

# THS403x 100MHz, Low-Noise, High-Speed Amplifiers

## 1 Features

- Ultra-low  $1.2\text{nV}/\sqrt{\text{Hz}}$  voltage noise
- High speed:
  - 100MHz bandwidth ( $G = 2$  ( $-1$ ),  $-3\text{dB}$ )
  - $100\text{V}/\mu\text{s}$  slew rate
- Very low distortion
  - $\text{THD} = -81\text{dBc}$  ( $f = 1\text{MHz}$ ,  $R_L = 150\Omega$ )
  - $\text{THD} = -96\text{dBc}$  ( $f = 1\text{MHz}$ ,  $R_L = 1\text{k}\Omega$ )
- Low  $0.3\text{mV}$  (typical) input offset voltage
- $200\text{mA}$  output current drive (typical)
- Typical operation from  $\pm 4.5\text{V}$  to  $\pm 16\text{V}$
- Offset nulling pins on the THS4031

## 2 Applications

- Low-noise, wide-band amplifier for industrial applications
- Voltage-controlled oscillators
- Active filters
- Video amplifiers
- Cable drivers
- [Ultrasound scanner](#)
- [Vector signal transceiver \(VST\)](#)
- [Data acquisition \(DAQ\)](#)

## 3 Description

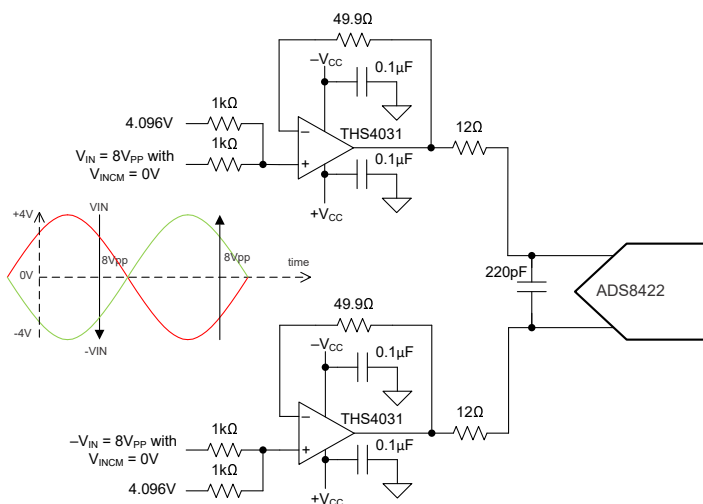
The THS4031 and THS4032 (THS403x) are ultra-low voltage noise, high-speed voltage feedback amplifiers that are an excellent choice for applications requiring low voltage noise, including communications and imaging. The single-amplifier THS4031 and the dual-amplifier THS4032 offer very good ac performance with 100MHz bandwidth ( $G = 2$ ),  $100\text{V}/\mu\text{s}$  slew rate, and  $70\text{ns}$  settling time ( $0.1\%$ ). The THS403x are unity-gain stable with 120MHz bandwidth. These amplifiers have a high drive capability of  $200\text{mA}$  and draw only  $7.5\text{mA}$  supply current per channel. With  $-96\text{dBc}$  of total harmonic distortion (THD) at  $f = 1\text{MHz}$  and a very low noise of  $1.2\text{nV}/\sqrt{\text{Hz}}$ , the THS403x are designed for applications requiring low distortion and low noise such as buffering analog-to-digital converters.

### Package Information

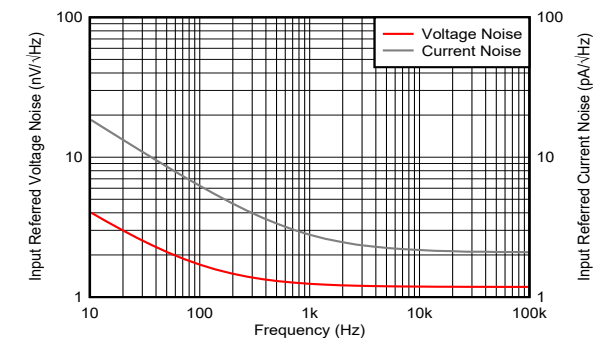
| PART NUMBER | AMPLIFIERS | PACKAGE <sup>(1)</sup> | PACKAGE SIZE <sup>(2)</sup>        |
|-------------|------------|------------------------|------------------------------------|
| THS4031     | One        | D (SOIC, 8)            | $4.9\text{mm} \times 6\text{mm}$   |
|             |            | DGN (HVSSOP, 8)        | $3.0\text{mm} \times 4.9\text{mm}$ |
| THS4032     | Two        | D (SOIC, 8)            | $4.9\text{mm} \times 6\text{mm}$   |
|             |            | DGN (HVSSOP, 8)        | $3.0\text{mm} \times 4.9\text{mm}$ |

(1) For more information, see [Section 10](#).

(2) The package size (length  $\times$  width) is a nominal value and includes pins, where applicable.



**High-Performance, Low-Noise Driver for 16-Bit SAR ADCs**



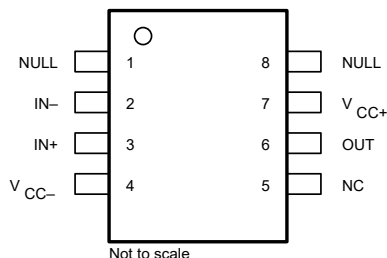
**Voltage and Current Noise vs Frequency**



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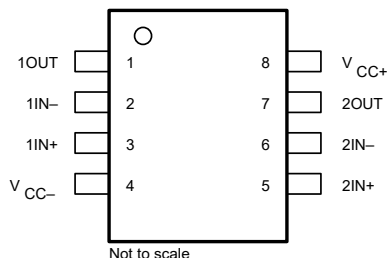
## 4 Pin Configuration and Functions



**Figure 4-1. THS4031: D Package, 8-Pin SOIC, or DGN Package, 8-pin HVSSOP (Top View)**

**Table 4-1. Pin Functions: THS4031**

| PIN              |      | TYPE   | DESCRIPTION                                                                                                                                                                                                                                                                                                           |
|------------------|------|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME             | NO.  |        |                                                                                                                                                                                                                                                                                                                       |
| IN–              | 2    | Input  | Inverting input                                                                                                                                                                                                                                                                                                       |
| IN+              | 3    | Input  | Noninverting input                                                                                                                                                                                                                                                                                                    |
| NC               | 5    | —      | No connection                                                                                                                                                                                                                                                                                                         |
| NULL             | 1, 8 | Input  | Voltage offset adjust                                                                                                                                                                                                                                                                                                 |
| OUT              | 6    | Output | Output of amplifier                                                                                                                                                                                                                                                                                                   |
| V <sub>CC–</sub> | 4    | —      | Negative power supply                                                                                                                                                                                                                                                                                                 |
| V <sub>CC+</sub> | 7    | —      | Positive power supply                                                                                                                                                                                                                                                                                                 |
| Thermal Pad      | Pad  | —      | Thermal pad. DGN (HVSSOP) package only. For the best thermal performance, connect this pad to a large copper plane. The thermal pad can be connected to any pin on the device, or any other potential on the board, as long as the voltage on the thermal pad remains between V <sub>CC+</sub> and V <sub>CC–</sub> . |



**Figure 4-2. THS4032: D Package, 8-Pin SOIC, or DGN Package, 8-pin HVSSOP (Top View)**

**Table 4-2. Pin Functions: THS4032**

| PIN              |     | TYPE   | DESCRIPTION                                                                                                                                                                                                                                                                                                           |
|------------------|-----|--------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| NAME             | NO. |        |                                                                                                                                                                                                                                                                                                                       |
| 1IN–             | 2   | Input  | Channel 1 inverting input                                                                                                                                                                                                                                                                                             |
| 1IN+             | 3   | Input  | Channel 1 noninverting input                                                                                                                                                                                                                                                                                          |
| 1OUT             | 1   | Output | Channel 1 output                                                                                                                                                                                                                                                                                                      |
| 2IN–             | 6   | Input  | Channel 2 inverting input                                                                                                                                                                                                                                                                                             |
| 2IN+             | 5   | Input  | Channel 2 noninverting input                                                                                                                                                                                                                                                                                          |
| 2OUT             | 7   | Output | Channel 2 output                                                                                                                                                                                                                                                                                                      |
| V <sub>CC–</sub> | 4   | —      | Negative power supply                                                                                                                                                                                                                                                                                                 |
| V <sub>CC+</sub> | 8   | —      | Positive power supply                                                                                                                                                                                                                                                                                                 |
| Thermal Pad      | Pad | —      | Thermal pad. DGN (HVSSOP) package only. For the best thermal performance, connect this pad to a large copper plane. The thermal pad can be connected to any pin on the device, or any other potential on the board, as long as the voltage on the thermal pad remains between V <sub>CC+</sub> and V <sub>CC–</sub> . |

## 5 Specifications

### 5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

|                        |                                                              |                                                                                          | MIN | MAX          | UNIT |
|------------------------|--------------------------------------------------------------|------------------------------------------------------------------------------------------|-----|--------------|------|
| $V_{CC-}$ to $V_{CC+}$ | Supply voltage                                               |                                                                                          |     | 33           | V    |
| $V_I$                  | Input voltage                                                |                                                                                          |     | $\pm V_{CC}$ | V    |
| $I_O$                  | Output current <sup>(2)</sup>                                |                                                                                          |     | 240          | mA   |
| $V_{IO}$               | Differential input voltage                                   |                                                                                          |     | $\pm 1.5$    | V    |
| $I_{IN}$               | Continuous input current                                     |                                                                                          |     | 10           | mA   |
| $T_A$                  | Operating free-air temperature                               | C-suffix                                                                                 | 0   | 70           | °C   |
|                        |                                                              | I-suffix                                                                                 | –40 | 85           |      |
| $T_J$                  | Junction temperature                                         | Any condition                                                                            |     | 150          | °C   |
|                        |                                                              | Maximum junction temperature, continuous operation, long term reliability <sup>(3)</sup> |     | 130          |      |
|                        | Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds |                                                                                          |     | 300          | °C   |
| $T_{stg}$              | Storage temperature                                          |                                                                                          | –65 | 150          | °C   |

- (1) Operation outside the *Absolute Maximum Ratings* may cause permanent device damage. *Absolute Maximum Ratings* do not imply functional operation of the device at these or any other conditions beyond those listed under *Recommended Operating Conditions*. If used outside the *Recommended Operating Conditions* but within the *Absolute Maximum Ratings*, the device may not be fully functional, and this may affect device reliability, functionality, performance, and shorten the device lifetime.
- (2) When continuously operating at any output current, do not exceed the maximum junction temperature. Keep the output current less than the absolute maximum rating regardless of time interval.
- (3) The maximum junction temperature for continuous operation is limited by package constraints. Operation greater than this temperature can result in reduced reliability, lifetime of the device, or both.

### 5.2 ESD Ratings

|             |                         |                                                                             | VALUE      | UNIT |
|-------------|-------------------------|-----------------------------------------------------------------------------|------------|------|
| $V_{(ESD)}$ | Electrostatic discharge | Human body model (HBM), per ANSI/ESDA/JEDEC JS-001, all pins <sup>(1)</sup> | $\pm 1000$ | V    |
|             |                         | Charged device model (CDM), per JEDEC specification JS-002 <sup>(2)</sup>   | $\pm 1000$ |      |

- (1) JEDEC document JEP155 states that 500V HBM allows safe manufacturing with a standard ESD control process.
- (2) JEDEC document JEP157 states that 250V CDM allows safe manufacturing with a standard ESD control process.

### 5.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)

|          |                                |               | MIN       | NOM      | MAX      | UNIT |
|----------|--------------------------------|---------------|-----------|----------|----------|------|
| $V_{CC}$ | Supply voltage                 | Dual-supply   | $\pm 4.5$ | $\pm 15$ | $\pm 16$ | V    |
|          |                                | Single-supply | 9         | 30       | 32       |      |
| $T_A$    | Operating free-air temperature | C-suffix      | 0         | 25       | 70       | °C   |
|          |                                | I-suffix      | –40       | 25       | 85       |      |

## 5.4 Thermal Information - THS4031

| THERMAL METRIC <sup>(1)</sup> |                                              | THS4031  |              | UNIT |
|-------------------------------|----------------------------------------------|----------|--------------|------|
|                               |                                              | D (SOIC) | DGN (HVSSOP) |      |
|                               |                                              | 8 PINS   | 8 PINS       |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 124.5    | 60.7         | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 65.0     | 87.4         | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 72.2     | 33           | °C/W |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 13.6     | 7.9          | °C/W |
| $\Psi_{JB}$                   | Junction-to-board characterization parameter | 71.3     | 32.9         | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | N/A      | 17.2         | °C/W |

(1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

## 5.5 Thermal Information - THS4032

| THERMAL METRIC <sup>(1)</sup> |                                              | THS4032  |              | UNIT |
|-------------------------------|----------------------------------------------|----------|--------------|------|
|                               |                                              | D (SOIC) | DGN (HVSSOP) |      |
|                               |                                              | 8 PINS   | 8 PINS       |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 120.6    | 52.0         | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 62.7     | 75.2         | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 63.9     | 24.5         | °C/W |
| $\Psi_{JT}$                   | Junction-to-top characterization parameter   | 16.2     | 4.0          | °C/W |
| $\Psi_{JB}$                   | Junction-to-board characterization parameter | 62.2     | 24.5         | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | N/A      | 9.1          | °C/W |

(1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

## 5.6 Electrical Characteristics - $R_L = 150\Omega$

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , and  $R_L = 150\Omega$  (unless otherwise noted)

