Application Report

Importance of Input Bias Current Return Paths in Instrumentation Amplifier Applications

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Precision Amplifiers

ABSTRACT

One of the common application problems many engineers face when designing with an instrumentation amplifier (IA) is neglecting a dc return path to ground in both ac and dc applications. If there is no dc path to ground or other bias voltage for the input bias current (Ib), the circuit does not function properly. This application report discusses how to simply solve this common problem.

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Trademarks

1 Typical Instrumentation Amplifier Operation

Instrumentation amplifiers are a two-stage circuit used to extract and amplify differential input signals in the presence of common-mode voltages, as shown in Figure 1-1. The first stage forms a high-input-impedance circuit that amplifies the differential signal but passes the common mode signal without amplification. The second stage of the design is typically a difference amplifier that largely removes the common-mode signal while referencing the output to a specific reference voltage.

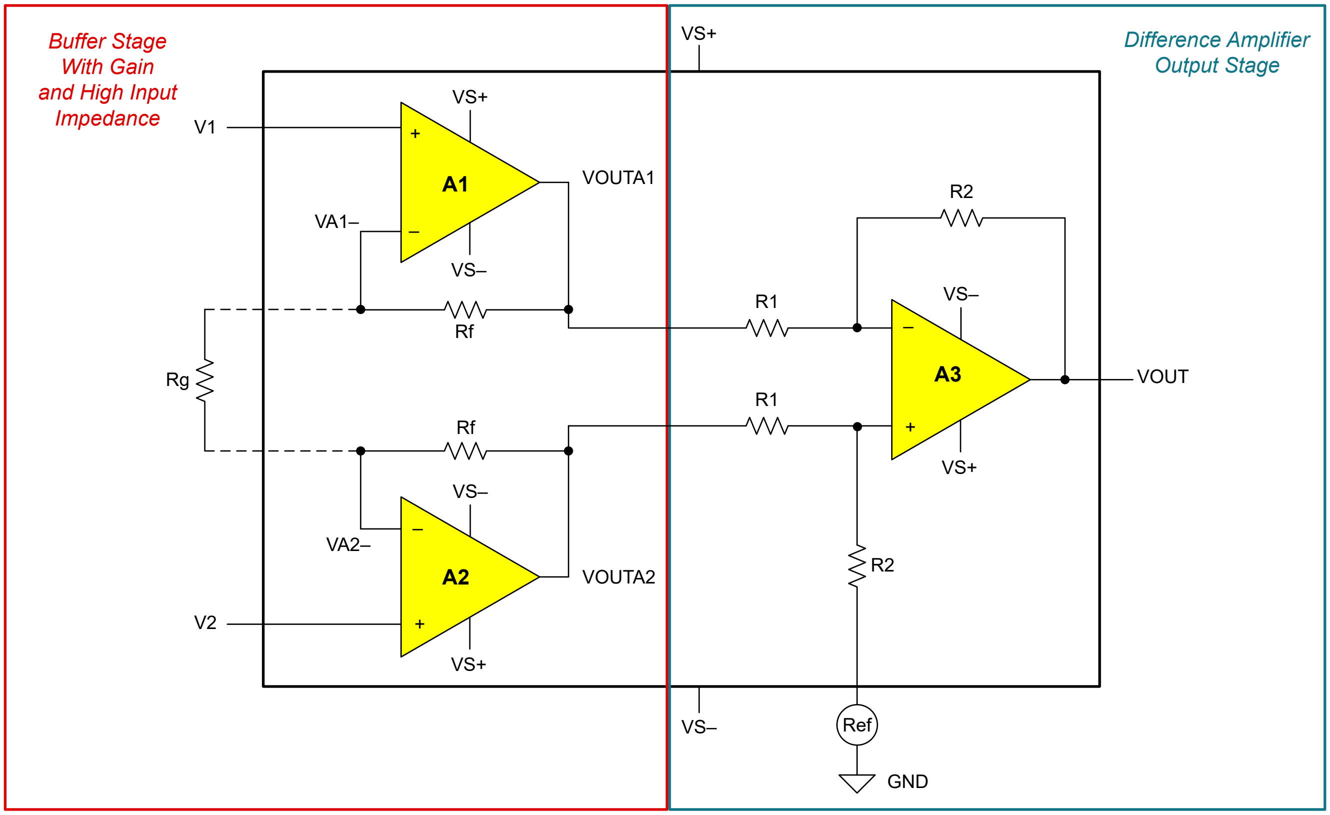

Figure 1-1. Typical Three-Amp IA

2 Problem Statement

In many IA applications, accurate, low-level ac signal processing is desired, while dc signals are rejected at the output. The easiest way to implement these functions is to ac-couple the IA. Designers ac-couple by adding capacitors in series with the IA inputs to block the dc input voltages, which effectively forms a high-pass filter. This method eliminates the need to accommodate the dc input signal before the IA gain stage pushes the dc input signal to saturation, a nonlinear operating condition. Therefore, this method of passing only the ac signal allows for higher gain and wider dynamic range.

