

# The Difference Between an Instrumentation Amplifier and a Current Sense Amplifier



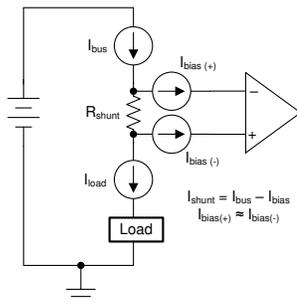
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## Introduction

Current sensing is an important function in a wide range of electronic applications. With so many different devices available, it is no surprise that there is some confusion when selecting a device, particularly when choosing between an instrumentation amplifier and a current sense amplifier. Both devices can perform the current sense function, but optimization of cost and accuracy will require an understanding of the differences between the two.

## Current Sense Amplifiers

A [current sense amplifier](#) (CSA) is a highly specialized current sensing device. The basic operating principle makes use of Ohm's law. The CSA takes the voltage drop across a shunt resistor on the supply bus as input and converts it into a signal proportional to the current flow at the output as [Figure 1](#) shows.



**Figure 1. Simplified Current Measurement Application Using a Shunt Resistor**

The input signal may be gained up at the output by a variety of available fixed gains. CSAs are available with traditional analog output as well as digital output on devices with integrated analog-to-digital converters (ADCs).

## Instrumentation Amplifiers

An [instrumentation amplifier](#) (IA) is a monolithic high-precision device that offers very high input impedance and common-mode rejection. The traditional three operational-amplifier topology IA consists of a difference amplifier with buffered inputs, which allow

the designer to set the gain to a wide range with a single resistor. The output of the IA is a single-ended signal representing the difference of the two signals at the inputs. In contrast to CSAs, IAs are versatile devices that are used in a wide range of applications beyond current sensing such as [pressure transmitters](#), [weigh scales](#), [analog input modules](#), [HEV/EVs](#), and [electrocardiograms](#) (ECGs) to name a few. In lieu of specialization, the IAs offer more design flexibility.

## Input Stage Topology

While similar in operating principle in a current sense application, a CSA and an IA differ fundamentally in input topology. CSAs use a variety of unique input stage designs, such as a common-base transistor input, that allow CSAs to handle common-mode voltage ( $V_{cm}$ ) levels far above and below the supply, as high as 120 V with a standard 5-V supply rail for example. This is often at the expense of higher input bias current ( $I_{bias}$ ) and lower input impedance. Additionally, CSAs may suffer from rapidly increasing  $I_{bias}$  with increasing  $V_{cm}$ . While some new-generation devices offer lower specifications, CSAs typically have  $\mu$ As of  $I_{bias}$  and offer M $\Omega$  range input impedance.

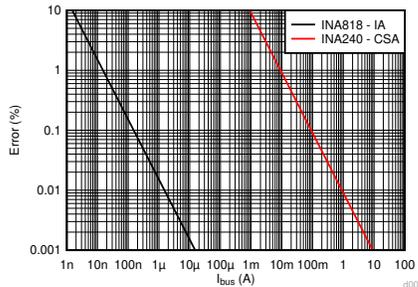
In contrast, the buffered input of an IA provides input impedance in the hundreds of G $\Omega$  range and  $I_{bias}$  in the nA range with almost no variation across  $V_{cm}$ . The trade-off to the input topology of an IA is a limitation in  $V_{cm}$  range, which is typically within hundreds of mV to a couple of volts of each supply. To implement a robust current measurement design, it is critical to consider the boundaries placed by  $I_{bias}$ ,  $V_{cm}$  range, and inherent error sources.

## Input Bias Current Implications

Input bias current is current that flows into the input transistors of a device. This is an especially important specification when measuring current, as it will determine the use cases for a particular device. A large  $I_{bias}$  will reduce the supply bus current ( $I_{bus}$ ) that needs to be measured. Ideally, the current flowing through the shunt resistor ( $I_{shunt}$ ) should equal  $I_{bus}$ , but instead is determined by [Equation 1](#).

$$I_{shunt} = I_{bus} - I_{bias} \quad (1)$$

The reduction of  $I_{bus}$  creates a significant measurement error if  $I_{bus}$  is small, and is therefore the primary limitation for measuring very small currents. Figure 2 shows how the error contribution from  $I_{bias}$  decreases as  $I_{bus}$  increases. Moreover,  $I_{bias}$  may vary not only with  $V_{cm}$  as mentioned previously but also with temperature.



**Figure 2. Percent Error due to Maximum Input Bias Current vs Supply Bus Current**

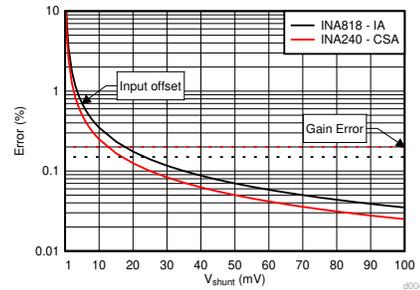
### Common-Mode Voltage Implications

Similar to  $I_{bias}$ ,  $V_{cm}$  range will determine the use case for a particular device. High-side and low-side current sensing typically expose the sensing device to  $V_{cm}$  values approximately equal to the supply bus voltage and ground, respectively. These conditions are especially important when supply voltages of the sensing device are limited. All devices must be operated within the recommended  $V_{cm}$  range to avoid erroneous measurements. Once  $I_{bias}$  and  $V_{cm}$  requirements are met, it is critical to consider input offset voltage and gain error as they will likely be the largest contributors of error to the desired measurement.

