# SoundPLUS™ High-Performance, Bipolar-Input AUDIO OPERATIONAL AMPLIFIERS

**Check for Samples: OPA1602, OPA1604**

## FEATURES

- **SUPERIOR SOUND QUALITY**
- **ULTRALOW NOISE: 2.5nV/√Hz at 1kHz**
- **ULTRALOW DISTORTION: 0.00003% at 1kHz**
- **HIGH SLEW RATE: 20V/µs**
- **WIDE BANDWIDTH: 35MHz (G = +1)**
- **HIGH OPEN-LOOP GAIN: 120dB**
- **UNITY GAIN STABLE**
- **LOW QUIESCENT CURRENT: 2.6mA PER CHANNEL**
- **RAIL-TO-RAIL OUTPUT**
- **WIDE SUPPLY RANGE: ±2.25V to ±18V**
- **DUAL AND QUAD VERSIONS AVAILABLE**

## APPLICATIONS

- **PROFESSIONAL AUDIO EQUIPMENT**
- **BROADCAST STUDIO EQUIPMENT**
- **ANALOG AND DIGITAL MIXERS**
- **HIGH-END A/V RECEIVERS**
- **HIGH-END BLU-RAY™ PLAYERS**

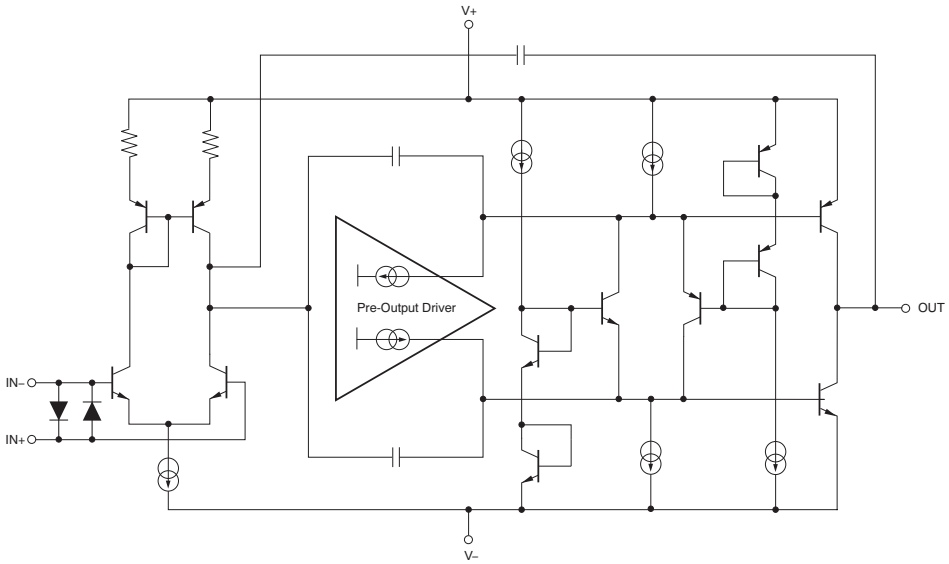
## DESCRIPTION

The OPA1602 and OPA1604 bipolar-input operational amplifiers achieve very low 2.5nV/√Hz noise density with an ultralow distortion of 0.00003% at 1kHz. The OPA1602 and OPA1604 series of op amps offer rail-to-rail output swing to within 600mV with 2kΩ load, which increases headroom and maximizes dynamic range. These devices also have a high output drive capability of ±30mA.

These devices operate over a very wide supply range of ±2.25V to ±18V, on only 2.6mA of supply current per channel. The OPA1602 and OPA1604 are unity-gain stable and provide excellent dynamic behavior over a wide range of load conditions.

These devices also feature completely independent circuitry for lowest crosstalk and freedom from interactions between channels, even when overdriven or overloaded.

The OPA1602 and OPA1604 are specified from –40°C to +85°C.

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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–) | 40 | V |
| Input Voltage | | (V–) – 0.5 to (V+) + 0.5 | V |
| Input Current (All pins except power-supply pins) | | ±10 | mA |
| Output Short-Circuit(2) | | Continuous | |
| Operating Temperature | | –55 to +125 | °C |
| Storage Temperature | | –65 to +150 | °C |
| Junction Temperature | | 200 | °C |
| ESD Ratings | Human Body Model (HBM) | 4 | kV |
| | Charged Device Model (CDM) | 1 | kV |
| | 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) Short-circuit to $V_S$/2 (ground in symmetrical dual supply setups), one amplifier per package.

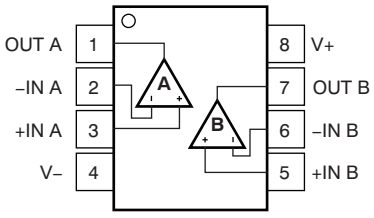
## PACKAGE INFORMATION(1)

| PRODUCT | PACKAGE-LEAD | PACKAGE DESIGNATOR | PACKAGE MARKING |
|---|---|---|---|
| OPA1602 | SO-8 | D | O1602A |
| | MSOP-8 | DGK | OCKQ |
| OPA1604 | SO-14 | D | O1604A |
| | TSSOP-14 | PW | O1604A |

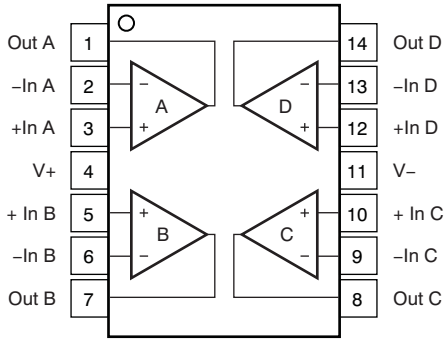
(1) For the most current package and ordering information see the Package Option Addendum at the end of this document, or see the TI web site at www.ti.com.

## PIN CONFIGURATIONS

**OPA1602**
**SO-8, MSOP-8**
**(TOP VIEW)**




**OPA1604**
**SO-14, TSSOP-14**
**(TOP VIEW)**





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## ELECTRICAL CHARACTERISTICS: $V_S$ = ±2.25V to ±18V

At $T_A$ = +25°C and $R_L$ = 2kΩ, unless otherwise noted. $V_{CM}$ = $V_{OUT}$ = midsupply, unless otherwise noted.

| PARAMETER | | CONDITIONS | OPA1602, OPA1604 MIN | TYP | MAX | UNIT |
|---|---|---|---|---|---|---|
| **AUDIO PERFORMANCE** | | | | | | |
| Total Harmonic Distortion + Noise | THD+N | G = +1, f = 1kHz, $V_O$ = 3$V_{RMS}$ | | 0.00003 | | % |
| | | | | –130 | | dB |
| Intermodulation Distortion | IMD | G = +1, $V_O$ = 3$V_{RMS}$ | | | | |
| | | SMPTE/DIN Two-Tone, 4:1 (60Hz and 7kHz) | | 0.00003 | | % |
| | | | | –130 | | dB |
| | | DIM 30 (3kHz square wave and 15kHz sine wave) | | 0.00003 | | % |
| | | | | –130 | | dB |
| | | CCIF Twin-Tone (19kHz and 20kHz) | | 0.00003 | | % |
| | | | | –130 | | dB |
| **FREQUENCY RESPONSE** | | | | | | |
| Gain-Bandwidth Product | GBW | G = +1 | | 35 | | MHz |
| Slew Rate | SR | G = –1 | | 20 | | V/µs |
| Full Power Bandwidth[1] | | $V_O$ = 1$V_P$ | | 3 | | MHz |
| Overload Recovery Time | | G = –10 | | 1 | | µs |
| **NOISE** | | | | | | |
| Input Voltage Noise | | f = 20Hz to 20kHz | | 2.5 | | $\mu V_{PP}$ |
| Input Voltage Noise Density | $e_n$ | f = 100Hz | | 2.5 | | nV/√Hz |
| | | f = 1kHz | | 2.5 | | nV/√Hz |
| Input Current Noise Density | $I_n$ | f = 100Hz | | 2.2 | | pA/√Hz |
| | | f = 1kHz | | 1.8 | | pA/√Hz |
| **OFFSET VOLTAGE** | | | | | | |
| Input Offset Voltage | $V_{OS}$ | $V_S$ = ±15V | | ±0.1 | ±1 | mV |
| vs Power Supply | PSRR | $V_S$ = ±2.25V to ±18V | | 0.5 | 2 | µV/V |
| Channel Separation (Dual and Quad) | | f = 1kHz | | -130 | | dB |
| **INPUT BIAS CURRENT** | | | | | | |
| Input Bias Current | $I_B$ | $V_{CM}$ = 0V | | ±20 | ±200 | nA |
| Input Offset Current | $I_{OS}$ | $V_{CM}$ = 0V | | ±20 | ±200 | nA |
| **INPUT VOLTAGE RANGE** | | | | | | |
| Common-Mode Voltage Range | $V_{CM}$ | | (V–) + 2 | | (V+) – 2 | V |
| Common-Mode Rejection Ratio | CMRR | (V–) + 2V ≤ $V_{CM}$ ≤ (V+) – 2V, $V_S$ ≥ ±5V | 114 | 120 | | dB |
| | | (V–) + 2V ≤ $V_{CM}$ ≤ (V+) – 2V, $V_S$ < ±5V | 100 | 110 | | dB |
| **INPUT IMPEDANCE** | | | | | | |
| Differential | | | | 20k \|\| 2 | | Ω \|\| pF |
| Common-Mode | | | | $10^9$ \|\| 2.5 | | Ω \|\| pF |
| **OPEN-LOOP GAIN** | | | | | | |
| Open-Loop Voltage Gain | $A_{OL}$ | (V–) + 0.6V ≤ $V_O$ ≤ (V+) – 0.6V, $R_L$ = 2kΩ, $V_S$ ≥ ±5V | 114 | 120 | | dB |
| | | (V–) + 0.6V ≤ $V_O$ ≤ (V+) – 0.6V, $R_L$ = 2kΩ, $V_S$ < ±5V | 106 | 114 | | dB |
| **OUTPUT** | | | | | | |
| Voltage Output | $V_{OUT}$ | $R_L$ = 2kΩ, $A_{OL}$ ≥ 114dB, $V_S$ ≥ ±5V | (V–) + 0.6 | | (V+) – 0.6 | V |
| | | $R_L$ = 2kΩ, $A_{OL}$ ≥ 106dB, $V_S$ < ±5V | (V–) + 0.6 | | (V+) – 0.6 | V |
| Output Current | $I_{OUT}$ | | See Typical Characteristics | | | mA |
| Open-Loop Output Impedance | $Z_O$ | f = 1MHz | | 25 | | Ω |
| Short-Circuit Current[2] | $I_{SC}$ | | | +70/–60 | | mA |
| Capacitive Load Drive | $C_{LOAD}$ | | See Typical Characteristics | | | pF |

(1) Full-power bandwidth = SR/(2π × $V_P$), where SR = slew rate.
(2) One channel at a time.

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## ELECTRICAL CHARACTERISTICS: $V_S$ = ±2.25V to ±18V (continued)

At $T_A$ = +25°C and $R_L$ = 2kΩ, unless otherwise noted. $V_{CM}$ = $V_{OUT}$ = midsupply, unless otherwise noted.

| PARAMETER | | CONDITIONS | OPA1602, OPA1604 | | | UNIT |
|---|---|---|---|---|---|---|
| | | | MIN | TYP | MAX | |
| **POWER SUPPLY** | | | | | | |
| Specified Voltage | $V_S$ | | ±2.25 | | ±18 | V |
| Quiescent Current(3) Dual, per channel | $I_Q$ | $I_{OUT}$ = 0A | | 2.6 | 3.2 | mA |
| Quad, per channel | $I_Q$ | $I_{OUT}$ = 0A | | 2.8 | 3.4 | mA |
| **TEMPERATURE RANGE** | | | | | | |
| Specified Range | | | –40 | | +85 | °C |
| Operating Range | | | –55 | | +125 | °C |

(3) $I_Q$ value is based on flash test.

## THERMAL INFORMATION: OPA1602

| THERMAL METRIC(1) | | OPA1602 D 8 PINS | OPA1602 DGK 8 PINS | UNITS |
|---|---|---|---|---|
| $\theta_{JA}$ | Junction-to-ambient thermal resistance | 105.4 | 154.7 | °C/W |
| $\theta_{JCtop}$ | Junction-to-case (top) thermal resistance | 58.6 | 49.7 | |
| $\theta_{JB}$ | Junction-to-board thermal resistance | 64.2 | 107.9 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 14.1 | 2.5 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 66.5 | 106.7 | |
| $\theta_{JCbot}$ | Junction-to-case (bottom) thermal resistance | N/A | N/A | |

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.

## THERMAL INFORMATION: OPA1604

| THERMAL METRIC(1) | | OPA1604 D 14 PINS | OPA1604 PW 14 PINS | UNITS |
|---|---|---|---|---|
| $\theta_{JA}$ | Junction-to-ambient thermal resistance | 92.8 | 122.5 | °C/W |
| $\theta_{JCtop}$ | Junction-to-case (top) thermal resistance | 44.4 | 36.5 | |
| $\theta_{JB}$ | Junction-to-board thermal resistance | 39.6 | 53.9 | |
| $\psi_{JT}$ | Junction-to-top characterization parameter | 10.4 | 2.5 | |
| $\psi_{JB}$ | Junction-to-board characterization parameter | 39.3 | 53.2 | |
| $\theta_{JCbot}$ | Junction-to-case (bottom) thermal resistance | N/A | N/A | |

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.


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## TYPICAL CHARACTERISTICS

At $T_A$ = +25°C, $V_S$ = ±15V, and $R_L$ = 2kΩ, unless otherwise noted.

