# Single-Supply, Low Cost Instrumentation Amplifier

# AD8223

## FEATURES

- Gain set with 1 resistor
  - Gain = 5 to 1000
- Inputs
  - Voltage range to 150 mV below negative rail
  - 25 nA maximum input bias current
  - 30 nV/√Hz, RTI noise @ 1 kHz
- Power supplies
  - Dual supply: ±2 V to ±12 V
  - Single supply: 3 V to 24 V
  - 500 µA maximum supply current

## APPLICATIONS

- Low power medical instrumentation
- Transducer interface
- Thermocouple amplifiers
- Industrial process controls
- Difference amplifiers
- Low power data acquisition

## CONNECTION DIAGRAM

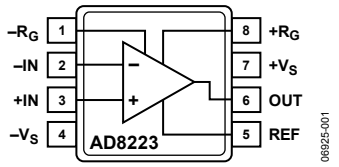


*Figure 1. 8-Lead SOIC (R) and 8-Lead MSOP (RM) Packages*

**Table 1. Instrumentation Amplifiers by Category**

| General-Purpose | Zero Drift | Mil Grade | Low Power | High Voltage PGA |
|---|---|---|---|---|
| AD8220[1] | AD8231[1] | AD620 | AD627[1] | AD8250 |
| AD8221 | AD8553[1] | AD621 | AD623[1] | AD8251 |
| AD8222 | AD8555[1] | AD524 | AD8223 | AD8253 |
| AD8224[1] | AD8556[1] | AD526 | | |
| AD8228 | AD8557[1] | AD624 | | |

[1] Rail-to-rail output.

## GENERAL DESCRIPTION

The AD8223 is an integrated single-supply instrumentation amplifier that delivers rail-to-rail output swing on a single supply (3 V to 24 V). The AD8223 conforms to the 8-lead industry standard pinout configuration.

The AD8223 is simple to use: one resistor sets the gain. With no external resistor, the AD8223 is configured for G = 5. With an external resistor, the AD8223 can be programmed for gains up to 1000.

The AD8223 has a wide input common-mode range and can amplify signals that have a 150 mV common-mode voltage below ground. Although the design of the AD8223 is optimized to operate from a single supply, the AD8223 still provides excellent performance when operated from a dual voltage supply (±2 V to ±12 V).

Low power consumption (1.5 mW at 3 V), wide supply voltage range, and rail-to-rail output swing make the AD8223 ideal for battery-powered applications. The rail-to-rail output stage maximizes the dynamic range when operating from low supply voltages. The AD8223 replaces discrete instrumentation amplifier designs and offers superior linearity, temperature stability, and reliability in a minimum of space.

**Rev. 0**
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## REVISION HISTORY

**10/08—Revision 0: Initial Version**

# SPECIFICATIONS

## SINGLE SUPPLY

$T_A$ = 25°C, $-V_S$ = 0 V, $+V_S$ = +5 V, and $R_L$ = 10 kΩ to 2.5 V, unless otherwise noted.

**Table 2**

| | | AD8223A | | | AD8223B | | | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | **Conditions** | **Min** | **Typ** | **Max** | **Min** | **Typ** | **Max** | **Unit** |
| COMMON-MODE REJECTION RATIO | | | | | | | | |
| DC to 60 Hz with 1 kΩ Source Imbalance | $V_{CM}$ = 0 V to 3 V | | | | | | | |
| G = 5 | | 80 | | | 86 | | | dB |
| G = 10 | | 86 | | | 90 | | | dB |
| G = 100 | | 90 | | | 96 | | | dB |
| G = 1000 | | 90 | | | 96 | | | dB |
| NOISE | $V_{IN+} = V_{IN-} = V_{REF}$ = 0 V | | | | | | | |
| Voltage Noise, 1 kHz | | | | | | | | |
| G = 5 | | | 50 | | | 50 | | nV/√Hz |
| G = 1000 | | | 30 | | | 30 | | nV/√Hz |
| RTI, 0.1 Hz to 10 Hz | | | | | | | | |
| G = 5 | | | 1.0 | | | 1.0 | | µV p-p |
| G = 1000 | | | 0.6 | | | 0.6 | | µV p-p |
| Current Noise, 1 kHz | | | 70 | | | 70 | | fA/√Hz |
| 0.1 Hz to 10 Hz | | | 1.2 | | | 1.2 | | pA p-p |
| VOLTAGE OFFSET | Total RTI error = $V_{OSI} + V_{OSO}/G$ | | | | | | | |
| Input Offset, $V_{OSI}$ | | | | 250 | | | 100 | µV |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 400 | | | 160 | µV |
| Average TC | $T_A$ = −40°C to +85°C | | | 2 | | | 1 | µV/°C |
| Output Offset, $V_{OSO}$ | | | | 1500 | | | 1000 | µV |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 2000 | | | 1500 | µV |
| Average TC | $T_A$ = −40°C to +85°C | | | 15 | | | 10 | µV/°C |
| Offset Referred to Input vs. Supply (PSR) | $+V_S$ = 4 V to 24 V, $-V_S$ = 0 V | | | | | | | |
| G = 5 | | 80 | | | 86 | | | dB |
| G = 10 | | 86 | | | 90 | | | dB |
| G = 100 | | 90 | | | 96 | | | dB |
| G = 1000 | | 90 | | | 96 | | | dB |
| INPUT CURRENT | | | | | | | | |
| Input Bias Current | | 5 | 12 | 25 | 5 | 12 | 25 | nA |
| Over Temperature | $T_A$ = −40°C to +85°C | 5 | | 28 | 5 | | 28 | nA |
| Average Temperature Coefficient | $T_A$ = −40°C to +85°C | | 50 | | | 50 | | pA/°C |
| Input Offset Current | | | 0.25 | 2 | | 0.25 | 2 | nA |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 2.5 | | | 2.5 | nA |
| Average Temperature Coefficient | $T_A$ = −40°C to +85°C | | 5 | | | 5 | | pA/°C |
| DYNAMIC RESPONSE | | | | | | | | |
| Small Signal −3 dB Bandwidth | | | | | | | | |
| G = 5 | | | 125 | | | 125 | | kHz |
| G = 10 | | | 125 | | | 125 | | kHz |
| G = 100 | | | 50 | | | 50 | | kHz |
| G = 1000 | | | 5 | | | 5 | | kHz |
| Slew Rate | | | 0.2 | | | 0.2 | | V/µs |

| Parameter | Conditions | AD8223A | | | AD8223B | | | Unit |
|---|---|---|---|---|---|---|---|---|
| | | Min | Typ | Max | Min | Typ | Max | |
| Settling Time to 0.01% | Step size = 3.5 V | | | | | | | |
| G = 5 | | | 18 | | | 18 | | µs |
| G = 10 | | | 18 | | | 18 | | µs |
| G = 100 | | | 18 | | | 18 | | µs |
| G = 1000 | | | 85 | | | 85 | | µs |
| GAIN | G = 5 + (80 kΩ/$R_G$) | | | | | | | |
| Gain Range | | 5 | | 1000 | 5 | | 1000 | V/V |
| Gain Error[1] | $V_{OUT}$ = 0.05 V to 4.5 V | | | | | | | |
| G = 5 | | | | 0.07 | | | 0.02 | % |
| G = 10 | | | 0.10 | 0.3 | | 0.10 | 0.2 | % |
| G = 100 | | | 0.10 | 0.3 | | 0.10 | 0.3 | % |
| G = 1000 | | | 0.10 | 0.3 | | 0.10 | 0.3 | % |
| Nonlinearity | $V_{OUT}$ = 0.05 V to 4.5 V | | | | | | | |
| G = 5 | | | 12 | | | 12 | | ppm |
| G = 1000 | | | 200 | | | 200 | | ppm |
| Gain vs. Temperature | $T_A$ = −40°C to +85°C | | | | | | | |
| G = 5 | | | | 10 | | | 2 | ppm/°C |
| G > 5[1] | | | 50 | | | 50 | | ppm/°C |
| INPUT | | | | | | | | |
| Input Impedance | | | | | | | | |
| Differential | | | 2\|\|2 | | | 2\|\|2 | | GΩ\|\|pF |
| Common-Mode | | | 2\|\|2 | | | 2\|\|2 | | GΩ\|\|pF |
| Common-Mode Input Voltage Range[2] | $V_{IN+}$ = $V_{IN-}$ | (−$V_S$) − 0.15 | | (+$V_S$) − 1.5 | (−$V_S$) − 0.15 | | (+$V_S$) − 1.5 | V |
| OUTPUT | | | | | | | | |
| Output Swing | $R_L$ = 10 kΩ to ground | +0.01 | | (+$V_S$) − 0.5 | +0.01 | | (+$V_S$) − 0.5 | V |
| | $R_L$ = 100 kΩ to ground | +0.01 | | (+$V_S$) − 0.15 | +0.01 | | (+$V_S$) − 0.15 | V |
| REFERENCE INPUT | | | | | | | | |
| $R_{IN}$ | | | 60 | ±20% | | 60 | ±20% | kΩ |
| $I_{IN}$ | $V_{IN+}$ = $V_{IN-}$ = $V_{REF}$ = 0 V | | +10 | +20 | | +10 | +20 | µA |
| Voltage Range | | −$V_S$ | | +$V_S$ | −$V_S$ | | +$V_S$ | V |
| Gain to Output | | | 1 ± 0.0002 | | | 1 ± 0.0002 | | V |
| POWER SUPPLY | | | | | | | | |
| Operating Range | | +3 | | +24 | +3 | | +24 | V |
| Quiescent Current | | | 350 | 500 | | 350 | 500 | µA |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 600 | | | 600 | µA |
| TEMPERATURE RANGE | | | | | | | | |
| For Specified Performance | | -40 | | +85 | −40 | | +85 | °C |

[1] Does not include effects of external resistor, $R_G$.
[2] Total input range depends on common-mode voltage, differential voltage, and gain. See Figure 18 through Figure 21, and the Input Voltage Range section in the Theory of Operation section for more information.

