Shunt-based current-sensing solutions for BMS applications in HEVs and EVs

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Introduction

Hybrid electric vehicles (HEV) and electric vehicles (EV) continue to gain share in the overall global automotive market. The battery management system (BMS) for these vehicles carries out the important tasks of keeping the battery operating inside the safe operating area (SOA), monitoring power distribution, and keeping track of the state of charge (SoC).

In a typical HEV and EV, both high- and low-voltage subsystems are present. The high-voltage subsystem operates at several hundred volts, and interfaces directly with utility grid or high-voltage dc sources. The low-voltage subsystem generally operates at 48 V and 12 V.

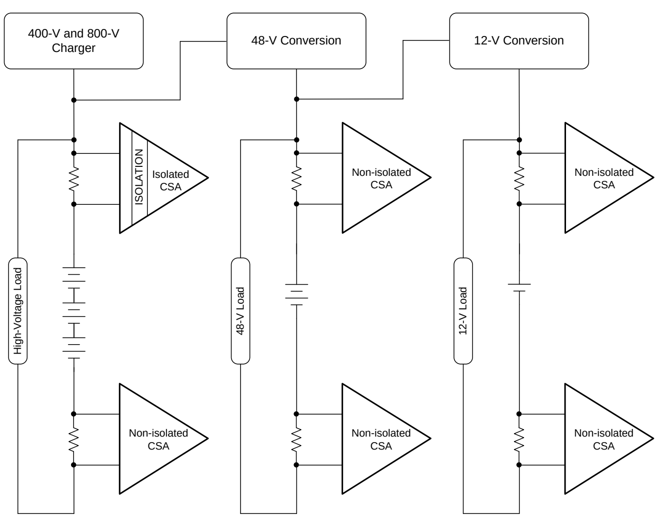

Figure 1. Topologies of Current Sensing in BMS

TI offers a variety of isolated current sensing devices that can be used in high-voltage BMS systems. Among them is the DRV425, which is fluxgate technology based. The TIPD205, *±100-A bus bar current sensor using open-loop fluxgate sensors reference design* illustrates how this design is achieved. A summary of other examples of isolated current sensing technology can be found in the *Comparing shunt- and hall-based isolated current-sensing solutions in HEV/EV application note*. Here, however, the focus is solely on a nonisolated, high-side, shunt-based current-sensing amplifier (CSA), also called a current shunt monitor (CSM), in 12-V to 48-V BMS subsystems.

Low Voltage (12-V to 48-V) BMS Current Sensing

The advantages of nonisolated shunt-based current sensing include simplicity, low cost, excellent linearity, and accuracy. On the other hand, limited common-mode range can restrict application in a high-side current-sensing configuration.

Another drawback of shunt-based current sensing is that at high-current levels, power dissipation by the shunt can potentially be significant.

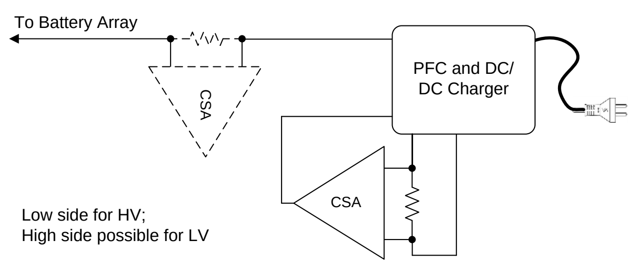

Figure 2. Current-Sensing Amplifiers in an HEV or EV Charger

Battery array is an important component of any HEV or EV. There are mainly two types of rechargeable batteries: The lead acid battery that has been around for over 100 years, and the Li-Ion battery that has only been put into practical use since the 1980s. At the time of this publication, there is a continued, tremendous research effort to introduce new types of batteries, such as aluminum air and zinc air batteries. The ultimate goal is to commercialize the next *game changer*; a battery that is safer, longer lasting, and lower maintenance with higher power density. When it comes to battery management, there are many differences between lead acid and Li-Ion batteries. However, there are also many similarities. Both types follow a certain constant voltage-constant current (CV-CI) charging profile. The CSA plays an important role in making sure the battery remains within the SOA. Charging current can be quite high, and can reach hundreds of amps. Historically, measuring this current with shunt-based topologies has been challenging. However, with the availability of ultra-low resistance shunts, the option is now viable.