**INPUT VOLTAGE NOISE DENSITY AND INPUT CURRENT NOISE DENSITY vs FREQUENCY**

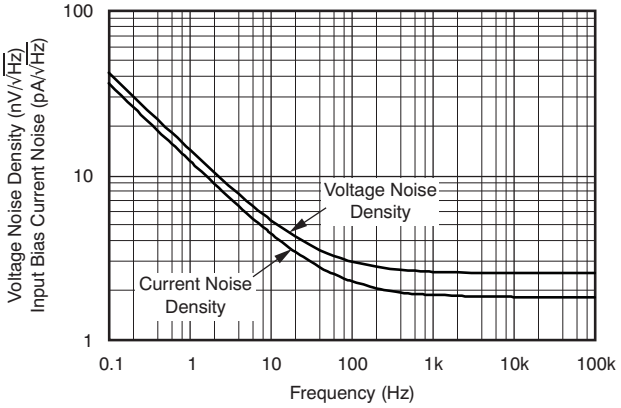


**Figure 1.**

**0.1Hz TO 10Hz NOISE**

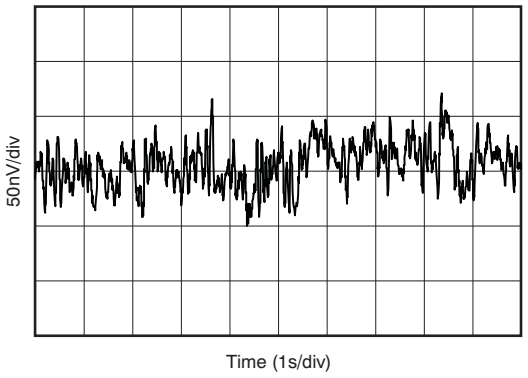


**Figure 2.**

**VOLTAGE NOISE vs SOURCE RESISTANCE**

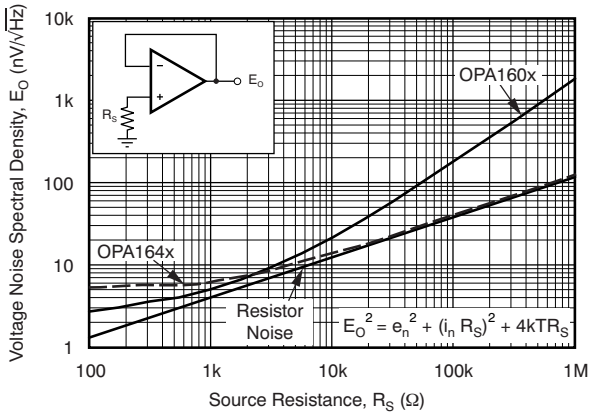


**Figure 3.**

**MAXIMUM OUTPUT VOLTAGE vs FREQUENCY**

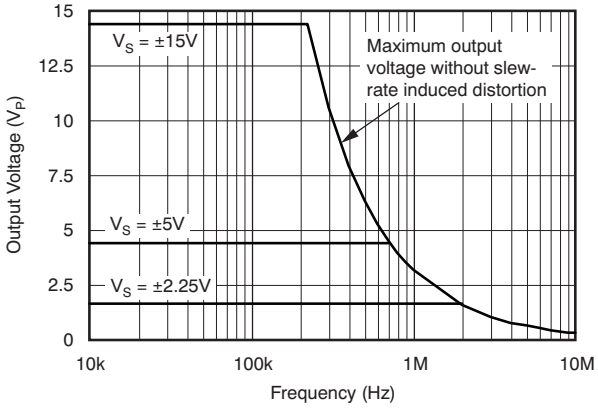


**Figure 4.**

**GAIN AND PHASE vs FREQUENCY**

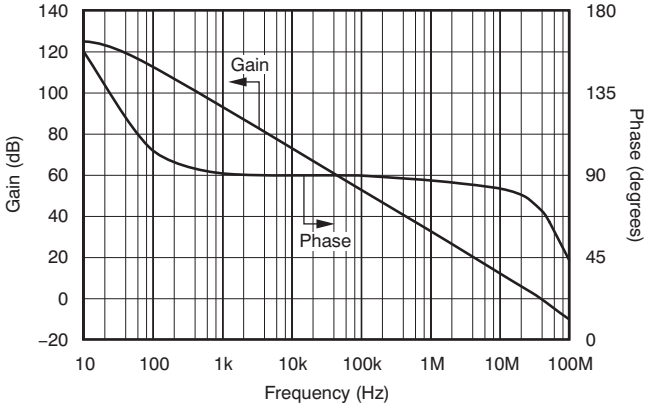


**Figure 5.**

**CLOSED-LOOP GAIN vs FREQUENCY**

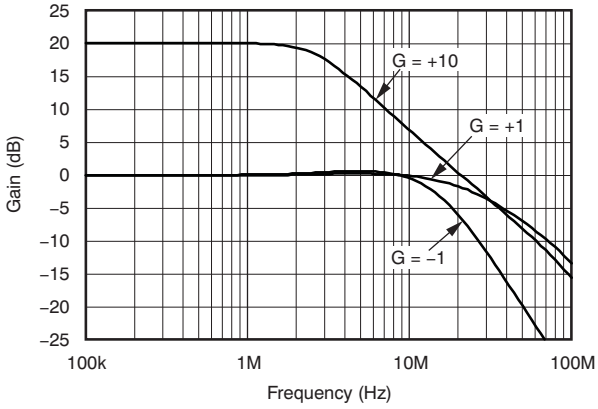


**Figure 6.**

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## TYPICAL CHARACTERISTICS (continued)

At $T_A$ = +25°C, $V_S$ = ±15V, and $R_L$ = 2kΩ, unless otherwise noted.

**THD+N RATIO vs FREQUENCY**

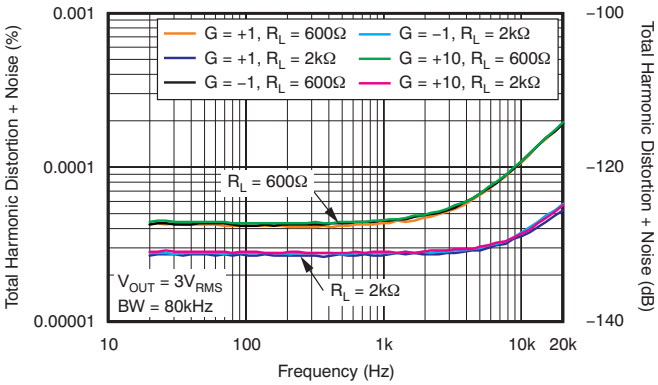


**Figure 7.**

**THD+N RATIO vs FREQUENCY**

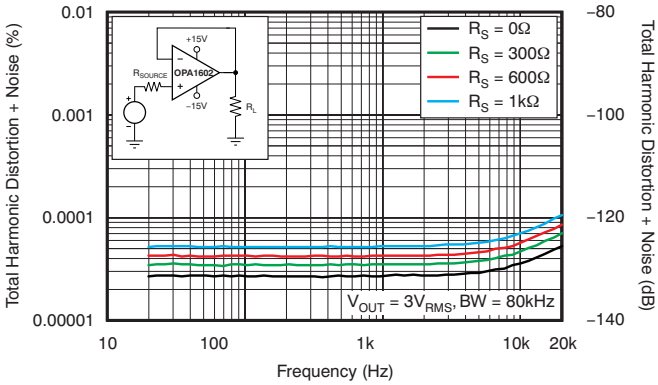


**Figure 8.**

**THD+N RATIO vs FREQUENCY**

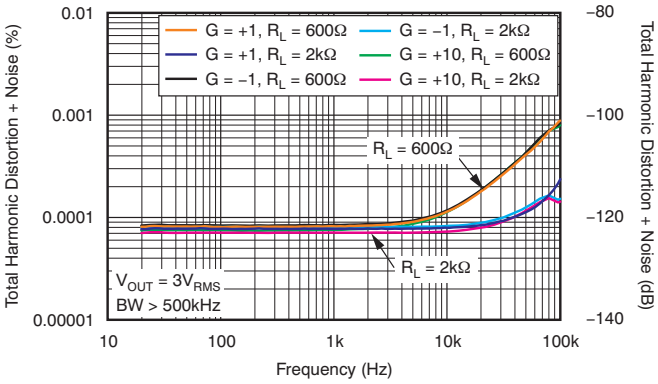


**Figure 9.**

**THD+N RATIO vs FREQUENCY**

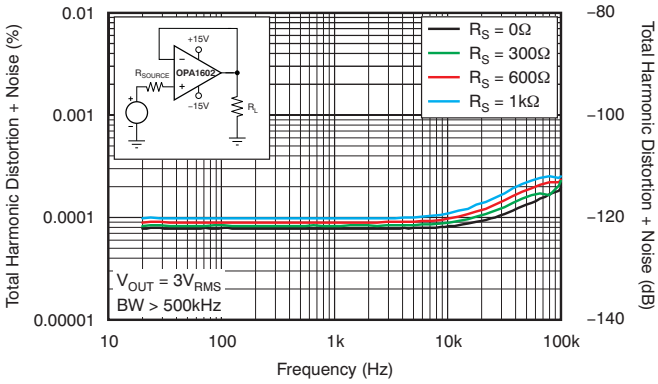


**Figure 10.**

**THD+N RATIO vs OUTPUT AMPLITUDE**

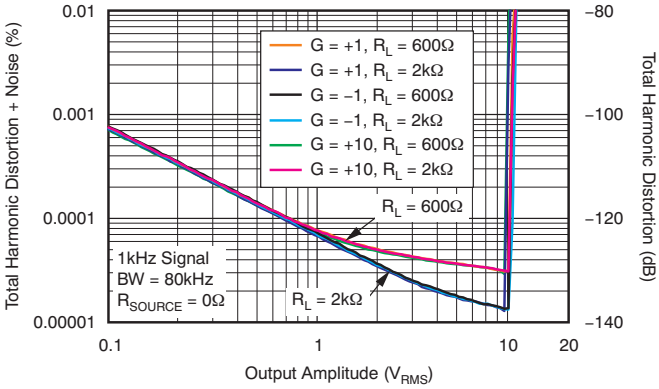


**Figure 11.**

**INTERMODULATION DISTORTION vs OUTPUT AMPLITUDE**

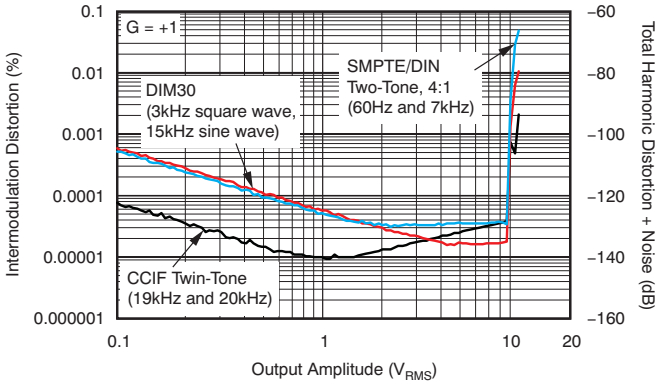


**Figure 12.**


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## TYPICAL CHARACTERISTICS (continued)

At $T_A$ = +25°C, $V_S$ = ±15V, and $R_L$ = 2kΩ, unless otherwise noted.

**CHANNEL SEPARATION vs FREQUENCY**

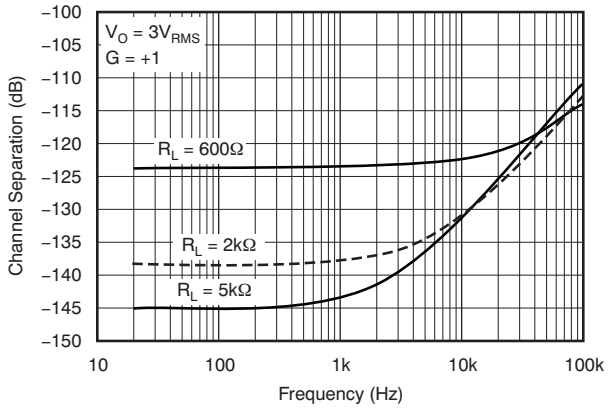


**Figure 13.**

**CMRR AND PSRR vs FREQUENCY (Referred to Input)**

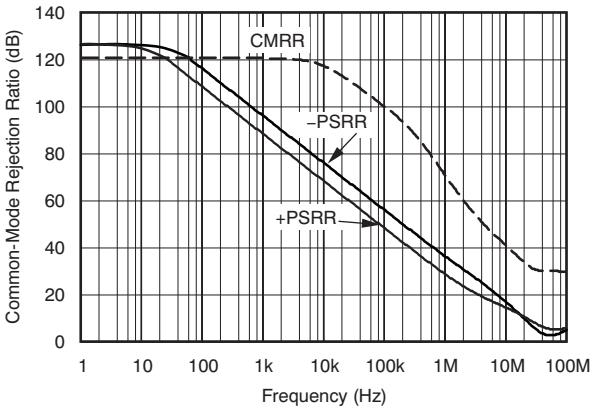


**Figure 14.**

**SMALL-SIGNAL STEP RESPONSE (100mV)**

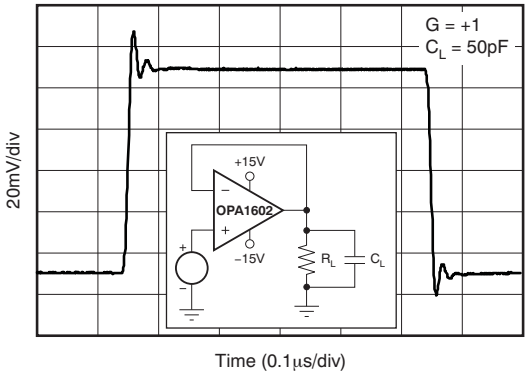


**Figure 15.**

**SMALL-SIGNAL STEP RESPONSE (100mV)**

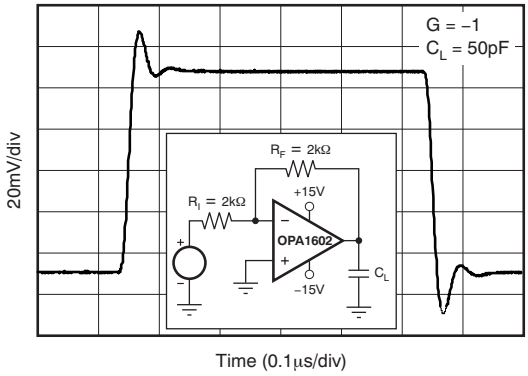


**Figure 16.**

**LARGE-SIGNAL STEP RESPONSE**

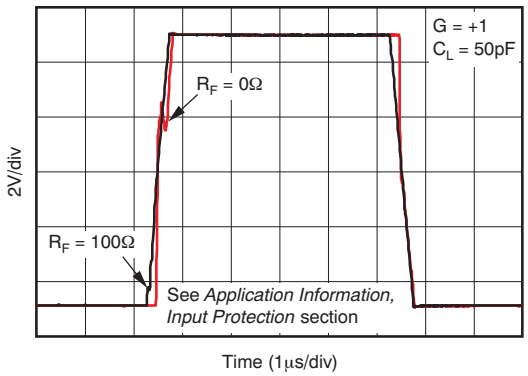


**Figure 17.**

**LARGE-SIGNAL STEP RESPONSE**

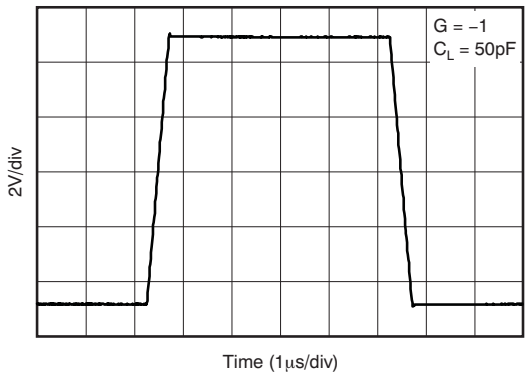


**Figure 18.**

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## TYPICAL CHARACTERISTICS (continued)

At $T_A$ = +25°C, $V_S$ = ±15V, and $R_L$ = 2kΩ, unless otherwise noted.