## DUAL SUPPLY

$T_A$ = 25°C, $-V_S$ = −12 V, $+V_S$ = +12 V, and $R_L$ = 10 kΩ to ground, unless otherwise noted.[1]

**Table 3.**

| Parameter | Conditions | AD8223A Min | AD8223A Typ | AD8223A Max | AD8223B Min | AD8223B Typ | AD8223B Max | Unit |
|---|---|---|---|---|---|---|---|---|
| COMMON-MODE REJECTION RATIO | | | | | | | | |
| DC to 60 Hz with 1 kΩ Source Imbalance | $V_{CM}$ = −10 V to 10 V | | | | | | | |
| G = 5 | | 80 | | | 86 | | | dB |
| G = 10 | | 86 | | | 90 | | | dB |
| G = 100 | | 90 | | | 96 | | | dB |
| G = 1000 | | 90 | | | 96 | | | dB |
| NOISE | $V_{IN+} = V_{IN-} = V_{REF}$ = 0 V | | | | | | | |
| Voltage Noise, 1 kHz | | | | | | | | |
| G = 5 | | | 50 | | | 50 | | nV/√Hz |
| G = 1000 | | | 30 | | | 30 | | nV/√Hz |
| RTI, 0.1 Hz to 10 Hz | | | | | | | | |
| G = 5 | | | 1.0 | | | 1.0 | | µV p-p |
| G = 1000 | | | 0.6 | | | 0.6 | | µV p-p |
| Current Noise, 1 kHz | | | 70 | | | 70 | | fA/√Hz |
| 0.1 Hz to 10 Hz | | | 1.2 | | | 1.2 | | pA p-p |
| VOLTAGE OFFSET | Total RTI error = $V_{OSI} + V_{OSO}/G$ | | | | | | | |
| Input Offset, $V_{OSI}$ | | | | 250 | | | 100 | µV |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 400 | | | 160 | µV |
| Average TC | $T_A$ = −40°C to +85°C | | | 2 | | | 1 | µV/°C |
| Output Offset, $V_{OSO}$ | | | | 1500 | | | 1000 | µV |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 2000 | | | 1500 | µV |
| Average TC | $T_A$ = −40°C to +85°C | | | 15 | | | 10 | µV/°C |
| Offset Referred to Input vs. Supply (PSR) | $+V_S$ = 5 V to 12 V, $-V_S$ = −5 V to −12 V | | | | | | | |
| G = 5 | | 80 | | | 86 | | | dB |
| G = 10 | | 86 | | | 90 | | | dB |
| G = 100 | | 90 | | | 96 | | | dB |
| G = 1000 | | 90 | | | 96 | | | dB |
| INPUT CURRENT | | | | | | | | |
| Input Bias Current | | 5 | 12 | 25 | 5 | 12 | 25 | nA |
| Over Temperature | $T_A$ = −40°C to +85°C | 5 | | 28 | 5 | | 28 | nA |
| Average Temperature Coefficient | $T_A$ = −40°C to +85°C | | 50 | | | 50 | | pA/°C |
| Input Offset Current | | | 0.25 | 2 | | 0.25 | 2 | nA |
| Over Temperature | $T_A$ = −40°C to +85°C | | | 2.5 | | | 2.5 | nA |
| Average Temperature Coefficient | $T_A$ = −40°C to +85°C | | 5 | | | 5 | | pA/°C |
| DYNAMIC RESPONSE | | | | | | | | |
| Small Signal −3 dB Bandwidth | | | | | | | | |
| G = 5 | | | 200 | | | 200 | | kHz |
| G = 10 | | | 200 | | | 200 | | kHz |
| G = 100 | | | 70 | | | 70 | | kHz |
| G = 1000 | | | 7 | | | 7 | | kHz |
| Slew Rate | | | 0.3 | | | 0.3 | | V/µs |
| Settling Time to 0.01% | Step size = 10 V | | | | | | | |
| G = 5 | | | 30 | | | 30 | | µs |
| G = 10 | | | 30 | | | 30 | | µs |
| G = 100 | | | 30 | | | 30 | | µs |
| G = 1000 | | | 150 | | | 150 | | µs |

| Parameter | Conditions | AD8223A Min | AD8223A Typ | AD8223A Max | AD8223B Min | AD8223B Typ | AD8223B Max | Unit |
|---|---|---|---|---|---|---|---|---|
| GAIN | $G = 5 + (80\ k\Omega/R_G)$ | | | | | | | |
| Gain Range | | 5 | | 1000 | 5 | | 1000 | V/V |
| Gain Error[2] | $V_{OUT} = -10\ V$ to $+10\ V$ | | | | | | | |
| G = 5 | | | | 0.07 | | | 0.02 | % |
| G = 10 | | | 0.10 | 0.3 | | 0.10 | 0.2 | % |
| G = 100 | | | 0.10 | 0.3 | | 0.10 | 0.3 | % |
| G = 1000 | | | 0.10 | 0.3 | | 0.10 | 0.3 | % |
| Nonlinearity | $V_{OUT} = -10\ V$ to $+10\ V$ | | | | | | | |
| G = 5 | | | 5 | | | 5 | | ppm |
| G = 1000 | | | 30 | | | 30 | | ppm |
| Gain vs. Temperature | $T_A = -40°C$ to $+85°C$ | | | | | | | |
| G = 5 | | | | 10 | | | 2 | ppm/°C |
| G > 5[1] | | | 50 | | | 50 | | ppm/°C |
| INPUT | | | | | | | | |
| Input Impedance | | | | | | | | |
| Differential | | | 2\|\|2 | | | 2\|\|2 | | GΩ\|\|pF |
| Common-Mode | | | 2\|\|2 | | | 2\|\|2 | | GΩ\|\|pF |
| Common-Mode Input Voltage Range[3] | $V_{IN+} = V_{IN-}$ | $(-V_S) - 0.15$ | | $(+V_S) - 1.5$ | $(-V_S) - 0.15$ | | $(+V_S) - 1.5$ | V |
| OUTPUT | | | | | | | | |
| Output Swing | $R_L = 10\ k\Omega$ to ground | $(-V_S) + 0.3$ | | $(+V_S) - 0.8$ | $(-V_S) + 0.3$ | | $(+V_S) - 0.8$ | V |
| | $R_L = 100\ k\Omega$ to ground | $(-V_S) + 0.1$ | | $(+V_S) - 0.3$ | $(-V_S) + 0.1$ | | $(+V_S) - 0.3$ | V |
| REFERENCE INPUT | | | | | | | | |
| $R_{IN}$ | | | 60 | ±20% | | 60 | ±20% | kΩ |
| $I_{IN}$ | $V_{IN+} = V_{IN-} = V_{REF} = 0\ V$ | | +10 | +20 | | +10 | +20 | µA |
| Voltage Range | | $-V_S$ | | $+V_S$ | $-V_S$ | | $+V_S$ | V |
| Gain to Output | | | $1 \pm 0.0002$ | | | $1 \pm 0.0002$ | | V |
| POWER SUPPLY | | | | | | | | |
| Operating Range | | ±2 | | ±12 | ±2 | | ±12 | V |
| Quiescent Current | | | | 650 | | | 650 | µA |
| Over Temperature | $T_A = -40°C$ to $+85°C$ | | | 850 | | | 850 | µA |
| TEMPERATURE RANGE | | | | | | | | |
| For Specified Performance | | −40 | | +85 | −40 | | +85 | °C |

[1] Because maximum supply voltage is 24 V between the negative and positive supply, these specifications at ±12V are at the part's limit. Operation at a nominal supply voltage slightly less than ±12 V is recommended to allow for power supply tolerances.
[2] Does not include effects of external resistor, $R_G$.
[3] Total input range depends on common-mode voltage, differential voltage, and gain. See Figure 18 through Figure 21 and the Input Voltage Range section in the Theory of Operation section for more information.

