

# OPA188 Precision, Low-Noise, Rail-to-Rail Output, 36-V, Zero-Drift Operational Amplifier

## 1 Features

- Low offset voltage: 25  $\mu\text{V}$  (maximum)
- Zero drift: 0.03  $\mu\text{V}/^\circ\text{C}$
- Low noise: 8.8 nV/ $\sqrt{\text{Hz}}$ 
  - 0.1-Hz to 10-Hz Noise: 0.25  $\mu\text{V}_{\text{PP}}$
- Excellent dc precision:
  - PSRR: 142 dB
  - CMRR: 146 dB
  - Open-loop gain: 136 dB
- Gain bandwidth: 2 MHz
- Quiescent current: 510  $\mu\text{A}$  (Maximum)
- Wide supply range:  $\pm 2\text{ V}$  to  $\pm 18\text{ V}$
- Rail-to-rail output
- Input includes negative rail
- RFI filtered inputs
- *MicroSIZE* packages

## 2 Applications

- [Weight scale](#)
- [Analog input module](#)
- [Flow transmitter](#)
- [Battery test](#)
- [DC power supply, ac source, electronic load](#)
- [Data acquisition \(DAQ\)](#)
- [Semiconductor test](#)

## 3 Description

The OPA188 operational amplifier uses TI's proprietary auto-zeroing techniques to provide low offset voltage (25- $\mu\text{V}$  maximum) and near [zero-drift](#) over time and temperature. This miniature, high-precision, low-quiescent current amplifier offers high input impedance and rail-to-rail output swing within 15 mV of the rails. The input common-mode range includes the negative rail. Either single or dual supplies can be used in the range from 4 V to 36 V ( $\pm 2\text{ V}$  to  $\pm 18\text{ V}$ ).

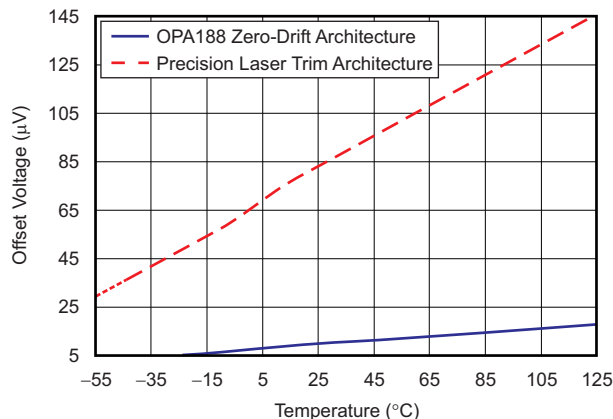
The single version is available in the *MicroSIZE* SOT-23-5, MSOP-8, and SO-8 packages. All versions are specified for operation from  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ .

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

| PART NUMBER | PACKAGE    | BODY SIZE (NOM)          |
|-------------|------------|--------------------------|
| OPA188      | SOIC (8)   | 4.90 mm $\times$ 3.91 mm |
|             | SOT-23 (5) | 2.90 mm $\times$ 1.60 mm |
|             | VSSOP (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.

### Auto-Zero Technology Provides Ultra-Low Temperature Drift



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## 4 Revision History

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

| Changes from Revision B (September 2016) to Revision C                                                 | Page     |
|--------------------------------------------------------------------------------------------------------|----------|
| • Deleted automotive (Q1) device test conditions from plots in this commercial device data sheet ..... | <b>8</b> |

| Changes from Revision A (March 2013) to Revision B                                                                                                                                                                                                                                                                                                             | Page     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| • Added Device Information, Device Comparison, ESD Ratings, and Recommended Operating Conditions tables, and <i>Detailed Description</i> , <i>Applications and Implementation</i> , <i>Power Supply Recommendations</i> , <i>Layout</i> , <i>Device and Documentation Support</i> , and <i>Mechanical, Packaging, and Orderable Information</i> sections ..... | <b>1</b> |
| • Deleted Package Information table; all information now available in the package option addendum at the end of the data sheet .....                                                                                                                                                                                                                           | <b>3</b> |
| • Changed <i>input bias current</i> maximum value for over-temperature test condition in Electrical Characteristics .....                                                                                                                                                                                                                                      | <b>5</b> |
| • Changed <i>input offset current</i> maximum value for over-temperature test condition in Electrical Characteristics .....                                                                                                                                                                                                                                    | <b>5</b> |
| • Changed <i>quiescent current</i> values in Electrical Characteristics.....                                                                                                                                                                                                                                                                                   | <b>5</b> |
| • Changed <i>input bias current</i> maximum value for over-temperature test condition in Electrical Characteristics .....                                                                                                                                                                                                                                      | <b>6</b> |
| • Changed <i>input offset current</i> maximum value for over-temperature test condition in Electrical Characteristics .....                                                                                                                                                                                                                                    | <b>6</b> |
| • Changed <i>quiescent current</i> maximum values in Electrical Characteristics.....                                                                                                                                                                                                                                                                           | <b>6</b> |

| Changes from Original (March 2013) to Revision A  | Page     |
|---------------------------------------------------|----------|
| • Changed document status to Production Data..... | <b>1</b> |

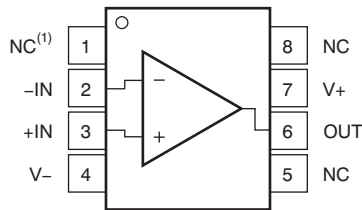
## 5 Device Comparison Table

### 5.1 Portfolio Comparison

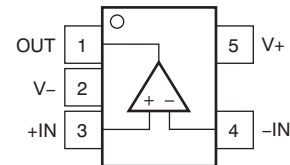
**Table 1. Zero-Drift Amplifier Portfolio**

| VERSION | PRODUCT               | OFFSET VOLTAGE<br>( $\mu\text{V}$ , maximum) | OFFSET VOLTAGE DRIFT<br>( $\mu\text{V}/^\circ\text{C}$ , maximum) | BANDWIDTH<br>(MHz) | INPUT VOLTAGE NOISE<br>( $\mu\text{V}_{\text{PP}}$ , $f = 0.1 \text{ Hz to } 10 \text{ Hz}$ ) |
|---------|-----------------------|----------------------------------------------|-------------------------------------------------------------------|--------------------|-----------------------------------------------------------------------------------------------|
| Single  | OPA188 (4 V to 36 V)  | $\pm 25$                                     | $\pm 0.085$                                                       | 2                  | 0.25                                                                                          |
|         | OPA333 (5 V)          | $\pm 10$                                     | $\pm 0.05$                                                        | 0.35               | 1.1                                                                                           |
|         | OPA378 (5 V)          | $\pm 50$                                     | $\pm 0.25$                                                        | 0.9                | 0.4                                                                                           |
|         | OPA735 (12 V)         | $\pm 5$                                      | $\pm 0.05$                                                        | 1.6                | 2.5                                                                                           |
| Dual    | OPA2188 (4 V to 36 V) | $\pm 25$                                     | $\pm 0.085$                                                       | 2                  | 0.25                                                                                          |
|         | OPA2333 (5 V)         | $\pm 10$                                     | $\pm 0.05$                                                        | 0.35               | 1.1                                                                                           |
|         | OPA2378 (5 V)         | $\pm 50$                                     | $\pm 0.25$                                                        | 0.9                | 0.4                                                                                           |
|         | OPA2735 (12 V)        | $\pm 5$                                      | $\pm 0.05$                                                        | 1.6                | 2.5                                                                                           |
| Quad    | OPA4330 (5 V)         | $\pm 50$                                     | $\pm 0.25$                                                        | 0.35               | 1.1                                                                                           |

## 6 Pin Configuration and Functions

**OPA188 D and DGK Packages  
8-Pin SOIC and 8-Pin VSSOP  
Top View**


(1) NC = no connection.

**OPA188 DBV Package  
5-Pin SOT-23  
Top View**

**Pin Functions**

| PIN  |         |     | I/O | DESCRIPTION                                   |
|------|---------|-----|-----|-----------------------------------------------|
| NAME | D, DGK  | DBV |     |                                               |
| +IN  | 3       | 3   | I   | Noninverting input                            |
| -IN  | 2       | 4   | I   | Inverting input                               |
| NC   | 1, 5, 8 | —   | —   | No internal connection (can be left floating) |
| OUT  | 6       | 1   | O   | Output                                        |
| V+   | 7       | 5   | —   | Positive (highest) power supply               |
| V-   | 4       | 2   | —   | Negative (lowest) power supply                |

## 7 Specifications

### 7.1 Absolute Maximum Ratings

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

|             |                                           |               | MIN        | MAX        | UNIT |
|-------------|-------------------------------------------|---------------|------------|------------|------|
| Voltage     | Supply                                    | Split supply  |            | ±20        | V    |
|             |                                           | Single supply |            | 40         |      |
|             | Signal input pins <sup>(2)</sup>          |               | (V–) – 0.5 | (V+) + 0.5 |      |
|             |                                           | Differential  |            | ±0.7       |      |
| Current     | Signal input pins <sup>(2)</sup>          |               |            | ±10        | mA   |
|             | Output short-circuit <sup>(3)</sup>       |               |            | Continuous |      |
| Temperature | Operating <sup>(4)</sup> , T <sub>A</sub> |               | –55        | 150        | °C   |
|             | Junction, T <sub>J</sub>                  |               |            | 150        |      |
|             | Storage, T <sub>stg</sub>                 |               | –65        | 150        |      |

- (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) Input terminals are diode-clamped to the power-supply rails. Input signals that can swing more than 0.5 V beyond the supply rails should be current-limited to 10 mA or less.
- (3) Short-circuit to ground, V–, or V+.
- (4) Provided device does not exceed maximum junction temperature (T<sub>J</sub>) at any time.

### 7.2 ESD Ratings

|                    |                         |                                                                                | VALUE | UNIT |
|--------------------|-------------------------|--------------------------------------------------------------------------------|-------|------|
| V <sub>(ESD)</sub> | Electrostatic discharge | Human-body model (HBM), per ANSI/ESDA/JEDEC JS-001 <sup>(1)</sup>              | ±1500 | V    |
|                    |                         | Charged-device model (CDM), per JEDEC specification JESD22-C101 <sup>(2)</sup> | ±1000 |      |

- (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 | NOM | MAX | UNIT |
|----------------|-----------------------------|---------------|-----|-----|-----|------|
| V <sub>S</sub> | Operating voltage range     | Split supply  | ±2  |     | ±18 | V    |
|                |                             | Single supply | 4   |     | 36  |      |
| T <sub>A</sub> | Specified temperature range |               | –40 |     | 125 | °C   |

### 7.4 Thermal Information

| THERMAL METRIC <sup>(1)</sup> |                                              | OPA188 |             |            | UNIT |
|-------------------------------|----------------------------------------------|--------|-------------|------------|------|
|                               |                                              | D (SO) | DBV (SOT23) | DGK (MSOP) |      |
|                               |                                              | 8 PINS | 5 PINS      | 8 PINS     |      |
| R <sub>θJA</sub>              | Junction-to-ambient thermal resistance       | 122.0  | 158.8       | 180.4      | °C/W |
| R <sub>θJC(top)</sub>         | Junction-to-case (top) thermal resistance    | 68.5   | 60.7        | 67.9       | °C/W |
| R <sub>θJB</sub>              | Junction-to-board thermal resistance         | 63.5   | 44.8        | 102.1      | °C/W |
| ψ <sub>JT</sub>               | Junction-to-top characterization parameter   | 13.7   | 1.6         | 10.4       | °C/W |
| ψ <sub>JB</sub>               | Junction-to-board characterization parameter | 62.8   | 44.2        | 100.3      | °C/W |
| R <sub>θJC(bot)</sub>         | Junction-to-case (bottom) thermal resistance | N/A    | N/A         | N/A        | °C/W |

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

## 7.5 Electrical Characteristics: High-Voltage Operation

at  $T_A = +25^\circ\text{C}$ ,  $V_S = \pm 4\text{ V}$  to  $\pm 18\text{ V}$  ( $V_S = 8\text{ V}$  to  $36\text{ V}$ ),  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2^{(1)}$ , and  $V_{CM} = V_{OUT} = V_S / 2^{(1)}$  (unless otherwise noted)

