



# 10 MHz, 20 V/ $\mu$ s, G = 1, 2, 4, 8 iCMOS<sup>®</sup> Programmable Gain Instrumentation Amplifier

## AD8251

### FEATURES

**Small package:** 10-lead MSOP

**Programmable gains:** 1, 2, 4, 8

**Digital or pin-programmable gain setting**

**Wide supply:**  $\pm 5$  V to  $\pm 15$  V

**Excellent dc performance**

**High CMRR:** 98 dB (minimum), G = 8

**Low gain drift:** 10 ppm/ $^{\circ}$ C (maximum)

**Low offset drift:** 1.8  $\mu$ V/ $^{\circ}$ C (maximum), G = 8

**Excellent ac performance**

**Fast settling time:** 785 ns to 0.001% (maximum)

**High slew rate:** 20 V/ $\mu$ s (minimum)

**Low distortion:** -110 dB THD at 1 kHz, 10 V swing

**High CMRR over frequency:** 80 dB to 50 kHz (minimum)

**Low noise:** 18 nV/ $\sqrt{\text{Hz}}$ , G = 10 (maximum)

**Low power:** 4 mA

### APPLICATIONS

**Data acquisition**

**Biomedical analysis**

**Test and measurement**

### GENERAL DESCRIPTION

The AD8251 is an instrumentation amplifier with digitally programmable gains that has G $\Omega$  input impedance, low output noise, and low distortion, making it suitable for interfacing with sensors and driving high sample rate analog-to-digital converters (ADCs). It has high bandwidth of 10 MHz, low THD of -110 dB, and fast settling time of 785 ns (maximum) to 0.001%. Offset drift and gain drift are guaranteed to 1.8  $\mu$ V/ $^{\circ}$ C and 10 ppm/ $^{\circ}$ C, respectively, for G = 8. In addition to its wide input common voltage range, it boasts a high common-mode rejection of 80 dB at G = 1 from dc to 50 kHz. The combination of precision dc performance coupled with high speed capabilities makes the AD8251 an excellent candidate for data acquisition. Furthermore, this monolithic solution simplifies design and manufacturing and boosts performance of instrumentation by maintaining a tight match of internal resistors and amplifiers.

The AD8251 user interface consists of a parallel port that allows users to set the gain in one of two different ways (see Figure 1 for the functional block diagram). A 2-bit word sent via a bus can be latched using the WR input. An alternative is to use transparent gain mode where the state of logic levels at the gain port determines the gain.

### FUNCTIONAL BLOCK DIAGRAM

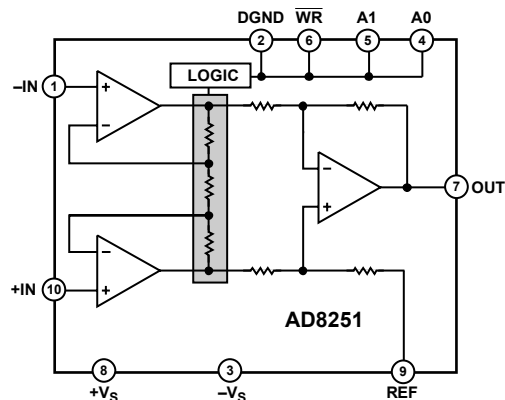


Figure 1.

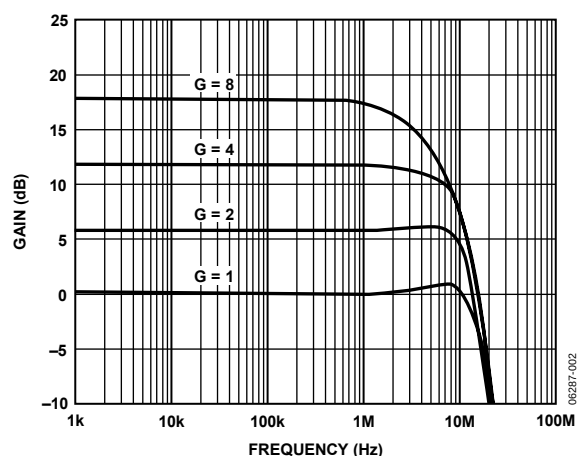


Figure 2. Gain vs. Frequency

Table 1. Instrumentation and Difference Amplifiers  
by Category

| High Performance    | Low Cost            | High Voltage | Mil Grade | Low Power          | Digital Gain        |
|---------------------|---------------------|--------------|-----------|--------------------|---------------------|
| AD8220 <sup>1</sup> | AD623 <sup>1</sup>  | AD628        | AD620     | AD627 <sup>1</sup> | AD8231 <sup>1</sup> |
| AD8221              | AD8553 <sup>1</sup> | AD629        | AD621     |                    | AD8250              |
| AD8222              |                     |              | AD524     |                    | AD8555 <sup>1</sup> |
| AD8224 <sup>1</sup> |                     |              | AD526     |                    | AD8556 <sup>1</sup> |
|                     |                     |              | AD624     |                    | AD8557 <sup>1</sup> |

<sup>1</sup> Rail-to-rail output.

The AD8251 is available in a 10-lead MSOP package and is specified over the -40 $^{\circ}$ C to +85 $^{\circ}$ C temperature range, making it an excellent solution for applications where size and packing density are important considerations.

Rev. 0

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## REVISION HISTORY

5/07—Revision 0: Initial Version

## SPECIFICATIONS

+V<sub>S</sub> = +15 V, -V<sub>S</sub> = -15 V, V<sub>REF</sub> = 0 V @ T<sub>A</sub> = 25°C, G = 1, R<sub>L</sub> = 2 kΩ, unless otherwise noted.

Table 2.

| Parameter                                     | Conditions                     | Min | Typ | Max          | Unit   |
|-----------------------------------------------|--------------------------------|-----|-----|--------------|--------|
| <b>COMMON-MODE REJECTION RATIO (CMRR)</b>     |                                |     |     |              |        |
| CMRR to 60 Hz with 1 kΩ Source Imbalance      | +IN = -IN = -10 V to +10 V     |     |     |              |        |
| G = 1                                         |                                | 80  | 94  |              | dB     |
| G = 2                                         |                                | 86  | 104 |              | dB     |
| G = 4                                         |                                | 92  | 105 |              | dB     |
| G = 8                                         |                                | 98  | 105 |              | dB     |
| CMRR to 50 kHz                                | +IN = -IN = -10 V to +10 V     |     |     |              |        |
| G = 1                                         |                                | 80  |     |              | dB     |
| G = 2                                         |                                | 84  |     |              | dB     |
| G = 4                                         |                                | 86  |     |              | dB     |
| G = 8                                         |                                | 86  |     |              | dB     |
| <b>NOISE</b>                                  |                                |     |     |              |        |
| Voltage Noise, 1 kHz, RTI                     |                                |     |     |              |        |
| G = 1                                         |                                |     |     | 40           | nV/√Hz |
| G = 2                                         |                                |     |     | 27           | nV/√Hz |
| G = 4                                         |                                |     |     | 22           | nV/√Hz |
| G = 8                                         |                                |     |     | 18           | nV/√Hz |
| 0.1 Hz to 10 Hz, RTI                          |                                |     |     |              |        |
| G = 1                                         |                                |     |     | 2.5          | μV p-p |
| G = 2                                         |                                |     |     | 2.5          | μV p-p |
| G = 4                                         |                                |     |     | 1.8          | μV p-p |
| G = 8                                         |                                |     |     | 1.2          | μV p-p |
| Current Noise, 1 kHz                          |                                |     | 5   |              | pA/√Hz |
| Current Noise, 0.1 Hz to 10 Hz                |                                |     | 60  |              | pA p-p |
| <b>VOLTAGE OFFSET</b>                         |                                |     |     |              |        |
| Offset RTI V <sub>OS</sub>                    | G = 1, 2, 4, 8                 |     |     | ±200 + 600/G | μV     |
| Over Temperature                              | T = -40°C to +85°C             |     |     | ±260 + 900/G | μV     |
| Average TC                                    | T = -40°C to +85°C             |     |     | ±1.2 + 5/G   | μV/°C  |
| Offset Referred to the Input vs. Supply (PSR) | V <sub>S</sub> = ±5 V to ±15 V |     |     | ±6 + 20/G    | μV/V   |
| <b>INPUT CURRENT</b>                          |                                |     |     |              |        |
| Input Bias Current                            |                                |     | 5   | 30           | nA     |
| Over Temperature                              | T = -40°C to +85°C             |     |     | 40           | nA     |
| Average TC                                    | T = -40°C to +85°C             |     |     | 400          | pA/°C  |
| Input Offset Current                          |                                |     | 5   | 30           | nA     |
| Over Temperature                              | T = -40°C to +85°C             |     |     | 30           | nA     |
| Average TC                                    | T = -40°C to +85°C             |     |     | 160          | pA/°C  |
| <b>DYNAMIC RESPONSE</b>                       |                                |     |     |              |        |
| Small Signal -3 dB Bandwidth                  |                                |     |     |              |        |
| G = 1                                         |                                | 10  |     |              | MHz    |
| G = 2                                         |                                | 10  |     |              | MHz    |
| G = 4                                         |                                | 8   |     |              | MHz    |
| G = 8                                         |                                | 2.5 |     |              | MHz    |
| Settling Time 0.01%                           | ΔOUT = 10 V step               |     |     |              |        |
| G = 1                                         |                                |     |     | 615          | ns     |
| G = 2                                         |                                |     |     | 460          | ns     |
| G = 4                                         |                                |     |     | 460          | ns     |
| G = 8                                         |                                |     |     | 625          | ns     |