For example, assume an IA has a 100-Hz sine wave with an amplitude of 100 mV in the presence of a 5-V common-mode voltage and a 3-V dc voltage. The desired output is a ±1-V signal. Using these operating conditions, the instrumentation amplifier must be configured with a gain of 10V/V. Applying the INA818, one of TI's high-precision, low-power, low-noise IAs, the circuit schematic and transient analysis is shown in Figure 2-1.

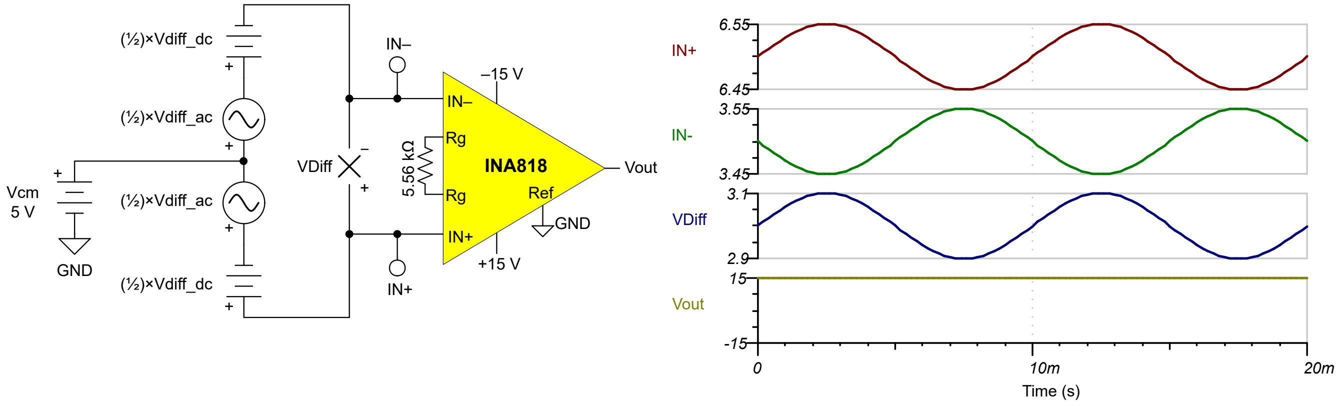

Figure 2-1. INA818 Schematic and Transient Analysis

While the 5-V common-mode voltage is rejected by the IA, the 3-V dc voltage sums with the input differential voltage shown by the VDiff curve. In a gain of 10V/V, the output signal is saturated against the positive power supply rail. Even though the desired signal to amplify was the 100 mV / 100 Hz sine wave, the 3-V dc voltage prevented the instrumentation amplifier output from representing only the amplified ac signal.

3 Common Mistake

Eliminating the dc nonlinearity at the output due to the presence of a dc input voltage is important. Engineers often mistakenly configure an ac-coupled IA circuit by adding a capacitor in series with each input terminal, but without providing a path for the input bias current. This mistake is illustrated in Figure 3-1. If a capacitor is connected in series with an instrumentation amplifier input without a dc path for current to flow, then over time, the Ib of the IA charges the capacitor until the output is driven to one of the rails, as shown by the IN+ trace in Figure 3-1.

