

Isolated Shunt-Based Current Sensing in High-Current HEV/EV Subsystems



Introduction

Global market for Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) is rapidly growing as these vehicles offer higher fuel-efficiency and lower emissions compared to gasoline or diesel vehicles and use power from renewable energy sources. To control energy flow and optimize efficiency in HEV/EV powertrain subsystems such as Traction Inverters, On-Board Chargers (OBC), DC-DC converters, and Battery Management Systems (BMS), precise and accurate current measurement is essential. These high-voltage subsystems need to measure large currents at high common-mode voltages. For technical and regulatory reasons, the current measurements require isolation as well as very high performance in harsh automotive environments.

Different Isolated Current Measurement Methods

Each HEV/EV application has different cost, accuracy, signal bandwidth, latency, measurement range, isolation ratings, and package size requirements. There are several isolated current measurements methods. However, the primary methods used in HEV/EV subsystems are either shunt-based (Figure 1) or hall-based (Figure 2).

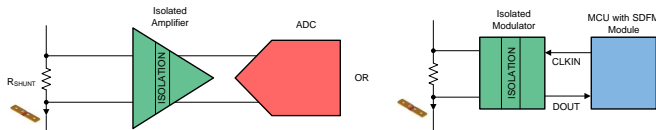


Figure 1. Shunt-Based - Uses Isolated Amplifier or Modulator to Measure the Voltage Drop Across the Shunt Resistor

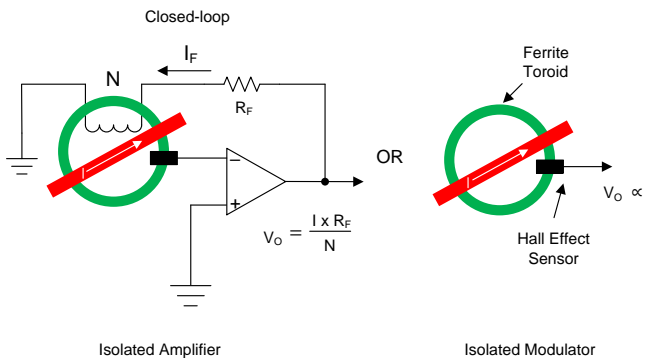


Figure 2. Hall-Based - Uses a Hall-Sensor (Closed-loop or Open-Loop) to Measure the Magnetic Field Generated by the Conductor Carrying Current

Comparison of Shunt- and Hall-Based Methods

Historically, designers preferred shunt-based solutions for low-current (<50 A), and hall-based solutions for high-current (>50 A) measurements. However, because of the increasing current measurement accuracy requirements, automotive suppliers are migrating from hall-based to shunt-based methods, especially in high-current environments. There is even a trend amongst automotive suppliers to move from isolated amplifier based to isolated modulator based solutions to further improve measurement accuracy.

Texas Instruments offers best-in-class **isolated amplifiers** and **isolated modulators** that help achieve very accurate isolated current measurements over temperature when paired with high-precision shunts. Table 1 below shows the basic differences between shunt- and hall-based isolated current sensing solutions in high-current automotive environments.

Table 1. Difference Between Shunt- and Hall-Based Isolated Current Sensing

Category	Shunt-based	Hall-based
Solution Size	similar	similar
Offset	very low	medium
Offset Drift over Temperature	low	medium
Accuracy	<0.5% after calibration	2-5% after calibration
Noise	very low	high
Bandwidth	similar	similar
Latency	similar	similar
Non-Linearity	very low	high
Long-term Stability	very high	medium
Cost	similar	similar
Vibration Impact	very low	low
Power Dissipation	low	very low
Customization	flexible	limited

Analysis of Shunt- and Hall-Based Methods

- Hall-sensors are inherently isolated, which allows a single-module approach. On the other hand, shunt-based solutions require an isolated amplifier or modulator, and an isolated power-supply for the high common-mode voltage side.
- Shunt-based solutions have very low initial offset, have lower offset drift over temperature and are less susceptible to external magnetic fields.
- Shunt-based solutions are linear over the entire

voltage range compared to hall-based solutions which are non-linear, especially at zero crossing and near the magnetic core saturation region.