# AD8251

| Parameter                         | Conditions                                                                                            | Min           | Typ            | Max          | Unit                    |
|-----------------------------------|-------------------------------------------------------------------------------------------------------|---------------|----------------|--------------|-------------------------|
| Settling Time 0.001%              | $\Delta\text{OUT} = 10\text{ V step}$                                                                 |               |                |              |                         |
| G = 1                             |                                                                                                       |               |                | 785          | ns                      |
| G = 2                             |                                                                                                       |               |                | 700          | ns                      |
| G = 4                             |                                                                                                       |               |                | 700          | ns                      |
| G = 8                             |                                                                                                       |               |                | 770          | ns                      |
| Slew Rate                         |                                                                                                       |               |                |              |                         |
| G = 1                             |                                                                                                       | 20            |                |              | V/ $\mu\text{s}$        |
| G = 2                             |                                                                                                       | 30            |                |              | V/ $\mu\text{s}$        |
| G = 4                             |                                                                                                       | 30            |                |              | V/ $\mu\text{s}$        |
| G = 8                             |                                                                                                       | 30            |                |              | V/ $\mu\text{s}$        |
| Total Harmonic Distortion + Noise | f = 1 kHz, $R_L = 10\text{ k}\Omega$ , $\pm 10\text{ V}$ ,<br>G = 1, 10 Hz to 22 kHz band-pass filter |               | –110           |              | dB                      |
| GAIN                              |                                                                                                       |               |                |              |                         |
| Gain Range                        | G = 1, 2, 4, 8                                                                                        | 1             |                | 8            | V/V                     |
| Gain Error                        | OUT = $\pm 10\text{ V}$                                                                               |               |                |              |                         |
| G = 1                             |                                                                                                       |               |                | 0.03         | %                       |
| G = 2, 4, 8                       |                                                                                                       |               |                | 0.04         | %                       |
| Gain Nonlinearity                 | OUT = $-10\text{ V to }+10\text{ V}$                                                                  |               |                |              |                         |
| G = 1                             | $R_L = 10\text{ k}\Omega$ , 2 k $\Omega$ , 600 $\Omega$                                               |               |                | 9            | ppm                     |
| G = 2                             | $R_L = 10\text{ k}\Omega$ , 2 k $\Omega$ , 600 $\Omega$                                               |               |                | 12           | ppm                     |
| G = 4                             | $R_L = 10\text{ k}\Omega$ , 2 k $\Omega$ , 600 $\Omega$                                               |               |                | 12           | ppm                     |
| G = 8                             | $R_L = 10\text{ k}\Omega$ , 2 k $\Omega$ , 600 $\Omega$                                               |               |                | 15           | ppm                     |
| Gain vs. Temperature              | All gains                                                                                             |               | 3              | 10           | ppm/ $^{\circ}\text{C}$ |
| INPUT                             |                                                                                                       |               |                |              |                         |
| Input Impedance                   |                                                                                                       |               |                |              |                         |
| Differential                      |                                                                                                       |               | 1  2pF         |              | G $\Omega$   pF         |
| Common Mode                       |                                                                                                       |               | 1  2pF         |              | G $\Omega$   pF         |
| Input Operating Voltage Range     | $V_S = \pm 5\text{ V to } \pm 15\text{ V}$                                                            | $-V_S + 1.5$  |                | $+V_S - 1.5$ | V                       |
| Over Temperature                  | T = $-40^{\circ}\text{C to }+85^{\circ}\text{C}$                                                      | $-V_S + 1.6$  |                | $+V_S - 1.7$ | V                       |
| OUTPUT                            |                                                                                                       |               |                |              |                         |
| Output Swing                      |                                                                                                       | –13.5         |                | +13.5        | V                       |
| Over Temperature                  | T = $-40^{\circ}\text{C to }+85^{\circ}\text{C}$                                                      | –13.5         |                | +13.5        | V                       |
| Short-Circuit Current             |                                                                                                       |               | 37             |              | mA                      |
| REFERENCE INPUT                   |                                                                                                       |               |                |              |                         |
| $R_{IN}$                          |                                                                                                       |               | 20             |              | k $\Omega$              |
| $I_{IN}$                          | +IN, –IN, REF = 0                                                                                     |               |                | 1            | $\mu\text{A}$           |
| Voltage Range                     |                                                                                                       | $-V_S$        |                | $+V_S$       | V                       |
| Gain to Output                    |                                                                                                       |               | $1 \pm 0.0001$ |              | V/V                     |
| DIGITAL LOGIC                     |                                                                                                       |               |                |              |                         |
| Digital Ground Voltage, DGND      | Referred to GND                                                                                       | $-V_S + 4.25$ | 0              | $+V_S - 2.7$ | V                       |
| Digital Input Voltage Low         | Referred to GND                                                                                       | DGND          |                | 2.1          | V                       |
| Digital Input Voltage High        | Referred to GND                                                                                       | 2.8           |                | $+V_S$       | V                       |
| Digital Input Current             |                                                                                                       |               | 1              |              | $\mu\text{A}$           |
| Gain Switching Time <sup>1</sup>  |                                                                                                       |               |                | 325          | ns                      |
| $t_{SU}$                          | See Figure 3 timing diagram                                                                           | 20            |                |              | ns                      |
| $t_{HD}$                          |                                                                                                       | 10            |                |              | ns                      |
| $t_{\overline{WR-LOW}}$           |                                                                                                       | 20            |                |              | ns                      |
| $t_{\overline{WR-HIGH}}$          |                                                                                                       | 40            |                |              | ns                      |

| Parameter                          | Conditions         | Min | Typ | Max | Unit |
|------------------------------------|--------------------|-----|-----|-----|------|
| POWER SUPPLY                       |                    |     |     |     |      |
| Operating Range                    |                    | ±5  |     | ±15 | V    |
| Quiescent Current, +I <sub>S</sub> |                    |     | 4.1 | 4.5 | mA   |
| Quiescent Current, −I <sub>S</sub> |                    |     | 3.7 | 4.5 | mA   |
| Over Temperature                   | T = −40°C to +85°C |     |     | 4.5 | mA   |
| TEMPERATURE RANGE                  |                    |     |     |     |      |
| Specified Performance              |                    | −40 |     | +85 | °C   |

<sup>1</sup> Add time for the output to slew and settle to calculate the total time for a gain change.

TIMING DIAGRAM

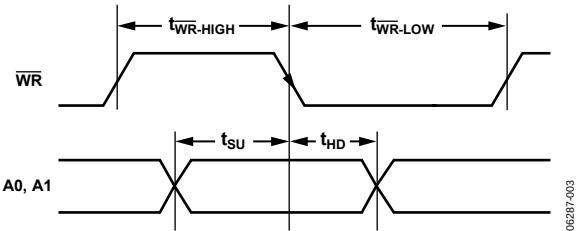


Figure 3. Timing Diagram for Latched Gain Mode (See the Timing for Latched Gain Mode Section)

## ABSOLUTE MAXIMUM RATINGS

Table 3.

| Parameter                                      | Rating                  |
|------------------------------------------------|-------------------------|
| Supply Voltage                                 | ±17 V                   |
| Power Dissipation                              | See Figure 4            |
| Output Short-Circuit Current                   | Indefinite <sup>1</sup> |
| Common-Mode Input Voltage                      | ±V <sub>S</sub>         |
| Differential Input Voltage                     | ±V <sub>S</sub>         |
| Digital Logic Inputs                           | ±V <sub>S</sub>         |
| Storage Temperature Range                      | –65°C to +125°C         |
| Operating Temperature Range <sup>2</sup>       | –40°C to +85°C          |
| Lead Temperature (Soldering 10 sec)            | 300°C                   |
| Junction Temperature                           | 140°C                   |
| θ <sub>JA</sub> (4-Layer JEDEC Standard Board) | 112°C/W                 |
| Package Glass Transition Temperature           | 140°C                   |

<sup>1</sup> Assumes the load is referenced to midsupply.

<sup>2</sup> Temperature for specified performance is –40°C to +85°C. For performance to +125°C, see the Typical Performance Characteristics section.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### MAXIMUM POWER DISSIPATION

The maximum safe power dissipation in the AD8251 package is limited by the associated rise in junction temperature (T<sub>J</sub>) on the die. The plastic encapsulating the die locally reaches the junction temperature. At approximately 140°C, which is the glass transition temperature, the plastic changes its properties. Even temporarily exceeding this temperature limit can change the stresses that the package exerts on the die, permanently shifting the parametric performance of the AD8251. Exceeding a junction temperature of 140°C for an extended period can result in changes in silicon devices, potentially causing failure.

The still-air thermal properties of the package and PCB (θ<sub>JA</sub>), the ambient temperature (T<sub>A</sub>), and the total power dissipated in the package (P<sub>D</sub>) determine the junction temperature of the die. The junction temperature is calculated as

$$T_J = T_A + (P_D \times \theta_{JA})$$

The power dissipated in the package (P<sub>D</sub>) is the sum of the quiescent power dissipation and the power dissipated in the

package due to the load drive for all outputs. The quiescent power is the voltage between the supply pins (V<sub>S</sub>) times the quiescent current (I<sub>S</sub>). Assuming the load (R<sub>L</sub>) is referenced to midsupply, the total drive power is V<sub>S</sub>/2 × I<sub>OUT</sub>, some of which is dissipated in the package and some in the load (V<sub>OUT</sub> × I<sub>OUT</sub>).

The difference between the total drive power and the load power is the drive power dissipated in the package.

$$P_D = \text{Quiescent Power} + (\text{Total Drive Power} - \text{Load Power})$$

$$P_D = (V_S \times I_S) + \left( \frac{V_S}{2} \times \frac{V_{OUT}}{R_L} \right) - \frac{V_{OUT}^2}{R_L}$$

In single-supply operation with R<sub>L</sub> referenced to –V<sub>S</sub>, the worst case is V<sub>OUT</sub> = V<sub>S</sub>/2.

Airflow increases heat dissipation, effectively reducing θ<sub>JA</sub>. In addition, more metal directly in contact with the package leads from metal traces, through holes, ground, and power planes reduces the θ<sub>JA</sub>.

Figure 4 shows the maximum safe power dissipation in the package vs. the ambient temperature on a 4-layer JEDEC standard board.

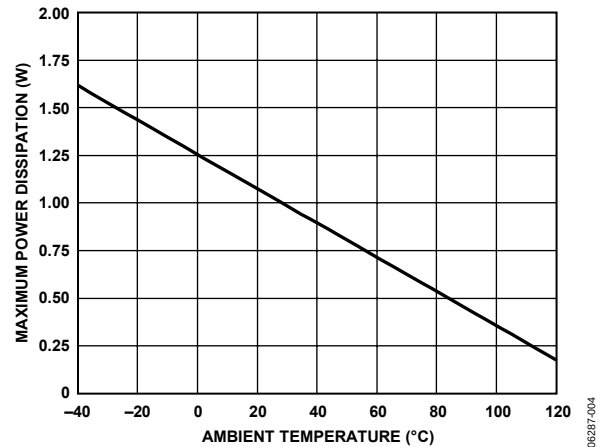


Figure 4. Maximum Power Dissipation vs. Ambient Temperature

### ESD CAUTION



#### ESD (electrostatic discharge) sensitive device.

Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

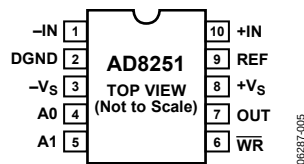


Figure 5. 10-Lead MSOP (RM-10) Pin Configuration

Table 4. Pin Function Descriptions

| Pin No. | Mnemonic        | Description                                           |
|---------|-----------------|-------------------------------------------------------|
| 1       | -IN             | Inverting Input Terminal. True differential input.    |
| 2       | DGND            | Digital Ground.                                       |
| 3       | -Vs             | Negative Supply Terminal.                             |
| 4       | A0              | Gain Setting Pin (LSB).                               |
| 5       | A1              | Gain Setting Pin (MSB).                               |
| 6       | $\overline{WR}$ | Write Enable.                                         |
| 7       | OUT             | Output Terminal.                                      |
| 8       | +Vs             | Positive Supply Terminal.                             |
| 9       | REF             | Reference Voltage Terminal.                           |
| 10      | +IN             | Noninverting Input Terminal. True differential input. |

## TYPICAL PERFORMANCE CHARACTERISTICS

$T_A$  @ 25°C,  $+V_S = +15$  V,  $-V_S = -15$  V,  $R_L = 10$  k $\Omega$ , unless otherwise noted.

