

# INA819 35- $\mu$ V Offset, 8-nV/ $\sqrt{\text{Hz}}$ Noise, Low-Power, Precision Instrumentation Amplifier

## 1 Features

- Low offset voltage: 10  $\mu$ V (typ), 35  $\mu$ V (max)
- Gain drift: 5 ppm/ $^{\circ}\text{C}$  ( $G = 1$ ), 35 ppm/ $^{\circ}\text{C}$  ( $G > 1$ ) (max)
- Noise: 8 nV/ $\sqrt{\text{Hz}}$
- Bandwidth: 2 MHz ( $G = 1$ ), 270 kHz ( $G = 100$ )
- Stable with 1-nF capacitive loads
- Inputs protected up to  $\pm 60$  V
- Common-mode rejection: 110 dB,  $G = 10$  (min)
- Power supply rejection: 110 dB,  $G = 1$  (min)
- Supply current: 385  $\mu$ A (max)
- Supply range:
  - Single supply: 4.5 V to 36 V
  - Dual supply:  $\pm 2.25$  V to  $\pm 18$  V
- Specified temperature range:  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$
- Packages: 8-pin SOIC, VSSOP, WSON

## 2 Applications

- Analog input module
- Flow transmitter
- Battery test
- LCD test
- Electrocardiogram (ECG)
- Surgical equipment
- Process analytics (pH, gas, concentration, force and humidity)

## 3 Description

The INA819 is a high-precision instrumentation amplifier that offers low power consumption and operates over a very wide single-supply or dual-supply range. A single external resistor sets any gain from 1 to 10,000. The device offers high precision as a result of super-beta input transistors, which provide exceptionally low input offset voltage, offset voltage drift, input bias current, input voltage, and current noise. Additional circuitry protects the inputs against overvoltage up to  $\pm 60$  V.

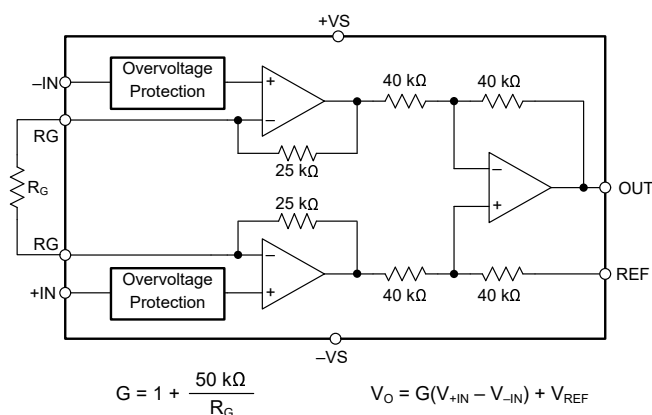
The INA819 is optimized to provide a high common-mode rejection ratio. At  $G = 1$ , the common-mode rejection ratio exceeds 90 dB across the full input common-mode range. The device is designed for low-voltage operation from a 4.5-V single supply, as well as dual supplies up to  $\pm 18$  V.

The INA819 is available in 8-pin SOIC, VSSOP, and WSON packages, and is specified over the  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$  temperature range.

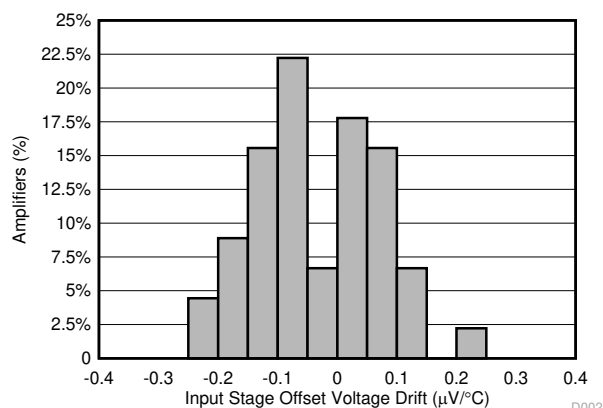
### Device Information<sup>(1)</sup>

| PART NUMBER | PACKAGE   | BODY SIZE (NOM)          |
|-------------|-----------|--------------------------|
| INA819      | SOIC (8)  | 4.90 mm $\times$ 3.91 mm |
|             | VSSOP (8) | 3.00 mm $\times$ 3.00 mm |
|             | WSON (8)  | 3.00 mm $\times$ 3.00 mm |

- (1) For all available packages, see the package option addendum at the end of the data sheet.



INA819 Simplified Internal Schematic



Typical Distribution of Input Stage Offset Voltage Drift



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## 4 Revision History

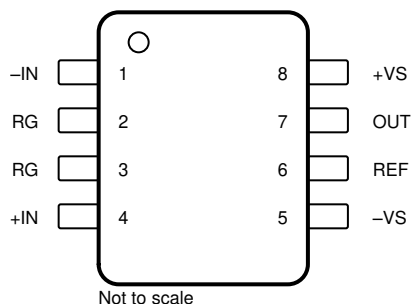
NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

|                                                                                                                                                                                                           |             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| <b>Changes from Revision C (June 2020) to Revision D (April 2022)</b> .....                                                                                                                               | <b>Page</b> |
| • Changed input stage offset voltage specification for INA819DRG from 10 $\mu$ V typical to 6 $\mu$ V typical, and from 35 $\mu$ V maximum to 30 $\mu$ V maximum, in <i>Typical Characteristics</i> ..... | 6           |
| • Changed maximum input stage offset voltage vs temperature specification for INA819DRG from 0.4 $\mu$ V/°C to 0.35 $\mu$ V/°C in <i>Typical Characteristics</i> .....                                    | 6           |
| • Changed Figures 7-10 and 7-11 to correct units from nA to pA.....                                                                                                                                       | 8           |
| • Changed input common-mode range calculator link from outdated Common-Mode Input Range Calculator for Instrumentation Amplifiers to Analog Engineers Calculator.....                                     | 22          |
| <b>Changes from Revision B (July 2019) to Revision C (June 2020)</b> .....                                                                                                                                | <b>Page</b> |
| • Added DRG (WSOP) package and associated content to data sheet.....                                                                                                                                      | 1           |
| • Added row for thermal pad to <i>Pin Functions</i> table .....                                                                                                                                           | 4           |
| • Added bullet regarding exposed thermal pad to end of <i>Layout Guidelines</i> section .....                                                                                                             | 32          |
| <b>Changes from Revision A (May 2019) to Revision B (July 2019)</b> .....                                                                                                                                 | <b>Page</b> |
| • Changed DGK (VSSOP) package from advanced information (preview) to production data (active).....                                                                                                        | 1           |
| <b>Changes from Revision * (December 2018) to Revision A (April 2019)</b> .....                                                                                                                           | <b>Page</b> |
| • Added 8-pin DGK (VSSOP) advanced information package and associated content to data sheet.....                                                                                                          | 1           |
| • Changed <i>Applications</i> bullets .....                                                                                                                                                               | 1           |

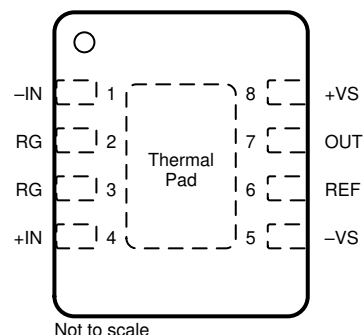
## 5 Device Comparison Table

| DEVICE                 | DESCRIPTION                                                                                                 | GAIN EQUATION                        | RG PINS AT PIN |
|------------------------|-------------------------------------------------------------------------------------------------------------|--------------------------------------|----------------|
| <a href="#">INA819</a> | 35-μV Offset, 0.4-μV/°C $V_{OS}$ Drift, 8-nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier      | $G = 1 + 50 \text{ k}\Omega / R_G$   | 2, 3           |
| <a href="#">INA818</a> | 35-μV Offset, 0.4-μV/°C $V_{OS}$ Drift, 8-nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier      | $G = 1 + 50 \text{ k}\Omega / R_G$   | 1, 8           |
| <a href="#">INA821</a> | 35-μV Offset, 0.4-μV/°C $V_{OS}$ Drift, 7-nV/√Hz Noise, High-Bandwidth, Precision Instrumentation Amplifier | $G = 1 + 49.4 \text{ k}\Omega / R_G$ | 2, 3           |
| <a href="#">INA828</a> | 50-μV Offset, 0.5-μV/°C $V_{OS}$ Drift, 7-nV/√Hz Noise, Low-Power, Precision Instrumentation Amplifier      | $G = 1 + 50 \text{ k}\Omega / R_G$   | 1, 8           |
| <a href="#">INA333</a> | 25-μV $V_{OS}$ , 0.1-μV/°C $V_{OS}$ Drift, 1.8-V to 5-V, RRO, 50-μA $I_Q$ , Chopper-Stabilized INA          | $G = 1 + 100 \text{ k}\Omega / R_G$  | 1, 8           |
| <a href="#">PGA280</a> | 20-mV to ±10-V Programmable Gain IA With 3-V or 5-V Differential Output; Analog Supply up to ±18 V          | Digital programmable                 | N/A            |
| <a href="#">INA159</a> | $G = 0.2 \text{ V}$ Differential Amplifier for ±10-V to 3-V and 5-V Conversion                              | $G = 0.2 \text{ V/V}$                | N/A            |
| <a href="#">PGA112</a> | Precision Programmable Gain Op Amp With SPI                                                                 | Digital programmable                 | N/A            |

## 6 Pin Configuration and Functions



**Figure 6-1. D (8-Pin SOIC) and DGK (8-Pin VSSOP) Packages, Top View**



**Figure 6-2. DRG Package, 8-Pin WSON, Top View**

**Table 6-1. Pin Functions**

| PIN         |      | TYPE   | DESCRIPTION                                                                           |
|-------------|------|--------|---------------------------------------------------------------------------------------|
| NAME        | NO.  |        |                                                                                       |
| -IN         | 1    | Input  | Negative (inverting) input                                                            |
| +IN         | 4    | Input  | Positive (noninverting) input                                                         |
| OUT         | 7    | Output | Output                                                                                |
| RG          | 2, 3 | —      | Gain setting pin. Place a gain resistor between pin 2 and pin 3.                      |
| REF         | 6    | Input  | Reference input. This pin must be driven by a low impedance source.                   |
| -VS         | 5    | —      | Negative supply                                                                       |
| +VS         | 8    | —      | Positive supply                                                                       |
| Thermal pad | —    | —      | Thermal pad internally connected to -VS. Connect externally to -VS or leave floating. |

## 7 Specifications

### 7.1 Absolute Maximum Ratings

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

|                                                   | MIN            | MAX            | UNIT |
|---------------------------------------------------|----------------|----------------|------|
| Supply voltage dual supply, $V_S = (V+) - (V-)$   |                | ±20            | V    |
| Supply voltage single supply, $V_S = (V+) - (V-)$ |                | 40             | V    |
| Signal input pins                                 | –60            | 60             | V    |
| VREF pin                                          | –20            | 20             | V    |
| Signal output pins maximum voltage                | $(-V_S) - 0.5$ | $(+V_S) + 0.5$ | V    |
| Signal output pins maximum current                | –50            | 50             | mA   |
| Output short-circuit <sup>(2)</sup>               | Continuous     |                |      |
| Operating Temperature, $T_A$                      | –50            | 150            | °C   |
| Junction Temperature, $T_J$                       |                | 175            | °C   |
| Storage Temperature, $T_{stg}$                    | –65            | 150            | °C   |

(1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

(2) Short-circuit to  $V_S / 2$ .

### 7.2 ESD Ratings

|             |                         | VALUE                                                                          | UNIT  |
|-------------|-------------------------|--------------------------------------------------------------------------------|-------|
| $V_{(ESD)}$ | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±1500 |
|             |                         | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±750  |

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

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

### 7.3 Recommended Operating Conditions

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

|                              |                       | MIN   | MAX | UNIT |
|------------------------------|-----------------------|-------|-----|------|
| Supply voltage, $V_S$        | Single-supply         | 4.5   | 36  | V    |
|                              | Dual-supply           | ±2.25 | ±18 |      |
| Specified temperature, $T_A$ | Specified temperature | –40   | 125 | °C   |

### 7.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | INA819   |             |            | UNIT |
|-------------------------------|----------------------------------------------|----------|-------------|------------|------|
|                               |                                              | D (SOIC) | DGK (VSSOP) | DRG (WSON) |      |
|                               |                                              | 8 PINS   | 8 PINS      | 8 PINS     |      |
| $R_{\theta JA}$               | Junction-to-ambient thermal resistance       | 119.6    | 215.4       | 55.6       | °C/W |
| $R_{\theta JC(top)}$          | Junction-to-case (top) thermal resistance    | 66.3     | 66.3        | 57.9       | °C/W |
| $R_{\theta JB}$               | Junction-to-board thermal resistance         | 61.9     | 97.8        | 28.6       | °C/W |
| $\psi_{JT}$                   | Junction-to-top characterization parameter   | 20.5     | 10.5        | 1.8        | °C/W |
| $\psi_{JB}$                   | Junction-to-board characterization parameter | 61.4     | 96.1        | 28.6       | °C/W |
| $R_{\theta JC(bot)}$          | Junction-to-case (bottom) thermal resistance | N/A      | N/A         | 12.1       | °C/W |

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

## 7.5 Electrical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

| PARAMETER        |                                                | TEST CONDITIONS                                                           |                     | MIN                                                                 | TYP      | MAX  | UNIT             |
|------------------|------------------------------------------------|---------------------------------------------------------------------------|---------------------|---------------------------------------------------------------------|----------|------|------------------|
| INPUT            |                                                |                                                                           |                     |                                                                     |          |      |                  |
| V <sub>OSI</sub> | Input stage offset voltage <sup>(1) (3)</sup>  |                                                                           | INA819ID            |                                                                     | 10       | 35   | μV               |
|                  |                                                |                                                                           | INA819IDGK          |                                                                     |          | 40   |                  |
|                  |                                                |                                                                           | INA819IDRG          |                                                                     | 6        | 30   |                  |
|                  |                                                | T <sub>A</sub> = −40°C to +125°C <sup>(2)</sup>                           | INA819ID, INA819DRG |                                                                     |          | 75   | μV/°C            |
|                  |                                                |                                                                           | INA819IDGK          |                                                                     |          | 80   |                  |
|                  |                                                | vs temperature, T <sub>A</sub> = −40°C to +125°C                          | INA819D, INA819DGK  |                                                                     |          | 0.4  |                  |
|                  |                                                |                                                                           | INA819DRG           |                                                                     |          | 0.35 |                  |
| V <sub>OSO</sub> | Output stage offset voltage <sup>(1) (3)</sup> |                                                                           |                     |                                                                     | 50       | 300  | μV               |
|                  |                                                | T <sub>A</sub> = −40°C to +125°C <sup>(2)</sup>                           |                     |                                                                     |          | 800  |                  |
|                  |                                                | vs temperature, T <sub>A</sub> = −40°C to +125°C                          |                     |                                                                     |          | 5    | μV/°C            |
| PSRR             | Power-supply rejection ratio                   | G = 1, RTI                                                                |                     | 110                                                                 | 120      |      | dB               |
|                  |                                                | G = 10, RTI                                                               |                     | 114                                                                 | 130      |      |                  |
|                  |                                                | G = 100, RTI                                                              |                     | 130                                                                 | 135      |      |                  |
|                  |                                                | G = 1000, RTI                                                             |                     | 136                                                                 | 140      |      |                  |
| Z <sub>id</sub>  | Differential impedance                         |                                                                           |                     | 100    1                                                            |          |      | GΩ    pF         |
| Z <sub>ic</sub>  | Common-mode impedance                          |                                                                           |                     | 100    4                                                            |          |      | GΩ    pF         |
|                  | RFI filter, −3-dB frequency                    |                                                                           |                     | 32                                                                  |          |      | MHz              |
| V <sub>CM</sub>  | Operating input range <sup>(4)</sup>           |                                                                           |                     | (V−) + 2                                                            | (V+) − 2 |      | V                |
|                  |                                                | V <sub>S</sub> = ±2.25 V to ±18 V, T <sub>A</sub> = −40°C to +125°C       |                     | See <a href="#">Figure 7-51</a> through <a href="#">Figure 7-54</a> |          |      |                  |
|                  | Input overvoltage range                        | T <sub>A</sub> = −40°C to +125°C <sup>(2)</sup>                           |                     |                                                                     |          | ±60  | V                |
| CMRR             | Common-mode rejection ratio                    | At DC to 60 Hz, RTI, V <sub>CM</sub> = (V−) + 2 V to (V+) − 2 V, G = 1    |                     | 90                                                                  | 105      |      | dB               |
|                  |                                                | At DC to 60 Hz, RTI, V <sub>CM</sub> = (V−) + 2 V to (V+) − 2 V, G = 10   |                     | 110                                                                 | 125      |      |                  |
|                  |                                                | At DC to 60 Hz, RTI, V <sub>CM</sub> = (V−) + 2 V to (V+) − 2 V, G = 100  |                     | 130                                                                 | 145      |      |                  |
|                  |                                                | At DC to 60 Hz, RTI, V <sub>CM</sub> = (V−) + 2 V to (V+) − 2 V, G = 1000 |                     | 140                                                                 | 150      |      |                  |
| BIAS CURRENT     |                                                |                                                                           |                     |                                                                     |          |      |                  |
| I <sub>B</sub>   | Input bias current                             | V <sub>CM</sub> = V <sub>S</sub> / 2                                      |                     |                                                                     | 0.15     | 0.5  | nA               |
|                  |                                                | T <sub>A</sub> = −40°C to +125°C                                          |                     |                                                                     |          | 2    |                  |
| I <sub>OS</sub>  | Input offset current                           | V <sub>CM</sub> = V <sub>S</sub> / 2                                      |                     |                                                                     | 0.15     | 0.5  | nA               |
|                  |                                                | T <sub>A</sub> = −40°C to +125°C                                          |                     |                                                                     |          | 2    |                  |
| NOISE VOLTAGE    |                                                |                                                                           |                     |                                                                     |          |      |                  |
| e <sub>NI</sub>  | Input stage voltage noise <sup>(6)</sup>       | f = 1 kHz, G = 100, R <sub>S</sub> = 0 Ω                                  |                     |                                                                     | 8        |      | nV/√Hz           |
|                  |                                                | f <sub>B</sub> = 0.1 Hz to 10 Hz, G = 100, R <sub>S</sub> = 0 Ω           |                     |                                                                     | 0.19     |      | μV <sub>PP</sub> |
| e <sub>NO</sub>  | Output stage voltage noise <sup>(6)</sup>      | f = 1 kHz, R <sub>S</sub> = 0 Ω                                           |                     |                                                                     | 80       |      | nV/√Hz           |
|                  |                                                | f <sub>B</sub> = 0.1 Hz to 10 Hz, R <sub>S</sub> = 0 Ω                    |                     |                                                                     | 2.6      |      | μV <sub>PP</sub> |
| I <sub>n</sub>   | Noise current                                  | f = 1 kHz                                                                 |                     |                                                                     | 130      |      | fA/√Hz           |
|                  |                                                | f <sub>B</sub> = 0.1 Hz to 10 Hz, G = 100                                 |                     |                                                                     | 4.7      |      | pA <sub>PP</sub> |

## 7.5 Electrical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

| PARAMETER          |                                    | TEST CONDITIONS                                                      | MIN                           | TYP     | MAX         | UNIT   |
|--------------------|------------------------------------|----------------------------------------------------------------------|-------------------------------|---------|-------------|--------|
| GAIN               |                                    |                                                                      |                               |         |             |        |
|                    | Gain equation                      |                                                                      | 1 + (50 kΩ / R <sub>G</sub> ) |         |             | V/V    |
| G                  | Gain                               |                                                                      | 1                             |         | 10000       | V/V    |
| GE                 | Gain error                         | G = 1, V <sub>O</sub> = ±10 V                                        |                               | ±0.005% | ±0.025%     |        |
|                    |                                    | G = 10, V <sub>O</sub> = ±10 V                                       |                               | ±0.025% | ±0.15%      |        |
|                    |                                    | G = 100, V <sub>O</sub> = ±10 V                                      |                               | ±0.025% | ±0.15%      |        |
|                    |                                    | G = 1000, V <sub>O</sub> = ±10 V                                     |                               | ±0.05%  |             |        |
|                    | Gain vs temperature <sup>(5)</sup> | G = 1, T <sub>A</sub> = −40°C to +125°C                              |                               |         | ±5          | ppm/°C |
|                    |                                    | G > 1, T <sub>A</sub> = −40°C to +125°C                              |                               |         | ±35         |        |
|                    | Gain nonlinearity                  | G = 1 to 10, V <sub>O</sub> = −10 V to +10 V, R <sub>L</sub> = 10 kΩ |                               | 1       | 10          | ppm    |
|                    |                                    | G = 100, V <sub>O</sub> = −10 V to +10 V, R <sub>L</sub> = 10 kΩ     |                               |         | 15          |        |
|                    |                                    | G = 1000, V <sub>O</sub> = −10 V to +10 V, R <sub>L</sub> = 10 kΩ    |                               | 10      |             |        |
|                    |                                    | G = 1 to 100, V <sub>O</sub> = −10 V to +10 V, R <sub>L</sub> = 2 kΩ |                               | 30      |             |        |
|                    |                                    |                                                                      |                               |         |             |        |
| OUTPUT             |                                    |                                                                      |                               |         |             |        |
|                    | Voltage swing                      |                                                                      | (V−) + 0.15                   |         | (V+) − 0.15 | V      |
|                    | Load capacitance stability         |                                                                      |                               | 1000    |             | pF     |
| Z <sub>O</sub>     | Closed-loop output impedance       | f = 10 kHz                                                           |                               | 5.0     |             | Ω      |
| I <sub>SC</sub>    | Short-circuit current              | Continuous to V <sub>S</sub> / 2                                     |                               | ±20     |             | mA     |
| FREQUENCY RESPONSE |                                    |                                                                      |                               |         |             |        |
| BW                 | Bandwidth, −3 dB                   | G = 1                                                                |                               | 2.0     |             | MHz    |
|                    |                                    | G = 10                                                               |                               | 890     |             | kHz    |
|                    |                                    | G = 100                                                              |                               | 270     |             |        |
|                    |                                    | G = 1000                                                             |                               | 30      |             |        |
| SR                 | Slew rate                          | G = 1, V <sub>O</sub> = ±10 V                                        |                               | 0.9     |             | V/μs   |
| t <sub>S</sub>     | Settling time                      | 0.01%, G = 1 to 100, V <sub>STEP</sub> = 10 V                        |                               | 12      |             | μs     |
|                    |                                    | 0.01%, G = 1000, V <sub>STEP</sub> = 10 V                            |                               | 40      |             |        |
|                    |                                    | 0.001%, G = 1 to 100, V <sub>STEP</sub> = 10 V                       |                               | 16      |             |        |
|                    |                                    | 0.001%, G = 1000, V <sub>STEP</sub> = 10 V                           |                               | 60      |             |        |
| REFERENCE INPUT    |                                    |                                                                      |                               |         |             |        |
| R <sub>IN</sub>    | Input impedance                    |                                                                      |                               | 40      |             | kΩ     |
|                    | Voltage range                      |                                                                      | (V−)                          |         | (V+)        | V      |
|                    | Gain to output                     |                                                                      |                               | 1       |             | V/V    |
|                    | Reference gain error               |                                                                      |                               | 0.01%   |             |        |
| POWER SUPPLY       |                                    |                                                                      |                               |         |             |        |
| I <sub>Q</sub>     | Quiescent current                  | V <sub>IN</sub> = 0 V                                                |                               | 350     | 385         | μA     |
|                    |                                    | vs temperature, T <sub>A</sub> = −40°C to +125°C                     |                               |         | 520         |        |

- (1) Total offset, referred-to-input (RTI):  $V_{\text{OS}} = (V_{\text{OSI}}) + (V_{\text{OSO}} / G)$ .
- (2) Specified by characterization.
- (3) Offset drifts are uncorrelated. Input-referred offset drift is calculated using:  $\Delta V_{\text{OS(RTI)}} = \sqrt{[\Delta V_{\text{OSI}}]^2 + (\Delta V_{\text{OSO}} / G)^2}$ .
- (4) Input voltage range of the Instrumentation Amplifier input stage. The input range depends on the common-mode voltage, differential voltage, gain, and reference voltage.
- (5) The values specified for  $G > 1$  do not include the effects of the external gain-setting resistor,  $R_G$ .
- (6) Total RTI voltage noise is equal to:  $e_{\text{N(RTI)}} = \sqrt{[e_{\text{NI}}]^2 + (e_{\text{NO}} / G)^2}$ .