# ABSOLUTE MAXIMUM RATINGS

**Table 4.**

| Parameter | Rating |
|---|---|
| Supply Voltage | ±12 V |
| Internal Power Dissipation | 650 mW |
| Differential Input Voltage | $\pm V_S$ |
| Output Short-Circuit Duration | Indefinite |
| Storage Temperature Range (R, RM) | −65°C to +125°C |
| Operating Temperature Range | −40°C to +85°C |
| Lead Temperature (Soldering, 10 sec) | 300°C |
| ESD (Human Body Model) | 1.5 kV |
| ESD (Charge Device Model) | 500 V |
| ESD (Machine Model) | 100 V |

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.

## THERMAL RESISTANCE

$\theta_{JA}$ is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

Specification is for the device in free air.

**Table 5. Thermal Resistance**

| Package Type | $\theta_{JA}$ | Unit |
|---|---|---|
| 8-Lead SOIC (R) | 155 | °C/W |
| 8-Lead MSOP (RM) | 200 | °C/W |

## 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

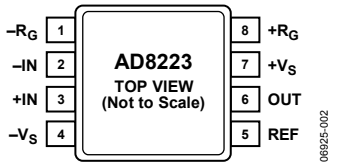



*Figure 2. Pin Configuration*

**Table 6. Pin Function Descriptions**

| Pin No. | Mnemonic | Descriptions |
|---|---|---|
| 1 | $-R_G$ | Gain Resistor Terminal. |
| 2 | −IN | Negative Input. |
| 3 | +IN | Positive Input. |
| 4 | $-V_S$ | Negative Supply. |
| 5 | REF | Reference. Connect to a low impedance source. Output is referenced to this node. |
| 6 | OUT | Output. |
| 7 | $+V_S$ | Positive Supply. |
| 8 | $+R_G$ | Gain Resistor Terminal. |

# TYPICAL PERFORMANCE CHARACTERISTICS

$T_A$ = 25°C, $V_S$ = ±5 V, $R_L$ = 10 kΩ, unless otherwise noted.

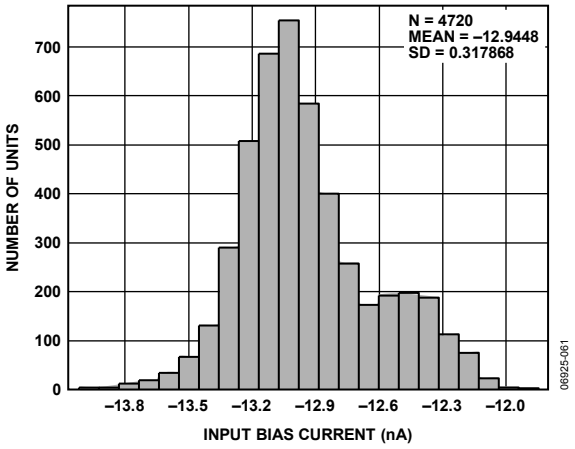



Figure 3. Typical Distribution of Input Bias Current

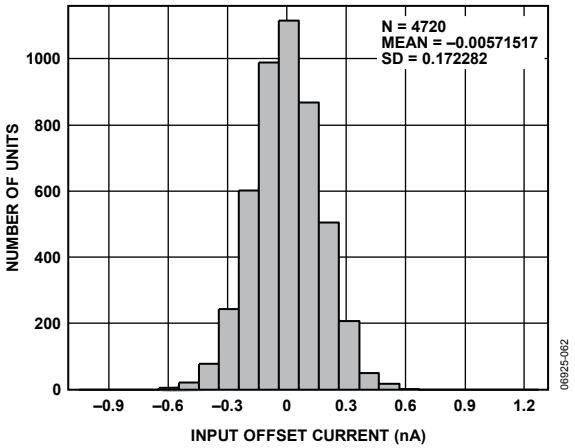



Figure 4. Typical Distribution of Input Offset Current

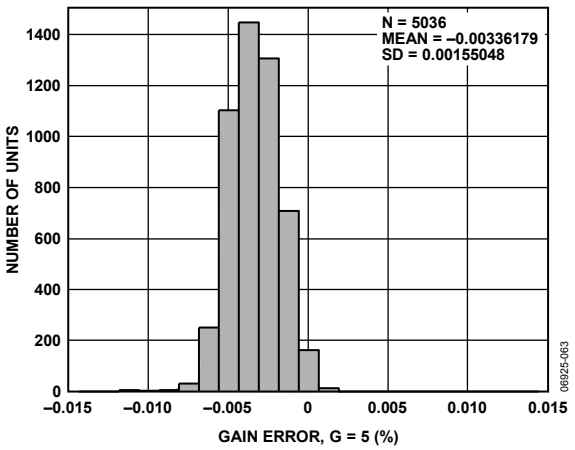



Figure 5. Typical Distribution for Gain Error (G = 5)