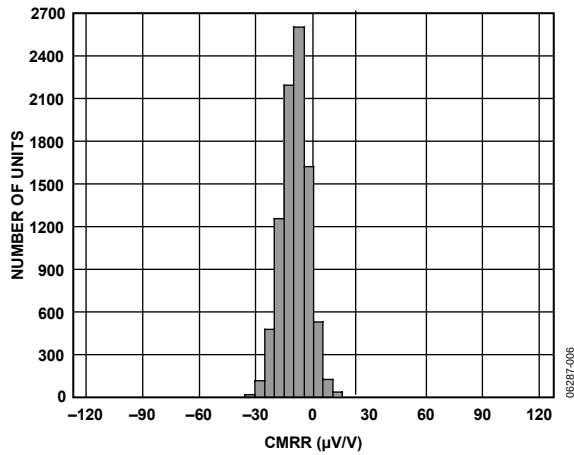


Figure 6. Typical Distribution of CMRR,  $G = 1$

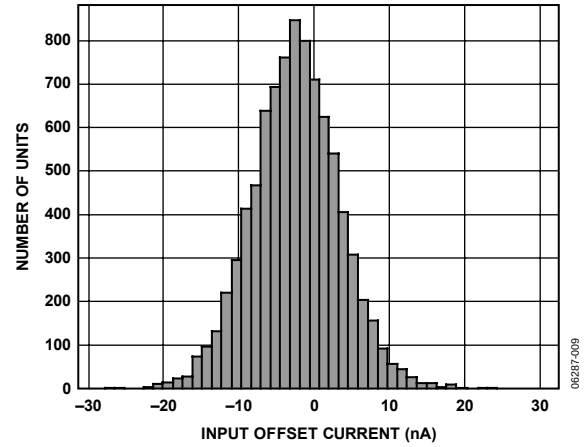


Figure 9. Typical Distribution of Input Offset Current

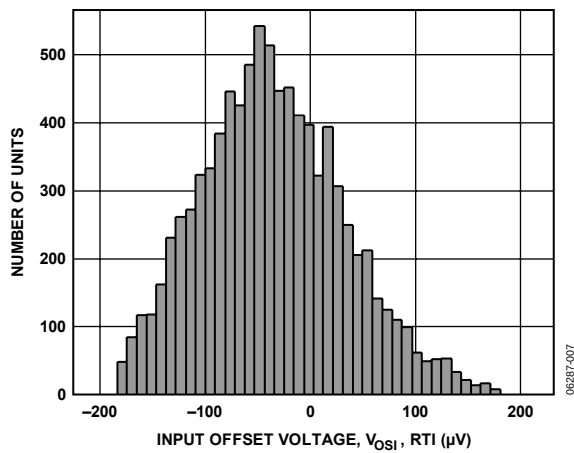


Figure 7. Typical Distribution of Offset Voltage,  $V_{OSI}$

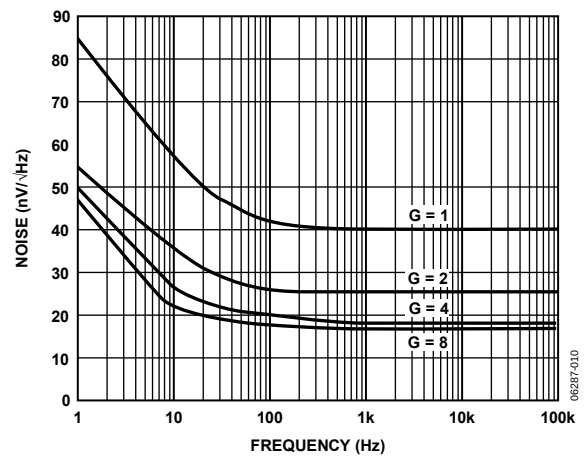


Figure 10. Voltage Spectral Density Noise vs. Frequency

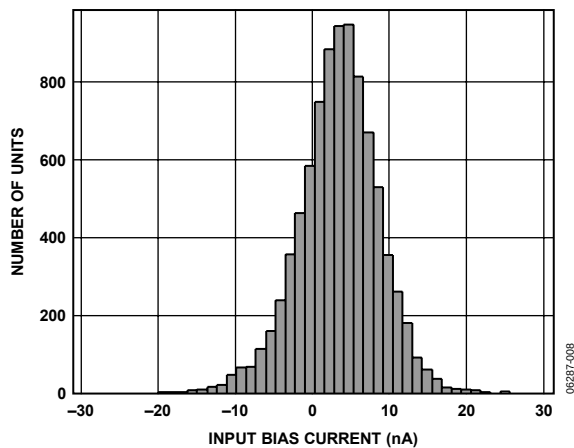


Figure 8. Typical Distribution of Input Bias Current

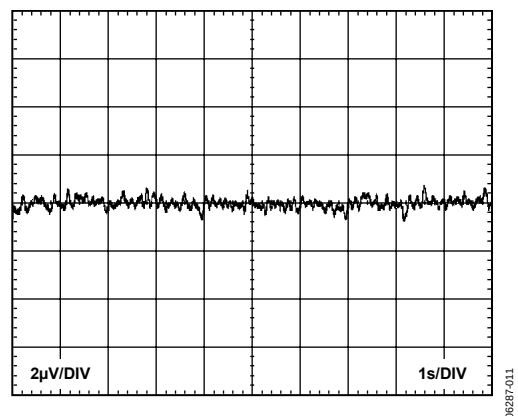


Figure 11. 0.1 Hz to 10 Hz RTI Voltage Noise,  $G = 1$



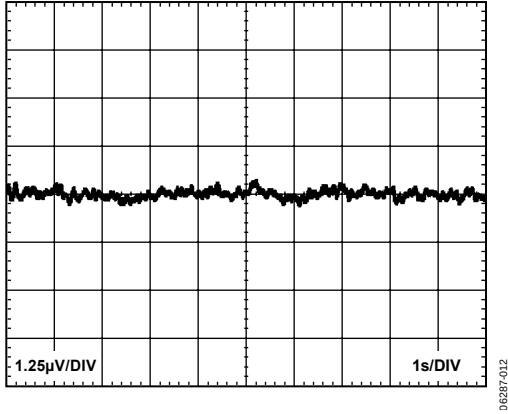


Figure 12. 0.1 Hz to 10 Hz RTI Voltage Noise, G = 8

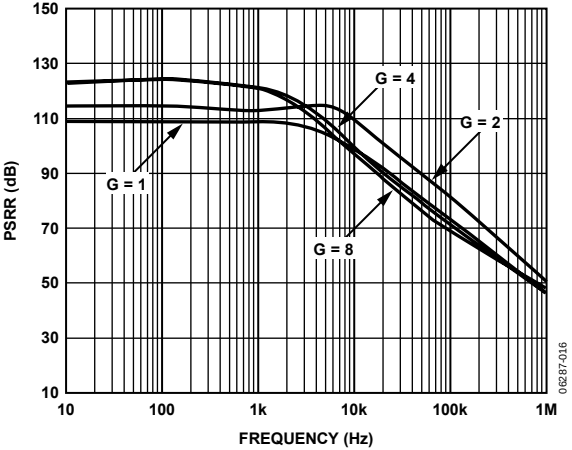


Figure 15. Positive PSRR vs. Frequency, RTI

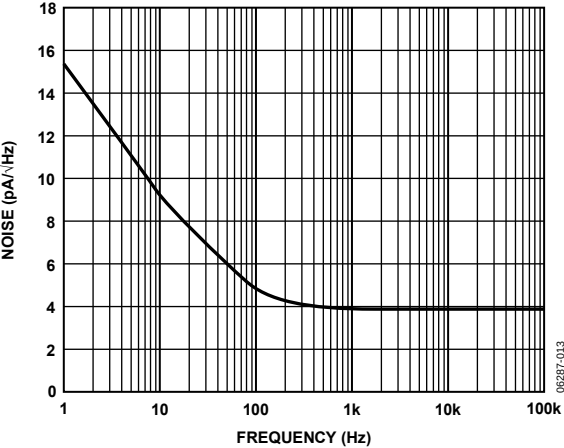


Figure 13. Current Noise Spectral Density vs. Frequency

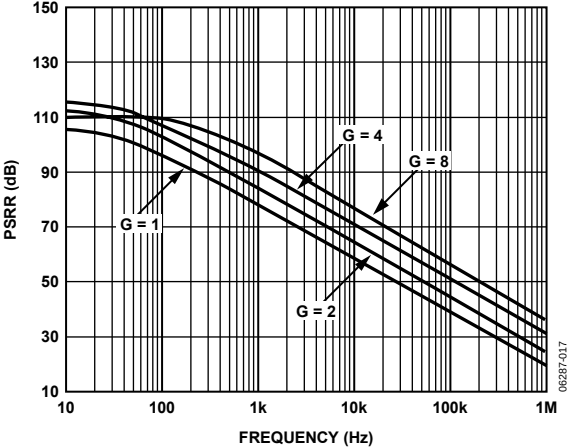


Figure 16. Negative PSRR vs. Frequency, RTI

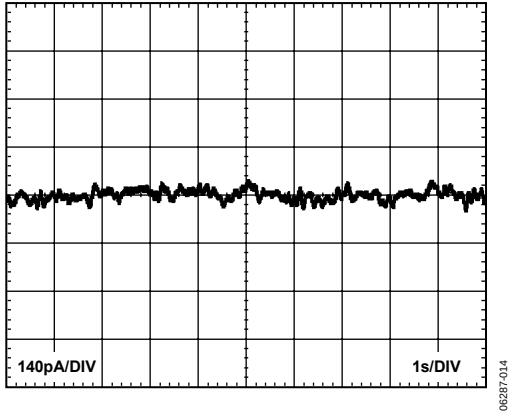


Figure 14. 0.1 Hz to 10 Hz Current Noise

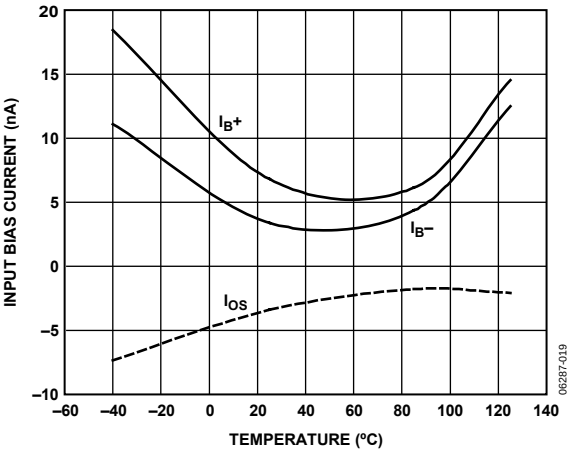


Figure 17. Input Bias Current and Offset Current vs. Temperature

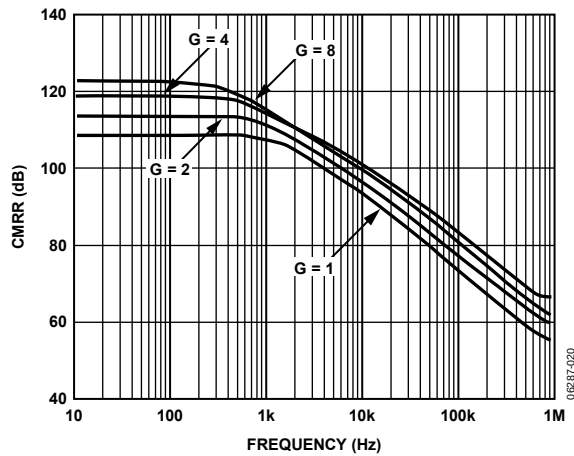


Figure 18. CMRR vs. Frequency

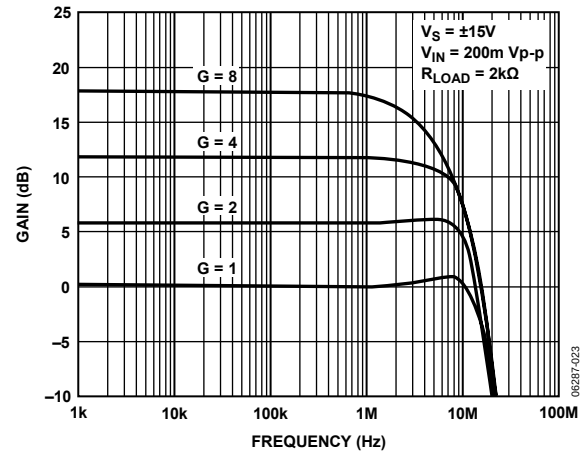


Figure 21. Gain vs. Frequency

