Rarely Asked Questions—Issue 133
Common Sense for Current Sensing

By Gustavo Castro

Question:

I need to measure a current but I don't know which amplifier to use. Where do I start?

Answer:

The measurement of electric current is essential in a vast number of applications, including actuator control, test and measurement, sensor conditioning, and energy metering, to name a few. Depending on the application, design engineers must identify the best method to sense and condition the current flowing in a circuit.[1] The problem arises when multiple options are available. For example, in precision current measurements, it is possible to use discrete op amps to build transimpedance amplifiers or use one of many integrated amplifier options, so which amplifier is most appropriate for measuring current in a particular application?

It should be obvious that current needs to be measured in series with the circuit in question, and it should be done without burdening it. Often, a small shunt device such as a resistor results in the development of a small voltage that needs to be amplified and/or level shifted before going any further. The resistance of the shunt is relatively low to minimize its burden and, in some cases, power dissipation. In any case, it imposes the challenge of dealing with a small voltage. Moreover, the shunt may not be grounded, which means the voltage should be measured differentially and shifted down from what it could be to a level that is constantly changing. Depending on the application, the current levels may vary over many orders of magnitude from attoamps to several amperes and more. To simplify the selection process, let's review some of the options and their use cases.

Inserting a shunt on the current path (Figure 1a) and using an op amp to buffer or amplify it is perhaps the most straightforward method, but it doesn't provide any level shifting. This method can be used for low-side current sensing. Minimizing the burden voltage is simply achieved by reducing the shunt value and increasing the amplifier gain (Figure 1b), but this often comes with a noise and precision penalty. A better way to reduce the burden voltage to a minimum—especially when low currents are involved—is a transimpedance amplifier circuit (TIA), also known as a current-to-voltage converter (or I-V converter). Figure 1c shows how using a TIA is equivalent to wrapping the shunt around an op amp, with the purpose of reducing the burden voltage to virtually zero.[2] This works well as long as the current is below the op amp's output current limit, which is often in the mA range. Because of the low and constant burden voltage, TIAs are often employed to measure the current output from sensors like photodiodes with extremely accurate results. TIAs can be impractical sometimes, such as when the current we wish to measure is not on the ground-side of a load. This is the case of high-side current sensing or measuring current in a remote loop. Instrumenta-

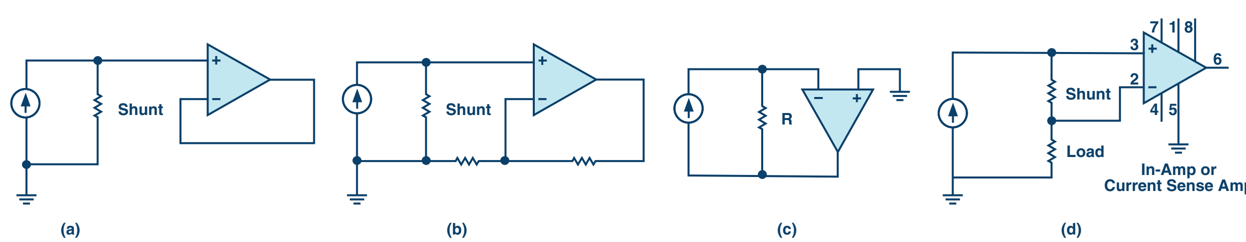

Figure 1. Current sense topologies.

tion amplifiers (in-amps) are convenient and high precision devices that can be employed here (Figure 1d). These are successfully used in many high precision current measurements, including 4 mA to 20 mA loop receivers, energy metering, and sensor interfaces, to name a few.

There are some instances in which the shunt rides on top of common-mode voltage swings that can exceed the supply range of a traditional amplifier, thus making the system too expensive (for example, it would require isolation). Unlike in-amps, difference amplifiers and current sense amplifier ICs make current measurements in the presence of large, commutating common-mode voltages. They are cost-effective and robust options that work very well in motor and actuator control.

Before you start a new current sense design, consider the options above and make sure to take a look at some of the online design tools, like the Photodiode Wizard and the Diamond Plot Tool for in-amps. The Photodiode Wizard can be also used to design a properly compensated TIA even if it is not meant to be used with a photodiode, assuming the sensor or cable capacitances are known. And the diamond plot tool can display immediate visualization of the region of operation of an in-amp based on the range of operation of the shunt. Or pay a visit to EngineerZone® to find out what others have done. I hope these options will help you figure out what makes the most sense for your current sensing application.

References

[1] Regarding the cartoon illustration, in the times of Benjamin Franklin, people didn't realize how dangerous his famous kite experiment was. A professor in St. Petersburg was killed instantly when a lightning bolt shot out of the rod into his forehead, while repeating the experiment.
Source: Camenzind, Hans. *Much Ado About Almost Nothing: Man's Encounter with the Electron.* Booklocker.com, 2007.

[2] Or almost zero, since amplifier offsets and input referred errors cannot be eliminated.

Current Sense Amplifiers. Analog Devices, Inc.

EngineerZone. Analog Devices, Inc.

Instrumentation Amplifiers. Analog Devices, Inc.

Instrumentation Amplifier Diamond Plot Tool. Analog Devices, Inc.

Photodiode Circuit Design Wizard. Analog Devices, Inc.

Gustavo Castro [gustavo.castro@analog.com] is a system applications engineer in the Linear and Precision Technology Group in Wilmington, MA. His main interests are analog and mixed-signal design for precision signal conditioning and electronic instrumentation. Prior to joining Analog Devices in 2011, he worked for 10 years designing high performance digital multimeters and precision dc sources at National Instruments. Gustavo received his B.S. degree in electronic systems from Tecnológico de Monterrey and his M.S. degree in microsystems and materials from Northeastern University. He holds three patents.

Gustavo Castro

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