External current sense amplifiers versus integrated onboard amplifiers for current sensing

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The requirement to measure current is common for many types of applications. Current measurements are used to improve operational system efficiency, as well as for system protection during unintended operating conditions. This measurement is common in applications such as motor control, battery charge management, power supply regulation, and in-rush current limiting for hot-swap protection. The design of the circuitry to measure this current can vary from discrete amplifiers designed specifically for current measurement to more integrated solutions where the entire current sensing function is contained within higher system-level devices.

One common example where current sensing is frequently integrated into a higher system-level device is in a battery fuel gauge. As shown in Figure 1 there are three signals that are typically measured in this application-specific device: temperature, voltage, and current. A battery monitoring device can benefit by integrating the necessary amplifiers and analog-to-digital converters (ADC) to perform these monitoring or measurement tasks all within a single functional controller. Onboard algorithms can leverage this internally measured information to create optimized tracking of battery status and health providing an overall optimized solution.

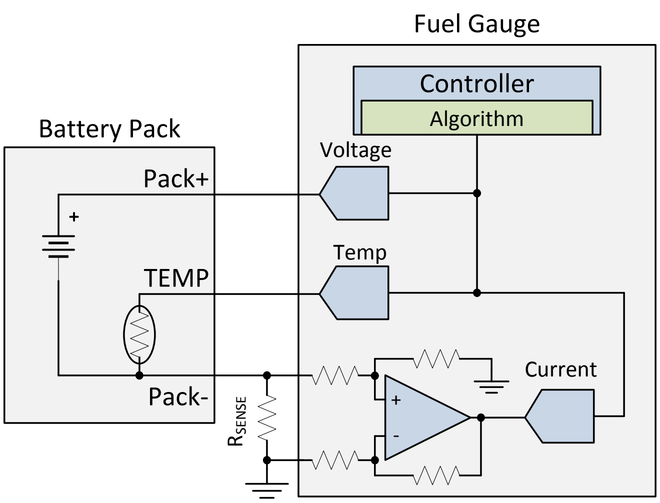

Figure 1. Battery Fuel Gauge

Integrating the measurement circuitry for these specific signals can result in a more straight-forward and reduced component count solution compared to a discrete approach using multiple individual specific-function devices. With fewer dedicated analog front-end amplifiers present to measure and amplify the small external signals, the overall solution is miniaturized, helping to support the continued form-factor reduction typical in battery-powered applications.

A gate driver for motor-drive applications is another location where a system-level controller commonly integrates operational amplifiers to perform onboard current measurements. Figure 2 shows a typical three-phase gate driver with onboard amplifiers used to measure the phase current of a motor passing the information to an external ADC.

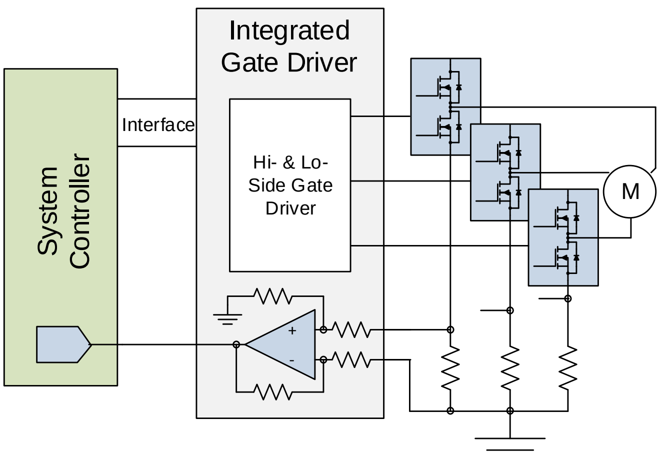

Figure 2. Gate Driver for Motor-Drive Applications

For both the battery fuel gauge and motor control gate driver, these complex devices benefit from the integration of adjacent measurement circuitry and the simplification of the overall design. However, one drawback to the integration of the current measurement circuitry for both of these functions is the limited ability to optimize the measurement accuracy. While integrating the amplifiers used to make the current measurements into the device reduces the external component count, the silicon processes that these devices are designed on are typically more optimized for power efficiencies of regulators, switching power supplies, and power transistors. These power-based silicon processes typically limit the capability of achieving high measurement accuracies from the analog circuitry built along side the power components.