| PARAMETER           |                                    |       | CONDITIONS                                                                                              |  | MIN   | TYP      | MAX        | UNIT                     |
|---------------------|------------------------------------|-------|---------------------------------------------------------------------------------------------------------|--|-------|----------|------------|--------------------------|
| OFFSET VOLTAGE      |                                    |       |                                                                                                         |  |       |          |            |                          |
| V <sub>OS</sub>     | Input offset voltage               |       |                                                                                                         |  |       | ±6       | ±25        | μV                       |
|                     |                                    |       | T <sub>A</sub> = −40°C to +125°C                                                                        |  | ±0.03 | ±0.085   | μV/°C      |                          |
| PSRR                | Power-supply rejection ratio       |       | V <sub>S</sub> = 4 V to 36 V, T <sub>A</sub> = −40°C to +125°C                                          |  |       | ±0.075   | ±0.3       | μV/V                     |
|                     | Long-term stability <sup>(2)</sup> |       |                                                                                                         |  |       | 4        |            | μV                       |
| INPUT BIAS CURRENT  |                                    |       |                                                                                                         |  |       |          |            |                          |
| I <sub>B</sub>      | Input bias current                 |       | V <sub>CM</sub> = V <sub>S</sub> / 2                                                                    |  |       | ±160     | ±1400      | pA                       |
|                     |                                    |       | T <sub>A</sub> = −40°C to +125°C                                                                        |  |       |          | ±18        | nA                       |
| I <sub>OS</sub>     | Input offset current               |       |                                                                                                         |  |       | ±320     | ±2800      | pA                       |
|                     |                                    |       | T <sub>A</sub> = −40°C to +125°C                                                                        |  |       |          | ±6         | nA                       |
| NOISE               |                                    |       |                                                                                                         |  |       |          |            |                          |
| e <sub>n</sub>      | Input voltage noise                |       | f = 0.1 Hz to 10 Hz                                                                                     |  |       | 250      |            | nV <sub>PP</sub>         |
|                     |                                    |       | f = 0.1 Hz to 10 Hz                                                                                     |  |       | 40       |            | nV <sub>rms</sub>        |
|                     | Input voltage noise density        |       | f = 1 kHz                                                                                               |  |       | 8.8      |            | nV/√Hz                   |
| i <sub>n</sub>      | Input current noise density        |       | f = 1 kHz                                                                                               |  |       | 7        |            | fA/√Hz                   |
| INPUT VOLTAGE RANGE |                                    |       |                                                                                                         |  |       |          |            |                          |
| V <sub>CM</sub>     | Common-mode voltage range          |       | T <sub>A</sub> = −40°C to +125°C                                                                        |  |       | V−       | (V+) − 1.5 | V                        |
| CMRR                | Common-mode rejection ratio        |       | (V−) < V <sub>CM</sub> < (V+) − 1.5 V                                                                   |  | 120   | 134      |            | dB                       |
|                     |                                    |       | (V−) + 0.5 V < V <sub>CM</sub> < (V+) − 1.5 V, V <sub>S</sub> = ±18 V                                   |  | 130   | 146      |            | dB                       |
|                     |                                    |       | (V−) + 0.5 V < V <sub>CM</sub> < (V+) − 1.5 V, V <sub>S</sub> = ±18 V, T <sub>A</sub> = −40°C to +125°C |  | 120   | 126      |            | dB                       |
| INPUT IMPEDANCE     |                                    |       |                                                                                                         |  |       |          |            |                          |
| Z <sub>ID</sub>     | Differential                       |       |                                                                                                         |  |       | 100    6 |            | MΩ    pF                 |
| Z <sub>IC</sub>     | Common-mode                        |       |                                                                                                         |  |       | 6    9.5 |            | 10 <sup>12</sup> Ω    pF |
| OPEN-LOOP GAIN      |                                    |       |                                                                                                         |  |       |          |            |                          |
| A <sub>OL</sub>     | Open-loop voltage gain             |       | (V−) + 0.5 V < V <sub>O</sub> < (V+) − 0.5 V                                                            |  | 130   | 136      |            | dB                       |
|                     |                                    |       | (V−) + 0.5 V < V <sub>O</sub> < (V+) − 0.5 V, T <sub>A</sub> = −40°C to +125°C                          |  | 120   | 126      |            | dB                       |
| FREQUENCY RESPONSE  |                                    |       |                                                                                                         |  |       |          |            |                          |
| GBW                 | Gain-bandwidth product             |       |                                                                                                         |  |       | 2        |            | MHz                      |
| SR                  | Slew rate                          |       | G = +1                                                                                                  |  |       | 0.8      |            | V/μs                     |
| t <sub>S</sub>      | Settling time                      | 0.1%  | V <sub>S</sub> = ±18 V, G = 1, 10-V step                                                                |  |       | 20       |            | μs                       |
|                     |                                    | 0.01% | V <sub>S</sub> = ±18 V, G = 1, 10-V step                                                                |  |       | 27       |            | μs                       |
| t <sub>OR</sub>     | Overload recovery time             |       | V <sub>IN</sub> × G = V <sub>S</sub>                                                                    |  |       | 1        |            | μs                       |
| THD+N               | Total harmonic distortion + noise  |       | 1 kHz, G = 1, V <sub>OUT</sub> = 1 Vrms                                                                 |  |       | 0.0001%  |            |                          |
| OUTPUT              |                                    |       |                                                                                                         |  |       |          |            |                          |
|                     | Voltage output swing from rail     |       | No load                                                                                                 |  |       | 6        | 15         | mV                       |
|                     |                                    |       | R <sub>L</sub> = 10 kΩ                                                                                  |  |       | 220      | 250        | mV                       |
|                     |                                    |       | T <sub>A</sub> = −40°C to +125°C                                                                        |  |       | 310      | 350        | mV                       |
| I <sub>SC</sub>     | Short-circuit current              |       | Sinking                                                                                                 |  |       | −18      |            | mA                       |
|                     |                                    |       | Sourcing                                                                                                |  |       | 16       |            | mA                       |
| R <sub>O</sub>      | Open-loop output resistance        |       | f = 1 MHz, I <sub>O</sub> = 0                                                                           |  |       | 120      |            | Ω                        |
| C <sub>LOAD</sub>   | Capacitive load drive              |       |                                                                                                         |  |       | 1        |            | nF                       |
| POWER SUPPLY        |                                    |       |                                                                                                         |  |       |          |            |                          |
| I <sub>Q</sub>      | Quiescent current (per amplifier)  |       | V <sub>S</sub> = ±4 V to V <sub>S</sub> = ±18 V                                                         |  |       | 450      | 510        | μA                       |
|                     |                                    |       | I <sub>O</sub> = 0 mA, T <sub>A</sub> = −40°C to +125°C                                                 |  |       |          | 600        | μA                       |

(1)  $V_S / 2 = \text{midsupply}$ .

(2) 1000-hour life test at  $125^\circ\text{C}$  demonstrated randomly distributed variation in the range of measurement limits—approximately 4  $\mu\text{V}$ .

## 7.6 Electrical Characteristics: Low-Voltage Operation

at  $T_A = 25^\circ\text{C}$ ,  $V_S = \pm 2\text{ V}$  to  $< \pm 4\text{ V}$  ( $V_S = 4\text{ V}$  to  $< 8\text{ V}$ ),  $R_L = 10\text{ k}\Omega$  connected to  $V_S / 2^{(1)}$ , and  $V_{CM} = V_{OUT} = V_S / 2^{(1)}$  (unless otherwise noted)

| PARAMETER           |                                    | CONDITIONS                                                                                                | MIN | TYP      | MAX        | UNIT                     |
|---------------------|------------------------------------|-----------------------------------------------------------------------------------------------------------|-----|----------|------------|--------------------------|
| OFFSET VOLTAGE      |                                    |                                                                                                           |     |          |            |                          |
| V <sub>OS</sub>     | Input offset voltage               |                                                                                                           |     | ±6       | ±25        | μV                       |
|                     |                                    | T <sub>A</sub> = −40°C to +125°C                                                                          |     | ±0.03    | ±0.085     | μV/°C                    |
| PSRR                | Power-supply rejection ratio       | V <sub>S</sub> = 4 V to 36 V,<br>T <sub>A</sub> = −40°C to +125°C                                         |     | 0.075    | 0.3        | μV/V                     |
|                     | Long-term stability <sup>(2)</sup> |                                                                                                           |     | 4        |            | μV                       |
| INPUT BIAS CURRENT  |                                    |                                                                                                           |     |          |            |                          |
| I <sub>B</sub>      | Input bias current                 |                                                                                                           |     | ±160     | ±1400      | pA                       |
|                     |                                    | T <sub>A</sub> = −40°C to +125°C                                                                          |     |          | ±18        | nA                       |
| I <sub>OS</sub>     | Input offset current               |                                                                                                           |     | ±320     | ±2800      | pA                       |
|                     |                                    | T <sub>A</sub> = −40°C to +125°C                                                                          |     |          | ±6         | nA                       |
| NOISE               |                                    |                                                                                                           |     |          |            |                          |
| e <sub>n</sub>      | Input voltage noise                | f = 0.1 Hz to 10 Hz                                                                                       |     | 250      |            | nV <sub>PP</sub>         |
|                     |                                    | f = 0.1 Hz to 10 Hz                                                                                       |     | 40       |            | nV <sub>rms</sub>        |
|                     | Input voltage noise density        | f = 1 kHz                                                                                                 |     | 8.8      |            | nV/√Hz                   |
| i <sub>n</sub>      | Input current noise density        | f = 1 kHz                                                                                                 |     | 7        |            | fA/√Hz                   |
| INPUT VOLTAGE RANGE |                                    |                                                                                                           |     |          |            |                          |
| V <sub>CM</sub>     | Common-mode voltage range          | T <sub>A</sub> = −40°C to +125°C                                                                          | V−  |          | (V+) − 1.5 | V                        |
| CMRR                | Common-mode rejection ratio        | (V−) < V <sub>CM</sub> < (V+) − 1.5 V                                                                     | 106 | 114      |            | dB                       |
|                     |                                    | (V−) + 0.5 V < V <sub>CM</sub> < (V+) − 1.5 V,<br>V <sub>S</sub> = ±2 V                                   | 114 | 120      |            | dB                       |
|                     |                                    | (V−) + 0.5 V < V <sub>CM</sub> < (V+) − 1.5 V,<br>V <sub>S</sub> = ±2 V, T <sub>A</sub> = −40°C to +125°C | 110 | 120      |            | dB                       |
| INPUT IMPEDANCE     |                                    |                                                                                                           |     |          |            |                          |
| Z <sub>ID</sub>     | Differential                       |                                                                                                           |     | 100    6 |            | MΩ    pF                 |
| Z <sub>IC</sub>     | Common-mode                        |                                                                                                           |     | 6    9.5 |            | 10 <sup>12</sup> Ω    pF |
| OPEN-LOOP GAIN      |                                    |                                                                                                           |     |          |            |                          |
| A <sub>OL</sub>     | Open-loop voltage gain             | (V−) + 0.5 V < V <sub>O</sub> < (V+) − 0.5 V,<br>R <sub>L</sub> = 5 kΩ                                    | 110 | 120      |            | dB                       |
|                     |                                    | (V−) + 0.5 V < V <sub>O</sub> < (V+) − 0.5 V                                                              | 120 | 130      |            | dB                       |
|                     |                                    | (V−) + 0.5 V < V <sub>O</sub> < (V+) − 0.5 V,<br>T <sub>A</sub> = −40°C to +125°C                         | 110 | 120      |            | dB                       |
| FREQUENCY RESPONSE  |                                    |                                                                                                           |     |          |            |                          |
| GBW                 | Gain-bandwidth product             |                                                                                                           |     | 2        |            | MHz                      |
| SR                  | Slew rate                          | G = +1                                                                                                    |     | 0.8      |            | V/μs                     |
| t <sub>OR</sub>     | Overload recovery time             | V <sub>IN</sub> × G = V <sub>S</sub>                                                                      |     | 1        |            | μs                       |
| THD+N               | Total harmonic distortion + noise  | 1 kHz, G = 1, V <sub>OUT</sub> = 1 V <sub>rms</sub>                                                       |     | 0.0001%  |            |                          |
| OUTPUT              |                                    |                                                                                                           |     |          |            |                          |
|                     | Voltage output swing from rail     | No load                                                                                                   |     | 6        | 15         | mV                       |
|                     |                                    | R <sub>L</sub> = 10 kΩ                                                                                    |     | 220      | 250        | mV                       |
|                     |                                    | T <sub>A</sub> = −40°C to +125°C                                                                          |     | 310      | 350        | mV                       |
| I <sub>SC</sub>     | Short-circuit current              | Sinking                                                                                                   |     | −18      |            | mA                       |
|                     |                                    | Sourcing                                                                                                  |     | 16       |            | mA                       |
| R <sub>O</sub>      | Open-loop output resistance        | f = 1 MHz, I <sub>O</sub> = 0                                                                             |     | 120      |            | Ω                        |
| C <sub>LOAD</sub>   | Capacitive load drive              |                                                                                                           |     | 1        |            | nF                       |
| POWER SUPPLY        |                                    |                                                                                                           |     |          |            |                          |
| I <sub>Q</sub>      | Quiescent current (per amplifier)  | V <sub>S</sub> = ±2 V to V <sub>S</sub> = ±4 V                                                            |     | 425      | 485        | μA                       |
|                     |                                    | I <sub>O</sub> = 0 mA, T <sub>A</sub> = −40°C to +125°C                                                   |     |          | 575        | μA                       |

(1)  $V_S / 2 = \text{midsupply}$ .

(2) 1000-hour life test at  $125^\circ\text{C}$  demonstrated randomly distributed variation in the range of measurement limits—approximately  $4\text{ }\mu\text{V}$ .

## 7.7 Typical Characteristics: Table of Graphs

### 7.7.1 Table of Graphs

**Table 2. Typical Characteristic Graphs**

| DESCRIPTION                                                    | FIGURE                               |
|----------------------------------------------------------------|--------------------------------------|
| Offset Voltage Production Distribution                         | <a href="#">Figure 1</a>             |
| Offset Voltage Drift Distribution                              | <a href="#">Figure 2</a>             |
| Offset Voltage vs Temperature                                  | <a href="#">Figure 3</a>             |
| Offset Voltage vs Common-Mode Voltage                          | <a href="#">Figure 4, Figure 5</a>   |
| Offset Voltage vs Power Supply                                 | <a href="#">Figure 6</a>             |
| Open-Loop Gain and Phase vs Frequency                          | <a href="#">Figure 7</a>             |
| Closed-Loop Gain vs Frequency                                  | <a href="#">Figure 8</a>             |
| $I_B$ and $I_{OS}$ vs Common-Mode Voltage                      | <a href="#">Figure 9</a>             |
| Input Bias Current vs Temperature                              | <a href="#">Figure 10</a>            |
| Output Voltage Swing vs Output Current (Maximum Supply)        | <a href="#">Figure 11</a>            |
| CMRR and PSRR vs Frequency (Referred-to-Input)                 | <a href="#">Figure 12</a>            |
| CMRR vs Temperature                                            | <a href="#">Figure 13, Figure 14</a> |
| PSRR vs Temperature                                            | <a href="#">Figure 15</a>            |
| 0.1-Hz to 10-Hz Noise                                          | <a href="#">Figure 16</a>            |
| Input Voltage Noise Spectral Density vs Frequency              | <a href="#">Figure 17</a>            |
| THD+N Ratio vs Frequency                                       | <a href="#">Figure 18</a>            |
| THD+N vs Output Amplitude                                      | <a href="#">Figure 19</a>            |
| Quiescent Current vs Supply Voltage                            | <a href="#">Figure 20</a>            |
| Quiescent Current vs Temperature                               | <a href="#">Figure 21</a>            |
| Open-Loop Gain vs Temperature                                  | <a href="#">Figure 22</a>            |
| Open-Loop Output Impedance vs Frequency                        | <a href="#">Figure 23</a>            |
| Small-Signal Overshoot vs Capacitive Load (100-mV Output Step) | <a href="#">Figure 24, Figure 25</a> |
| No Phase Reversal                                              | <a href="#">Figure 26</a>            |
| Positive Overload Recovery                                     | <a href="#">Figure 27</a>            |
| Negative Overload Recovery                                     | <a href="#">Figure 28</a>            |
| Small-Signal Step Response (100 mV)                            | <a href="#">Figure 29, Figure 30</a> |
| Large-Signal Step Response                                     | <a href="#">Figure 31, Figure 32</a> |
| Large-Signal Settling Time (10-V Positive Step)                | <a href="#">Figure 33</a>            |
| Large-Signal Settling Time (10-V Negative Step)                | <a href="#">Figure 34</a>            |
| Short-Circuit Current vs Temperature                           | <a href="#">Figure 35</a>            |
| Maximum Output Voltage vs Frequency                            | <a href="#">Figure 36</a>            |
| EMIRR IN+ vs Frequency                                         | <a href="#">Figure 37</a>            |

## 7.8 Typical Characteristics

at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)

