HOW2POWER TODAY
Your Power Design Newsletter

Exclusive Technology Feature

ISSUE: July 2019

Sense Current Over A Wider Range For Better Battery Management

by Bonnie Baker, Maxim Integrated, Tucson, Ariz.

The liberating world of portable and mobile devices allows equipment and instruments to be used far from any wire connections. This freedom can be uplifting, at least for a while; until the battery runs low. For these battery-powered devices, internal current monitoring can prolong the battery life and can also provide predictive information to improve maintenance.

The proper way to determine the battery's discharge status is to track the current outflow to the device over time. Some say that the appropriate solution to this current-sensing challenge is to use an ultra-small resistor value in the power-supply path followed by a difference amplifier. The position of this sensing resistor is in the current path.

This appears to be an effective and appropriate solution. However, the hidden sensing resistor and following amplifier provide a somewhat restricted measurement range and require a relatively large footprint on the PCB. The situation is enough to rob users of their liberated feeling. This article examines ways to overcome this challenge with an innovative solution to the current-sensing issues. Specifically, the use of an active sensing transistor alternative in the power supply's current path, which is implemented in the MAX40016 current-sense amplifier, overcomes both of the sense resistor's limitations with a 4X increased dynamic range and 20x PCB real estate savings.

Traditional Resistive Current-Sensing System

Current flow can be a critical characteristic in portable systems. The measured values of real-time currents can provide very accurate equipment status information, such as the need for early maintenance notifications or recognition of fault conditions.

A current-sense amplifier (CSA) or current-shunt monitor is a device that senses a voltage drop across a current-sense resistor (R_{SENSE}). The buffering or gain of the voltage across R_{SENSE} appears at the output (V_{OUT}) of the CSA. Careful placement of the current-sensing resistor (R_{SENSE}) in the circuit will provide appropriate battery discharge information (Fig. 1).

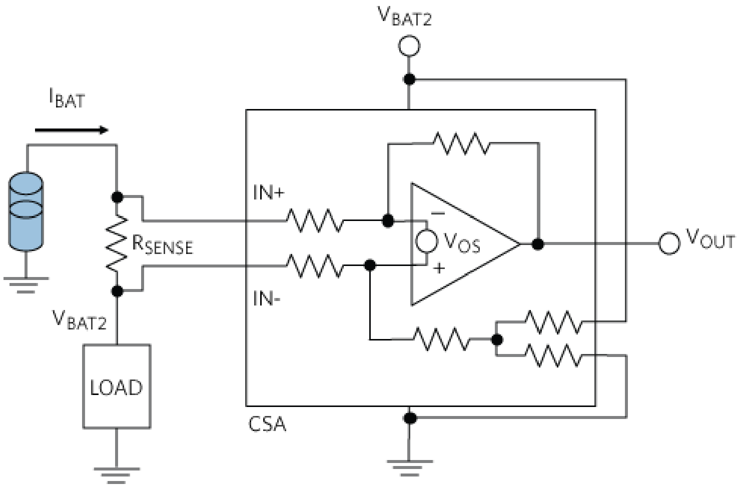

Fig. 1. Current-sense amplifiers or current-shunt monitors measure the current exiting a battery over time.

The integrated circuit in Fig. 1 is a CSA. The internal amplifier and resistor configuration in this device renders a difference amplifier function. The value of R_{SENSE} is very low in comparison to the values of the internal CSA resistors, consequently the voltage across R_{SENSE} captures the majority of the battery output current, I_{BAT}.

An appropriate device to follow the circuit in Fig. 2 is an analog-to-digital converter (ADC). The digitization of the output voltage (V_{OUT}) captures the instantaneous battery current. A downstream microcontroller can track the battery current over time to provide the battery's cumulative discharge over time—a technique sometimes referred to as coulomb counting or fuel gauging.

A Closer Look At The CSA System

The Achilles heel in the CSA system is the sense resistor's magnitude, R_{SENSE}, as determined by the maximum battery current, and the amplifier's offset voltage, V_{OS}. The first design step for the CSA circuit is to define the system's measurement range. In our example we will use a load current (I_L) range of 0.1 A to 1 A. The maximum value of R_{SENSE} equals:

$$R_{SENSE} \leq \frac{V_{OUT}/_{Gain}}{I_{LMAX}} \qquad (1)$$

where V_{OUT} is the maximum allowable CSA output swing, Gain is the CSA signal gain, and $I_{L(MAX)}$ is the maximum load current.

The magnitudes of R_{SENSE} and the maximum power dissipation ($R_{SENSE} \times I_{L(MAX)}^2$) define the physical dimensions of the resistor selected. For example, if V_{OUT} equals 5 V, the gain equals 5 and the maximum R_{SENSE} value is 1 Ω, this resistance allows an $I_{L(MAX)}$ of 1 A. With this maximum current there will be a 1-V drop between the battery and the load.

The amplifier's error values define the low-range accuracy of this system. The most significant amplifier error is the input offset voltage. The system offset-error percentage equals:

$$Offset\ Error(\%) = \frac{V_{OS} \times 100}{R_{SENSE} \times {I_{LMAX}}^2} \qquad (2)$$

where Offset Error is the CSA system offset error, V_{OS} is the amplifier's offset voltage, R_{SENSE} is the current sensing resistor, and $I_{L(MAX)}$ is the maximum load current.

The magnitude of this error impacts the accuracy of the lower-value battery currents and consequently impacts the dynamic range of the CSA system.