**SMALL-SIGNAL OVERSHOOT vs CAPACITIVE LOAD (100mV Output Step)**

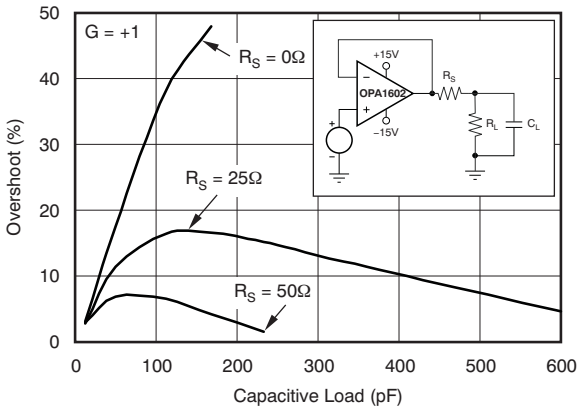


**Figure 19.**

**SMALL-SIGNAL OVERSHOOT vs CAPACITIVE LOAD (100mV Output Step)**

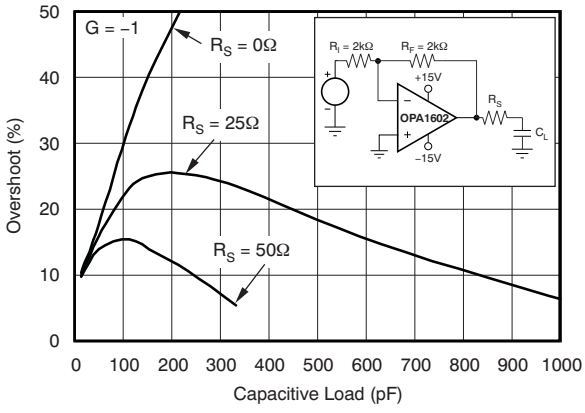


**Figure 20.**

**SMALL-SIGNAL OVERSHOOT vs FEEDBACK CAPACITOR (100mV Output Step)**

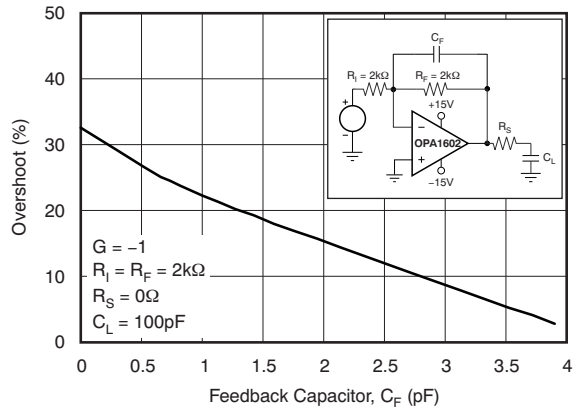


**Figure 21.**

**OPEN-LOOP GAIN vs TEMPERATURE**

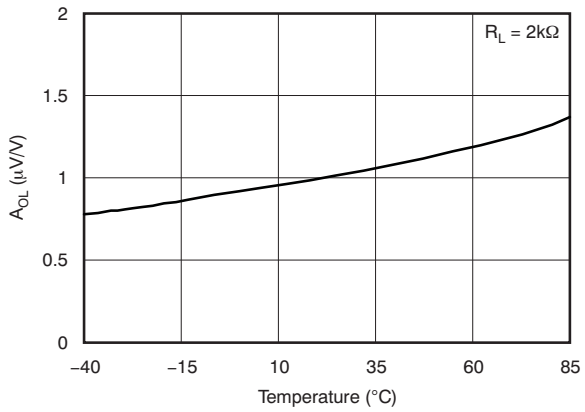


**Figure 22.**

**$I_B$ AND $I_{OS}$ vs TEMPERATURE**

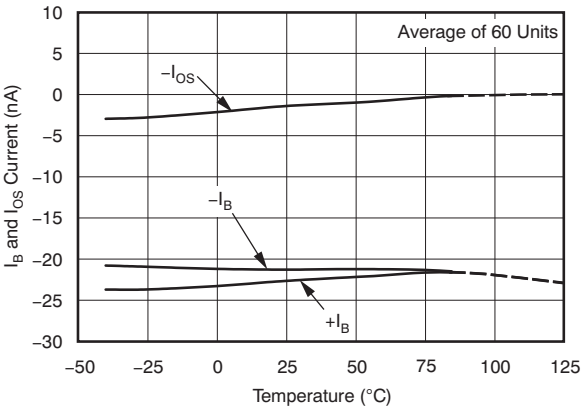


**Figure 23.**

**$I_B$ AND $I_{OS}$ vs COMMON-MODE VOLTAGE**

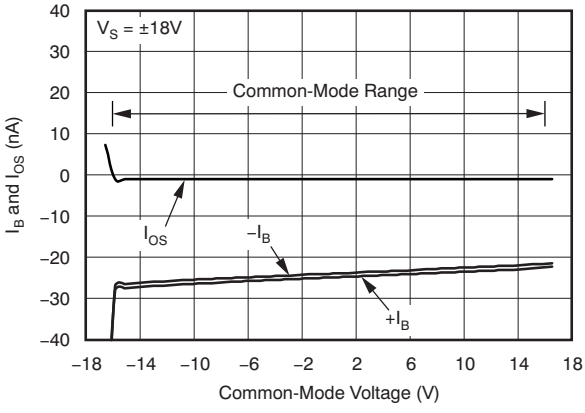


**Figure 24.**


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## TYPICAL CHARACTERISTICS (continued)

At $T_A$ = +25°C, $V_S$ = ±15V, and $R_L$ = 2kΩ, unless otherwise noted.

**QUIESCENT CURRENT vs TEMPERATURE**

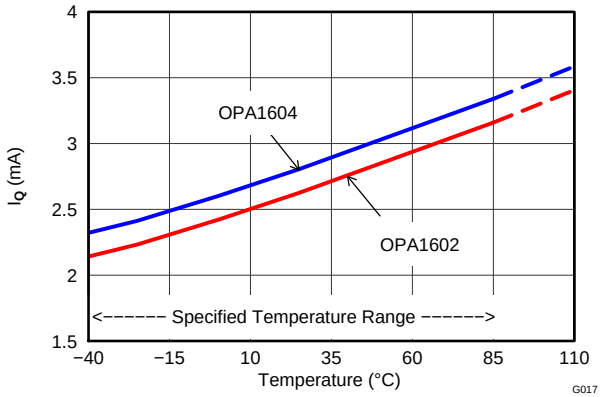


**Figure 25.**

**QUIESCENT CURRENT vs SUPPLY VOLTAGE**

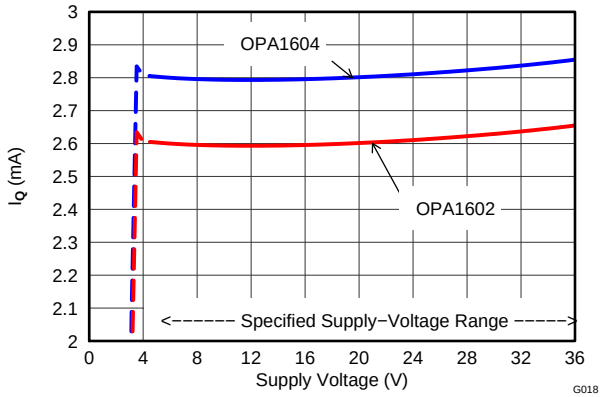


**Figure 26.**

**$I_Q$ WARMUP**
**(Difference from $I_Q$ at Startup, Per Channel)**

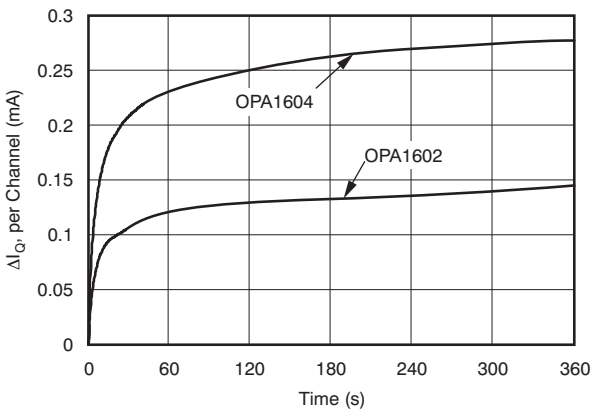


**Figure 27.**

**SHORT-CIRCUIT CURRENT vs TEMPERATURE**

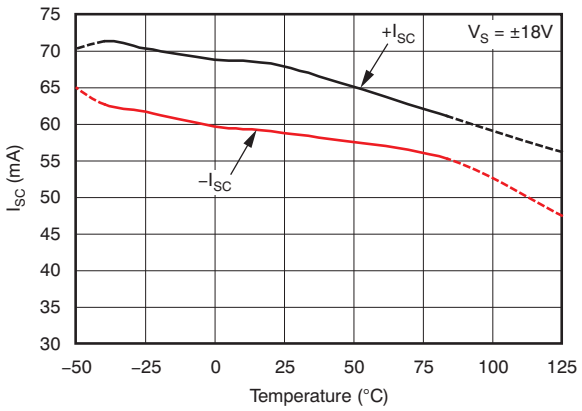


**Figure 28.**

**OUTPUT VOLTAGE vs OUTPUT CURRENT**

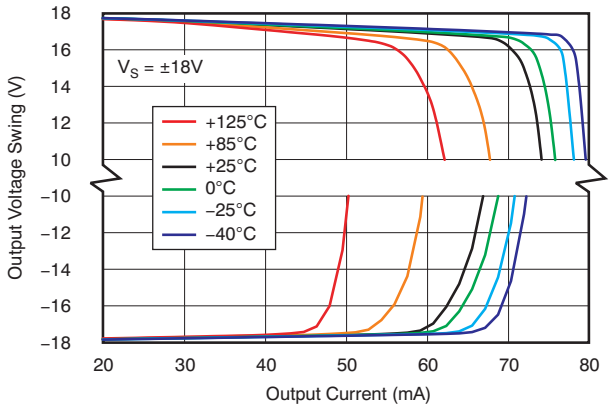


**Figure 29.**

**OPEN-LOOP OUTPUT IMPEDANCE vs FREQUENCY**

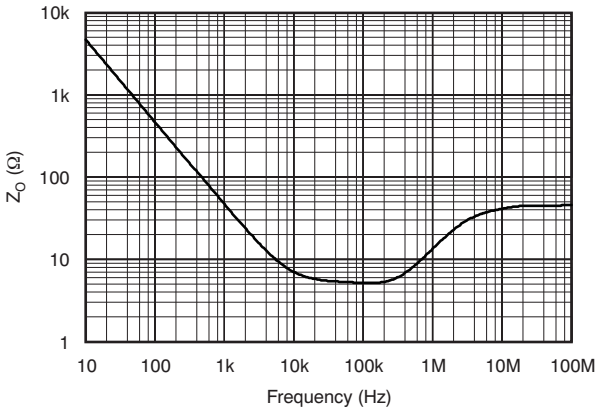


**Figure 30.**

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## APPLICATION INFORMATION

The OPA1602 and OPA1604 are unity-gain stable, precision dual and quad op amps with very low noise. Applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases, 0.1µF capacitors are adequate. Figure 31 shows a simplified schematic of the OPA160x (one channel shown).

### OPERATING VOLTAGE

The OPA160x series op amps operate from ±2.25V to ±18V supplies while maintaining excellent performance. The OPA160x series can operate with as little as +4.5V between the supplies and with up to +36V between the supplies. However, some applications do not require equal positive and negative output voltage swing. With the OPA160x series, power-supply voltages do not need to be equal. For example, the positive supply could be set to +25V with the negative supply at –5V.

In all cases, the common-mode voltage must be maintained within the specified range. In addition, key parameters are assured over the specified temperature range of $T_A$ = –40°C to +85°C. Parameters that vary significantly with operating voltage or temperature are shown in the Typical Characteristics.