## 7.6 Typical Characteristics

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

**Table 7-1. Table of Graphs**

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## 7.6 Typical Characteristics

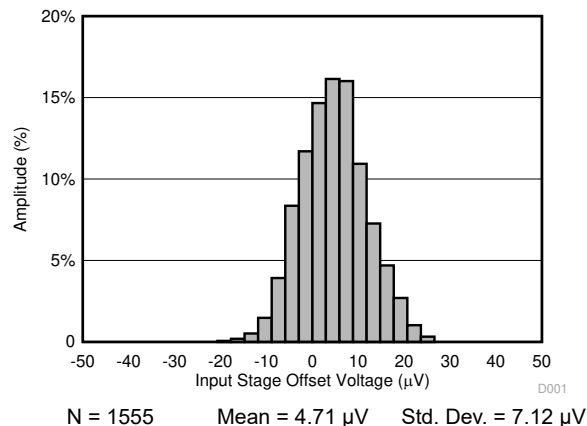
at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

**Table 7-1. Table of Graphs (continued)**

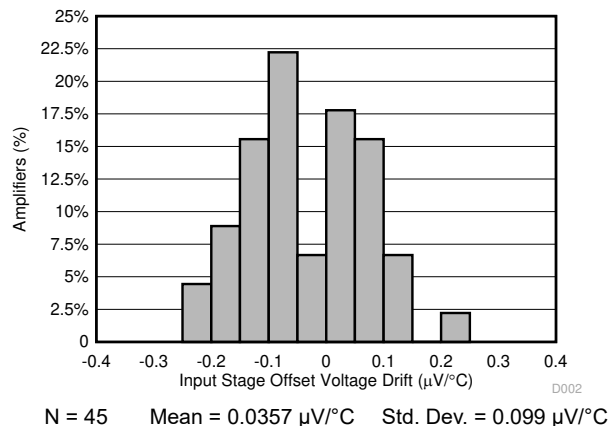
| DESCRIPTION                                                                 | FIGURE                      |
|-----------------------------------------------------------------------------|-----------------------------|
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| Input Common-Mode Voltage vs Output Voltage, $V_S = \pm 15\text{ V}$        | <a href="#">Figure 7-54</a> |

## 7.6 Typical Characteristics

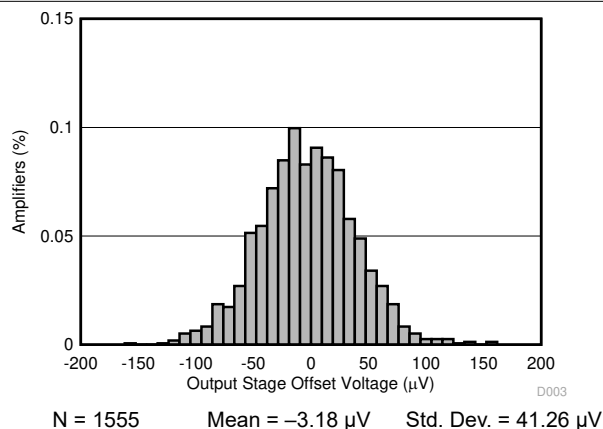
at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



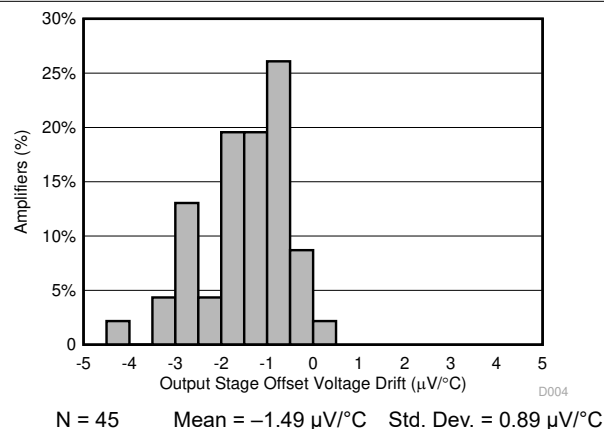
**Figure 7-1. Typical Distribution of Input Stage Offset Voltage**



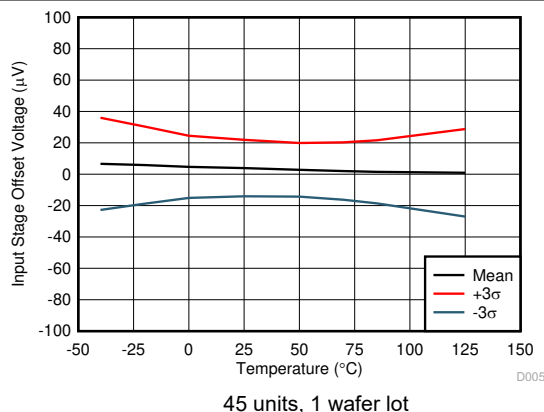
**Figure 7-2. Typical Distribution of Input Stage Offset Voltage Drift**



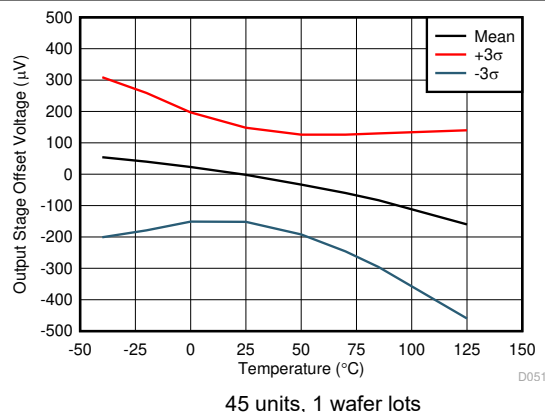
**Figure 7-3. Typical Distribution of Output Stage Offset Voltage**



**Figure 7-4. Typical Distribution of Output Stage Offset Voltage Drift**



**Figure 7-5. Input Stage Offset Voltage vs Temperature**



**Figure 7-6. Output Stage Offset Voltage vs Temperature**

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

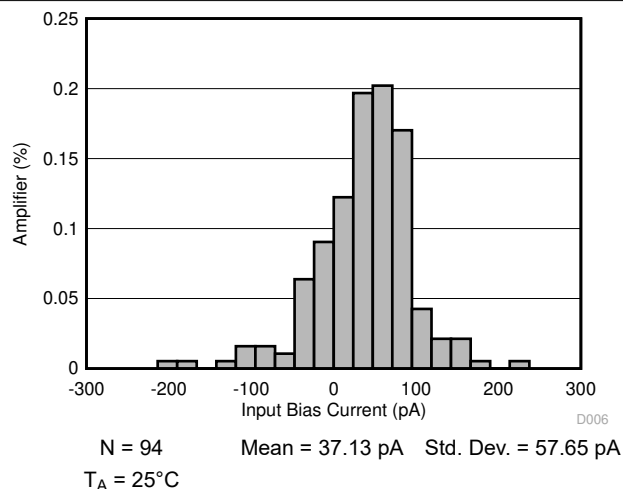


Figure 7-7. Typical Distribution of Input Bias Current

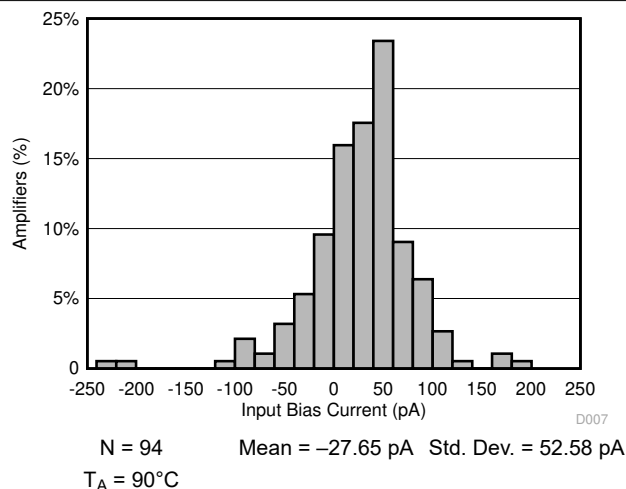


Figure 7-8. Typical Distribution of Input Bias Current

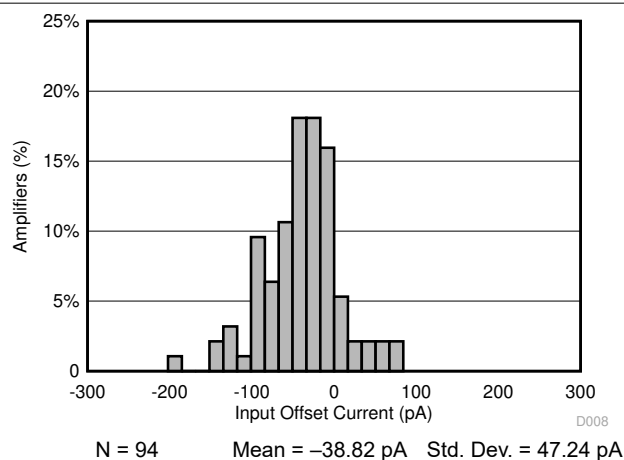


Figure 7-9. Typical Distribution of Input Offset Current

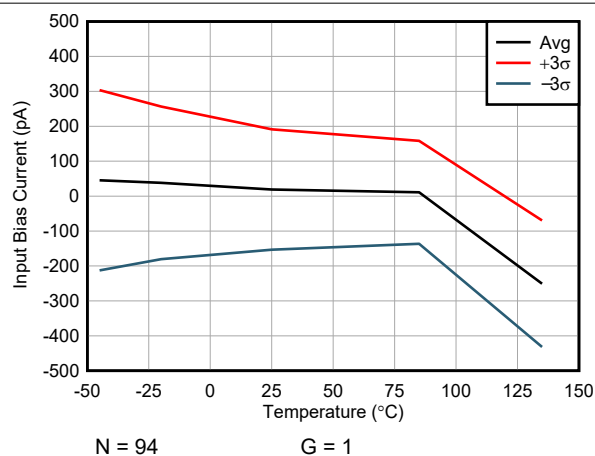


Figure 7-10. Input Bias Current vs Temperature

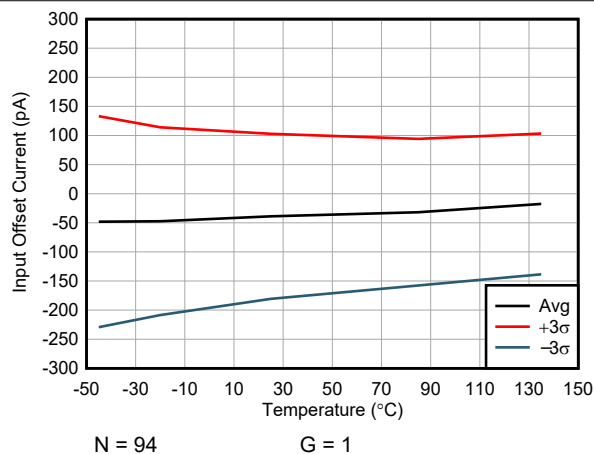


Figure 7-11. Input Offset Current vs Temperature

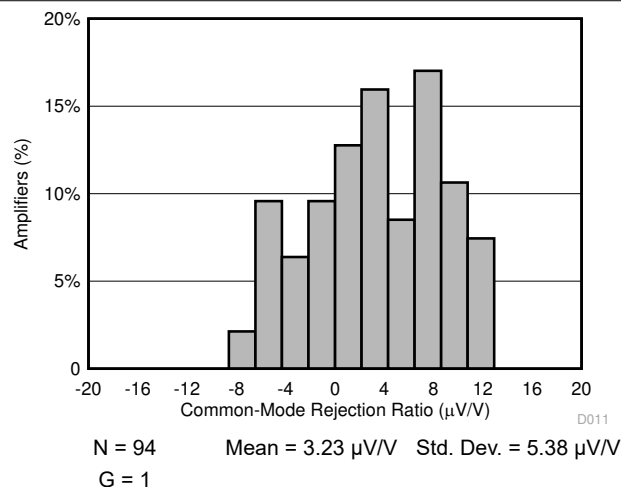


Figure 7-12. Typical CMRR Distribution

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

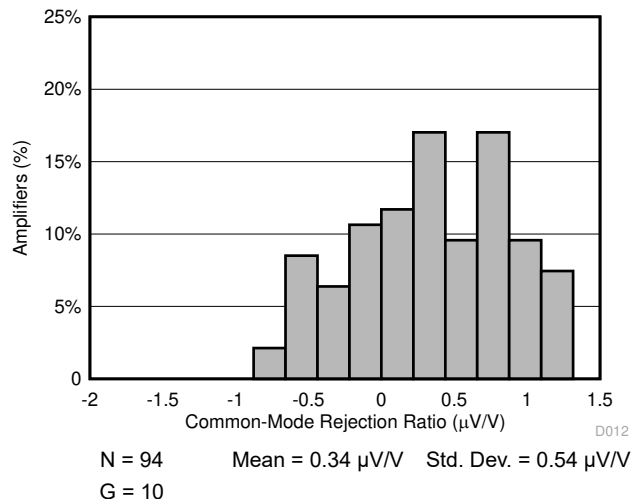


Figure 7-13. Typical CMRR Distribution

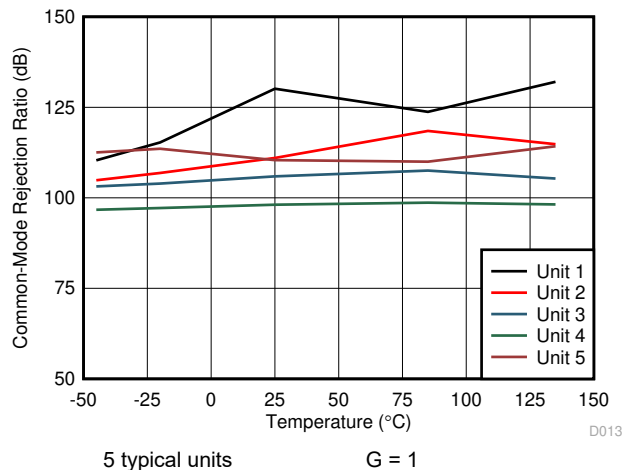


Figure 7-14. CMRR vs Temperature

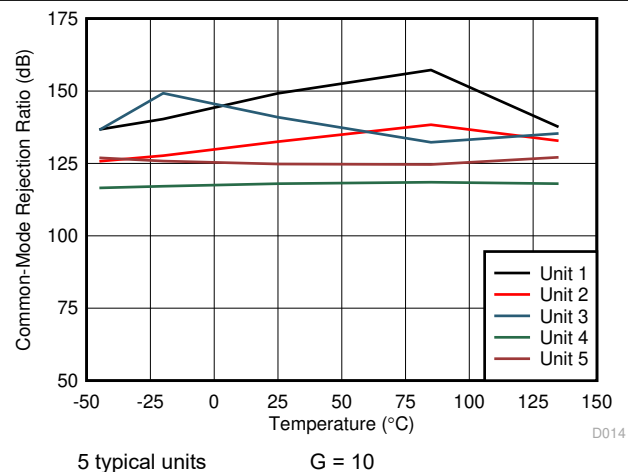


Figure 7-15. CMRR vs Temperature

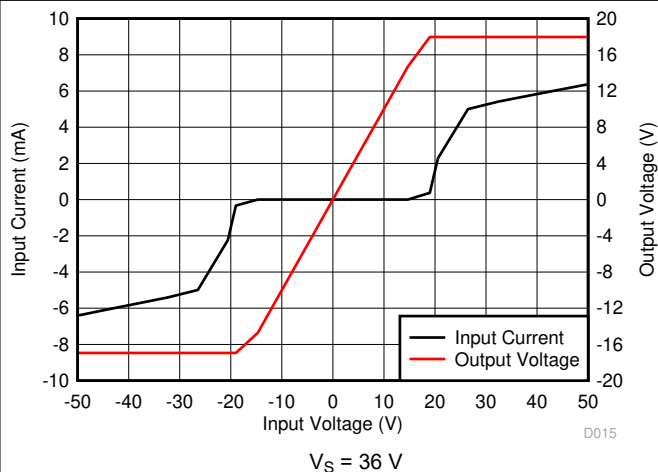


Figure 7-16. Input Current vs Input Overvoltage

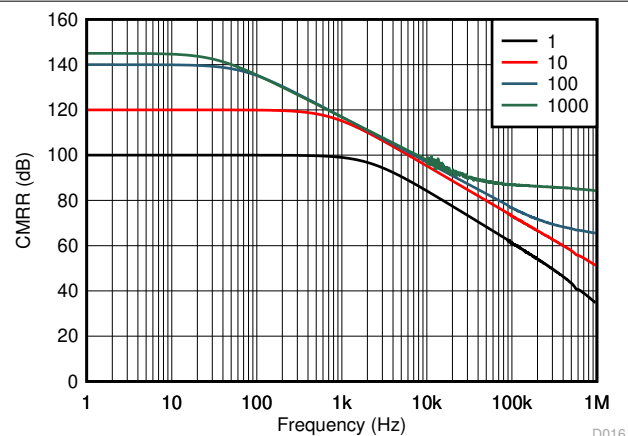


Figure 7-17. CMRR vs Frequency (RTI)

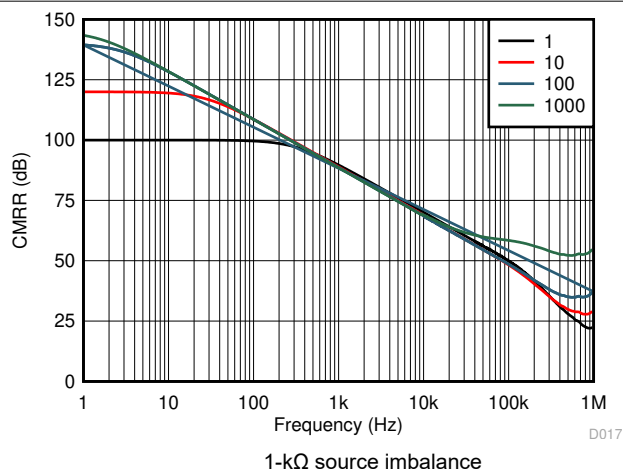


Figure 7-18. CMRR vs Frequency (RTI)

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

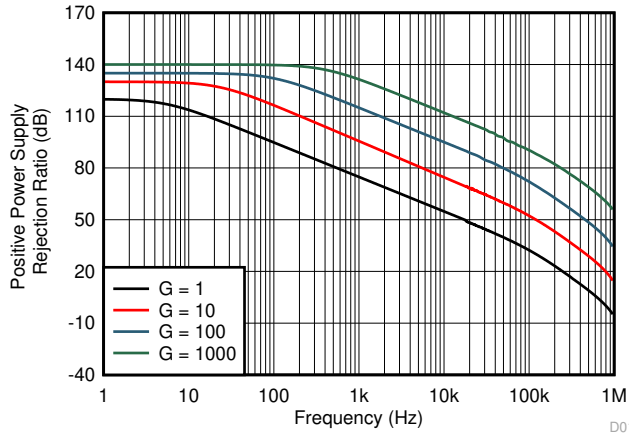


Figure 7-19. Positive PSRR vs Frequency (RTI)