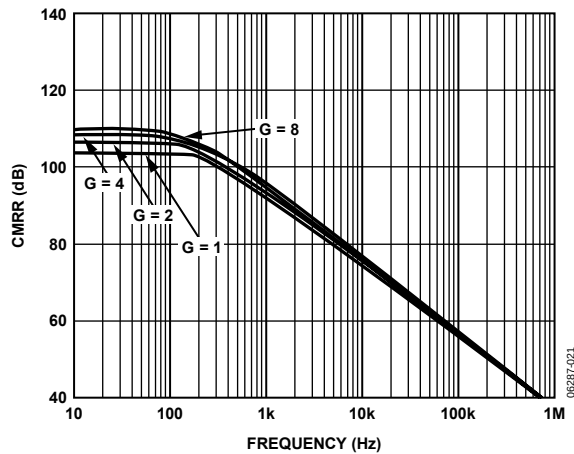


Figure 19. CMRR vs. Frequency, 1 k $\Omega$  Source Imbalance

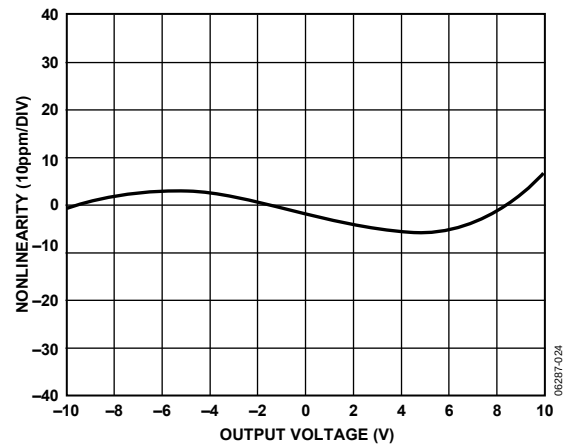


Figure 22. Gain Nonlinearity,  $G = 1$ ,  $R_L = 10\text{ k}\Omega$ ,  $2\text{ k}\Omega$ ,  $600\Omega$

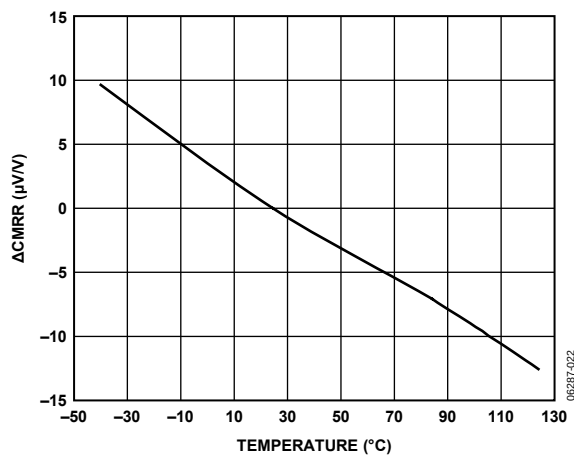


Figure 20. CMRR vs. Temperature,  $G = 1$

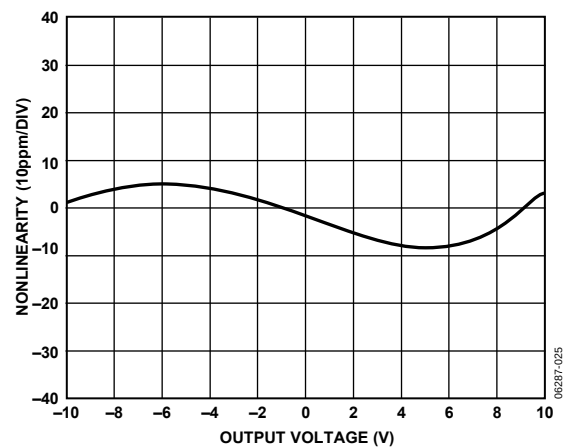
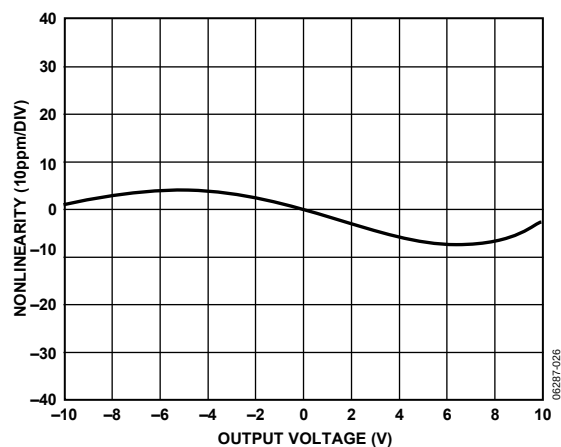
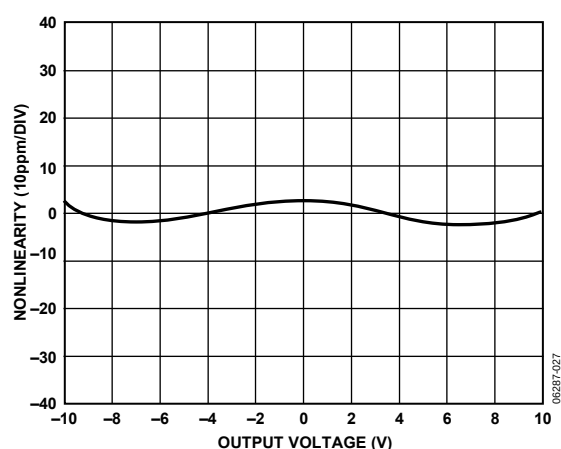
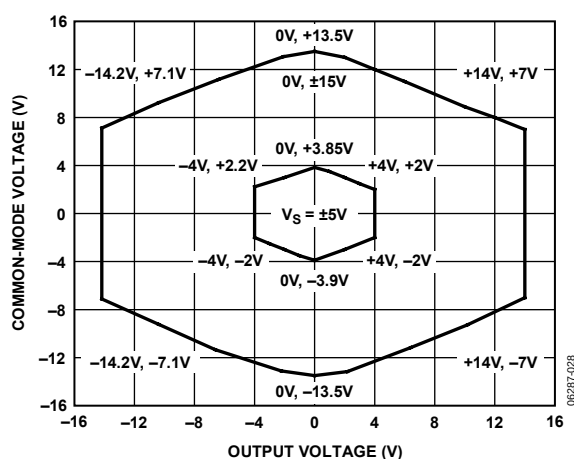
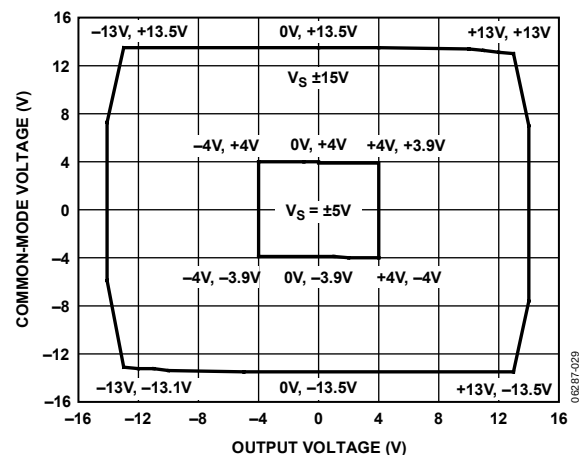
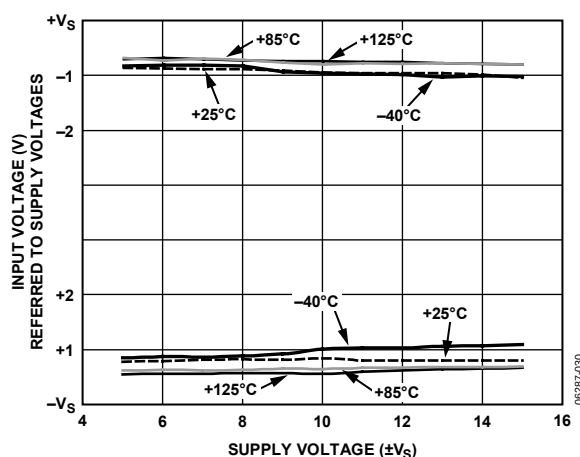
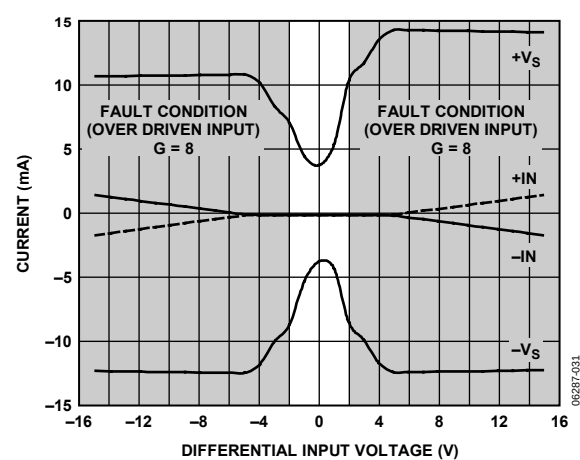


Figure 23. Gain Nonlinearity,  $G = 2$ ,  $R_L = 10\text{ k}\Omega$ ,  $2\text{ k}\Omega$ ,  $600\Omega$

Figure 24. Gain Nonlinearity,  $G = 4$ ,  $R_L = 10\text{ k}\Omega$ ,  $2\text{ k}\Omega$ ,  $600\text{ }\Omega$ Figure 25. Gain Nonlinearity,  $G = 8$ ,  $R_L = 10\text{ k}\Omega$ ,  $2\text{ k}\Omega$ ,  $600\text{ }\Omega$ Figure 26. Input Common-Mode Voltage Range vs. Output Voltage,  $G = 1$ Figure 27. Input Common-Mode Voltage Range vs. Output Voltage,  $G = 8$ Figure 28. Input Voltage Limit vs. Supply Voltage,  $G = 1$ ,  $V_{REF} = 0\text{ V}$ ,  $R_L = 10\text{ k}\Omega$ Figure 29. Fault Current Draw vs. Input Voltage,  $G = 8$ ,  $R_L = 10\text{ k}\Omega$