| PARAMETER                        |                                             | TEST CONDITIONS                                                              |                                  | MIN    | TYP   | MAX    | UNIT |
|----------------------------------|---------------------------------------------|------------------------------------------------------------------------------|----------------------------------|--------|-------|--------|------|
| DYNAMIC PERFORMANCE              |                                             |                                                                              |                                  |        |       |        |      |
| BW                               | Small-signal bandwidth (–3dB)               | Gain = –1V/V or 2V/V                                                         | V <sub>CC</sub> = ±15V           | 100    |       | MHz    |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V            | 90     |       |        |      |
|                                  | Bandwidth for 0.1dB flatness                | Gain = –1V/V or 2V/V                                                         | V <sub>CC</sub> = ±15V           | 9      |       | MHz    |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V            | 9      |       |        |      |
| SR                               | Slew rate <sup>(1)</sup>                    | Gain = –1V/V                                                                 | V <sub>CC</sub> = ±15V, 20V step | 100    |       | V/μs   |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V, 5V step   | 80     |       |        |      |
| t <sub>S</sub>                   | Settling time                               | To 0.1%, gain = –1V/V                                                        | V <sub>CC</sub> = ±15V, 5V step  | 70     |       | ns     |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V, 2.5V step | 55     |       |        |      |
|                                  |                                             | To 0.01%, gain = –1V/V                                                       | V <sub>CC</sub> = ±15V, 5V step  | 90     |       |        |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V, 2.5V step | 80     |       |        |      |
| NOISE AND DISTORTION PERFORMANCE |                                             |                                                                              |                                  |        |       |        |      |
| THD                              | Total harmonic distortion                   | Gain = 2V/V, V <sub>CC</sub> = ±5V or ±15V, f = 1MHz V <sub>O(pp)</sub> = 2V | THS4031                          | –81    |       | dBc    |      |
|                                  |                                             |                                                                              | THS4032                          | –72    |       |        |      |
| V <sub>n</sub>                   | Input voltage noise                         | V <sub>CC</sub> = ±5V or ±15V, f > 10kHz                                     |                                  | 1.2    |       | nV/√Hz |      |
| I <sub>n</sub>                   | Input current noise                         | V <sub>CC</sub> = ±5V or ±15V, f > 10kHz                                     |                                  | 2.3    |       | pA/√Hz |      |
|                                  | Differential gain error                     | Gain = 2V/V, 40 IRE modulation, NTSC and PAL, ±100 IRE ramp                  | V <sub>CC</sub> = ±15V           | 0.015% |       |        |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V            | 0.02%  |       |        |      |
|                                  | Differential phase error                    |                                                                              | V <sub>CC</sub> = ±15V           | 0.025  |       | °      |      |
|                                  |                                             |                                                                              | V <sub>CC</sub> = ±5V            | 0.03   |       |        |      |
|                                  | Channel-to-channel crosstalk (THS4032 only) | V <sub>CC</sub> = ±5V or ±15V, f = 1MHz                                      |                                  | –61    |       | dBc    |      |
| DC PERFORMANCE                   |                                             |                                                                              |                                  |        |       |        |      |
|                                  | Open-loop gain                              | V <sub>CC</sub> = ±15V, V <sub>O</sub> = ±10V                                | T <sub>A</sub> = 25°C            | 93     | 100   | dB     |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      | 92     |       |        |      |
|                                  |                                             | V <sub>CC</sub> = ±5V, V <sub>O</sub> = ±2.5V                                | T <sub>A</sub> = 25°C            | 90     | 98    |        |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      | 89     |       |        |      |
| V <sub>OS</sub>                  | Input offset voltage                        | V <sub>CC</sub> = ±5V or ±15V                                                | T <sub>A</sub> = 25°C            | 0.3    | 2     | mV     |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      |        | 3     |        |      |
|                                  | Offset voltage drift                        | V <sub>CC</sub> = ±5V or ±15V, T <sub>A</sub> = full range                   |                                  | 2      |       | μV/°C  |      |
| I <sub>B</sub>                   | Input bias current                          | V <sub>CC</sub> = ±5V or ±15V                                                | T <sub>A</sub> = 25°C            | 9      | 20    | μA     |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      |        | 33    |        |      |
| I <sub>OS</sub>                  | Input offset current                        | V <sub>CC</sub> = ±5V or ±15V                                                | T <sub>A</sub> = 25°C            | 30     | 250   | nA     |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      |        | 400   |        |      |
|                                  | Input offset current                        | V <sub>CC</sub> = ±5V or ±15V, T <sub>A</sub> = full range                   |                                  | 0.2    |       | nA/°C  |      |
| INPUT CHARACTERISTICS            |                                             |                                                                              |                                  |        |       |        |      |
| V <sub>ICR</sub>                 | Common-mode input voltage range             | V <sub>CC</sub> = ±15V                                                       |                                  | ±13.5  | ±14.3 | V      |      |
|                                  |                                             | V <sub>CC</sub> = ±5V                                                        |                                  | ±3.8   | ±4.3  |        |      |
| CMRR                             | Common-mode rejection ratio                 | V <sub>CC</sub> = ±15V, V <sub>ICR</sub> = ±12V                              | T <sub>A</sub> = 25°C            | 85     | 95    | dB     |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      | 80     |       |        |      |
|                                  |                                             | V <sub>CC</sub> = ±5V, V <sub>ICR</sub> = ±2.5V                              | T <sub>A</sub> = 25°C            | 90     | 100   |        |      |
|                                  |                                             |                                                                              | T <sub>A</sub> = full range      | 85     |       |        |      |
| R <sub>i</sub>                   | Input resistance                            |                                                                              |                                  | 2      |       | MΩ     |      |
| C <sub>i</sub>                   | Input capacitance                           |                                                                              |                                  | 1.5    |       | pF     |      |

## 5.6 Electrical Characteristics - $R_L = 150\Omega$ (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , and  $R_L = 150\Omega$  (unless otherwise noted)

| PARAMETER              |                                 | TEST CONDITIONS                               |                             | MIN | TYP   | MAX  | UNIT |
|------------------------|---------------------------------|-----------------------------------------------|-----------------------------|-----|-------|------|------|
| OUTPUT CHARACTERISTICS |                                 |                                               |                             |     |       |      |      |
| V <sub>O</sub>         | Output voltage swing            | V <sub>CC</sub> = ±15V, R <sub>L</sub> = 250Ω |                             | ±12 | ±12.9 |      | V    |
|                        |                                 | V <sub>CC</sub> = ±5V                         |                             | ±3  | ±3.5  |      |      |
| I <sub>O</sub>         | Output current <sup>(2)</sup>   | R <sub>L</sub> = 10Ω                          | V <sub>CC</sub> = ±15V      | 60  | 200   |      | mA   |
|                        |                                 |                                               | V <sub>CC</sub> = ±5V       | 50  | 160   |      |      |
| R <sub>O</sub>         | Output resistance               | Open loop                                     |                             | 5   |       |      | Ω    |
| POWER SUPPLY           |                                 |                                               |                             |     |       |      |      |
| I <sub>CC</sub>        | Supply current (each amplifier) | V <sub>CC</sub> = ±15V                        | T <sub>A</sub> = 25°C       | 7.5 |       | 10   | mA   |
|                        |                                 |                                               | T <sub>A</sub> = full range |     |       | 11   |      |
|                        |                                 | V <sub>CC</sub> = ±5V                         | T <sub>A</sub> = 25°C       | 6.5 |       | 9    |      |
|                        |                                 |                                               | T <sub>A</sub> = full range |     |       | 10.5 |      |
| PSRR                   | Power-supply rejection ratio    | V <sub>CC</sub> = ±5V or ±15V                 | T <sub>A</sub> = 25°C       | 85  | 95    |      | dB   |
|                        |                                 |                                               | T <sub>A</sub> = full range | 80  |       |      |      |

(1) Slew rate is measured from an output level range of 25% to 75%.

(2) Keep junction temperature less than the absolute maximum rating when the output is heavily loaded or shorted; see also [Section 5.1](#).

## 5.7 Electrical Characteristics - $R_L = 1\text{k}\Omega$

at  $T_A$  = full range,  $V_{CC} = \pm 15\text{V}$ , and  $R_L = 1\text{k}\Omega$  (unless otherwise noted)

| PARAMETER                        |                                     | TEST CONDITIONS                                                             |                                  | MIN                | TYP   | MAX | UNIT  |
|----------------------------------|-------------------------------------|-----------------------------------------------------------------------------|----------------------------------|--------------------|-------|-----|-------|
| DYNAMIC PERFORMANCE              |                                     |                                                                             |                                  |                    |       |     |       |
|                                  | Unity gain bandwidth                | V <sub>CC</sub> = ±15V, closed loop                                         |                                  | 100 <sup>(1)</sup> | 120   |     | MHz   |
| BW                               | Small-signal bandwidth (–3dB)       | Gain = –1V/V or 2V/V                                                        | V <sub>CC</sub> = ±15V           |                    | 100   |     | MHz   |
|                                  |                                     |                                                                             | V <sub>CC</sub> = ±5V            |                    | 90    |     |       |
|                                  | Bandwidth for 0.1dB flatness        | Gain = –1V/V or 2V/V                                                        | V <sub>CC</sub> = ±15V           |                    | 9     |     | MHz   |
|                                  |                                     |                                                                             | V <sub>CC</sub> = ±5V            |                    | 9     |     |       |
|                                  | Full power bandwidth <sup>(2)</sup> | V <sub>CC</sub> = ±15V, V <sub>O(pp)</sub> = 20V                            |                                  |                    | 1.6   |     | MHz   |
|                                  |                                     | V <sub>CC</sub> = ±5V, V <sub>O(pp)</sub> = 5V                              |                                  |                    | 5.1   |     |       |
| SR                               | Slew rate                           |                                                                             |                                  | 80 <sup>(1)</sup>  | 100   |     | V/μs  |
| t <sub>s</sub>                   | Settling time                       | To 0.1%, gain = –1V/V                                                       | V <sub>CC</sub> = ±15V, 5V step  |                    | 70    |     | ns    |
|                                  |                                     |                                                                             | V <sub>CC</sub> = ±5V, 2.5V step |                    | 55    |     |       |
|                                  |                                     | To 0.01%, gain = –1V/V                                                      | V <sub>CC</sub> = ±15V, 5V step  |                    | 90    |     |       |
|                                  |                                     |                                                                             | V <sub>CC</sub> = ±5V, 2.5V step |                    | 80    |     |       |
| NOISE AND DISTORTION PERFORMANCE |                                     |                                                                             |                                  |                    |       |     |       |
| THD                              | Total harmonic distortion           | Gain =2V/V, V <sub>CC</sub> = ±5V or ±15V, f = 1MHz V <sub>O(pp)</sub> = 2V | THS4031                          |                    | –96   |     | dBc   |
|                                  |                                     |                                                                             | THS4032                          |                    | –90   |     |       |
| DC PERFORMANCE                   |                                     |                                                                             |                                  |                    |       |     |       |
|                                  | Open-loop gain                      | V <sub>CC</sub> = ±15V, V <sub>O</sub> = ±10V                               | T <sub>A</sub> = 25°C            | 93                 | 100   |     | dB    |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      | 92                 |       |     |       |
|                                  |                                     | V <sub>CC</sub> = ±5V, V <sub>O</sub> = ±2.5V                               | T <sub>A</sub> = 25°C            | 92                 | 98    |     |       |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      | 91                 |       |     |       |
| V <sub>OS</sub>                  | Input offset voltage                | V <sub>CC</sub> = ±5V or ±15V                                               | T <sub>A</sub> = 25°C            |                    | 0.3   | 2   | mV    |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      |                    |       | 3   |       |
|                                  | Offset voltage drift                | V <sub>CC</sub> = ±5V or ±15V, T <sub>A</sub> = full range                  |                                  |                    | 2     |     | μV/°C |
| I <sub>IB</sub>                  | Input bias current                  | V <sub>CC</sub> = ±5V or ±15V                                               | T <sub>A</sub> = 25°C            |                    | 9     | 20  | μA    |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      |                    |       | 33  |       |
| I <sub>OS</sub>                  | Input offset current                | V <sub>CC</sub> = ±5V or ±15V                                               | T <sub>A</sub> = 25°C            |                    | 30    | 250 | nA    |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      |                    |       | 400 |       |
|                                  | Input offset current drift          | V <sub>CC</sub> = ±5V or ±15V, T <sub>A</sub> = full range                  |                                  |                    | 0.2   |     | nA/°C |
| INPUT CHARACTERISTICS            |                                     |                                                                             |                                  |                    |       |     |       |
| V <sub>ICR</sub>                 | Common-mode input voltage range     | V <sub>CC</sub> = ±15V                                                      |                                  | ±13.5              | ±14.3 |     | V     |
|                                  |                                     | V <sub>CC</sub> = ±5V                                                       |                                  | ±3.8               | ±4.3  |     |       |
| CMRR                             | Common-mode rejection ratio         | V <sub>CC</sub> = ±15V, V <sub>ICR</sub> = ±12V                             | T <sub>A</sub> = 25°C            | 85                 | 95    |     | dB    |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      | 80                 |       |     |       |
|                                  |                                     | V <sub>CC</sub> = ±5V, V <sub>ICR</sub> = ±2.5V                             | T <sub>A</sub> = 25°C            | 90                 | 100   |     |       |
|                                  |                                     |                                                                             | T <sub>A</sub> = full range      | 85                 |       |     |       |
| R <sub>i</sub>                   | Input resistance                    |                                                                             |                                  |                    | 2     |     | MΩ    |
| C <sub>i</sub>                   | Input capacitance                   |                                                                             |                                  |                    | 1.5   |     | pF    |

## 5.7 Electrical Characteristics - $R_L = 1k\Omega$ (continued)

at  $T_A = \text{full range}$ ,  $V_{CC} = \pm 15V$ , and  $R_L = 1k\Omega$  (unless otherwise noted)

| PARAMETER              |                                 | TEST CONDITIONS               |                             | MIN  | TYP   | MAX | UNIT |
|------------------------|---------------------------------|-------------------------------|-----------------------------|------|-------|-----|------|
| OUTPUT CHARACTERISTICS |                                 |                               |                             |      |       |     |      |
| V <sub>O</sub>         | Output voltage swing            | V <sub>CC</sub> = ±15V        |                             | ±13  | ±13.6 |     | V    |
|                        |                                 | V <sub>CC</sub> = ±5V         |                             | ±3.4 | ±3.8  |     |      |
| R <sub>O</sub>         | Output resistance               | Open loop                     |                             | 5    |       |     | Ω    |
| POWER SUPPLY           |                                 |                               |                             |      |       |     |      |
| I <sub>CC</sub>        | Supply current (each amplifier) | V <sub>CC</sub> = ±15V        | T <sub>A</sub> = 25°C       | 7.5  |       | 10  | mA   |
|                        |                                 |                               | T <sub>A</sub> = full range | 11   |       |     |      |
|                        |                                 | V <sub>CC</sub> = ±5V         | T <sub>A</sub> = 25°C       | 6.5  |       | 9   |      |
|                        |                                 |                               | T <sub>A</sub> = full range | 10   |       |     |      |
| PSRR                   | Power-supply rejection ratio    | V <sub>CC</sub> = ±5V or ±15V | T <sub>A</sub> = 25°C       | 85   | 95    |     | dB   |
|                        |                                 |                               | T <sub>A</sub> = full range | 80   |       |     |      |

- (1) This minimum value is not tested.
- (2) Full power bandwidth = slew rate /  $[\pi V_{O(pp)}]$ .