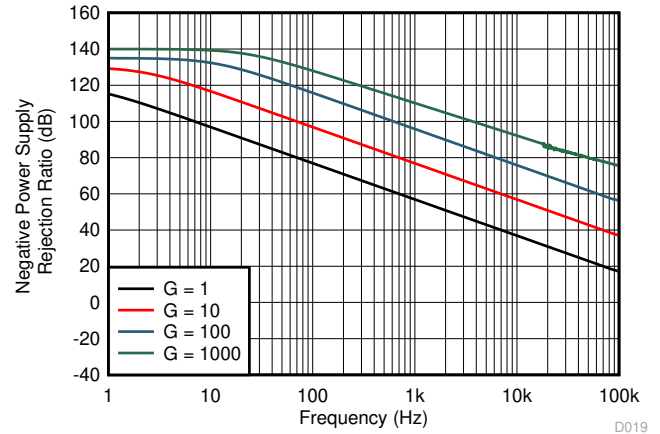


Figure 7-20. Negative PSRR vs Frequency (RTI)

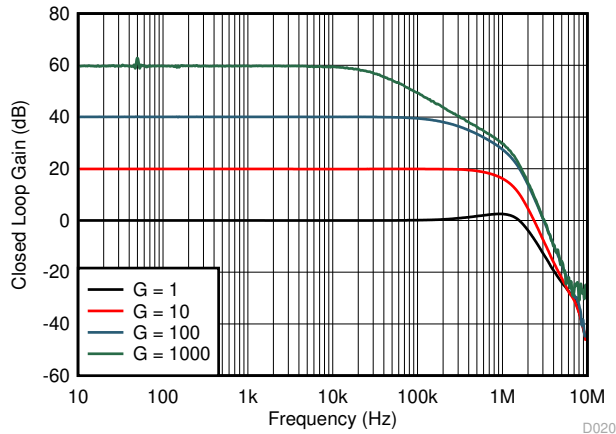


Figure 7-21. Gain vs Frequency

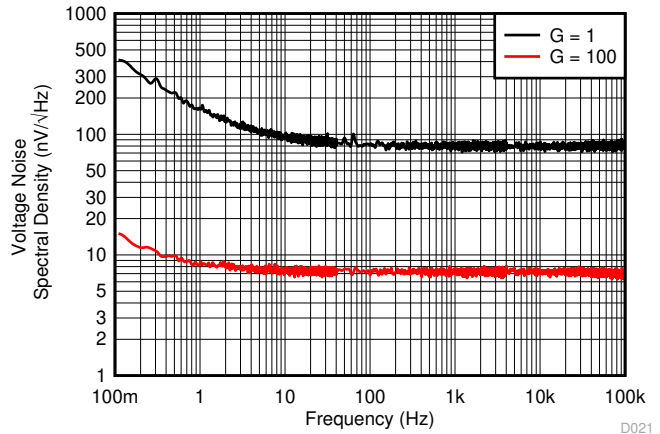


Figure 7-22. Voltage Noise Spectral Density vs Frequency (RTI)

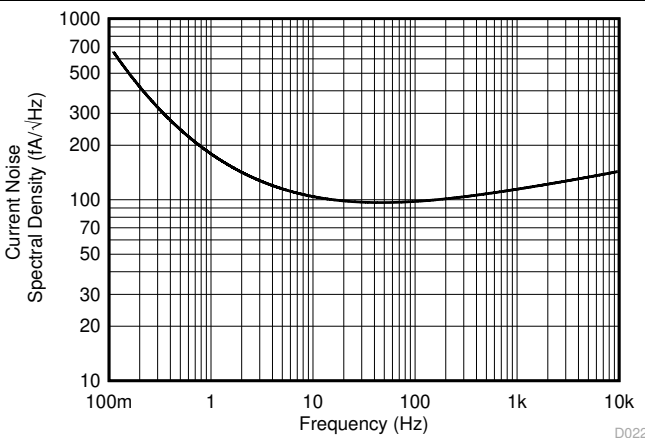


Figure 7-23. Current Noise Spectral Density vs Frequency (RTI)

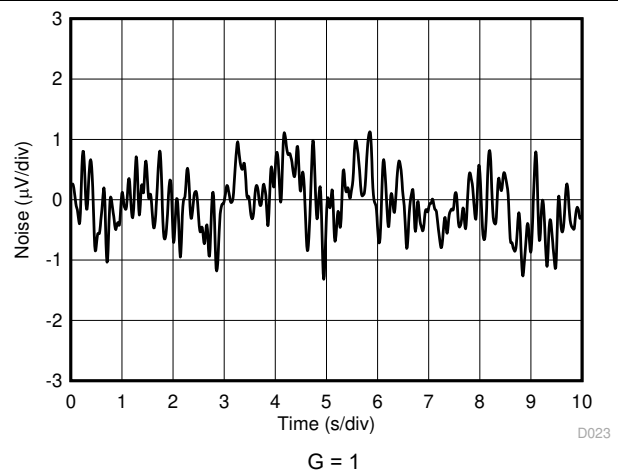


Figure 7-24. 0.1-Hz to 10-Hz RTI Voltage Noise

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

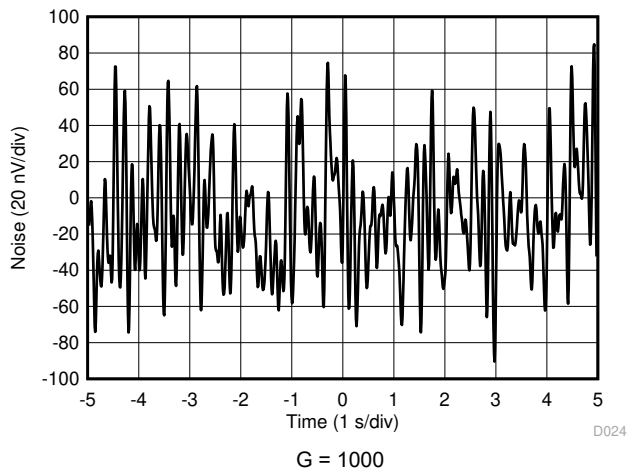


Figure 7-25. 0.1-Hz to 10-Hz RTI Voltage Noise

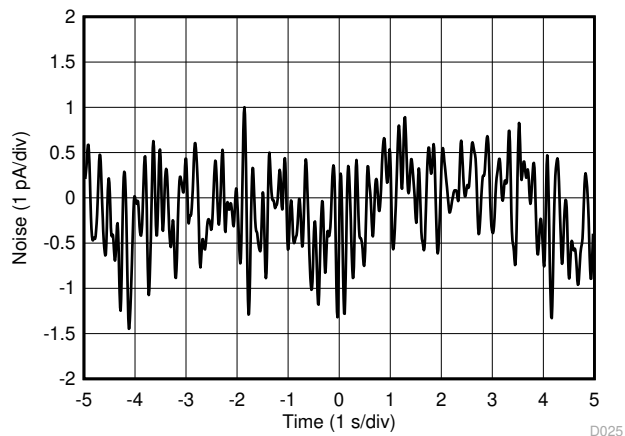


Figure 7-26. 0.1-Hz to 10-Hz RTI Current Noise

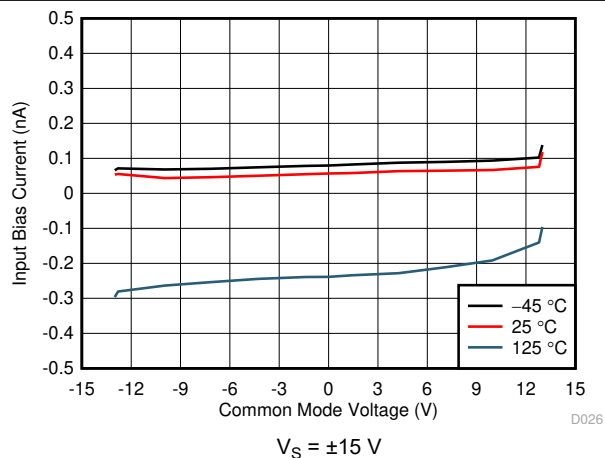


Figure 7-27. Input Bias Current vs Common-Mode Voltage

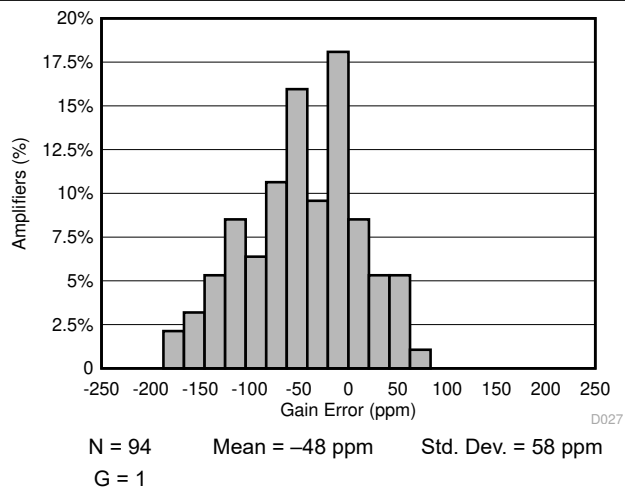


Figure 7-28. Typical Distribution of Gain Error,  $G = 1$

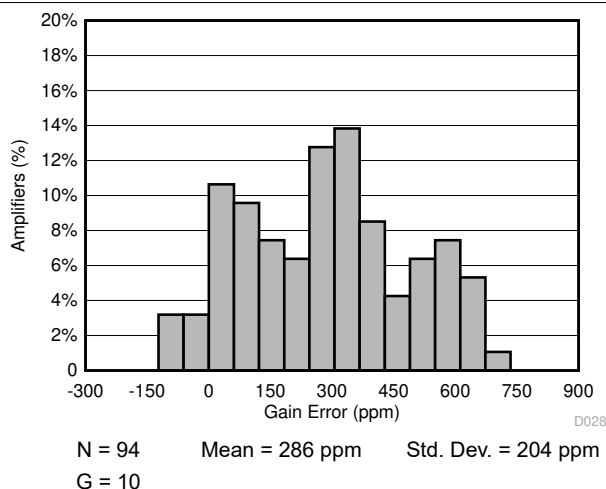


Figure 7-29. Typical Distribution of Gain Error,  $G = 10$

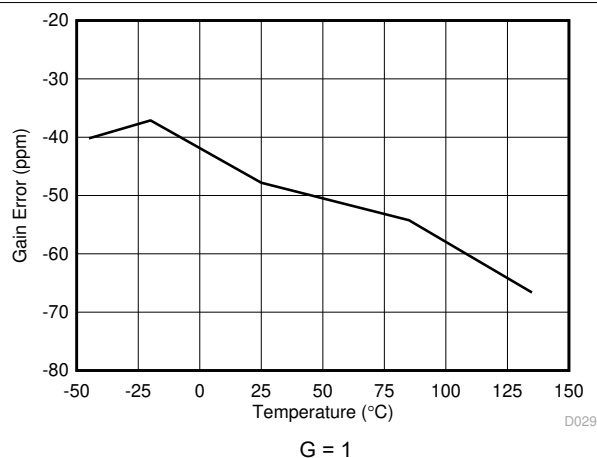


Figure 7-30. Gain Error vs Temperature

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{\text{REF}} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

