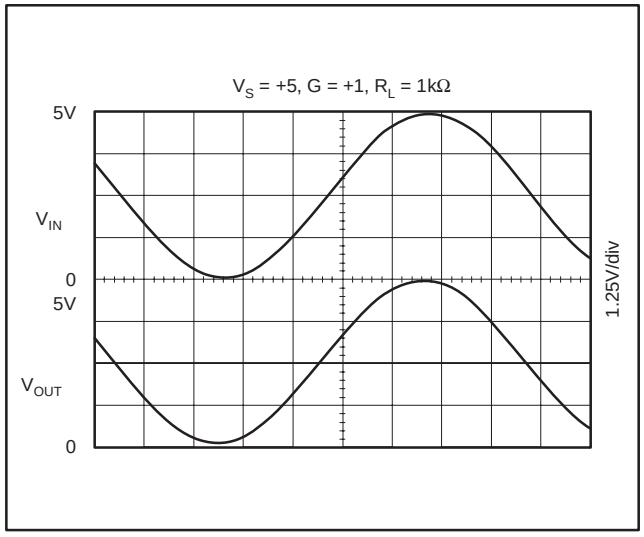



**Figure 1. Rail-to-Rail Input and Output**

## OPERATING VOLTAGE

OPA350 series op amps are fully specified from +2.7V to +5.5V. However, supply voltage may range from +2.5V to +5.5V. Parameters are tested over the specified supply range—a unique feature of the OPA350 series. In addition, many specifications apply from −40°C to +85°C. Most behavior remains virtually unchanged throughout the full operating voltage range. Parameters that vary significantly with operating voltage or temperature are shown in the typical characteristics.

## RAIL-TO-RAIL INPUT

The tested input common-mode voltage range of the OPA350 series extends 100mV 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+) – 1.8V to 100mV above the positive supply, while the P-channel pair is on for inputs from 100mV below the negative supply to approximately (V+) – 1.8V. There is a small transition region, typically (V+) – 2V to (V+) – 1.6V, in which both pairs are on. This 400mV transition region can vary ±400mV with process variation. Thus, the transition region (both input stages on) can range from (V+) – 2.4V to (V+) – 2.0V on the low end, up to (V+) – 1.6V to (V+) – 1.2V on the high end.

OPA350 series op amps are laser-trimmed to reduce offset voltage difference between the N-channel and P-channel input stages, resulting in improved common-mode rejection and a smooth transition between the N-channel pair and the P-channel pair. However, within the 400mV transition region PSRR, CMRR, offset voltage, offset drift, and THD may be degraded compared to operation outside this region.

A double-folded cascode adds the signal from the two input pairs and presents a differential signal to the class AB output stage. Normally, input bias current is approximately 500fA. However, large inputs (greater than 300mV beyond the supply rails) can turn on the OPA350's input protection diodes, causing excessive current to flow in or out of the input pins. Momentary voltages greater than 300mV beyond the power supply can be tolerated if the current on the input pins is limited to 10mA. This is easily accomplished with an input resistor, as shown in Figure 3. Many input signals are inherently current-limited to less than 10mA; therefore, a limiting resistor is not required.

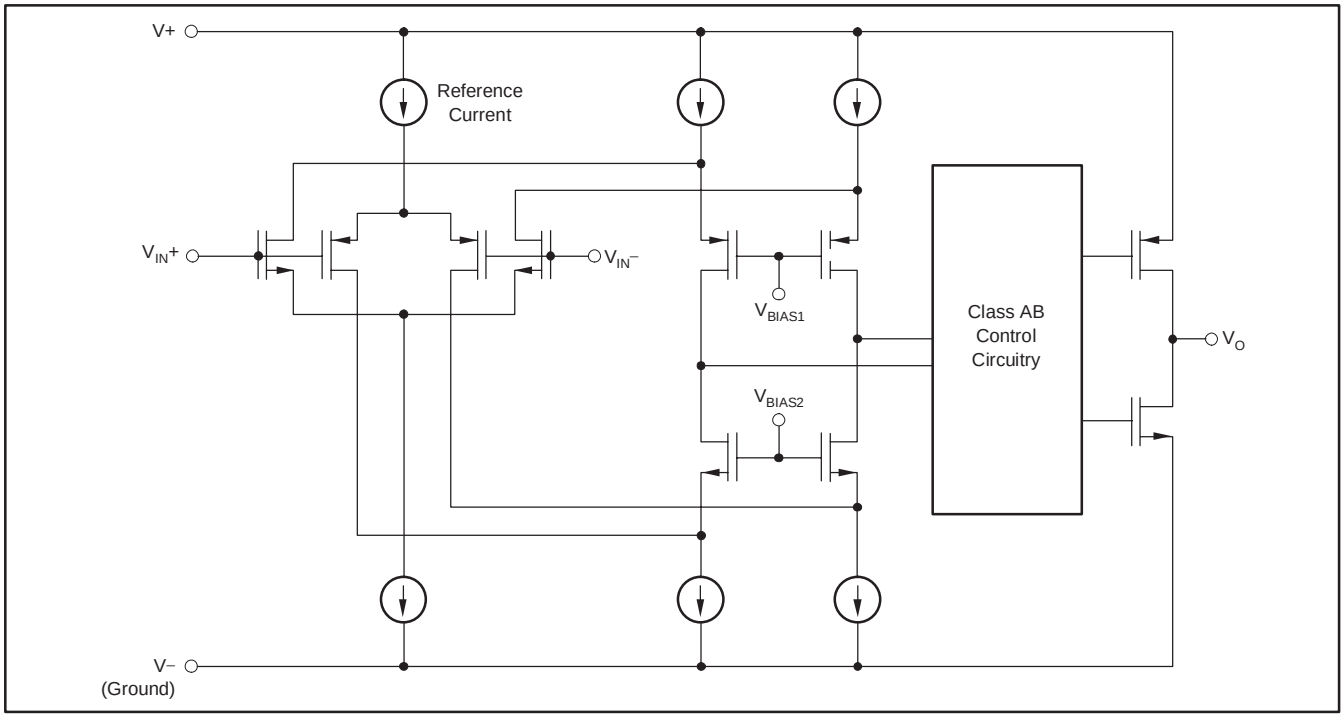



**Figure 2. Simplified Schematic**

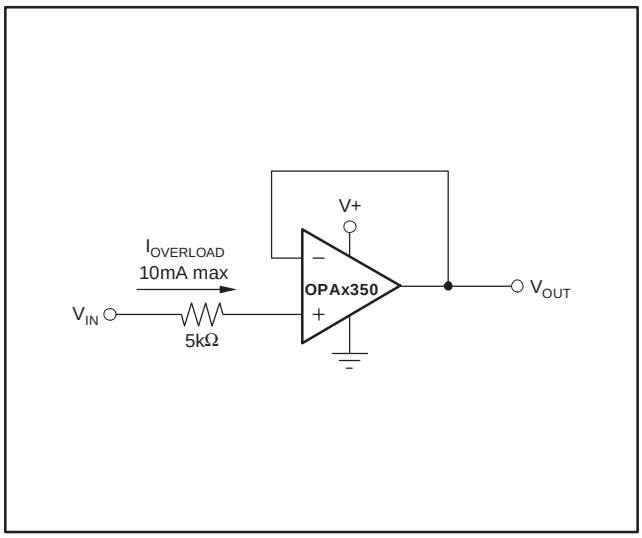



**Figure 3. Input Current Protection for Voltages Exceeding the Supply Voltage**

## RAIL-TO-RAIL OUTPUT

A class AB output stage with common-source transistors is used to achieve rail-to-rail output. For light resistive loads (>10kΩ), the output voltage swing is typically ten millivolts from the supply rails. With heavier resistive loads (600Ω to 10kΩ), the output can swing to within a few tens of millivolts from the supply rails and maintain high open-loop gain. See the typical characteristics *Output Voltage Swing vs Output Current* and *Open-Loop Gain vs Output Voltage*.

## CAPACITIVE LOAD AND STABILITY

OPA350 series op amps can drive a wide range of capacitive loads. However, all op amps under certain conditions may become unstable. Op amp configuration, gain, and load value are just a few of the factors to consider when determining stability. An op amp in unity-gain configuration is the most susceptible to the effects of capacitive load. The capacitive load reacts with the op amp's output impedance, along with any additional load resistance, to create a pole in the small-signal response that degrades the phase margin.