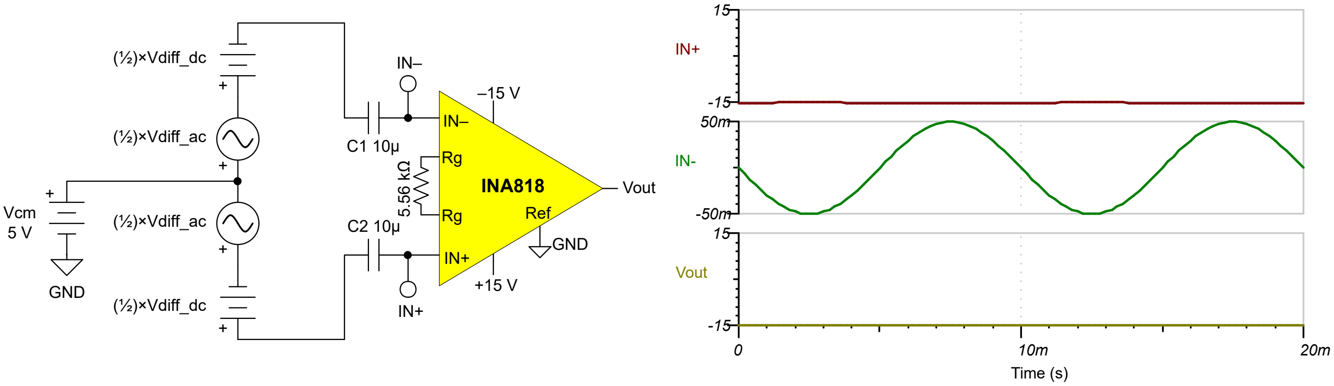

Figure 3-1. Incorrect AC-Coupling Schematic and Transient Analysis

4 Proposed Solution

A simple solution to this problem is to connect a resistor from each IA input to a system ground or other bias voltage. This solution provides a path for the input bias current to properly bias the IA inputs. In a dual-supply configuration (a sample schematic is shown in Figure 4-1A), each resistor is connected to ground. In a single-supply configuration, in order to maximize the input voltage range, the input bias resistors are usually connected to a voltage (Vbias) at mid-supply, as shown in Figure 4-1B. This mid-supply connection serves a secondary purpose in that a typical IA input generally cannot swing all the way to the power-supply rails. Thus, connecting the resistors to mid-supply maximizes the IA input dynamic range. Similarly, because the output of an IA cannot swing to the rails, connecting a reference voltage (Vref) to mid-supply maximizes the output voltage dynamic swing. Be aware that both Vref and Vbias must be able to sink and source current; therefore, using a low drop-out regulator (LDO) here may be unacceptable because an LDO can only source current. A buffer or a voltage reference is usually needed to drive the reference pin on an IA.