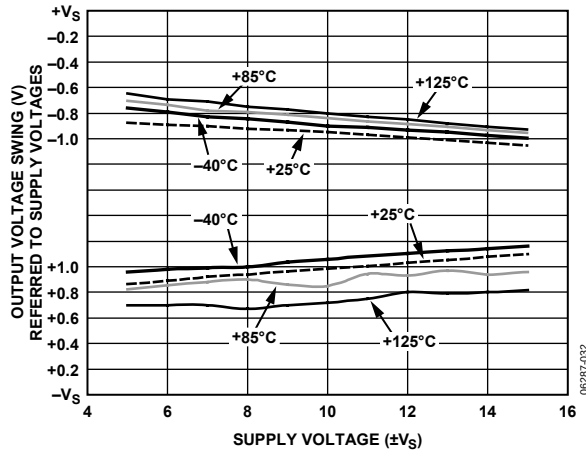


Figure 30. Output Voltage Swing vs. Supply Voltage,  $G = 8$ ,  $R_L = 2 \text{ k}\Omega$

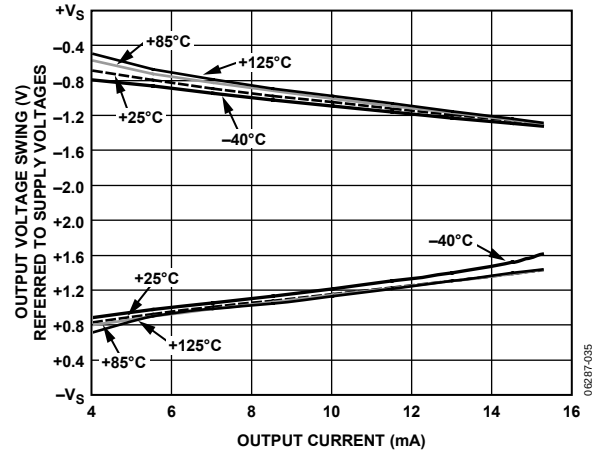


Figure 33. Output Voltage Swing vs. Output Current

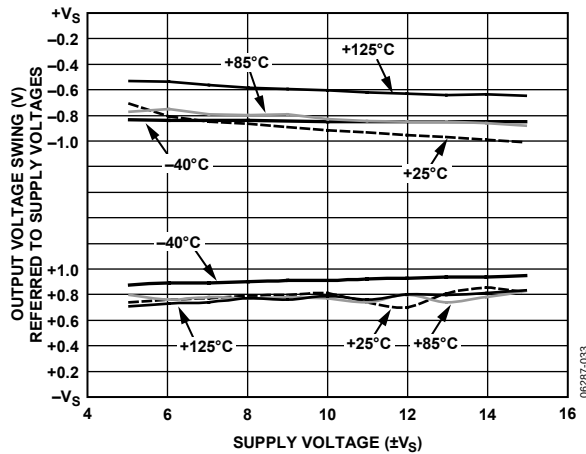


Figure 31. Output Voltage Swing vs. Supply Voltage,  $G = 8$ ,  $R_L = 10 \text{ k}\Omega$

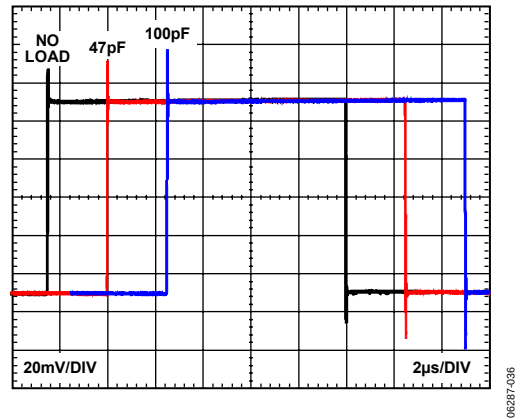


Figure 34. Small Signal Pulse Response for Various Capacitive Loads

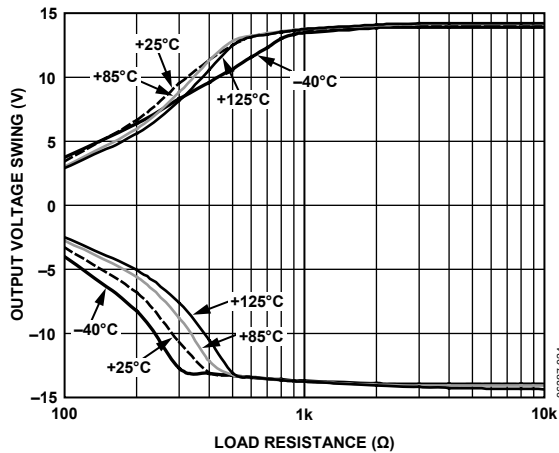


Figure 32. Output Voltage Swing vs. Load Resistance

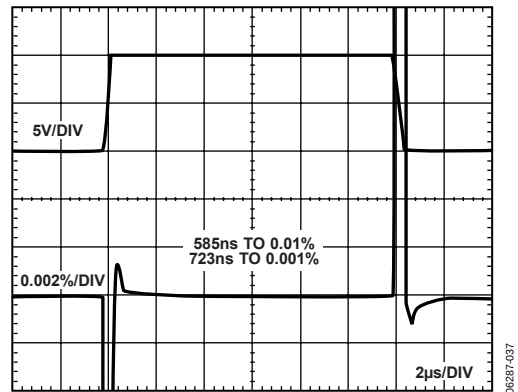


Figure 35. Large Signal Pulse Response and Settling Time,  $G = 1$ ,  $R_L = 10 \text{ k}\Omega$

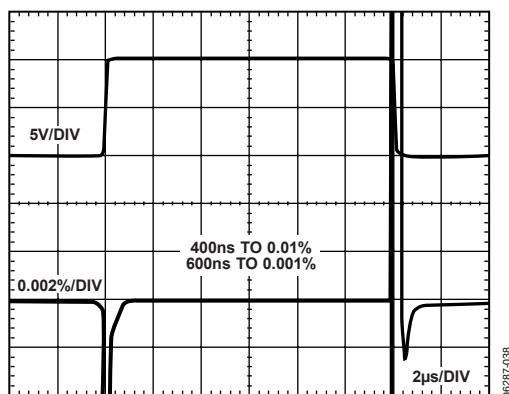


Figure 36. Large Signal Pulse Response and Settling Time,  
 $G = 2$ ,  $R_L = 10\text{ k}\Omega$

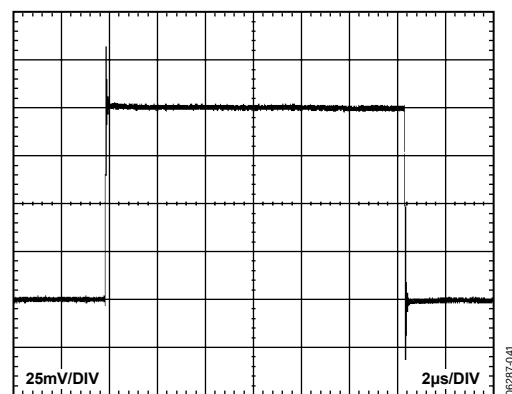


Figure 39. Small Signal Response,  
 $G = 1$ ,  $R_L = 2\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

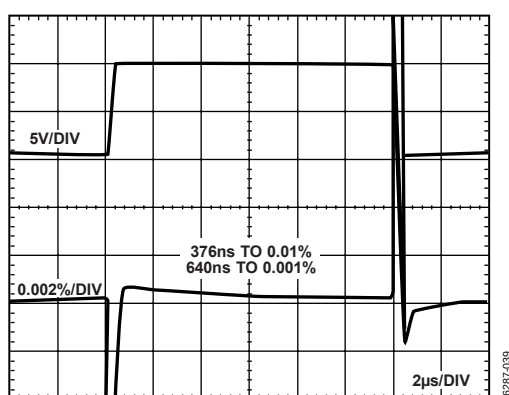


Figure 37. Large Signal Pulse Response and Settling Time,  
 $G = 4$ ,  $R_L = 10\text{ k}\Omega$

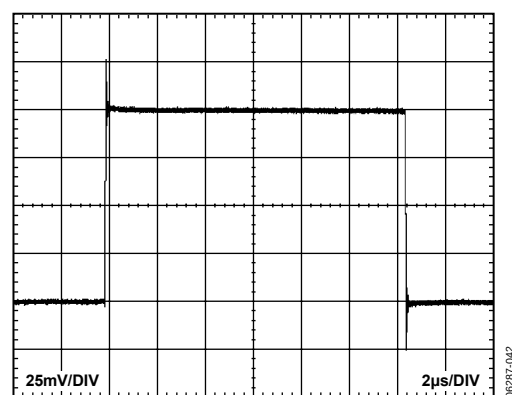


Figure 40. Small Signal Response,  
 $G = 2$ ,  $R_L = 2\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

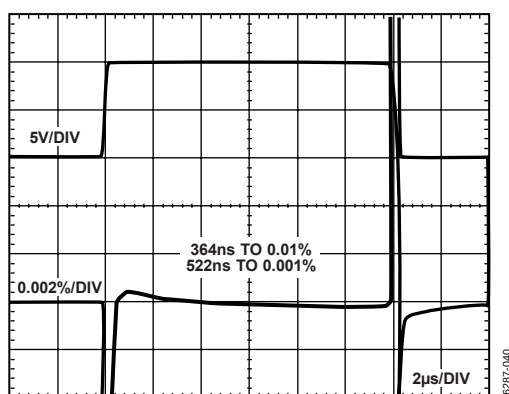


Figure 38. Large Signal Pulse Response and Settling Time,  
 $G = 8$ ,  $R_L = 10\text{ k}\Omega$

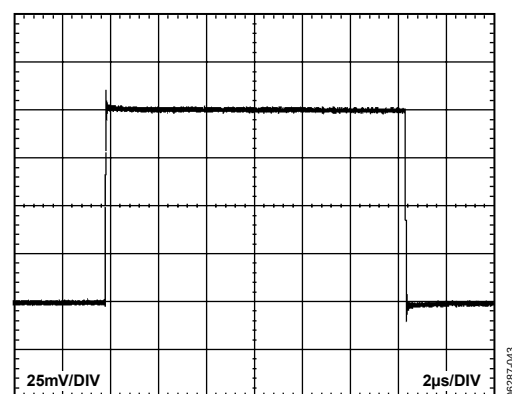


Figure 41. Small Signal Response,  
 $G = 4$ ,  $R_L = 2\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

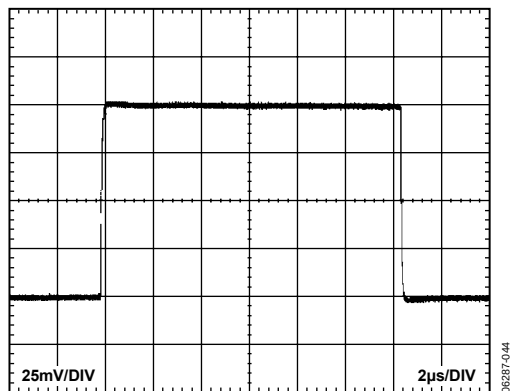


Figure 42. Small Signal Response,  $G = 8$ ,  $R_L = 2\text{ k}\Omega$ ,  $C_L = 100\text{ pF}$