In unity gain, OPA350 series op amps perform well with very large capacitive loads. Increasing gain enhances the amplifier's ability to drive more capacitance. The typical characteristic *Small-Signal Overshoot vs Capacitive Load* shows performance with a 1kΩ resistive load. Increasing load resistance improves capacitive load drive capability.

## FEEDBACK CAPACITOR IMPROVES RESPONSE

For optimum settling time and stability with high-impedance feedback networks, it may be necessary to add a feedback capacitor across the feedback resistor, $R_F$, as shown in Figure 4. This capacitor compensates for the zero created by the feedback network impedance and the OPA350's input capacitance (and any parasitic layout capacitance). The effect becomes more significant with higher impedance networks.

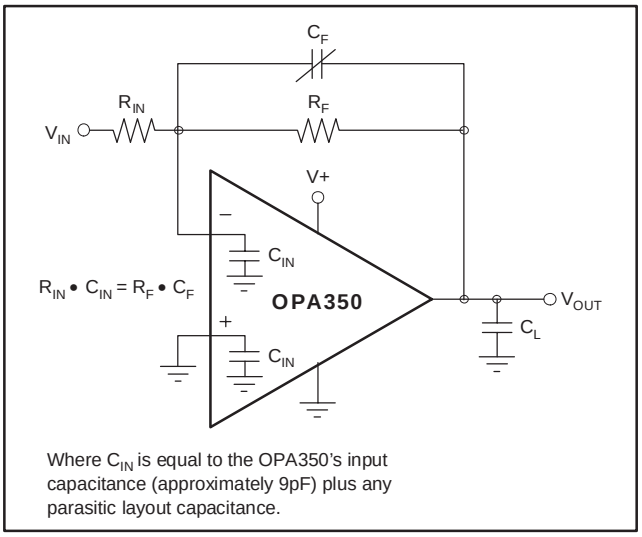



**Figure 4. Feedback Capacitor Improves Dynamic Performance**

It is suggested that a variable capacitor be used for the feedback capacitor since input capacitance may vary between op amps and layout capacitance is difficult to determine. For the circuit shown in Figure 4, the value of the variable feedback capacitor should be chosen so that the input resistance times the input capacitance of the OPA350 (typically 9pF) plus the estimated parasitic layout capacitance equals the feedback capacitor times the feedback resistor:

$$R_{IN} \cdot C_{IN} = R_F \cdot C_F$$

where $C_{IN}$ is equal to the OPA350's input capacitance (sum of differential and common-mode) plus the layout capacitance. The capacitor can be varied until optimum performance is obtained.

## DRIVING A/D CONVERTERS

OPA350 series op amps are optimized for driving medium speed (up to 500kHz) sampling A/D converters. However, they also offer excellent performance for higher speed converters. The OPA350 series provides an effective means of buffering the A/D's input capacitance and resulting charge injection while providing signal gain.

Figure 5 shows the OPA350 driving an ADS7861. The ADS7861 is a dual, 500kHz, 12-bit sampling converter in the tiny SSOP-24 package. When used with the miniature package options of the OPA350 series, the combination is ideal for space-limited applications. For further information, consult the ADS7861 data sheet (SBAS110A).

## OUTPUT IMPEDANCE

The low frequency open-loop output impedance of the OPA350's common-source output stage is approximately 1kΩ. When the op amp is connected with feedback, this value is reduced significantly by the loop gain of the op amp. For example, with 122dB of open-loop gain, the output impedance is reduced in unity-gain to less than 0.001Ω. For each decade rise in the closed-loop gain, the loop gain is reduced by the same amount which results in a ten-fold increase in effective output impedance (see the typical characteristic, *Output Impedance vs Frequency*).

At higher frequencies, the output impedance will rise as the open-loop gain of the op amp drops. However, at these frequencies the output also becomes capacitive due to parasitic capacitance. This prevents the output impedance from becoming too high, which can cause stability problems when driving capacitive loads. As mentioned previously, the OPA350 has excellent capacitive load drive capability for an op amp with its bandwidth.

## VIDEO LINE DRIVER

Figure 6 shows a circuit for a single supply, G = 2 composite video line driver. The synchronized outputs of a composite video line driver extend below ground. As shown, the input to the op amp should be ac-coupled and shifted positively to provide adequate signal swing to account for these negative signals in a single-supply configuration.

The input is terminated with a 75Ω resistor and ac-coupled with a 47μF capacitor to a voltage divider that provides the dc bias point to the input. In Figure 6, this point is approximately (V−) + 1.7V. Setting the optimal bias point requires some understanding of the nature of composite video signals. For best performance, one should be careful to avoid the distortion caused by the transition region of the OPA350's complementary input stage. Refer to the discussion of rail-to-rail input.