## 5.8 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)

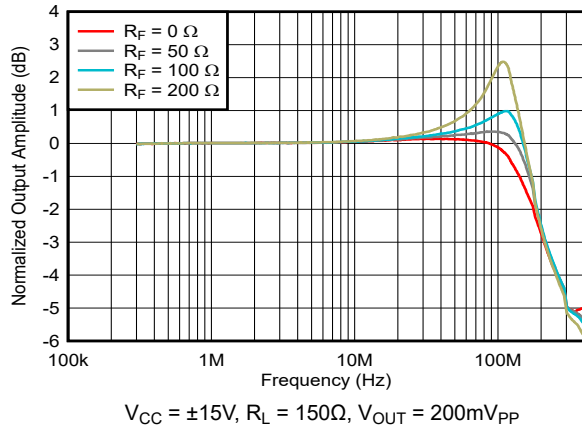


Figure 5-1. Frequency Response vs Feedback Resistance

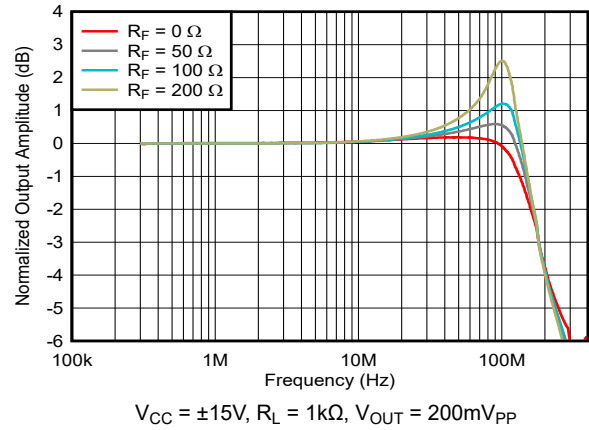


Figure 5-2. Frequency Response vs Feedback Resistance

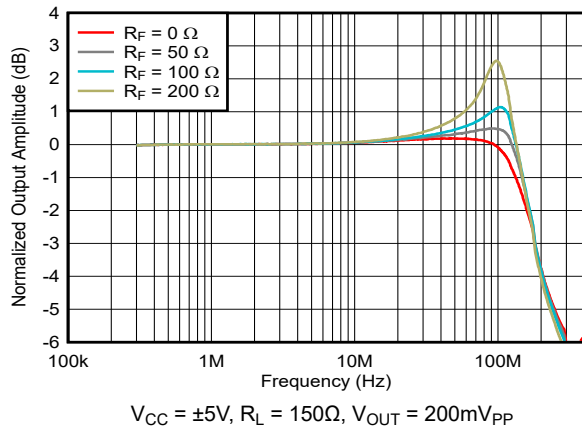


Figure 5-3. Frequency Response vs Feedback Resistance

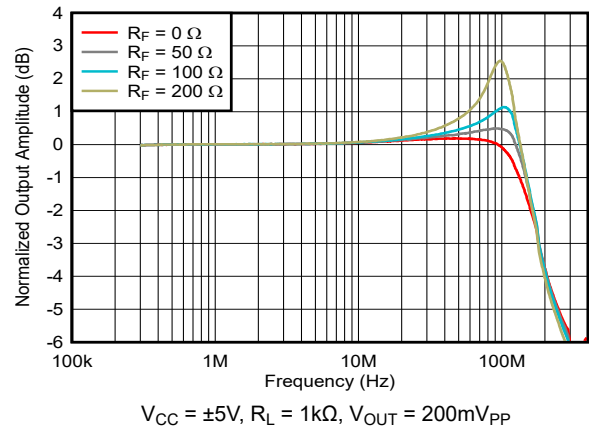


Figure 5-4. Frequency Response vs Feedback Resistance

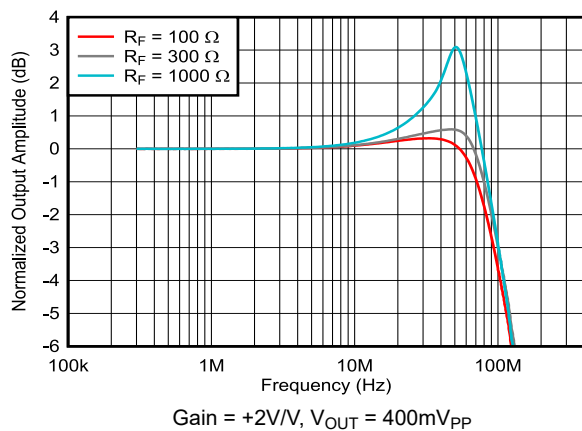


Figure 5-5. Frequency Response vs Feedback Resistance

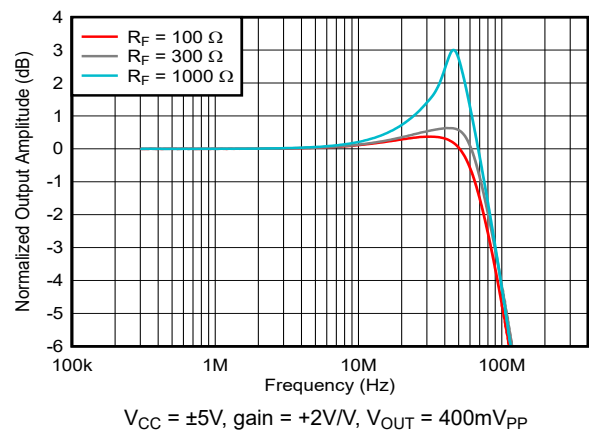
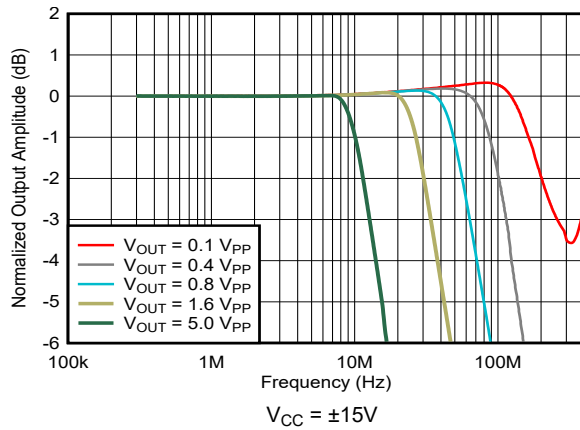


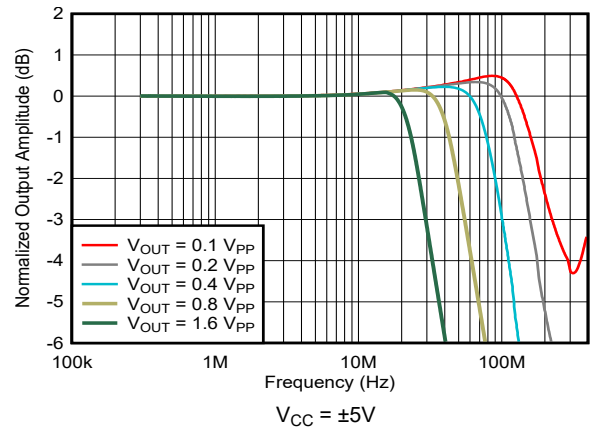
Figure 5-6. Frequency Response vs Feedback Resistance

## 5.8 Typical Characteristics (continued)

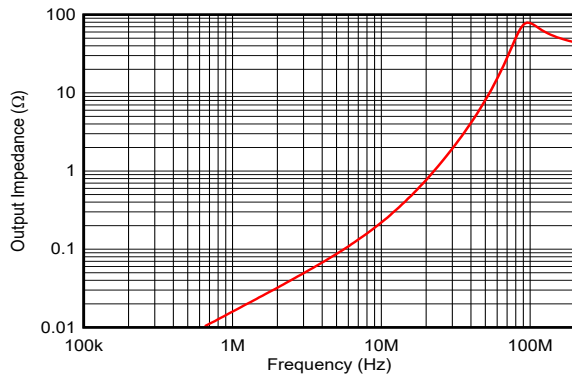
at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)



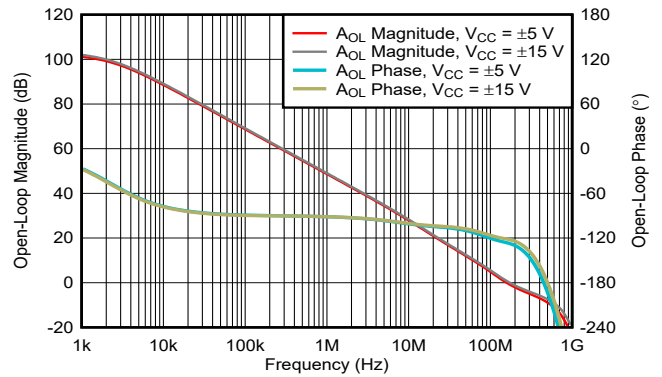
**Figure 5-7. Large-Signal Frequency Response**



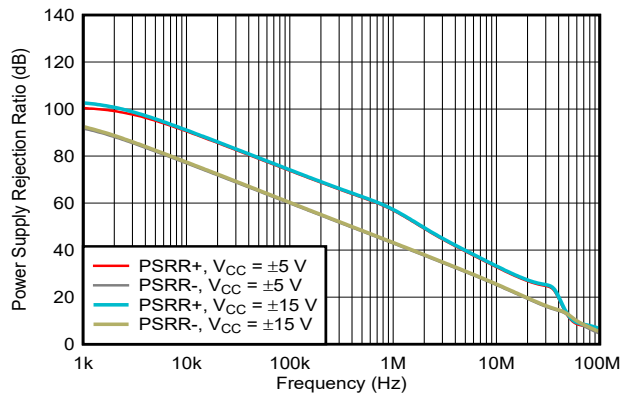
**Figure 5-8. Large-Signal Frequency Response**



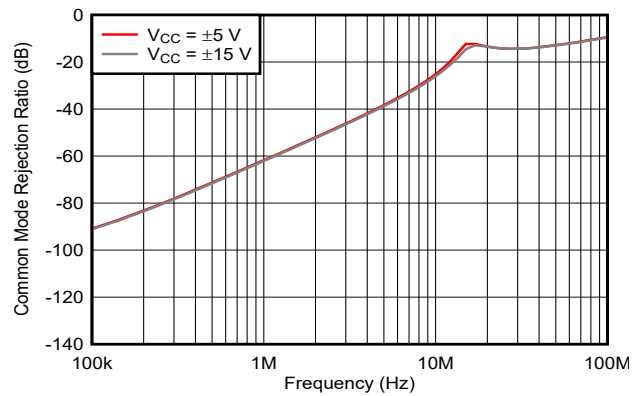
**Figure 5-9. Closed-Loop Output Impedance**



**Figure 5-10. Open-Loop Gain and Phase Response**



**Figure 5-11. Power-Supply Rejection Ratio vs Frequency**



**Figure 5-12. Common-Mode Rejection Ratio vs Frequency**

## 5.8 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)

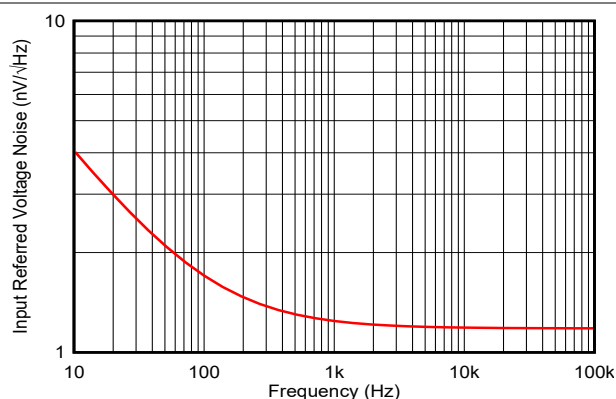


Figure 5-13. Input-Referred Voltage Noise vs Frequency

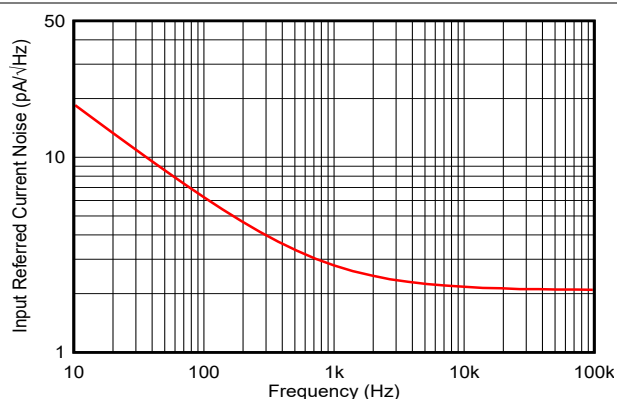
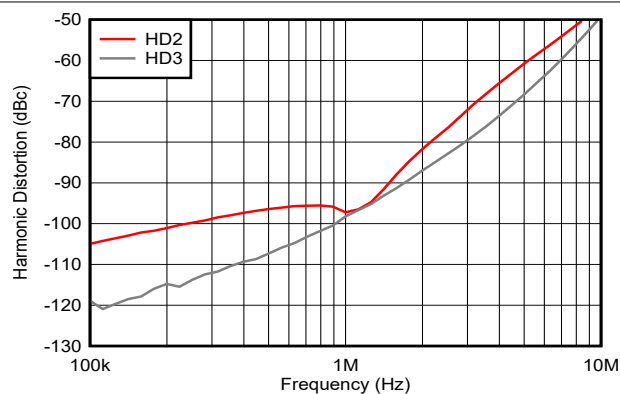
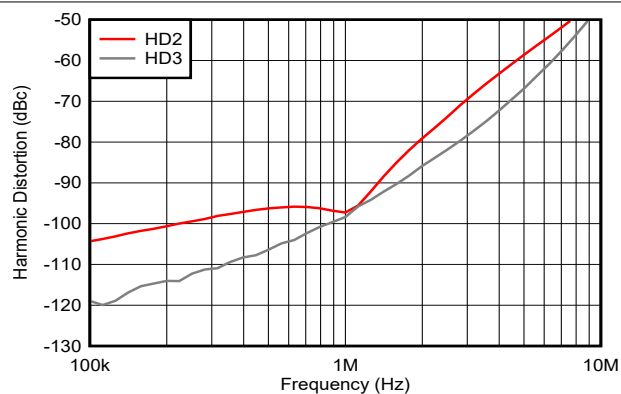


Figure 5-14. Input-Referred Current Noise vs Frequency



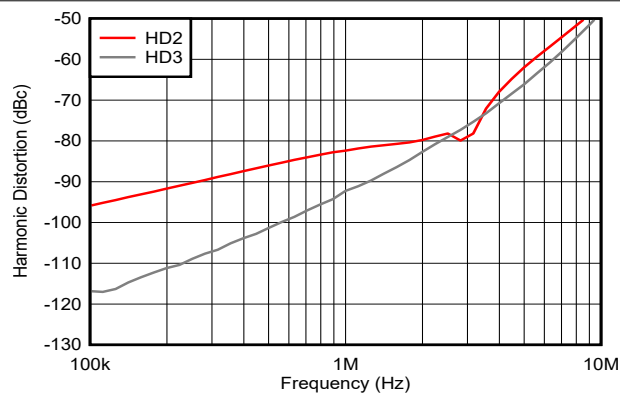
$V_{CC} = \pm 15\text{V}$ , gain =  $+2\text{V/V}$ ,  $R_L = 1\text{k}\Omega$ ,  $V_{OUT} = 2V_{PP}$

Figure 5-15. THS4031 Harmonic Distortion vs Frequency



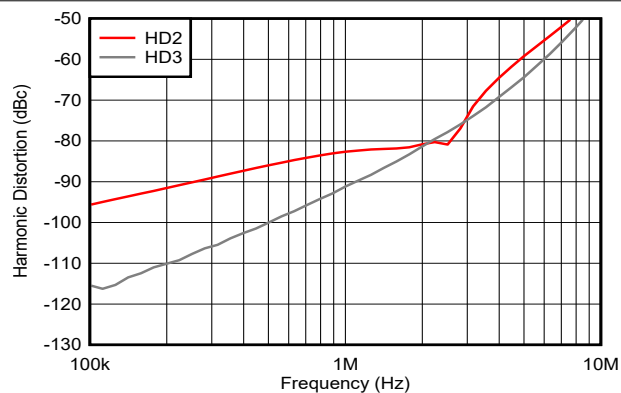
$V_{CC} = \pm 5\text{V}$ , gain =  $+2\text{V/V}$ ,  $R_L = 1\text{k}\Omega$ ,  $V_{OUT} = 2V_{PP}$

Figure 5-16. THS4031 Harmonic Distortion vs Frequency



$V_{CC} = \pm 15\text{V}$ , gain =  $+2\text{V/V}$ ,  $R_L = 150\Omega$ ,  $V_{OUT} = 2V_{PP}$

Figure 5-17. THS4031 Harmonic Distortion vs Frequency

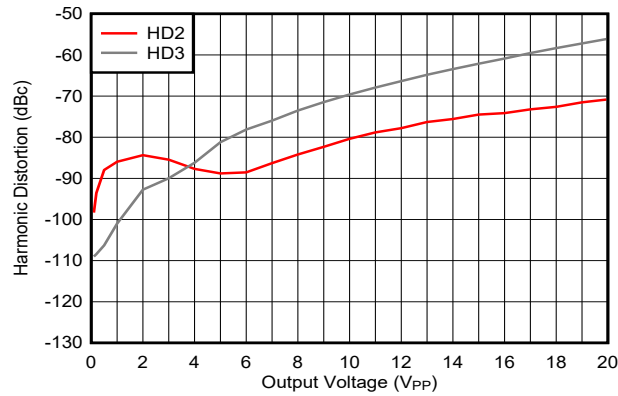


$V_{CC} = \pm 5\text{V}$ , gain =  $+2\text{V/V}$ ,  $R_L = 150\Omega$ ,  $V_{OUT} = 2V_{PP}$

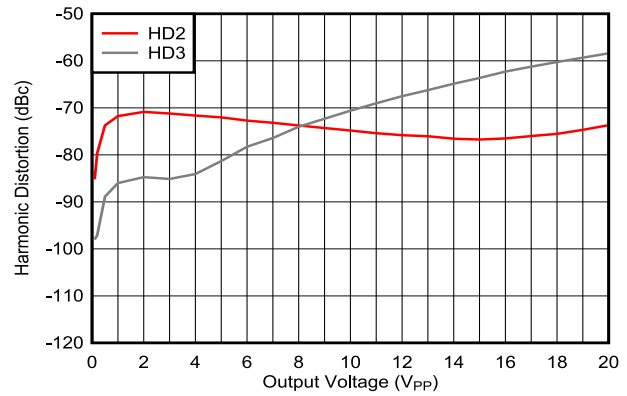
Figure 5-18. THS4031 Harmonic Distortion vs Frequency

## 5.8 Typical Characteristics (continued)

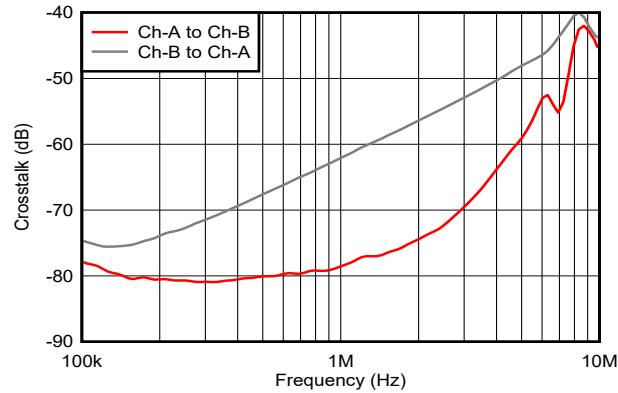
at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)