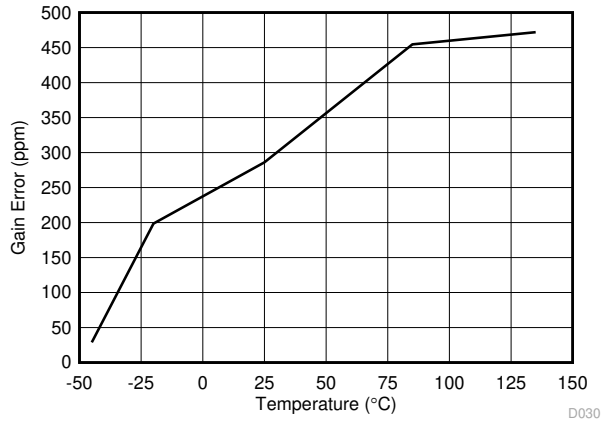


Figure 7-31. Gain Error vs Temperature

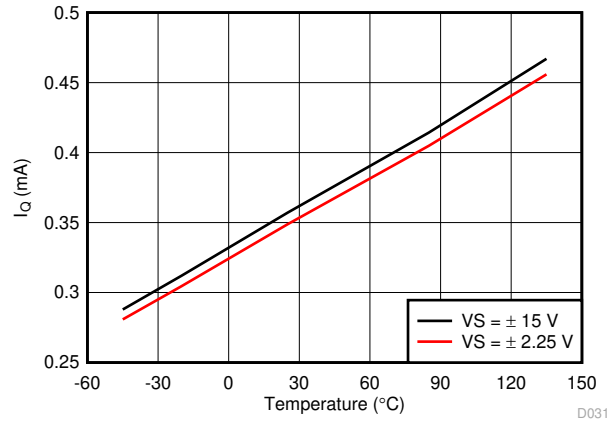


Figure 7-32. Supply Current vs Temperature

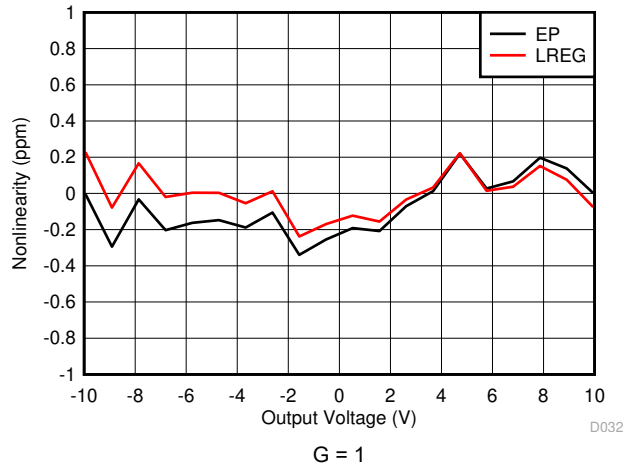


Figure 7-33. Gain Nonlinearity

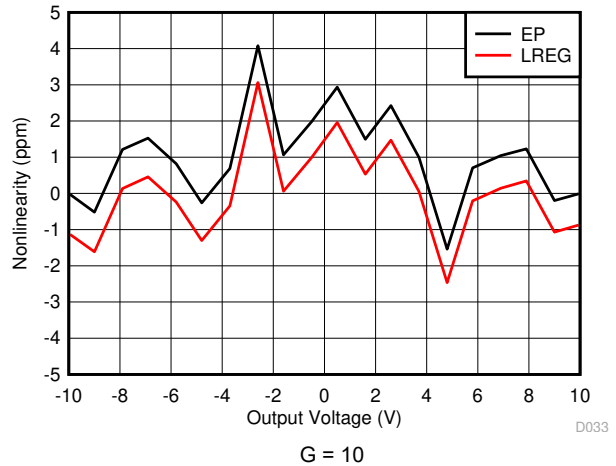


Figure 7-34. Gain Nonlinearity

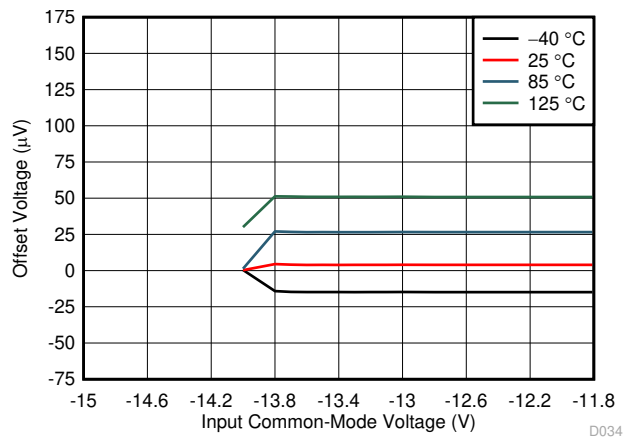


Figure 7-35. Offset Voltage vs Negative Common-Mode Voltage

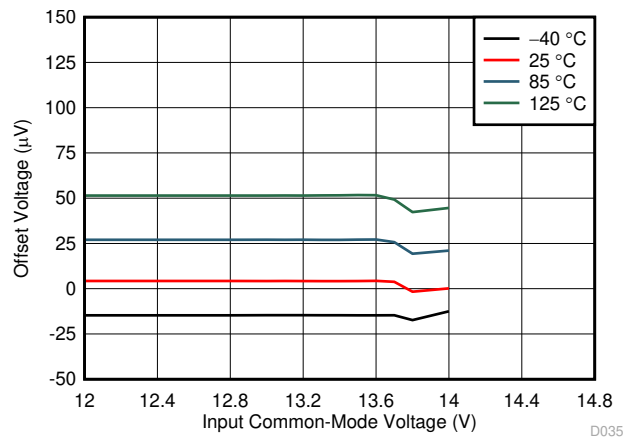


Figure 7-36. Offset Voltage vs Positive Common-Mode Voltage

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

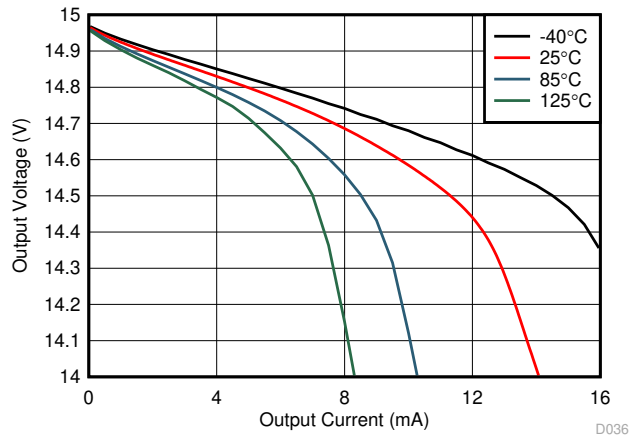


Figure 7-37. Positive Output Voltage Swing vs Output Current

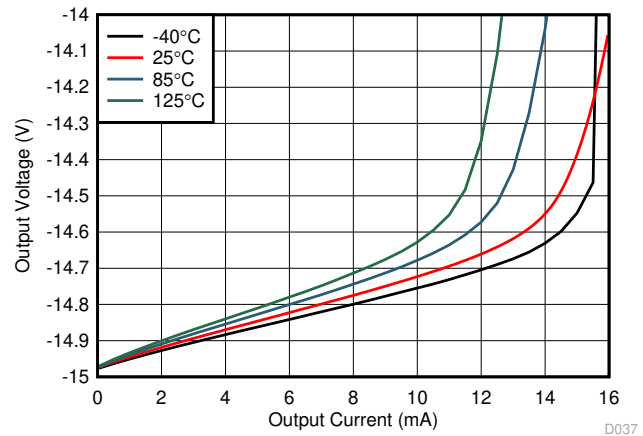


Figure 7-38. Negative Output Voltage Swing vs Output Current

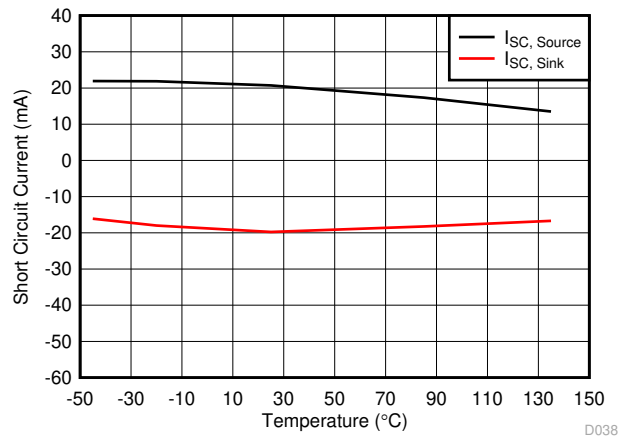


Figure 7-39. Short Circuit Current vs Temperature

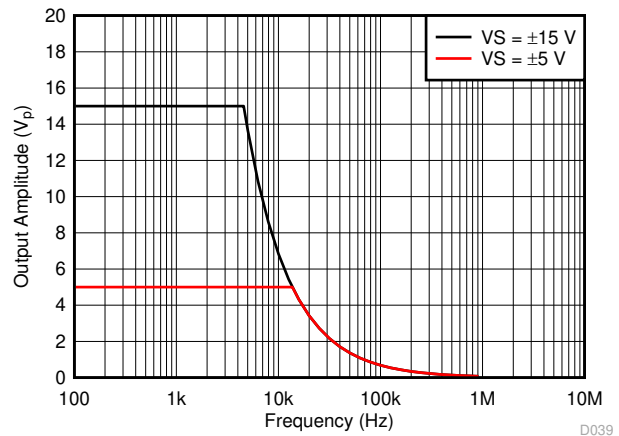


Figure 7-40. Large-Signal Frequency Response

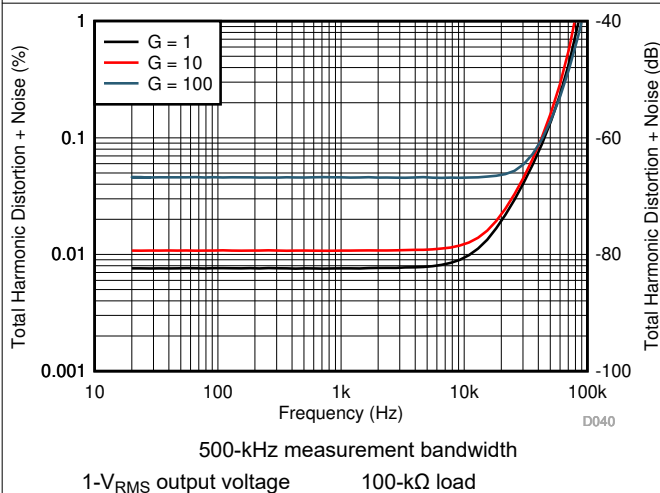


Figure 7-41. THD+N vs Frequency

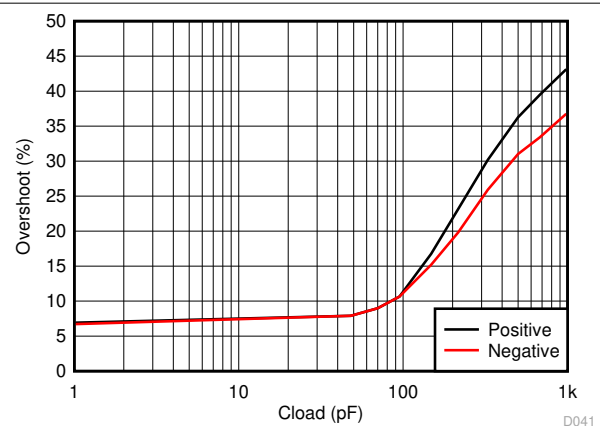
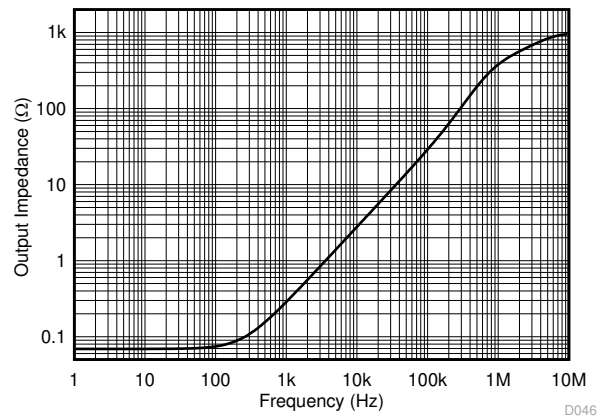
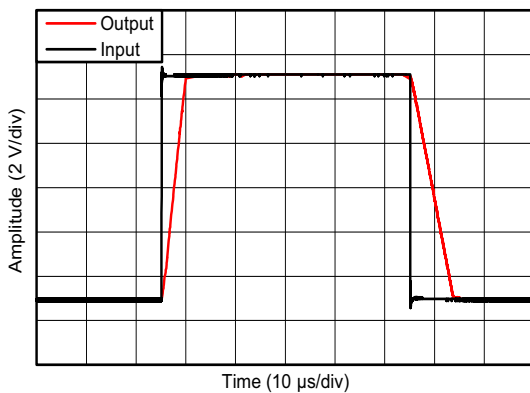
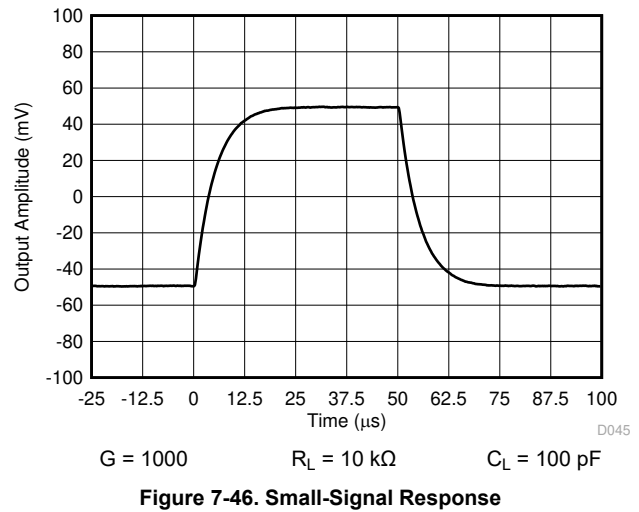
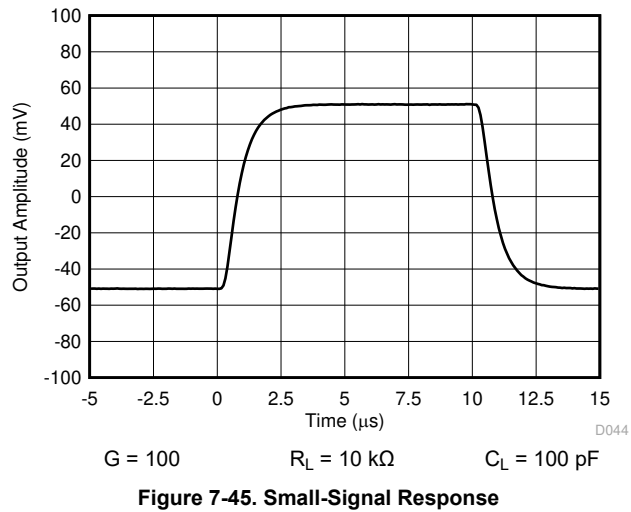
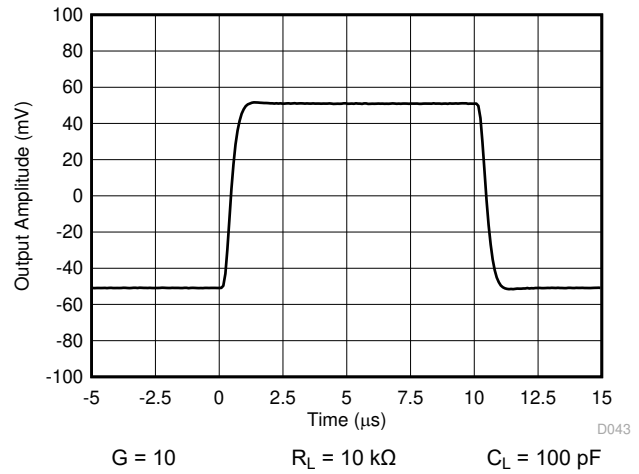
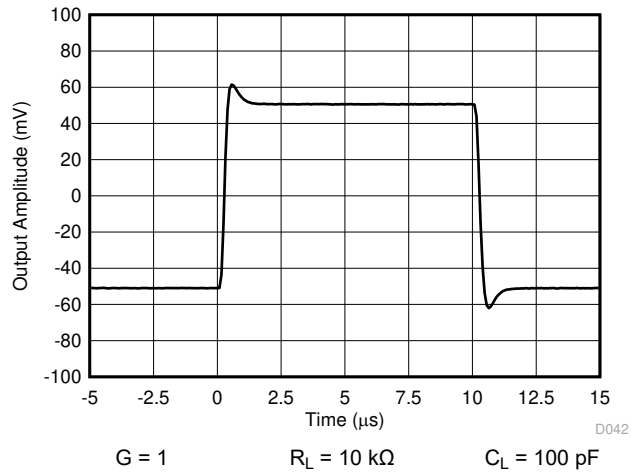


Figure 7-42. Overshoot vs Capacitive Loads

## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)



## 7.6 Typical Characteristics (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 15\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ ,  $V_{REF} = 0\text{ V}$ , and  $G = 1$  (unless otherwise noted)

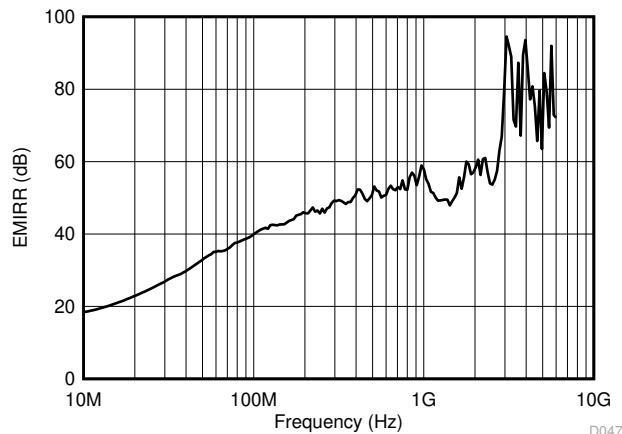


Figure 7-49. Differential-Mode EMI Rejection Ratio

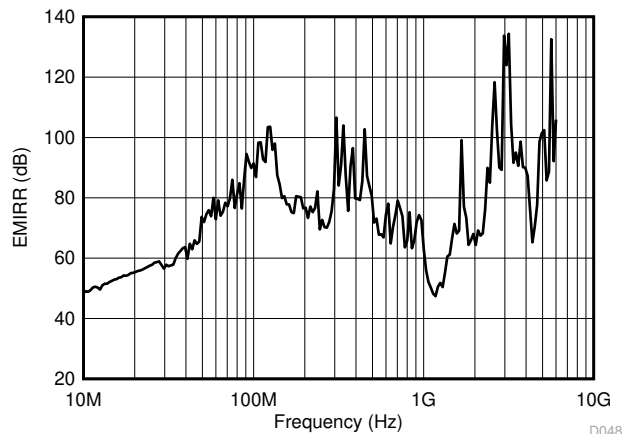


Figure 7-50. Common-Mode EMI Rejection Ratio

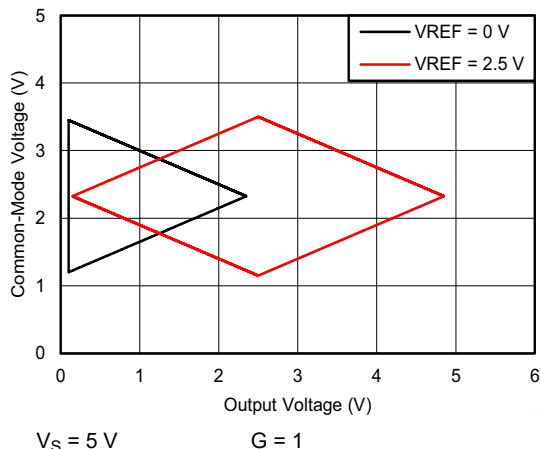


Figure 7-51. Input Common-Mode Voltage vs Output Voltage

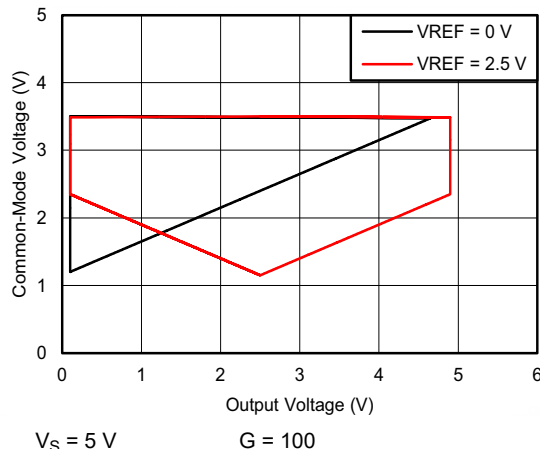


Figure 7-52. Input Common-Mode Voltage vs Output Voltage

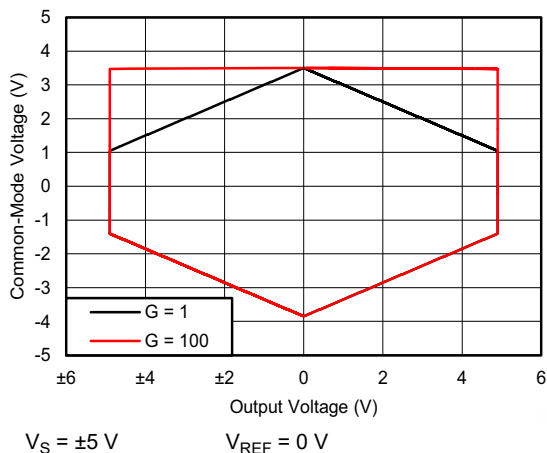


Figure 7-53. Input Common-Mode Voltage vs Output Voltage

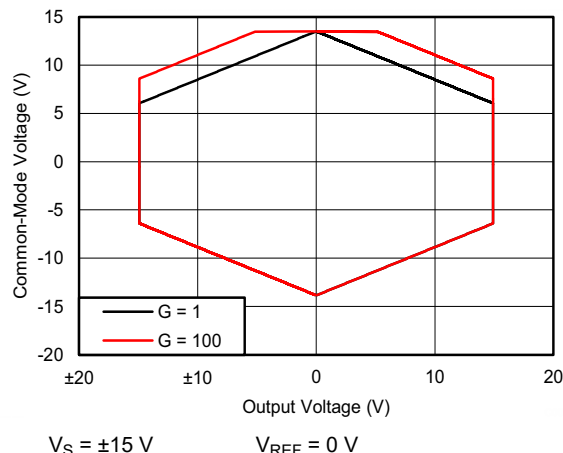


Figure 7-54. Input Common-Mode Voltage vs Output Voltage

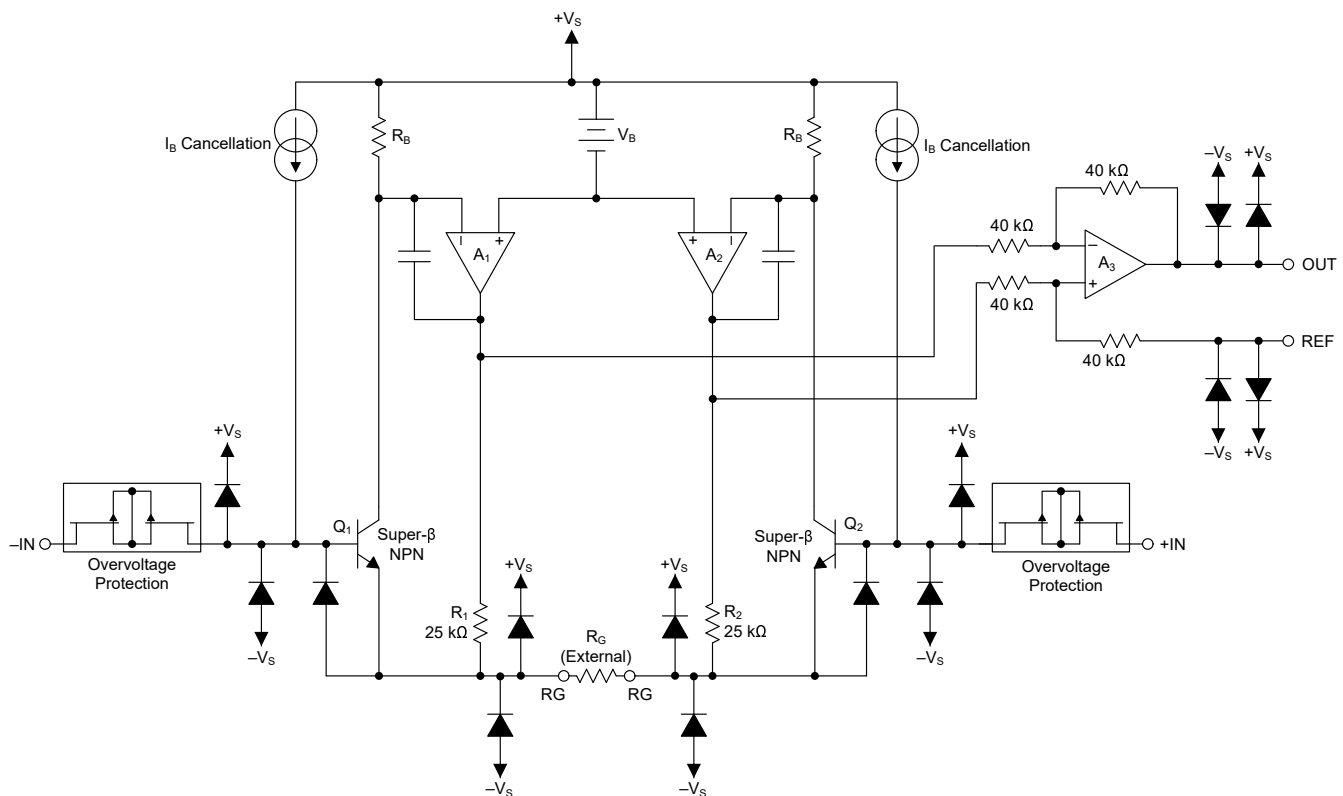
## 8 Detailed Description

### 8.1 Overview

The INA819 is a monolithic precision instrumentation amplifier that incorporates a current-feedback input stage and a four-resistor difference amplifier output stage. The functional block diagram in the next section shows how the differential input voltage is buffered by  $Q_1$  and  $Q_2$  and is forced across  $R_G$ , which causes a signal current to flow through  $R_G$ ,  $R_1$ , and  $R_2$ . The output difference amplifier,  $A_3$ , removes the common-mode component of the input signal and refers the output signal to the REF pin. The  $V_{BE}$  and voltage drop across  $R_1$  and  $R_2$  produce output voltages on  $A_1$  and  $A_2$  that are approximately 0.8 V lower than the input voltages.

Each input is protected by two field-effect transistors (FETs) that provide a low series resistance under normal signal conditions, and preserve excellent noise performance. When excessive voltage is applied, these transistors limit input current to approximately 8 mA.

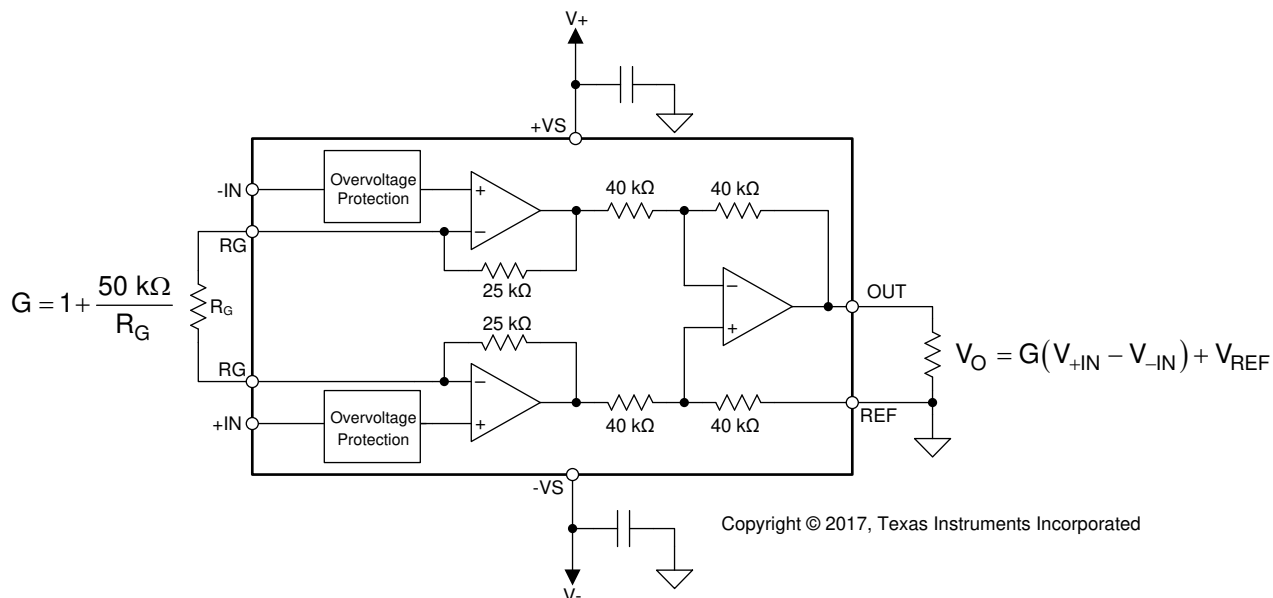
### 8.2 Functional Block Diagram



## 8.3 Feature Description

### 8.3.1 Setting the Gain

Figure 8-1 shows that the gain of the INA819 is set by a single external resistor ( $R_G$ ) connected between the RG pins (pins 1 and 8).



**Figure 8-1. Simplified Diagram of the INA819 With Gain and Output Equations**

The value of  $R_G$  is selected according to Equation 1:

$$G = 1 + \frac{50 \text{ k}\Omega}{R_G} \quad (1)$$

Table 8-1 lists several commonly used gains and resistor values. The 50-kΩ term in Equation 1 is a result of the sum of the two internal 25-kΩ feedback resistors. These on-chip resistors are laser-trimmed to accurate absolute values. The accuracy and temperature coefficients of these resistors are included in the gain accuracy and drift specifications of the INA819. As shown in Figure 8-1 and explained in more details in Section 11, make sure to connect low-ESR, 0.1-μF ceramic bypass capacitors between each supply pin and ground that are placed as close to the device as possible.

**Table 8-1. Commonly Used Gains and Resistor Values**

| DESIRED GAIN | $R_G$ (Ω) | NEAREST 1% $R_G$ (Ω) |
|--------------|-----------|----------------------|
| 1            | NC        | NC                   |
| 2            | 50 k      | 49.9 k               |
| 5            | 12.5 k    | 12.4 k               |
| 10           | 5.556 k   | 5.49 k               |
| 20           | 2.632 k   | 2.61 k               |
| 50           | 1.02 k    | 1.02 k               |
| 100          | 505.1     | 511                  |
| 200          | 251.3     | 249                  |
| 500          | 100.2     | 100                  |
| 1000         | 50.05     | 49.9                 |

### 8.3.1.1 Gain Drift

The stability and temperature drift of the external gain setting resistor ( $R_G$ ) also affects gain. The contribution of  $R_G$  to gain accuracy and drift is determined from Equation 1.