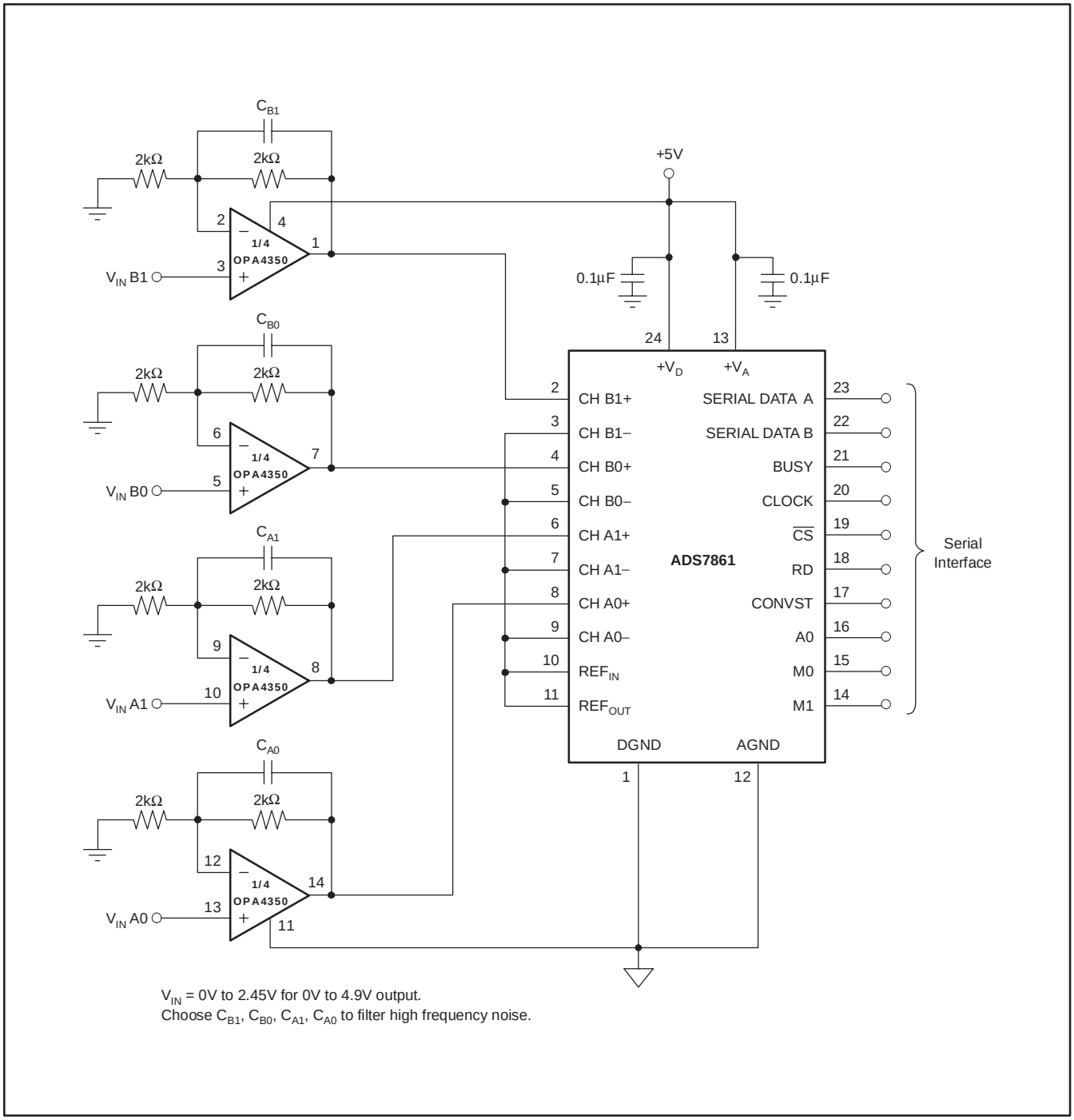



**Figure 5. OPA4350 Driving Sampling A/D Converter**

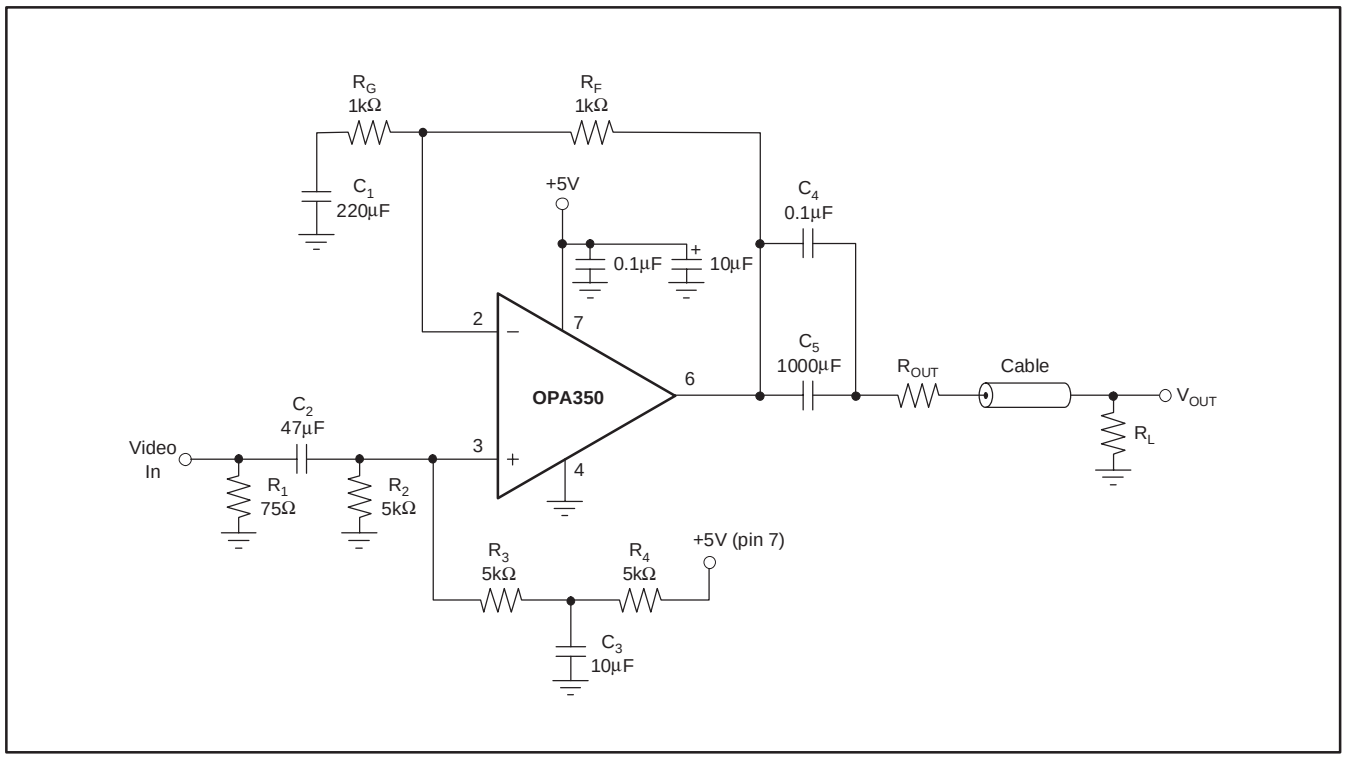



**Figure 6. Single-Supply Video Line Driver**

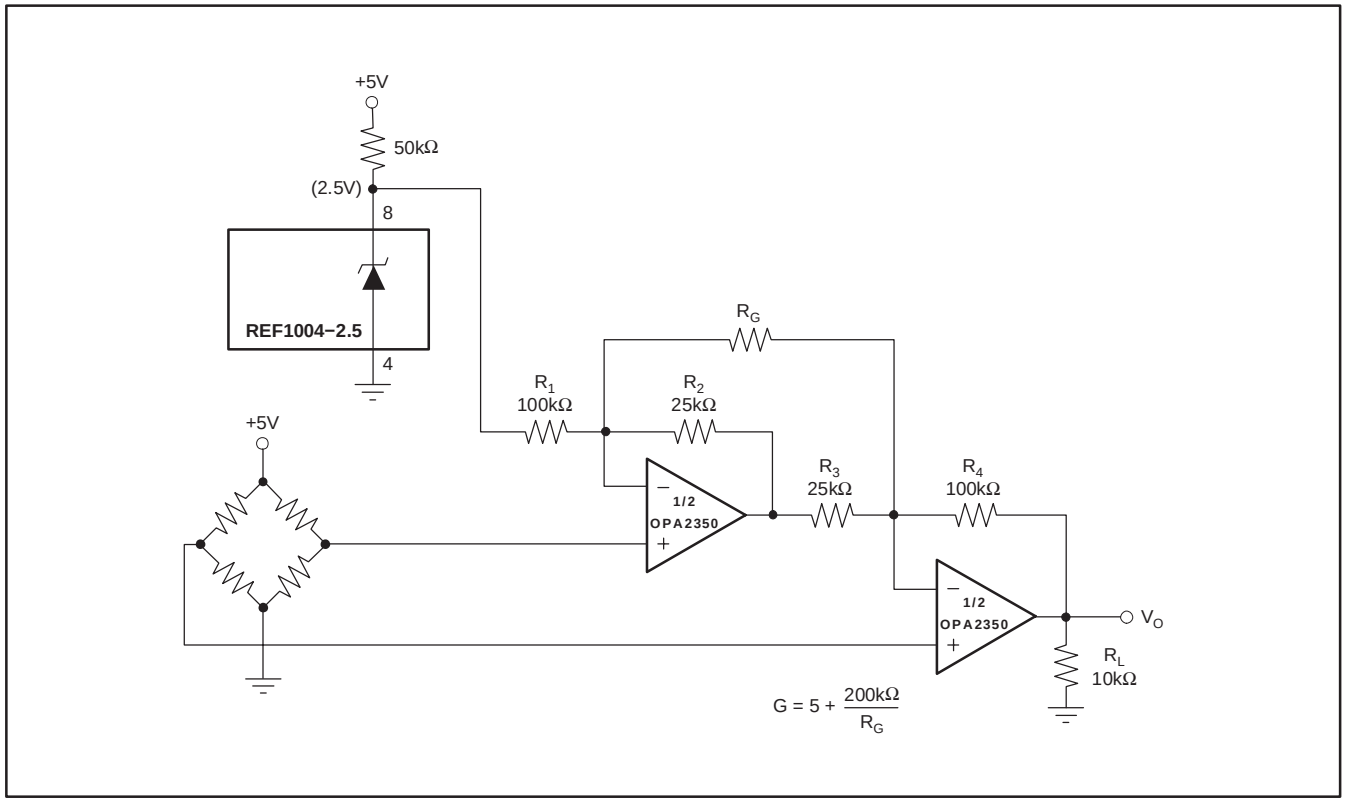



**Figure 7. Two Op-Amp Instrumentation Amplifier With Improved High Frequency Common-Mode Rejection**

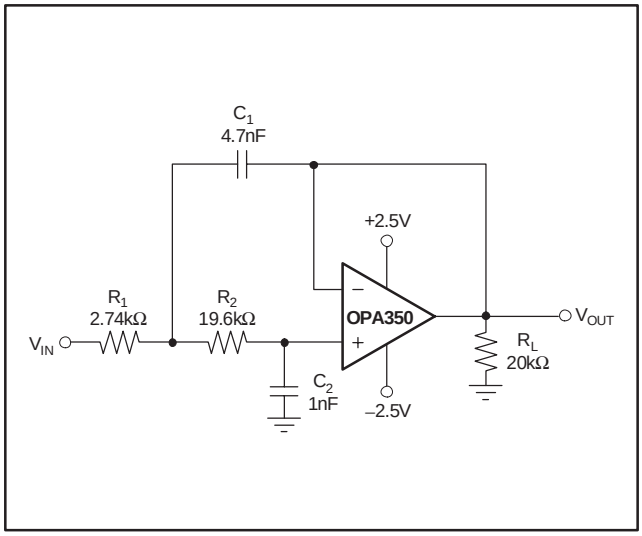



**Figure 8. 10kHz Low-Pass Filter**

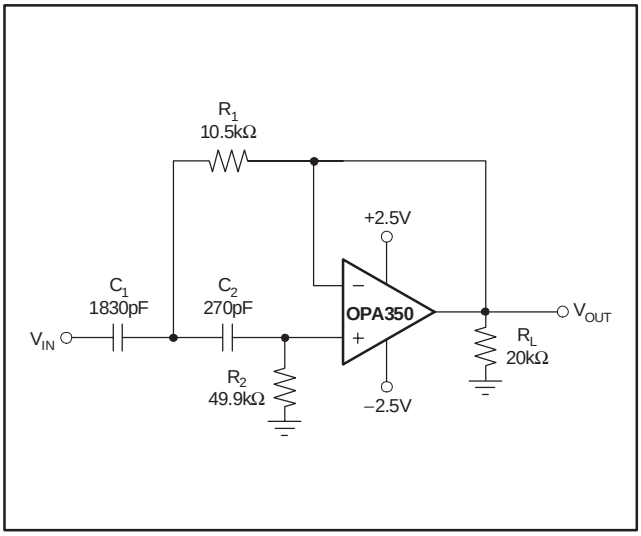



**Figure 9. 10kHz High-Pass Filter**

## PACKAGING INFORMATION

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/ Ball Finish | MSL Peak Temp (3) | Samples (Requires Login) |
|---|---|---|---|---|---|---|---|---|---|
| OPA2350EA/250 | ACTIVE | VSSOP | DGK | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA2350EA/250G4 | ACTIVE | VSSOP | DGK | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA2350EA/2K5 | ACTIVE | VSSOP | DGK | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA2350EA/2K5G4 | ACTIVE | VSSOP | DGK | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA2350PA | ACTIVE | PDIP | P | 8 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | N / A for Pkg Type | |
| OPA2350PAG4 | ACTIVE | PDIP | P | 8 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | N / A for Pkg Type | |
| OPA2350UA | ACTIVE | SOIC | D | 8 | 75 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA2350UA/2K5 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA2350UA/2K5G4 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA2350UAG4 | ACTIVE | SOIC | D | 8 | 75 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA350EA/250 | ACTIVE | VSSOP | DGK | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA350EA/250G4 | ACTIVE | VSSOP | DGK | 8 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA350EA/2K5 | ACTIVE | VSSOP | DGK | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA350EA/2K5G4 | ACTIVE | VSSOP | DGK | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAUAG | Level-2-260C-1 YEAR | |
| OPA350PA | ACTIVE | PDIP | P | 8 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | N / A for Pkg Type | |