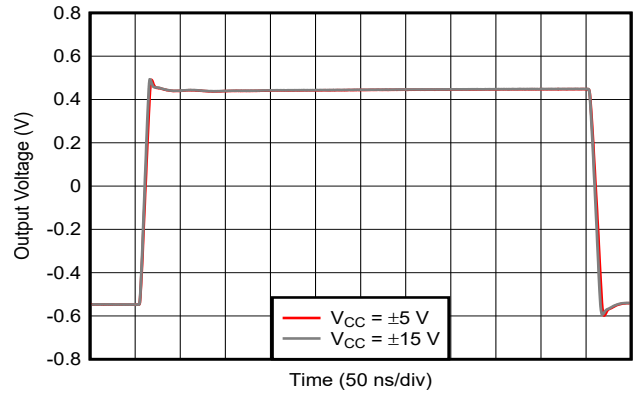
**Figure 5-19. Harmonic Distortion vs Peak-to-Peak Output Voltage**



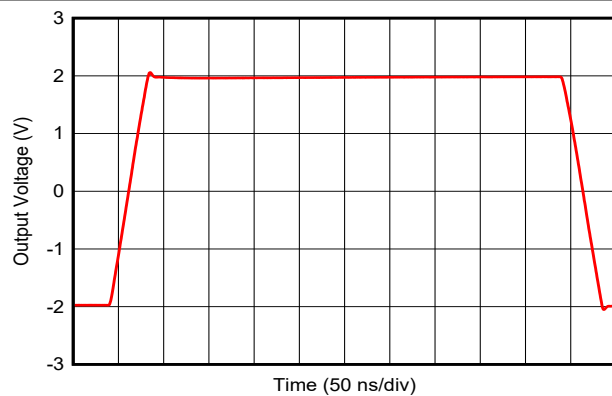
**Figure 5-20. Harmonic Distortion vs Peak-to-Peak Output Voltage**



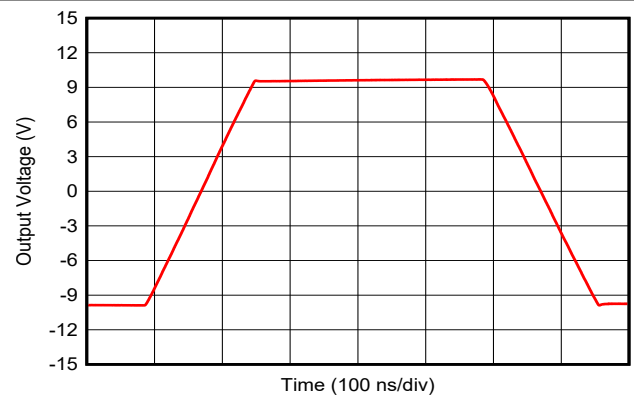
**Figure 5-21. THS4032 Crosstalk vs Frequency**



**Figure 5-22. 1V Step Response**



**Figure 5-23. 4V Step Response**



**Figure 5-24. 20V Step Response**

## 5.8 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)

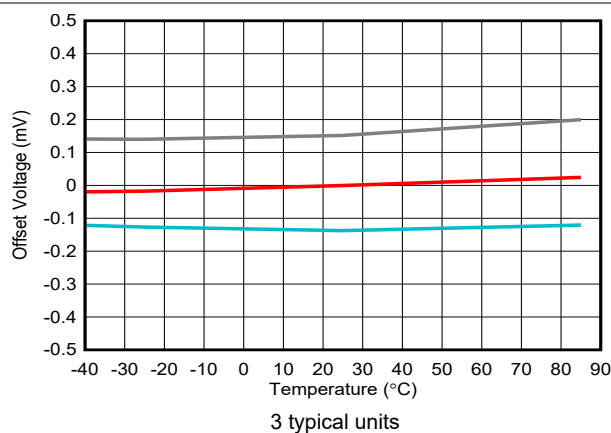


Figure 5-25. Input Offset Voltage vs Ambient Temperature

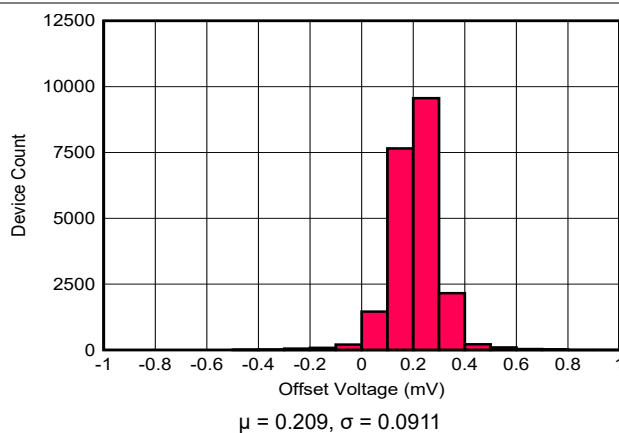


Figure 5-26. Voltage Offset Distribution

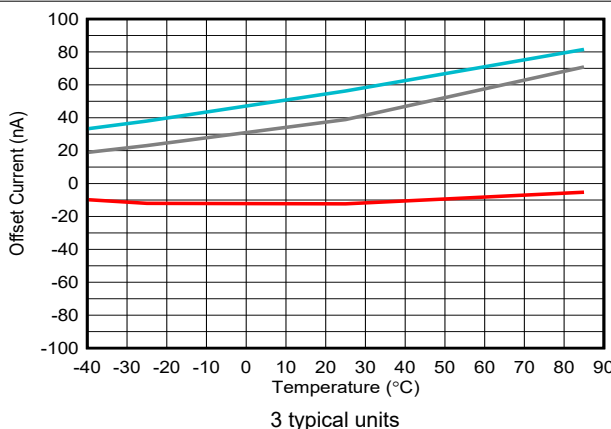


Figure 5-27. Input Offset Current vs Ambient Temperature

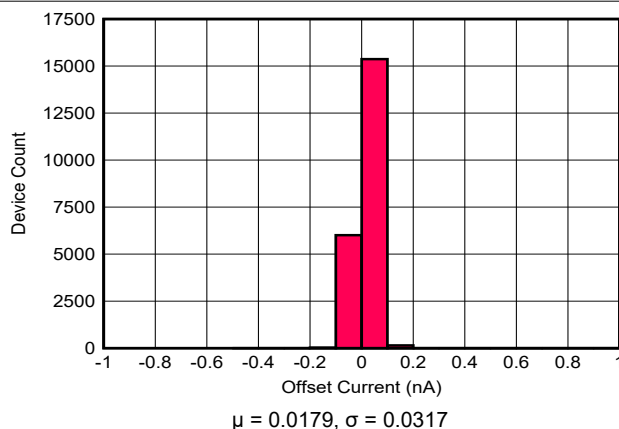


Figure 5-28. Input Offset Current vs Ambient Temperature

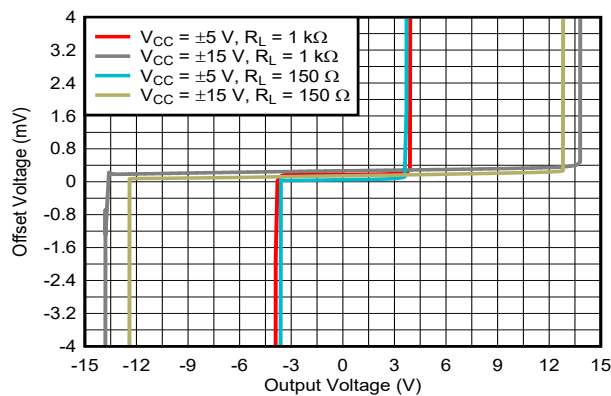


Figure 5-29. Offset Voltage vs Output Voltage

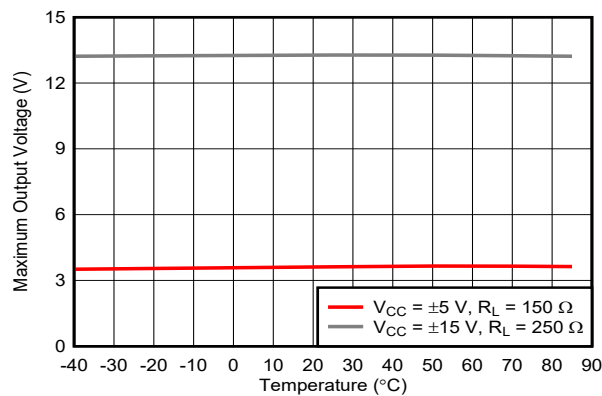


Figure 5-30. Maximum Output Voltage Swing vs Ambient Temperature

## 5.8 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{V}$ , gain =  $+1\text{V/V}$ ,  $R_L = 150\Omega$ , and  $R_F = 300\Omega$  (unless otherwise noted)

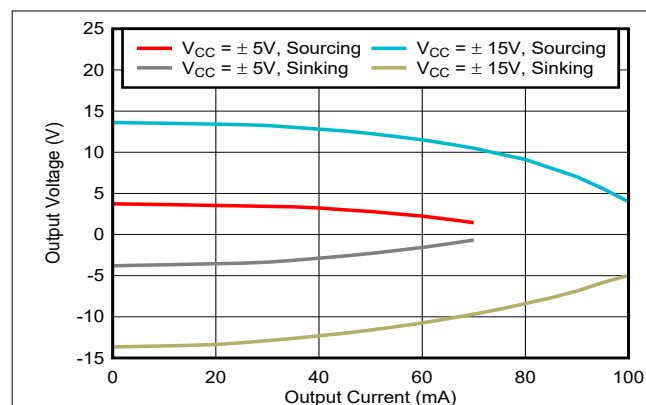


Figure 5-31. Output Swing vs Load Current

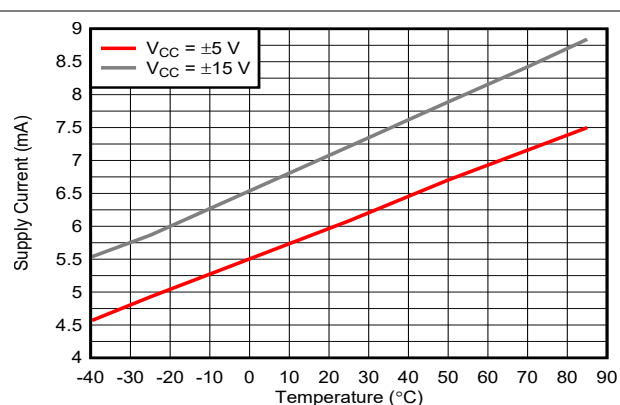


Figure 5-32. Supply Current vs Ambient Temperature

## 6 Detailed Description

### 6.1 Overview

The THS403x are high-speed operational amplifiers configured in a voltage-feedback architecture. These amplifiers are built using a 30V, complementary bipolar process with NPN and PNP transistors that possess an  $f_T$  of several GHz. This configuration results in exceptionally high-performance amplifiers with wide bandwidth, high slew rate, fast settling time, and low distortion.

### 6.2 Functional Block Diagrams

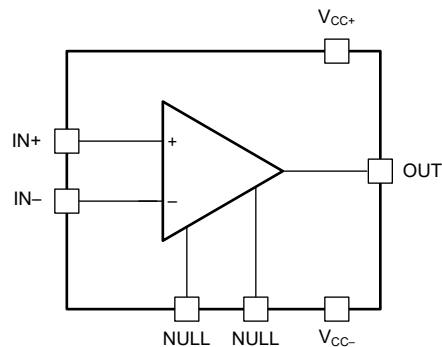


Figure 6-1. THS4031: Single Channel

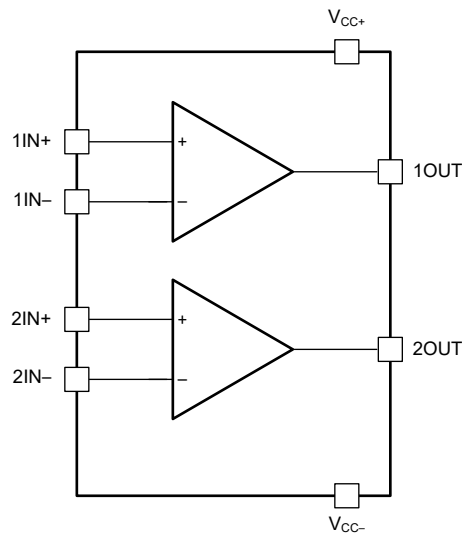
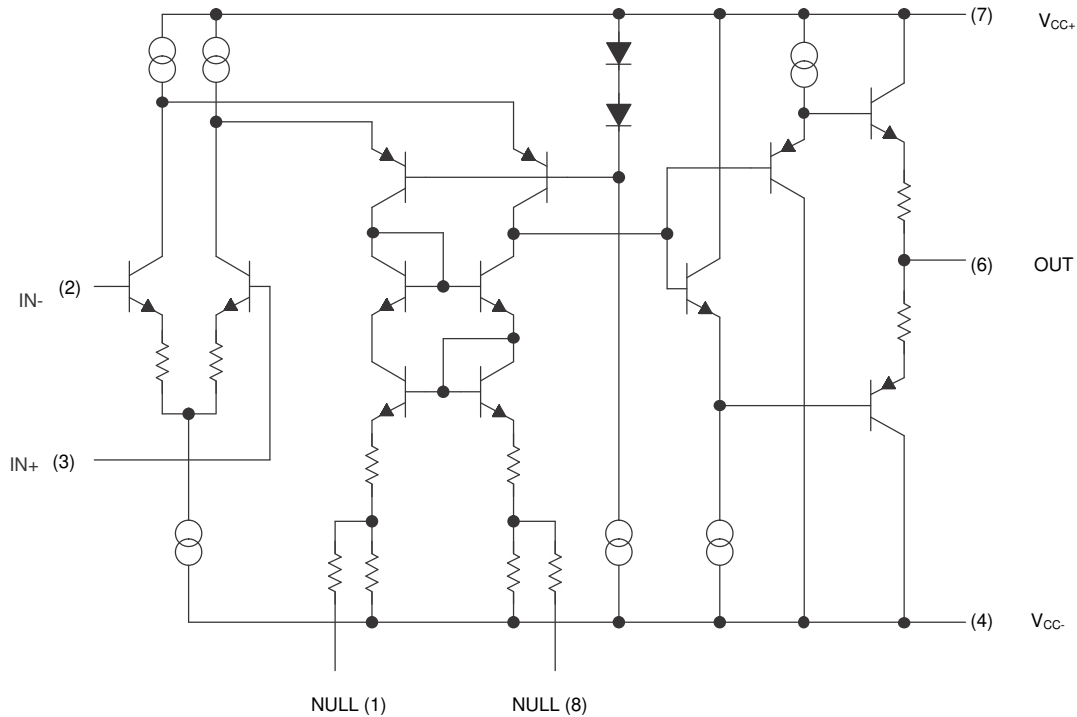


Figure 6-2. THS4032: Dual Channel

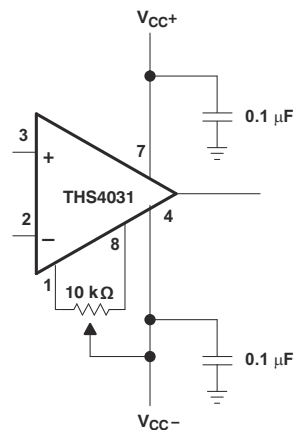


**Figure 6-3. THS4031 Simplified Schematic**

## 6.3 Feature Description

### 6.3.1 Offset Nulling

The THS403x have a very low input offset voltage for high-speed amplifiers. However, if additional correction is required, an offset nulling function has been provided on the THS4031. To adjust the input offset voltage, place a potentiometer between pin 1 and pin 8 of the device, and tie the wiper to the negative supply. [Figure 6-4](#) shows this feature.



**Figure 6-4. Offset Nulling Schematic**

## 6.4 Device Functional Modes

The THS403x family has a single functional mode and can be used with both single-supply or split power-supply configurations. The power-supply voltage must be greater than 9V ( $\pm 4.5$ V) and less than 32V ( $\pm 16$ V).