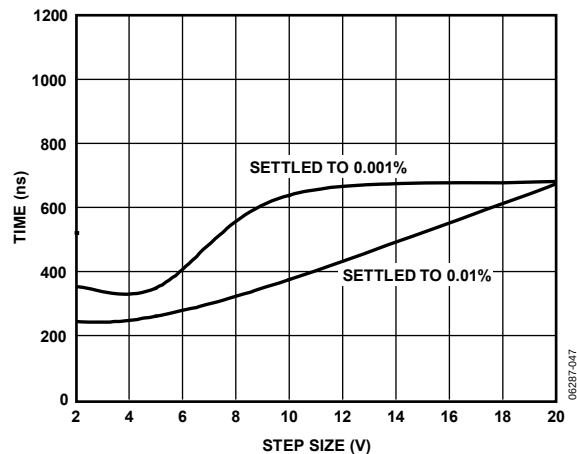


Figure 45. Settling Time vs. Step Size,  $G = 4$ ,  $R_L = 10\text{ k}\Omega$

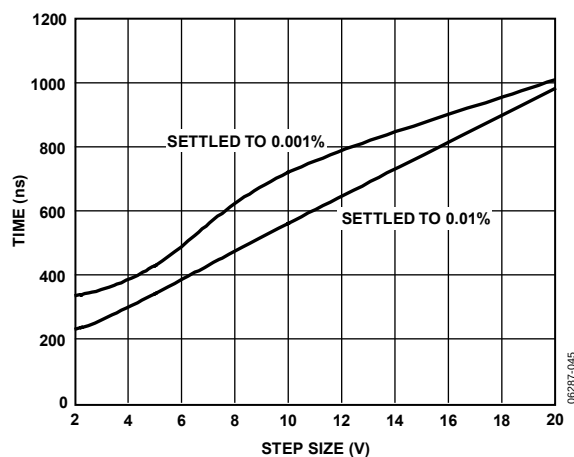


Figure 43. Settling Time vs. Step Size,  $G = 1$ ,  $R_L = 10\text{ k}\Omega$

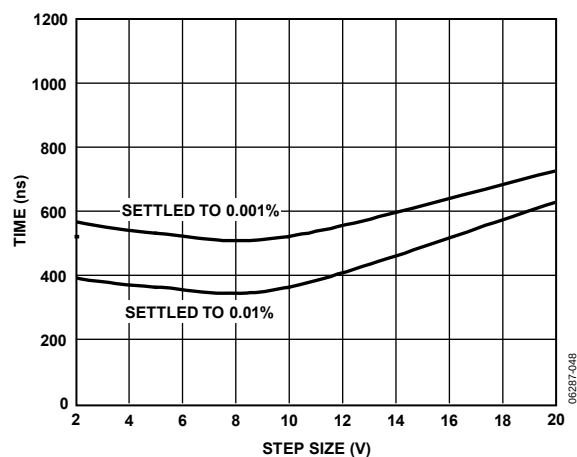


Figure 46. Settling Time vs. Step Size,  $G = 8$ ,  $R_L = 10\text{ k}\Omega$

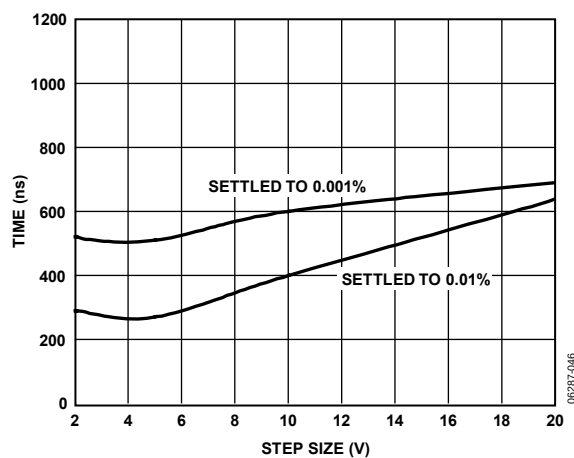


Figure 44. Settling Time vs. Step Size,  $G = 2$ ,  $R_L = 10\text{ k}\Omega$

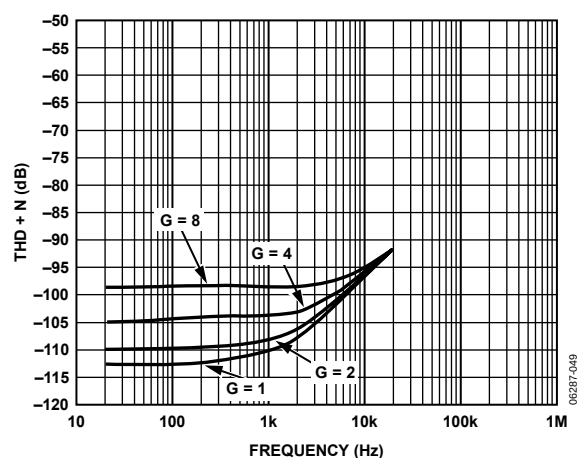


Figure 47. Total Harmonic Distortion vs. Frequency, 10 Hz to 22 kHz Band-Pass Filter,  $2\text{ k}\Omega$  Load

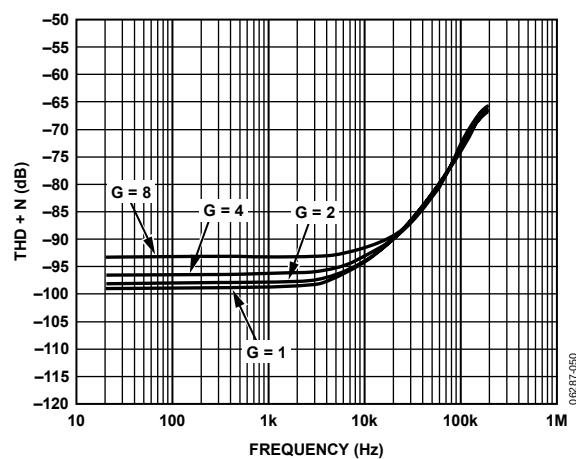


Figure 48. Total Harmonic Distortion vs. Frequency,  
10 Hz to 500 kHz Band-Pass Filter, 2 k $\Omega$  Load

## THEORY OF OPERATION

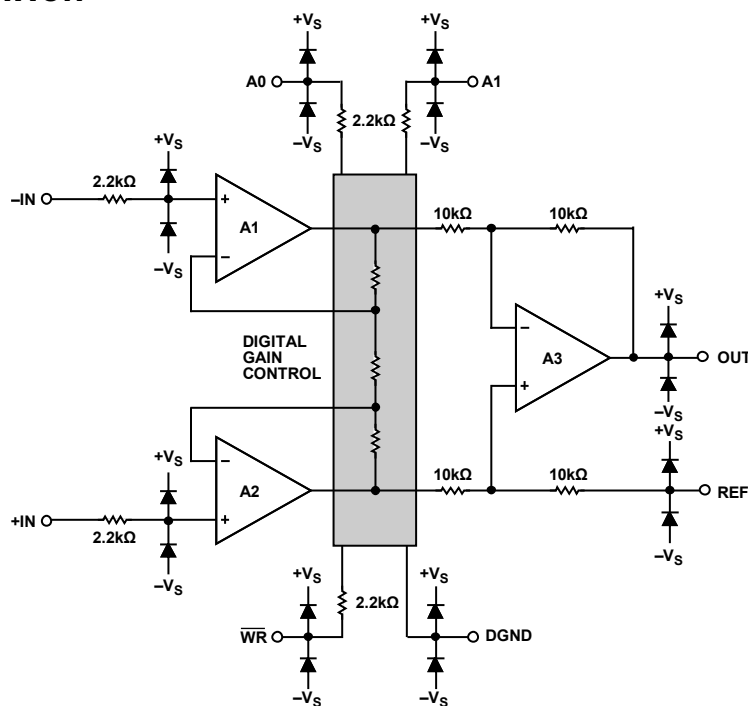


Figure 49. Simplified Schematic

The AD8251 is a monolithic instrumentation amplifier based on the classic, three op amp topology, as shown in Figure 49. It is fabricated on the Analog Devices, Inc. proprietary iCMOS process that provides precision, linear performance, and a robust digital interface. A parallel interface allows users to digitally program gains of 1, 2, 4, and 8. Gain control is achieved by switching resistors in an internal, precision, resistor array (as shown in Figure 49). Although the AD8251 has a voltage feedback topology, gain bandwidth product increases for gains of 1, 2, and 4 because each gain has its own frequency compensation. This results in maximum bandwidth at higher gains.

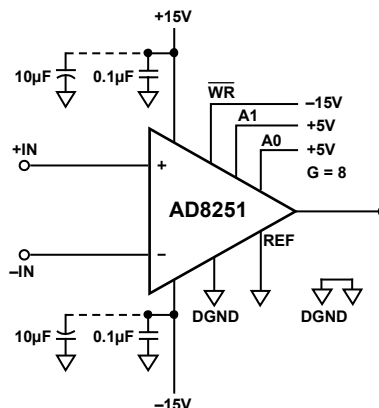
All internal amplifiers employ distortion cancellation circuitry and achieve high linearity and ultralow THD. Laser trimmed resistors allow for a maximum gain error of less than 0.03% for  $G = 1$  and minimum CMRR of 98 dB for  $G = 8$ . A pinout optimized for high CMRR over frequency enables the AD8251 to offer a guaranteed minimum CMRR over frequency of 80 dB at 50 kHz ( $G = 1$ ). The balanced input reduces the parasitics that, in the past, had adversely affected CMRR performance.

## GAIN SELECTION

This section shows users how to configure the AD8251 for basic operation. Logic low and logic high voltage limits are listed in the Specifications section. Typically, logic low is 0 V and logic high is 5 V; both voltages are measured with respect to DGND. Refer to the specifications table (Table 2) for the permissible voltage range of DGND. The gain of the AD8251 can be set using two methods.

## Transparent Gain Mode

The easiest way to set the gain is to program it directly via a logic high or logic low voltage applied to A0 and A1. Figure 50 shows an example of this gain setting method, referred to throughout the data sheet as transparent gain mode. Tie WR to the negative supply to engage transparent gain mode. In this mode, any change in voltage applied to A0 and A1 from logic low to logic high, or vice versa, immediately results in a gain change. Table 5 is the truth table for transparent gain mode, and Figure 50 shows the AD8251 configured in transparent gain mode.



NOTE:  
1. IN TRANSPARENT GAIN MODE,  $\overline{WR}$  IS TIED TO  $-V_S$ . THE VOLTAGE LEVELS ON A0 AND A1 DETERMINE THE GAIN. IN THIS EXAMPLE, BOTH A0 AND A1 ARE SET TO LOGIC HIGH, RESULTING IN A GAIN OF 8.