| OPA350PAG4 | ACTIVE | PDIP | P | 8 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | N / A for Pkg Type | |
| OPA350UA | ACTIVE | SOIC | D | 8 | 75 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |

| Orderable Device | Status (1) | Package Type | Package Drawing | Pins | Package Qty | Eco Plan (2) | Lead/ Ball Finish | MSL Peak Temp (3) | Samples (Requires Login) |
|---|---|---|---|---|---|---|---|---|---|
| OPA350UA/2K5 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA350UA/2K5G4 | ACTIVE | SOIC | D | 8 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA350UAG4 | ACTIVE | SOIC | D | 8 | 75 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350EA/250 | ACTIVE | SSOP | DBQ | 16 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350EA/250G4 | ACTIVE | SSOP | DBQ | 16 | 250 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350EA/2K5 | ACTIVE | SSOP | DBQ | 16 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350EA/2K5G4 | ACTIVE | SSOP | DBQ | 16 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350UA | ACTIVE | SOIC | D | 14 | 50 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350UA/2K5 | ACTIVE | SOIC | D | 14 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350UA/2K5G4 | ACTIVE | SOIC | D | 14 | 2500 | Green (RoHS & no Sb/Br) | CU NIPDAU | Level-2-260C-1 YEAR | |
| OPA4350UAG4 | ACTIVE | SOIC | D | 14 | 50 | 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)

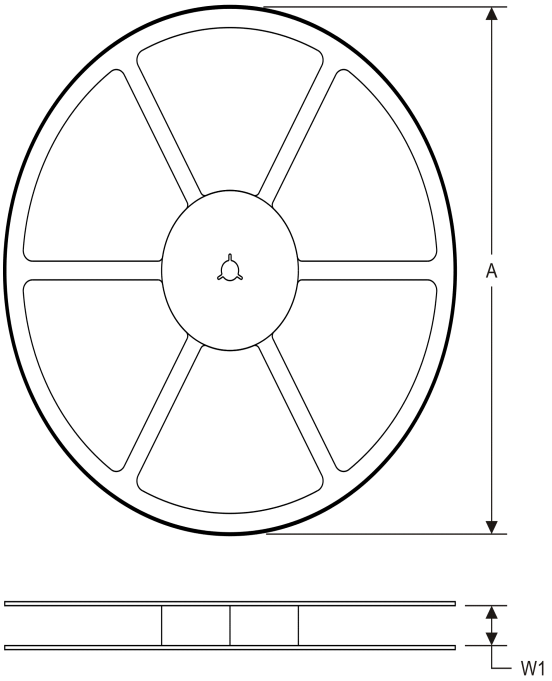
**(3)** MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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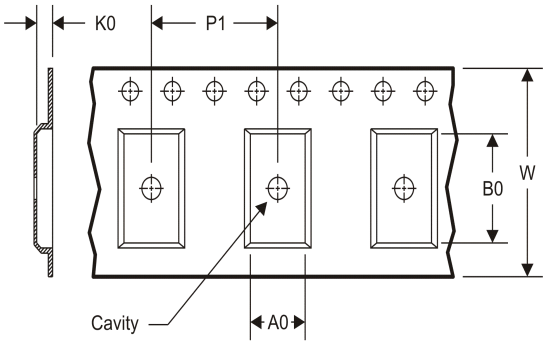
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## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**




**TAPE DIMENSIONS**



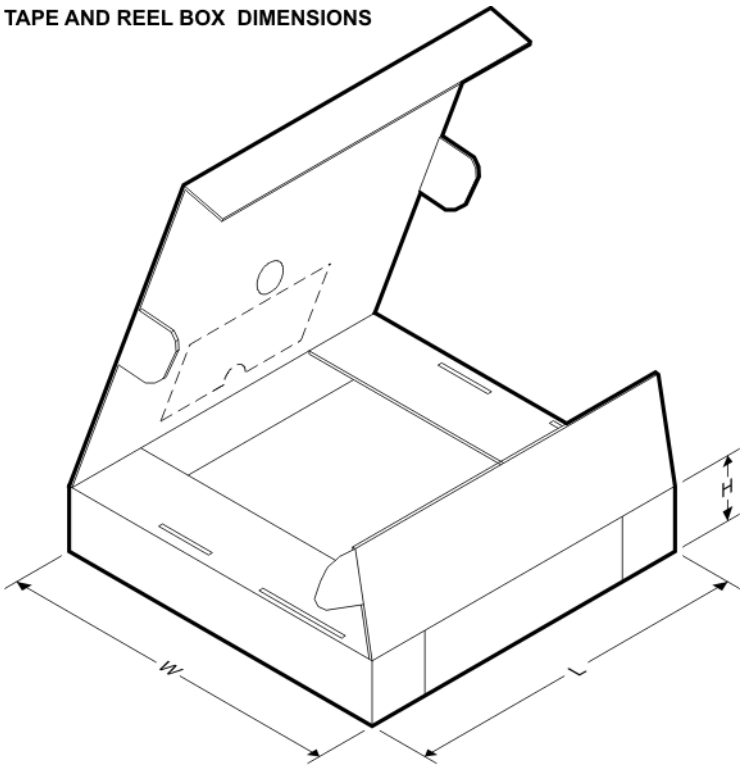

| | |
|---|---|
| A0 | Dimension designed to accommodate the component width |
| B0 | Dimension designed to accommodate the component length |
| K0 | Dimension designed to accommodate the component thickness |
| W | Overall width of the carrier tape |
| P1 | Pitch between successive cavity centers |