## 7 Application and Implementation

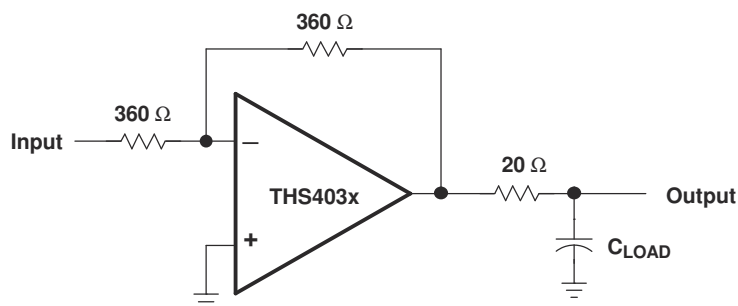
### Note

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation to confirm system functionality.

### 7.1 Application Information

#### 7.1.1 Driving a Capacitive Load

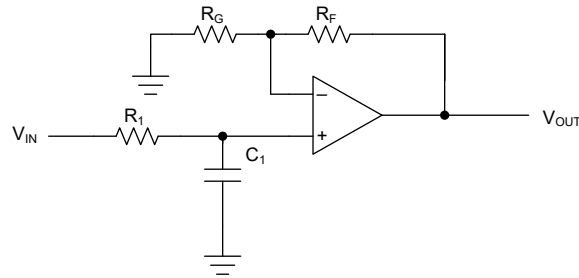
The THS403x devices are internally compensated to maximize bandwidth and slew-rate performance. Take additional precautions when driving capacitive loads with a high-performance amplifier to maintain stability. As a result of the internal compensation, significant capacitive loading directly on the output node decreases the device phase margin, and potentially leads to high-frequency ringing or oscillations. Therefore, for capacitive loads greater than 10pF, place an isolation resistor in series with the output of the amplifier. [Figure 7-1](#) shows this configuration. For most applications, a minimum resistance of 20Ω is recommended. In 75Ω transmission systems, setting the series resistor value to 75Ω is a beneficial choice because this value isolates any capacitance loading and provides source impedance matching.



**Figure 7-1. Driving a Capacitive Load**

### 7.1.2 Low-Pass Filter Configurations

When receiving low-level signals, limiting the bandwidth of the incoming signals into the system is often required. [Figure 7-2](#) shows that the simplest way to accomplish this limiting is to place an RC filter at the noninverting pin of the amplifier.



**Figure 7-2. Single-Pole Low-Pass Filter**

$$\frac{V_{OUT}}{V_{IN}} = \left(1 + \frac{R_F}{R_G}\right) \times \left(\frac{1}{1 + sR_1C_1}\right) \quad (1)$$

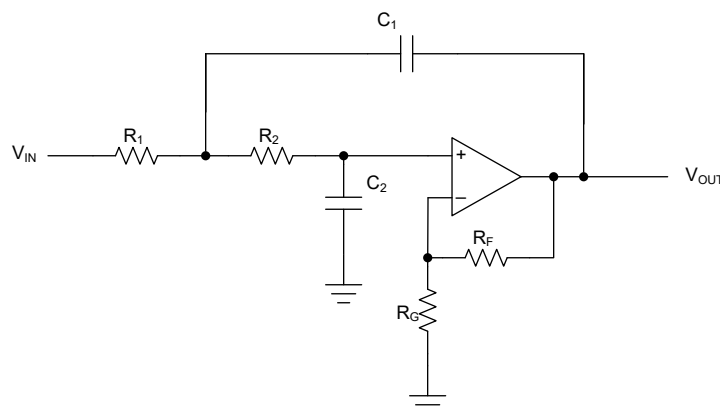
If more attenuation at higher frequencies is required, a multiple-pole filter is required. [Figure 7-3](#) shows a common implementation of a second-order filter called a Sallen-Key filter. When designing this type of filter, choose an amplifier whose bandwidth is approximately an order of magnitude larger than the desired filter bandwidth. See [Active Low-pass Filter Design](#) for more detailed active-filter design information.

Assuming  $R_1 = R_2 = R$  and  $C_1 = C_2 = C$ , use [Equation 2](#) to set the bandwidth of the filter.

$$f_{3dB} = \frac{1}{2\pi RC} \quad (2)$$

The Q-factor of a filter controls the amount of peaking of the small-signal frequency response and the settling time of the pulse response. Set Q to 0.707 to provide a Butterworth response with a maximally flat pass band. Use [Equation 3](#) to choose the ratio of  $R_F$  and  $R_G$  to obtain the desired Q value.

$$\frac{R_F}{R_G} = 2 - \frac{1}{Q} \quad (3)$$



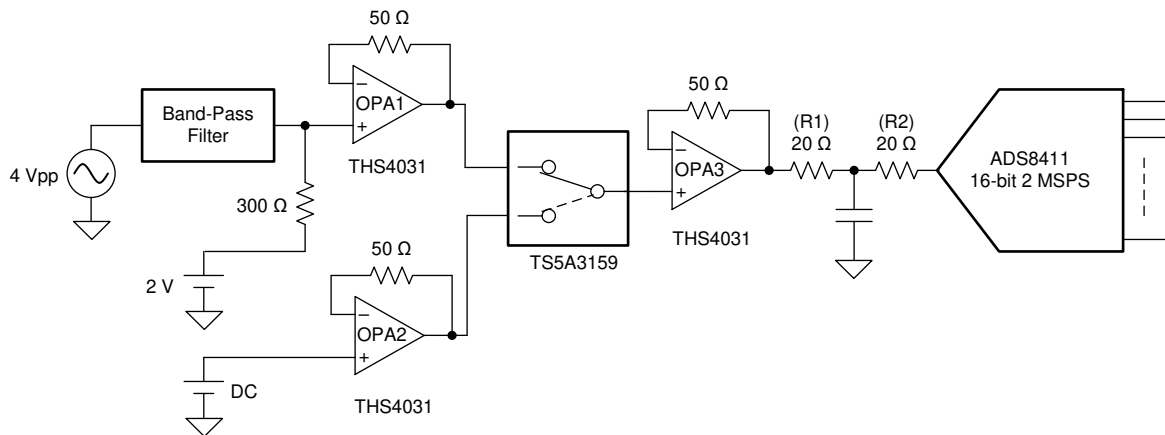
**Figure 7-3. Two-Pole Low-Pass Sallen-Key Filter**

## 7.2 Typical Application

This section demonstrates multiplexing several analog input signals to a high-performance driver amplifier which subsequently drives a single high-resolution, high-speed SAR analog-to-digital converter (ADC). This example uses the [ADS8411](#) and the [TS5A3159](#) or [TS5A3359](#) as the ADC and the multiplexer, respectively. This application uses the THS403x as the operational amplifier.

As detailed in [Figure 7-4](#), the example system consists of an ADC (ADS8411), a driving operational amplifier (THS4031), a multiplexer (TS5A3159), an ac source, a dc source, and two driving operational amplifiers.

The driving amplifiers OPA1 and OPA2 are shown as two THS4031 amplifiers. Alternatively, use a single THS4032 to save on cost and board space. The purpose of these op-amps is make the input sources present a low impedance to rest of the circuit. Additionally, to maintain signal fidelity, these operational amplifiers must have low noise and distortion. The third THS4031 labeled OPA3 in [Figure 7-4](#) is used to maintain switching speed and drive the ADC. The passive band-pass filter before the ADC reduces unwanted noise.



**Figure 7-4. Multiplexing Setup to Drive a High-Performance ADC**

### 7.2.1 Design Requirements

The objective is to design a multiplexed digitizer system with the dynamic performance shown in [Table 7-1](#).

**Table 7-1. Design Specifications**

| DEVICE SPEED (MSPS) | INPUT FREQUENCY (kHz) | SNR (dB) | THD (dB) | CROSSTALK (dB) |
|---------------------|-----------------------|----------|----------|----------------|
| 2                   | 20                    | > 84     | < -90    | < -110         |
| 2                   | 100                   | > 84     | < -90    | < -96          |

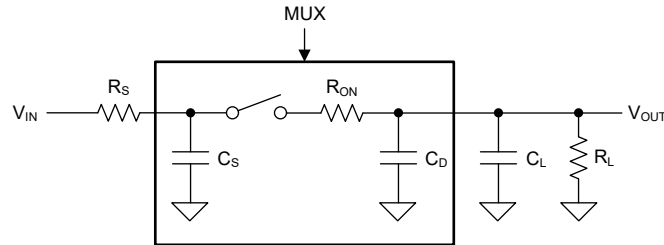
### 7.2.2 Detailed Design Procedure

The ADS8411 is a 16-bit, 2MSPS analog-to-digital converter (ADC) with a 4V reference. The ADS8411 has a unipolar single-ended input and includes a 16-bit capacitor-based SAR ADC, with inherent sample and hold. The output is a 16-bit parallel interface.

The TS5A3159 is a single-pole, double-throw (SPDT) analog switch that is designed to operate from 1.65V to 5.5V. The TS5A3159 offers a low on-state resistance and an excellent on resistance matching with the break-before-make feature to prevent signal distortion during the transfer of a signal from one channel to another. Additionally, the TS5A3159 provides excellent total harmonic distortion (THD) performance and consumes low power. The TS5A3359 is a single-pole, triple-throw (SP3T) version of the same switch.

### 7.2.2.1 Multiplexer Selection

Figure 7-5 shows an equivalent circuit diagram of one of the channels of a multiplexer.  $C_S$  is the input capacitance of the channel;  $C_D$  is the output capacitance of the channel.  $R_{ON}$  is the resistance of the channel when the channel is turned ON.  $C_L$  and  $R_L$  are the load capacitance and resistance, respectively.  $V_{IN}$  is the input voltage of the source.  $R_S$  is the resistance of the source.  $V_{OUT}$  is the output voltage of the multiplexer.



**Figure 7-5. Multiplexer Equivalent Circuit**

Settling time is improved when the values of  $R_S$ ,  $R_{ON}$ ,  $C_S$ ,  $C_D$ , and  $C_L$  are small, and the value of  $R_L$  is large.

For TS5A3159:

- $R_{ON} = 1\Omega$
- $C_S = C_D = 84\text{pF}$

Typical values for the extrinsic parameters are

- $R_S = 50\Omega$
- $C_L = 5\text{pF}$
- $R_L = 10\text{k}\Omega$
- $T_{RC}$  (time constant) = 8.65ns

For a 16-bit system, at least 18-bit settling is desired to minimize distortion from settling artifacts. For an 18-bit settling, the circuit response time required is  $(18 \times \ln 2) \times T_{RC} = 108\text{ns}$ , which is less than 2MSPS sampling time of 500ns. If the settling time is more than the conversion time of the ADC, the output of the multiplexer does not settle to the required accuracy resulting in distortion.

One more important parameter to consider when selecting a multiplexer is the on-state resistance variation with voltage. This variation also affects distortion because  $R_{ON}$  and  $R_L$  act like a resistor divider circuit. Any variation of  $R_{ON}$  with voltage affects the output voltage.

### 7.2.2.2 Signal Source

The input signal source must be a low-noise, low-distortion source with low source resistance. As discussed in the earlier section, the source resistance also must be small to avoid impacting settling time. If the source is not a low-noise and low-distortion source, a passive band-pass filter can be added to improve the signal quality as shown in Figure 7-4.

### 7.2.2.3 Driving Amplifier

The driving operational amplifier (OPA3 in Figure 7-4) in this application must have good slew rate, bandwidth, low noise, and distortion. The input of the operational amplifier can result in a maximum step of 4V because of MUX switching. As a result, even if the signal bandwidth is low, the driving amplifier must settle from a 4V step within one ADC sampling frame to avoid signal distortion. In this example, the settling requirement due to the ADC selection is 500ns. The THS4031 is a good choice in this application due to the high slew rate and low distortion of this operational amplifier.

### 7.2.2.3.1 Driving Amplifier Bandwidth Restriction

The restriction of excess bandwidth by use of a passive RC filter before the ADC results in better SNR and THD. However, restricting the bandwidth too much results in an excessive operational amplifier settling time. If the amplifier output does not settle quick enough, some residual charge of the previous channel remains in the next sampling interval and appears as crosstalk. One approach to solve this settling issue is to reduce the throughput of the ADC. However, often the high sample rate ADC was chosen to the need to acquire higher frequency signals limiting the freedom to reduce the ADC throughput. Due to these tradeoffs, the choice of the filter capacitor becomes critical. Figure 7-6 and Figure 7-7 show SNR and crosstalk as a function of the filter capacitor.

Figure 7-8 shows input settling behavior with three different filter capacitor values. The value of the capacitor changes to filter bandwidth. As the filter bandwidth increases, the settling time improves as shown in Equation 4.

$$\text{Filter Bandwidth} \cong \frac{1}{2\pi R_1 C_1} \quad (4)$$

### 7.2.3 Application Curves

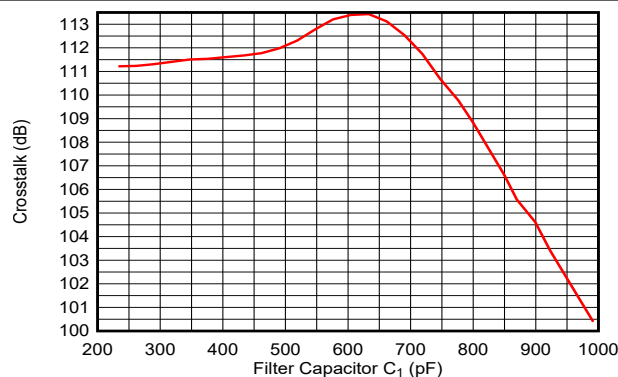


Figure 7-6. SNR vs Filter Capacitor

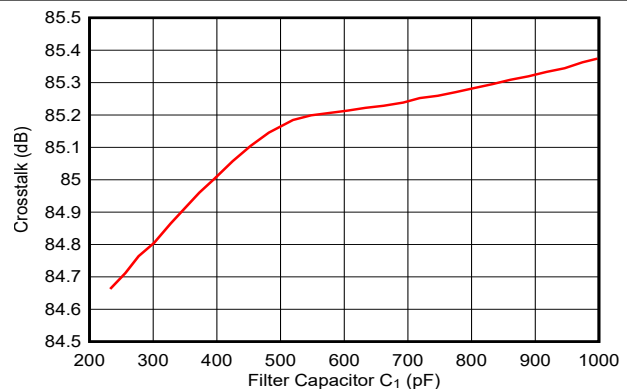


Figure 7-7. Crosstalk vs Filter Capacitor

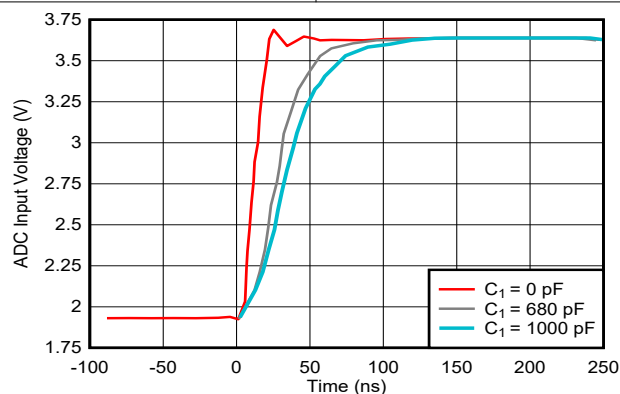


Figure 7-8. Input to ADC for Various Values of Filter Capacitors

## 7.3 Power Supply Recommendations

The THS403x family operates off a single supply or with dual supplies. Choose supplies that provide for the required headroom to supply rails as specified by the common-mode input range (CMIR). Operating from a single supply has numerous advantages. With the negative supply at ground, the dc errors due to the  $-PSRR$  term are minimized. Decouple supplies with low inductance capacitors to ground as close to the amplifier as possible. When operating on a board with high-speed digital signals, provide isolation between digital signal noise and the analog input pins. When using a ground plane, remove the ground plane close to input sensitive pins to reduce stray parasitics that adversely impact device performance. For split-supply operation, an optional supply decoupling capacitor across the two power supplies improves second harmonic distortion performance.

## 7.4 Layout

### 7.4.1 Layout Guidelines

To achieve the levels of high-frequency performance of the THS403x, follow proper printed-circuit board (PCB), high-frequency design techniques. The following is a general set of guidelines. In addition, a THS403x evaluation board is available to use as a guide for layout or for evaluating the device performance.