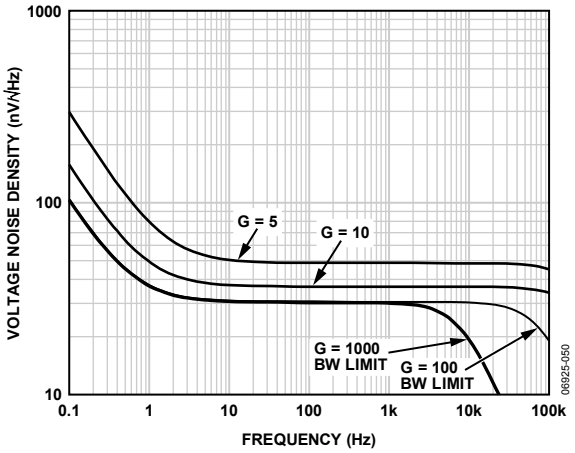



Figure 6. Voltage Noise Density vs. Frequency

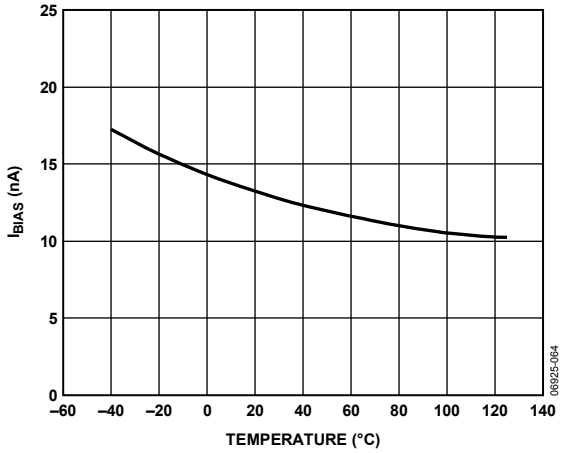



Figure 7. $I_{BIAS}$ vs. Temperature

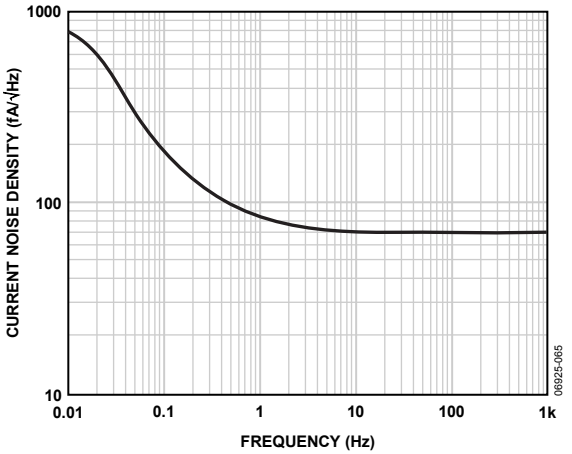



Figure 8. Current Noise Density vs. Frequency

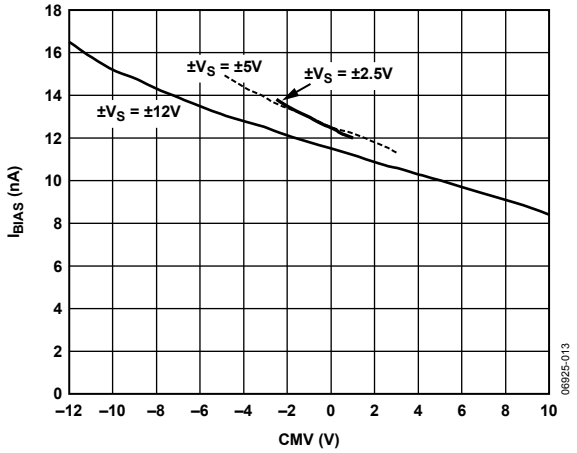



Figure 9. $I_{BIAS}$ vs. CMV

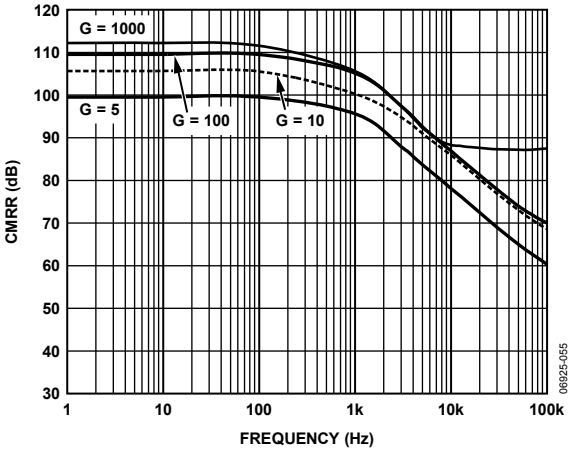



Figure 12. CMRR vs. Frequency, $\pm V_S = \pm 12$

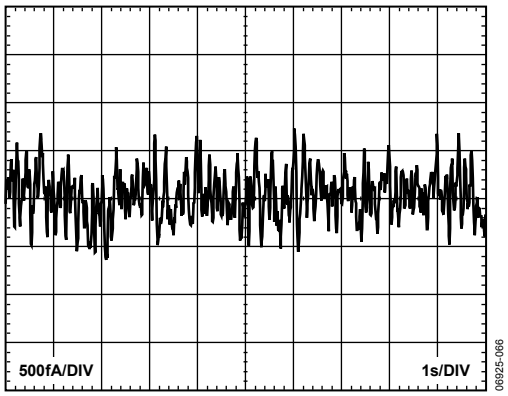



Figure 10. 0.1 Hz to 10 Hz Current Noise

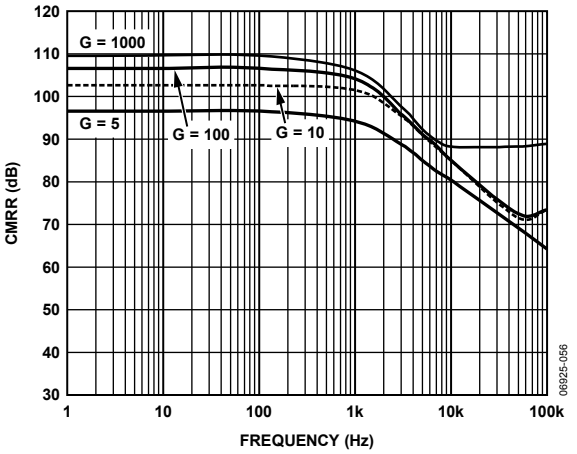



Figure 13. CMRR vs. Frequency, $+V_S = +5$ V

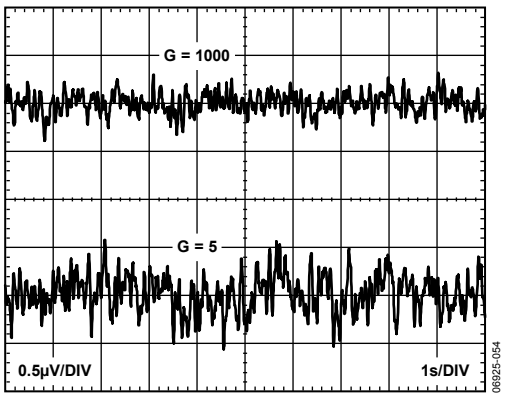



Figure 11. 0.1 Hz to 10 Hz RTI and RTO Voltage Noise

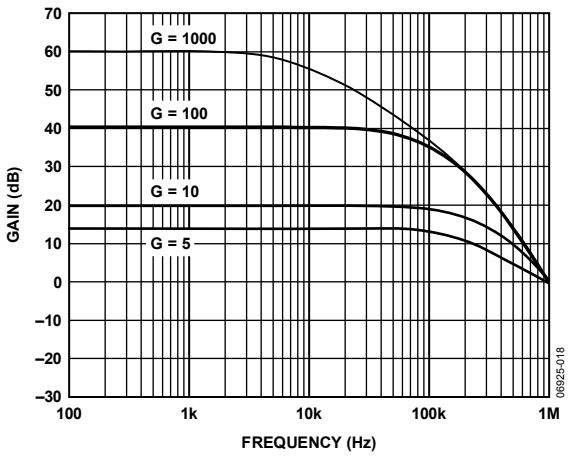



Figure 14. Gain vs. Frequency, $\pm V_S = \pm 12$ V

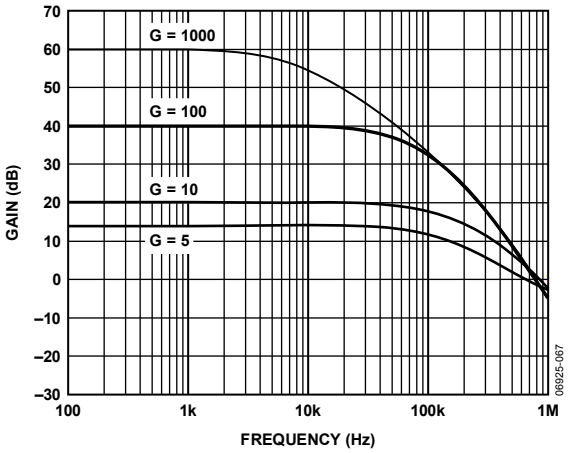



Figure 15. Gain vs. Frequency, $+V_S = +5$ V

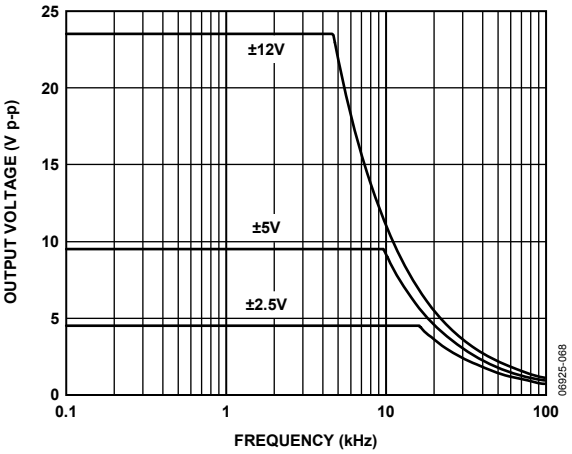



Figure 16. Large Signal Frequency Response

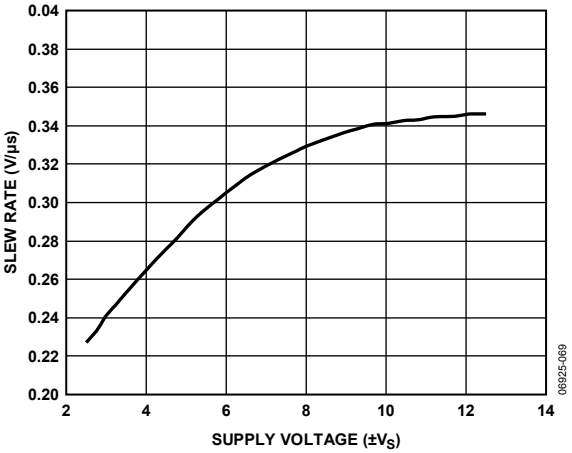



Figure 17. Slew Rate vs. Supply Voltage

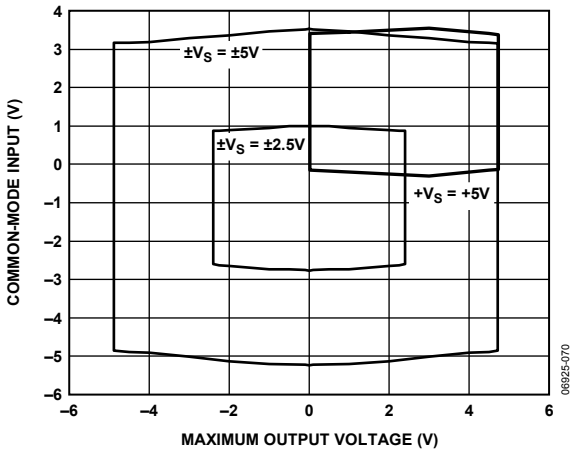



Figure 18. Common-Mode Input vs. Maximum Output Voltage, $G = 5$, Small Supplies

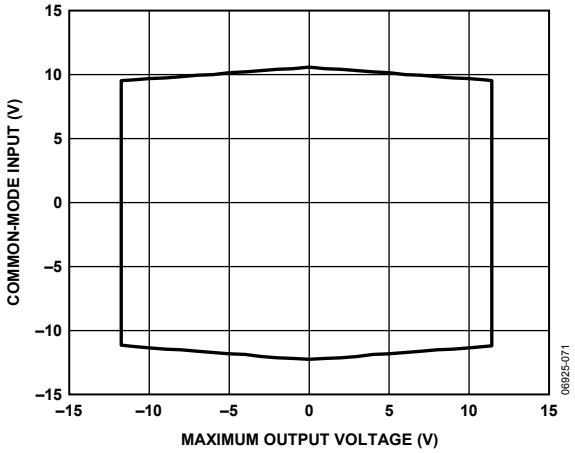



Figure 19. Common-Mode Input vs. Maximum Output Voltage, $G = 5$, $\pm V_S = \pm 12$ V