**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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OPA2350EA/250 | VSSOP | DGK | 8 | 250 | 180.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA2350EA/2K5 | VSSOP | DGK | 8 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA2350UA/2K5 | SOIC | D | 8 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| OPA350EA/250 | VSSOP | DGK | 8 | 250 | 180.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA350EA/2K5 | VSSOP | DGK | 8 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA350UA/2K5 | SOIC | D | 8 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| OPA4350EA/250 | SSOP | DBQ | 16 | 250 | 180.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| OPA4350EA/2K5 | SSOP | DBQ | 16 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| OPA4350UA/2K5 | SOIC | D | 14 | 2500 | 330.0 | 16.4 | 6.5 | 9.0 | 2.1 | 8.0 | 16.0 | Q1 |

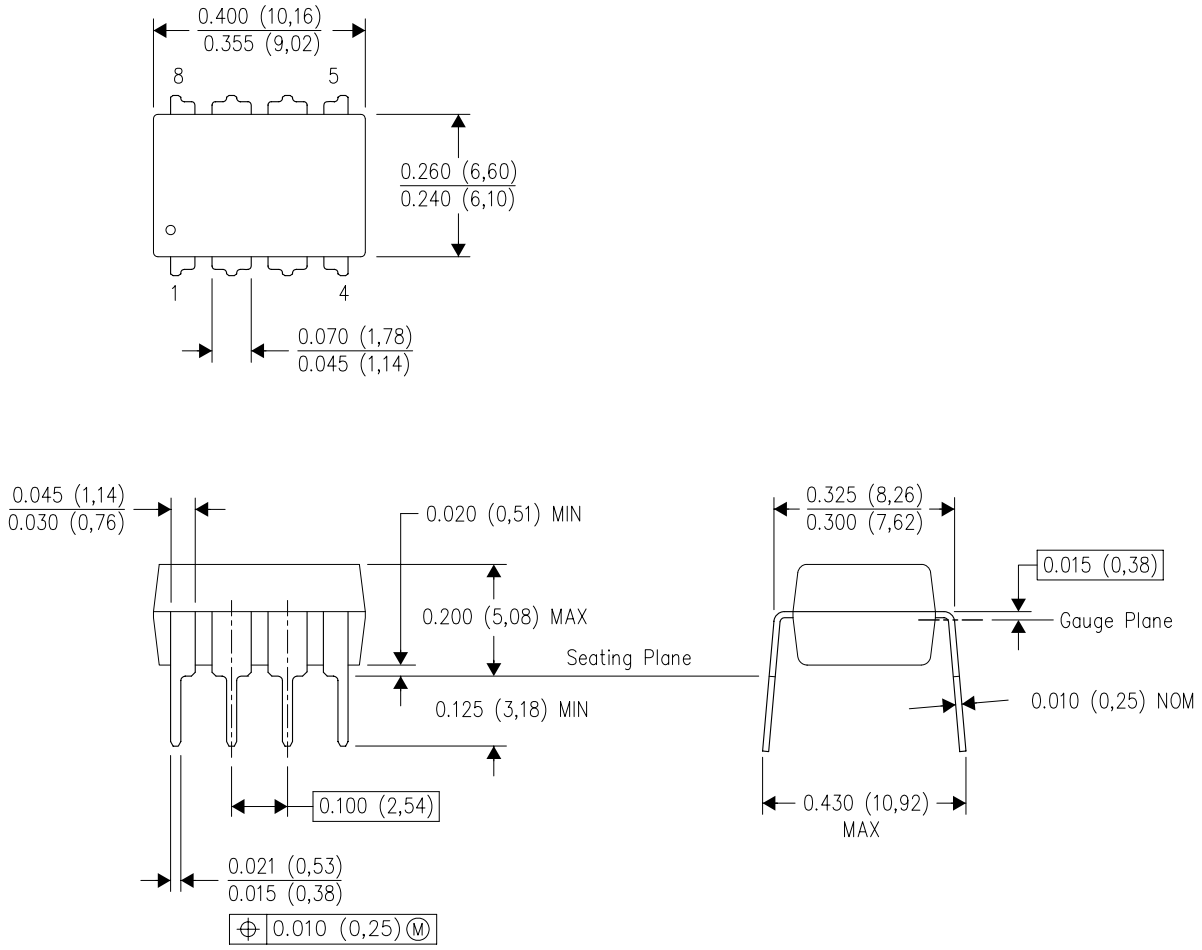
**TAPE AND REEL BOX DIMENSIONS**




*All dimensions are nominal

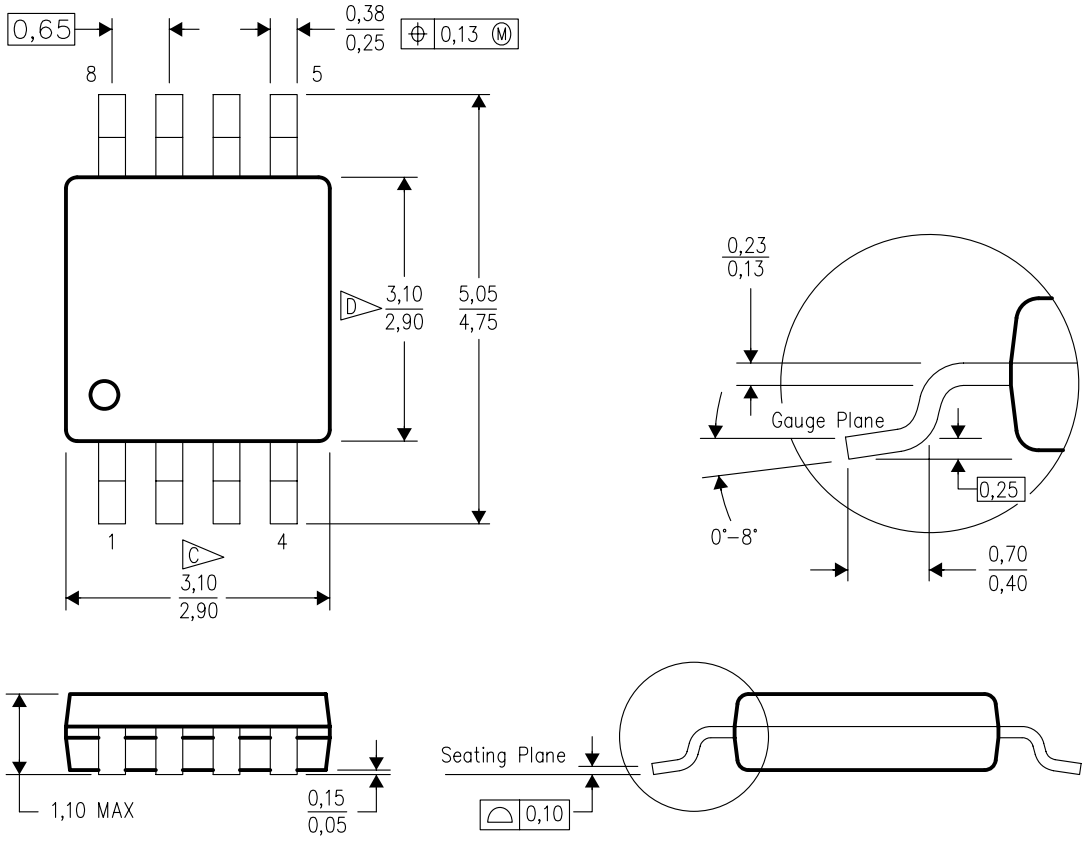
| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| OPA2350EA/250 | VSSOP | DGK | 8 | 250 | 210.0 | 185.0 | 35.0 |
| OPA2350EA/2K5 | VSSOP | DGK | 8 | 2500 | 367.0 | 367.0 | 35.0 |
| OPA2350UA/2K5 | SOIC | D | 8 | 2500 | 367.0 | 367.0 | 35.0 |
| OPA350EA/250 | VSSOP | DGK | 8 | 250 | 210.0 | 185.0 | 35.0 |
| OPA350EA/2K5 | VSSOP | DGK | 8 | 2500 | 367.0 | 367.0 | 35.0 |
| OPA350UA/2K5 | SOIC | D | 8 | 2500 | 367.0 | 367.0 | 35.0 |
| OPA4350EA/250 | SSOP | DBQ | 16 | 250 | 210.0 | 185.0 | 35.0 |
| OPA4350EA/2K5 | SSOP | DBQ | 16 | 2500 | 367.0 | 367.0 | 35.0 |
| OPA4350UA/2K5 | SOIC | D | 14 | 2500 | 367.0 | 367.0 | 38.0 |

P (R–PDIP–T8) PLASTIC DUAL–IN–LINE PACKAGE




NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS–001 variation BA.