The best gain drift of 5 ppm/°C (maximum) is achieved when the INA819 uses  $G = 1$  without  $R_G$  connected. In this case, gain drift is limited by the mismatch of the temperature coefficient of the integrated 40-kΩ resistors in the differential amplifier ( $A_3$ ). At gains greater than 1, gain drift increases as a result of the individual drift of the 25-kΩ resistors in the feedback of  $A_1$  and  $A_2$ , relative to the drift of the external gain resistor ( $R_G$ .) The low temperature coefficient of the internal feedback resistors improves the overall temperature stability of applications using gains greater than 1 V/V over alternate solutions.

Low resistor values required for high gain make wiring resistance an important consideration. Sockets add to the wiring resistance and contribute additional gain error (such as a possible unstable gain error) at gains of approximately 100 or greater. To maintain stability, avoid parasitic capacitance of more than a few picofarads at  $R_G$  connections. Careful matching of any parasitics on the  $R_G$  pins maintains optimal CMRR over frequency; see Figure 7-17.

### 8.3.2 EMI Rejection

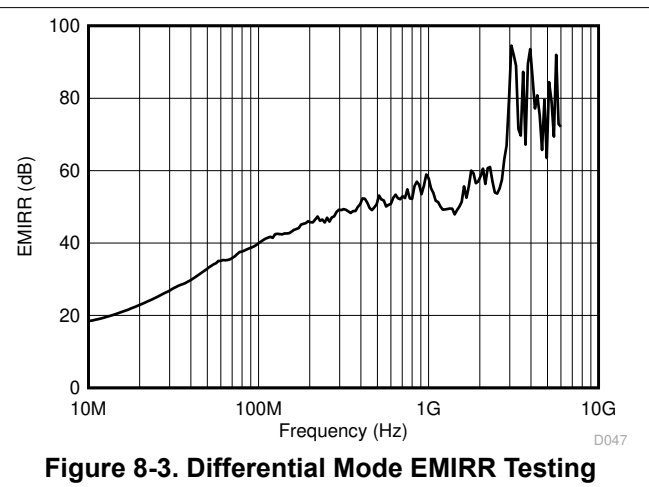
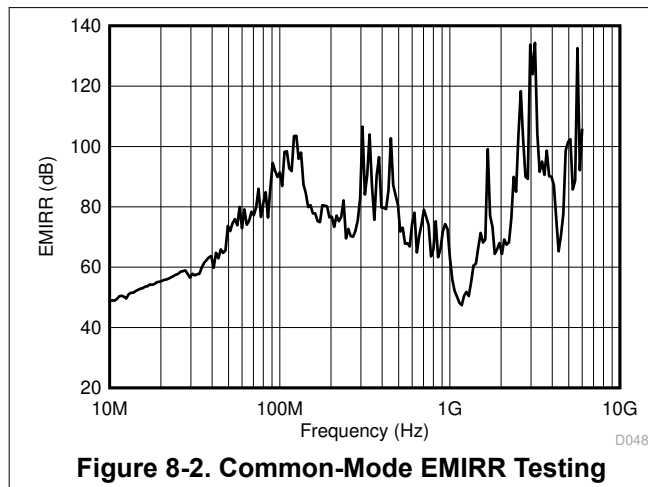
Texas Instruments developed a method to accurately measure the immunity of an amplifier over a broad frequency spectrum extending from 10 MHz to 6 GHz. This method uses an EMI rejection ratio (EMIRR) to quantify the ability of the INA819 to reject EMI. The offset resulting from an input EMI signal is calculated using Equation 2:

$$\Delta V_{OS} = \left( \frac{V_{RF\_PEAK}^2}{100 \text{ mV}_p} \right) \cdot 10^{-\left( \frac{EMIRR \text{ (dB)}}{20} \right)} \quad (2)$$

where

- $V_{RF\_PEAK}$  is the peak amplitude of the input EMI signal.

Figure 8-2 and Figure 8-3 show the INA819 EMIRR graph for differential and common-mode EMI rejection across this frequency range. Table 8-2 lists the EMIRR values for the INA819 at frequencies commonly encountered in real-world applications. Applications listed in Table 8-2 are centered on or operated near the frequency shown. Depending on the end-system requirements, additional EMI filters may be required near the signal inputs of the system. Incorporating known good practices such as using short traces, low-pass filters, and damping resistors combined with parallel and shielded signal routing may be required.

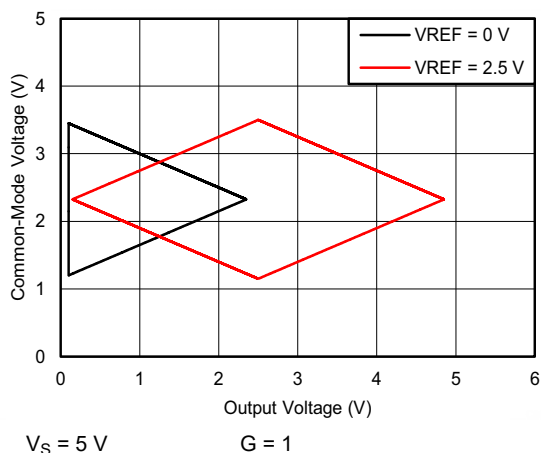
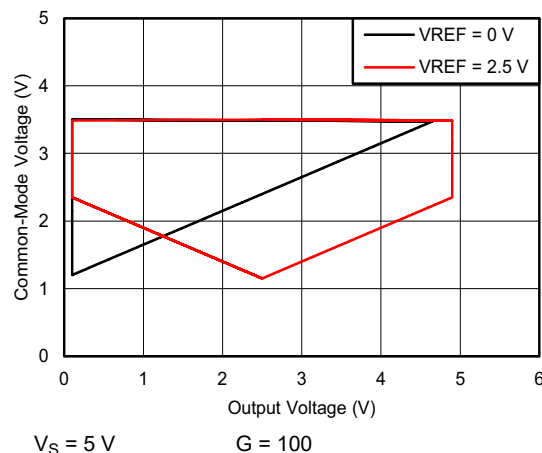
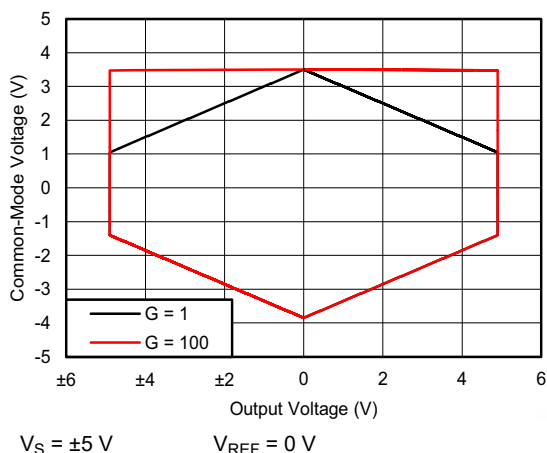
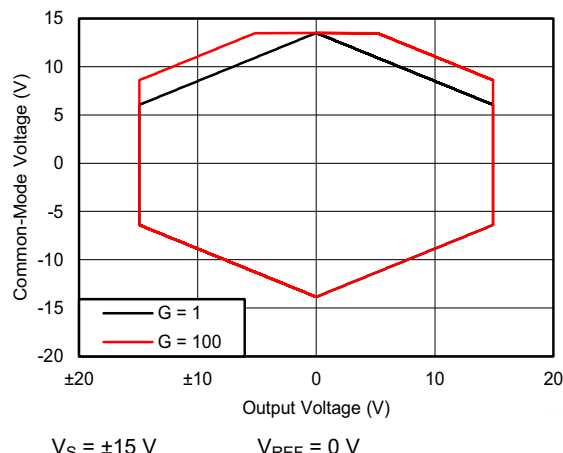


**Table 8-2. INA819 EMIRR for Frequencies of Interest**

| FREQUENCY | APPLICATION OR ALLOCATION                                                                                                                                                        | DIFFERENTIAL EMIRR | COMMON-MODE EMIRR |
|-----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-------------------|
| 400 MHz   | Mobile radio, mobile satellite, space operation, weather, radar, ultrahigh-frequency (UHF) applications                                                                          | 52 dB              | 80 dB             |
| 900 MHz   | Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (up to 1.6 GHz), GSM, aeronautical mobile, UHF applications                     | 55 dB              | 71 dB             |
| 1.8 GHz   | GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)                                                                                  | 58 dB              | 73 dB             |
| 2.4 GHz   | 802.11b, 802.11g, 802.11n, Bluetooth®, mobile personal communications, industrial, scientific and medical (ISM) radio band, amateur radio and satellite, S-band (2 GHz to 4 GHz) | 59 dB              | 95 dB             |
| 3.6 GHz   | Radiolocation, aero communication and navigation, satellite, mobile, S-band                                                                                                      | 78 dB              | 96 dB             |
| 5 GHz     | 802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)                                                | 70 dB              | 100 dB            |

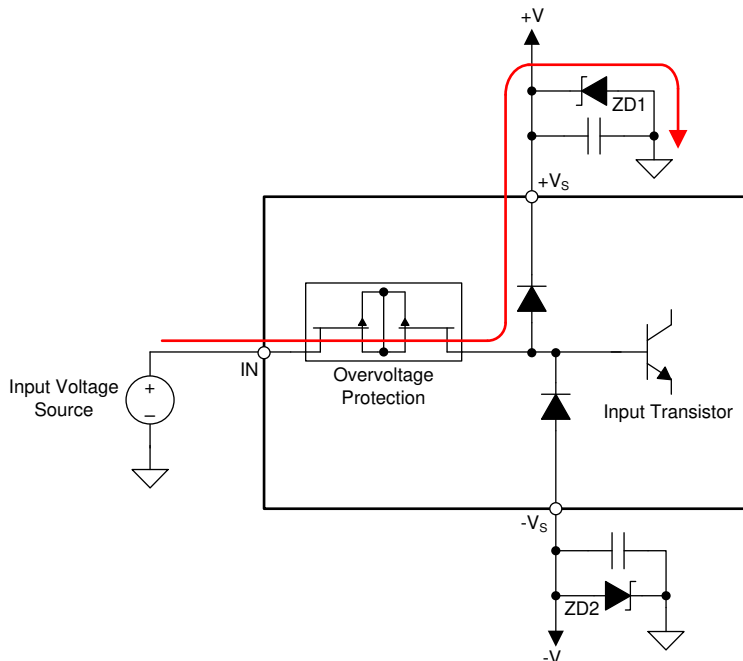
### 8.3.3 Input Common-Mode Range

The linear input voltage range of the INA819 input circuitry extends within 1.5 volts (typical) of both power supplies and maintains excellent common-mode rejection throughout this range. The common-mode range for the most common operating conditions are shown in Figure 8-4 to Figure 8-7. The common-mode range for other operating conditions is best calculated using the [Analog Engineers Calculator](#).


**Figure 8-4. Input Common-Mode Voltage vs Output Voltage**

**Figure 8-5. Input Common-Mode Voltage vs Output Voltage**

**Figure 8-6. Input Common-Mode Voltage vs Output Voltage**

**Figure 8-7. Input Common-Mode Voltage vs Output Voltage**

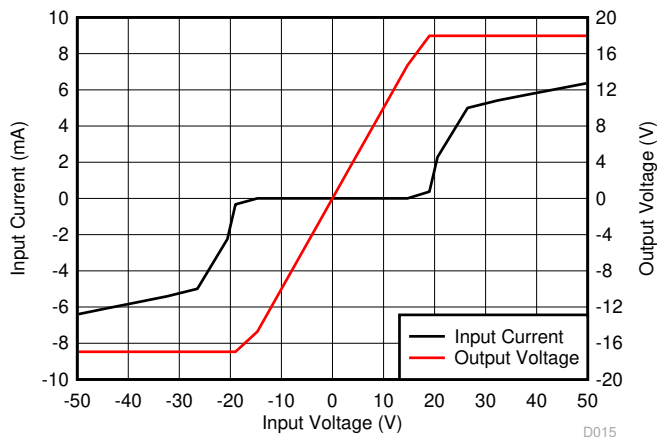
### 8.3.4 Input Protection

The inputs of the INA819 device are individually protected for voltages up to  $\pm 60$  V. For example, a condition of  $-60$  V on one input and  $+60$  V on the other input does not cause damage. Internal circuitry on each input provides low series impedance under normal signal conditions. If the input is overloaded, the protection circuitry limits the input current to a value of approximately 8 mA.



**Figure 8-8. Input Current Path During an Overvoltage Condition**

During an input overvoltage condition, current flows through the input protection diodes into the power supplies; see Figure 8-8. If the power supplies are unable to sink current, then Zener diode clamps (ZD1 and ZD2 in Figure 8-8) must be placed on the power supplies to provide a current pathway to ground. Figure 8-9 shows the input current for input voltages from  $-50$  V to  $50$  V when the INA819 is powered by  $\pm 15$ -V supplies.



**Figure 8-9. Input Current vs Input Overvoltage**

### 8.3.5 Operating Voltage

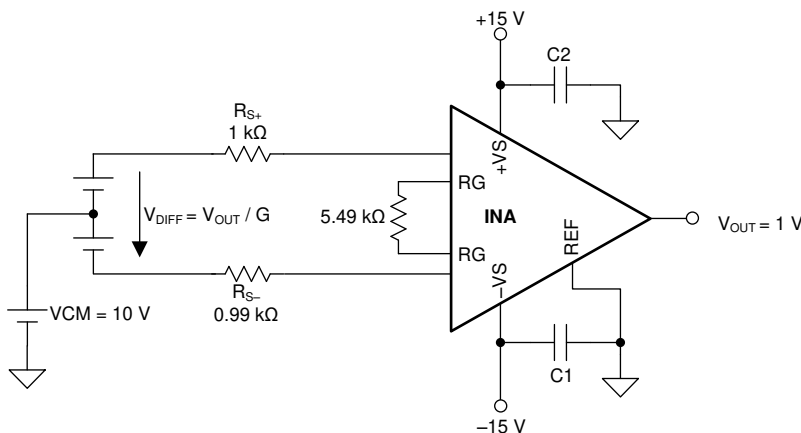
The INA819 operates over a power-supply range of 4.5 V to 36 V ( $\pm 2.25$  V to  $\pm 18$  V).

#### CAUTION

Supply voltages higher than 40 V ( $\pm 20$  V) can permanently damage the device. Parameters that vary over supply voltage or temperature are shown in [Section 7.6](#).

### 8.3.6 Error Sources

Most modern signal-conditioning systems calibrate errors at room temperature. However, calibration of errors that result from a change in temperature is normally difficult and costly. Therefore, minimize these errors by choosing high-precision components, such as the INA819, that have improved specifications in critical areas that impact the precision of the overall system. [Figure 8-10](#) shows an example application.



**Figure 8-10. Example Application with  $G = 10$  V/V and 1-V Output Voltage**

Resistor-adjustable devices (such as the INA819) show the lowest gain error in  $G = 1$  because of the inherently well-matched drift of the internal resistors of the differential amplifier. At gains greater than 1 (for instance,  $G = 10$  V/V or  $G = 100$  V/V), the gain error becomes a significant error source because of the contribution of the resistor drift of the 25-k $\Omega$  feedback resistors in conjunction with the external gain resistor. Except for very high gain applications, the gain drift is by far the largest error contributor compared to other drift errors, such as offset drift.

The INA819 offers excellent gain error over temperature for both  $G > 1$  and  $G = 1$  (no external gain resistor). [Table 8-4](#) summarizes the major error sources in common INA applications and compares the three cases of  $G = 1$  (no external resistor) and  $G = 10$  (5.49-k $\Omega$  external resistor) and  $G = 100$  (511- $\Omega$  external resistor). All calculations are assuming an output voltage of  $V_{OUT} = 1$  V. Thus, the input signal  $V_{DIFF}$  (given by  $V_{DIFF} = V_{OUT}/G$ ) exhibits smaller and smaller amplitudes with increasing gain  $G$ . In this example,  $V_{DIFF} = 1$  mV at  $G = 1000$ . All calculations refer the error to the input for easy comparison and system evaluation. As [Table 8-4](#) shows, errors generated by the input stage (such as input offset voltage) are more dominant at higher gain, while the effects of output stage are suppressed because they are divided by the gain when referring them back to the input. The gain error and gain drift error are much more significant for gains greater than 1 because of the contribution of the resistor drift of the 25-k $\Omega$  feedback resistors in conjunction with the external gain resistor. In most applications, static errors (absolute accuracy errors) can readily be removed during calibration in production, while the drift errors are the key factors limiting overall system performance.

**Table 8-3. System Specifications for Error Calculation**

| QUANTITY                      | VALUE | UNIT   |
|-------------------------------|-------|--------|
| V <sub>OUT</sub>              | 1     | V      |
| V <sub>CM</sub>               | 10    | V      |
| V <sub>S</sub>                | 1     | V      |
| R <sub>S+</sub>               | 1000  | Ω      |
| R <sub>S-</sub>               | 999   | Ω      |
| RG tolerance                  | 0.01  | %      |
| RG drift                      | 10    | ppm/°C |
| Temperature range upper limit | 105   | °C     |

**Table 8-4. Error Calculation**

| ERROR SOURCE                                            | ERROR CALCULATION                                                                                                                 | INA819 VALUES                                  |                  |                         |                           |                            |
|---------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------|------------------|-------------------------|---------------------------|----------------------------|
|                                                         |                                                                                                                                   | SPECIFICATION                                  | UNIT             | G = 1<br>ERROR<br>(ppm) | G = 100<br>ERROR<br>(ppm) | G = 1000<br>ERROR<br>(ppm) |
| ABSOLUTE ACCURACY AT 25°C                               |                                                                                                                                   |                                                |                  |                         |                           |                            |
| Input offset voltage                                    | V <sub>OSI</sub> / V <sub>DIFF</sub>                                                                                              | 35                                             | μV               | 35                      | 350                       | 3500                       |
| Output offset voltage                                   | V <sub>OSO</sub> / (G × V <sub>DIFF</sub> )                                                                                       | 300                                            | μV               | 300                     | 300                       | 300                        |
| Input offset current                                    | I <sub>OS</sub> × maximum (R <sub>S+</sub> , R <sub>S-</sub> ) / V <sub>DIFF</sub>                                                | 0.5                                            | nA               | 1                       | 5                         | 50                         |
| CMRR (min)                                              | V <sub>CM</sub> / (10 <sup>CMRR/20</sup> × V <sub>DIFF</sub> )                                                                    | 90 (G = 1),<br>110 (G = 10),<br>130 (G = 100)  | dB               | 316                     | 316                       | 316                        |
| PSRR (min)                                              | (V <sub>CC</sub> – V <sub>S</sub> ) / (10 <sup>PSRR/20</sup> × V <sub>DIFF</sub> )                                                | 110 (G = 1),<br>114 (G = 10),<br>130 (G = 100) | dB               | 3                       | 20                        | 32                         |
| Gain error from INA (max)                               | GE(%) × 10 <sup>4</sup>                                                                                                           | 0.02 (G = 1),<br>0.15 (G = 10, 100)            | %                | 200                     | 1500                      | 1500                       |
| Gain error from external resistor RG (max)              | GE(%) × 10 <sup>4</sup>                                                                                                           | 0.01                                           | %                | 100                     | 100                       | 100                        |
| Total absolute accuracy error (ppm) at 25°C, worst case | sum of all errors                                                                                                                 | —                                              | —                | 955                     | 2591                      | 5798                       |
| Total absolute accuracy error (ppm) at 25°C, average    | rms sum of all errors                                                                                                             | —                                              | —                | 491                     | 1604                      | 3835                       |
| DRIFT TO 105°C                                          |                                                                                                                                   |                                                |                  |                         |                           |                            |
| Gain drift from INA (max)                               | GTC × (T <sub>A</sub> – 25)                                                                                                       | 5 (G = 1),<br>35 (G = 10, 100)                 | ppm/°C           | 400                     | 2800                      | 2800                       |
| Gain drift from external resistor RG (max)              | GTC × (T <sub>A</sub> – 25)                                                                                                       | 10                                             | ppm/°C           | 800                     | 800                       | 800                        |
| Input offset voltage drift (max)                        | (V <sub>OSI_TC</sub> / V <sub>DIFF</sub> ) × (T <sub>A</sub> – 25)                                                                | 0.4                                            | μV/°C            | 32                      | 320                       | 3200                       |
| Output offset voltage drift                             | [V <sub>OSO_TC</sub> / (G × V <sub>DIFF</sub> )] × (T <sub>A</sub> – 25)                                                          | 5                                              | μV/°C            | 400                     | 400                       | 400                        |
| Offset current drift                                    | I <sub>OS_TC</sub> × maximum (R <sub>S+</sub> , R <sub>S-</sub> ) × (T <sub>A</sub> – 25) / V <sub>DIFF</sub>                     | 20                                             | pA/°C            | 2                       | 16                        | 160                        |
| Total drift error to 105°C (ppm), worst case            | sum of all errors                                                                                                                 | —                                              | —                | 1634                    | 4336                      | 7360                       |
| Total drift error to 105°C (ppm), typical               | rms sum of all errors                                                                                                             | —                                              | —                | 980                     | 2957                      | 4348                       |
| RESOLUTION                                              |                                                                                                                                   |                                                |                  |                         |                           |                            |
| Gain nonlinearity                                       |                                                                                                                                   | 10 (G = 1, 10),<br>15 (G = 100)                | ppm of FS        | 10                      | 10                        | 15                         |
| Voltage noise (at 1 kHz)                                | $\sqrt{\text{BW}} \times \sqrt{e_{\text{NI}}^2 + \left[\frac{e_{\text{NO}}}{\text{G}}\right]^2} \times \frac{6}{V_{\text{DIFF}}}$ | e <sub>NI</sub> = 8,<br>e <sub>NO</sub> = 90   | μV <sub>PP</sub> | 1204                    | 1070                      | 3941                       |
| Current noise (at 1kHz)                                 | I <sub>N</sub> × maximum (R <sub>S+</sub> , R <sub>S-</sub> ) × √BW / V <sub>DIFF</sub>                                           | 0.13                                           | pA/√ Hz          | 0.3                     | 2                         | 11                         |
| Total resolution error (ppm), worst case                | sum of all errors                                                                                                                 | —                                              | —                | 1214                    | 1080                      | 3956                       |
| Total resolution error (ppm), typical                   | rms sum of all errors                                                                                                             | —                                              | —                | 1204                    | 1070                      | 3941                       |
| TOTAL ERROR                                             |                                                                                                                                   |                                                |                  |                         |                           |                            |
| Total error (ppm), worst case                           | sum of all errors                                                                                                                 | —                                              | —                | 3802                    | 8007                      | 17113                      |
| Total error (ppm), typical                              | rms sum of all errors                                                                                                             | —                                              | —                | 1628                    | 3530                      | 7010                       |

## 8.4 Device Functional Modes

The INA819 has a single functional mode and operates when the power-supply voltage is greater than 4.5 V ( $\pm 2.25$  V). The maximum power-supply voltage for the INA819 is 36 V ( $\pm 18$  V.)