Figure 50. Transparent Gain Mode, A0 and A1 = High,  $G = 8$



Table 5. Truth Table Logic Levels for Transparent Gain Mode

| WR     | A1   | A0   | Gain |
|--------|------|------|------|
| $-V_S$ | Low  | Low  | 1    |
| $-V_S$ | Low  | High | 2    |
| $-V_S$ | High | Low  | 4    |
| $-V_S$ | High | High | 8    |

### Latched Gain Mode

Some applications have multiple programmable devices such as multiplexers or other programmable gain instrumentation amplifiers on the same PCB. In such cases, devices can share a data bus. The gain of the AD8251 can be set using  $\overline{\text{WR}}$  as a latch, allowing other devices to share A0 and A1. Figure 51 shows a schematic using this method, known as latched gain mode. The AD8251 is in this mode when  $\overline{\text{WR}}$  is held at logic high or logic low, typically 5 V and 0 V, respectively. The voltages on A0 and A1 are read on the downward edge of the  $\overline{\text{WR}}$  signal as it transitions from logic high to logic low. This latches in the logic levels on A0 and A1, resulting in a gain change. See the truth table listing in Table 6 for more on these gain changes.

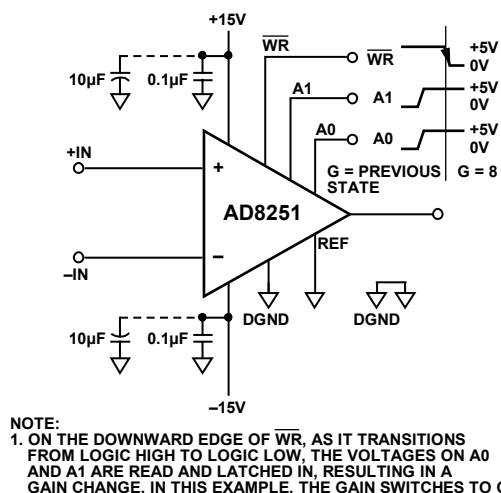
Figure 51. Latched Gain Mode,  $G = 8$ 

Table 6. Truth Table Logic Levels for Latched Gain Mode

| WR           | A1             | A0             | Gain        |
|--------------|----------------|----------------|-------------|
| High to Low  | Low            | Low            | Change to 1 |
| High to Low  | Low            | High           | Change to 2 |
| High to Low  | High           | Low            | Change to 4 |
| High to Low  | High           | High           | Change to 8 |
| Low to Low   | X <sup>1</sup> | X <sup>1</sup> | No Change   |
| Low to High  | X <sup>1</sup> | X <sup>1</sup> | No Change   |
| High to High | X <sup>1</sup> | X <sup>1</sup> | No Change   |

<sup>1</sup> X = don't care.

On power-up, the AD8251 defaults to a gain of 1 when in latched gain mode. In contrast, if the AD8251 is configured in transparent gain mode, it starts at the gain indicated by the voltage levels on A0 and A1 on power-up.

### Timing for Latched Gain Mode

In latched gain mode, logic levels at A0 and A1 have to be held for a minimum setup time,  $t_{\text{SU}}$ , before the downward edge of  $\overline{\text{WR}}$  latches in the gain. Similarly, they must be held for a minimum hold time of  $t_{\text{HD}}$  after the downward edge of  $\overline{\text{WR}}$  to ensure that the gain is latched in correctly. After  $t_{\text{HD}}$ , A0 and A1 may change logic levels but the gain does not change (until the next downward edge of  $\overline{\text{WR}}$ ). The minimum duration that  $\overline{\text{WR}}$  can be held high is  $t_{\text{WR-HIGH}}$ , and  $t_{\text{WR-LOW}}$  is the minimum duration that  $\overline{\text{WR}}$  can be held low. Digital timing specifications are listed in Table 2. The time required for a gain change is dominated by the settling time of the amplifier. A timing diagram is shown in Figure 52.

When sharing a data bus with other devices, logic levels applied to those devices can potentially feed through to the output of the AD8251. Feedthrough can be minimized by decreasing the edge rate of the logic signals. Furthermore, careful layout of the PCB also reduces coupling between the digital and analog portions of the board.

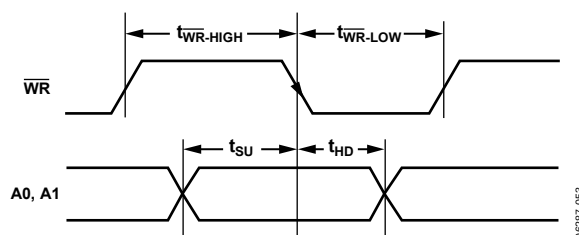


Figure 52. Timing Diagram for Latched Gain Mode

## POWER SUPPLY REGULATION AND BYPASSING

The AD8251 has high PSRR. However, for optimal performance, a stable dc voltage should be used to power the instrumentation amplifier. Noise on the supply pins can adversely affect performance. As in all linear circuits, bypass capacitors must be used to decouple the amplifier.

Place a 0.1  $\mu\text{F}$  capacitor close to each supply pin. A 10  $\mu\text{F}$  tantalum capacitor can be used farther away from the part (see Figure 53) and, in most cases, it can be shared by other precision integrated circuits.

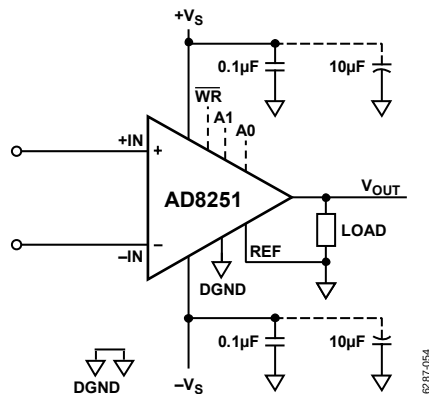


Figure 53. Supply Decoupling, REF, and Output Referred to Ground

## INPUT BIAS CURRENT RETURN PATH

The AD8251 input bias current must have a return path to its local analog ground. When the source, such as a thermocouple, cannot provide a return current path, one should be created (see Figure 54).

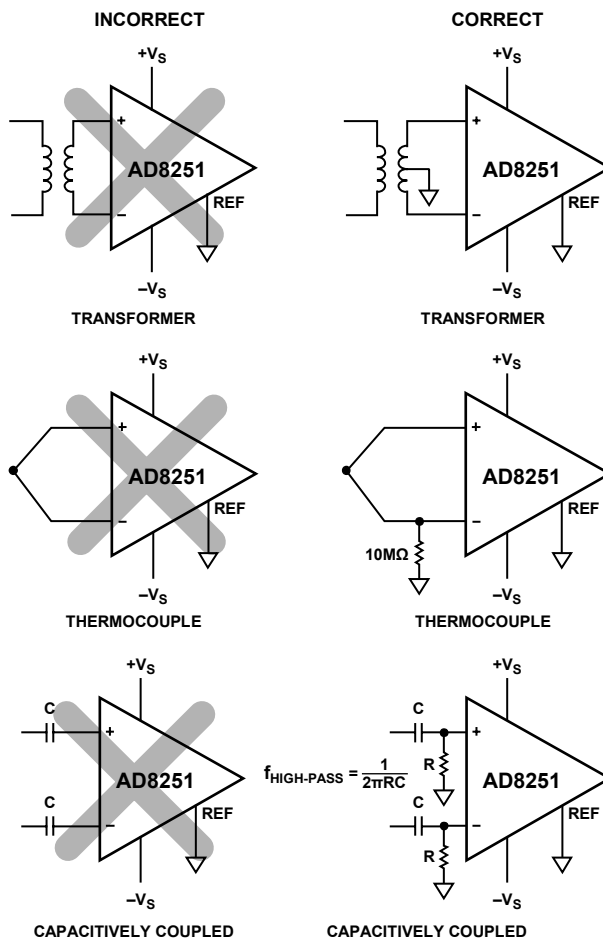


Figure 54. Creating an  $I_{BIAS}$  Path

## INPUT PROTECTION

All terminals of the AD8251 are protected against ESD. Note that 2.2 k $\Omega$  series resistors precede the ESD diodes as shown in Figure 49. They limit current into the diodes and allow for dc overload conditions 13 V above the positive supply and 13 V below the negative supply. An external resistor should be used in series with each of the inputs to limit current for voltages greater than 13 V beyond either supply rail. In either scenario, the AD8251 safely handles a continuous 6 mA current at room temperature. For applications where the AD8251 encounters extreme overload voltages, external series resistors and low leakage diode clamps such as BAV199Ls, FJH1100s, or SP720s should be used.

## REFERENCE TERMINAL

The reference terminal, REF, is at one end of a 10 k $\Omega$  resistor (see Figure 49). The instrumentation amplifier output is referenced to the voltage on the REF terminal; this is useful when the output signal needs to be offset to voltages other than its local analog ground. For example, a voltage source can be tied to the REF pin to level shift the output so that the AD8251 can interface with a single-supply ADC. The allowable reference voltage range is a function of the gain, common-mode input, and supply voltages. The REF pin should not exceed either +V<sub>S</sub> or -V<sub>S</sub> by more than 0.5 V.

For best performance, especially in cases where the output is not measured with respect to the REF terminal, source impedance to the REF terminal should be kept low because parasitic resistance can adversely affect CMRR and gain accuracy.

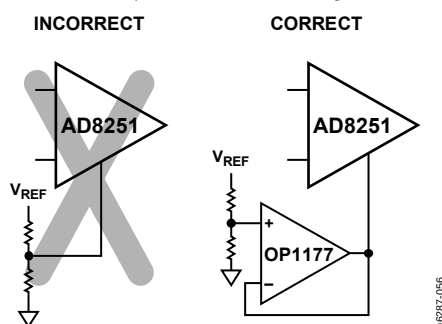


Figure 55. Driving the Reference Pin

## COMMON-MODE INPUT VOLTAGE RANGE

The three op amp architecture of the AD8251 applies gain and then removes the common-mode voltage. Therefore, internal nodes in the AD8251 experience a combination of both the gained signal and the common-mode signal. This combined signal can be limited by the voltage supplies even when the individual input and output signals are not. Figure 26 and Figure 27 show the allowable common-mode input voltage ranges for various output voltages, supply voltages, and gains.

## LAYOUT

### Grounding

In mixed-signal circuits, low level analog signals need to be isolated from the noisy digital environment. Designing with the AD8251 is no exception. Its supply voltages are referenced to an analog ground. Its digital circuit is referenced to a digital ground. Although it is convenient to tie both grounds to a single ground plane, the current traveling through the ground wires and PC board can cause an error. Therefore, use separate analog and digital ground planes. Only at one point, star ground, should analog and digital ground meet.

The output voltage of the AD8251 develops with respect to the potential on the reference terminal. Take care to tie REF to the appropriate local analog ground or to connect it to a voltage that is referenced to the local analog ground.

## Coupling Noise

To prevent coupling noise onto the AD8251, follow these guidelines:

- Do not run digital lines under the device.
- Run the analog ground plane under the AD8251.
- Shield fast switching signals with digital ground to avoid radiating noise to other sections of the board, and never run them near analog signal paths.
- Avoid crossover of digital and analog signals.
- Connect digital and analog ground at one point only (typically under the ADC).
- Power supply lines should use large traces to ensure a low impedance path. Decoupling is necessary; follow the guidelines listed in the Power Supply Regulation and Bypassing section.