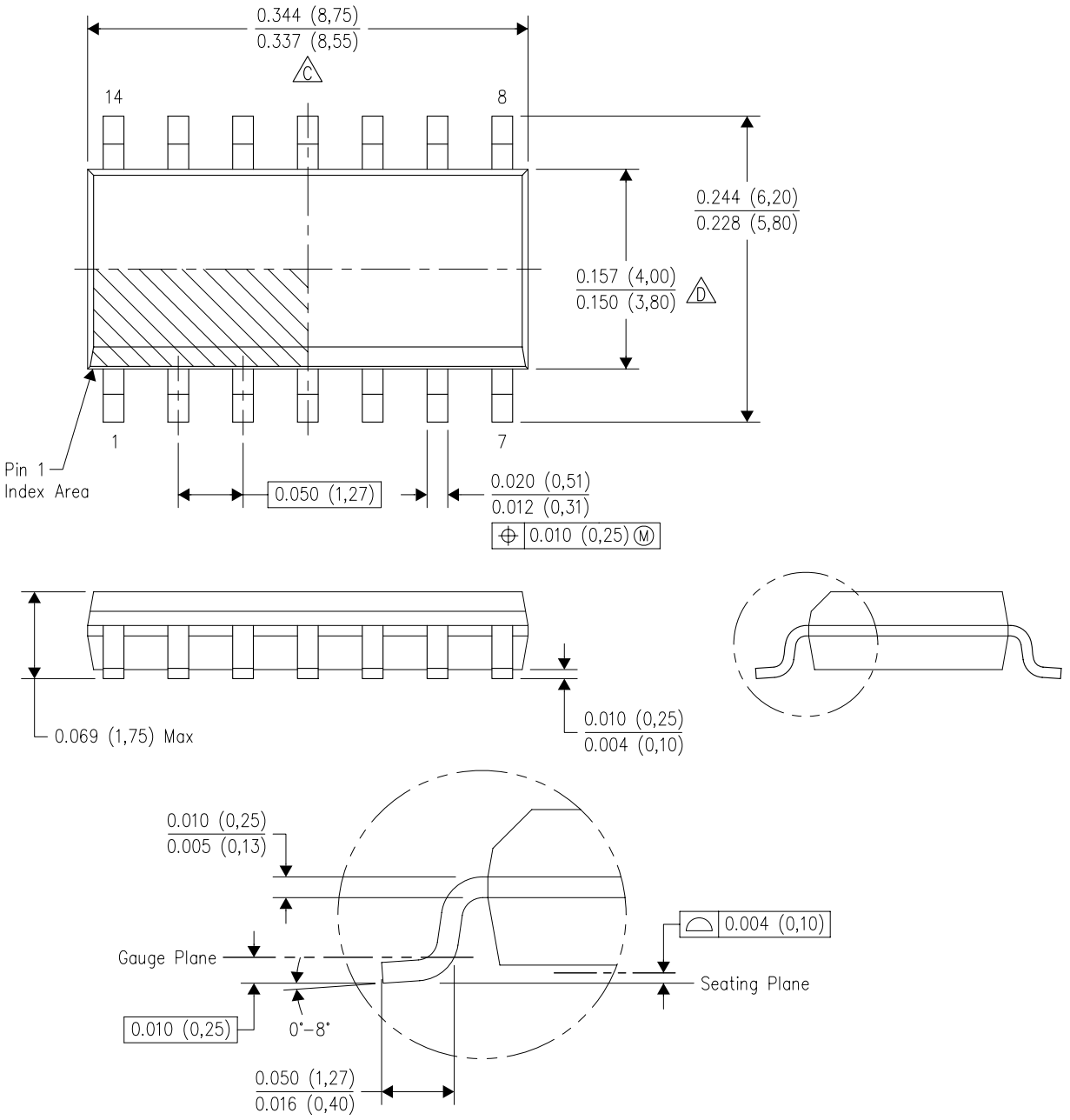
## DGK (S–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE




4073329/E 05/06

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.