For example, if V_{OS} equals 1 mV, R_{SENSE} equals 1 Ω and $I_{L(MAX)}$ equals 1 A, the system offset error percentage is 10%.

Next-Generation Current-Sensing System

A dramatic step forward would be to throw away the two-decade, R_{SENSE} resistor solution altogether and replace it with a four-decade, integrated current-sensing element (Fig. 2).

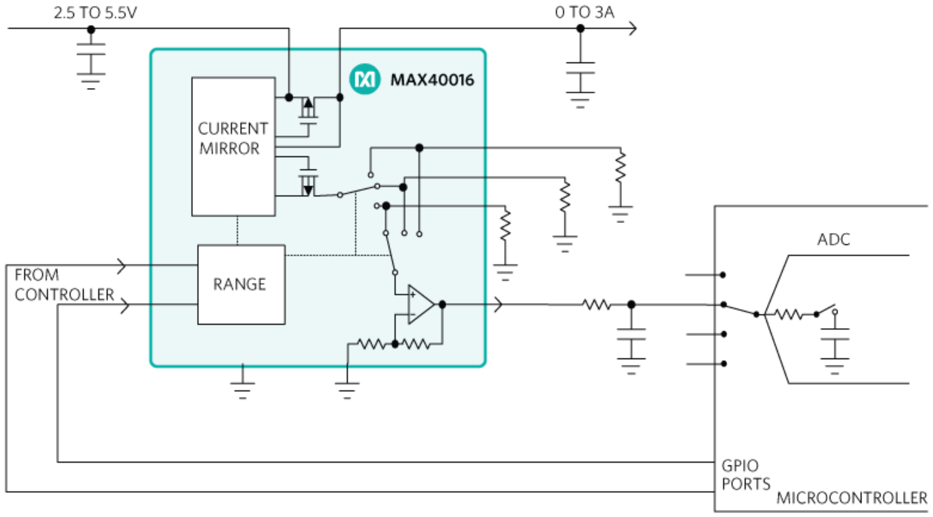

Fig. 2. Four-decade current-sensing device senses current over four decades into an ADC.

A four-decade current-sense device accepts the power-supply current, through an active on-chip transistor. The device shown in Fig. 2 (the MAX40016, see the reference) maintains accuracy from 300 µA to 3 A with a voltage drop of 35 mV to 60 mV across the transistor sensing element.

Having an integrated sense element allows factory trimming, which saves the user from having to calibrate independent CSA sense resistors. The device shown contains a four-decade current-sense element and uses external resistor(s) to select the full-scale current range. The low internal noise level of this device allows an external unipolar 10-bit to 12-bit ADC to acquire a two-decade span of data and a 12-bit to 16-bit ADC to acquire a three-decade span of data.

The integrated current-sense element in the MAX40016 saves significant board space compared to the expensive external R_{SENSE} (Fig. 3). In this figure, the combination of the CSA in a µMAX package with a 1-Ω current-sense resistor consumes ~35.6 mm^2 of PCB real estate. With a PCB area of ~1.7 mm^2, the four-decade CSA consumes 10 to 20 times less PCB real estate than the typical CSA plus R_{SENSE}.

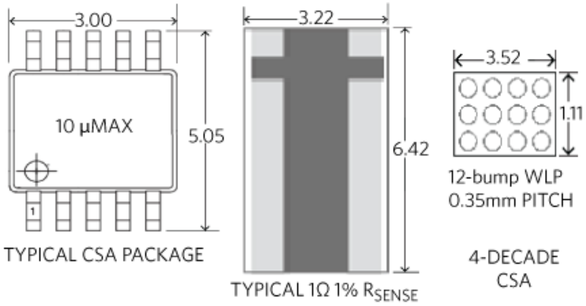

Fig. 3. The PCB real-estate consumption of the four-decade CSA compared to the typical CSA combined with an external sense resistor (R_{SENSE}).

The drift of the big 1-Ω current-sense resistor is typically very high, from 20 ppm/°C to 400 ppm/°C, with the least expensive resistors drifting the most. The resistor price increases for good initial accuracy and lower temperature drift. In contrast, the MAX40016, has higher accuracy and an overall wider range, while also providing the aforementioned space savings.

Conclusion

In the classical current-sensing circuit, designing for the sense resistor can be an unwelcome challenge. The upfront design effort is often tedious and the sensing resistor used is not only costly but consumes significant PCB area. Replacing the sensing resistor and CSA with an integrated R_{SENSE} device is a simple and liberating option. The small, compact solution we have presented saves 20 times the board space of typical solutions and provides a four-decade sensing range while maintaining accuracy from 300 µA to 3 A.

Reference

MAX40016 4-Decade Current-Sense Amplifier with Internal R_{SENSE}, MAX40016 product page.

About The Author

Bonnie Baker is an electronics engineer who has written three analog design books, starting with A Baker's Dozen: Real Analog Solutions for Digital Engineering (2005). In past roles, Burr-Brown, Microchip, Texas Instruments, and Maxim Integrated facilitated her involvement in analog design and analog systems for the last 30+ years. Bonnie holds a master's of science in electrical engineering from the University of Arizona in Tucson and a bachelor's degree in music education from Northern Arizona University in Flagstaff. In addition to her analog design fascination, Bonnie has a drive to share her knowledge and experience through the authorship of over 500 articles, design notes, and application notes.

For further reading on current sensing methods, see the How2Power Design Guide, locate the Design Area category and select "Test and Measurement".