Application Brief

Shunt-Based Current-Sensing Solutions for BMS Applications in HEVs and EVs

Guang Zhou and Dan Harmon

BMS Topologies and Current Measurement Methodologies

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 inside the safe operating area (SOA), monitoring power distribution, and tracking 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.

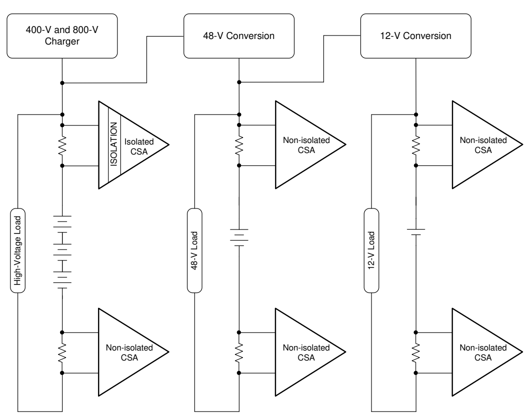

Figure 1. Topologies of Current Sensing in BMS

High-voltage battery, top-of-stack measurements require an isolated solution. Magnetic solutions enable the require isolation, but typically will not be able to support the full current range. TI offers isolated shunt-based current sensing solutions, such as the AMC3301-Q1. 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 brief. Isolation is not typically required for top-of-the-stack 48-V or 12-V battery systems nor in bottom-of-the-stack implementations.

The focus in this document is on non-isolated, shunt-based current-sensing amplifiers (CSA), also called current shunt monitors (CSM), and digital power monitors (DPM) for bottom-of-stack or top-of-stack in 12-V to 48-V BMS subsystems. The advantages of non-isolated shunt-based current sensing include simplicity, low cost, excellent linearity, and accuracy. A drawback of shunt-based current sensing is the power dissipation requirements for the shunt resistor at the maximum current levels.

Current Sense 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. Both lead acid and Li-Ion batteries follow a certain constant voltage-constant current charging profile. The CSA plays an important role in making sure the battery remains within the SOA.

Operational current for the traction inverter and charging current can be greater than 1000 A in many systems. However, these BMS systems must also be able to measure currents equal to or less than 1 A when the vehicle is off as many systems continue to function such as keyless entry or vehicle-to-world communications. BMS systems must monitor the power distribution as accurately as possible during both operation and vehicle off-state 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 is one of the important methods to determine SoC. In addition to the precision monitoring of the battery, most automotive BMS systems will require a redundant measurement with relaxed accuracy requirements to enable system level functional safety goals.

The extreme difference between the traction motor current (>1000 A) and the off-vehicle communications current (<1 A) creates a multi-decade, high-precision, bidirectional (charging versus vehicle operation) current measurement challenge.

Sizing the Shunt Resistor

Historically, measuring the high current with shunt-based topologies has been challenging. However, with the availability of ultra-low resistance shunts, the option is now viable. A typical analog current sense amplifier will have a fixed gain between 20 V/V and 200 V/V and operate from a 5-V supply. This 5-V supply determines the maximum output voltage (ignoring swing to supply limitations), and when we divide by the two gain extremes, we get a full-scale input voltage range of 250 mV to 25 mV. Assuming a bidirectional maximum current measurement of ±1000 A, we can calculate a maximum shunt value of 125 µΩ to 12.5 µΩ. As discussed in the TI Precision Labs - Current sense amplifiers videos, the amplifier offset will dominate the offset error at the low current range. If we use the ultra-precise INA240-Q1 with an offset of 25 µV, we get an error of 20% and 200% respectively on the two shunt resistors. Table 1 summarizes these calculations along with the power dissipation across these shunts at 1000 A.

Table 1. INA240-Q1 Shunt Resistor Value, Offset Error, and Power Dissipation Calculations for ±1000-A BMS Application

GAIN OPTION	INA240A1: 20 V/V	INA240A4: 200 V/V
Full scale input	250 mV	25 mV
Maximum shunt	125 µΩ	12.5 µΩ
Offset error at 1 A	20%	200%
P_{DIS} at 1000 A	125 W	12.5 W

Solving the Multi-Decade Challenge

This is where an ultra-precise, low-offset solution is required. TI's DPMs are specialized analog-to-digital converters (ADC) dedicated to measuring current. Most can also monitor bus voltage and can calculate the power as well. The full-scale input range is scaled down from that of a typical ADC to accommodate the typical small signal voltage drop across a shunt resistor. The INA229-Q1 (SPI Interface) and INA228-Q1 (I^2C interface) are 20-bit DPMs with V_{OFFSET} = 1 µV and a ±163.84-mV full-scale input range. Having a defined full-scale input range makes calculating the maximum shunt resistor value fairly straight forward, simply divide the full-scale input by the maximum current: 163.84 mV ÷ 1000 A = 163.84 µΩ. A more commonly available 100-µΩ shunt resistor is used to calculate a 1% error at 1 A.

The final error check is to verify that the integrated ADC is capable of resolving a signal level less than the offset error level. The INA228-Q1 and INA229-Q1 feature a 20-bit delta-sigma converter with one bit being the sign bit. Dividing the full-scale input of 163.84 mV by 19 bits of resolution results in 312.5 nV per least significant bit (LSB). This corresponds to 3.1 mA on a 100-µΩ shunt resistor, well below the target minimum current level of 1 A.

If even lower current levels are needed to be accurately measured, system calibration may become necessary. *Zero-drift* devices enable single-point calibration, and make such challenging designs possible by offering stable performance over temperature.

For current sensing in HEV and EV BMS subsystems, the INA229-Q1 or INA228-Q1 are excellent choices for any bottom-of-stack implementations or top-of-stack implementations in 48-V or 12-V systems with an 85-V common-mode specification and ultra-low offset of ±1 µV. The industry standard digital interface can further simplify the design by taking advantage of an existing communication bus. The INA240-Q1 with its 80-V common mode voltage range could be used in 48-V system top-of-stack measurements for either the redundancy implementation or in applications requiring less total dynamic range. All three devices are manufactured with TI proprietary *Zero-Drift* technology, which enable single temperature calibration, if needed, to address lower current accuracy.

Automotive Device Recommendations

In addition to the INA229-Q1 and INA228-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
INA239-Q1	SPI	85-V, Bidirectional, *Zero-Drift,* 16-Bit, Low- or High-Side, SPI Current/Voltage/ Power Monitor
INA238-Q1	I^2C, SMBUS	85-V, Bidirectional, *Zero-Drift,* 16-Bit, Low- or High-Side, I^2C Current/Voltage/ Power Monitor
INA226-Q1	I^2C, SMBUS	36-V, Bidirectional, *Zero-Drift,* 16-Bit, Low- or High-Side, I^2C Current/Voltage/ Power Monitor

Table 3. Adjacent Tech Notes

LITERATURE NUMBER	LITERATURE TITLE
SBAA325	Current Sensing With INA226-Q1 in HEV/EV Low Voltage BMS Subsystems
SBOA170	Integrated, Current Sensing Analog-to-Digital Converter

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