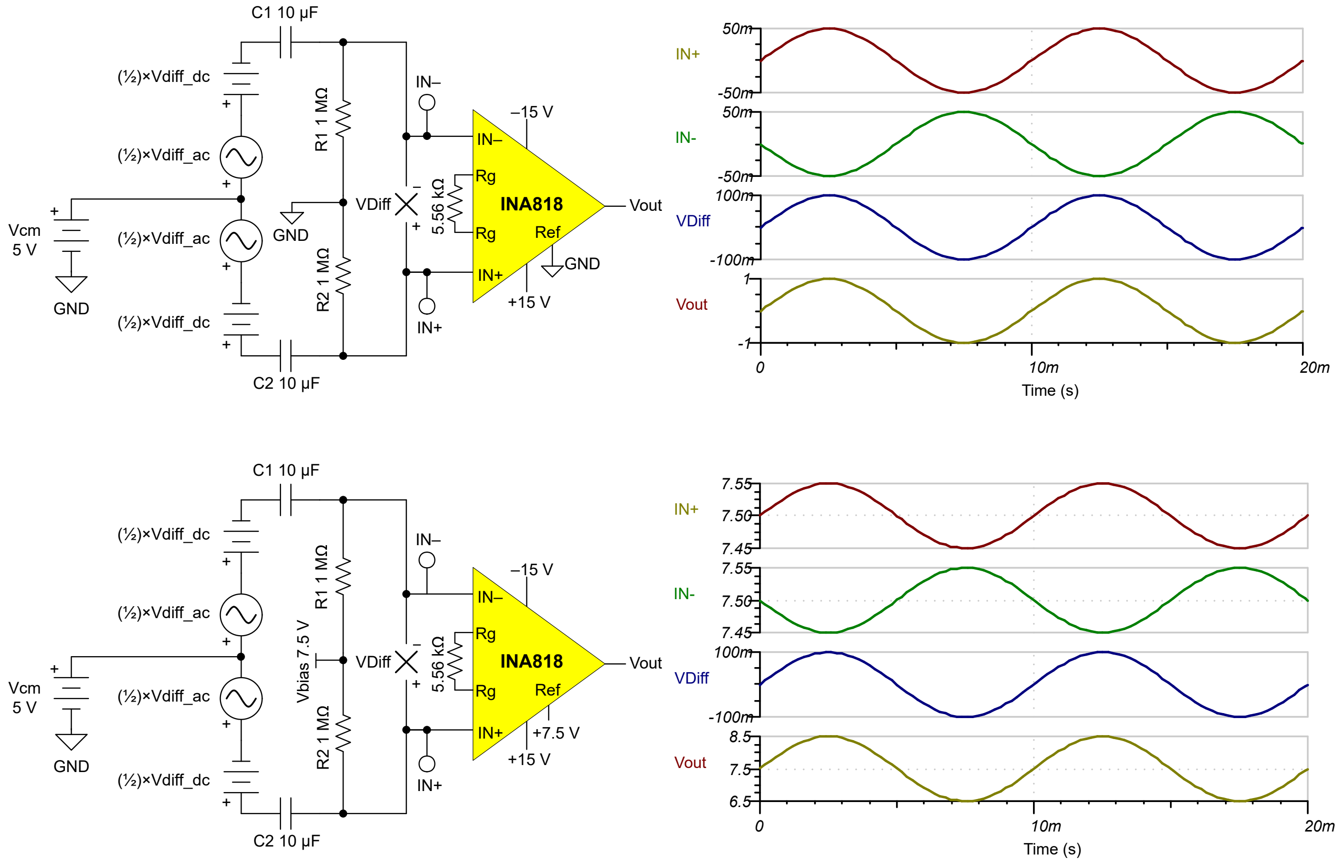

Figure 4-1. Correct AC Coupling for Single and Dual Supply Configurations

5 Component Selection and Trade-Offs

Adding resistors and capacitors comes with trade-offs, including increased noise and limited board space. Typical resistor values used for this purpose, seen as R1 and R2 in Figure 5-1, range from 100 kΩ to 1 MΩ. The values are usually chosen to be large compared to the differential source resistance. However, large resistor values introduce higher thermal noise and dc offset due to the instrumentation amplifier input bias current flowing through the resistors and developing a voltage drop across the resistors. Additionally, the input bias current flows into the input impedances and produces voltages that add to the overall system error, as shown in Figure 5-1 and Equation 1:

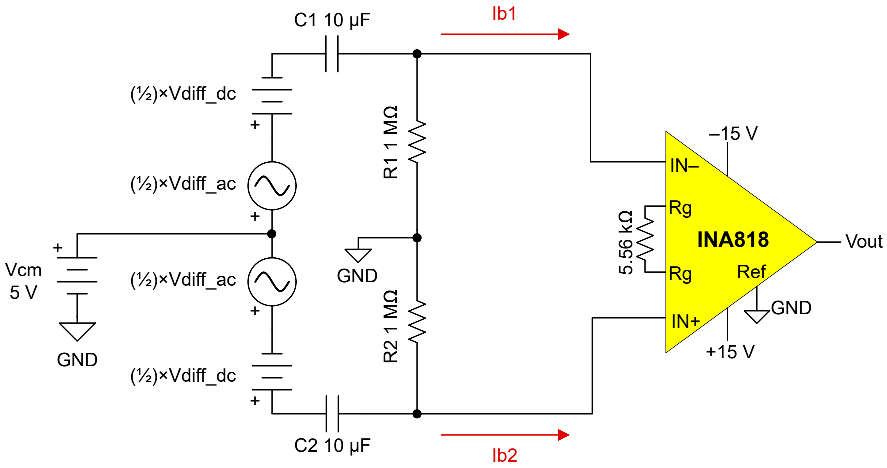

Figure 5-1. IA Input Bias Current

$$Vos_{in}(Ib) = (Ib1 \times R1) - (Ib2 \times R2) \tag{1}$$

Using higher-value capacitors allows for smaller resistors; however, large capacitors consume more board space. In addition to the value of the capacitor, the type of capacitor plays a large role in component selection. Depending on the application, a designer may need to opt for a specific capacitor grade because the grade may have an impact on linearity and distortion performance. C0G-grade capacitors offer the most stable capacitance of any ceramic capacitor over temperature, voltage, and frequency, and thus produce the lowest distortion. Ceramic X7R- and X5R-grade capacitors are not as stable over temperature, voltage, and frequency, and may result in unacceptable distortion over frequency.