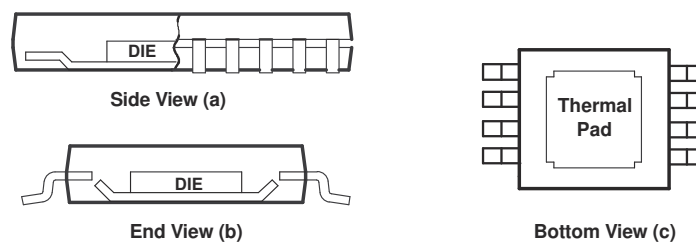
- **Ground planes**—make sure that the ground plane used on the board provides all components with a low-inductive ground connection. However, in the areas of the amplifier inputs and output, the ground plane can be removed to minimize stray capacitance.
- **Proper power-supply decoupling**—use a 6.8 $\mu$ F tantalum capacitor in parallel with a 0.1 $\mu$ F ceramic capacitor on each supply pin. Sharing the tantalum capacitor among several amplifiers is possible depending on the application, but always use a 0.1 $\mu$ F ceramic capacitor on the supply pin of every amplifier. In addition, place the 0.1 $\mu$ F capacitor as close as possible to the supply pin. As this distance increases, the inductance in the connecting trace makes the capacitor less effective. Strive for distances of less than 0.1 inch (2.54mm) between the device power pins and the ceramic capacitors.
- **Short trace runs or compact part placements**—optimum high-frequency performance is achieved when stray series inductance is minimized. To minimize stray inductance, make the circuit layout as compact as possible, thereby minimizing the length of all trace runs. Pay particular attention to the inputs of the amplifier, keeping the trace lengths as short as possible. This layout helps to minimize stray capacitance at the input of the amplifier.
- **Sockets**—TI does not recommend sockets for high-speed operational amplifiers. The additional lead inductance in the socket pins often leads to stability problems. Surface-mount packages soldered directly to the printed-circuit board is the best implementation.
- **Short trace runs and compact part placements**—Improved high-frequency performance is achieved when stray series inductance is minimized. To reduce stray series inductance, the circuit layout must be made as compact as possible, thereby minimizing the length of all trace runs. Particular attention must be paid to the inverting input of the amplifier. The length must be kept as short as possible to minimize stray capacitance at the input of the amplifier.

#### 7.4.1.1 General PowerPAD™ Integrated Circuit Package Design Considerations

The THS403x are available in a thermally-enhanced DGN package, which is a member of the PowerPAD™ integrated circuit package family. This package is constructed using a downset lead frame upon which the die is mounted [see [Figure 7-9\(a\)](#) and [Figure 7-9\(b\)](#)]. This arrangement results in the lead frame exposed as a thermal pad on the underside of the package [see [Figure 7-9\(c\)](#)]. Because this thermal pad has direct thermal contact with the die, excellent thermal performance can be achieved by providing a good thermal path away from the thermal pad.

The PowerPAD integrated circuit package allows for both assembly and thermal management in one manufacturing operation. During the surface-mount solder operation (when the leads are soldered), the thermal pad can be soldered to a copper area under the package. By using thermal paths within this copper area, heat is conducted away from the package into a ground plane or other heat-dissipating device.

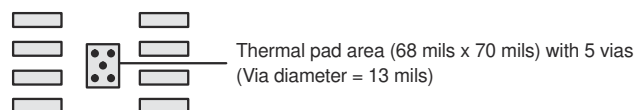
The PowerPAD integrated circuit package represents a breakthrough in combining the small area and ease of assembly of surface mount with the more-recent, awkward mechanical methods of sinking heat.



Note: The thermal pad is electrically isolated from all pins in the package.

**Figure 7-9. Views of Thermally-Enhanced DGN Package**

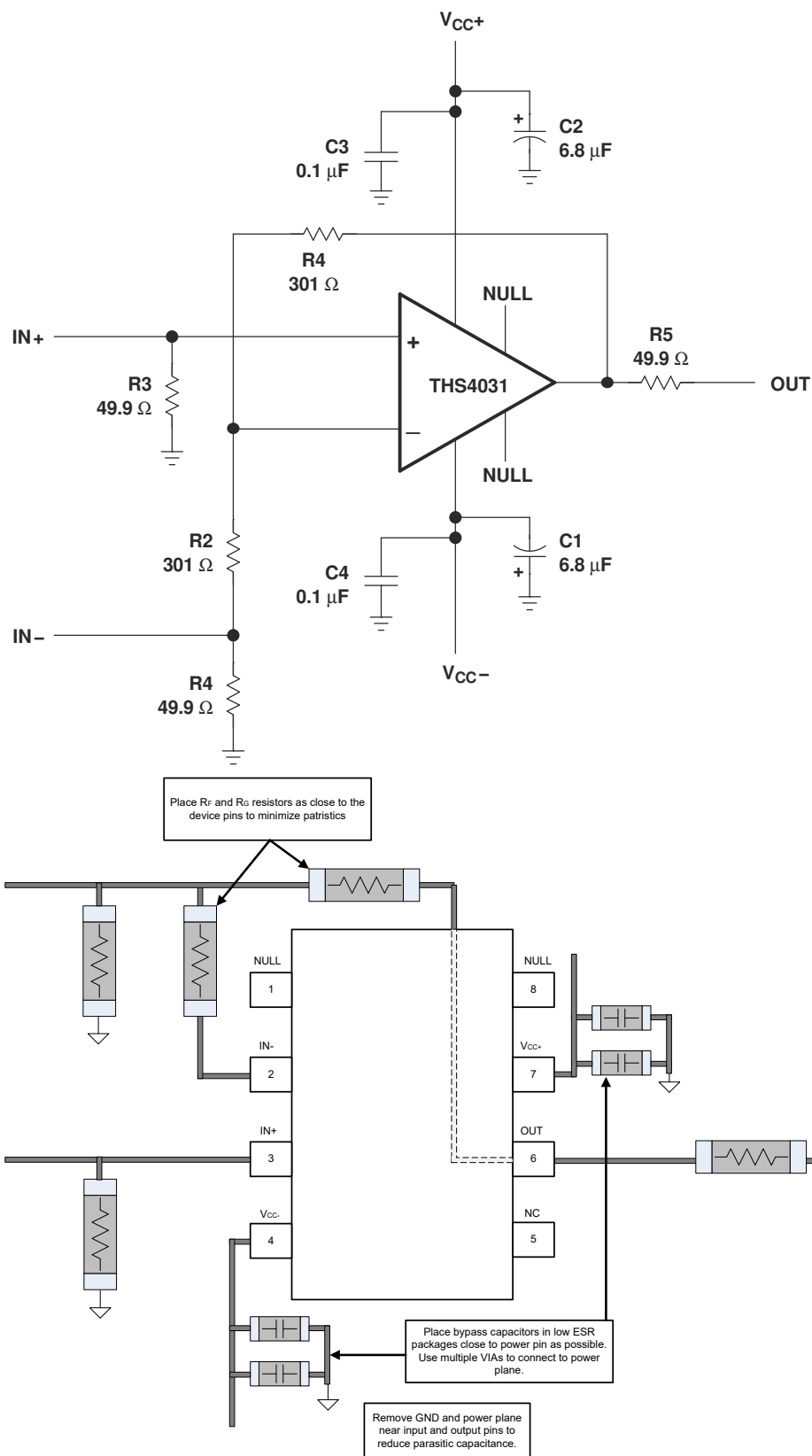
Although there are many ways to properly dissipate heat from this device, the following steps show the recommended approach.



**Figure 7-10. PowerPAD™ PCB Etch and Via Pattern**

1. Prepare the PCB with a top-side etch pattern as shown in [Figure 7-10](#). There must be etch for the leads as well as etch for the thermal pad.
2. Place five holes in the area of the thermal pad. These holes must be 13 mils (0.3302mm) in diameter. The reason to keep the holes small is to discourage solder wicking through the holes during reflow.
3. Additional vias can be placed anywhere along the thermal plane outside of the thermal pad area. This action helps dissipate the heat generated by the THS403x device. The additional vias can be of any diameter because wicking is not a concern outside of the thermal pad area.
4. Connect all holes to the internal ground plane.
5. When connecting these holes to the ground plane, *do not* use the typical web or spoke via connection methodology. Web connections have a high thermal-resistance connection that is useful for slowing the heat transfer during soldering operations. This makes the soldering of vias that have plane connections easier. In this application, however, low thermal resistance is desired for the most efficient heat transfer. Therefore, the holes under the THS403x package must connect to the internal ground plane with a complete connection around the entire circumference of the plated-through hole.
6. The top-side solder mask must leave the pins of the package and the thermal pad area with the five holes exposed. The bottom-side solder mask must cover the five holes of the thermal pad area, which prevents solder from pulling away from the thermal pad area during the reflow process.
7. Apply solder paste to the exposed thermal pad area and to all the device pins.
8. With these preparatory steps in place, the THS403x device is placed in position and run through the solder reflow operation as any standard surface-mount component.

## 7.4.2 Layout Example



**Figure 7-11. Layout Recommendations**

## 8 Device and Documentation Support

### 8.1 Documentation Support

#### 8.1.1 Related Documentation

For related documentation, see the following:

- Texas Instruments, [Noise Analysis for High-Speed Op Amps](#), application report
- Texas Instruments, [PowerPAD™ Thermally-Enhanced Package](#), application report
- Texas Instruments, [THS4031 High-Speed Op Amp](#), EVM user's guide
- Texas Instruments, [THS4032 Dual High-Speed Op Amp](#), EVM user's guide

### 8.2 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](http://ti.com). Click on *Notifications* to register and receive a weekly digest of any product information that has changed. For change details, review the revision history included in any revised document.

### 8.3 Support Resources

[TI E2E™ support forums](#) are an engineer's go-to source for fast, verified answers and design help — straight from the experts. Search existing answers or ask your own question to get the quick design help you need.

Linked content is provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

### 8.4 Trademarks

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All trademarks are the property of their respective owners.

### 8.5 Electrostatic Discharge Caution



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.

### 8.6 Glossary

[TI Glossary](#) This glossary lists and explains terms, acronyms, and definitions.

## 9 Revision History

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

| Changes from Revision K (May 2024) to Revision L (July 2024)                                                                                                                                                             | Page |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| • Added thermal pad information in Tables 4-1 and 4-2.....                                                                                                                                                               | 3    |
| • Updated <i>Thermal Information: THS4032</i> for the D and DGN packages.....                                                                                                                                            | 5    |
| • Changed title of <i>Electrical Characteristics - THS4031, R<sub>L</sub> = 150Ω</i> to <i>Electrical Characteristics - R<sub>L</sub> = 150Ω</i> ...                                                                     | 6    |
| • Moved Total harmonic distortion for THS4032 from <i>Electrical Characteristics - THS4032, R<sub>L</sub> = 150Ω</i> to <i>Electrical Characteristics - R<sub>L</sub> = 150Ω</i> .....                                   | 6    |
| • Moved Channel-to-channel crosstalk from <i>Electrical Characteristics - THS4032, R<sub>L</sub> = 150Ω</i> to <i>Electrical Characteristics - R<sub>L</sub> = 150Ω</i> .....                                            | 6    |
| • Deleted Supply voltage from <i>Electrical Characteristics</i> .....                                                                                                                                                    | 6    |
| • Changed title of <i>Electrical Characteristics - THS4031, R<sub>L</sub> = 1kΩ</i> to <i>Electrical Characteristics - R<sub>L</sub> = 1kΩ</i> .....                                                                     | 8    |
| • Changed Total harmonic distortion for THS4032 from -96 dBc to -90 dBc and moved from <i>Electrical Characteristics - THS4032, R<sub>L</sub> = 1kΩ</i> to <i>Electrical Characteristics - R<sub>L</sub> = 1kΩ</i> ..... | 8    |
| • Changed unit from μA to nA for Input offset current in <i>Electrical Characteristics - R<sub>L</sub> = 1kΩ</i> .....                                                                                                   | 8    |
| • Changed title of <i>Typical Characteristics - THS4031</i> section to <i>Typical Characteristics</i> .....                                                                                                              | 10   |

|                                                                                                                                                                                                                   |    |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| • Deleted <i>Typical Characteristics</i> - THS4032 section.....                                                                                                                                                   | 10 |
| • Changed title of Figure 5-15, Figure 5-16, Figure 5-17, and Figure 5-18 from <i>Harmonic Distortion vs Frequency</i> to <i>THS4031 Harmonic Distortion vs Frequency</i> in <i>Typical Characteristics</i> ..... | 10 |
| • Changed max voltage from 33V ( $\pm 16.5V$ ) to 32V ( $\pm 16V$ ) in <i>Device Functional Modes</i> .....                                                                                                       | 17 |

| <b>Changes from Revision J (February 2024) to Revision K (May 2024)</b>                                                                                               | <b>Page</b> |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| • Deleted Total harmonic distortion + noise and Intermodulation distortion specifications from <i>Electrical Characteristics</i> - THS4031, $R_L = 150\ \Omega$ ..... | 6           |
| • Deleted Total harmonic distortion + noise and Intermodulation distortion specifications from <i>Electrical Characteristics</i> - THS4031, $R_L = 1\ k\Omega$ .....  | 8           |
| • Changed gain from +2 V/V to +1 V/V in <i>Typical Characteristics</i> - THS4031 .....                                                                                | 10          |
| • Changed abscissa axis label from 10ns/div to 100ns/div in Figure 5-23, <i>20V Step Response</i> .....                                                               | 10          |

## 10 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

## PACKAGING INFORMATION

| Orderable part number            | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|----------------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">THS4031CD</a>        | Obsolete      | Production           | SOIC (D)   8     | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | 4031C               |
| <a href="#">THS4031CDGN</a>      | Obsolete      | Production           | HVSSOP (DGN)   8 | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | ACM                 |
| <a href="#">THS4031CDGNR</a>     | Obsolete      | Production           | HVSSOP (DGN)   8 | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | ACM                 |
| <a href="#">THS4031CDR</a>       | Obsolete      | Production           | SOIC (D)   8     | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | 4031C               |
| <a href="#">THS4031ID</a>        | Obsolete      | Production           | SOIC (D)   8     | -                     | -           | Call TI                              | Call TI                           | -40 to 85    | 4031I               |
| <a href="#">THS4031IDGN</a>      | Obsolete      | Production           | HVSSOP (DGN)   8 | -                     | -           | Call TI                              | Call TI                           | -40 to 85    | ACN                 |
| <a href="#">THS4031IDGNR</a>     | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU   NIPDAU                      | Level-2-260C-1 YEAR               | -40 to 85    | ACN                 |
| <a href="#">THS4031IDGNR.B</a>   | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 85    | ACN                 |
| <a href="#">THS4031IDGNRG4</a>   | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 85    | ACN                 |
| <a href="#">THS4031IDGNRG4.B</a> | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 85    | ACN                 |
| <a href="#">THS4031IDR</a>       | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU   NIPDAU                      | Level-1-260C-UNLIM                | -40 to 85    | 4031I               |
| <a href="#">THS4031IDR.B</a>     | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4031I               |
| <a href="#">THS4031IDRG4</a>     | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4031I               |
| <a href="#">THS4031IDRG4.B</a>   | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4031I               |
| <a href="#">THS4032CDGN</a>      | Obsolete      | Production           | HVSSOP (DGN)   8 | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | ABD                 |
| <a href="#">THS4032CDR</a>       | Obsolete      | Production           | SOIC (D)   8     | -                     | -           | Call TI                              | Call TI                           | 0 to 70      | 4032C               |
| <a href="#">THS4032ID</a>        | Obsolete      | Production           | SOIC (D)   8     | -                     | -           | Call TI                              | Call TI                           | -40 to 85    | 4032I               |
| <a href="#">THS4032IDGN</a>      | Obsolete      | Production           | HVSSOP (DGN)   8 | -                     | -           | Call TI                              | Call TI                           | -40 to 85    | ABG                 |
| <a href="#">THS4032IDGNR</a>     | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 85    | ABG                 |
| <a href="#">THS4032IDGNR.B</a>   | Active        | Production           | HVSSOP (DGN)   8 | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 85    | ABG                 |
| <a href="#">THS4032IDR</a>       | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4032I               |
| <a href="#">THS4032IDR.B</a>     | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4032I               |
| <a href="#">THS4032IDRG4</a>     | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4032I               |
| <a href="#">THS4032IDRG4.A</a>   | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4032I               |
| <a href="#">THS4032IDRG4.B</a>   | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-1-260C-UNLIM                | -40 to 85    | 4032I               |

<sup>(1)</sup> **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.