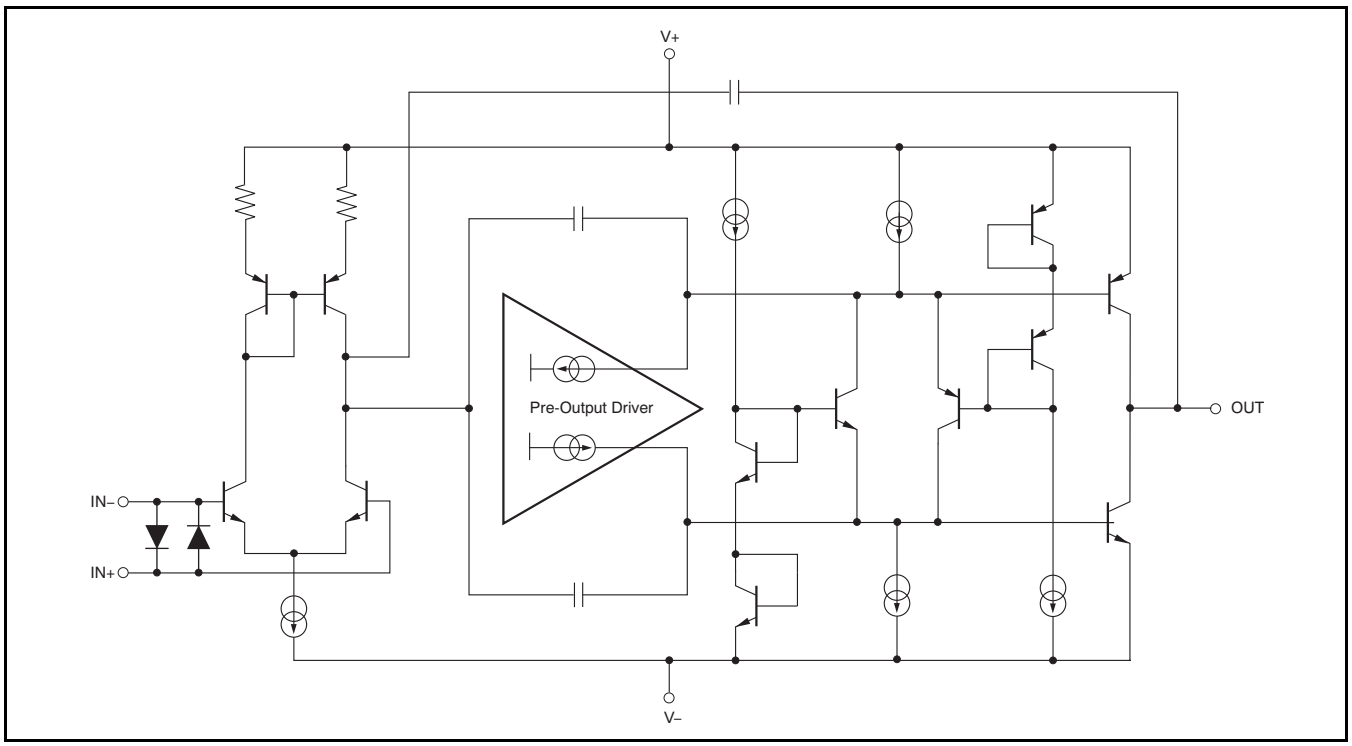


**Figure 31. OPA160x Simplified Schematic**


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## INPUT PROTECTION

The input terminals of the OPA1602 and OPA1604 are protected from excessive differential voltage with back-to-back diodes, as Figure 32 illustrates. In most circuit applications, the input protection circuitry has no consequence. However, in low-gain or G = +1 circuits, fast ramping input signals can forward bias these diodes because the output of the amplifier cannot respond rapidly enough to the input ramp. This effect is illustrated in Figure 17 of the Typical Characteristics. If the input signal is fast enough to create this forward bias condition, the input signal current must be limited to 10mA or less. If the input signal current is not inherently limited, an input series resistor ($R_I$) and/or a feedback resistor ($R_F$) can be used to limit the signal input current. This resistor degrades the low-noise performance of the OPA160x and is examined in the following *Noise Performance* section. Figure 32 shows an example configuration when both current-limiting input and feeback resistors are used.

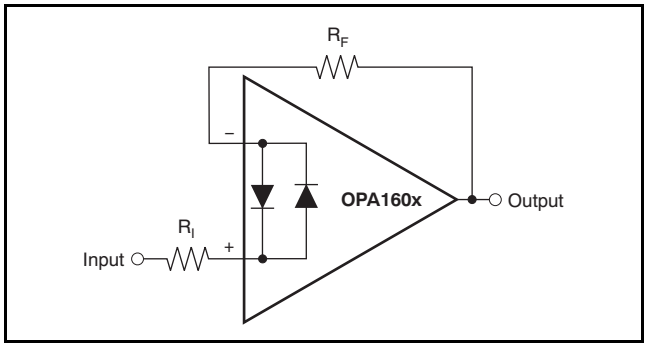


**Figure 32. Pulsed Operation**

## NOISE PERFORMANCE

Figure 33 shows the total circuit noise for varying source impedances with the op amp in a unity-gain configuration (no feedback resistor network, and therefore no additional noise contributions).

The OPA160x (GBW = 35MHz, G = +1) is shown with total circuit noise calculated. The op amp itself contributes both a voltage noise component and a current noise component. The voltage noise is commonly modeled as a time-varying component of the offset voltage. The current noise is modeled as the time-varying component of the input bias current and reacts with the source resistance to create a voltage component of noise. Therefore, the lowest noise op amp for a given application depends on the source impedance. For low source impedance, current noise is negligible, and voltage noise generally dominates. The low voltage noise of the OPA160x series op amps makes them a better choice for low source impedances of less than 1kΩ.

The equation in Figure 33 shows the calculation of the total circuit noise, with these parameters:

- $e_n$ = Voltage noise
- $i_n$ = Current noise
- $R_S$ = Source impedance
- k = Boltzmann's constant = $1.38 \times 10^{-23}$ J/K
- T = Temperature in degrees Kelvin (K)

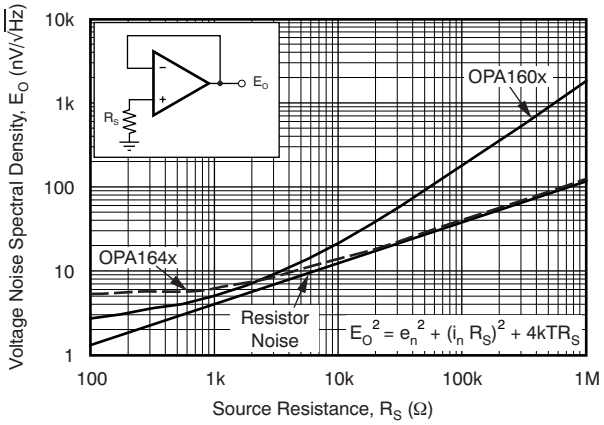


**Figure 33. Noise Performance of the OPA160x in Unity-Gain Buffer Configuration**

## BASIC NOISE CALCULATIONS

Design of low-noise op amp circuits requires careful consideration of a variety of possible noise contributors: noise from the signal source, noise generated in the op amp, and noise from the feedback network resistors. The total noise of the circuit is the root-sum-square combination of all noise components.

The resistive portion of the source impedance produces thermal noise proportional to the square root of the resistance. Figure 33 plots this equation. The source impedance is usually fixed; consequently, select the op amp and the feedback resistors to minimize the respective contributions to the total noise.

Figure 34 illustrates both inverting and noninverting op amp circuit configurations with gain. In circuit configurations with gain, the feedback network resistors also contribute noise. The current noise of the op amp reacts with the feedback resistors to create additional noise components. The feedback resistor values can generally be chosen to make these noise sources negligible. The equations for total noise are shown for both configurations.

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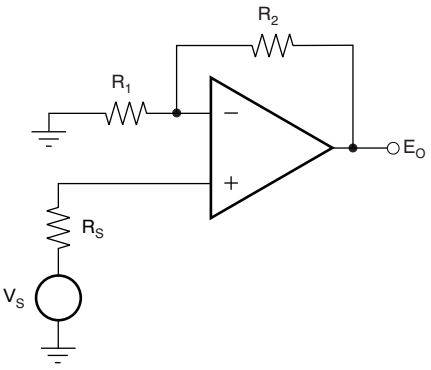
**A) Noise in Noninverting Gain Configuration**




Noise at the output:

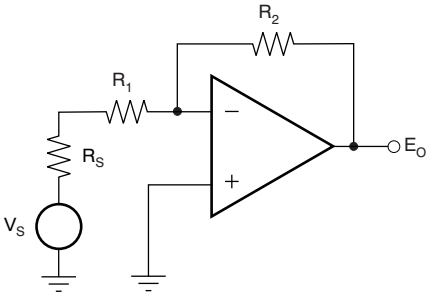
$$E_O^2 = \left(1 + \frac{R_2}{R_1}\right)^2 e_n^2 + \left(\frac{R_2}{R_1}\right)^2 e_1^2 + e_2^2 + \left(1 + \frac{R_2}{R_1}\right)^2 e_s^2$$

Where $e_S = \sqrt{4kTR_S}$ = thermal noise of $R_S$

$e_1 = \sqrt{4kTR_1}$ = thermal noise of $R_1$

$e_2 = \sqrt{4kTR_2}$ = thermal noise of $R_2$

**B) Noise in Inverting Gain Configuration**




Noise at the output:

$$E_O^2 = \left(1 + \frac{R_2}{R_1 + R_S}\right)^2 e_n^2 + \left(\frac{R_2}{R_1 + R_S}\right)^2 e_1^2 + e_2^2 + \left(\frac{R_2}{R_1 + R_S}\right)^2 e_s^2$$

Where $e_S = \sqrt{4kTR_S}$ = thermal noise of $R_S$

$e_1 = \sqrt{4kTR_1}$ = thermal noise of $R_1$

$e_2 = \sqrt{4kTR_2}$ = thermal noise of $R_2$

Note: For the OPA160x series of op amps at 1kHz, $e_n = 2.5nV/\sqrt{Hz}$ and $i_n = 1.8pA\sqrt{Hz}$.

**Figure 34. Noise Calculation in Gain Configurations**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## TOTAL HARMONIC DISTORTION MEASUREMENTS

The OPA160x series op amps have excellent distortion characteristics. THD + noise is below 0.00008% (G = +1, $V_O$ = 3$V_{RMS}$, BW = 80kHz) throughout the audio frequency range, 20Hz to 20kHz, with a 2kΩ load (see Figure 7 for characteristic performance).

The distortion produced by the OPA160x series op amps is below the measurement limit of many commercially available distortion analyzers. However, a special test circuit (such as Figure 35 shows) can be used to extend the measurement capabilities.

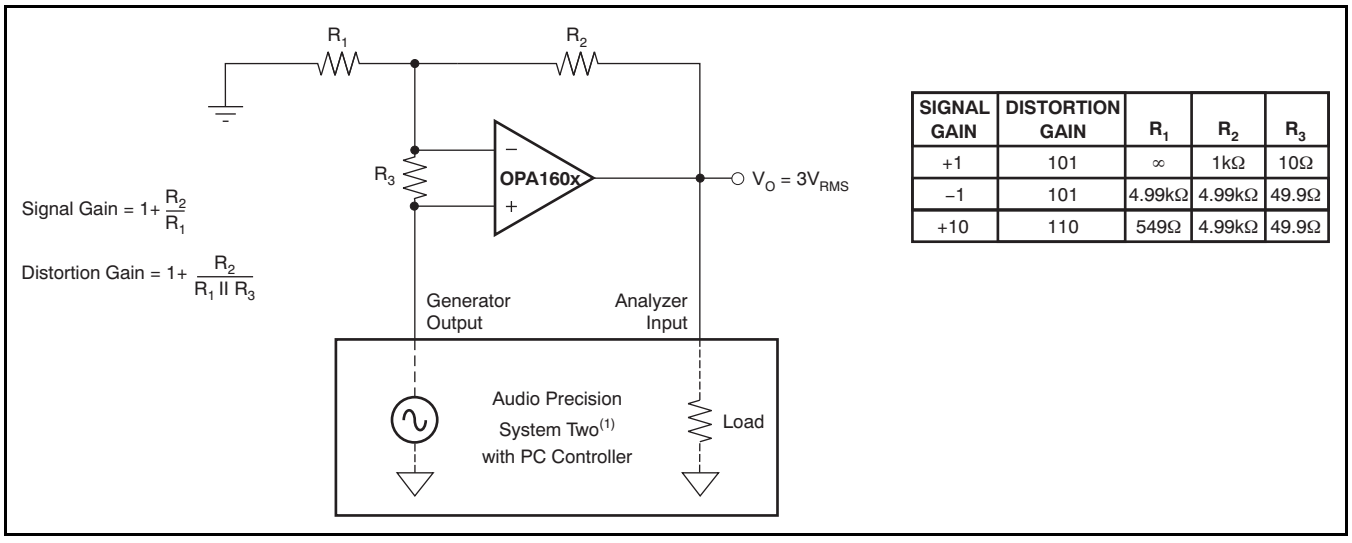
Op amp distortion can be considered an internal error source that can be referred to the input. Figure 35 shows a circuit that causes the op amp distortion to be gained up (refer to the table in Figure 35 for the distortion gain factor for various signal gains). The addition of $R_3$ to the otherwise standard noninverting amplifier configuration alters the feedback factor or noise gain of the circuit. The closed-loop gain is unchanged, but the feedback available for error correction is reduced by the distortion gain factor, thus extending the resolution by the same amount. Note that the input signal and load applied to the op amp are the same as with conventional feedback without $R_3$. The value of $R_3$ should be kept small to minimize its effect on the distortion measurements.

The validity of this technique can be verified by duplicating measurements at high gain and/or high frequency where the distortion is within the measurement capability of the test equipment. Measurements for this data sheet were made with an Audio Precision System Two distortion/noise analyzer, which greatly simplifies such repetitive measurements. The measurement technique can, however, be performed with manual distortion measurement instruments.

## CAPACITIVE LOADS

The dynamic characteristics of the OPA1602 and OPA1604 have been optimized for commonly encountered gains, loads, and operating conditions. The combination of low closed-loop gain and high capacitive loads decreases the phase margin of the amplifier and can lead to gain peaking or oscillations. As a result, heavier capacitive loads must be isolated from the output. The simplest way to achieve this isolation is to add a small resistor ($R_S$ equal to 50Ω, for example) in series with the output.

This small series resistor also prevents excess power dissipation if the output of the device becomes shorted. Figure 19 illustrates a graph of *Small-Signal Overshoot vs Capacitive Load* for several values of $R_S$. Also, refer to Applications Bulletin AB-028 (literature number SBOA015, available for download from the TI web site) for details of analysis techniques and application circuits.




| SIGNAL GAIN | DISTORTION GAIN | $R_1$ | $R_2$ | $R_3$ |
|---|---|---|---|---|
| +1 | 101 | ∞ | 1kΩ | 10Ω |
| –1 | 101 | 4.99kΩ | 4.99kΩ | 49.9Ω |
| +10 | 110 | 549Ω | 4.99kΩ | 49.9Ω |

(1) For measurement bandwidth, see Figure 7 through Figure 12.