In addition to the trade-offs of noise, offset error, and board space, these added components may affect overall precision. The resistors and capacitors added to the circuit in both input paths must be precisely matched to each other. That means R1 must match R2, and C1 must match C2. Any mismatch of these components degrades the ac common-mode rejection ratio (CMRR), which in turn converts this common-mode signal into a differential signal, and introduces error at the output of the circuit. One way to preserve CMRR is by lowering the cut-off frequency of the RC combination. However, this method requires larger-value resistors and capacitors, which again contributes to noise and board space. Another way of increasing precision is to add a third resistor that is typically one-tenth value of the other two resistors. Connect this third resistor between the instrumentation amplifier inputs.

Figure 5-2 shows the output error improvement by adding the third resistor. These circuits showcase the INA849, which has an input bias current of 50 nA (maximum). As shown in Equation 1, the input bias current flows into the input impedances to produce a voltage that then appears at the output of the instrumentation amplifier as error. Again, if the IA is configured with gain, the error is also amplified, adding even more error at the output. Adding a third resistor between the inputs of the IA, as shown in the following circuits, reduces the overall input impedance, which results in less system error at the output. In the left circuit, two perfectly matched 10-MΩ resistors are used. Adding the third 1-MΩ resistor reduces the output error significantly.

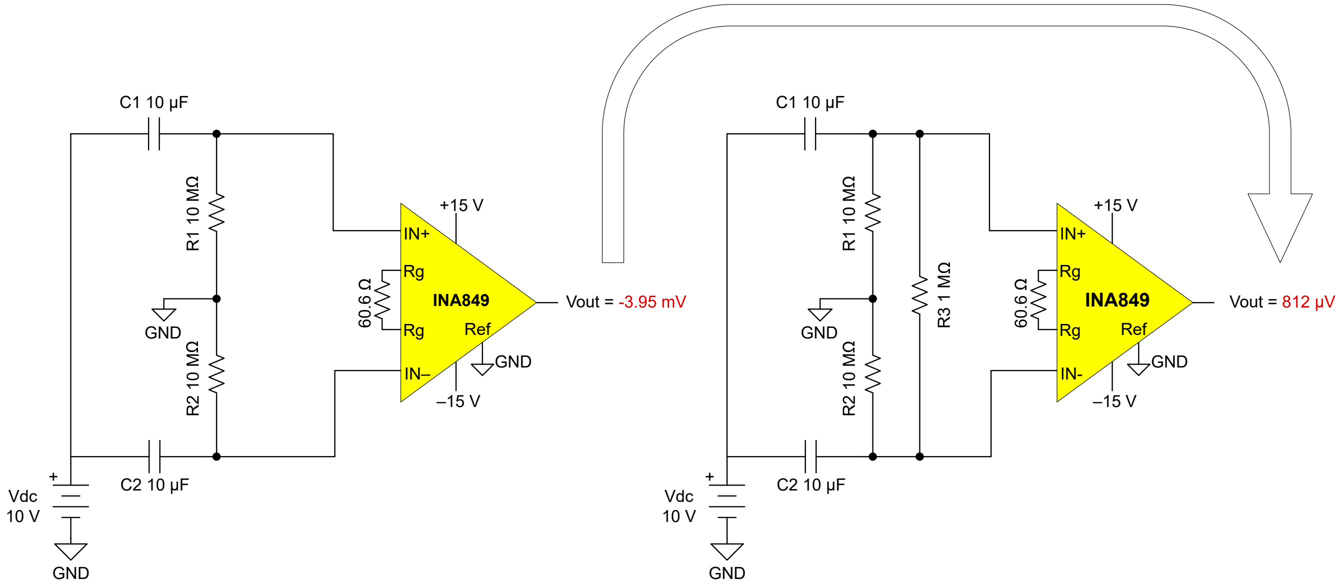

Figure 5-2. Offset Improvement With Third Input Resistor, Perfectly Matched Resistors