## Common-Mode Rejection

The AD8251 has high CMRR over frequency, giving it greater immunity to disturbances, such as line noise and its associated harmonics, in contrast to typical in amps whose CMRR falls off around 200 Hz. They often need common-mode filters at the inputs to compensate for this shortcoming. The AD8251 is able to reject CMRR over a greater frequency range, reducing the need for input common-mode filtering.

Careful board layout maximizes system performance. To maintain high CMRR over frequency, lay out the input traces symmetrically. Ensure that the traces maintain resistive and capacitive balance; this holds for additional PCB metal layers under the input pins and traces. Source resistance and capacitance should be placed as close to the inputs as possible. Should a trace cross the inputs (from another layer), it should be routed perpendicular to the input traces.

## RF INTERFERENCE

RF rectification is often a problem when amplifiers are used in applications where there are strong RF signals. The disturbance can appear as a small dc offset voltage. High frequency signals can be filtered with a low-pass, RC network placed at the input of the instrumentation amplifier, as shown in Figure 56. The filter limits the input signal bandwidth according to the following relationship:

$$FilterFreq_{DIFF} = \frac{1}{2 \pi R(2C_D + C_C)}$$

$$FilterFreq_{CM} = \frac{1}{2 \pi RC_C}$$

where  $C_D \geq 10 C_C$ .

# AD8251

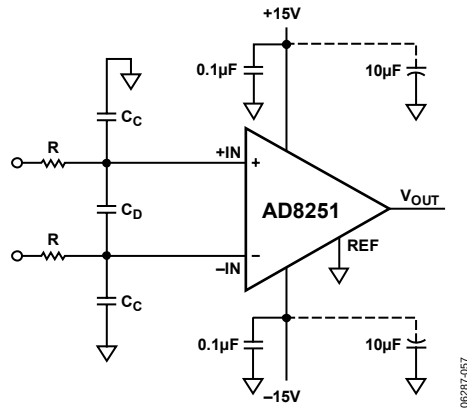


Figure 56. RFI Suppression

Values of  $R$  and  $C_C$  should be chosen to minimize RFI. Mismatch between the  $R \times C_C$  at the positive input and the  $R \times C_C$  at negative input degrades the CMRR of the AD8251. By using a value of  $C_D$  that is 10 times larger than the value of  $C_C$ , the effect of the mismatch is reduced and performance is improved.

## DRIVING AN ANALOG-TO-DIGITAL CONVERTER

An instrumentation amplifier is often used in front of an analog-to-digital converter to provide CMRR. Usually, instrumentation amplifiers require a buffer to drive an ADC. However, the low output noise, low distortion, and low settle time of the AD8251 make it an excellent ADC driver.

In this example, a 1 nF capacitor and a 49.9  $\Omega$  resistor create an antialiasing filter for the AD7612. The 1 nF capacitor also serves to store and deliver necessary charge to the switched capacitor input of the ADC. The 49.9  $\Omega$  series resistor reduces the burden of the 1 nF load from the amplifier and isolates it from the kickback current injected from the switched capacitor input of the AD7612. Selecting too small a resistor improves the correlation between the voltage at the output of the AD8251 and the voltage at the input of the AD7612 but may destabilize the AD8251. A trade-off must be made between selecting a resistor small enough to maintain accuracy and large enough to maintain stability.

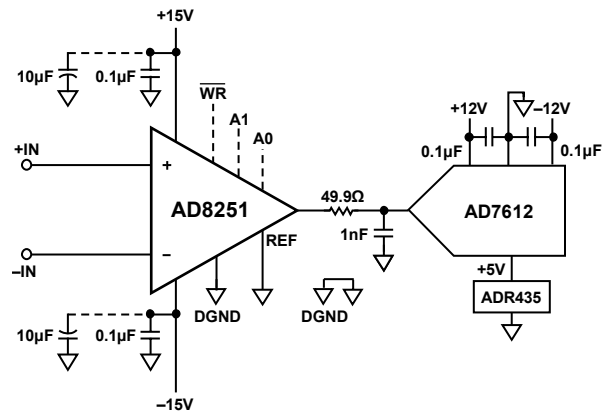


Figure 57. Driving an ADC



# AD8251

## DATA ACQUISITION

The AD8251 makes an excellent instrumentation amplifier for use in data acquisition systems. Its wide bandwidth, low distortion, low settling time, and low noise enable it to condition signals in front of a variety of 16-bit ADCs.

Figure 61 shows a schematic of the AD825x data acquisition demonstration board. The quick slew rate of the AD8251 allows it to condition rapidly changing signals from the multiplexed inputs. An FPGA controls the [AD7612](#), AD8251, and [ADG1209](#). In addition, mechanical switches and jumpers allow users to pin strap the gains when in transparent gain mode.

This system achieved  $-106$  dB of THD at 1 kHz and a signal-to-noise ratio of 91 dB during testing, as shown in Figure 60.

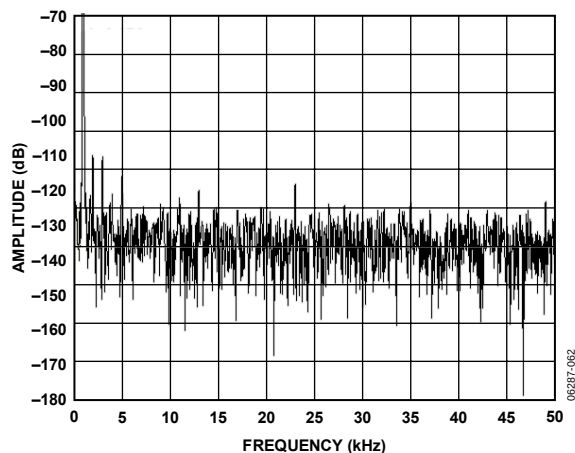


Figure 60. FFT of the AD825x DAQ Demo Board Using the AD8251 1 kHz Signal

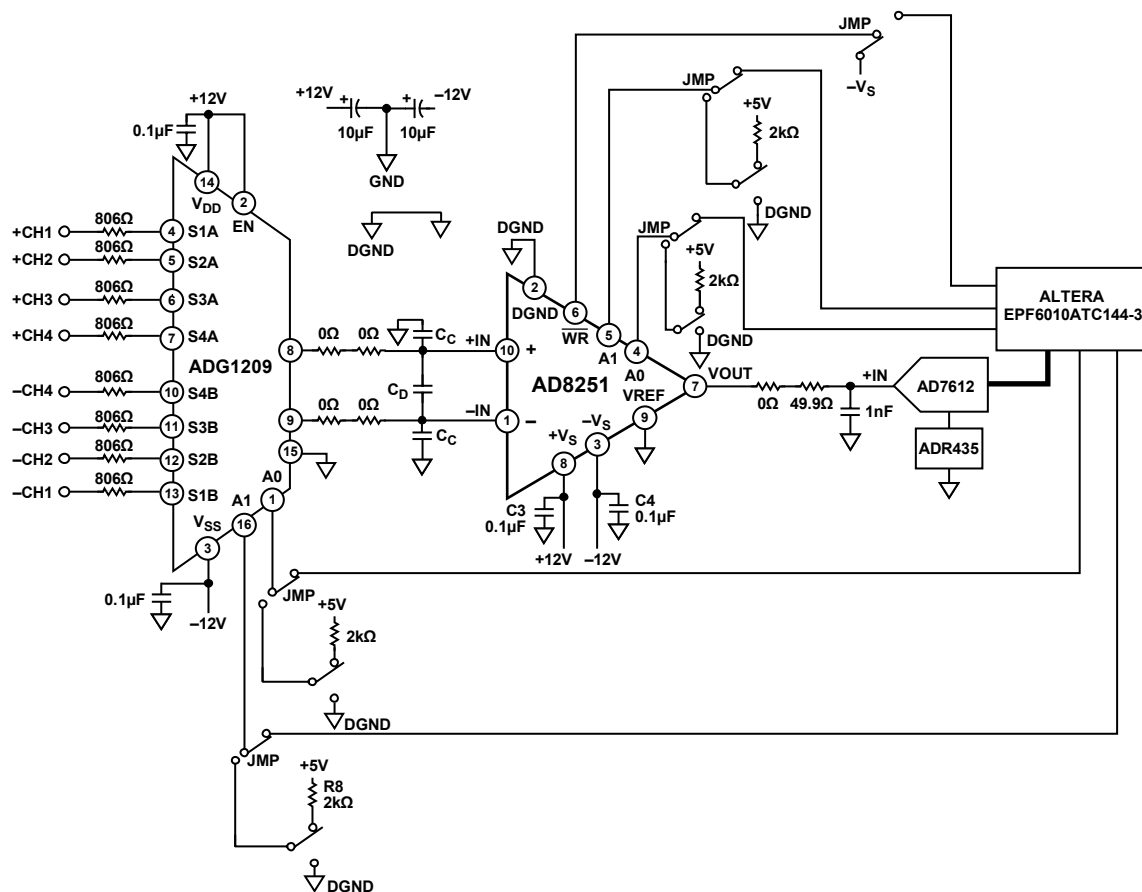
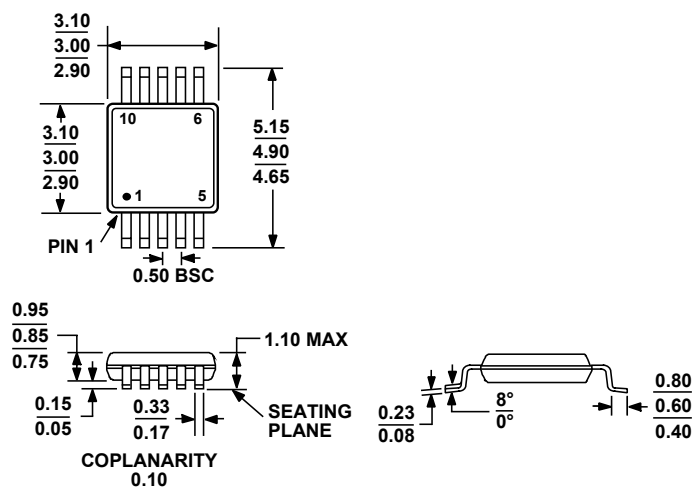


Figure 61. Schematic of ADG1209, AD8251, and AD7612 in the AD825x DAQ Demo Board

## OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MO-187-BA

Figure 62. 10-Lead Mini Small Outline Package [MSOP]  
(RM-10)

Dimensions shown in millimeters

## ORDERING GUIDE

| Model                      | Temperature Range | Package Description | Package Option | Branding |
|----------------------------|-------------------|---------------------|----------------|----------|
| AD8251ARMZ <sup>1</sup>    | −40°C to +85°C    | 10-Lead MSOP        | RM-10          | H0T      |
| AD8251ARMZ-RL <sup>1</sup> | −40°C to +85°C    | 10-Lead MSOP        | RM-10          | H0T      |
| AD8251ARMZ-R7 <sup>1</sup> | −40°C to +85°C    | 10-Lead MSOP        | RM-10          | H0T      |
| AD8251-EVALZ <sup>1</sup>  |                   | Evaluation Board    |                |          |

<sup>1</sup> Z = RoHS Compliant Part.

**AD8251**

**NOTES**