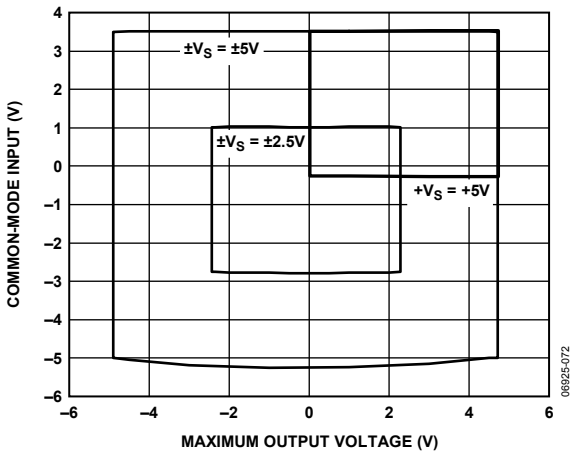



Figure 20. Common-Mode Input vs. Maximum Output Voltage, $G = 100$, Small Supplies

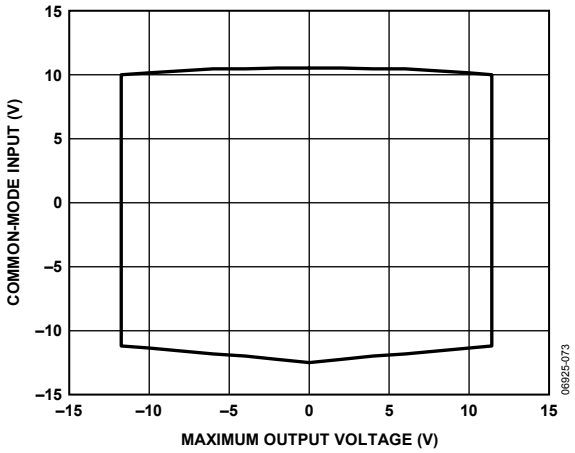



*Figure 21. Common-Mode Input vs. Maximum Output Voltage, G = 100, ±$V_S$ = ±12 V*

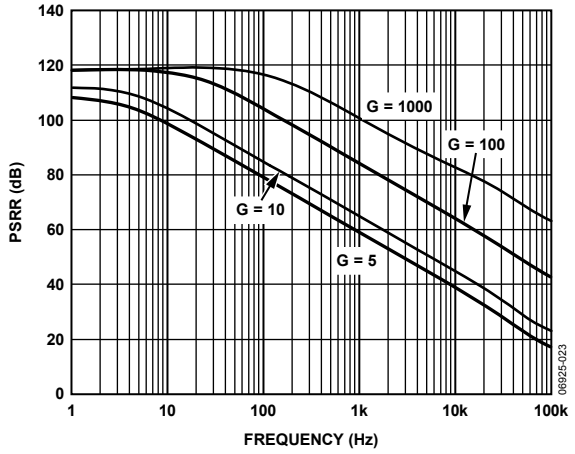



*Figure 22. Positive PSRR vs. Frequency, ±$V_S$ = ±12 V*

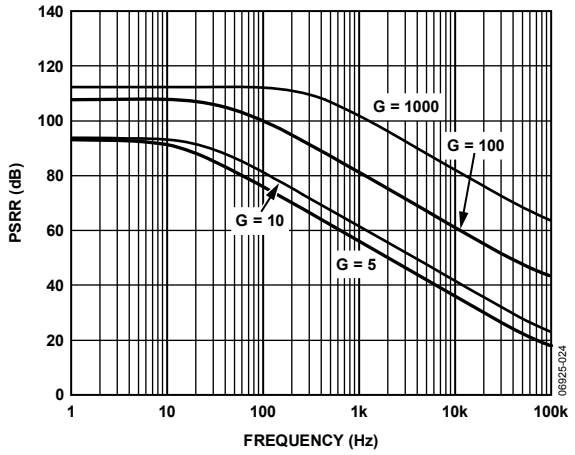



*Figure 23. Positive PSRR vs. Frequency, +$V_S$ = +5 V*

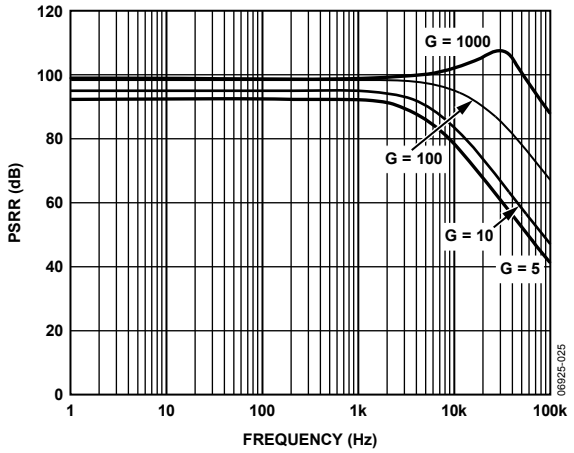



*Figure 24. Negative PSRR vs. Frequency, ±$V_S$ = ±12 V*

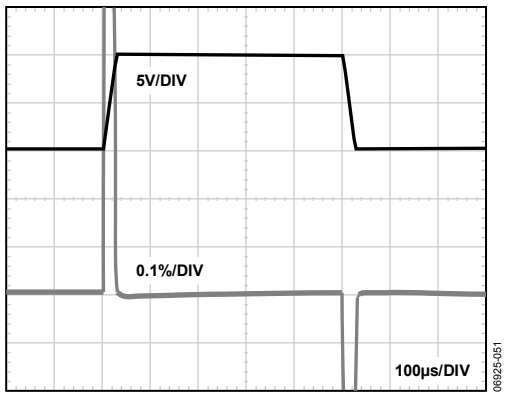



*Figure 25. Large Signal Response, G = 5*

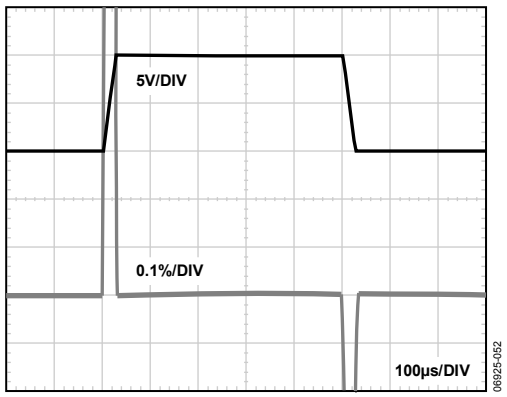



*Figure 26. Large Signal Pulse Response, G = 100, $C_L$ = 100 pF*

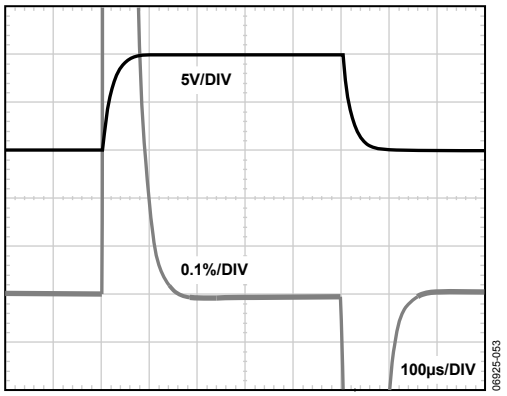



Figure 27. Large Signal Pulse Response, G = 1000, $C_L$ = 100 pF

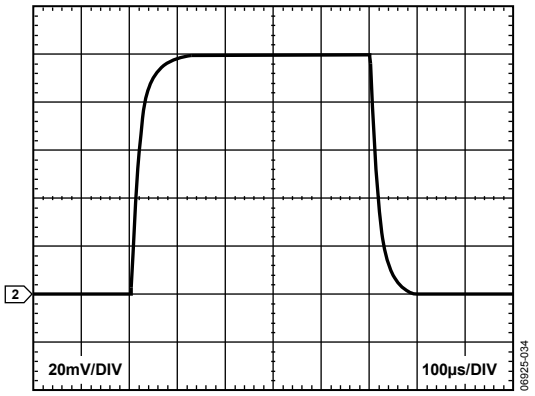



Figure 29. Small Signal Pulse Response, G = 1000, $R_L$ = 25 kΩ, $C_L$ = 100 pF

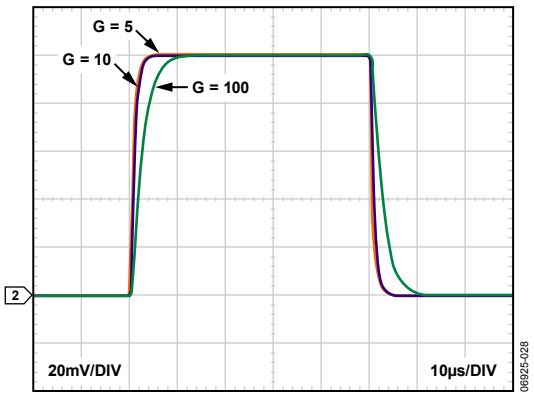



Figure 28. Small Signal Pulse Response, G = 5, 10, 100; $R_L$ = 10 kΩ

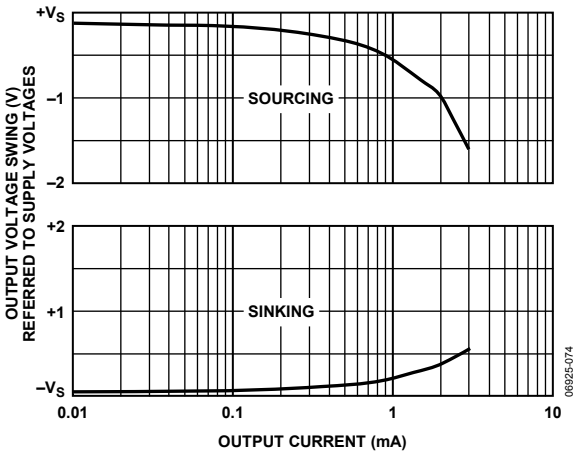



Figure 30. Output Voltage Swing vs. Output Current

# THEORY OF OPERATION

## AMPLIFIER ARCHITECTURE

The AD8223 is an instrumentation amplifier based on a classic 3-op amp approach, modified to ensure operation even at common-mode voltages at the negative supply rail. The architecture allows lower voltage offsets, better CMRR, and higher gain accuracy than competing instrumentation amplifiers in its class.