**Figure 35. Distortion Test Circuit**

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## POWER DISSIPATION

The OPA1602 and OPA1604 series op amps are capable of driving 2kΩ loads with a power-supply voltage up to ±18V and full operating temperature range. Internal power dissipation increases when operating at high supply voltages. Copper leadframe construction used in the OPA160x series op amps improves heat dissipation compared to conventional materials. Circuit board layout can also help minimize junction temperature rise. Wide copper traces help dissipate the heat by acting as an additional heat sink. Temperature rise can be further minimized by soldering the devices to the circuit board rather than using a socket.

## ELECTRICAL OVERSTRESS

Designers often ask questions about the capability of an operational amplifier to withstand electrical overstress. These questions tend to focus on the device inputs, but may involve the supply voltage pins or even the output pin. Each of these different pin functions have electrical stress limits determined by the voltage breakdown characteristics of the particular semiconductor fabrication process and specific circuits connected to the pin. Additionally, internal electrostatic discharge (ESD) protection is built into these circuits to protect them from accidental ESD events both before and during product assembly.

It is helpful to have a good understanding of this basic ESD circuitry and its relevance to an electrical overstress event. Figure 36 illustrates the ESD circuits contained in the OPA160x (indicated by the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where they meet at an absorption device internal to the operational amplifier. This protection circuitry is intended to remain inactive during normal circuit operation.

An ESD event produces a short duration, high-voltage pulse that is transformed into a short duration, high-current pulse as it discharges through a semiconductor device. The ESD protection circuits are designed to provide a current path around the operational amplifier core to prevent it from being damaged. The energy absorbed by the protection circuitry is then dissipated as heat.

When an ESD voltage develops across two or more of the amplifier device pins, current flows through one or more of the steering diodes. Depending on the path that the current takes, the absorption device may activate. The absorption device internal to the OPA160x triggers when a fast ESD voltage pulse is impressed across the supply pins. Once triggered, it quickly activates, clamping the ESD pulse to a safe voltage level.

When the operational amplifier connects into a circuit such as that illustrated in Figure 36, the ESD protection components are intended to remain inactive and not become involved in the application circuit operation. However, circumstances may arise where an applied voltage exceeds the operating voltage range of a given pin. Should this condition occur, there is a risk that some of the internal ESD protection circuits may be biased on, and conduct current. Any such current flow occurs through steering diode paths and rarely involves the absorption device.

Figure 36 depicts a specific example where the input voltage, $V_{IN}$, exceeds the positive supply voltage ($+V_S$) by 500mV or more. Much of what happens in the circuit depends on the supply characteristics. If $+V_S$ can sink the current, one of the upper input steering diodes conducts and directs current to $+V_S$. Excessively high current levels can flow with increasingly higher $V_{IN}$. As a result, the datasheet specifications recommend that applications limit the input current to 10mA.

If the supply is not capable of sinking the current, $V_{IN}$ may begin sourcing current to the operational amplifier, and then take over as the source of positive supply voltage. The danger in this case is that the voltage can rise to levels that exceed the operational amplifier absolute maximum ratings. In extreme but rare cases, the absorption device triggers on while $+V_S$ and $–V_S$ are applied. If this event happens, a direct current path is established between the $+V_S$ and $–V_S$ supplies. The power dissipation of the absorption device is quickly exceeded, and the extreme internal heating destroys the operational amplifier.

Another common question involves what happens to the amplifier if an input signal is applied to the input while the power supplies $+V_S$ and/or $–V_S$ are at 0V. Again, it depends on the supply characteristic while at 0V, or at a level below the input signal amplitude. If the supplies appear as high impedance, then the operational amplifier supply current may be supplied by the input source via the current steering diodes. This state is not a normal bias condition; the amplifier most likely will not operate normally. If the supplies are low impedance, then the current through the steering diodes can become quite high. The current level depends on the ability of the input source to deliver current, and any resistance in the input path.


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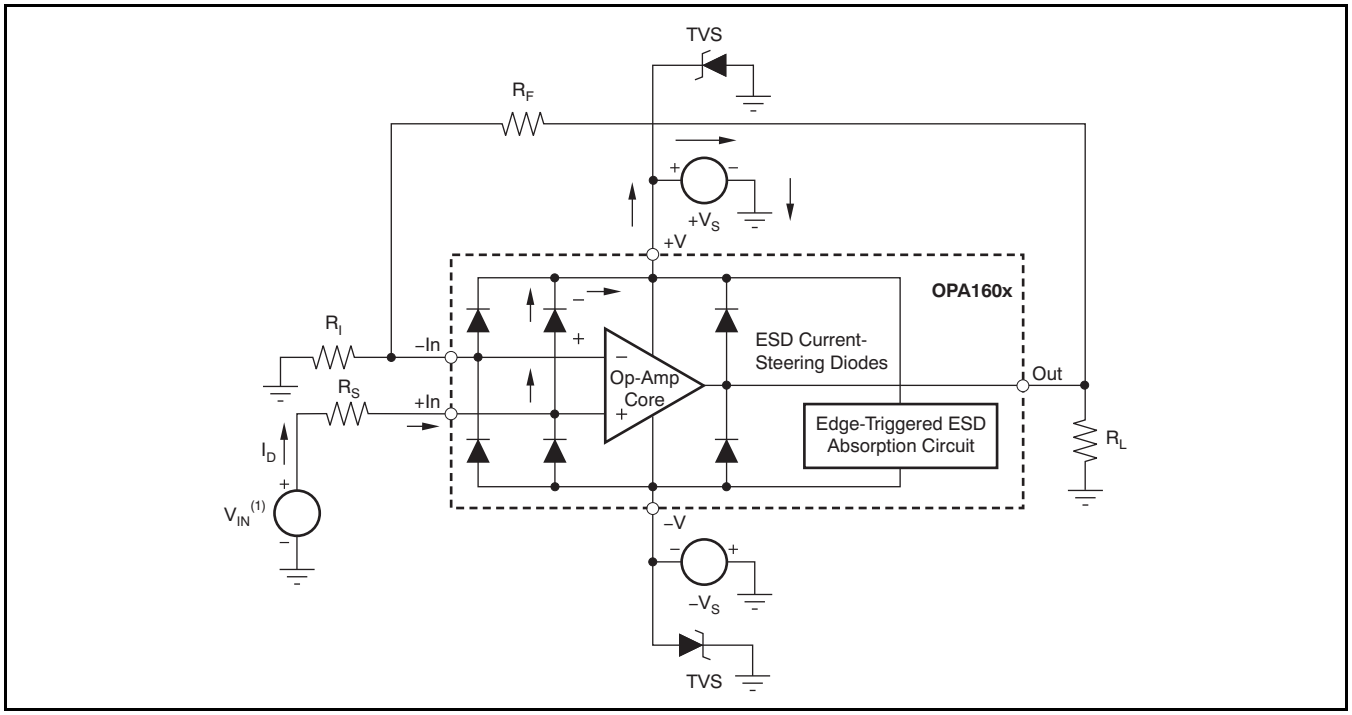
If there is an uncertainty about the ability of the supply to absorb this current, external zener diodes may be added to the supply pins as shown in Figure 36.

The zener voltage must be selected such that the diode does not turn on during normal operation. However, its zener voltage should be low enough so that the zener diode conducts if the supply pin begins to rise above the safe operating supply voltage level.




(1) $V_{IN} = +V_S + 500mV$.

**Figure 36. Equivalent Internal ESD Circuitry and Its Relation to a Typical Circuit Application (Single Channel Shown)**

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## APPLICATION CIRCUIT

An additional application idea is shown in Figure 37.

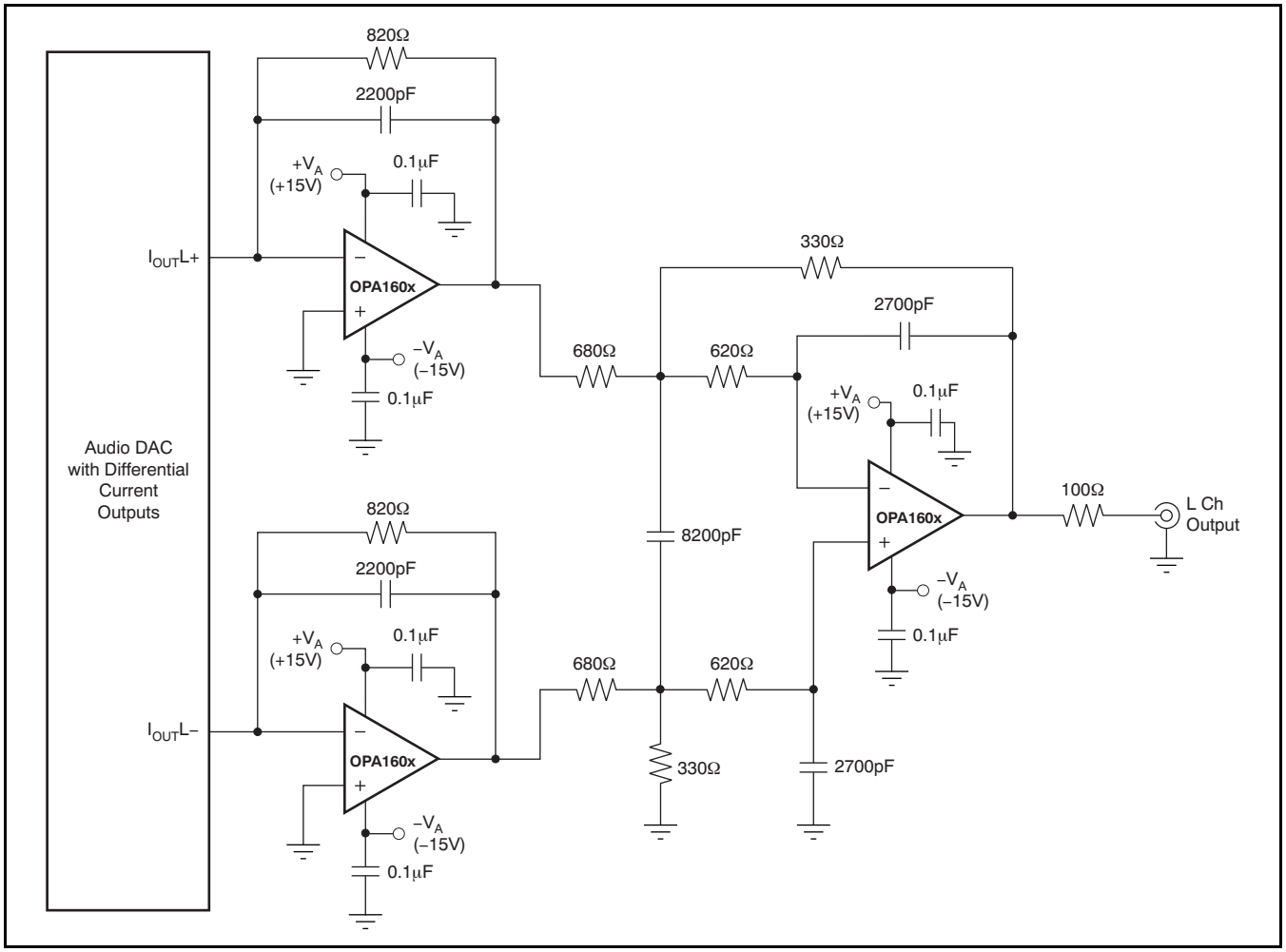


**Figure 37. Audio DAC I/V Converter and Output Filter**


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## REVISION HISTORY

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

**Changes from Revision A (April, 2011) to Revision B** **Page**

- Revised minimum and typical *Common-mode rejection ratio* specifications ..... 3
- Added footnote (2) to *Electrical Characteristics* table ..... 3
- Added separate quiescent current specifications for dual and quad versions ..... 4
- Added footnote (3) to *Electrical Characteristics* table ..... 4
- Corrected product identification and values in OPA1602 *Thermal Information* table ..... 4
- Added values to OPA1604 *Thermal Information* table. ..... 4
- Updated device name in Figure 3 ..... 5
- Updated Figure 25 to show both devices ..... 9
- Updated Figure 26 to show both devices ..... 9
- Updated device name in Figure 33 ..... 11
- Changed *Power Dissipation* section ..... 14

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## PACKAGING INFORMATION

| Orderable part number | Status (1) | Material type (2) | Package \| Pins | Package qty \| Carrier | RoHS (3) | Lead finish/ Ball material (4) | MSL rating/ Peak reflow (5) | Op temp (°C) | Part marking (6) |
|---|---|---|---|---|---|---|---|---|---|
| OPA1602AID | Active | Production | SOIC (D) \| 8 | 75 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01602A |
| OPA1602AID.B | Active | Production | SOIC (D) \| 8 | 75 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01602A |
| OPA1602AIDGK | Active | Production | VSSOP (DGK) \| 8 | 80 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OCKQ |
| OPA1602AIDGK.B | Active | Production | VSSOP (DGK) \| 8 | 80 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OCKQ |
| OPA1602AIDGKR | Active | Production | VSSOP (DGK) \| 8 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OCKQ |
| OPA1602AIDGKR.B | Active | Production | VSSOP (DGK) \| 8 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OCKQ |
| OPA1602AIDR | Active | Production | SOIC (D) \| 8 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01602A |
| OPA1602AIDR.B | Active | Production | SOIC (D) \| 8 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01602A |
| OPA1604AID | Active | Production | SOIC (D) \| 14 | 50 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01604A |
| OPA1604AID.B | Active | Production | SOIC (D) \| 14 | 50 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01604A |
| OPA1604AIDR | Active | Production | SOIC (D) \| 14 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01604A |
| OPA1604AIDR.B | Active | Production | SOIC (D) \| 14 | 2500 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | 01604A |
| OPA1604AIPW | Active | Production | TSSOP (PW) \| 14 | 90 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OPA1604 |
| OPA1604AIPW.B | Active | Production | TSSOP (PW) \| 14 | 90 \| TUBE | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OPA1604 |
| OPA1604AIPWR | Active | Production | TSSOP (PW) \| 14 | 2000 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OPA1604 |
| OPA1604AIPWR.B | Active | Production | TSSOP (PW) \| 14 | 2000 \| LARGE T&R | Yes | NIPDAU | Level-2-260C-1 YEAR | -40 to 85 | OPA1604 |

(1) **Status:** For more details on status, see our product life cycle.

