

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

Daniel Terrazas

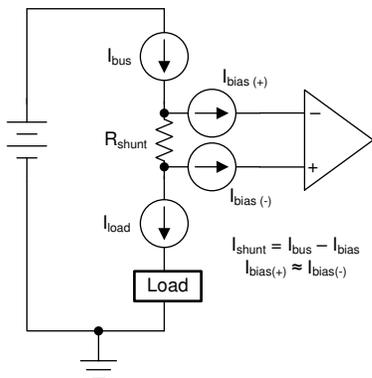


## Introduction

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.

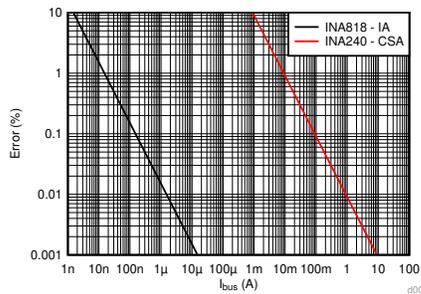
In contrast, the buffered input of an IA provides input impedance in the hundreds of G $\Omega$  range and  $I_{bias}$  in the nA range with almost no variation across  $V_{cm}$ . The trade-off to the input topology of an IA is a limitation in  $V_{cm}$  range, which is typically within hundreds of mV 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

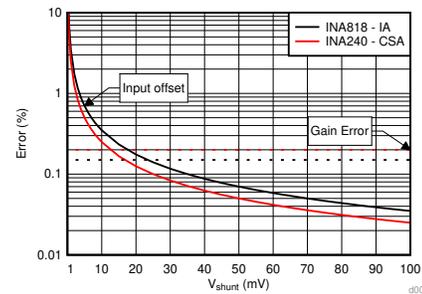
Input bias current is current that flows into the input transistors of a device. This is an especially important specification when measuring current, as it will determine the use cases for a particular device. A large  $I_{bias}$  will reduce the supply bus current ( $I_{bus}$ ) that needs to be measured. 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**



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

### 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.

### 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 Flexible gain Range of applications High accuracy	Wide $V_{cm}$ range Specialized integration Small package sizes 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	<b>INA333-Q1</b> : 25- $\mu$ V, 0.1- $\mu$ V/ $^{\circ}$ C, 0.2-nA $I_{bias}$ , 0.25% GE <b>INA818</b> : 2-MHz, 35- $\mu$ V, 8-nV/ $\sqrt{Hz}$ , 0.15-nA $I_{bias}$ , 0.15% GE	<b>INA819</b> : 2-MHz, 35- $\mu$ V, 8-nV/ $\sqrt{Hz}$ , 0.15-nA $I_{bias}$ , 0.15% GE <b>INA821</b> : 4.7-MHz, 35- $\mu$ V, 7-nV/ $\sqrt{Hz}$ , 0.15% GE
Current sense amplifiers	<b>INA186</b> : 50- $\mu$ V, 0.5-nA $I_{bias}$ , 1% GE, -0.2 V to +40 V $V_{cm}$ <b>INA185</b> : 55- $\mu$ V, tiny package, -0.2 V to +26 V $V_{cm}$	<b>INA293-Q1</b> : 200- $\mu$ V, 20- $\mu$ A $I_{bias}$ , 0.2% GE -4 V to +110 V $V_{cm}$ <b>INA240</b> : 25- $\mu$ V, 90- $\mu$ A $I_{bias}$ , 0.2% GE, -4 V to +80 V $V_{cm}$

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to TI's Terms of Sale ([www.ti.com/legal/termsofsale.html](http://www.ti.com/legal/termsofsale.html)) or other applicable terms available either on [ti.com](http://ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2020, Texas Instruments Incorporated