## 9 Application and Implementation

### Note

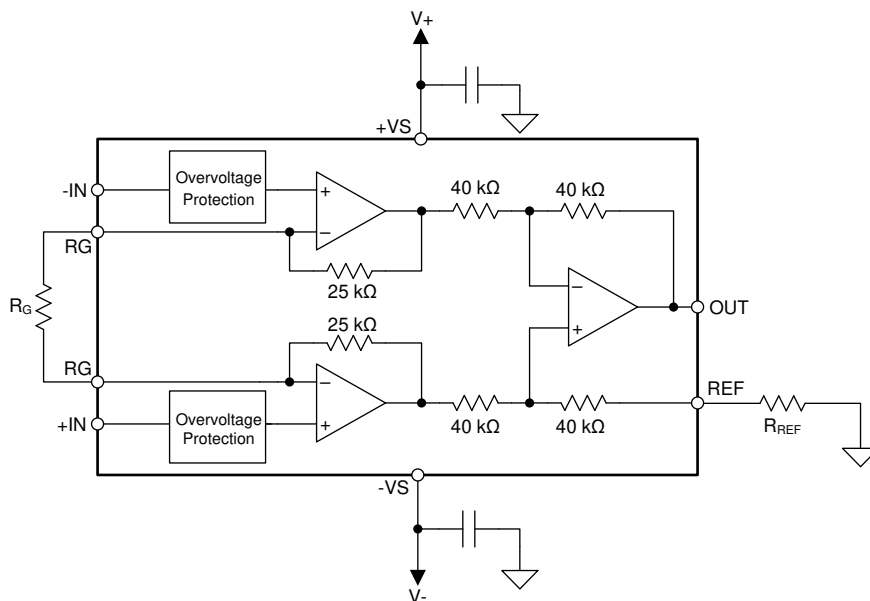
Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes, as well as validating and testing their design implementation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

### 9.1 Application Information

#### 9.1.1 Reference Pin

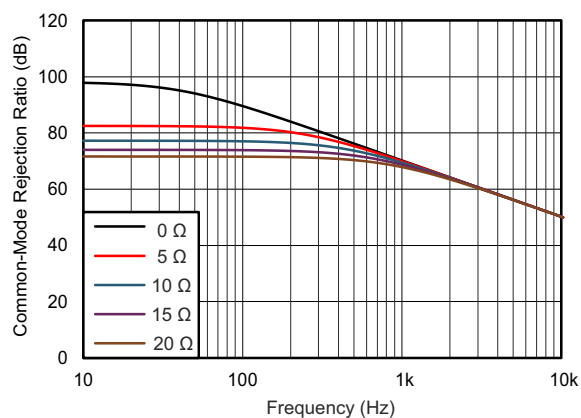
The output voltage of the INA819 is developed with respect to the voltage on the reference pin (REF.) Often, in dual-supply operation, REF (pin 6) is connected to the low-impedance system ground. In single-supply operation, offsetting the output signal to a precise midsupply level is useful (for example, 2.5 V in a 5-V supply environment). To accomplish this level shift, a voltage source must be connected to the REF pin to level-shift the output so that the INA819 drives a single-supply analog-to-digital converter (ADC).

The voltage source applied to the reference pin must have a low output impedance. As shown in Figure 9-1, any resistance at the reference pin (shown as  $R_{REF}$  in Figure 9-1) is in series with an internal 40-k $\Omega$  resistor.



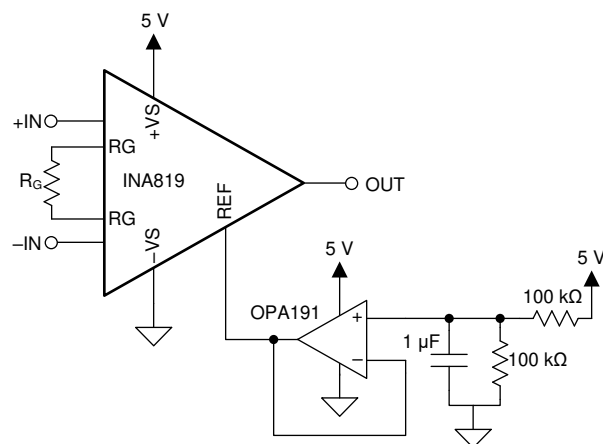
**Figure 9-1. Parasitic Resistance Shown at the Reference Pin**

The parasitic resistance at the reference pin ( $R_{REF}$ ) creates an imbalance in the four resistors of the internal difference amplifier that results in a degraded common-mode rejection ratio (CMRR). Figure 9-2 shows the degradation in CMRR of the INA819 as a result of increased resistance at the reference pin. For the best performance, keep the source impedance to the REF pin ( $R_{REF}$ ) less than 5  $\Omega$ .



**Figure 9-2. The Effect of Increasing Resistance at the Reference Pin**

Voltage reference devices are an excellent option for providing a low-impedance voltage source for the reference pin. However, if a resistor voltage divider generates a reference voltage, the divider must be buffered by an op amp, as Figure 9-3 shows, to avoid CMRR degradation.



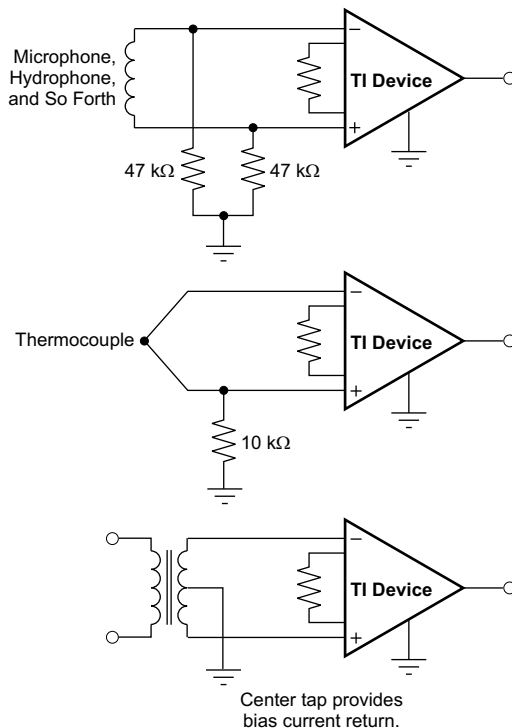
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**Figure 9-3. Using an Op Amp to Buffer Reference Voltages**

### 9.1.2 Input Bias Current Return Path

The input impedance of the INA819 is extremely high—approximately 100 G $\Omega$ . However, a path must be provided for the input bias current of both inputs. This input bias current is typically 150 pA. High input impedance means that this input bias current changes very little with varying input voltage.

For proper operation, input circuitry must provide a path for input bias current. Figure 9-4 shows various provisions for an input bias current path. Without a bias current path, the inputs float to a potential that exceeds the common-mode range of the INA819, and the input amplifiers saturate. If the differential source resistance is low, the bias current return path can connect to one input (as shown in the thermocouple example in Figure 9-4). With a higher source impedance, using two equal resistors provides a balanced input with possible advantages of a lower input offset voltage as a result of bias current and better high-frequency common-mode rejection.



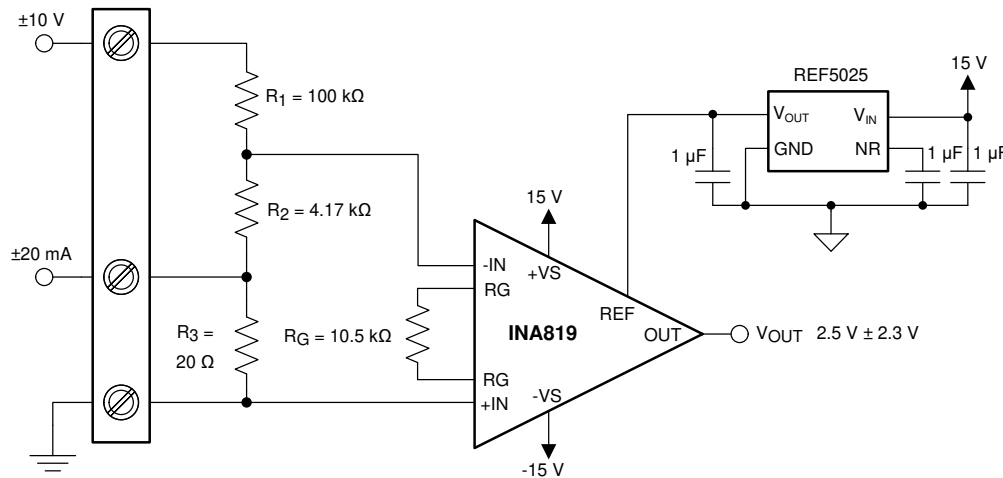
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**Figure 9-4. Providing an Input Common-Mode Current Path**

## 9.2 Typical Applications

### 9.2.1 Three-Pin Programmable Logic Controller (PLC)

Figure 9-5 shows a three-pin programmable-logic controller (PLC) design for the INA819. This PLC reference design accepts inputs of  $\pm 10$  V or  $\pm 20$  mA. The output is a single-ended voltage of  $2.5 \text{ V} \pm 2.3 \text{ V}$  (or 200 mV to 4.8 V). Many PLCs typically have these input and output ranges.



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**Figure 9-5. PLC Input ( $\pm 10$  V, 4 mA to 20 mA)**

#### 9.2.1.1 Design Requirements

For this application, the design requirements are as follows:

- 4-mA to 20-mA input with less than 20-Ω burden
- $\pm 20$ -mA input with less than 20-Ω burden
- $\pm 10$ -V input with impedance of approximately 100 kΩ
- Maximum 4-mA to 20-mA or  $\pm 20$ -mA burden voltage equal to  $\pm 0.4 \text{ V}$
- Output range within 0 V to 5 V

#### 9.2.1.2 Detailed Design Procedure

There are two modes of operation for the circuit shown in Figure 9-5: current input and voltage input. This design requires  $R_1 \gg R_2 \gg R_3$ . Given this relationship, Equation 3 calculates the current input mode transfer function.

$$V_{\text{OUT-I}} = V_D \times G + V_{\text{REF}} = -(I_{\text{IN}} \times R_3) \times G + V_{\text{REF}} \quad (3)$$

where

- $G$  represents the gain of the instrumentation amplifier.
- $V_D$  represents the differential voltage at the INA819 inputs.
- $V_{\text{REF}}$  is the voltage at the INA819 REF pin.
- $I_{\text{IN}}$  is the input current.

Equation 4 shows the transfer function for the voltage input mode.

$$V_{\text{OUT-V}} = V_D \times G + V_{\text{REF}} = -\left[V_{\text{IN}} \times \frac{R_2}{R_1 + R_2}\right] \times G + V_{\text{REF}} \quad (4)$$

where

- $V_{\text{IN}}$  is the input voltage.

$R_1$  sets the input impedance of the voltage input mode. The minimum typical input impedance is 100 k $\Omega$ . The  $R_1$  value is 100 k $\Omega$  because increasing the  $R_1$  value also increases noise. The value of  $R_3$  must be extremely small compared to  $R_1$  and  $R_2$ . 20  $\Omega$  for  $R_3$  is selected because that resistance value is much smaller than  $R_1$  and yields an input voltage of  $\pm 400$  mV when operated in current mode ( $\pm 20$  mA).

Use Equation 5 to calculate  $R_2$  given  $V_D = \pm 400$  mV,  $V_{IN} = \pm 10$  V, and  $R_1 = 100$  k $\Omega$ .

$$V_D = V_{IN} \times \frac{R_2}{R_1 + R_2} \rightarrow R_2 = \frac{R_1 \times V_D}{V_{IN} - V_D} = 4.167 \text{ k}\Omega \quad (5)$$

The value obtained from Equation 5 is not a standard 0.1% value, so 4.17 k $\Omega$  is selected.  $R_1$  and  $R_2$  also use 0.1% tolerance resistors to minimize error.

Use Equation 6 to calculate the ideal gain of the instrumentation amplifier.

$$G = \frac{V_{OUT} - V_{REF}}{V_D} = \frac{4.8 \text{ V} - 2.5 \text{ V}}{400 \text{ mV}} = 5.75 \frac{\text{V}}{\text{V}} \quad (6)$$

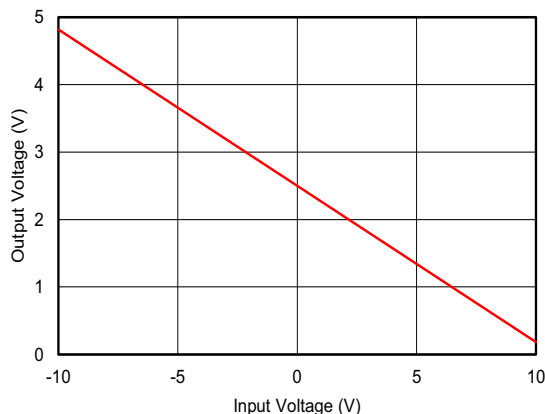
Equation 7 calculates the gain-setting resistor value using the INA819 gain equation (Equation 1).

$$R_G = \frac{50 \text{ k}\Omega}{G - 1} = \frac{50 \text{ k}\Omega}{5.75 - 1} = 10.5 \text{ k}\Omega \quad (7)$$

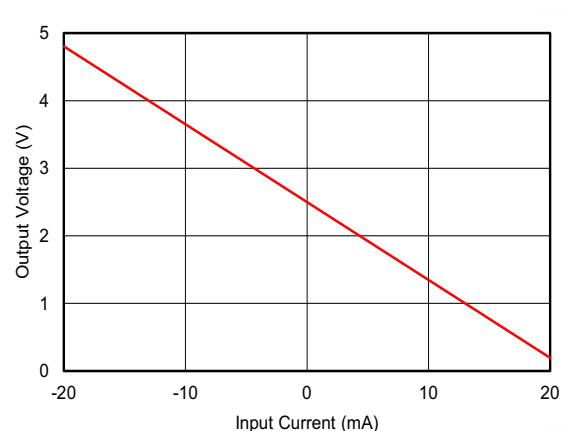
Use a standard 0.1% resistor value of 10.5 k $\Omega$  for this design.

### 9.2.1.3 Application Curves

Figure 9-6 and Figure 9-7 show typical characteristic curves for the circuit in Figure 9-5.



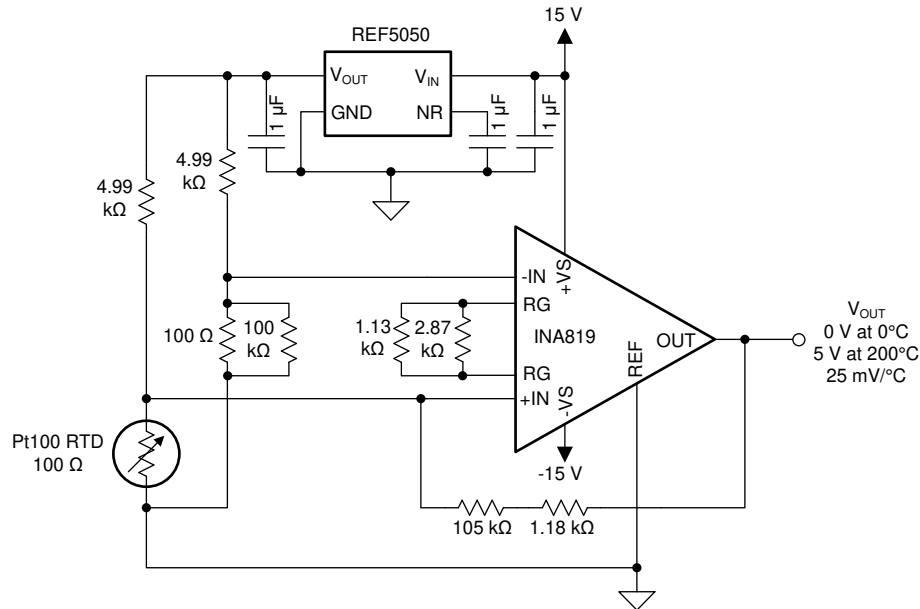
**Figure 9-6. PLC Output Voltage vs Input Voltage**



**Figure 9-7. PLC Output Voltage vs Input Current**

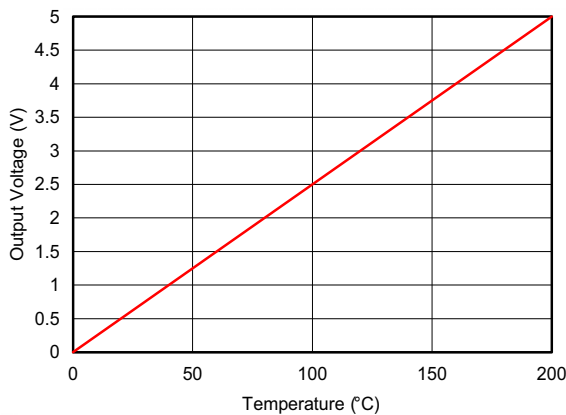
## 9.2.2 Resistance Temperature Detector Interface

Figure 9-8 illustrates a 3-wire interface circuit for resistance temperature detectors (RTDs). The circuit incorporates analog linearization and has an output voltage range from 0 V to 5 V. The linearization technique employed is described in [Analog linearization of resistance temperature detectors analog application journal](#). Series and parallel combinations of standard 1% resistor values are used to achieve less than 0.02°C of error over a 200°C temperature span.

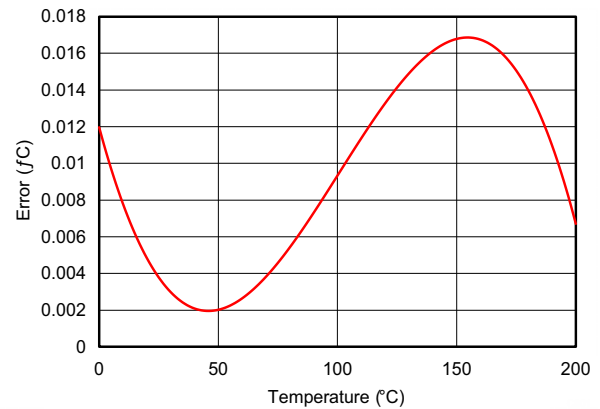


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**Figure 9-8. A 3-Wire Interface for RTDs With Analog Linearization**



**Figure 9-9. Transfer Function of a 3-Wire RTD Interface**



**Figure 9-10. Temperature Error Over the Full Temperature Range**

## 10 Power Supply Recommendations

The nominal performance of the INA819 is specified with a supply voltage of  $\pm 15$  V and midsupply reference voltage. The device also operates using power supplies from  $\pm 2.25$  V (4.5 V) to  $\pm 18$  V (36 V) and non-midsupply reference voltages with excellent performance. Parameters that can vary significantly with operating voltage and reference voltage are shown in the [Section 7.6](#) section.