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

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

**OTHER QUALIFIED VERSIONS OF THS4031, THS4032 :**

- Enhanced Product : [THS4032-EP](#)
- Military : [THS4031M](#)

NOTE: Qualified Version Definitions:

- Enhanced Product - Supports Defense, Aerospace and Medical Applications
- Military - QML certified for Military and Defense Applications

## 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 |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| THS4031IDGNR   | HVSSOP       | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4031IDGNRG4 | HVSSOP       | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4031IDR     | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| THS4031IDRG4   | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| THS4032IDGNR   | HVSSOP       | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4032IDR     | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| THS4032IDRG4   | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 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) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| THS4031IDGNR   | HVSSOP       | DGN             | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4031IDGNRG4 | HVSSOP       | DGN             | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4031IDR     | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4031IDRG4   | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4032IDGNR   | HVSSOP       | DGN             | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4032IDR     | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| THS4032IDRG4   | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |

## GENERIC PACKAGE VIEW

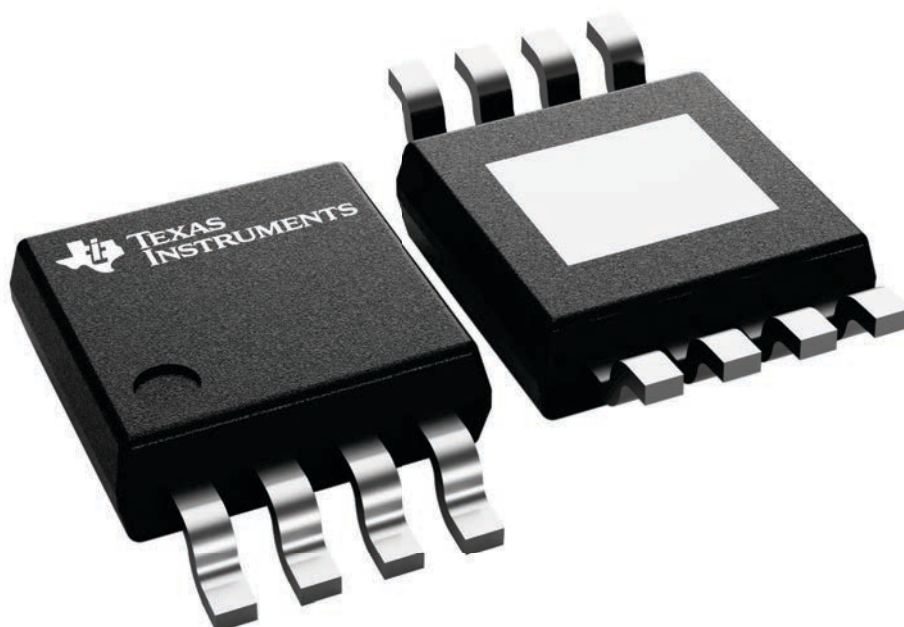
**DGN 8**

**PowerPAD™ HVSSOP - 1.1 mm max height**

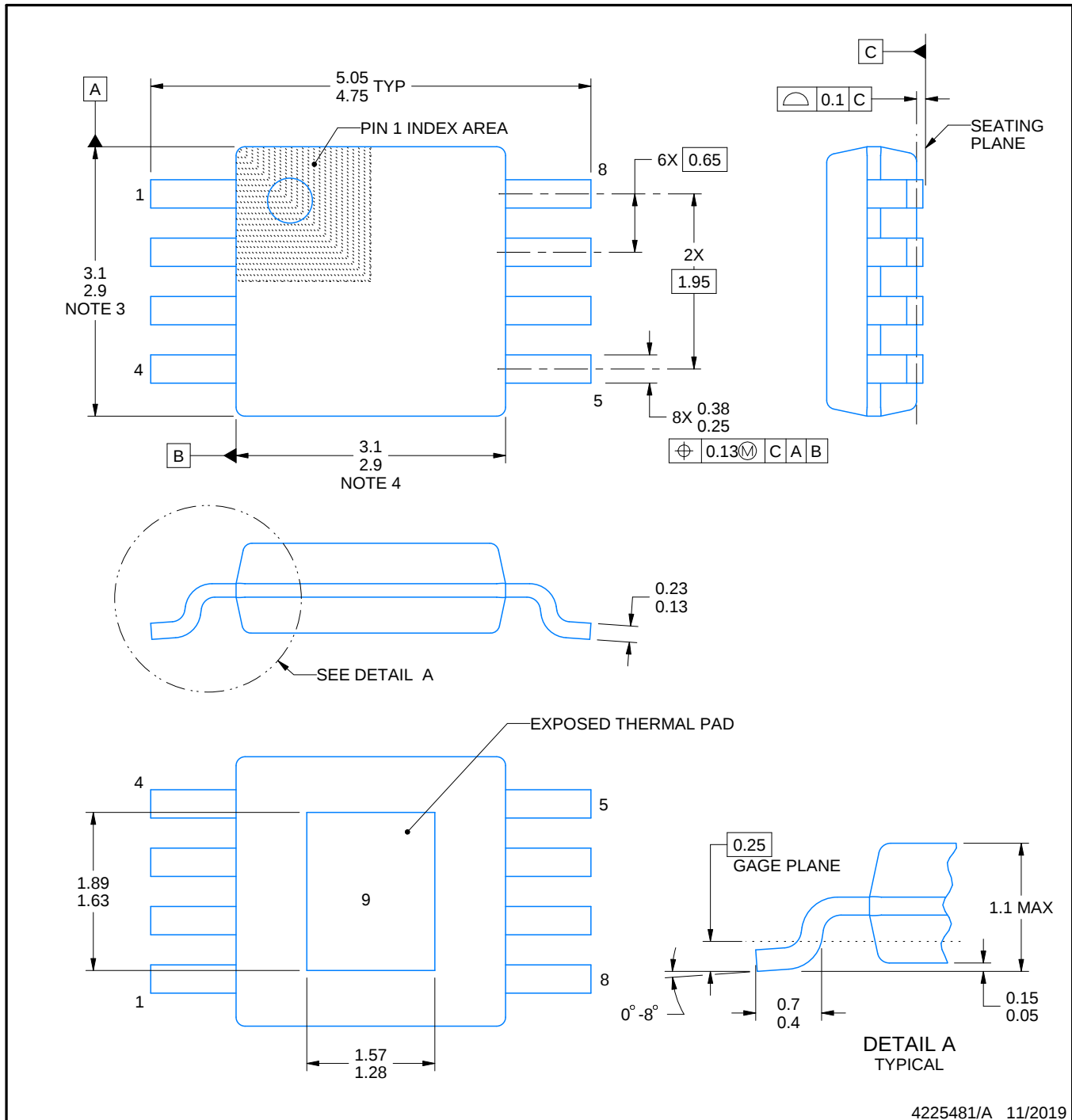
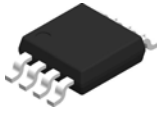
3 x 3, 0.65 mm pitch

SMALL OUTLINE PACKAGE

This image is a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.



4225482/B



4225481/A 11/2019

## NOTES:

PowerPAD is a trademark of Texas Instruments.

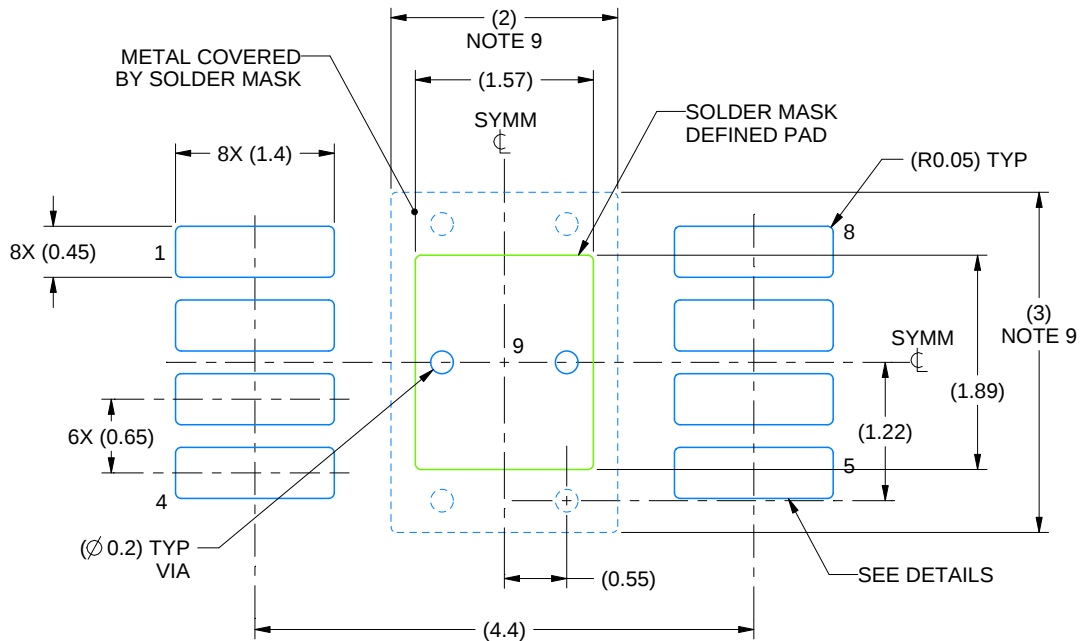
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or 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.

# EXAMPLE BOARD LAYOUT

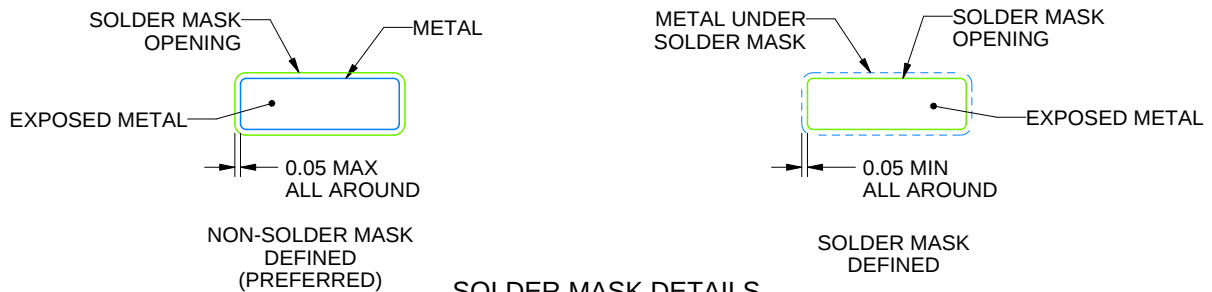
DGN0008D

PowerPAD™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 15X



SOLDER MASK DETAILS

4225481/A 11/2019

NOTES: (continued)

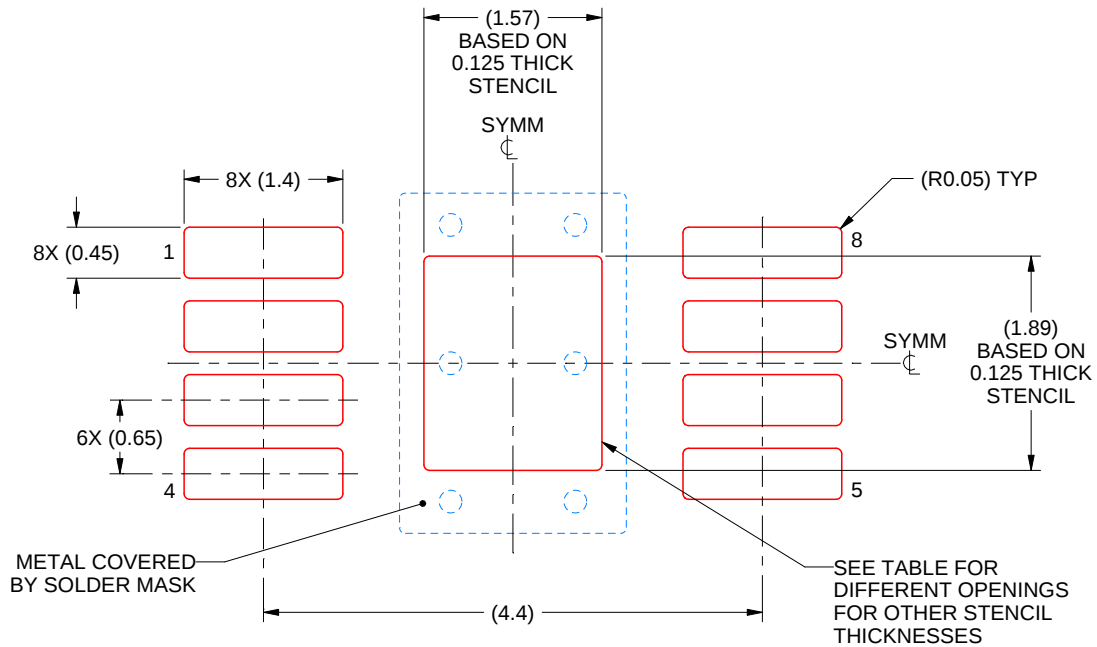
6. Publication IPC-7351 may have alternate designs.
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
8. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It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

# EXAMPLE STENCIL DESIGN

DGN0008D

PowerPAD™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



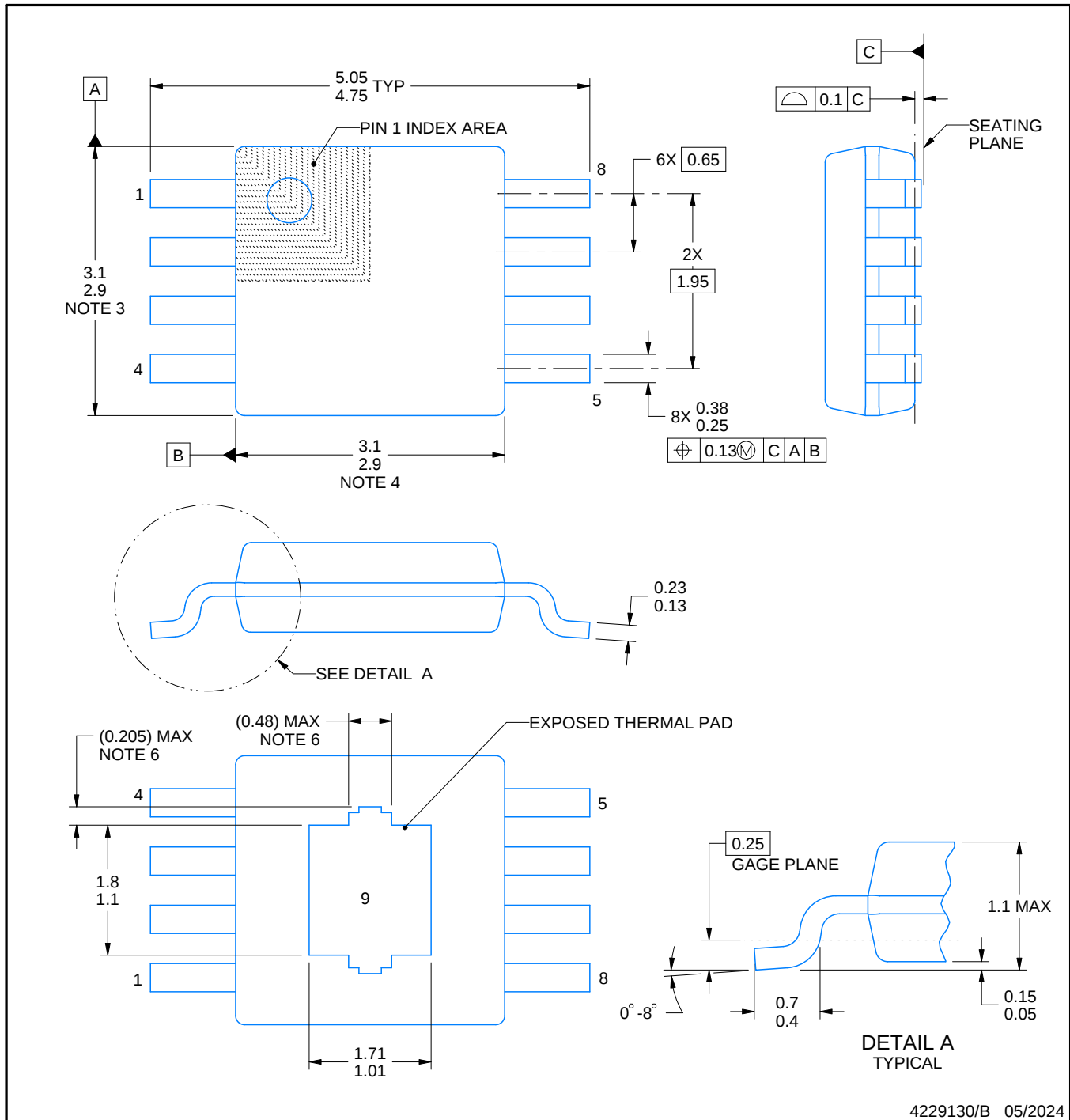
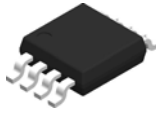
**SOLDER PASTE EXAMPLE**  
EXPOSED PAD 9:  
100% PRINTED SOLDER COVERAGE BY AREA  
SCALE: 15X

| STENCIL THICKNESS | SOLDER STENCIL OPENING |
|-------------------|------------------------|
| 0.1               | 1.76 X 2.11            |
| 0.125             | 1.57 X 1.89 (SHOWN)    |
| 0.15              | 1.43 X 1.73            |
| 0.175             | 1.33 X 1.60            |

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NOTES: (continued)

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



4229130/B 05/2024

## NOTES:

PowerPAD is a trademark of Texas Instruments.