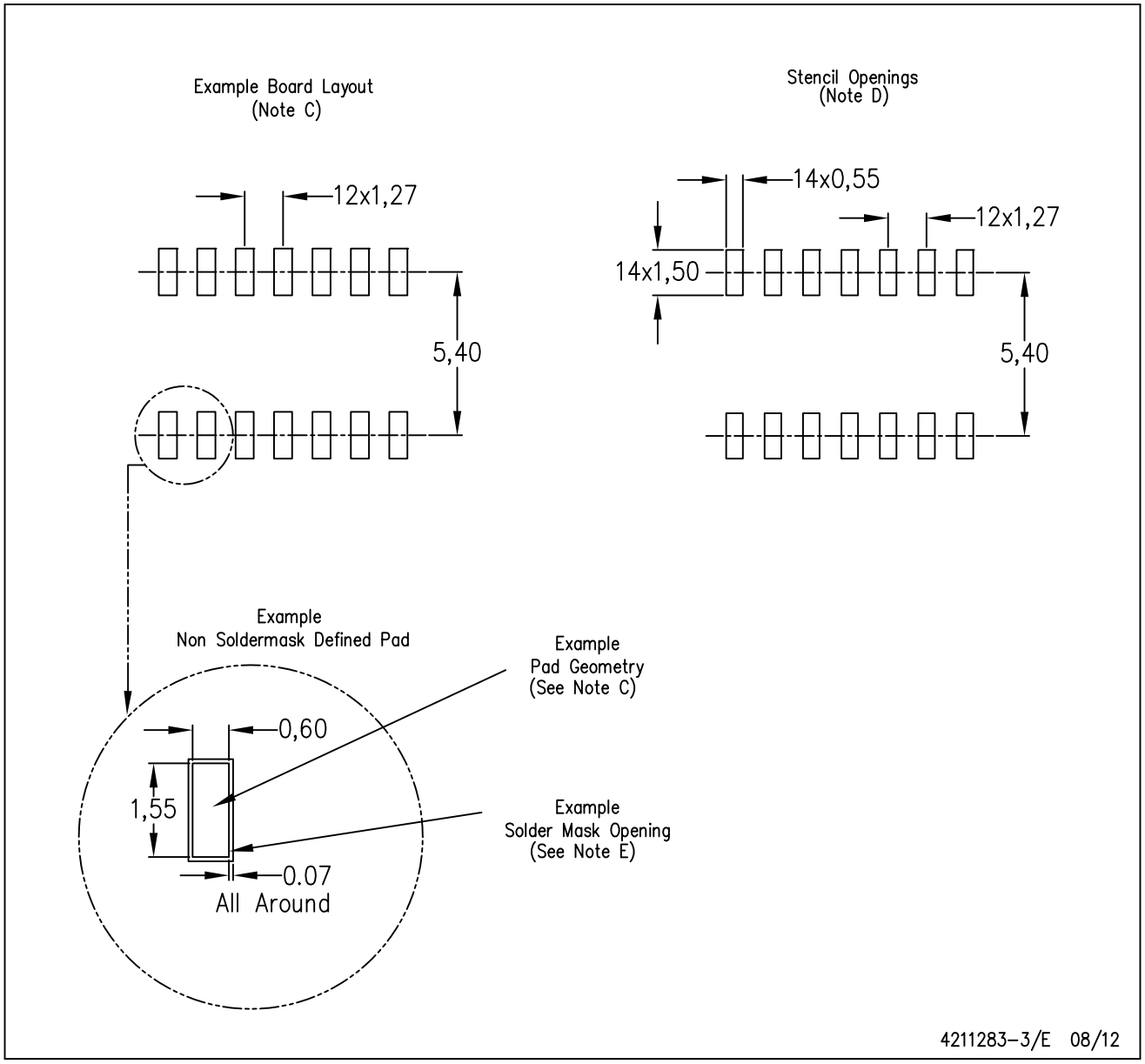
D (R–PDSO–G14) PLASTIC SMALL OUTLINE




4040047–5/M 06/11

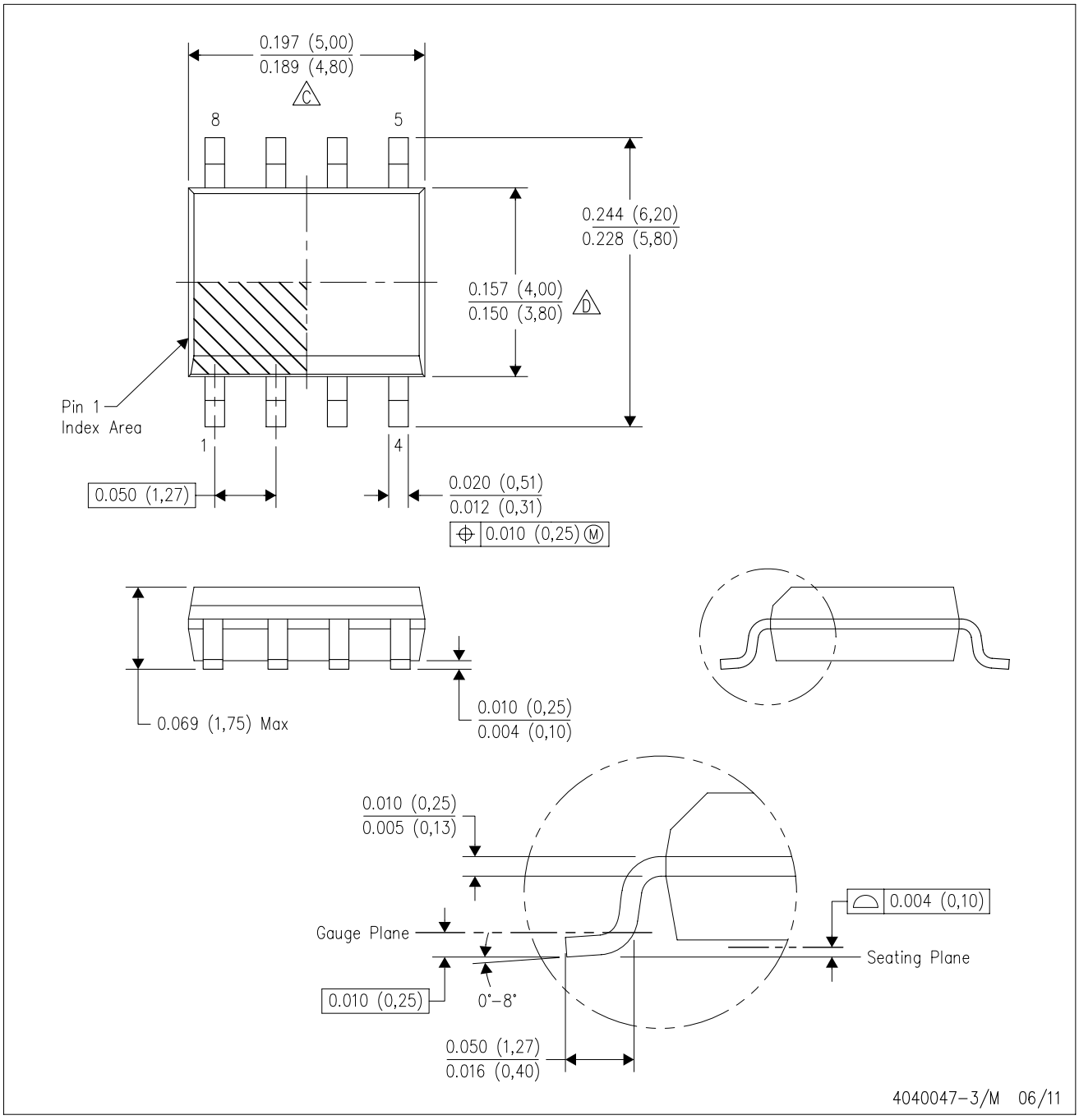
NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AB.