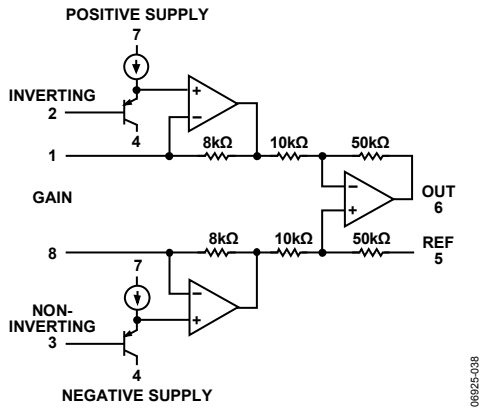



*Figure 31. Simplified Schematic*

Figure 31 shows a simplified schematic of the AD8223. The AD8223 has three stages. In the first stage, the input signal is applied to PNP transistors. These PNP transistors act as voltage buffers and allow input voltages below ground. The second stage consists of a pair of 8 kΩ resistors, the $R_G$ resistor, and a pair of amplifiers. This stage allows the amplification of the AD8223 to be set with a single external resistor. The third stage is a differential amplifier composed of an op amp, two 10 kΩ resistors, and two 50 kΩ resistors. This stage removes the common-mode signal and applies an additional gain of 5.

The transfer function of the AD8223 is

$$V_{OUT} = G(V_{IN+} - V_{IN-}) + V_{REF}$$

where:

$$G = 5 + \frac{80\ \text{k}\Omega}{R_G}$$

## GAIN SELECTION

Placing a resistor across the $R_G$ terminals sets the gain of the AD8223, which can be calculated by referring to Table 7 or by using the following gain equation:

$$R_G = \frac{80\ \text{k}\Omega}{G - 5}$$

**Table 7. Gains Achieved Using 1% Resistors**

| 1% Standard Table Value of $R_G$ (Ω) | Desired Gain | Calculated Gain |
|---|---|---|
| 26.7 k | 8 | 7.99 |
| 15.8 k | 10 | 10.1 |
| 5.36 k | 20 | 19.9 |
| 2.26 k | 40 | 40.4 |
| 1.78 k | 50 | 49.9 |
| 845 | 100 | 99.7 |
| 412 | 200 | 199 |
| 162 | 500 | 499 |
| 80.6 | 1000 | 998 |

The AD8223 defaults to G = 5 when no gain resistor is used. Add the tolerance and gain drift of the $R_G$ resistor to the specifications of the AD8223 to determine the total gain accuracy of the system. When the gain resistor is not used, gain depends only on internal resistor matching, so gain error and gain drift are minimal.

## INPUT VOLTAGE RANGE

The 3-op amp architecture of the AD8223 applies gain and then removes the common-mode voltage. Therefore, internal nodes in the AD8223 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. To determine whether the signal can be limited, refer to Figure 18 through Figure 21. Alternatively, use the parameters in the Specifications section to verify that the input and output are not limited and then use the following formula to make sure the internal nodes are not limited.

To check if it is limited by the internal nodes,

$$-V_S + 0.01\ \text{V} < 0.6 + V_{CM} \pm \frac{|V_{DIFF}| \times Gain}{10} < +V_S - 0.1\ \text{V}$$

If more common-mode range is required, a solution is to apply less gain in the instrumentation amplifier and more in a later stage.

## REFERENCE TERMINAL

The output voltage of the AD8223 is developed with respect to the potential on the reference terminal. This is useful when the output signal needs to be offset to a precise midsupply level. For example, a voltage source can be tied to the REF pin to level-shift the output so that the AD8223 can drive a single-supply ADC. The REF pin is protected with ESD diodes and should not exceed either $+V_S$ or $-V_S$ by more than 0.3 V.

For best performance, keep the source impedance to the REF terminal below 5 Ω. As shown in Figure 31, the reference terminal, REF, is at one end of a 50 kΩ resistor. Additional impedance at the REF terminal adds to this resistor and results in poorer CMRR performance.

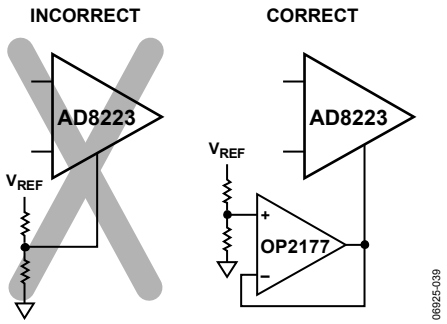



*Figure 32. Driving the Reference Pin*

## INPUT PROTECTION

Internal supply referenced clamping diodes allow the input, reference, output, and gain terminals of the AD8223 to safely withstand overvoltages of 0.3 V above or below the supplies. This is true for all gains, and for power-on and power-off. This last case is particularly important because the signal source and amplifier can be powered separately.

If the overvoltage is expected to exceed this value, limit the current through these diodes to about 10 mA using external current limiting resistors. This is shown in Figure 33. The size of this resistor is defined by the supply voltage and the required overvoltage protection.

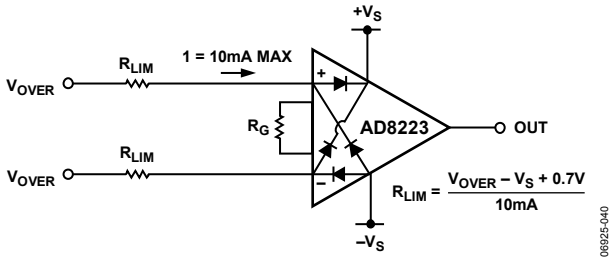



*Figure 33. Input Protection*

## RF INTERFERENCE (RFI)

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, R-C network placed at the input of the instrumentation amplifier, as shown in Figure 34. 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 $C_D \geq 10C_C$.

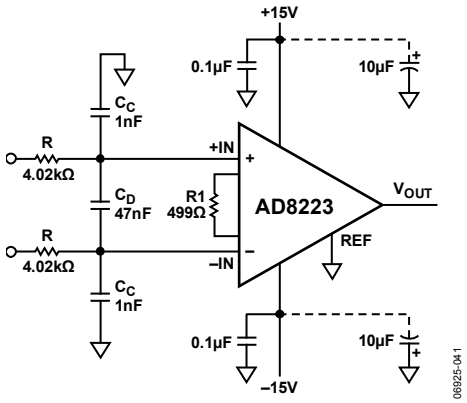



*Figure 34. RFI Suppression*

Figure 34 shows an example in which the differential filter frequency is approximately 400 Hz, and the common-mode filter frequency is approximately 40 kHz. The typical dc offset shift over frequency is less than 1.5 µV, and the RF signal rejection of the circuit is better than 71 dB.

The resistors were selected to be large enough to isolate the circuit input from the capacitors but not large enough to significantly increase the circuit noise. Choose values of R and $C_C$ to minimize RFI. Mismatch between the R × $C_C$ at positive input and the R × $C_C$ at negative input degrades the CMRR of the AD8223. Because of their higher accuracy and stability, COG/NPO type ceramic capacitors are recommended for the $C_C$ capacitors. The dielectric for the $C_D$ capacitor is not as critical.

## GROUND RETURNS FOR INPUT BIAS CURRENTS

Input bias currents are those dc currents that must flow to bias the input transistors of an amplifier. These are usually transistor base currents. When amplifying floating input sources such as transformers or ac-coupled sources, there must be a direct dc path into each input so that the bias current can flow. Figure 35 shows how a bias current path can be provided for the cases of transformer coupling, capacitive ac-coupling, and a thermocouple application.

In dc-coupled resistive bridge applications, providing this path is generally not necessary because the bias current simply flows from the bridge supply through the bridge and into the amplifier. However, if the impedances that the two inputs see are large and differ by a large amount (>10 kΩ), the offset current of the input stage causes dc errors proportional to the input offset voltage of the amplifier.