Unfortunately, resistors cannot be perfectly matched in production; instead, resistors are labeled according to tolerance. A 1% 1-MΩ resistor can be up to 1% off and still be within tolerance. Figure 5-3 shows two circuits, where R1 and R2 varied 1% in opposite directions; the worst possible scenario. However, adding the third resistor significantly reduced the output error. Depending on the system requirements, this third resistor can allow a designer to use lower tolerance resistors and still achieve a high-precision output.

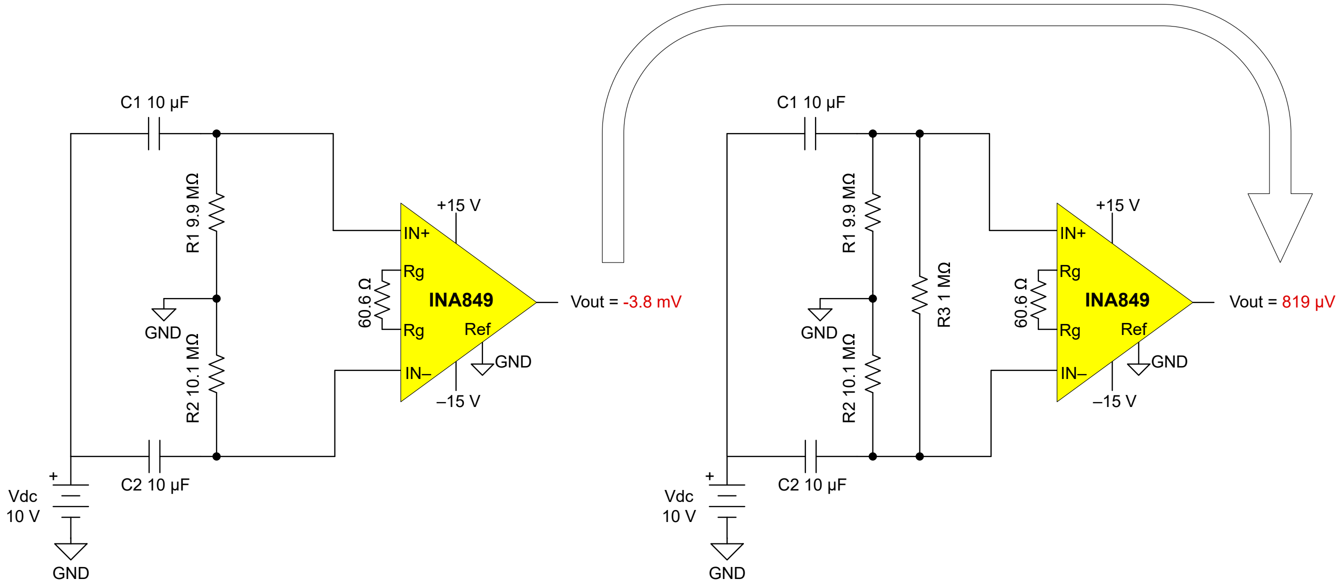

Figure 5-3. Offset Improvement With Third Input Resistor, 1% Resistors

Be aware that this third resistor has a unique set of drawbacks. While adding the third resistor allows a designer to counteract the impact of large resistor mismatch between R1 and R2, adding the third resistor does reduce the overall impedance. Reducing the input impedance may affect the sensor circuit driving the IA. The designer must make sure the impedance formed by R1 through R3 is still large compared to the source output impedance. Reducing the input impedance also changes the corner frequency of the dc-blocking high-pass filter. Depending on the application, this corner frequency may need to adjusted by increasing the size of the coupling capacitors.

6 Common Applications

Instrumentation amplifiers are frequently used to amplify differential voltages in the presence of common-mode noise. Some common applications include microphone preamplifiers and thermocouple amplifiers.