The most influential parameters affecting measurement accuracy for current sense amplifiers are input offset voltage and gain error, as well as the corresponding drift over the device operating temperature range. The offset voltages for many integrated amplifiers used for current measurement typically have input offset voltages in the 3-mV to 5-mV range. For a 100-mV signal (differential voltage developed across a shunt resistor as current passes through it) a 5-mV offset creates a 5% measurement error. The maximum temperature drift of an amplifier offset voltage can be as high as 100 µV/°C. A 50° shift in temperature for an amplifier with a 100-µV/°C drift characteristic results in an additional 5 mV of offset, or an extra 5% measurement error based on the 100-mV input signal.

The mismatch in resistance values in the amplifier gain network also creates additional measurement uncertainty. Measurement errors associated with the resistive gain network are typically in the range of 2% (±1% resistors results in 2% mismatch). The temperature coefficients of these components typically range from tens of ppm/°C to hundreds of ppm/°C in additional resistor value variance. Each 200 ppm/°C resistor can vary by as much as ±1% measurement uncertainty (total extra 2% error) due to resistor drift alone with a 50° shift in temperature.

As an example, the measurement error for an integrated operational amplifier with a 5-mV input offset voltage, 100-µV/°C drift, and using 1%, 200-ppm/°C gain setting resistors with a temperature variance of 50°C is approximately 10.8% (see this video series for additional information on calculating total measurement error for current sense amplifiers). Of this measurement error, 5% is attributed to the component drift due to the change in system temperature.

For many applications, a 10% measurement accuracy is sufficient to provide a necessary level of control. For others, the system can be calibrated to remove the initial errors of the system. However, additional error will be reintroduced into the measurement as the system temperature varies. Dedicated current sense amplifiers are able to solve many of the limitations present with the amplifiers integrated into these system-level devices.

The INA199 is a current sensing amplifier capable of accurately monitoring currents on voltage rails ranging from 0 V to 26 V, while being powered off of supply voltages as low as 2.7 V, as shown in Figure 3. This device features integrated, precision-matched resistors, allowing for a maximum gain error of 1% and a 10 ppm/°C gain drift (or an additional 0.1% error over a 100° change of temperature). This device also has a 150-µV input offset voltage with a drift specification of 0.5-µV/°C (or an additional 50 µV over a 100° change of temperature). Under the same conditions, the INA199 has a maximum error of approximately 1.1%, with only 0.05% of this error attributed to the change in temperature.

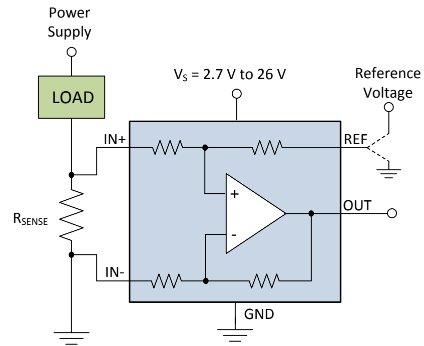

Figure 3. INA199 Current Sense Amplifier

Alternate Device Recommendations

For applications requiring higher measurement accuracy, additional devices are available. The INA210 is similar to the INA199, but with a lower input offset voltage (35 µV), and lower gain error (0.5%). The INA301 features an onboard comparator to easily allow for detection of out-of-range conditions or short-circuit events. The INA226 is a device that integrates a 16-bit ADC to provide a maximum input offset voltage of 10 µV and a maximum gain error of 0.1%.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
INA190	Highest Accuracy, Low I_Q, Low I_B, Enable	Cost
INA191	Highest Accuracy, Small WCSP package, Low I_Q, Low I_B,1.8 V Enable	Cost
INA210	High Accuracy	Slightly Higher Cost
INA301	High Accuracy, Bandwidth, Over-Limit Comparator	Package Size, Cost
INA226	Digital Interface, Highest Accuracy	Package Size, Cost

Table 2. Adjacent Tech Notes

SBOA162	Measuring current to detect out-of-range conditions
SBOA165	Precision current measurement on high voltage power rail
SBOA169	Precision, low-side current measurement
SBOA179	integrated, current sensing analog-to-digital converter