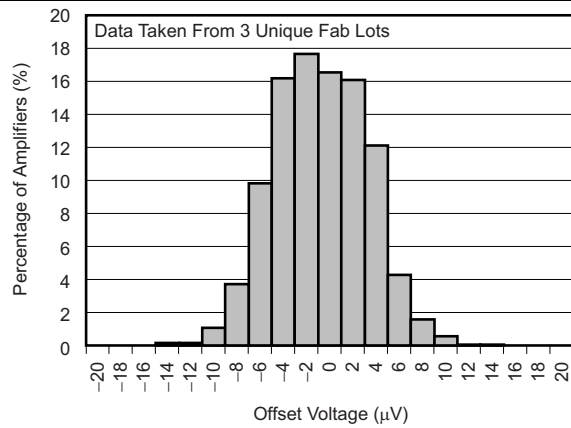


Figure 1. Offset Voltage Production Distribution

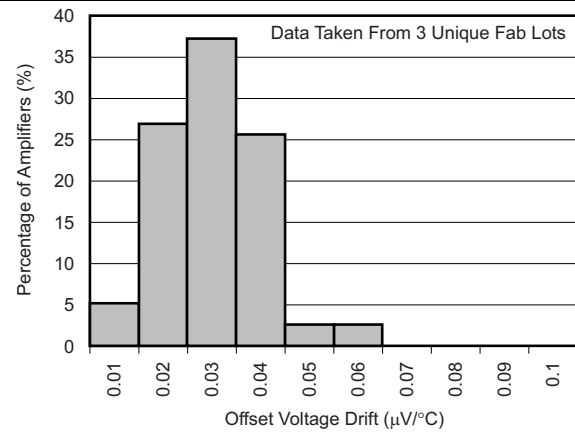


Figure 2. Offset Voltage Drift Distribution

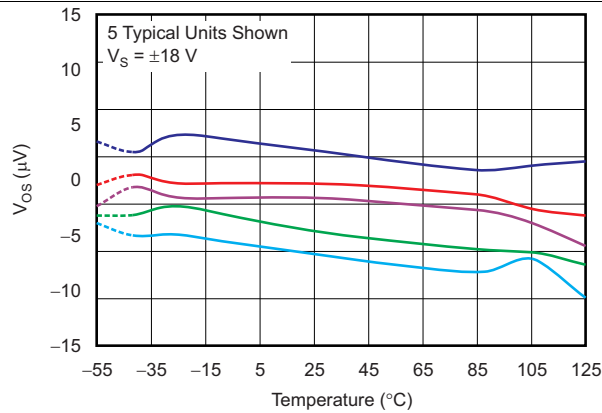


Figure 3. Offset Voltage vs Temperature

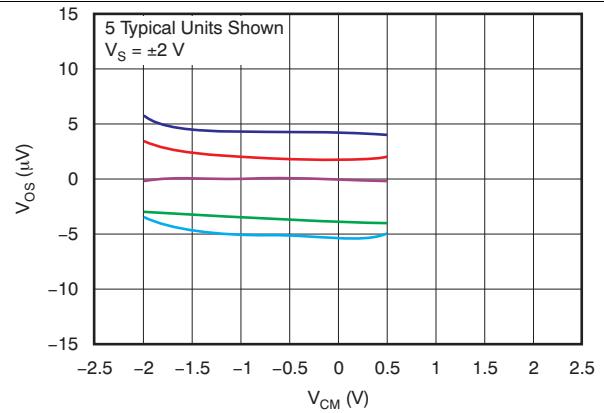


Figure 4. Offset Voltage vs Common-Mode Voltage

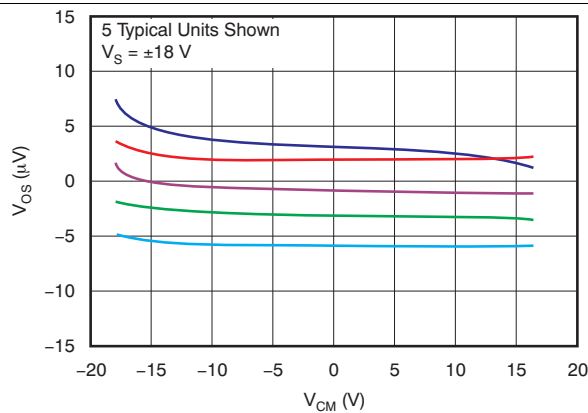


Figure 5. Offset Voltage vs Common-Mode Voltage

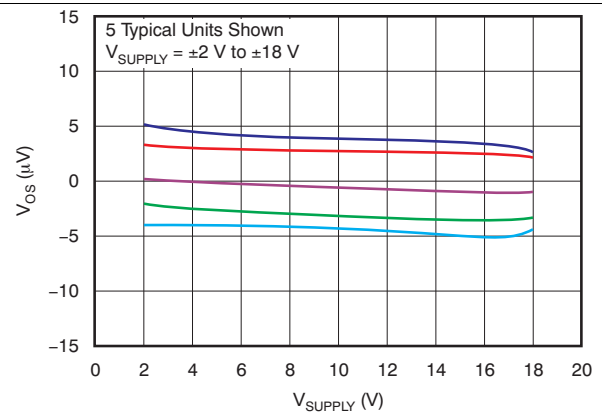
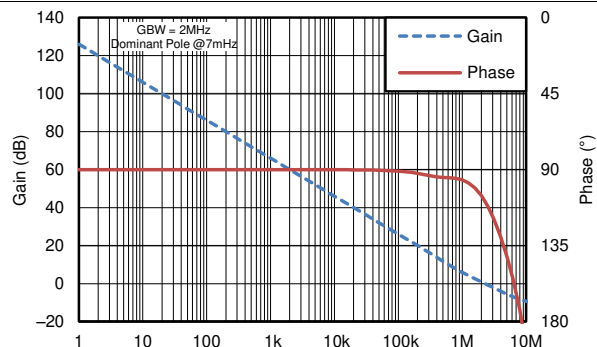


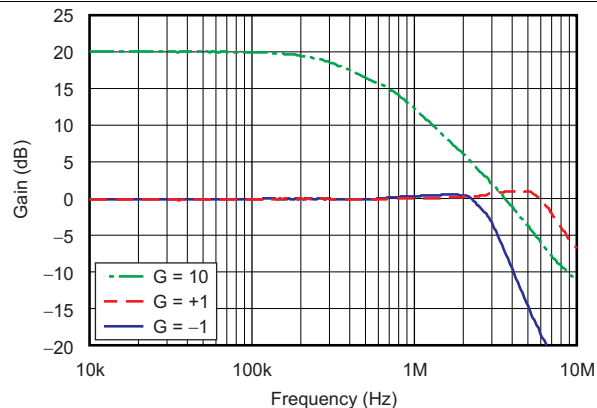
Figure 6. Offset Voltage vs Power Supply

## Typical Characteristics (continued)

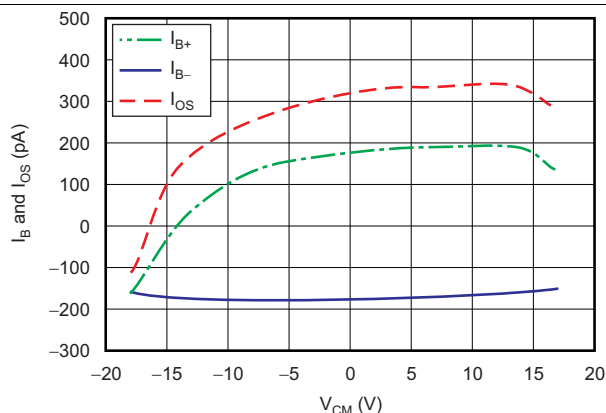
at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



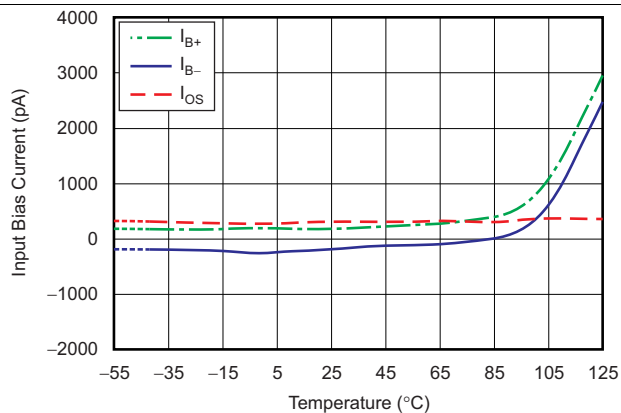
**Figure 7. Open-Loop Gain and Phase vs Frequency**



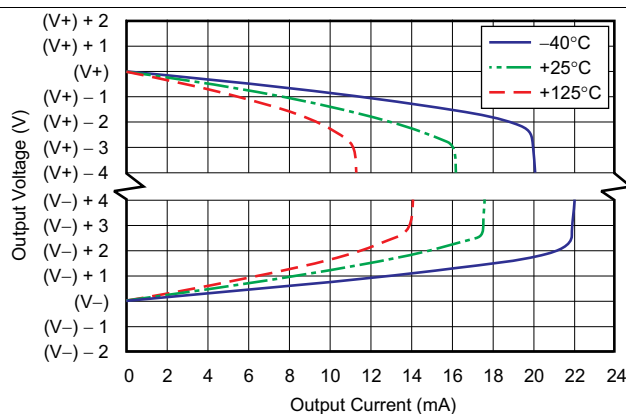
**Figure 8. Closed-Loop Gain vs Frequency**



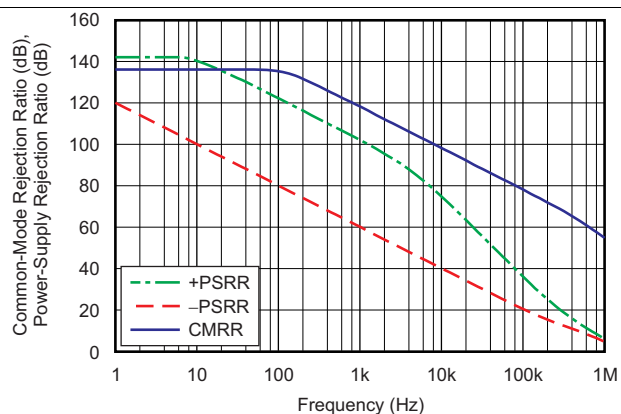
**Figure 9.  $I_B$  and  $I_{OS}$  vs Common-Mode Voltage**



**Figure 10. Input Bias Current vs Temperature**



**Figure 11. Output Voltage Swing vs Output Current (Maximum Supply)**



**Figure 12. CMRR and PSRR vs Frequency (Referred-to-Input)**

## Typical Characteristics (continued)

at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)

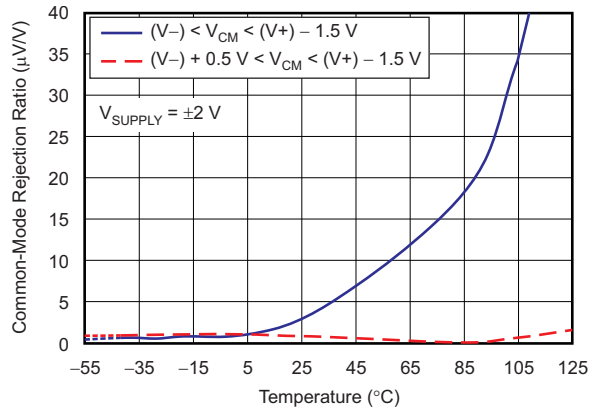


Figure 13. CMRR vs Temperature

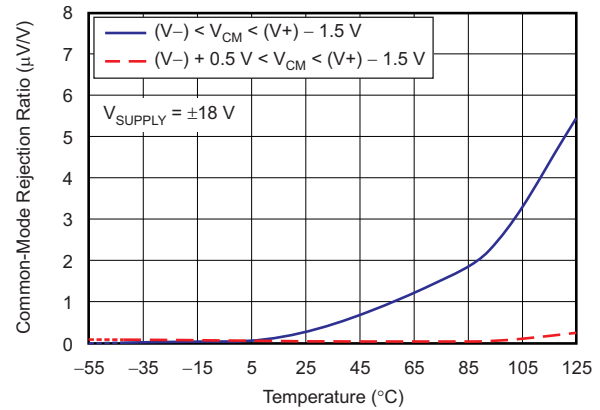


Figure 14. CMRR vs Temperature

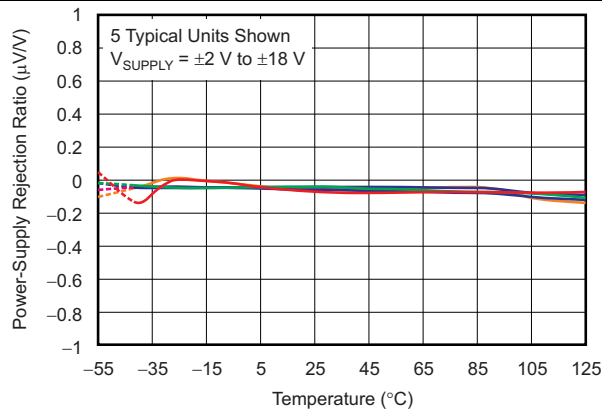
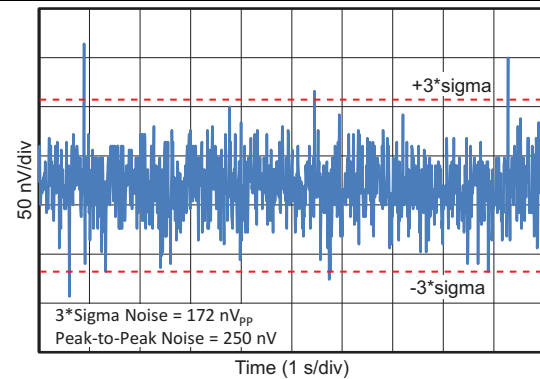


Figure 15. PSRR vs Temperature



C016

Figure 16. 0.1-Hz to 10-Hz Noise

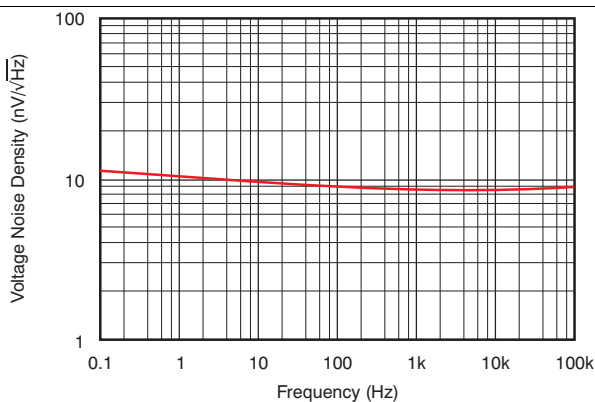


Figure 17. Input Voltage Noise Spectral Density vs Frequency

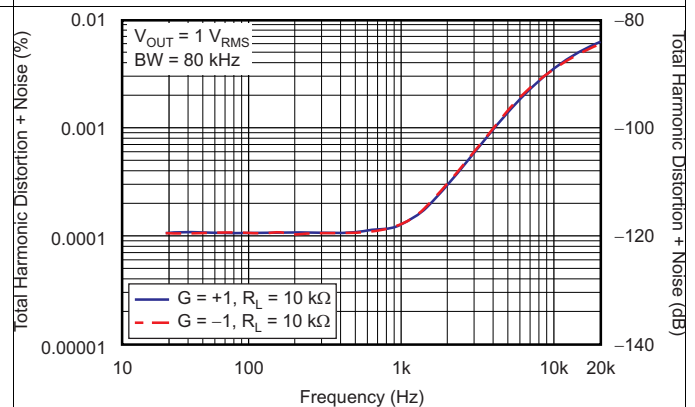
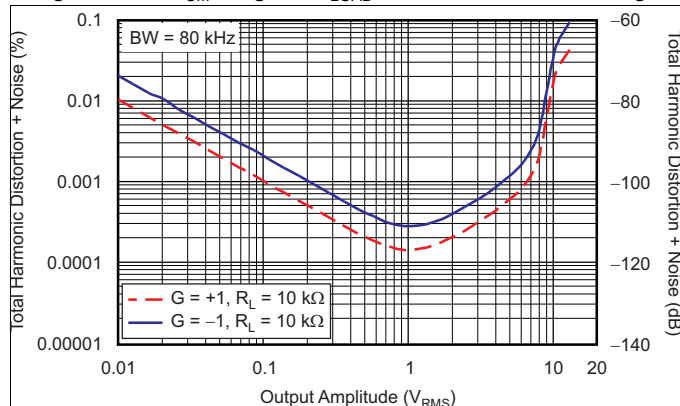