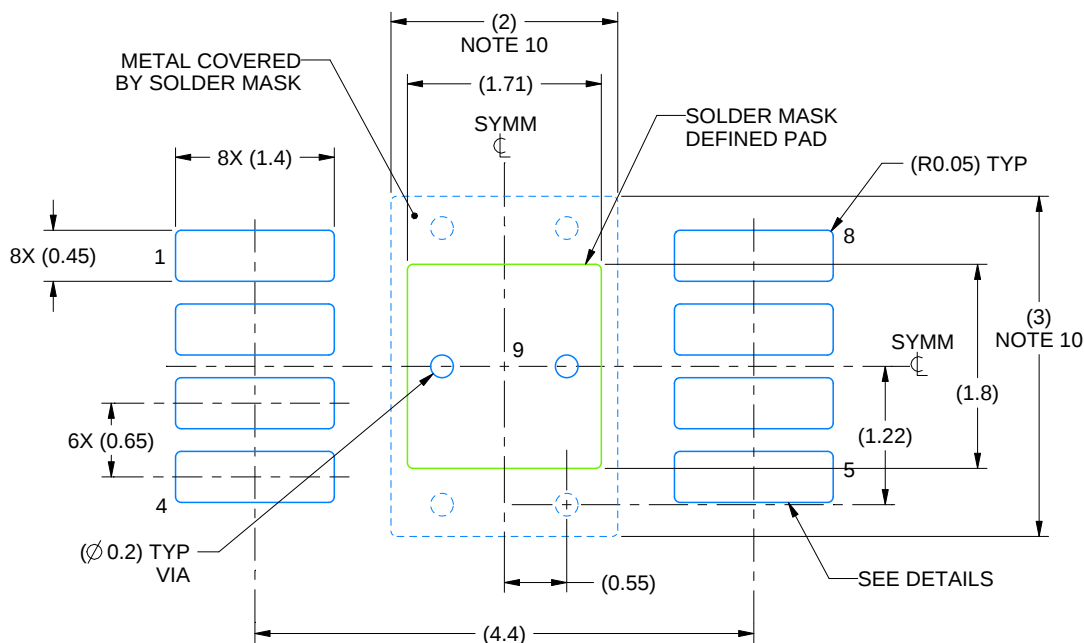
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or 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.
6. Features may differ or may not be present.

# EXAMPLE BOARD LAYOUT

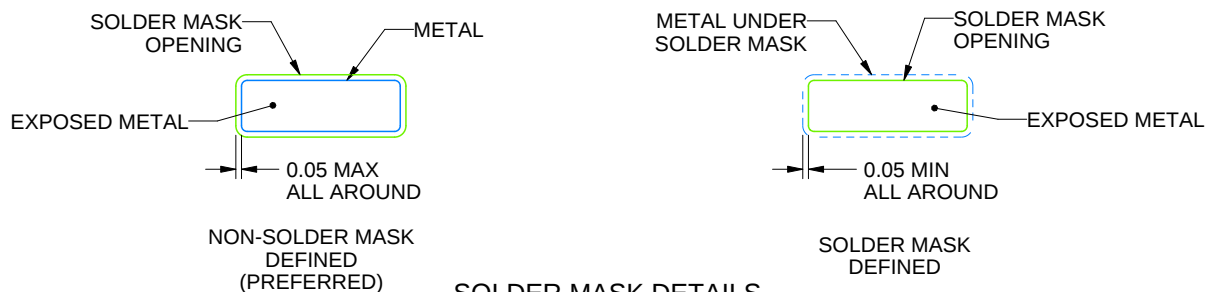
DGN0008H

PowerPAD™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 15X



SOLDER MASK DETAILS

4229130/B 05/2024

NOTES: (continued)

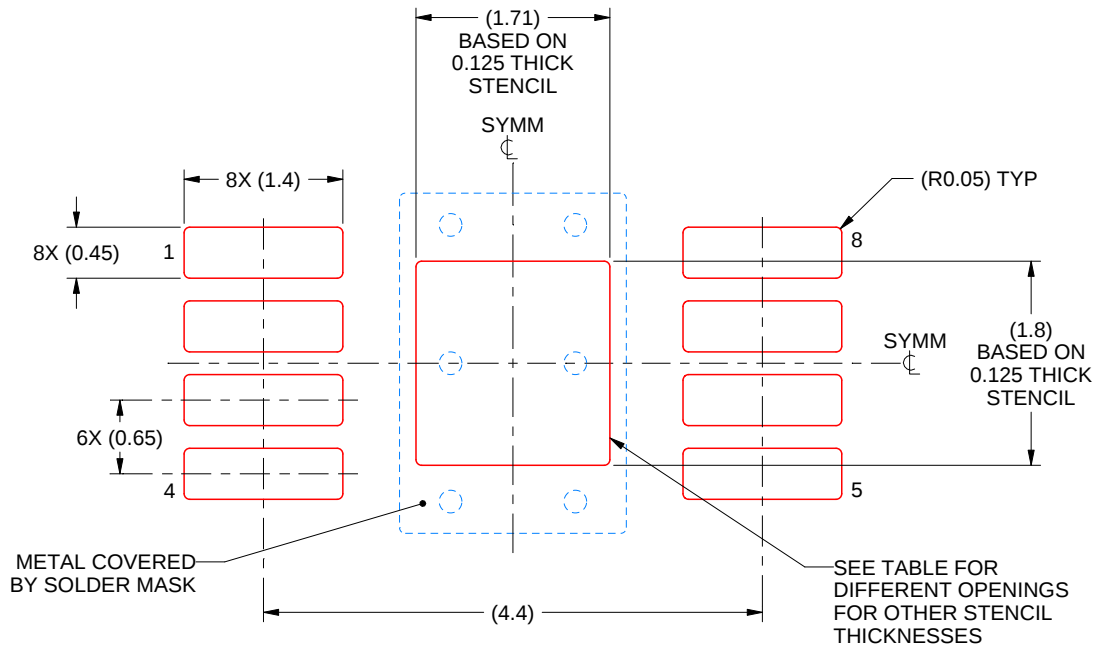
7. Publication IPC-7351 may have alternate designs.
8. Solder mask tolerances between and around signal pads can vary based on board fabrication site.
9. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It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

# EXAMPLE STENCIL DESIGN

DGN0008H

PowerPAD™ VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



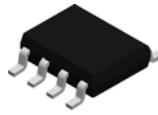
**SOLDER PASTE EXAMPLE**  
EXPOSED PAD 9:  
100% PRINTED SOLDER COVERAGE BY AREA  
SCALE: 15X

| STENCIL THICKNESS | SOLDER STENCIL OPENING |
|-------------------|------------------------|
| 0.1               | 1.91 X 2.01            |
| 0.125             | 1.71 X 1.80 (SHOWN)    |
| 0.15              | 1.56 X 1.64            |
| 0.175             | 1.45 X 1.52            |

4229130/B 05/2024

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.

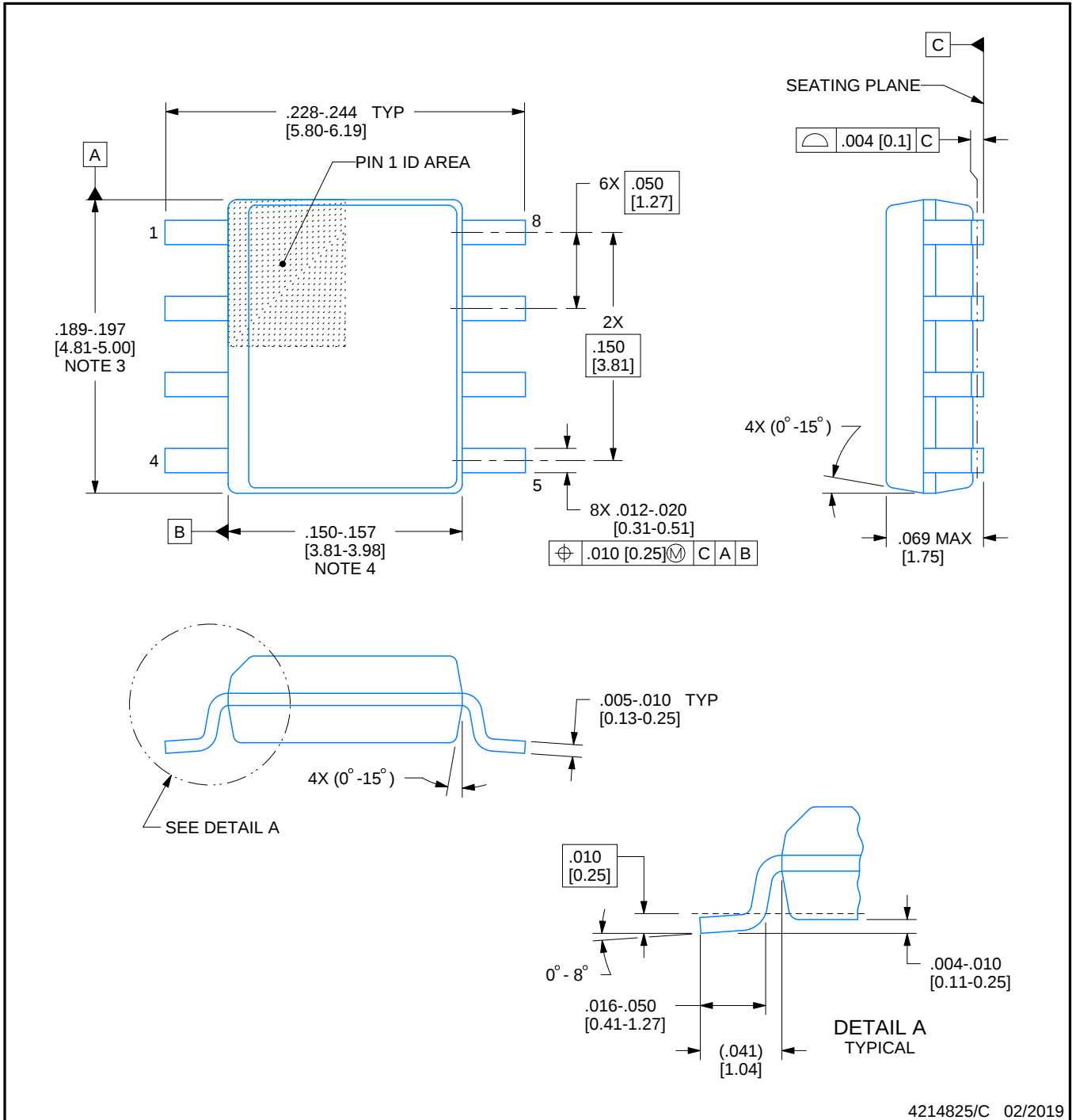


**D0008A**

# PACKAGE OUTLINE

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

## NOTES:

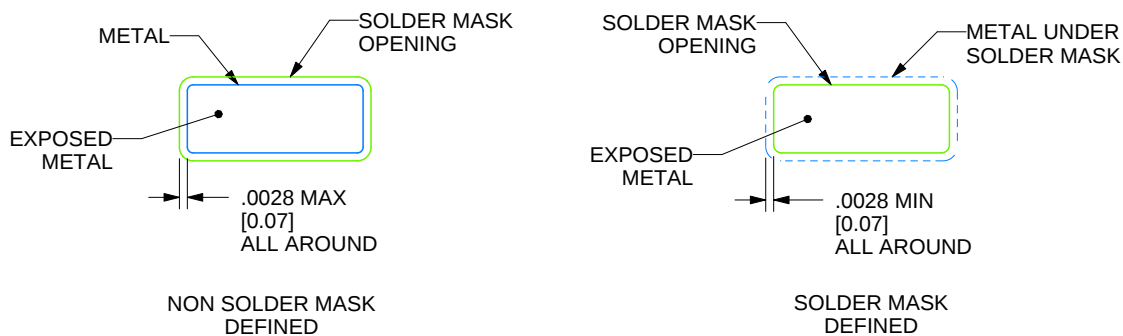
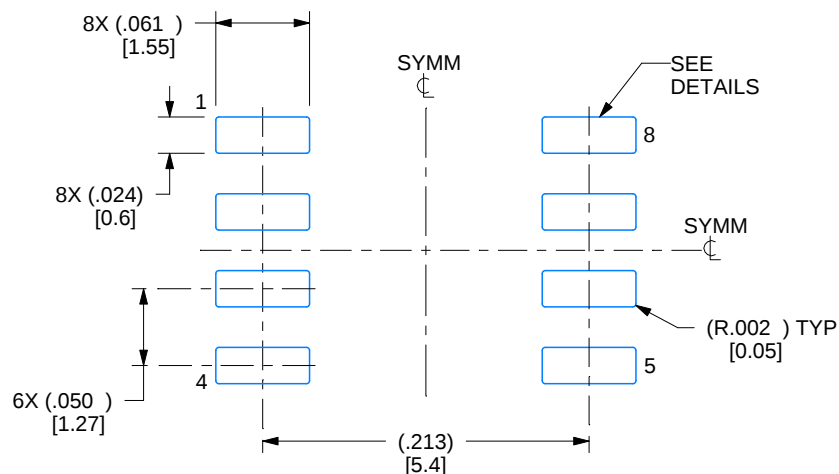
1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate 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.

# EXAMPLE BOARD LAYOUT

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

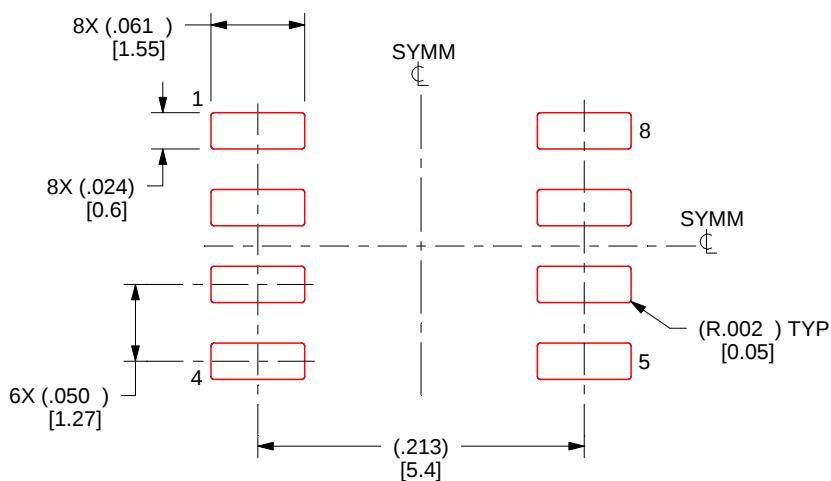
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## 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.

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