(2) **Material type:** When designated, preproduction parts are prototypes/experimental devices, and are not yet approved or released for full production. Testing and final process, including without limitation quality assurance, reliability performance testing, and/or process qualification, may not yet be complete, and this item is subject to further changes or possible discontinuation. If available for ordering, purchases will be subject to an additional waiver at checkout, and are intended for early internal evaluation purposes only. These items are sold without warranties of any kind.

(3) **RoHS values:** Yes, No, RoHS Exempt. See the TI RoHS Statement for additional information and value definition.

(4) **Lead finish/Ball material:** Parts may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

(5) **MSL rating/Peak reflow:** The moisture sensitivity level ratings and peak solder (reflow) temperatures. In the event that a part has multiple moisture sensitivity ratings, only the lowest level per JEDEC standards is shown. Refer to the shipping label for the actual reflow temperature that will be used to mount the part to the printed circuit board.

(6) **Part marking:** There may be an additional marking, which relates to the logo, the lot trace code information, or the environmental category of the part.

Multiple part markings will be inside parentheses. Only one part marking contained in parentheses and separated by a "~" will appear on a part. If a line is indented then it is a continuation of the previous line and the two combined represent the entire part marking for that device.

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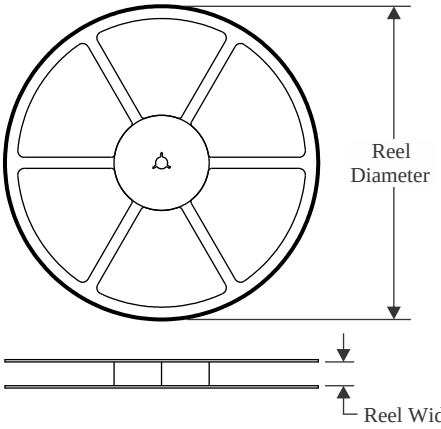
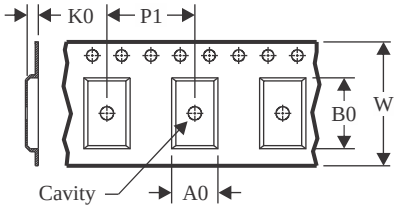
## TAPE AND REEL INFORMATION

**REEL DIMENSIONS**

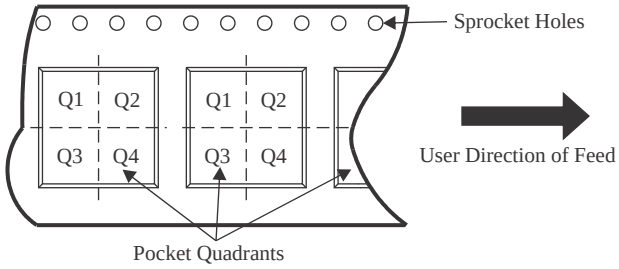



**TAPE DIMENSIONS**




| | |
|---|---|
| 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 |

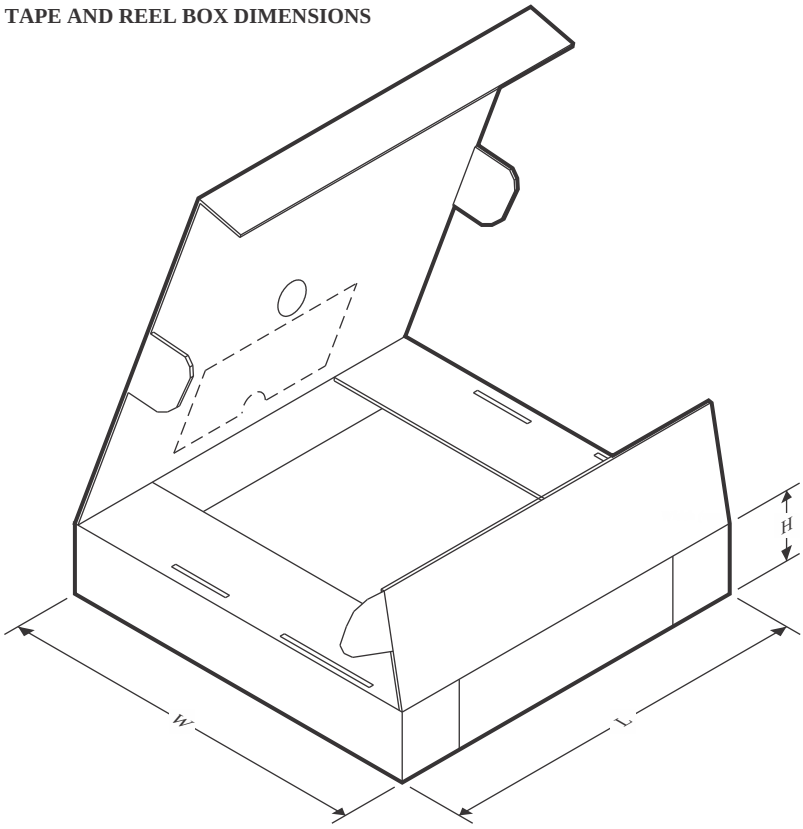
**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**




*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 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OPA1602AIDGKR | VSSOP | DGK | 8 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA1602AIDGKR | VSSOP | DGK | 8 | 2500 | 330.0 | 12.4 | 5.3 | 3.4 | 1.4 | 8.0 | 12.0 | Q1 |
| OPA1602AIDR | SOIC | D | 8 | 2500 | 330.0 | 12.4 | 6.4 | 5.2 | 2.1 | 8.0 | 12.0 | Q1 |
| OPA1604AIDR | SOIC | D | 14 | 2500 | 330.0 | 16.4 | 6.5 | 9.0 | 2.1 | 8.0 | 16.0 | Q1 |
| OPA1604AIPWR | TSSOP | PW | 14 | 2000 | 330.0 | 12.4 | 6.9 | 5.6 | 1.6 | 8.0 | 12.0 | Q1 |

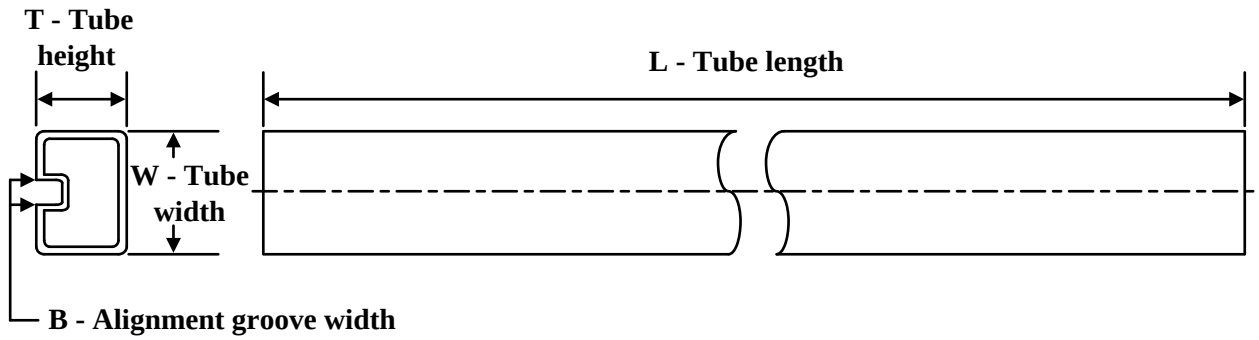
TAPE AND REEL BOX DIMENSIONS




*All dimensions are nominal

| Device | Package Type | Package Drawing | Pins | SPQ | Length (mm) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|---|---|
| OPA1602AIDGKR | VSSOP | DGK | 8 | 2500 | 346.0 | 346.0 | 29.0 |
| OPA1602AIDGKR | VSSOP | DGK | 8 | 2500 | 353.0 | 353.0 | 32.0 |
| OPA1602AIDR | SOIC | D | 8 | 2500 | 353.0 | 353.0 | 32.0 |
| OPA1604AIDR | SOIC | D | 14 | 2500 | 353.0 | 353.0 | 32.0 |
| OPA1604AIPWR | TSSOP | PW | 14 | 2000 | 353.0 | 353.0 | 32.0 |

## TUBE




*All dimensions are nominal

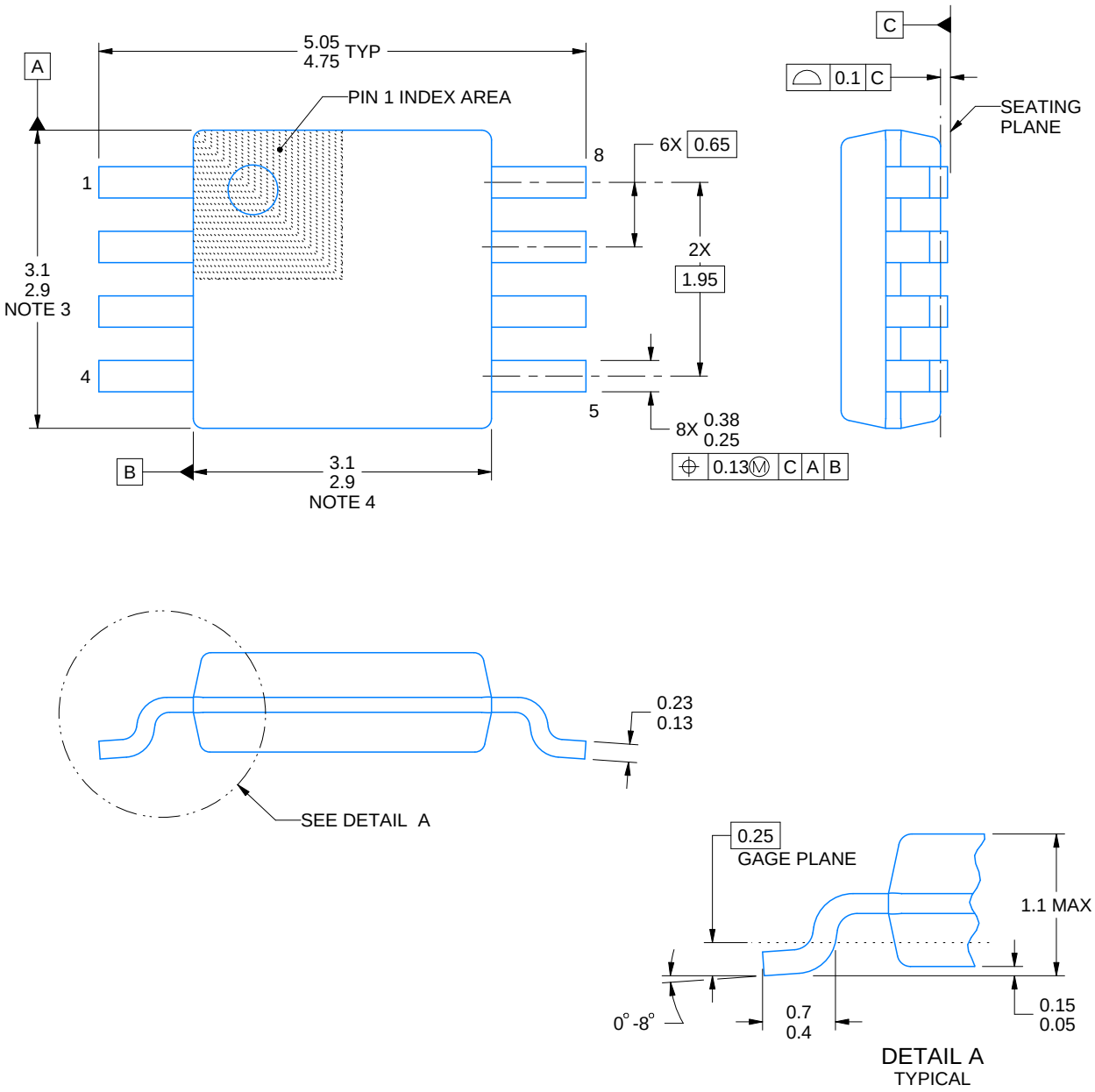
| Device | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (µm) | B (mm) |
|---|---|---|---|---|---|---|---|---|
| OPA1602AID | D | SOIC | 8 | 75 | 506.6 | 8 | 3940 | 4.32 |
| OPA1602AID.B | D | SOIC | 8 | 75 | 506.6 | 8 | 3940 | 4.32 |
| OPA1604AID | D | SOIC | 14 | 50 | 506.6 | 8 | 3940 | 4.32 |
| OPA1604AID.B | D | SOIC | 14 | 50 | 506.6 | 8 | 3940 | 4.32 |
| OPA1604AIPW | PW | TSSOP | 14 | 90 | 530 | 10.2 | 3600 | 3.5 |
| OPA1604AIPW.B | PW | TSSOP | 14 | 90 | 530 | 10.2 | 3600 | 3.5 |