### Error Sources

Input offset voltage ( $V_{os}$ ) is important when dealing with small voltage drops across the shunt resistor ( $V_{shunt}$ ). A small  $V_{shunt}$  is typical since shunt resistors must be kept as small as possible to limit load disturbance and power dissipation. At large  $V_{shunt}$  values, the impact of  $V_{os}$  decreases and gain error (GE), which does not change with  $V_{shunt}$ , becomes the dominant source of error as illustrated in Figure 3. Essentially  $I_{bias}$ ,  $V_{os}$ , and GE will determine the lower bound of current measurement that is achievable by the device within the target accuracy. Similar to  $I_{bias}$ ,  $V_{os}$  and GE will also drift with temperature so it is important to consider the operating conditions. Consideration for common-mode rejection, power supply rejection, and noise are also important for accurate results. A more thorough analysis would involve the root sum square of all error sources. For a comprehensive error analysis on IAs, see the

### Comprehensive Error Calculation for Instrumentation Amplifiers tech note.



**Figure 3. Percent Error due to Maximum Input Offset Voltage and Maximum Gain Error Versus Shunt Resistor Voltage**

### Choosing a Device

In current sense applications where the load supply bus voltage exceeds the supply voltage of the sensing device, a CSA may be needed as the IA has limited  $V_{cm}$  range. The size and expense of the system should also be considered since CSAs are generally available in smaller packages and at a lower cost. Conversely, if the current to be measured is expected to be very small, an IA will typically be a good choice given the low  $I_{bias}$ ,  $V_{os}$ , and GE. An IA will also be attractive for designs that require flexible gain and higher bandwidth (BW) since CSAs typically offer fixed gain and lower BW. To summarize, when choosing a device for a current sensing application, it is important to consider the error, size, and expense of the system as well as the expected  $I_{bus}$ ,  $V_{cm}$ , and BW range of the application.

**Table 1. Instrumentation and Current Sense Amplifier Summary**

|                 | Instrumentation Amplifier   | Current Sense Amplifier   |
|-----------------|---|---|
| $I_{bus}$ sense | nA to 10s of amps   | mA to 10s of amps   |
| $V_{cm}$ range  | $V_s(-)$ to $V_s(+)$  | Independent of supply   |
| Strengths       | Sensing small currents<br>Flexible gain<br>Range of applications<br>High accuracy | Wide $V_{cm}$ range<br>Specialized integration<br>Small package sizes<br>Cost |
| Challenges      | $V_{cm}$ limitations  | Small current sense   |

Make sure to check out the [Instrumentation Amplifiers](#) and [Current Sense Amplifiers](#) training video series.

**Table 2. Recommended Devices**

|                            |  |   |
|----------------------------|--|---|
| Instrumentation amplifiers | <p><b>INA333-Q1</b> : 25-<math>\mu</math>V, 0.1-<math>\mu</math>V/<math>^{\circ}</math>C, 0.2-nA <math>I_{bias}</math>, 0.25% GE</p> <p><b>INA818</b> : 2-MHz, 35-<math>\mu</math>V, 8-nV/<math>\sqrt{\text{Hz}}</math>, 0.15-nA <math>I_{bias}</math>, 0.15% GE</p> | <p><b>INA819</b> : 2-MHz, 35-<math>\mu</math>V, 8-nV/<math>\sqrt{\text{Hz}}</math>, 0.15-nA <math>I_{bias}</math>, 0.15% GE</p> <p><b>INA821</b> : 4.7-MHz, 35-<math>\mu</math>V, 7-nV/<math>\sqrt{\text{Hz}}</math>, 0.15% GE</p>  |
| Current sense amplifiers   | <p><b>INA186</b> : 50-<math>\mu</math>V, 0.5-nA <math>I_{bias}</math>, 1% GE, -0.2 V to +40 V <math>V_{cm}</math></p> <p><b>INA185</b> : 55-<math>\mu</math>V, tiny package, -0.2 V to +26 V <math>V_{cm}</math></p>   | <p><b>INA293-Q1</b> : 200-<math>\mu</math>V, 20-<math>\mu</math>A <math>I_{bias}</math>, 0.2% GE -4 V to +110 V <math>V_{cm}</math></p> <p><b>INA240</b> : 25-<math>\mu</math>V, 90-<math>\mu</math>A <math>I_{bias}</math>, 0.2% GE, -4 V to +80 V <math>V_{cm}</math></p> |

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