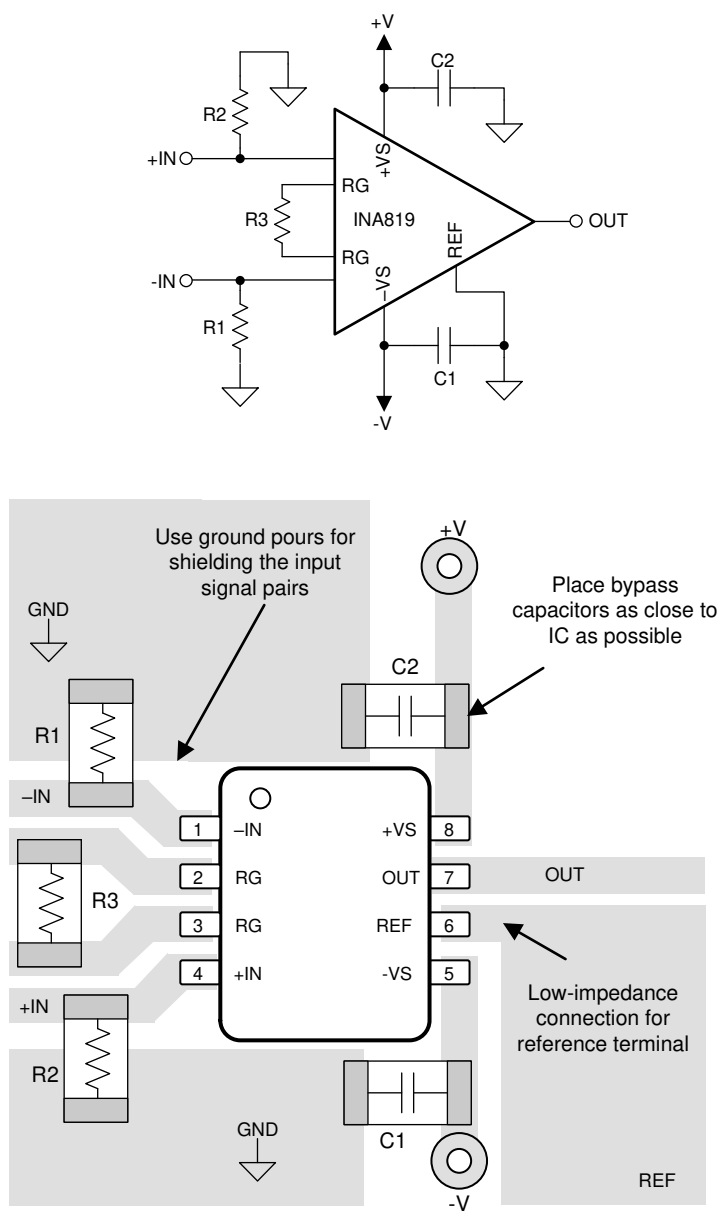
## 11 Layout

### 11.1 Layout Guidelines

Attention to good layout practices is always recommended. For best operational performance of the device, use good PCB layout practices, including:

- Take care to make sure that both input paths are well-matched for source impedance and capacitance to avoid converting common-mode signals into differential signals. Even slight mismatch in parasitic capacitance at the gain setting pins can degrade CMRR over frequency. For example, in applications that implement gain switching using switches or PhotoMOS® relays to change the value of  $R_G$ , select the component so that the switch capacitance is as small as possible and most importantly so that capacitance mismatch between the  $R_G$  pins is minimized.
- Noise can propagate into analog circuitry through the power pins of the circuit as a whole and of the device. Bypass capacitors reduce the coupled noise by providing low-impedance power sources local to the analog circuitry.
  - Connect low-ESR, 0.1- $\mu$ F ceramic bypass capacitors between each supply pin and ground, placed as close to the device as possible. A single bypass capacitor from  $V+$  to ground is applicable for single-supply applications.
- To reduce parasitic coupling, run the input traces as far away from the supply or output traces as possible. If these traces cannot be kept separate, crossing the sensitive trace perpendicular is much better than in parallel with the noisy trace.
- Place the external components as close to the device as possible. As shown in [Figure 11-1](#), keep  $R_G$  close to the pins to minimize parasitic capacitance.
- Keep the traces as short as possible.
- Connect exposed thermal pad to negative supply  $-V$ .

## 11.2 Layout Example



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**Figure 11-1. Example Schematic and Associated PCB Layout**

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Development Support

##### 12.1.1.1 PSpice® for TI

PSpice® for TI is a design and simulation environment that helps evaluate performance of analog circuits. Create subsystem designs and prototype solutions before committing to layout and fabrication, reducing development cost and time to market.

##### 12.1.1.2 TINA-TI™ Simulation Software (Free Download)

TINA-TI™ simulation software is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI simulation software is a free, fully-functional version of the TINA™ software, preloaded with a library of macromodels, in addition to a range of both passive and active models. TINA-TI simulation software provides all the conventional dc, transient, and frequency domain analysis of SPICE, as well as additional design capabilities.

Available as a [free download](#) from the Analog eLab Design Center, TINA-TI simulation software offers extensive post-processing capability that allows users to format results in a variety of ways. Virtual instruments offer the ability to select input waveforms and probe circuit nodes, voltages, and waveforms, creating a dynamic quick-start tool.

---

#### Note

These files require that either the TINA software or TINA-TI software be installed. Download the free TINA-TI simulation software from the [TINA-TI™ software folder](#).

---

### 12.2 Documentation Support

#### 12.2.1 Related Documentation

For related documentation see the following:

Texas Instruments, [Comprehensive Error Calculation for Instrumentation Amplifiers application note](#)

#### 12.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). Click on *Subscribe to updates* 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.

#### 12.4 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.

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PSpice® is a registered trademark of Cadence Design Systems, Inc.

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## 12.6 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.

## 12.7 Glossary

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

## 13 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 Device | Status<br>(1) | Package Type | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2) | Lead finish/<br>Ball material<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|--------------|--------------------|------|----------------|-----------------|--------------------------------------|----------------------|--------------|-------------------------|-------------------------|
| INA819ID         | ACTIVE        | SOIC         | D                  | 8    | 75             | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | INA819                  | <a href="#">Samples</a> |
| INA819IDGKR      | ACTIVE        | VSSOP        | DGK                | 8    | 2500           | RoHS & Green    | NIPDAUAG   SN                        | Level-2-260C-1 YEAR  | -40 to 125   | 1X3Q                    | <a href="#">Samples</a> |
| INA819IDGKT      | ACTIVE        | VSSOP        | DGK                | 8    | 250            | RoHS & Green    | NIPDAUAG   SN                        | Level-2-260C-1 YEAR  | -40 to 125   | 1X3Q                    | <a href="#">Samples</a> |
| INA819IDR        | ACTIVE        | SOIC         | D                  | 8    | 2500           | RoHS & Green    | NIPDAU                               | Level-2-260C-1 YEAR  | -40 to 125   | INA819                  | <a href="#">Samples</a> |
| INA819IDRGR      | ACTIVE        | SON          | DRG                | 8    | 3000           | RoHS & Green    | NIPDAU                               | Level-1-260C-UNLIM   | -40 to 125   | INA819                  | <a href="#">Samples</a> |
| INA819IDRGT      | ACTIVE        | SON          | DRG                | 8    | 250            | RoHS & Green    | NIPDAU                               | Level-1-260C-UNLIM   | -40 to 125   | INA819                  | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

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

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

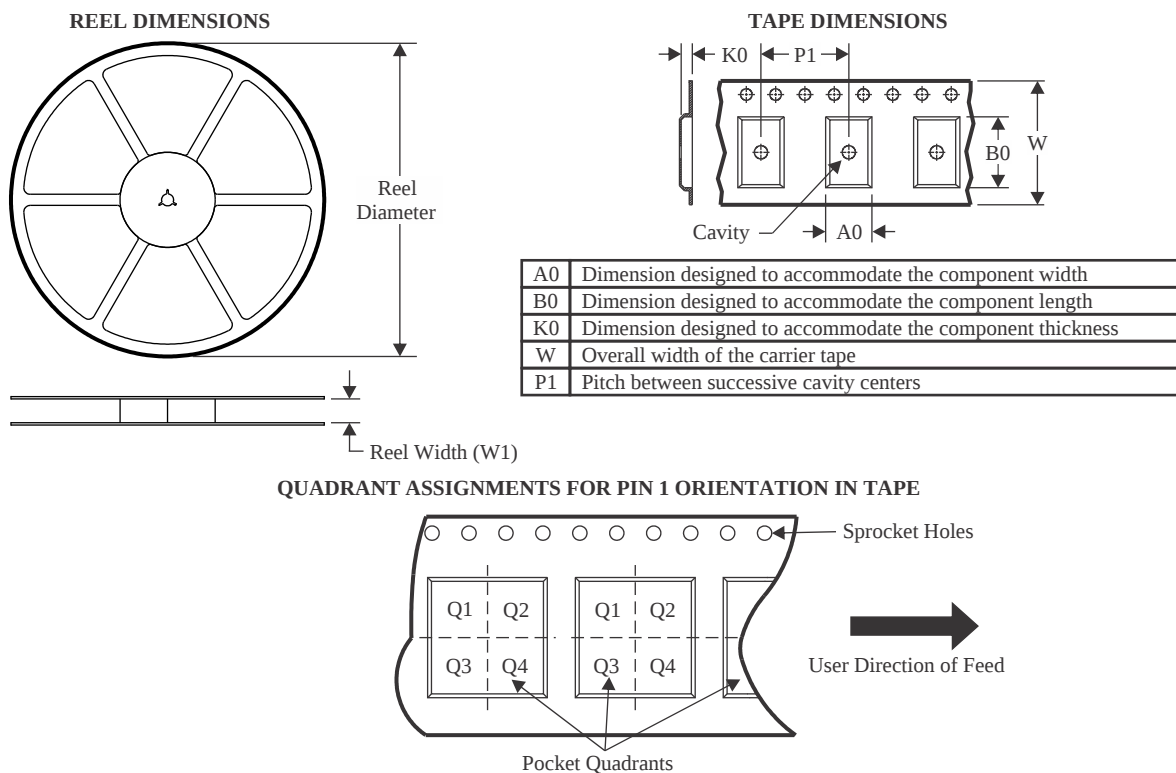
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices 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.

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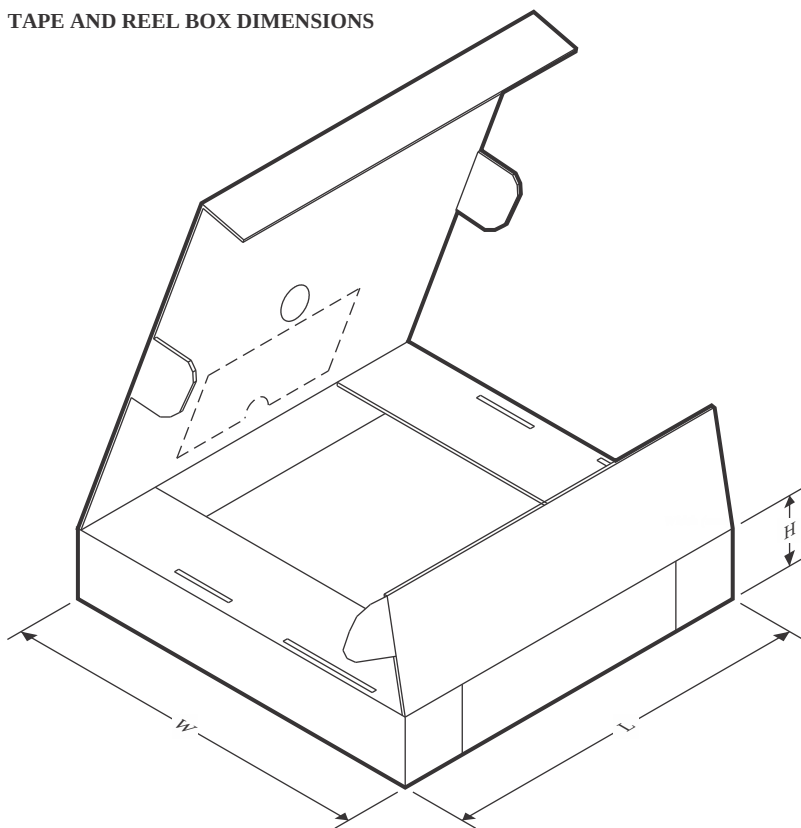
## TAPE AND REEL INFORMATION



\*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 |
|-------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| INA819IDGKR | VSSOP        | DGK             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| INA819IDGKR | VSSOP        | DGK             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| INA819IDGKT | VSSOP        | DGK             | 8    | 250  | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| INA819IDGKT | VSSOP        | DGK             | 8    | 250  | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| INA819IDR   | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| INA819IDRGR | SON          | DRG             | 8    | 3000 | 330.0              | 12.4               | 3.3     | 3.3     | 1.1     | 8.0     | 12.0   | Q2            |
| INA819IDRGT | SON          | DRG             | 8    | 250  | 180.0              | 12.4               | 3.3     | 3.3     | 1.1     | 8.0     | 12.0   | Q2            |

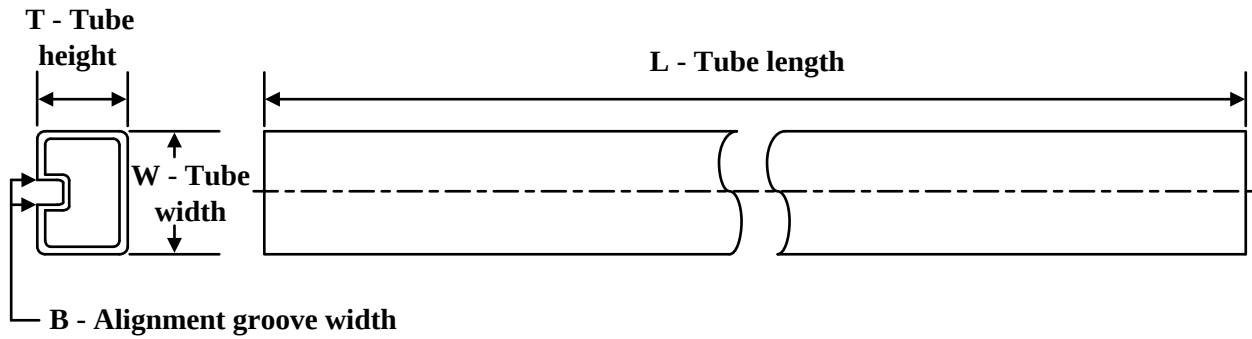
## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

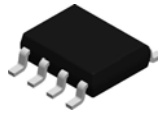
| Device      | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|-------------|--------------|-----------------|------|------|-------------|------------|-------------|
| INA819IDGKR | VSSOP        | DGK             | 8    | 2500 | 366.0       | 364.0      | 50.0        |
| INA819IDGKR | VSSOP        | DGK             | 8    | 2500 | 366.0       | 364.0      | 50.0        |
| INA819IDGKT | VSSOP        | DGK             | 8    | 250  | 366.0       | 364.0      | 50.0        |
| INA819IDGKT | VSSOP        | DGK             | 8    | 250  | 366.0       | 364.0      | 50.0        |
| INA819IDR   | SOIC         | D               | 8    | 2500 | 356.0       | 356.0      | 35.0        |
| INA819IDRGR | SON          | DRG             | 8    | 3000 | 367.0       | 367.0      | 35.0        |
| INA819IDRGT | SON          | DRG             | 8    | 250  | 210.0       | 185.0      | 35.0        |

## TUBE



\*All dimensions are nominal

| Device   | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|----------|--------------|--------------|------|-----|--------|--------|--------|--------|
| INA819ID | D            | SOIC         | 8    | 75  | 506.6  | 8      | 3940   | 4.32   |

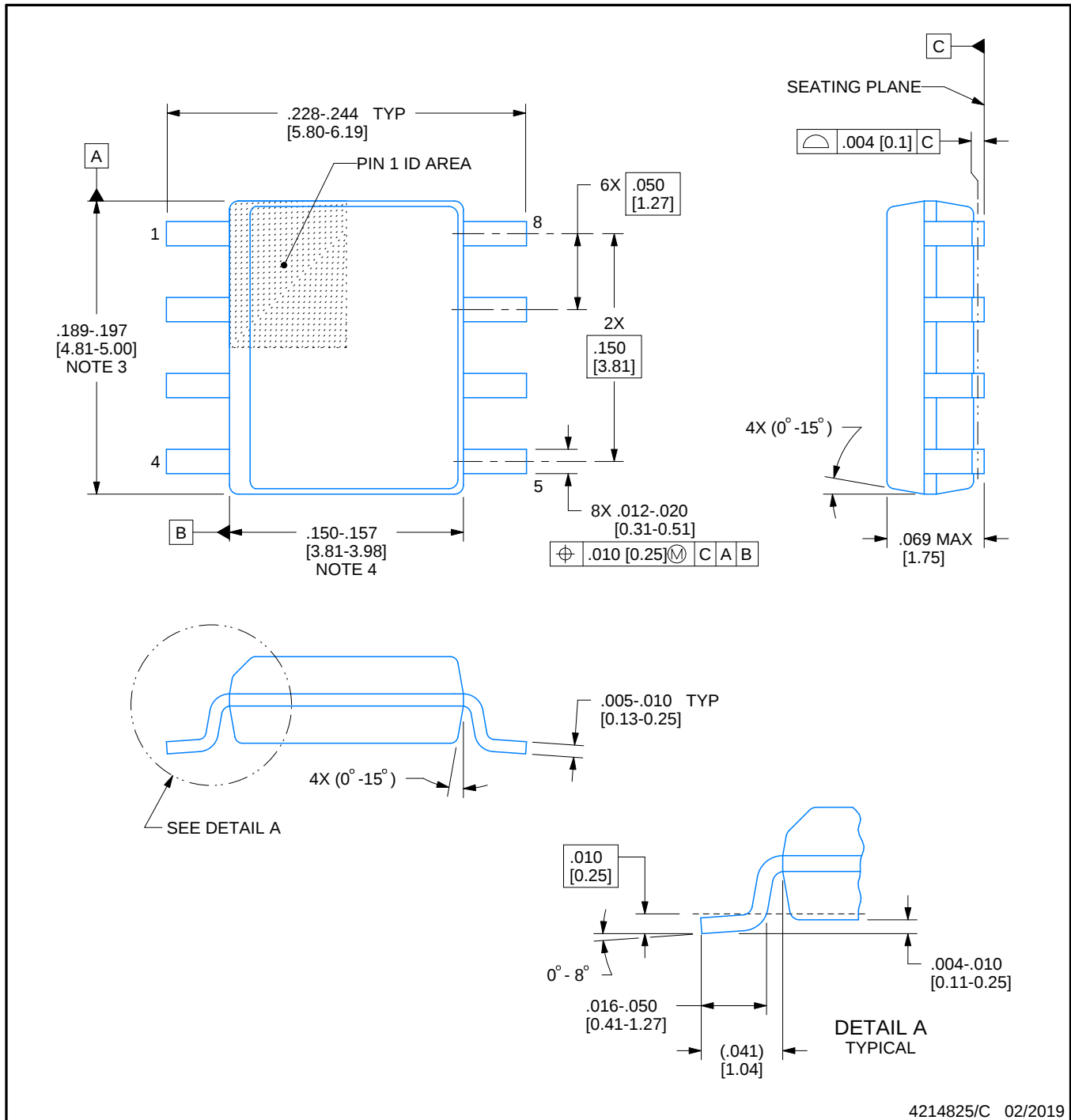


**D0008A**

# PACKAGE OUTLINE

**SOIC - 1.75 mm max height**

SMALL OUTLINE INTEGRATED CIRCUIT



4214825/C 02/2019

## NOTES:

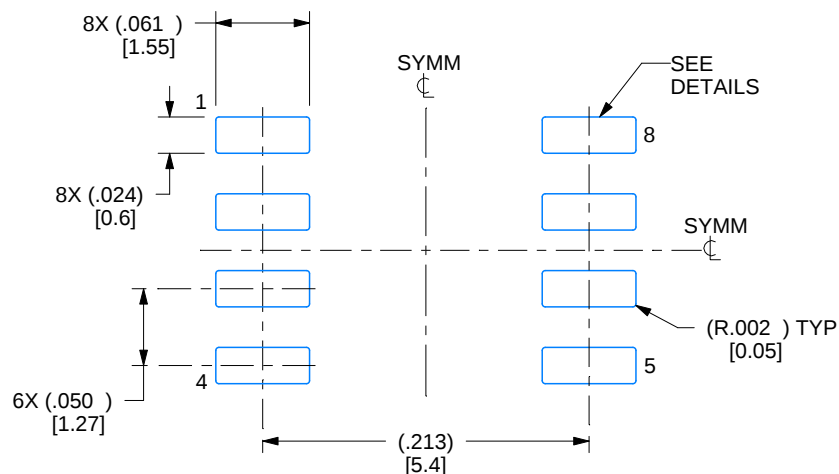
1. Linear dimensions are in inches [millimeters]. Dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. This dimension does not include mold flash, protrusions, or gate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

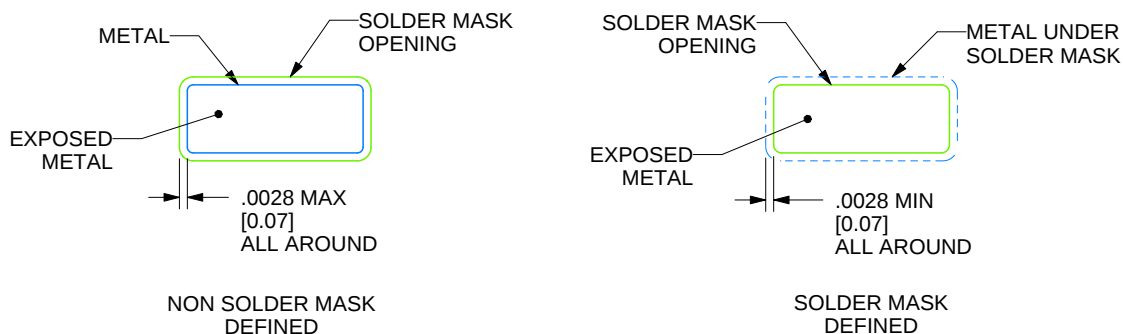
D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:8X



SOLDER MASK DETAILS

4214825/C 02/2019

NOTES: (continued)

6. Publication IPC-7351 may have alternate designs.

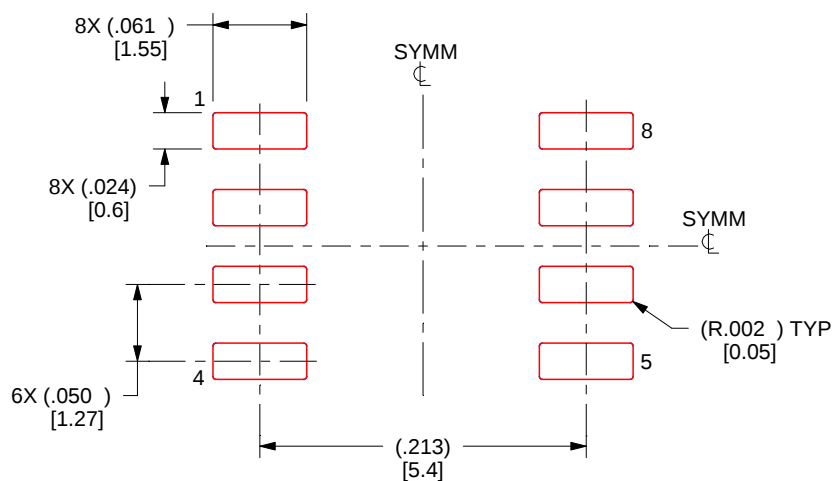
7. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