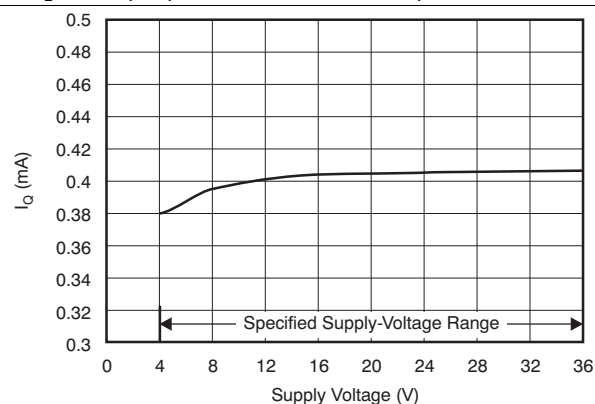
Figure 18. THD+N Ratio vs Frequency

## Typical Characteristics (continued)

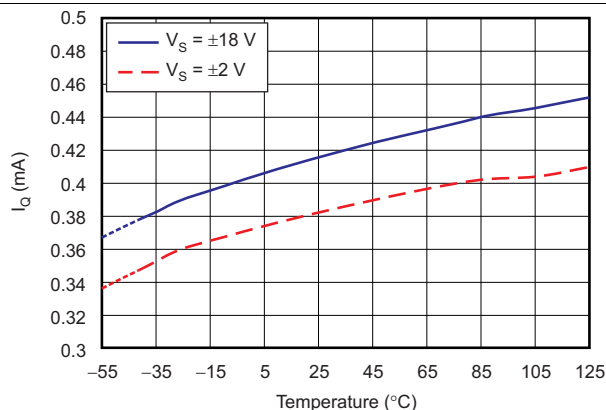
at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



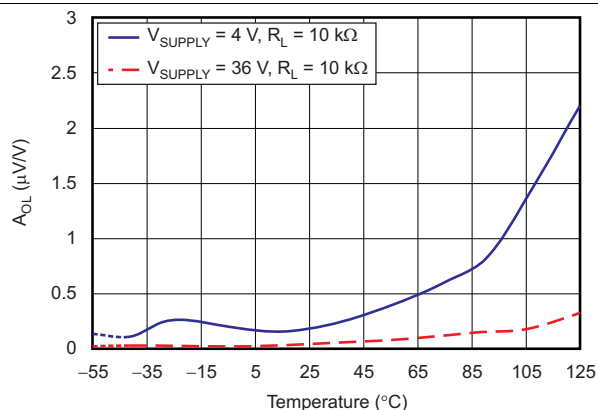
**Figure 19. THD+N vs Output Amplitude**



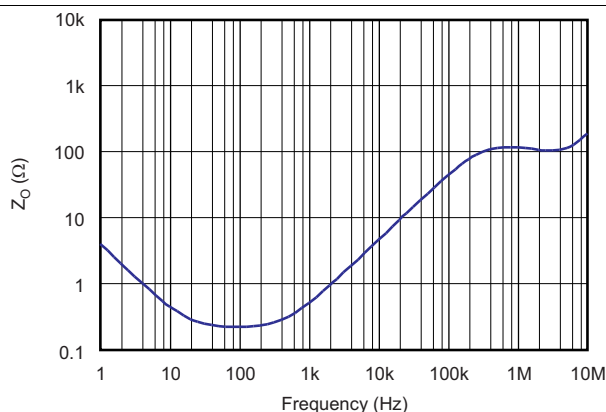
**Figure 20. Quiescent Current vs Supply Voltage**



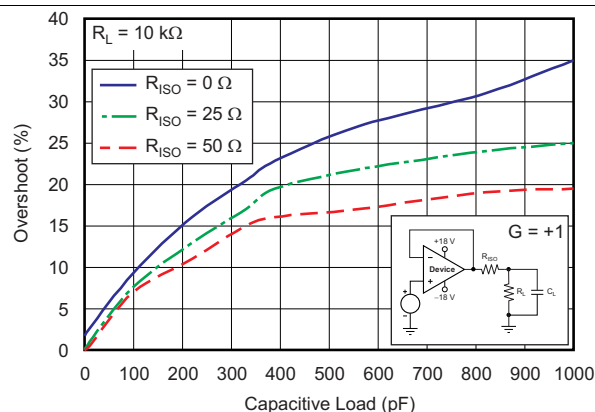
**Figure 21. Quiescent Current vs Temperature**



**Figure 22. Open-Loop Gain vs Temperature**



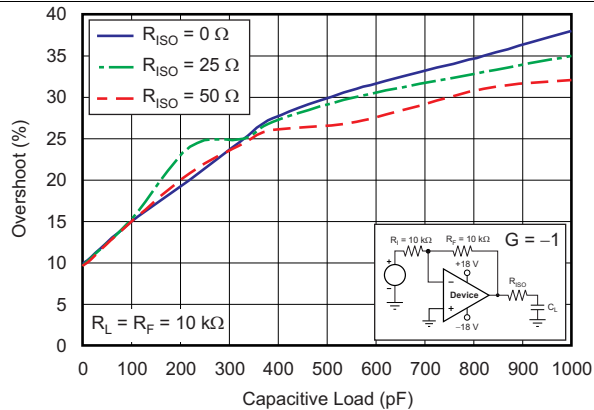
**Figure 23. Open-Loop Output Impedance vs Frequency**



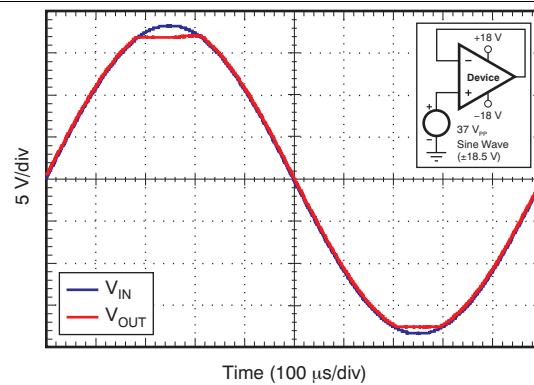
**Figure 24. Small-Signal Overshoot vs Capacitive Load (100-mV Output Step)**

## Typical Characteristics (continued)

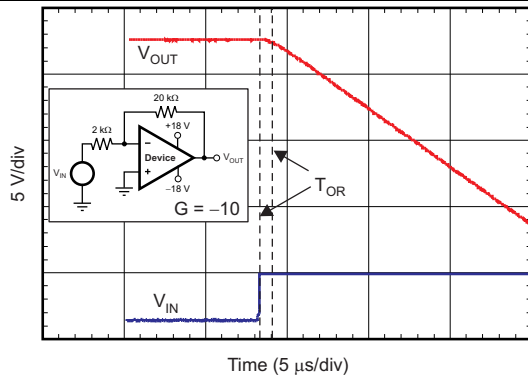
at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



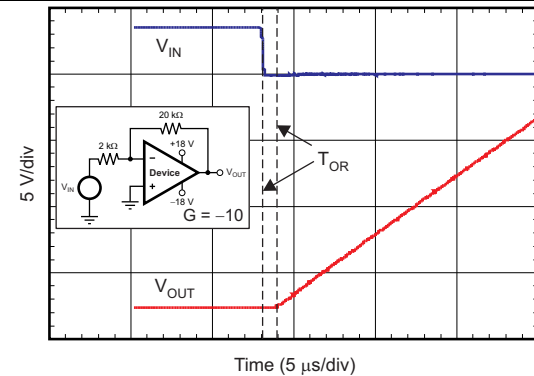
**Figure 25. Small-Signal Overshoot vs Capacitive Load (100-mV Output Step)**



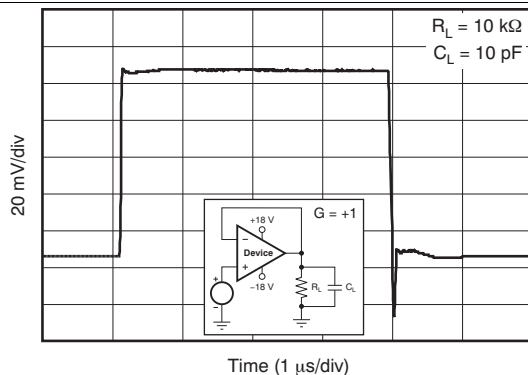
**Figure 26. No Phase Reversal**



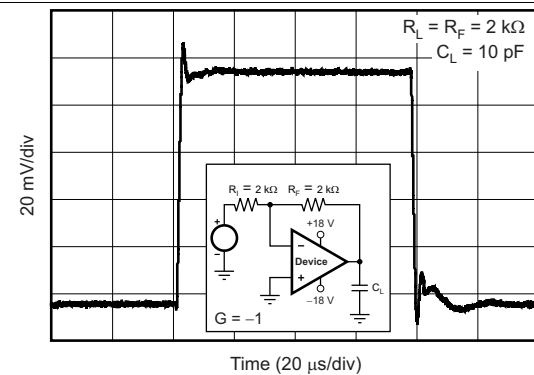
**Figure 27. Positive Overload Recovery**



**Figure 28. Negative Overload Recovery**



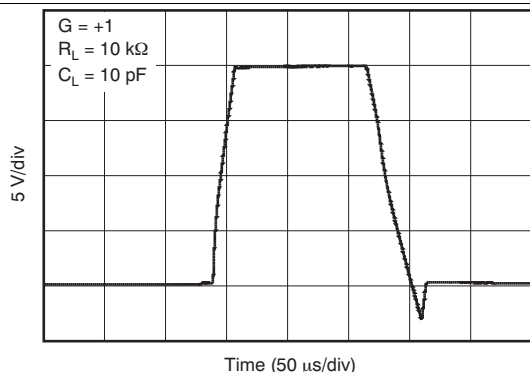
**Figure 29. Small-Signal Step Response (100 mV)**



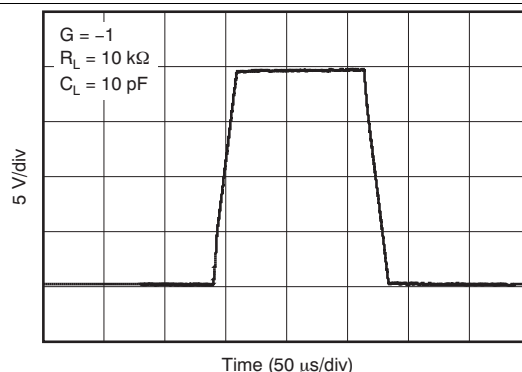
**Figure 30. Small-Signal Step Response (100 mV)**

## Typical Characteristics (continued)

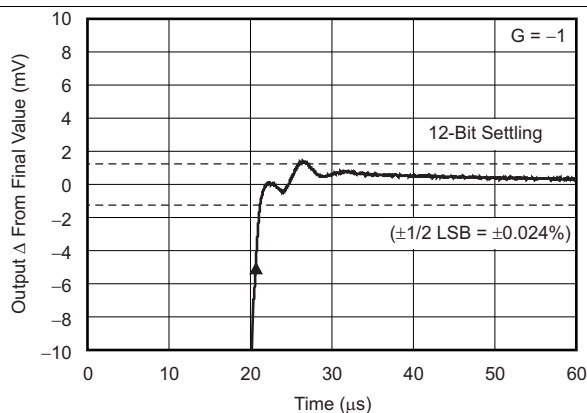
at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



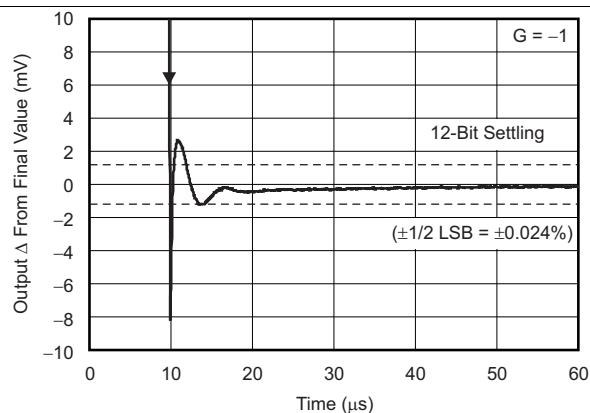
**Figure 31. Large-Signal Step Response**



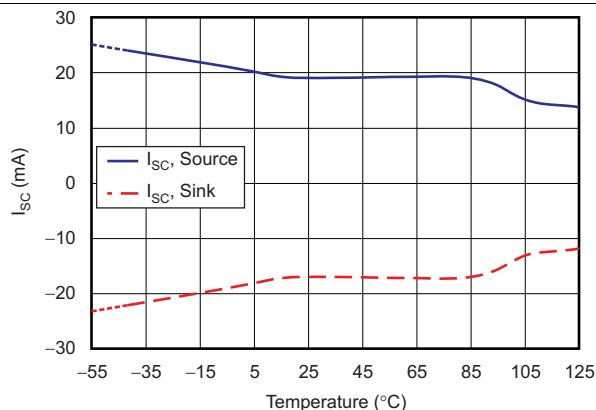
**Figure 32. Large-Signal Step Response**



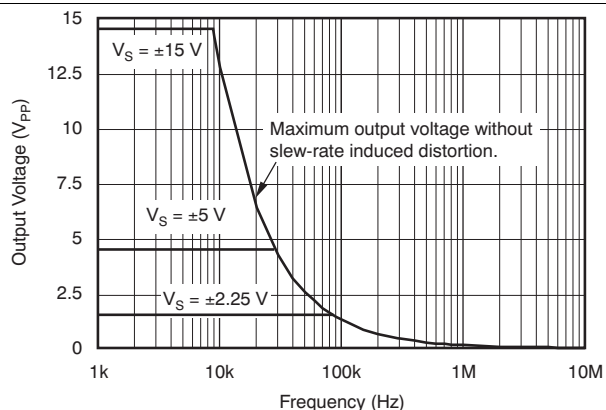
**Figure 33. Large-Signal Settling Time  
(10-V Positive Step)**



**Figure 34. Large-Signal Settling Time  
(10-V Negative Step)**



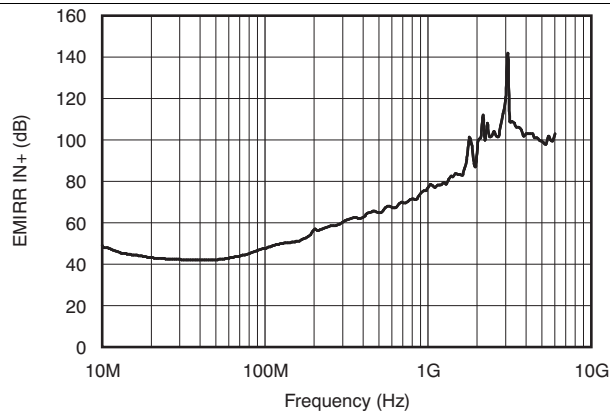
**Figure 35. Short-Circuit Current vs Temperature**



**Figure 36. Maximum Output Voltage vs Frequency**

## Typical Characteristics (continued)

at  $V_S = \pm 18\text{ V}$ ,  $V_{CM} = V_S / 2$ ,  $R_{LOAD} = 10\text{ k}\Omega$  connected to  $V_S / 2$ , and  $C_L = 100\text{ pF}$  (unless otherwise noted)