# PACKAGE OUTLINE

## DGK0008A

## VSSOP - 1.1 mm max height

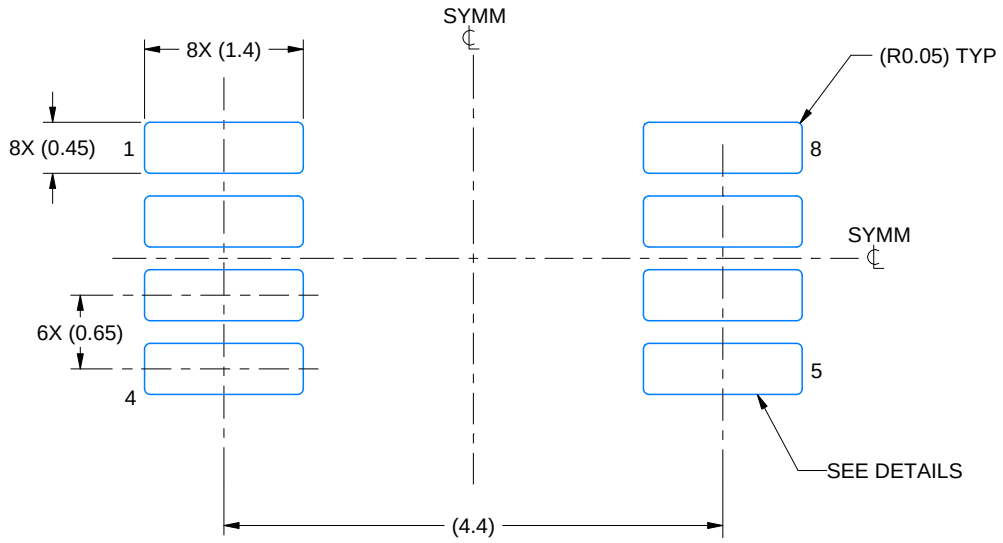
SMALL OUTLINE PACKAGE



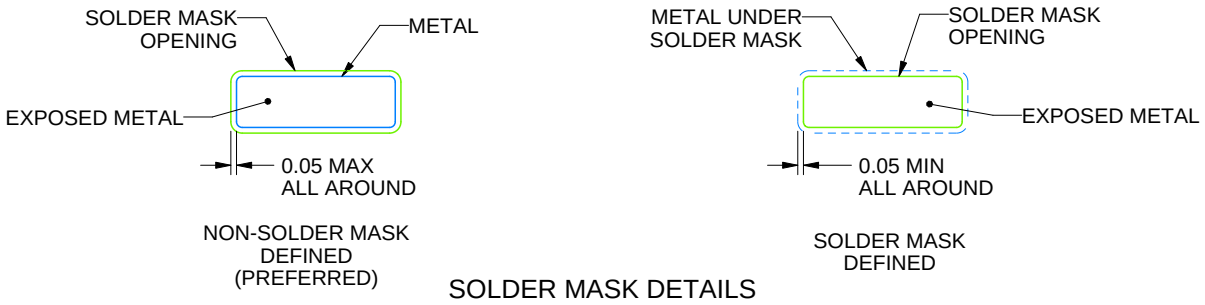

PowerPAD is a trademark of Texas Instruments.

NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-187.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 15X

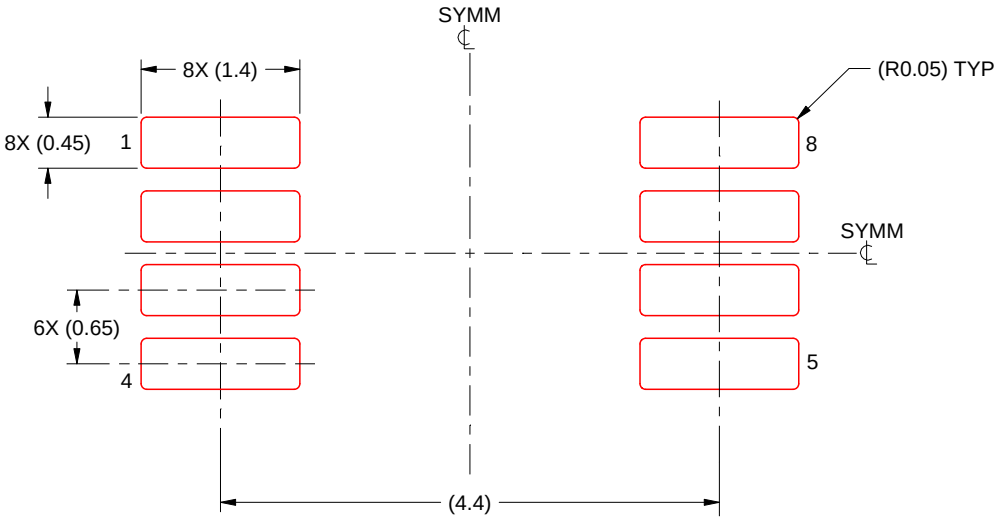



SOLDER MASK DETAILS

4214862/A 04/2023

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.
9. Size of metal pad may vary due to creepage requirement.

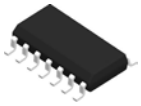



SOLDER PASTE EXAMPLE
SCALE: 15X

4214862/A 04/2023

NOTES: (continued)

11. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
12. Board assembly site may have different recommendations for stencil design.

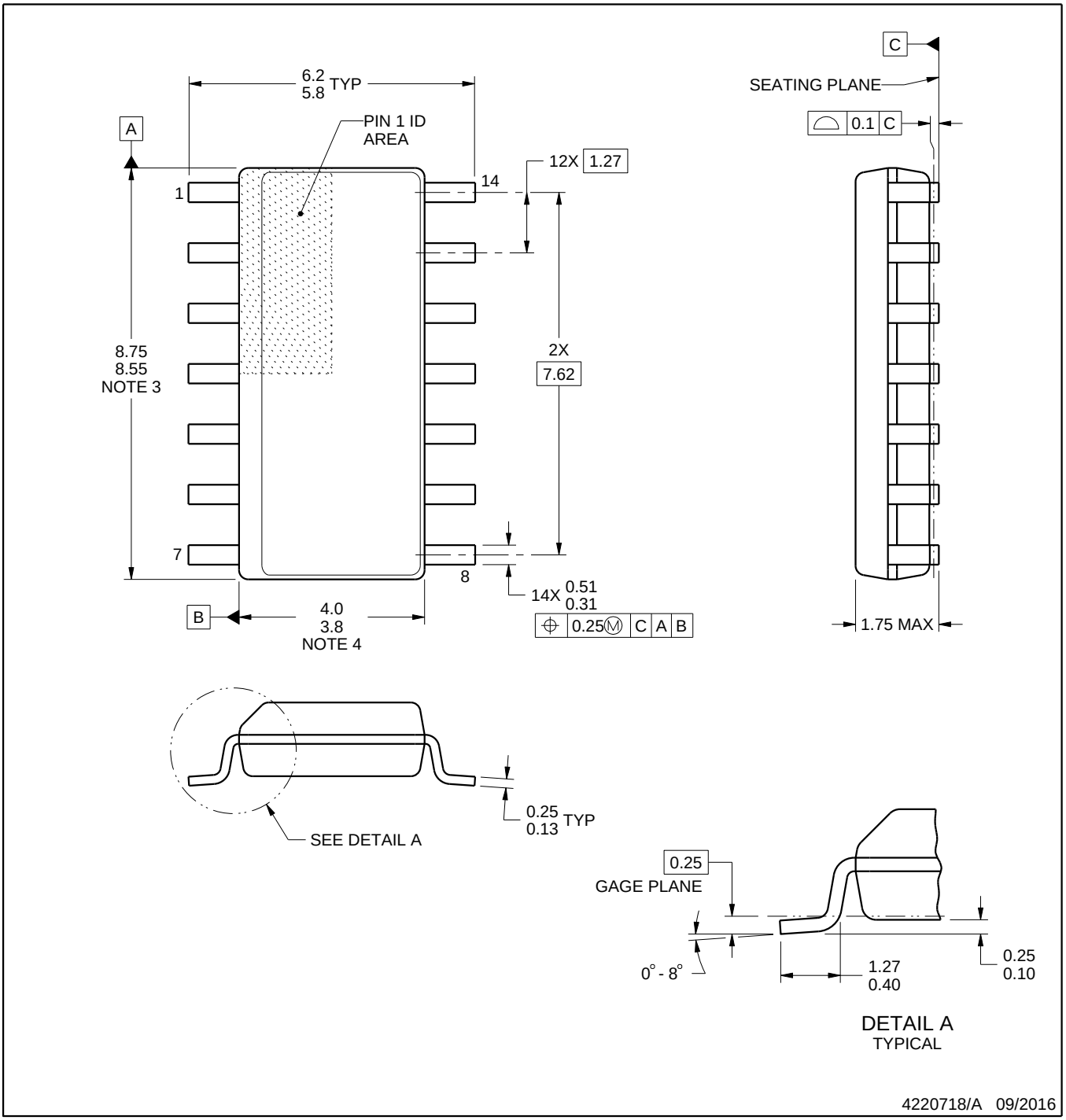


# PACKAGE OUTLINE

## D0014A

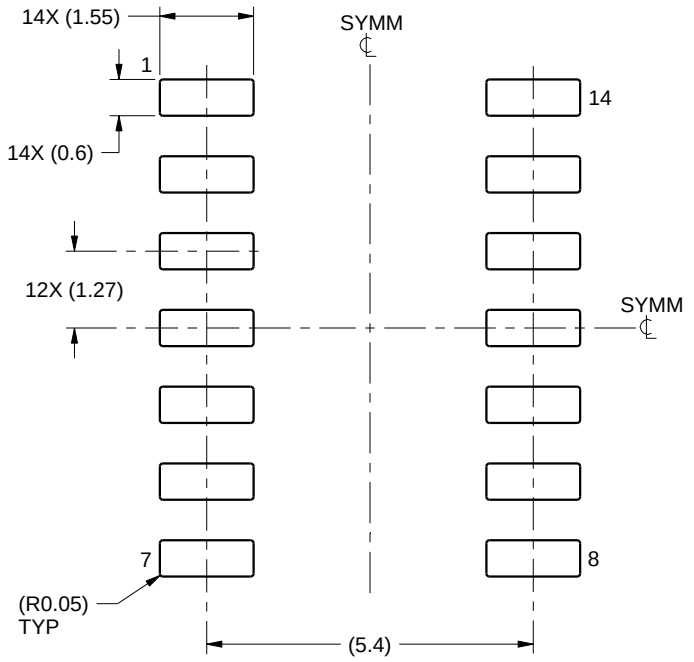
## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

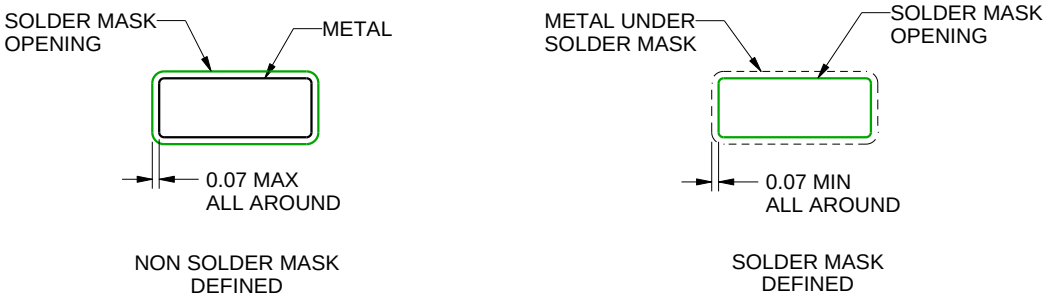



NOTES:

1. All linear dimensions are in millimeters. Dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm, per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.43 mm, per side.
5. Reference JEDEC registration MS-012, variation AB.




LAND PATTERN EXAMPLE
SCALE:8X




SOLDER MASK DETAILS

4220718/A 09/2016

NOTES: (continued)

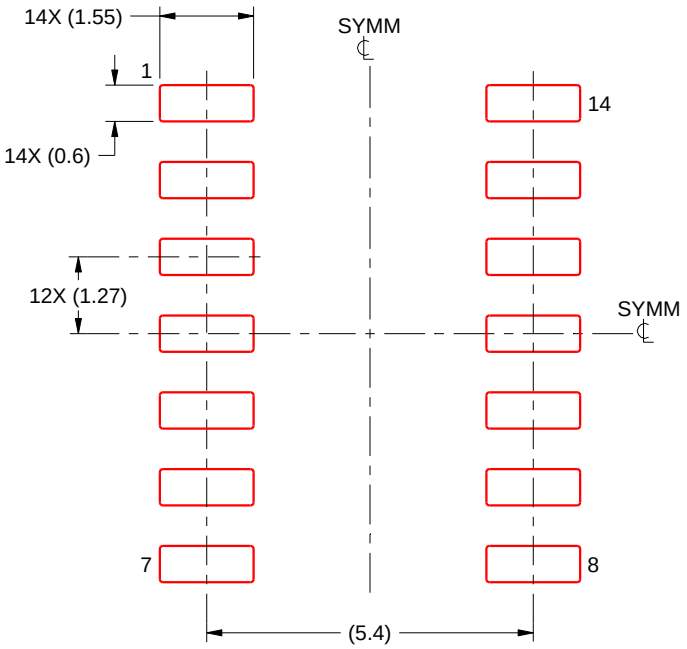
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