- Shunt-based solutions achieve better DC accuracy over temperature compared to hall-based solutions with basic one-time calibration. This is particularly true at low currents where they have significantly better DC accuracy because of its limited sensitivity to external magnetic fields.
- The voltage drop across the in-line shunt results in thermal dissipation and power loss. However, with improvements in shunt technology, the shunts have become lighter, the ohmic values have decreased and the accuracy and drift performance have improved. The use of low-value ohmic shunts results in less thermal dissipation. Additionally, Texas Instruments' isolated amplifiers and modulators support very small input voltage ranges (± 50 mV and ± 250 mV) with a superior overall accuracy. This allows systems to have lesser thermal dissipation without compromising the overall measurement accuracy.
- Hall-based sensors generally have a limited operating temperature range, typically from -40°C to $+85^{\circ}\text{C}$, whereas shunt-based solutions can support higher operating temperature ranges, typically from -40°C to $+125^{\circ}\text{C}$.
- Both hall-based and shunt-based isolated amplifier solutions offer similar signal bandwidth, typically up to few hundred kilohertz (kHz). However, isolated modulators provide a high-speed bit-stream output that allows the user to implement and customize digital filtering externally. This allows the user to develop high signal bandwidth and low latency solutions.

Isolated Shunt-Based Current Sensing in Traction Inverters

A traction inverter controls the electric motor and is a key component in the HEV/EV drivetrain. A traction inverter requires accurate current sensing at high common mode voltages. Current measurements in traction inverters can therefore be realized using one of two shunt-based methods.

As shown in Figure 3, the voltage drop across the shunt on the hot (high common-mode voltage) side is isolated from the cold side with an automotive grade, reinforced isolated amplifier such as AMC1301-Q1.

Figure 4 shows the second shunt-based measurement method that uses an automotive-grade, reinforced isolated modulator such as AMC1305M25-Q1 to isolate the voltage drop across the shunt on the hot side from the cold side.

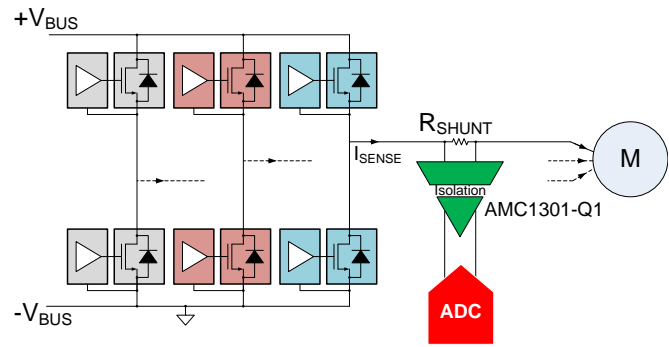


Figure 3. Isolated Current Measurement Using Isolated Amplifiers

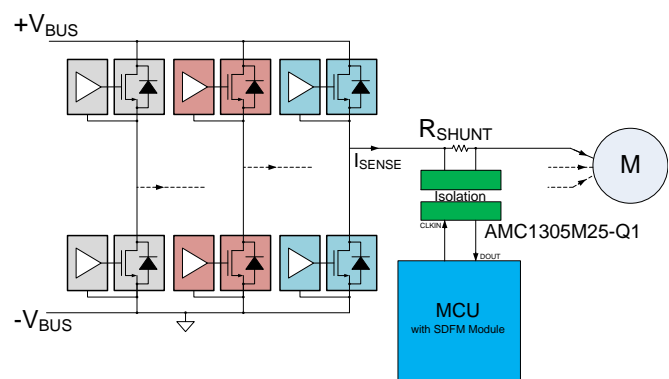


Figure 4. Isolated Current Measurement Using Isolated Modulators

For improved measurement accuracy, use an isolated modulator as this solution eliminates an additional analog-to-digital conversion stage and the subsequent errors associated with it. The high-speed bit-stream output from isolated modulators is filtered by microcontrollers (MCUs) such as TI's C2000 family that have a built-in sigma-delta filter module (SDFM) or by an FPGA. This allows the user to fine-tune signal bandwidth and accuracy.

Automotive Isolated Device Recommendations

Device	Isolation	Description
AMC1305-Q1	Reinforced	$\pm 50/250$ mV Isolated Modulator
AMC1301-Q1	Reinforced	± 250 mV Isolated Amplifier
AMC1200-Q1	Basic	± 250 mV Isolated Amplifier

Conclusion

Multiple measurement methods exist for isolated current sensing in HEV/EV subsystems including shunt-based and hall-based methods. With advancements in affordable high-precision shunts and high-performance isolated amplifiers and modulators, shunt-based solutions have become good alternatives to traditional hall-based solutions.

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