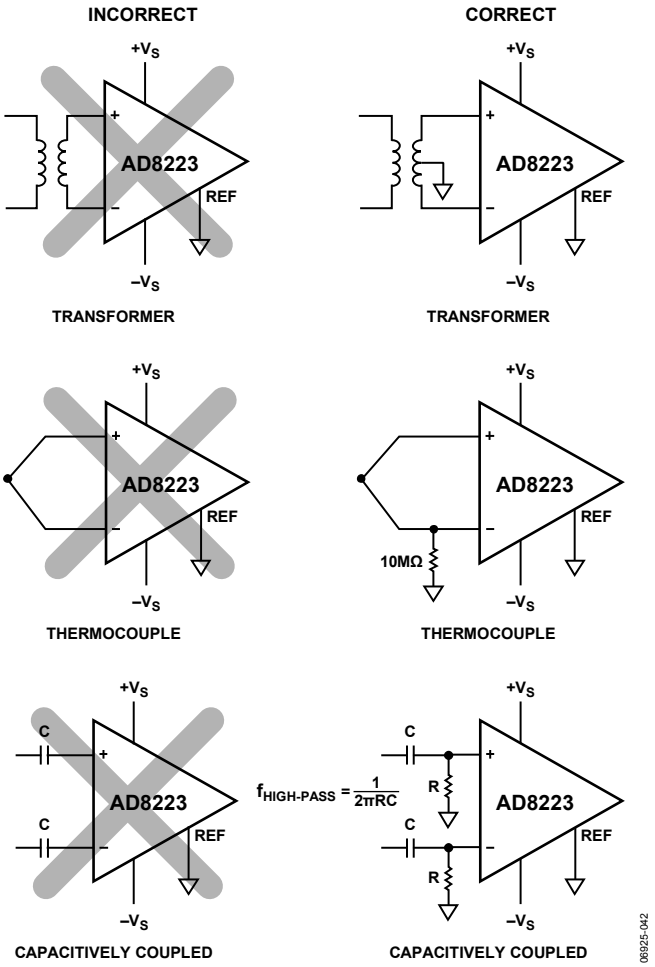



*Figure 35. Creating an $I_{BIAS}$ Path*

# APPLICATIONS INFORMATION

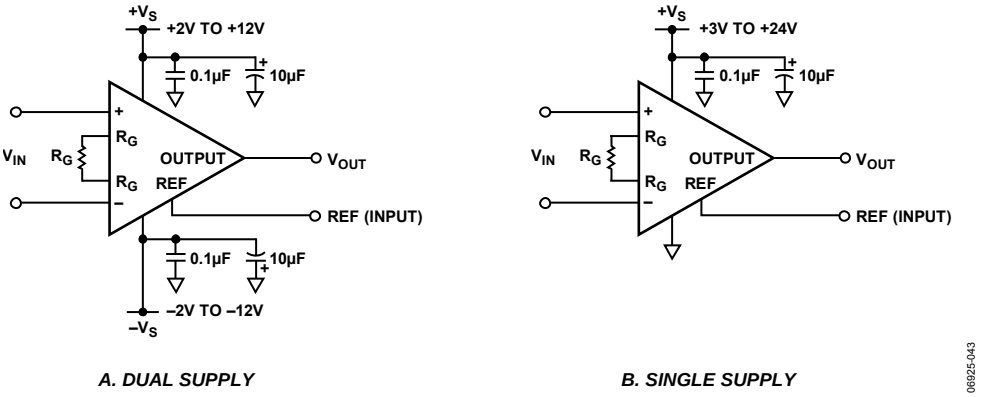



Figure 36. Basic Connections

## BASIC CONNECTION

Figure 36 shows the basic connection circuit for the AD8223. The $+V_S$ and $-V_S$ terminals are connected to the power supply. The supply can be either bipolar ($V_S$ = ±2 V to ±12 V) or single supply ($-V_S$ = 0 V, $+V_S$ = +3 V to +24 V). Power supplies should be capacitively decoupled close to the power pins of the device. For best results, use surface-mount 0.1 µF ceramic chip capacitors and 10 µF electrolytic tantalum capacitors.

The input voltage, which can be either single-ended (tie either −IN or +IN to ground) or differential, is amplified by the programmed gain. The output signal appears as the voltage difference between the output pin and the externally applied voltage on the REF input.

## DIFFERENTIAL OUTPUT

Figure 37 shows how to create a differential output in-amp. An OP1177 op amp creates the inverted output. Because the op amp drives the AD8223 reference pin, the AD8223 can still ensure that the differential voltage is correct. Errors from the op amp or mismatched resistors are common to both outputs and are thus common mode. These common-mode errors should be rejected by the next device in the signal chain.

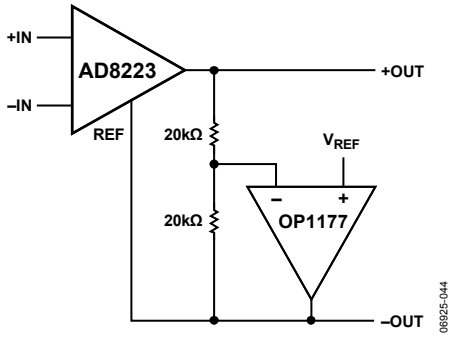



Figure 37. Differential Output Using Op Amp

## OUTPUT BUFFERING

The AD8223 is designed to drive loads of 10 kΩ or greater. If the load is less than this value, buffer the AD8223 output with a precision single-supply op amp such as the OP113. This op amp can swing from 0 V to 4 V on its output while driving a load as small as 600 Ω.

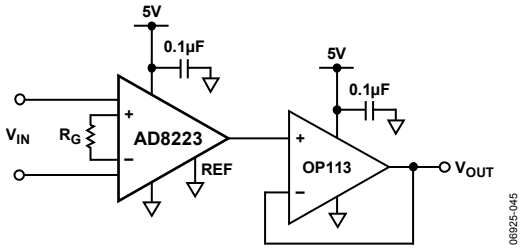



Figure 38. Output Buffering

## CABLES

### *Receiving from a Cable*

In many applications, shielded cables are used to minimize noise; for best CMR over frequency, the shield should be properly driven. Figure 39 shows an active guard drive that is configured to improve ac common-mode rejection by bootstrapping the capacitances of input cable shields, thus minimizing the capacitance mismatch between the inputs.

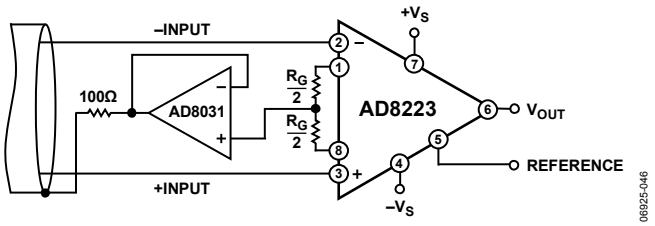



Figure 39. Common-Mode Shield Driver

### *Driving a Cable*

All cables have a certain capacitance per unit length, which varies widely with cable type. The capacitive load from the cable may cause peaking in the output response of the AD8223. To reduce the peaking, use a resistor between the AD8223 and the cable. Because cable capacitance and desired output response vary widely, this resistor is best determined empirically. A good starting point is 75 Ω.

The AD8232 operates at a low enough frequency that transmission line effects are rarely an issue; therefore, the resistor need not match the characteristic impedance of the cable.

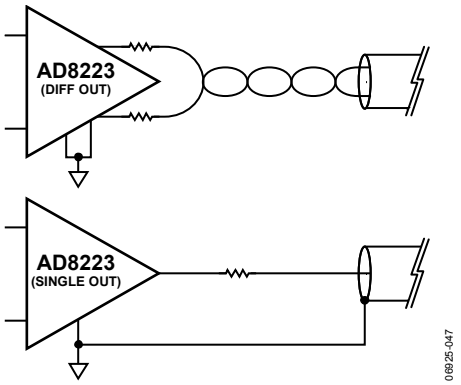



*Figure 40. Driving a Cable*

## A SINGLE-SUPPLY DATA ACQUISITION SYSTEM

Interfacing bipolar signals to single-supply analog-to-digital converters (ADCs) presents a challenge. The bipolar signal must be mapped into the input range of the ADC. Figure 41 shows how this translation can be achieved.

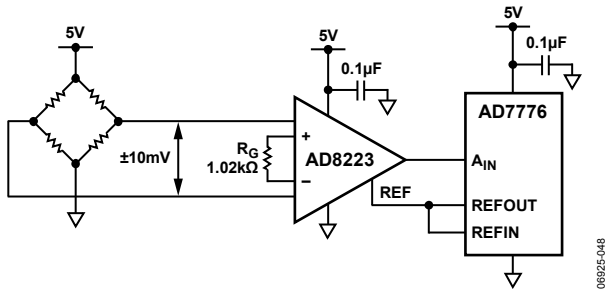



*Figure 41. A Single-Supply Data Acquisition System*

The bridge circuit is excited by a +5 V supply. The full-scale output voltage from the bridge (±10 mV), therefore, has a common-mode level of 2.5 V. The AD8223 removes the common-mode component and amplifies the input signal by a factor of 100 ($R_G$ = 1.02 kΩ). This results in an output signal of ±1 V. To prevent this signal from running into the AD8223 ground rail, the voltage on the REF pin must be raised to at least 1 V. In this example, the 2 V reference voltage from the AD7776 ADC is used to bias the AD8223 output voltage to 2 V ± 1 V, which corresponds to the input range of the ADC.