**Figure 37. EMIRR IN+ vs Frequency**

## 8 Detailed Description

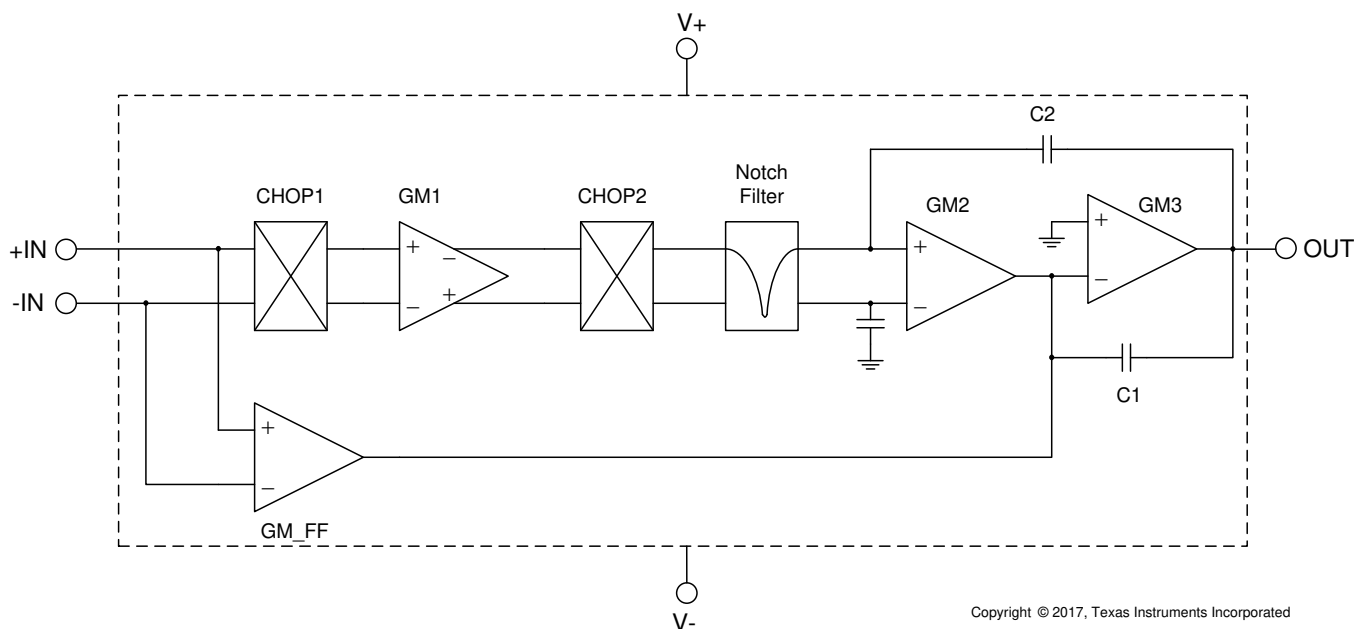
### 8.1 Overview

The OPA188 operational amplifier combines precision offset and drift with excellent overall performance, making this device an excellent choice for many precision applications. The precision offset drift of only  $0.085 \mu\text{V}/^\circ\text{C}$  provides stability over the entire temperature range. In addition, this device offers excellent overall performance with high CMRR, PSRR, and  $A_{OL}$ . As with all amplifiers, applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases,  $0.1\text{-}\mu\text{F}$  capacitors are adequate.

The OPA188 device is part of a family of zero-drift, low-power, rail-to-rail output operational amplifiers. These devices operate from  $4\text{ V}$  to  $36\text{ V}$ , are unity-gain stable, and are designed for a wide range of general-purpose applications. The zero-drift architecture provides ultra-low input offset voltage and near-zero input offset voltage drift over temperature and time. This choice of architecture also offers outstanding ac performance, such as ultra-low broadband noise and zero flicker noise.

### 8.2 Functional Block Diagram

Figure 38 shows a representation of the proprietary OPA188 architecture. Table 3 lists the active and passive component counts for this device. The component count allows for accurate reliability calculations.



**Figure 38. Functional Block Diagram**

**Table 3. Component Count**

| COMPONENT   | COUNT |
|-------------|-------|
| Transistors | 636   |
| Diodes      | 5     |
| Resistors   | 41    |
| Capacitors  | 72    |

### 8.3 Feature Description

The OPA188 is unity-gain stable and free from unexpected output phase reversal. This device uses a proprietary, periodic zero-drift technique to provide low input offset voltage and very low input offset voltage drift over temperature. For lowest offset voltage and precision performance, optimize circuit layout and mechanical conditions. Avoid temperature gradients that create thermoelectric (Seebeck) effects in the thermocouple junctions formed from connecting dissimilar conductors. Cancel these thermally-generated potentials by ensuring the potentials are equal on both input pins. Other layout and design considerations include:

- Use low thermoelectric-coefficient conditions (avoid dissimilar metals).
- Thermally isolate components from power supplies or other heat sources.
- Shield the operational amplifier and input circuitry from air currents, such as cooling fans.

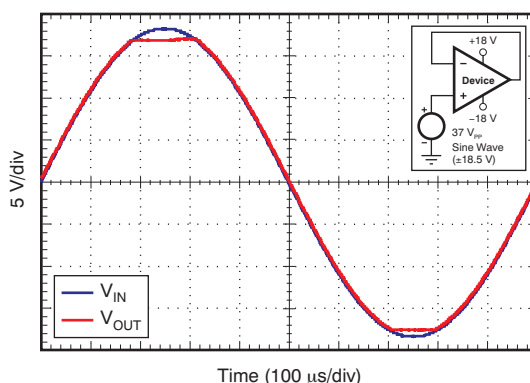
Follow these guidelines to reduce the likelihood of junctions being at different temperatures, which may cause thermoelectric voltages of 0.1  $\mu\text{V}/^\circ\text{C}$  or higher, depending on the materials used.

#### 8.3.1 Operating Characteristics

The OPA188 is specified for operation from 4 V to 36 V ( $\pm 2$  V to  $\pm 18$  V). Many specifications apply from  $-40^\circ\text{C}$  to  $+125^\circ\text{C}$ . Parameters that can exhibit significant variance with regard to operating voltage or temperature are presented in [Typical Characteristics](#).

#### 8.3.2 Phase-Reversal Protection

The OPA188 has an internal phase-reversal protection. Many op amps exhibit a phase reversal when the input is driven beyond the linear common-mode range. This condition is most often encountered in noninverting circuits when the input is driven beyond the specified common-mode voltage range, causing the output to reverse into the opposite rail. The OPA188 input prevents phase reversal with excessive common-mode voltage. Instead, the output limits into the appropriate rail; [Figure 39](#) shows this performance.



**Figure 39. No Phase Reversal**

#### 8.3.3 Input Bias Current Clock Feedthrough

Zero-drift amplifiers (such as the OPA188) use switching on the inputs to correct for the intrinsic offset and drift of the amplifier. Charge injection from the integrated switches on the inputs can introduce very short transients in the input bias current of the amplifier. The extremely short duration of these pulses prevents the device from being amplified. However, the devices may be coupled to the output of the amplifier through the feedback network. The most effective method to prevent transients in the input bias current from producing additional noise at the amplifier output is to use a low-pass filter such as an RC network.

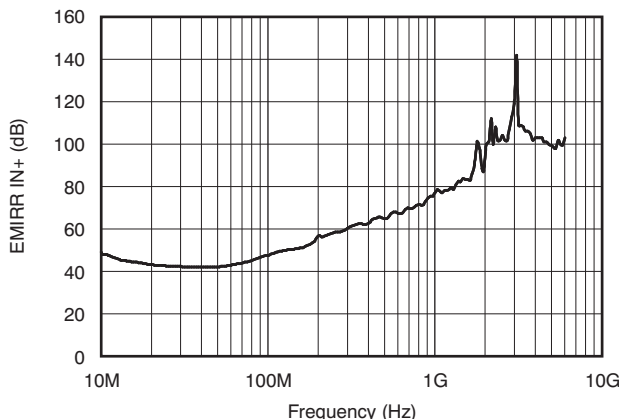
#### 8.3.4 Internal Offset Correction

The OPA188 op amp uses an auto-calibration technique with a time-continuous 750-kHz op amp in the signal path. This amplifier is zero-corrected every 3  $\mu\text{s}$  using a proprietary technique. Upon power up, the amplifier requires approximately 100  $\mu\text{s}$  to achieve the specified  $V_{OS}$  accuracy. This design has no aliasing or flicker noise.

## Feature Description (continued)

### 8.3.5 EMI Rejection

The OPA188 uses integrated electromagnetic interference (EMI) filtering to reduce the effects of EMI interference from sources such as wireless communications and densely-populated boards with a mix of analog signal chain and digital components. EMI immunity can be improved with circuit design techniques; the benefits from these design improvements. Texas Instruments™ has developed the ability to accurately measure and quantify the immunity of an operational amplifier over a broad frequency spectrum extending from 10 MHz to 6 GHz. Figure 40 shows the results of this testing on the OPA188. Table 4 lists the EMIRR IN+ values for the OPA188 at particular frequencies commonly encountered in real-world applications. Applications listed in Table 4 may be centered on or operated near the particular frequency shown. Detailed information can also be found in *EMI Rejection Ratio of Operational Amplifiers*, available for download from [www.ti.com](http://www.ti.com).



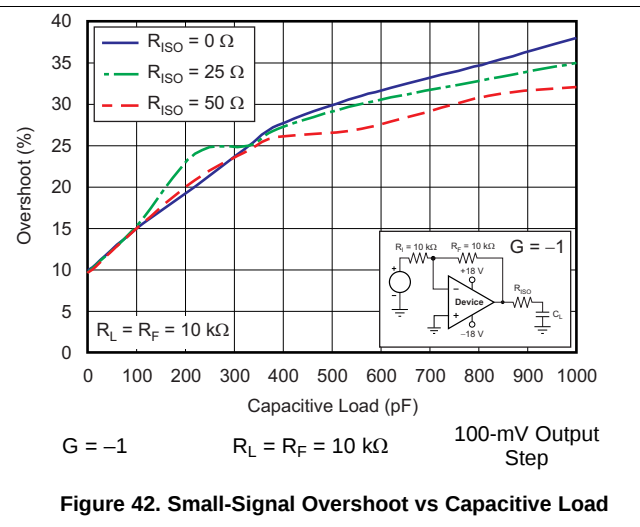
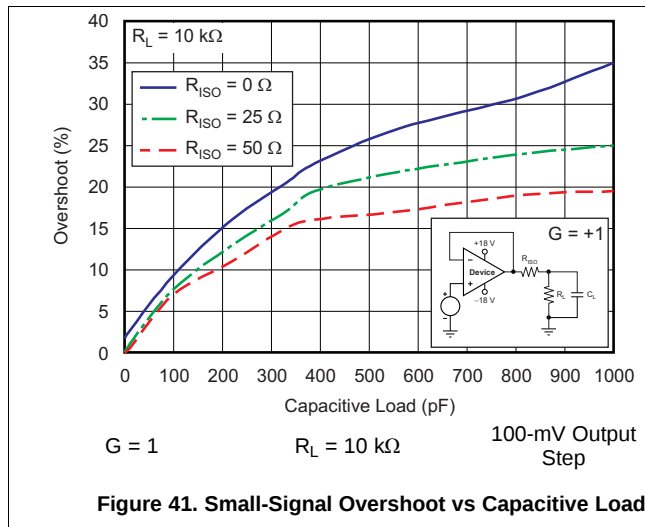
**Figure 40. EMIRR Testing**

**Table 4. OPA188 EMIRR IN+ for Frequencies of Interest**

| FREQUENCY | APPLICATION OR ALLOCATION                                                                                                                                                                | EMIRR IN+ |
|-----------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| 400 MHz   | Mobile radio, mobile satellite, space operation, weather, radar, ultra-high frequency (UHF) applications                                                                                 | 62.2 dB   |
| 900 MHz   | Global system for mobile communications (GSM) applications, radio communication, navigation, GPS (to 1.6 GHz), GSM, aeronautical mobile, UHF applications                                | 74.7 dB   |
| 1.8 GHz   | GSM applications, mobile personal communications, broadband, satellite, L-band (1 GHz to 2 GHz)                                                                                          | 100.7 dB  |
| 2.4 GHz   | 802.11b, 802.11g, 802.11n, <i>Bluetooth</i> ®, mobile personal communications, industrial, scientific and medical (ISM) radio band, amateur radio and satellite, S-band (2 GHz to 4 GHz) | 102.4 dB  |
| 3.6 GHz   | Radiolocation, aero communication and navigation, satellite, mobile, S-band                                                                                                              | 104.8 dB  |
| 5 GHz     | 802.11a, 802.11n, aero communication and navigation, mobile communication, space and satellite operation, C-band (4 GHz to 8 GHz)                                                        | 100.3 dB  |

### 8.3.6 Capacitive Load and Stability

The device dynamic characteristics are optimized for a range of common operating conditions. The combination of low closed-loop gain and high capacitive loads decreases the amplifier phase margin and can lead to gain peaking or oscillations. As a result, larger capacitive loads must be isolated from the output. The simplest way to achieve this isolation is to add a small resistor (for example,  $R_{OUT}$  equal to 50  $\Omega$ ) in series with the output. Figure 41 and Figure 42 show graphs of small-signal overshoot versus capacitive load for several values of  $R_{OUT}$ . For details of analysis techniques and application circuits, see *Feedback Plots Define Op Amp AC Performance*, available for download from [www.ti.com](http://www.ti.com).



### 8.3.7 Electrical Overstress

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

Having a good understanding of this basic ESD circuitry and its relevance to an electrical overstress event is helpful. See [Figure 43](#) for an illustration of the ESD circuits contained in the OPA188 (indicated by the dashed line area). The ESD protection circuitry involves several current-steering diodes connected from the input and output pins and routed back to the internal power-supply lines, where the diodes meet at an internal absorption device of the operational amplifier. This protection circuitry is intended to remain inactive during normal circuit operation.

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

When an ESD voltage develops across two or more amplifier device pins, current flows through one or more steering diodes. Depending on the path that the current takes, the absorption device may activate. The absorption device has a trigger, or threshold voltage, that is above the normal operating voltage of the OPA188 but below the device breakdown voltage level. When this threshold is exceeded, the absorption device quickly activates and clamps the voltage across the supply rails to a safe level.