## EXAMPLE STENCIL DESIGN

D0008A

SOIC - 1.75 mm max height

SMALL OUTLINE INTEGRATED CIRCUIT



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

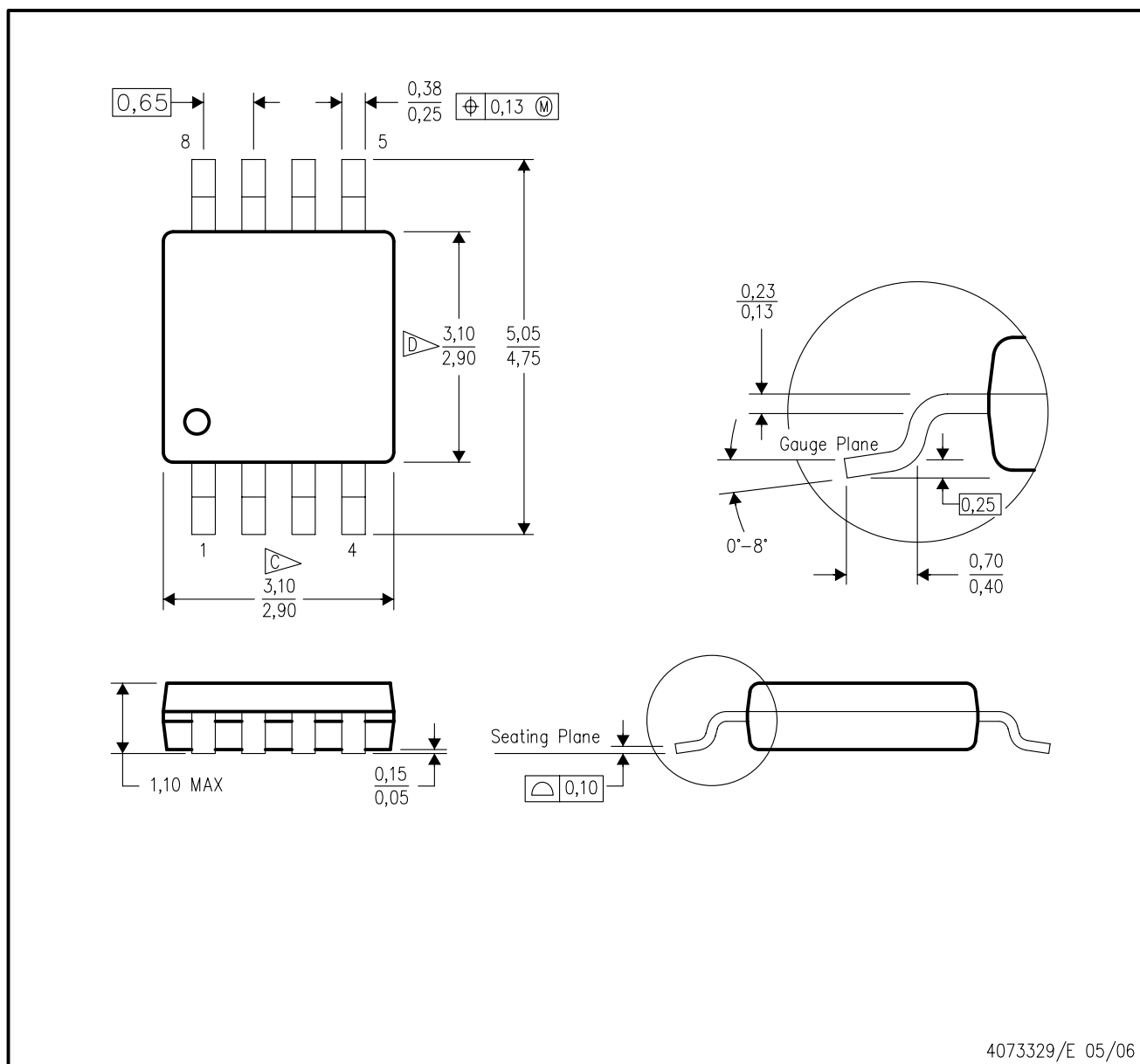
4214825/C 02/2019

NOTES: (continued)

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

## DGK (S-PDSO-G8)

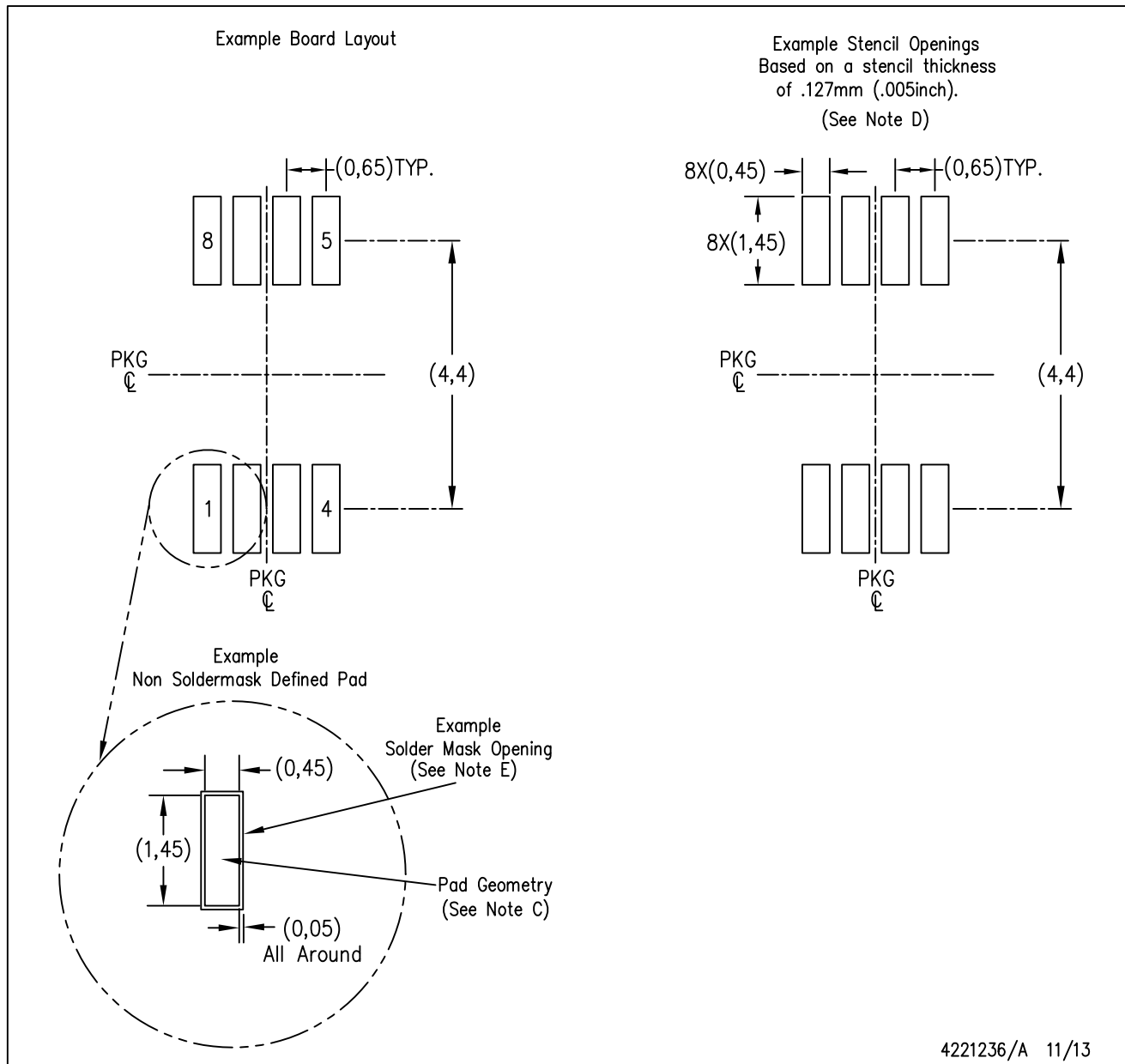
## PLASTIC SMALL-OUTLINE PACKAGE



4073329/E 05/06

DGK (S-PDSO-G8)

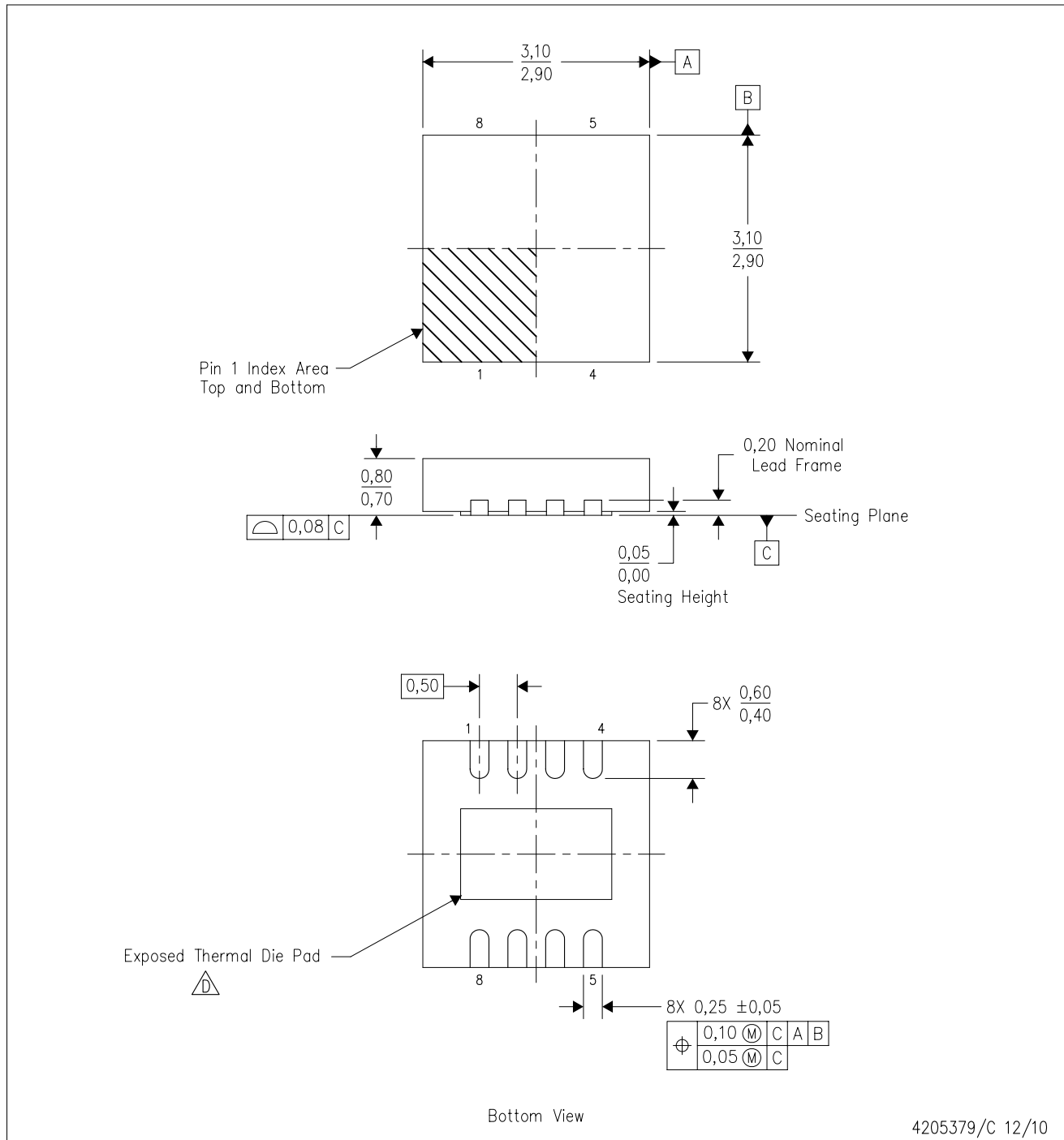
PLASTIC SMALL OUTLINE PACKAGE



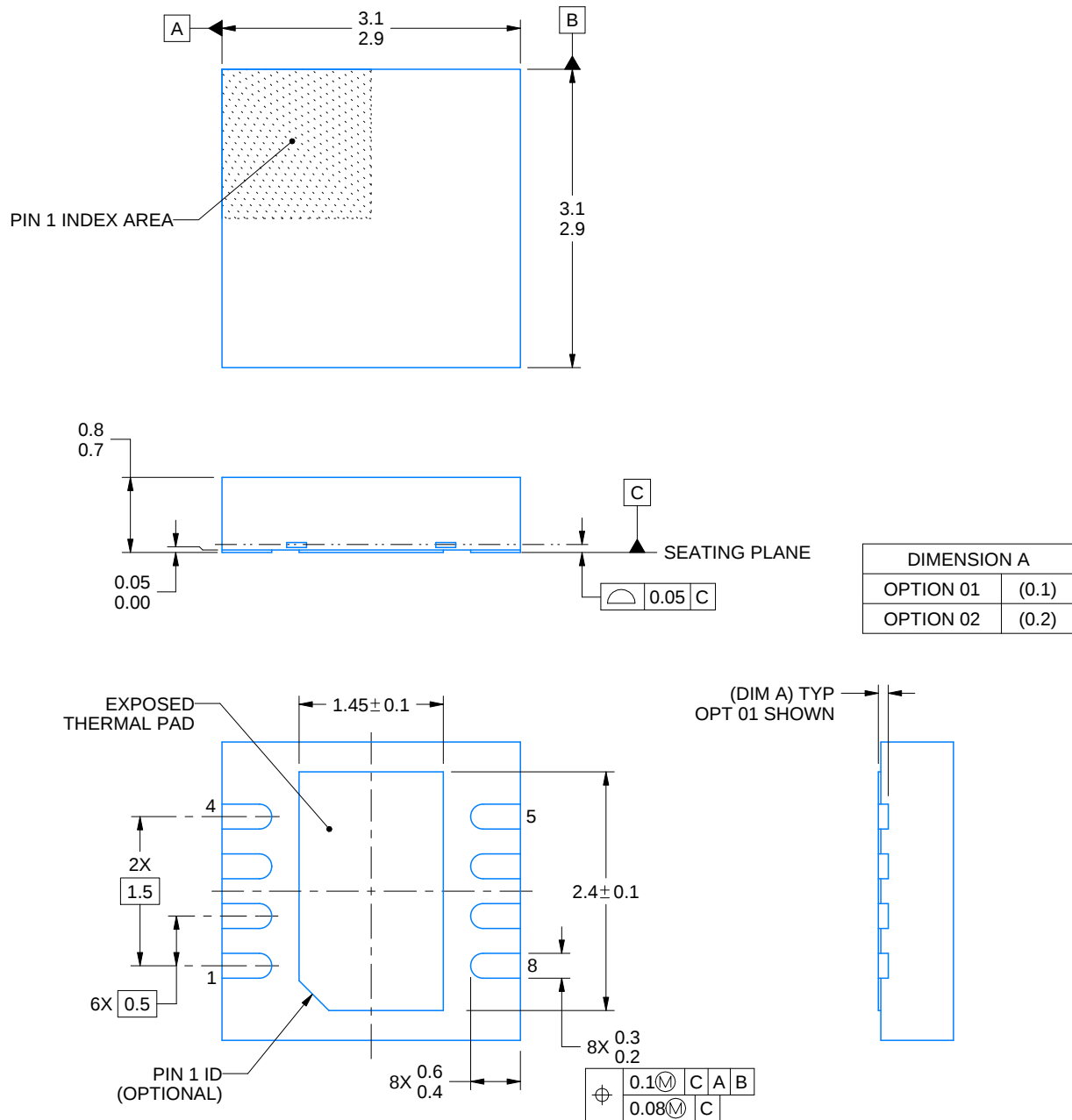
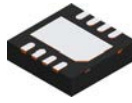
- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Publication IPC-7351 is recommended for alternate designs.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact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

DRG (S-PWSON-N8)

PLASTIC SMALL OUTLINE NO-LEAD



4205379/C 12/10



4218886/A 01/2020

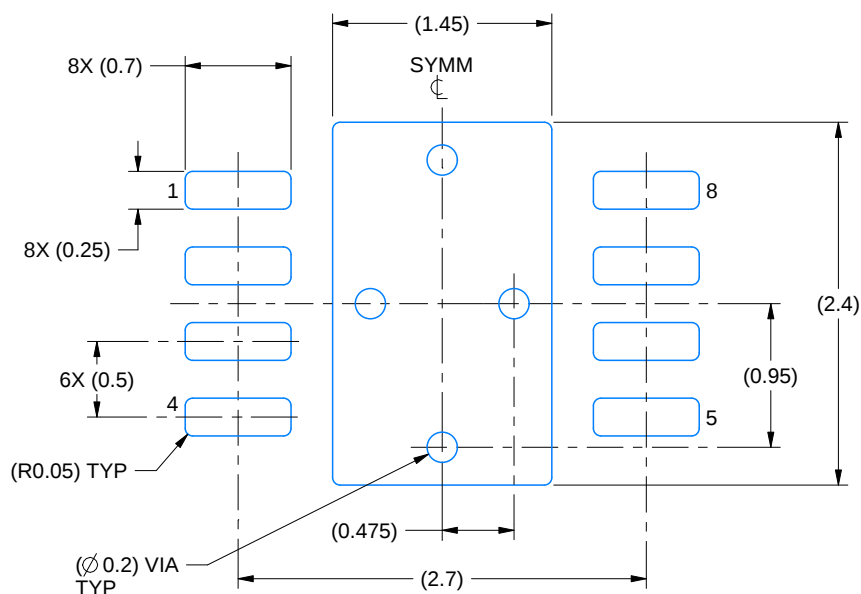
## NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. The package thermal pad must be soldered to the printed circuit board for thermal and mechanical performance.

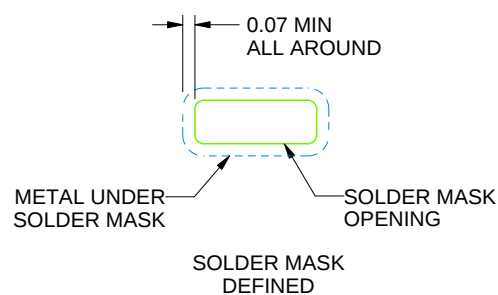
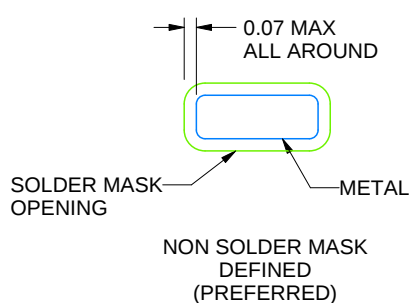
**DRG0008B**

**WSN - 0.8 mm max height**

PLASTIC SMALL OUTLINE - NO LEAD



LAND PATTERN EXAMPLE  
SCALE:20X



## SOLDER MASK DETAILS

4218886/A 01/2020

NOTES: (continued)

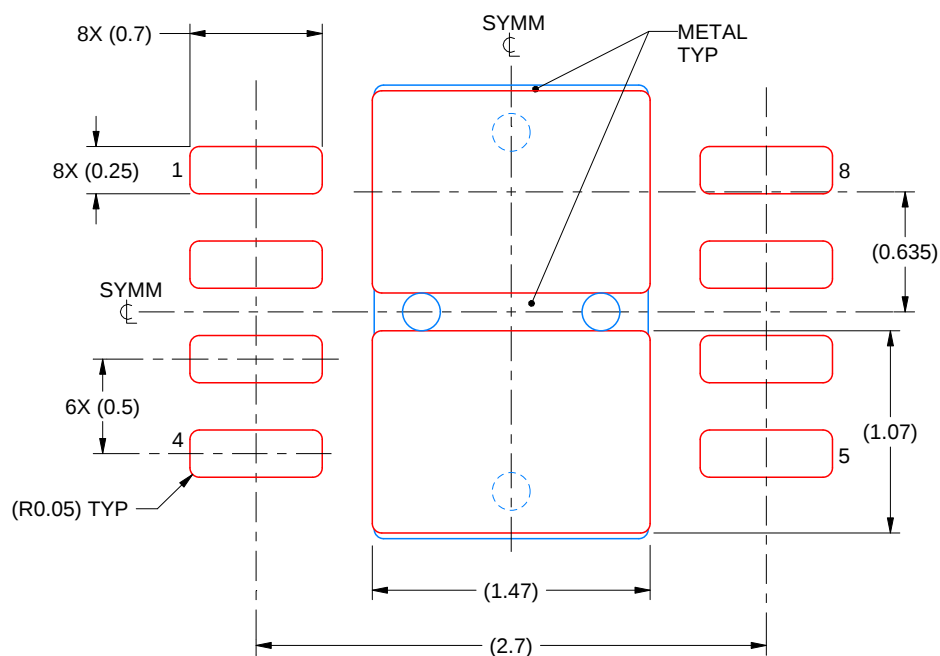
4. This package is designed to be soldered to a thermal pad on the board. For more information, see Texas Instruments literature number SLUA271 ([www.ti.com/lit/slua271](http://www.ti.com/lit/slua271)).
5. Vias are optional depending on application, refer to device data sheet. If any vias are implemented, refer to their locations shown on this view. It is recommended that vias under paste be filled, plugged or tented.

# EXAMPLE STENCIL DESIGN

DRG0008B

WSN - 0.8 mm max height

PLASTIC SMALL OUTLINE - NO LEAD



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL

EXPOSED PAD  
82% PRINTED SOLDER COVERAGE BY AREA  
SCALE:25X

4218886/A 01/2020

NOTES: (continued)

6. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.

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