On the other hand, a BMS system must monitor the power distribution as accurately as possible during normal operation in order to provide overall system health and safety information. State of charge (SoC), which is the equivalent of a fuel gauge for the battery pack in an HEV or EV, correlates to driving range. Current sensing and integration is one of the important methods to determine SoC. Even when the engine is shut off, not all onboard electronics are completely turned off. These off-state currents contribute to the overall leakage current, and there is a strong desire to have the leakage current monitored and accounted for.

Ideally, a single current-sense amplifier must monitor the entire current range, from several hundred amps down to a few amps, possibly even to milliamps. Maintaining accuracy within such a wide dynamic range is often one of the greatest challenges in designing for BMS current sensing.

Sizing the Shunt Resistor

The maximum current and power rating of the shunt resistor often determines the highest shunt value that can be used. The higher the shunt resistance, the bigger the shunt voltage, and the smaller the relative error due to system nonidealities, such as amplifier offset, gain error, and drift. However, the higher the shunt voltage, the higher the power dissipation. Excessive power dissipation causes temperature rise, which not only degrades system performance, but also can potentially be destructive when not properly controlled. On the other hand, the lowest shunt value is determined by the minimum current and accuracy of the current-sense amplifier.

As an example, suppose the CSA offset is 10 µV, while all other error sources are negligible, and the shunt resistance is 100 µΩ. Without calibration, for a 100-mA current, the reported current could be anywhere between 0 mA and 200 mA. If the shunt is changed to 1 mΩ, the same current is reported anywhere between 90 mA and 110 mA. In practice, a shunt resistor is often chosen to be between the two extreme values.

Choose the Correct Current Sense Amplifier

TI's precision, nonisolated current sense amplifiers offer a wide choice in terms of key parameters, such as common-mode voltage, bandwidth, offset, drift, and power consumption. Sensing current accurately over a wide dynamic range is a great challenge. The problem is especially acute at the lower end, where system error can easily overwhelm the useful signal. A system calibration becomes necessary in order to be able to subtract system error from the measurements.

Zero-drift current-sense amplifiers enable single-point calibration, and make such challenging designs possible by offering stable performance over temperature.

The INA240-Q1 is an excellent choice for 48-V systems because of its 80-V common-mode specification. The INA226-Q1 is a digital-output current-sense amplifier designed for up to a 36-V common-mode voltage.

The device integrates a high-performance ADC within the same chip, offering an exceptional 10-µV max offset specification. Both devices are manufactured with TI proprietary *Zero-Drift* technology, which makes single temperature calibration possible.

Table 1. Comparison Between INA240A1 and INA226

Key Specifications	INA240A1	INA226
Output	Analog Out	I^2C
Maximum V_{CM}	80 V	36 V
Minimum V_{CM}	–4 V	0 V
Supply voltage (V_S)	2.7 V to 5.5 V	2.7 V to 5.5 V
Shunt voltage (V_S= 5 V)	±125 mV	±81.9175 mV
V_{OS} at 12 V	±25 µV, max	±10 µV, max
V_{OS} drift	0.25 µV/°C	0.1 µV/°C
Gain error	0.20%	0.10%
Noise density	40 nV/√Hz	NA

Automotive Digital Output CSA Recommendations

In addition to the INA226-Q1, TI offers other digital output current, voltage, and power monitors. Some example products and adjacent technical documents are compiled in Table 2 and Table 3.

Table 2. Alternative Device Recommendations

Device	Digital Interface	Description
INA220-Q1	I^2C, SMBUS	26-V, Bidirectional, Zero-Drift, Low- or High-Side, I^2C Current/Power Monitor
INA3221-Q1	I2C, SMBUS	26-V, Triple-Channel, Bidirectional, Zero-Drift, Low- or High-Side, I^2C, Current and Voltage Monitor w/Alerts

Table 3. Adjacent Tech Notes

Literature Number	Literature Title
SBAA325	Current Sensing with INA226-Q1 in HEV/EV Low Voltage BMS Subsystems
SBOA295	High Voltage, High-Side Floating Current Sensing Circuit Using Current Output Current Sense Amplifier

Conclusion

For current sensing in HEV and EV low-voltage BMS subsystems, in addition to low-side, a high-side shunt-based solution is a viable option. *Zero-Drift* technology enables one-time calibration, which makes low-current measurement possible. Digital output devices can further simplify the design by taking advantage of the existing communication bus.

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