The Difference Between an Instrumentation Amplifier and a Current Sense Amplifier

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TEXAS INSTRUMENTS

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.

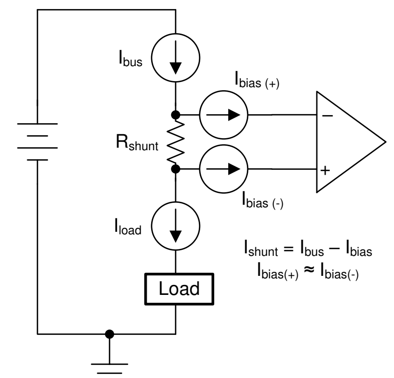

Figure 1. Simplified Current Measurement Application Using a Shunt Resistor

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 µAs of I_{bias} and offer MΩ range input impedance.

In contrast, the buffered input of an IA provides input impedance in the hundreds of GΩ 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.

$$I_{shunt} = I_{bus} - I_{bias} \tag{1}$$

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.

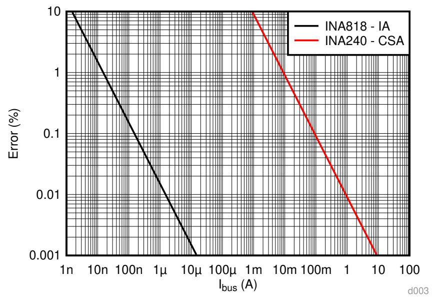

Figure 2. Percent Error due to Maximum Input Bias Current vs Supply Bus Current

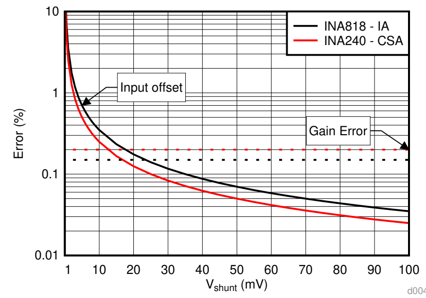

Figure 3. Percent Error due to Maximum Input Offset Voltage and Maximum Gain Error Versus Shunt Resistor Voltage

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	**INA333-Q1:** 25-µV, 0.1-µV/°C, 0.2-nA I_{bias}, 0.25% GE **INA818:** 2-MHz, 35-µV, 8-nV/√Hz, 0.15-nA I_{bias}, 0.15% GE	**INA819:** 2-MHz, 35-µV, 8-nV/√Hz, 0.15-nA I_{bias}, 0.15% GE **INA821:** 4.7-MHz, 35-µV, 7-nV/√Hz, 0.15% GE
Current sense amplifiers	**INA186:** 50-µV, 0.5-nA I_{bias}, 1% GE, –0.2 V to +40 V V_{cm} **INA185:** 55-µV, tiny package, –0.2 V to +26 V V_{cm}	**INA293-Q1:** 200-µV, 20-µA I_{bias}, 0.2% GE –4 V to +110 V V_{cm} **INA240:** 25-µV, 90-µA I_{bias}, 0.2% GE, –4 V to +80 V V_{cm}

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