## D0014A

## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

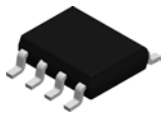



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:8X

4220718/A 09/2016

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

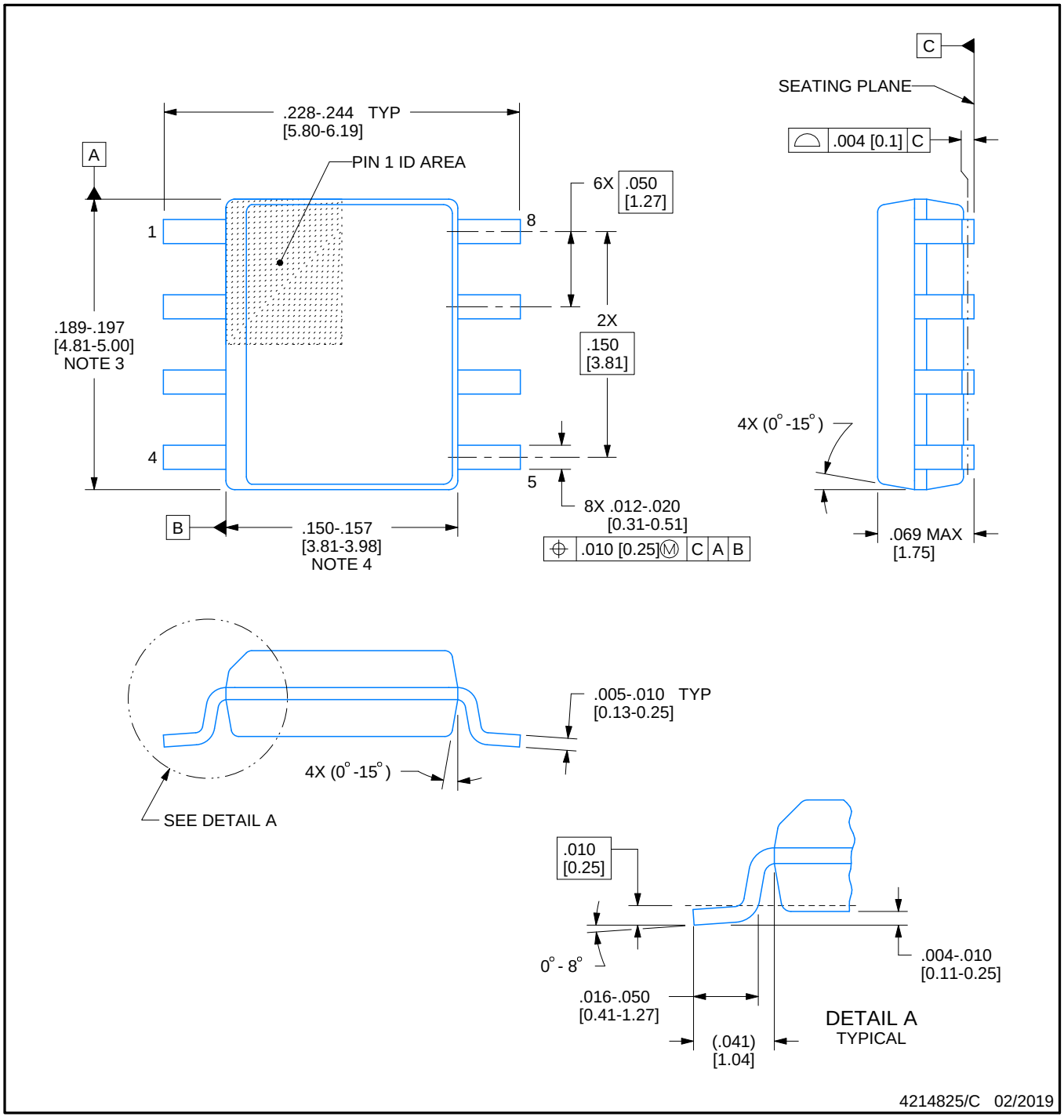


# PACKAGE OUTLINE

## D0008A

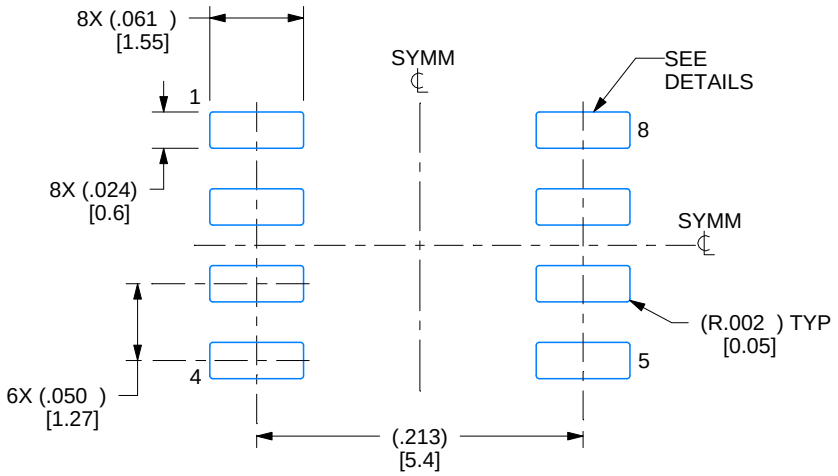
## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT

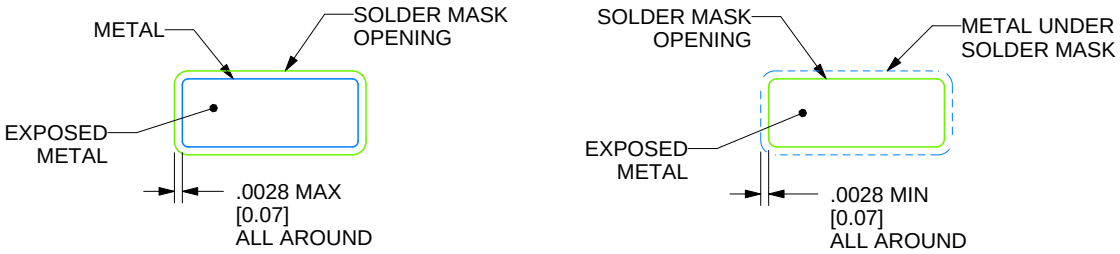



NOTES:

1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 [0.15] per side.
4. This dimension does not include interlead flash.
5. Reference JEDEC registration MS-012, variation AA.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:8X




SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

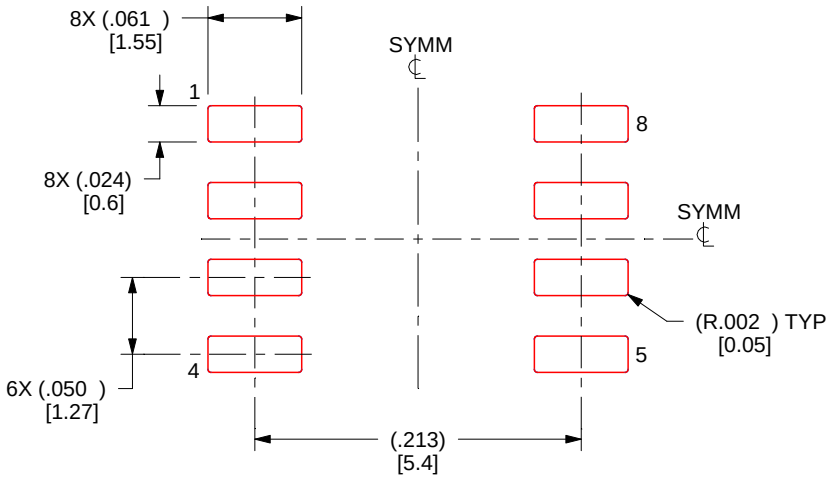
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

# EXAMPLE STENCIL DESIGN

## D0008A

## SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT




SOLDER PASTE EXAMPLE
BASED ON .005 INCH [0.125 MM] THICK STENCIL
SCALE:8X

4214825/C 02/2019

NOTES: (continued)

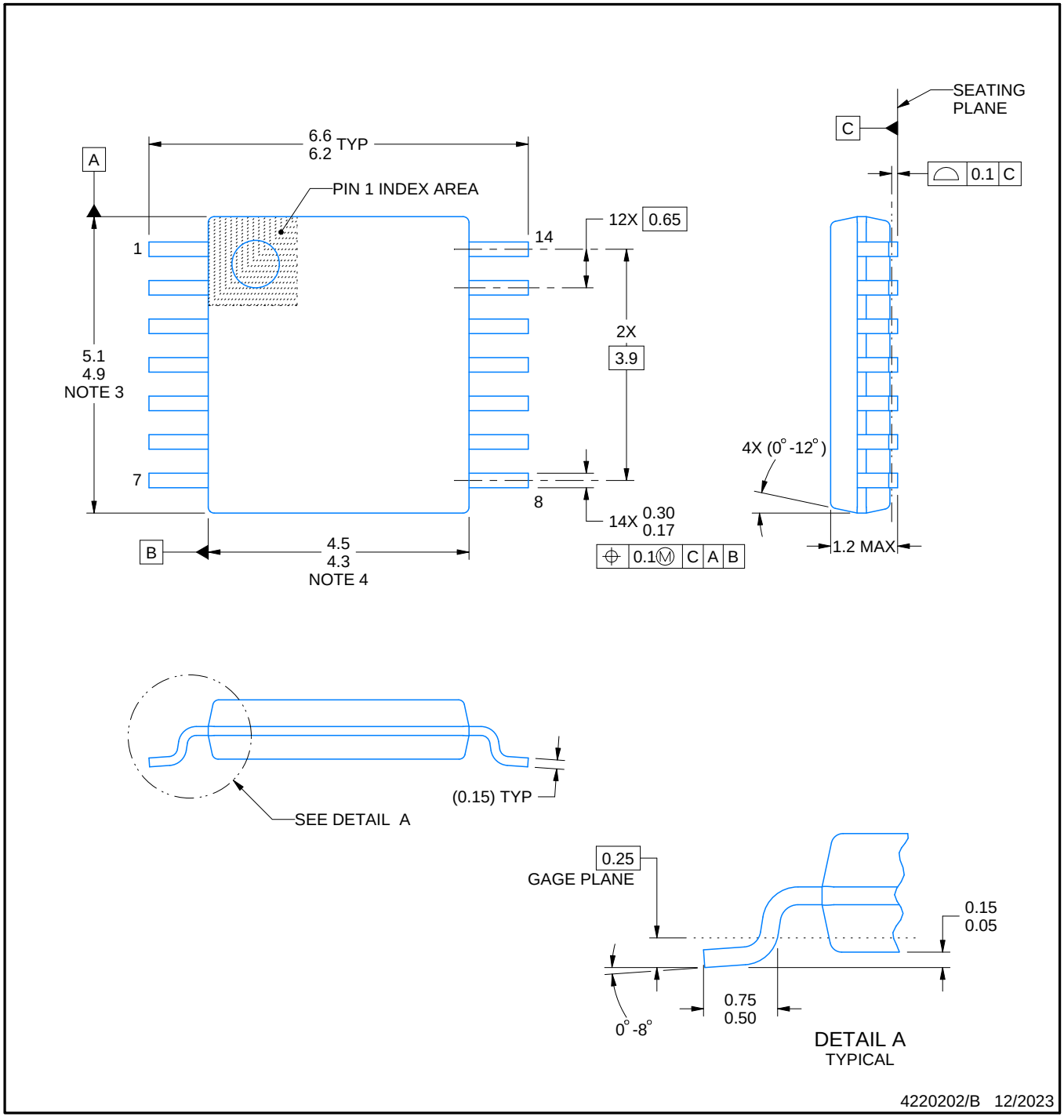
8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

# PACKAGE OUTLINE

## PW0014A

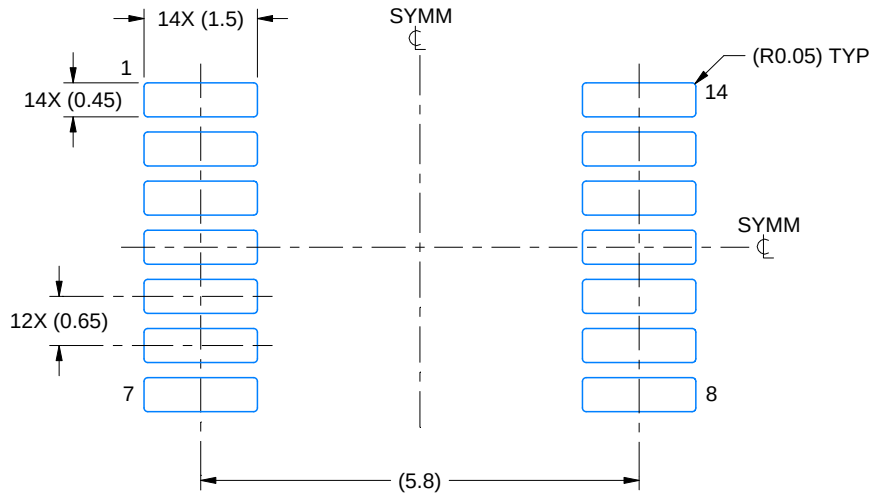
## TSSOP - 1.2 mm max height

SMALL OUTLINE PACKAGE

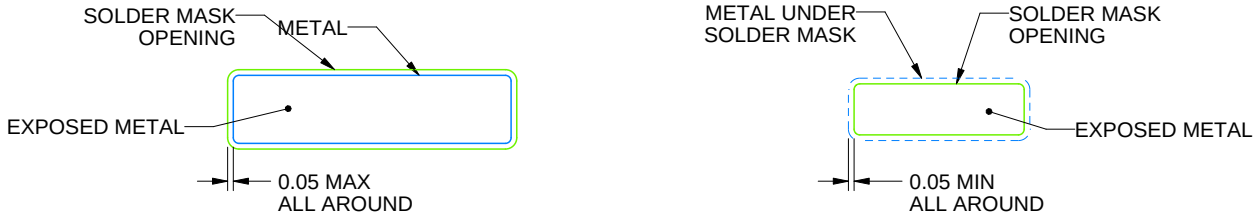



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.15 mm per side.
4. This dimension does not include interlead flash. Interlead flash shall not exceed 0.25 mm per side.
5. Reference JEDEC registration MO-153.




LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE: 10X

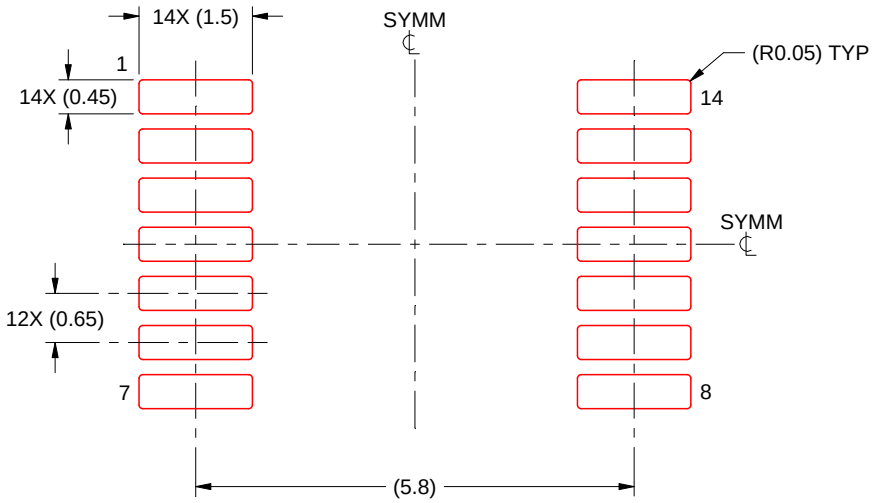



SOLDER MASK DETAILS

4220202/B 12/2023

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.




SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE: 10X

4220202/B 12/2023

NOTES: (continued)

8. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
9. Board assembly site may have different recommendations for stencil design.

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