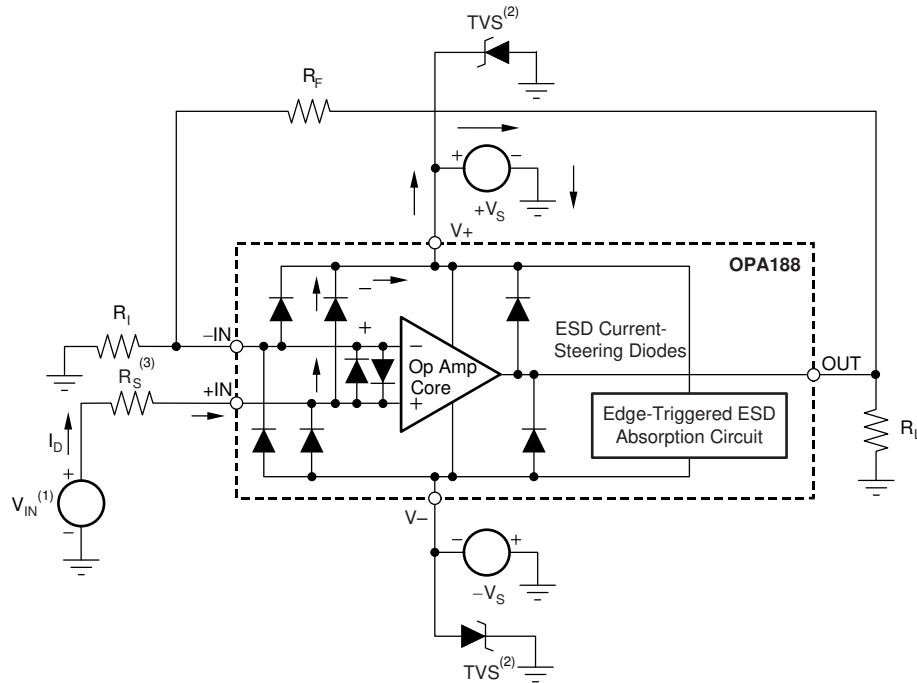
When the operational amplifier connects into a circuit (such as [Figure 43](#) shows), the ESD protection components are intended to remain inactive and do not become involved in the operation of the application circuit. However, circumstances may arise where an applied voltage exceeds the operating voltage range of a given pin. If this condition occurs, there is a risk that some internal ESD protection circuits may be biased on and conduct current. Any such current flow occurs through steering-diode paths and rarely involves the absorption device.

[Figure 43](#) shows a specific example where the input voltage,  $V_{IN}$ , exceeds the positive supply voltage ( $+V_S$ ) by 500 mV or more. Much of what happens in the circuit depends on the supply characteristics. If  $+V_S$  can sink the current, one of the upper-input steering diodes conducts and directs current to  $+V_S$ . Excessively high current levels can flow with increasingly higher  $V_{IN}$ . As a result, the data sheet specifications recommend that applications limit the input current to 10 mA.

If the supply is not capable of sinking the current,  $V_{IN}$  may begin sourcing current to the operational amplifier, and then take over as the source of positive supply voltage. The danger in this case is that the voltage can rise to levels that exceed the absolute maximum ratings of the operational amplifier.

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

If there is any uncertainty about the ability of the supply to absorb this current, external zener diodes may be added to the supply pins, as shown in Figure 43. The zener voltage must be selected such that the diode does not turn on during normal operation. However, the zener voltage must be low enough so that the zener diode conducts if the supply pin begins to rise above the safe operating supply voltage level.



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- (1)  $V_{IN} = +V_S + 500 \text{ mV}$ .
- (2) TVS:  $+V_{S(max)} > V_{TVSBR(min)} > +V_S$ .
- (3) Suggested value is approximately 1 k $\Omega$ .

**Figure 43. Equivalent Internal ESD Circuitry Relative to a Typical Circuit Application**

The OPA188 input terminals are protected from excessive differential voltage with back-to-back diodes, as shown in Figure 43. In most circuit applications, the input protection circuitry has no consequence. However, in low-gain and  $G = 1$  circuits, fast-ramping input signals can forward-bias these diodes because the output of the amplifier cannot respond rapidly enough to the input ramp. If the input signal is fast enough to create this forward-bias condition, the input signal current must be limited to 10 mA or less. If the input signal current is not inherently limited, an input series resistor can be used to limit the signal input current. This input series resistor degrades the low-noise performance of the OPA188. Figure 43 shows an example configuration that implements a current-limiting feedback resistor.

## 8.4 Device Functional Modes

The OPA188 has a single functional mode, and is operational when the power-supply voltage is greater than 4.5 V ( $\pm 2.25 \text{ V}$ ). The maximum power supply voltage for the OPA188 is 36 V ( $\pm 18 \text{ V}$ ).

## 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. Customers should validate and test their design implementation to confirm system functionality.

### 9.1 Application Information

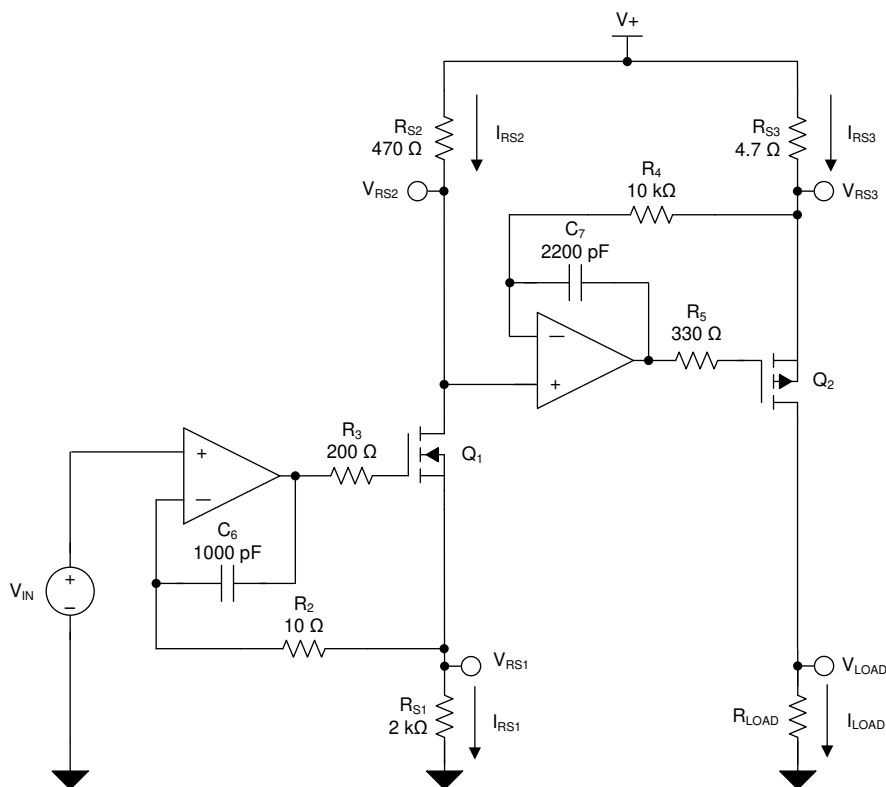
The OPA188 operational amplifier combines precision offset and drift with excellent overall performance, making this device an excellent choice for many precision applications. The precision offset drift of only  $0.085 \mu\text{V}/^\circ\text{C}$  provides stability over the entire temperature range. In addition, the device pairs excellent CMRR, PSRR, and  $A_{OL}$  dc performance with outstanding low-noise operation. As with all amplifiers, applications with noisy or high-impedance power supplies require decoupling capacitors close to the device pins. In most cases,  $0.1\text{-}\mu\text{F}$  capacitors are adequate.

The following application examples highlight only a few of the circuits where the OPA188 can be used.

### 9.2 Typical Applications

#### 9.2.1 High-Side Voltage-to-Current (V-I) Converter

The circuit shown in Figure 44 is a high-side voltage-to-current (V-I) converter. The converter translates an input voltage of 0 V to 2 V to an output current of 0 mA to 100 mA. Figure 45 shows the measured transfer function for this circuit. The low offset voltage and offset drift of the OPA188 facilitate excellent dc accuracy for the circuit.



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**Figure 44. High-Side Voltage-to-Current (V-I) Converter**

## Typical Applications (continued)

### 9.2.1.1 Design Requirements

The design requirements are:

- Supply voltage: 5 V dc
- Input: 0 V to 2 V dc
- Output: 0 mA to 100 mA dc

### 9.2.1.2 Detailed Design Procedure

The V-I transfer function of the circuit is based on the relationship between the input voltage,  $V_{IN}$ , and the three current sensing resistors,  $R_{S1}$ ,  $R_{S2}$ , and  $R_{S3}$ . The relationship between  $V_{IN}$  and  $R_{S1}$  determines the current that flows through the first stage of the design. The current gain from the first stage to the second stage is based on the relationship between  $R_{S2}$  and  $R_{S3}$ .

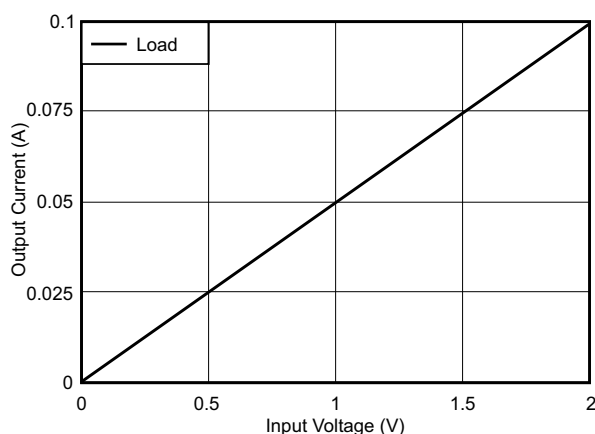
For a successful design, pay close attention to the dc characteristics of the operational amplifier chosen for the application. To meet the performance goals, this application benefits from an operational amplifier with low offset voltage, low temperature drift, and rail-to-rail output. The OPA188 CMOS operational amplifier is a high-precision, ultra-low offset, ultra-low drift amplifier, optimized for low-voltage, single-supply operation, with an output swing to within 15 mV of the positive rail. The devices in the OPA188 family use chopping techniques to provide low initial offset voltage and near-zero drift over time and temperature. Low offset voltage and low drift reduce the offset error in the system, making this device appropriate for precise dc control. The rail-to-rail output stage of the OPA188 makes sure that the output swing of the operational amplifier is able to fully control the gate of the MOSFET devices within the supply rails.

A detailed error analysis, design procedure, and additional measured results are given in reference design TIPD102, a step-by-step process to design a [High-Side Voltage-to-Current \(V-I\) Converter](#).

For step-by-step design procedure, circuit schematics, bill of materials, PCB files, simulation results, and test results, refer to [Precision Design Guide TIPD102, High-Side Voltage-to-Current \(V-I\) Converter](#).

### 9.2.1.3 Application Curves

Figure 45 shows the measured transfer function for the high-side voltage-to-current converter shown in Figure 44.



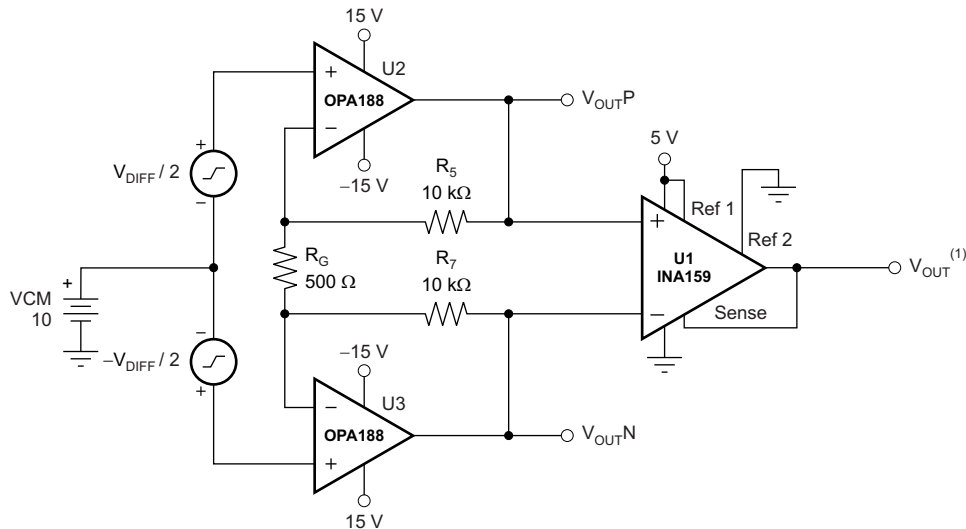
**Figure 45. Measured Transfer Function for High-Side V-I Converter**

## 9.2.2 Discrete INA + Attenuation for ADC With 3.3-V Supply

### NOTE

The TINA-TI files shown in the following sections require that either the TINA software (from DesignSoft™) or TINA-TI software be installed. Download the free TINA-TI software from the [TINA-TI folder](#).

Figure 46 shows an example of how the OPA188 is used as a high-voltage, high-impedance front-end for a precision, discrete instrumentation amplifier with attenuation. The [INA159](#) provides the attenuation that allows this circuit to easily interface with 3.3-V or 5-V analog-to-digital converters (ADCs). Click the following link to download the TINA-TI file: [Discrete INA](#).

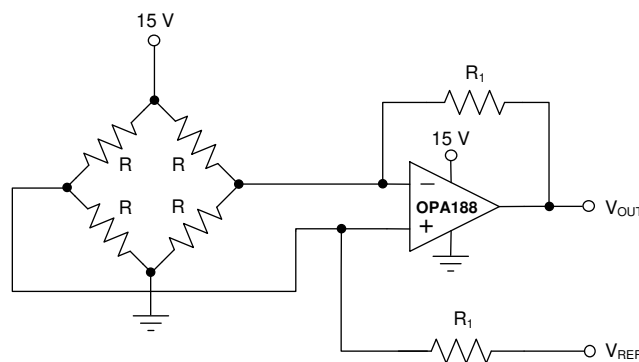


$$(1) \quad V_{OUT} = V_{DIFF} \times (41 / 5) + (Ref\ 1) / 2.$$

**Figure 46. Discrete INA + Attenuation for ADC With 3.3-V Supply**

## 9.2.3 Bridge Amplifier

Figure 47 shows the basic configuration for a bridge amplifier. Click the following link to download the TINA-TI file: [Bridge Amplifier Circuit](#).



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**Figure 47. Bridge Amplifier**

## 9.2.4 Low-Side Current Monitor

Figure 48 shows the OPA188 configured in a low-side current-sensing application. The load current ( $I_{LOAD}$ ) creates a voltage drop across the shunt resistor ( $R_{SHUNT}$ ). This voltage is amplified by the OPA188, with a gain of 201. The load current is set from 0 A to 500 mA, which corresponds to an output voltage range from 0 V to 10 V. The output range can be adjusted by changing the shunt resistor or gain of the configuration. Click the following link to download the TINA-TI file: [Current-Sensing Circuit](#).

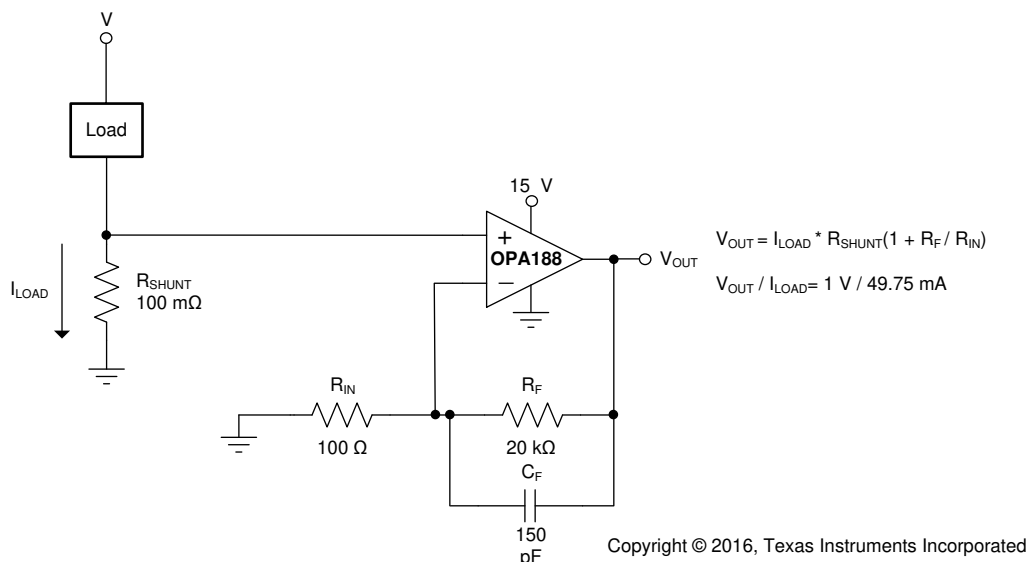


Figure 48. Low-Side Current Monitor

## 9.2.5 Programmable Power Supply

Figure 49 shows the OPA188 configured as a precision programmable power supply using the 16-bit, voltage output DAC8581 and the OPA548 high-current amplifier. This application amplifies the digital-to-analog converter (DAC) voltage by a value of five, and handles a large variety of capacitive and current loads. The OPA188 in the front-end provides precision and low drift across a wide range of inputs and conditions. Click the following link to download the TINA-TI file: [Programmable Power-Supply Circuit](#).