For a typical two-terminal electret microphone with a dc component to bias the internal JFET, an instrumentation amplifier can be used to amplify the differential voltage, as shown in Figure 6-1. The microphone parameters determine the required biasing resistors. For a microphone with an output impedance of 2.2 kΩ, do not use biasing resistors low enough to load the microphone and cause distortion, and large enough to induce excessive thermal noise. This trade-off must be evaluated and determined by the system requirements. After the biasing resistors are selected, the coupling capacitors can be calculated based on the frequency band required to pass.

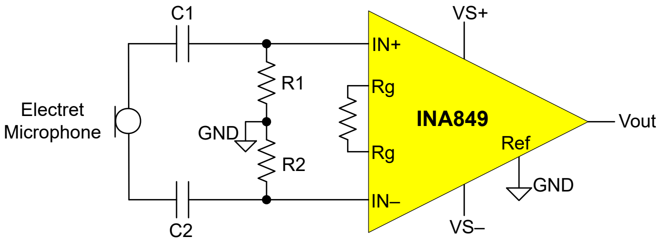

Figure 6-1. AC-Coupled Microphone Preamp Circuit

Another common application is temperature measurement with a thermocouple. A thermocouple is essentially a low-impedance short that produces a small-signal dc offset based on the Seebeck effect. This offset can be measured using an IA, as shown in Figure 6-2. The thermocouple has a low output impedance; therefore, two biasing resistors are not required. One biasing resistor can provide the necessary path to ground without creating a large offset error due to Ib.

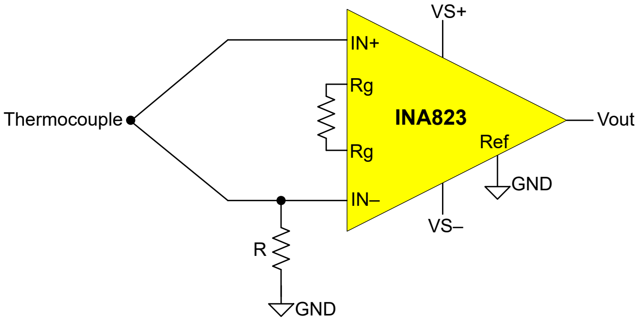

Figure 6-2. Thermocouple Biasing Circuit

7 Conclusion

Many applications that require low-level ac signal processing in the presence of large dc potentials require special additional circuitry. Simple mistakes while building the circuit can cause large errors and unexpected outputs. Providing a dc path to ground in dc or ac applications is a necessary step in circuit design. Properly designing these circuits requires an understanding of the sensor output impedance or the output impedance of the circuit driving the instrumentation amplifier, as well as the trade-offs in component selection.

See Table 7-1 for a list of some of TI's high-precision low-Ib instrumentation amplifiers.

Table 7-1. Recommended High-Precision, Low-Ib Instrumentation Amplifiers From TI

Part Number	Description
INA849	Ultra-low-noise (1 nV/√Hz), wide-bandwidth (28 MHz), high-precision (35 µV), super-beta, 36-V IA with low input bias current (20 nA, maximum)
INA823	Low-power (250 µA), wide-supply (2.7 V to 36 V), precision, (150 µV), super-beta IA with low input bias current (15 nA), overvoltage protection, and below ground input voltage
INA821	Wide-bandwidth (4.7 MHz), low-noise (7 nV/√Hz), high-precision (35 µV), super-beta, 36-V IA with low input bias current (0.5 nA, maximum) and overvoltage protection
INA819	Low-power (350 µA), low-noise (8 nV/√Hz), high-precision (35 µV), super-beta, 36-V IA with low input bias current (0.5 nA, maximum) and overvoltage protection (alternative pinout available: INA818)
INA188	Zero-drift (0.2 µV/°C, 55 µV), low-noise (12 nV/√Hz), 36-V, CMOS IA with low input bias current (2.5 nA, maximum)
INA333	Micro-power (50 µA), zero-drift (0.1 µV/°C, 25 µV), 5.5-V CMOS IA with low input bias current (0.2 nA, maximum)
INA331	Very-low-bias-current (10 pA, maximum), low-power (0.01 µA with shutdown), low-current-noise (0.5 fA/√Hz), 5.5-V CMOS IA
INA121	Very-low-bias (50 pA, maximum), low-current-noise (1 fA/√Hz), 36-V, FET-input IA with overvoltage protection

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