D (R–PDSO–G14) PLASTIC SMALL OUTLINE



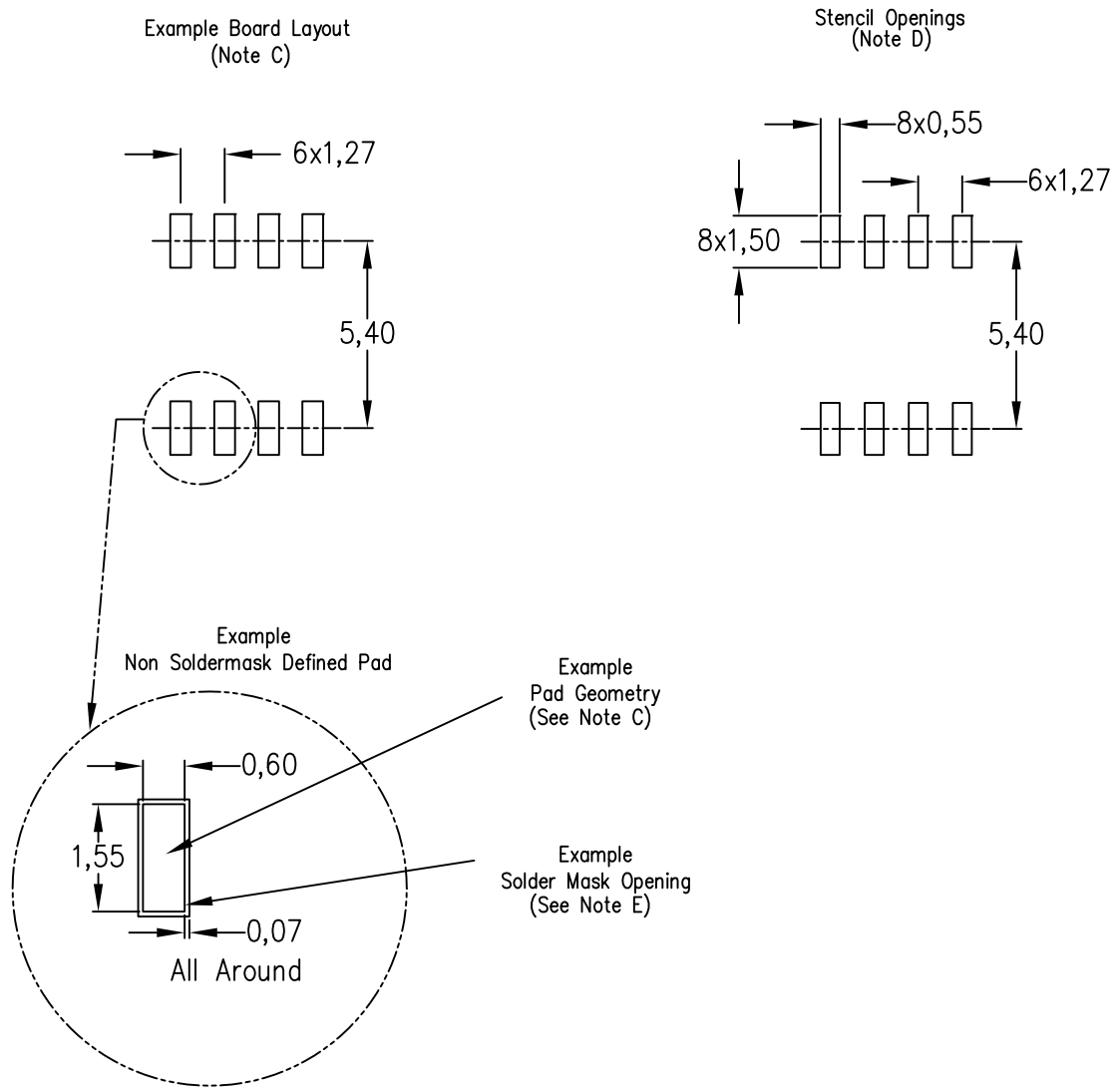

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



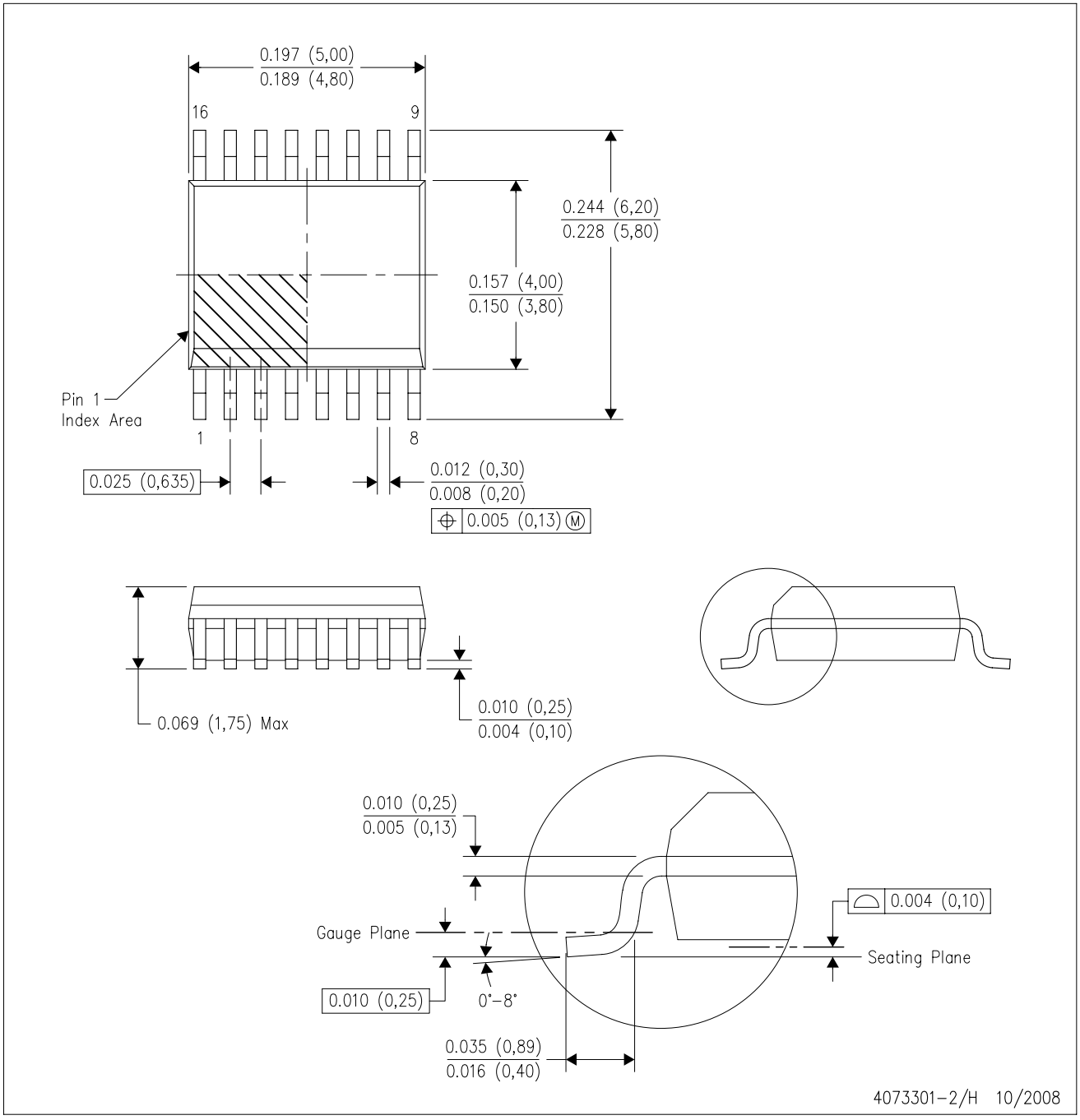

NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
D. Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
E. Reference JEDEC MS–012 variation AA.

D (R–PDSO–G8) PLASTIC SMALL OUTLINE



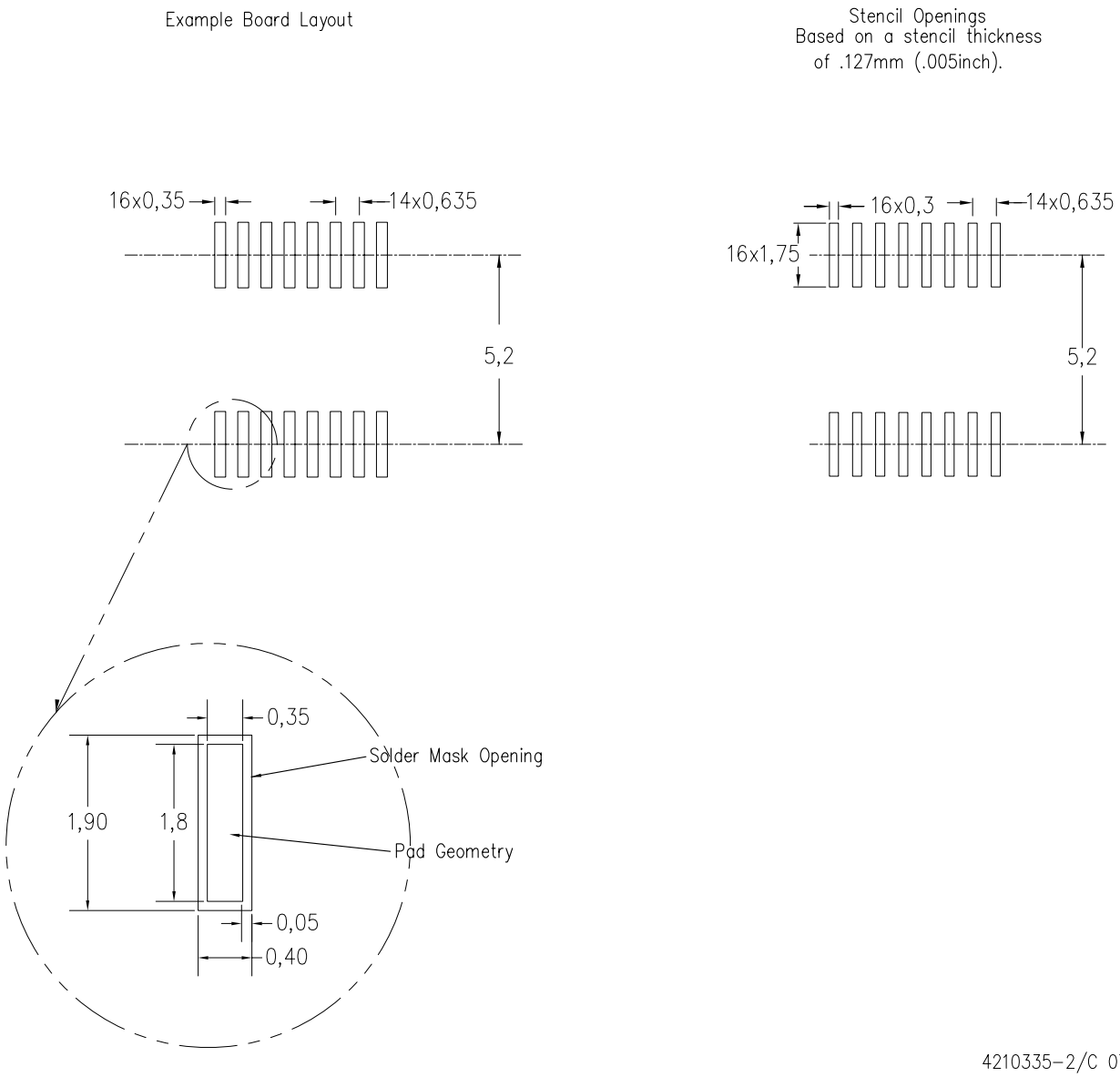

NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC–7525 for other stencil recommendations.
E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

DBQ (R–PDSO–G16) PLASTIC SMALL–OUTLINE PACKAGE




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) per side.
D. Falls within JEDEC MO–137 variation AB.

# DBQ (R–PDSO–G16) PLASTIC SMALL OUTLINE PACKAGE




NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
D. Publication IPC–7351 is recommended for alternate designs.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC–7525 for other stencil recommendations.

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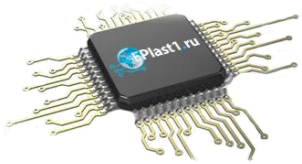
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