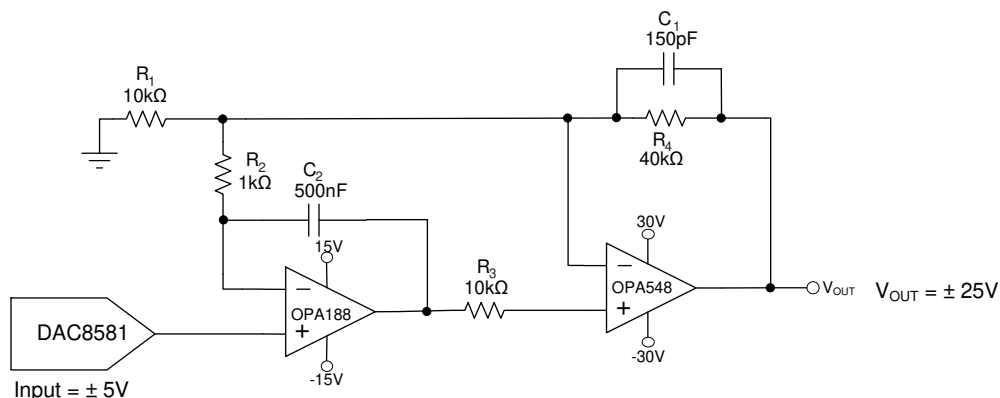
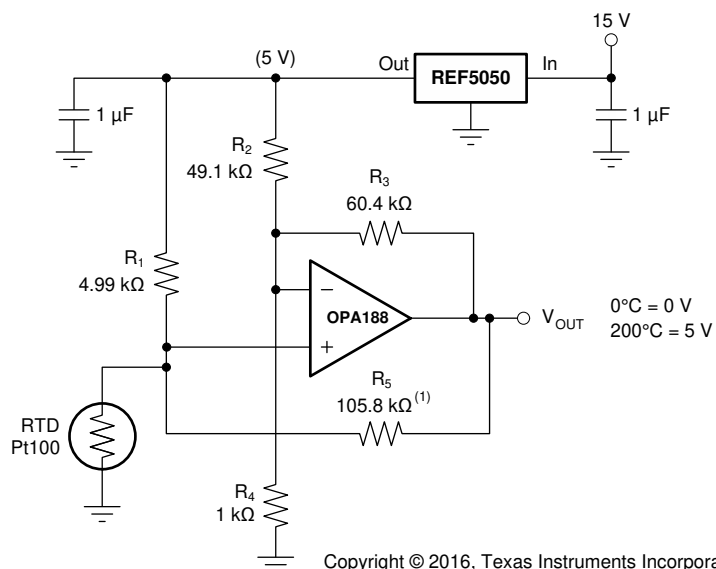


Figure 49. Programmable Power Supply

### 9.2.6 RTD Amplifier With Linearization

See [Analog Linearization Of Resistance Temperature Detectors](#) for an in-depth analysis of [Figure 50](#) . Click the following link to download the TINA-TI file: [RTD Amplifier with Linearization](#).



(1)  $R_5$  provides positive-varying excitation to linearize output.

**Figure 50. RTD Amplifier With Linearization**

## 10 Power Supply Recommendations

The OPA188 is specified for operation from 4 V to 36 V ( $\pm 2$  V to  $\pm 18$  V); many specifications apply from  $-40^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . [Typical Characteristics](#) presents parameters that can exhibit significant variance with regard to operating voltage or temperature.

### CAUTION

Supply voltages larger than 40 V can permanently damage the device (see the [Absolute Maximum Ratings](#)).

Place 0.1- $\mu\text{F}$  bypass capacitors close to the power-supply pins to reduce errors coupling in from noisy or high-impedance power supplies. For more detailed information on bypass capacitor placement, see [Layout](#).

## 11 Layout

### 11.1 Layout Guidelines

For best operational performance of the device, use good printed circuit board (PCB) layout practices, including:

- Connect Low-ESR, 0.1- $\mu\text{F}$  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 to single-supply applications.
- To reduce parasitic coupling, run the input traces as far away from the supply lines as possible.
- Use a ground plane to help distribute heat and reduces EMI noise pickup.
- Place the external components as close to the device as possible. This configuration prevents parasitic errors (such as the Seebeck effect) from occurring.
- Consider a driven, low-impedance guard ring around the critical traces. A guard ring can significantly reduce leakage currents from nearby traces that are at different potentials.

### 11.2 Layout Example

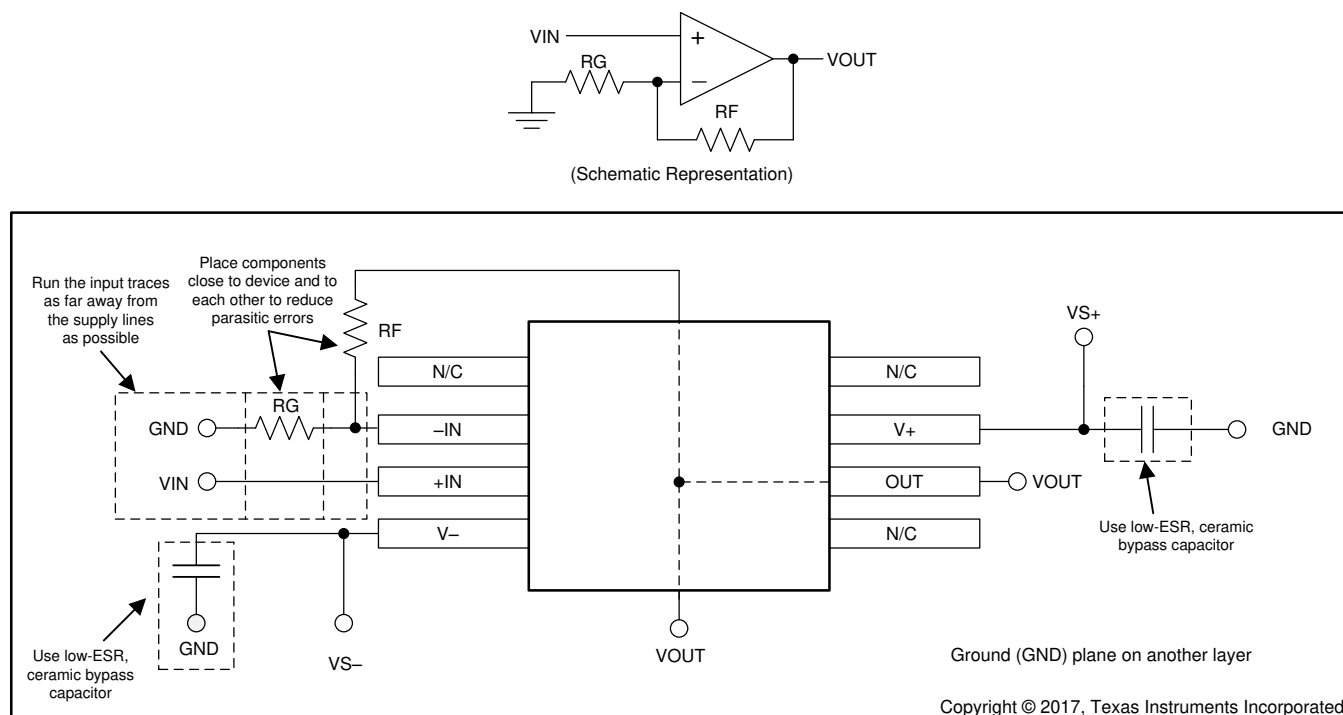


Figure 51. Layout Example

## 12 Device and Documentation Support

### 12.1 Device Support

#### 12.1.1 Development Support

##### 12.1.1.1 TINA-TI™ (Free Download Software)

TINA™ is a simple, powerful, and easy-to-use circuit simulation program based on a SPICE engine. TINA-TI 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 provides all the conventional dc, transient, and frequency domain analysis of SPICE as well as additional design capabilities.

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

### 12.2 Documentation Support

#### 12.2.1 Related Documentation

For related documentation see the following:

- Texas Instruments, [EMI Rejection Ratio of Operational Amplifiers application report](#)
- Texas Instruments, [Feedback Plots Define Op Amp AC Performance application report](#)
- Texas Instruments, [Analog Linearization Of Resistance Temperature Detectors technical brief](#)
- Texas Instruments, [High-Side Voltage-to-Current \(V-I\) Converter design guide](#)

### 12.3 Receiving Notification of Documentation Updates

To receive notification of documentation updates, navigate to the device product folder on [ti.com](#). In the upper right corner, click on *Alert me* 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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### 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

[SLYZ022](#) — *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 part number        | Status<br>(1) | Material type<br>(2) | Package   Pins   | Package qty   Carrier | RoHS<br>(3) | Lead finish/<br>Ball material<br>(4) | MSL rating/<br>Peak reflow<br>(5) | Op temp (°C) | Part marking<br>(6) |
|------------------------------|---------------|----------------------|------------------|-----------------------|-------------|--------------------------------------|-----------------------------------|--------------|---------------------|
| <a href="#">OPA188AID</a>    | Active        | Production           | SOIC (D)   8     | 75   TUBE             | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |
| OPA188AID.B                  | Active        | Production           | SOIC (D)   8     | 75   TUBE             | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |
| <a href="#">OPA188AIDBVR</a> | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| OPA188AIDBVR.B               | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| OPA188AIDBVRG4               | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| OPA188AIDBVRG4.B             | Active        | Production           | SOT-23 (DBV)   5 | 3000   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| <a href="#">OPA188AIDBVT</a> | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| OPA188AIDBVT.B               | Active        | Production           | SOT-23 (DBV)   5 | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXZ                 |
| <a href="#">OPA188AIDGKR</a> | Active        | Production           | VSSOP (DGK)   8  | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXX                 |
| OPA188AIDGKR.B               | Active        | Production           | VSSOP (DGK)   8  | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXX                 |
| <a href="#">OPA188AIDGKT</a> | Active        | Production           | VSSOP (DGK)   8  | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXX                 |
| OPA188AIDGKT.B               | Active        | Production           | VSSOP (DGK)   8  | 250   SMALL T&R       | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | QXX                 |
| <a href="#">OPA188AIDR</a>   | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |
| OPA188AIDR.B                 | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |
| OPA188AIDRG4                 | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |
| OPA188AIDRG4.B               | Active        | Production           | SOIC (D)   8     | 2500   LARGE T&R      | Yes         | NIPDAU                               | Level-2-260C-1 YEAR               | -40 to 125   | OPA188              |

<sup>(1)</sup> **Status:** For more details on status, see our [product life cycle](#).

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

<sup>(3)</sup> **RoHS values:** Yes, No, RoHS Exempt. See the [TI RoHS Statement](#) for additional information and value definition.

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

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

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

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

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**OTHER QUALIFIED VERSIONS OF OPA188 :**

- Automotive : [OPA188-Q1](#)

NOTE: Qualified Version Definitions:

- Automotive - Q100 devices qualified for high-reliability automotive applications targeting zero defects

## 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 |
|----------------|--------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| OPA188AIDBVR   | SOT-23       | DBV             | 5    | 3000 | 180.0              | 8.4                | 3.23    | 3.17    | 1.37    | 4.0     | 8.0    | Q3            |
| OPA188AIDBVRG4 | SOT-23       | DBV             | 5    | 3000 | 180.0              | 8.4                | 3.23    | 3.17    | 1.37    | 4.0     | 8.0    | Q3            |
| OPA188AIDBVT   | SOT-23       | DBV             | 5    | 250  | 180.0              | 8.4                | 3.23    | 3.17    | 1.37    | 4.0     | 8.0    | Q3            |
| OPA188AIDGKR   | VSSOP        | DGK             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| OPA188AIDGKT   | VSSOP        | DGK             | 8    | 250  | 177.8              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| OPA188AIDR     | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| OPA188AIDRG4   | SOIC         | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device         | Package Type | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|----------------|--------------|-----------------|------|------|-------------|------------|-------------|
| OPA188AIDBVR   | SOT-23       | DBV             | 5    | 3000 | 202.0       | 201.0      | 28.0        |
| OPA188AIDBVRG4 | SOT-23       | DBV             | 5    | 3000 | 202.0       | 201.0      | 28.0        |
| OPA188AIDBVT   | SOT-23       | DBV             | 5    | 250  | 202.0       | 201.0      | 28.0        |
| OPA188AIDGKR   | VSSOP        | DGK             | 8    | 2500 | 346.0       | 346.0      | 29.0        |
| OPA188AIDGKT   | VSSOP        | DGK             | 8    | 250  | 202.0       | 201.0      | 28.0        |
| OPA188AIDR     | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |
| OPA188AIDRG4   | SOIC         | D               | 8    | 2500 | 353.0       | 353.0      | 32.0        |

## TUBE



\*All dimensions are nominal

| Device      | Package Name | Package Type | Pins | SPQ | L (mm) | W (mm) | T (μm) | B (mm) |
|-------------|--------------|--------------|------|-----|--------|--------|--------|--------|
| OPA188AID   | D            | SOIC         | 8    | 75  | 506.6  | 8      | 3940   | 4.32   |
| OPA188AID.B | D            | SOIC         | 8    | 75  | 506.6  | 8      | 3940   | 4.32   |