## AMPLIFYING SIGNALS WITH LOW COMMON-MODE VOLTAGE

Because the common-mode input range of the AD8223 extends 0.15 V below ground, it is possible to measure small differential signals that have low, or no, common-mode components. Figure 42 shows a thermocouple application in which one side of the J-type thermocouple is grounded.

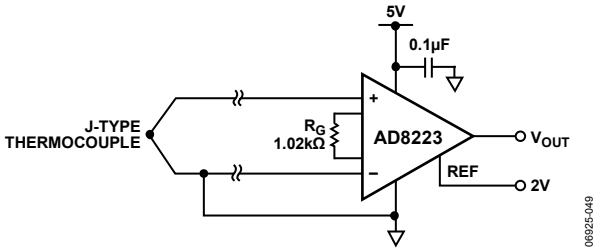
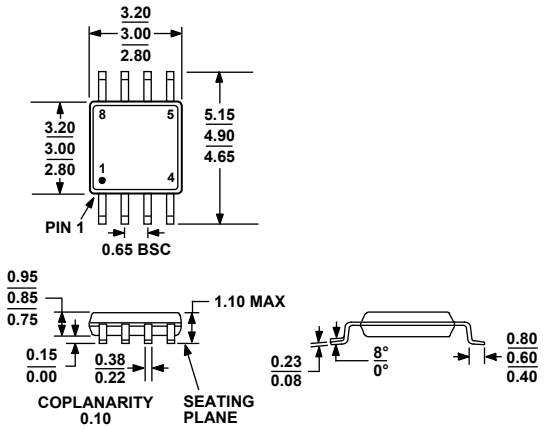



*Figure 42. Amplifying Bipolar Signals with Low Common-Mode Voltage*

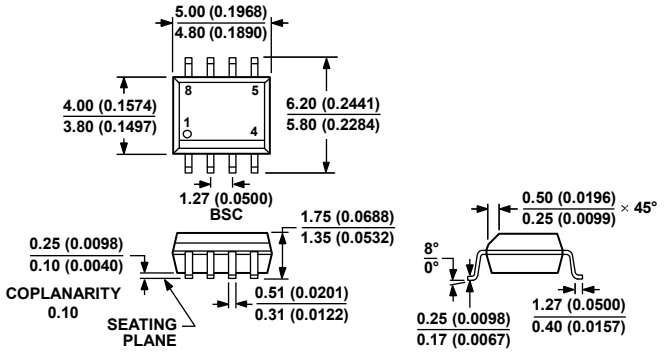
Over a temperature range of −200°C to +200°C, the J-type thermocouple delivers a voltage ranging from −7.890 mV to +10.777 mV. A programmed gain on the AD8223 of 100 ($R_G$ = 845) and a voltage on the AD8223 REF pin of 2 V results in the AD8223 output voltage ranging from 1.110 V to 3.077 V relative to ground.

# OUTLINE DIMENSIONS




COMPLIANT TO JEDEC STANDARDS MO-187-AA

*Figure 43. 8-Lead Mini Small Outline Package [MSOP]*
*(RM-8)*
*Dimensions shown in millimeters*




COMPLIANT TO JEDEC STANDARDS MS-012-AA
CONTROLLING DIMENSIONS ARE IN MILLIMETERS; INCH DIMENSIONS
(IN PARENTHESES) ARE ROUNDED-OFF MILLIMETER EQUIVALENTS FOR
REFERENCE ONLY AND ARE NOT APPROPRIATE FOR USE IN DESIGN.

012407-A

*Figure 44. 8-Lead Standard Small Outline Package [SOIC_N]*
*Narrow Body*
*(R-8)*
*Dimensions shown in millimeters and (inches)*

## ORDERING GUIDE

| Model | Temperature Range | Package Description | Package Option | Branding |
|---|---|---|---|---|
| AD8223AR | −40°C to +85°C | 8-Lead SOIC_N | R-8 | |
| AD8223AR-RL | −40°C to +85°C | 8-Lead SOIC_N,13" Tape and Reel | R-8 | |
| AD8223AR-R7 | −40°C to +85°C | 8-Lead SOIC_N, 7" Tape and Reel | R-8 | |
| AD8223ARM | −40°C to +85°C | 8-Lead MSOP | RM-8 | Y0U |
| AD8223ARM-RL | −40°C to +85°C | 8-Lead MSOP, 13" Tape and Reel | RM-8 | Y0U |
| AD8223ARM-R7 | −40°C to +85°C | 8-Lead MSOP, 7" Tape and Reel | RM-8 | Y0U |
| AD8223ARMZ[1] | −40°C to +85°C | 8-Lead MSOP | RM-8 | Y0Q |
| AD8223ARMZ-RL[1] | −40°C to +85°C | 8-Lead MSOP, 13" Tape and Reel | RM-8 | Y0Q |
| AD8223ARMZ-R7[1] | −40°C to +85°C | 8-Lead MSOP, 7" Tape and Reel | RM-8 | Y0Q |
| AD8223ARZ[1] | −40°C to +85°C | 8-Lead SOIC_N | R-8 | |
| AD8223ARZ-RL[1] | −40°C to +85°C | 8-Lead SOIC_N, 13" Tape and Reel | R-8 | |
| AD8223ARZ-R7[1] | −40°C to +85°C | 8-Lead SOIC_N, 7" Tape and Reel | R-8 | |
| AD8223BR | −40°C to +85°C | 8-Lead SOIC_N | R-8 | |
| AD8223BR-RL | −40°C to +85°C | 8-Lead SOIC_N, 13" Tape and Reel | R-8 | |
| AD8223BR-R7 | −40°C to +85°C | 8-Lead SOIC_N, 7" Tape and Reel | R-8 | |
| AD8223BRM | −40°C to +85°C | 8-Lead MSOP | RM-8 | Y0V |
| AD8223BRM-RL | −40°C to +85°C | 8-Lead MSOP, 13" Tape and Reel | RM-8 | Y0V |
| AD8223BRM-R7 | −40°C to +85°C | 8-Lead MSOP, 7" Tape and Reel | RM-8 | Y0V |
| AD8223BRMZ[1] | −40°C to +85°C | 8-Lead MSOP | RM-8 | Y0R |
| AD8223BRMZ-RL[1] | −40°C to +85°C | 8-Lead MSOP, 13" Tape and Reel | RM-8 | Y0R |
| AD8223BRMZ-R7[1] | −40°C to +85°C | 8-Lead MSOP, 7" Tape and Reel | RM-8 | Y0R |
| AD8223BRZ[1] | −40°C to +85°C | 8-Lead SOIC_N | R-8 | |
| AD8223BRZ-RL[1] | −40°C to +85°C | 8-Lead SOIC_N, 13" Tape and Reel | R-8 | |
| AD8223BRZ-R7[1] | −40°C to +85°C | 8-Lead SOIC_N, 7" Tape and Reel | R-8 | |

[1] Z = RoHS Compliant Part.

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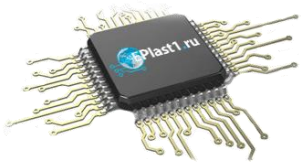
Компания «ЭлектроПласт» предлагает заключение долгосрочных отношений при поставках импортных электронных компонентов на взаимовыгодных условиях!

Наши преимущества:

- Оперативные поставки широкого спектра электронных компонентов отечественного и импортного производства напрямую от производителей и с крупнейших мировых складов;
- Поставка более 17-ти миллионов наименований электронных компонентов;
- Поставка сложных, дефицитных, либо снятых с производства позиций;
- Оперативные сроки поставки под заказ (от 5 рабочих дней);
- Экспресс доставка в любую точку России;
- Техническая поддержка проекта, помощь в подборе аналогов, поставка прототипов;
- Система менеджмента качества сертифицирована по Международному стандарту ISO 9001;
- Лицензия ФСБ на осуществление работ с использованием сведений, составляющих государственную тайну;
- Поставка специализированных компонентов (Xilinx, Altera, Analog Devices, Intersil, Interpoint, Microsemi, Aeroflex, Peregrine, Syfer, Eurofarad, Texas Instrument, Miteq, Cobham, E2V, MA-COM, Hittite, Mini-Circuits,General Dynamics и др.);

Помимо этого, одним из направлений компании «ЭлектроПласт» является направление «Источники питания». Мы предлагаем Вам помощь Конструкторского отдела:

- Подбор оптимального решения, техническое обоснование при выборе компонента;
- Подбор аналогов;
- Консультации по применению компонента;
- Поставка образцов и прототипов;
- Техническая поддержка проекта;
- Защита от снятия компонента с производства.




**Как с нами связаться**

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