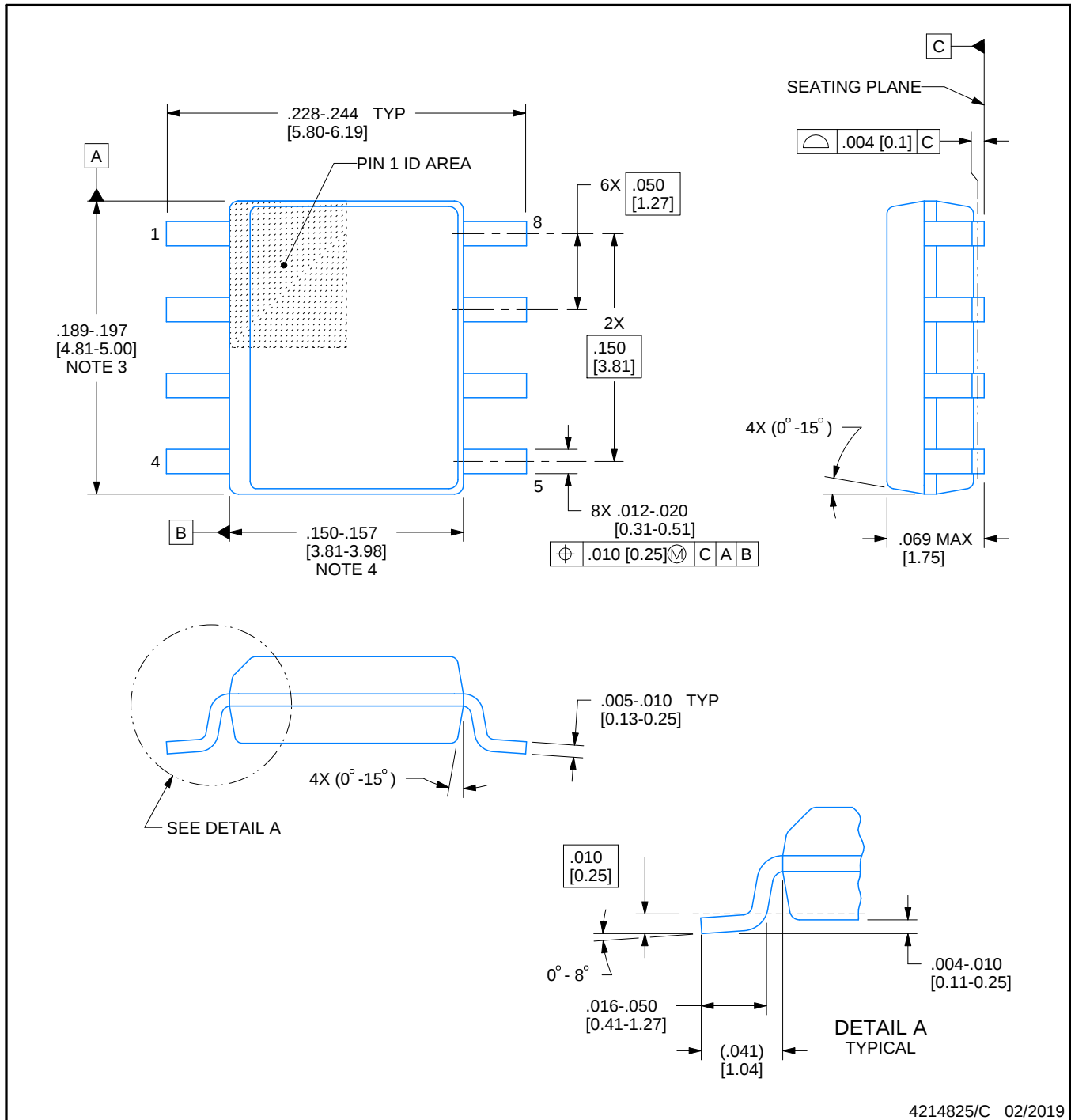


**D0008A**

# 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.

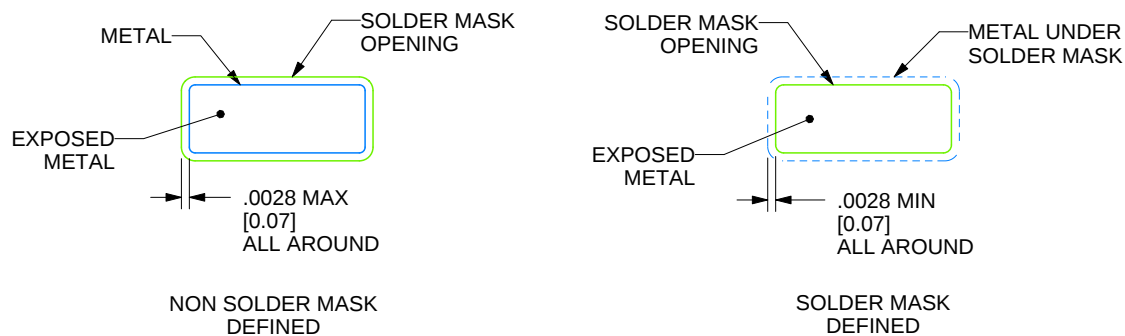
**D0008A**

**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

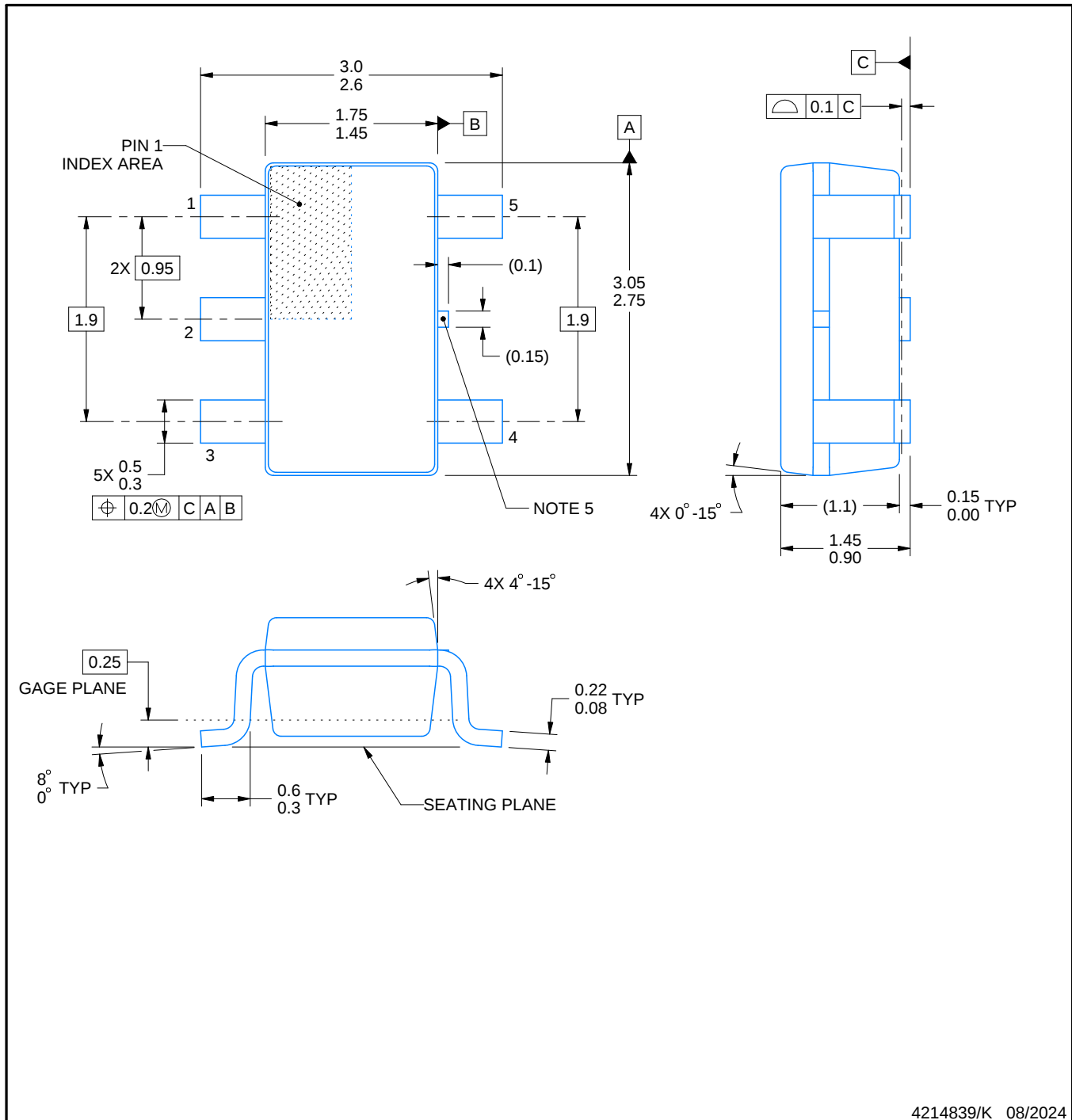
4214825/C 02/2019

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.

**DBV0005A****PACKAGE OUTLINE****SOT-23 - 1.45 mm max height**

SMALL OUTLINE TRANSISTOR

**NOTES:**

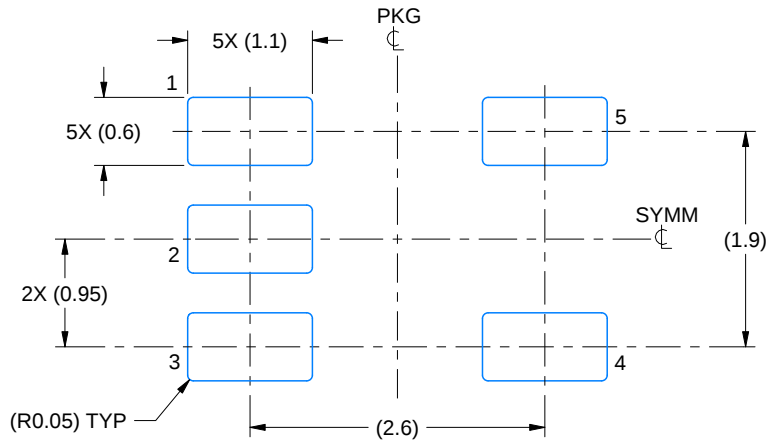
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC MO-178.
4. Body dimensions do not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.25 mm per side.
5. Support pin may differ or may not be present.

# EXAMPLE BOARD LAYOUT

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE:15X



SOLDER MASK DETAILS

4214839/K 08/2024

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

DBV0005A

SOT-23 - 1.45 mm max height

SMALL OUTLINE TRANSISTOR



SOLDER PASTE EXAMPLE  
BASED ON 0.125 mm THICK STENCIL  
SCALE:15X

4214839/K 08/2024

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.

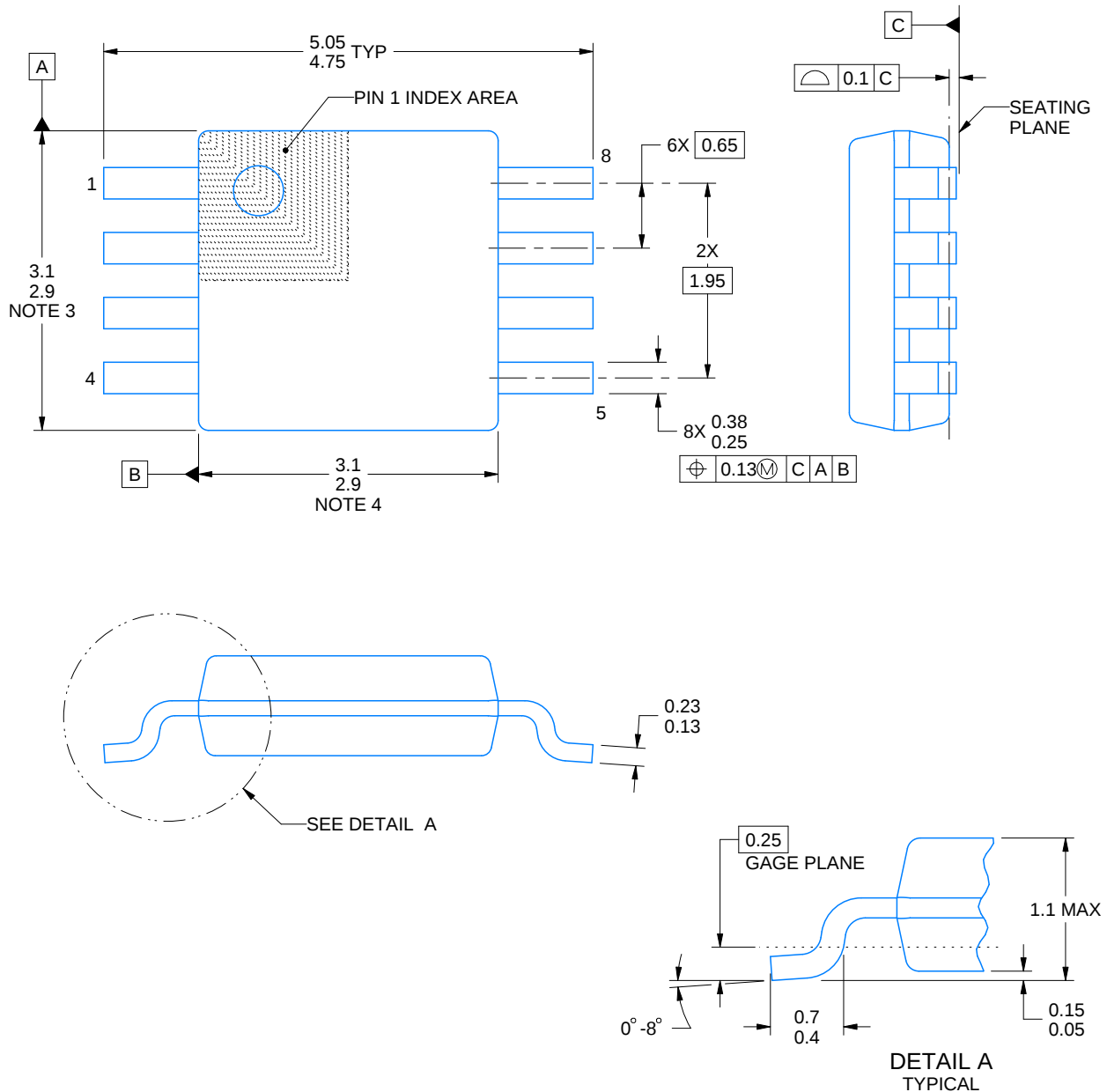
DGK0008A



# PACKAGE OUTLINE

## VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



4214862/A 04/2023

### NOTES:

PowerPAD is a trademark of Texas Instruments.

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

# EXAMPLE BOARD LAYOUT

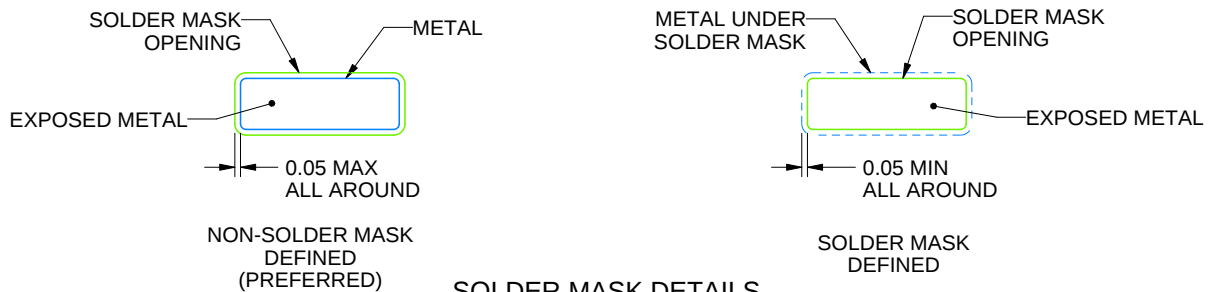
DGK0008A

<sup>TM</sup> VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



LAND PATTERN EXAMPLE  
EXPOSED METAL SHOWN  
SCALE: 15X



SOLDER MASK DETAILS

4214862/A 04/2023

NOTES: (continued)

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

## EXAMPLE STENCIL DESIGN

DGK0008A

<sup>TM</sup> VSSOP - 1.1 mm max height

SMALL OUTLINE PACKAGE



SOLDER PASTE EXAMPLE  
SCALE: 15X

4214862/A 04/2023

NOTES: (continued)

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

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