Electronic Design

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Precise Coreless Current Sensing Optimizes Traction-Inverter Torque Control

Sponsored by Texas Instruments: A multi-axial coreless approach to Hall-effect current sensing opens the door to a compact, high-frequency GaN/SiC switching solution.

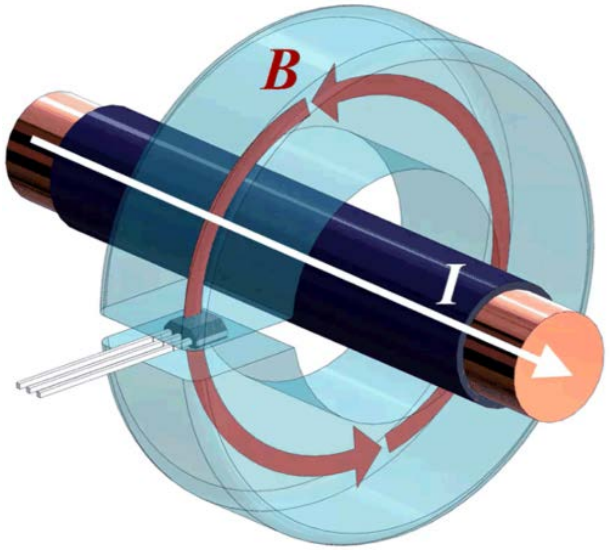
As automakers bring new electric and hybrid-electric vehicles to market, they look to reduce the size and weight to improve efficiency and driving range. In addition, they want to provide precise traction-inverter control to minimize torque ripple, vibration, uneven acceleration, and unwanted noise. Accurate traction-motor phase-current measurement is essential to meeting these goals.

Core vs. Coreless

Traditionally, engineers have measured traction-motor phase current using a C-core implementation, in which a Hall-effect sensor is placed in the air gap of a magnetic core surrounding each conductor *(Fig. 1)*.

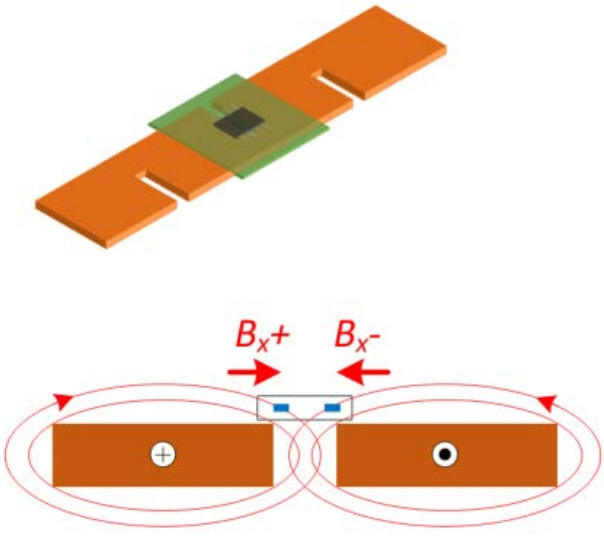
The C-core, however, has several drawbacks. It's subject to saturation, for example, and eddy-current losses can prevent the devices from operating at the high d*i*/d*t* levels required for high-frequency silicon-carbide (SiC) and gallium-nitride (GaN) devices. The core can also exhibit unfavorable hysteresis because of mismatched magnetic paths during current rise and fall times, and zero-offset drift can occur because of residual magnetization after current surges. In addition, air-gap variation and mismatched mounting tolerances can lead to poor assembly consistency. Finally, cores require a large footprint and are heavy.

Consequently, designers have shifted to coreless measurement systems. Such an approach eliminates the magnetic core and mounts the Hall-effect sensor on a circuit board adjacent to the busbar. But, if not properly designed, a coreless implementation may introduce issues related to phase-to-phase crosstalk as well as displacement errors due to vibration and offset errors caused by external magnetic fields.



1. Traditionally, a Hall-effect sensor in the gap of a magnetic core surrounding a conductor has measured current in each phase of a traction-motor.

To minimize these errors, chip designers can integrate multiple sensor elements in differential configurations, but these configurations often require busbar modifications to match the sensing elements' placement within the integrated device. A horizontal differential configuration, for instance, requires that notches be cut in the busbar to establish the magnetic-field orientation necessary to measure horizonal



2. The coreless Hall-effect horizontal differential configuration requires that notches be cut in the busbar to establish the proper magnetic-field orientation.

(*x*-axis) magnetic fields B_X^+ and B_X^- in the positive and negative directions, respectively *(Fig. 2)*.

Multi-Axial Current Sensing

To optimize accuracy while eliminating the need for busbar modification, Texas Instruments offers the TMCS2100-Q1 programmable, coreless, high-precision, Hall-effect current-sensing device. *Figure 3* shows six devices mounted on a PCB over a three-phase busbar, with two devices per phase. No busbar modifications are necessary. TI recommends that the busbars be spaced more than 5 mm apart and that the distance from each device to the busbar be 3 mm to 11 mm to optimize the signal-to-noise ratio.

The device's multi-sensor architecture measures horizontal and vertical magnetic fields. Thus, it provides sufficient information for a proprietary algorithm to suppress crosstalk while limiting vibration error to less than 1% for movements up to 0.4 mm in any direction or as low as 0.25% at 0.1 mm of movement. TI reports that the device is roughly 20X more accurate than single-axis coreless alternatives.

Multi-Axial Sensor Details

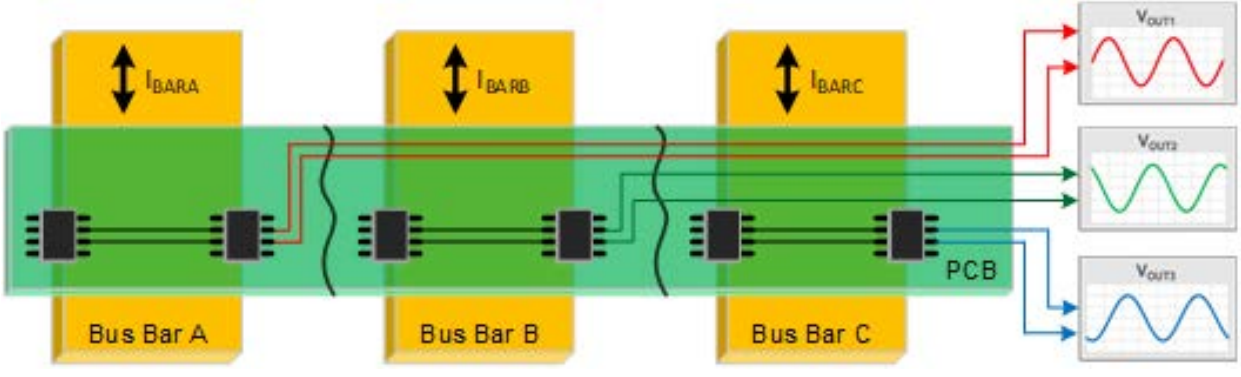
TI designed the TMCS2100-Q1 specifically for high-voltage, high-current, multiphase systems. Features include a programmable gain, fully differential output, 250-kHz bandwidth, 2.6-µs response time, 0.7-µs propagation delay, and 500-ns overcurrent-detection response time.

The device supports active frequency compensation to minimize eddy-current-induced amplitude errors. After characterization, the device minimizes phase-to-phase magnetic crosstalk errors and keeps measurement errors below 0.5% at full-scale current ranges that can exceed 1,000 A.

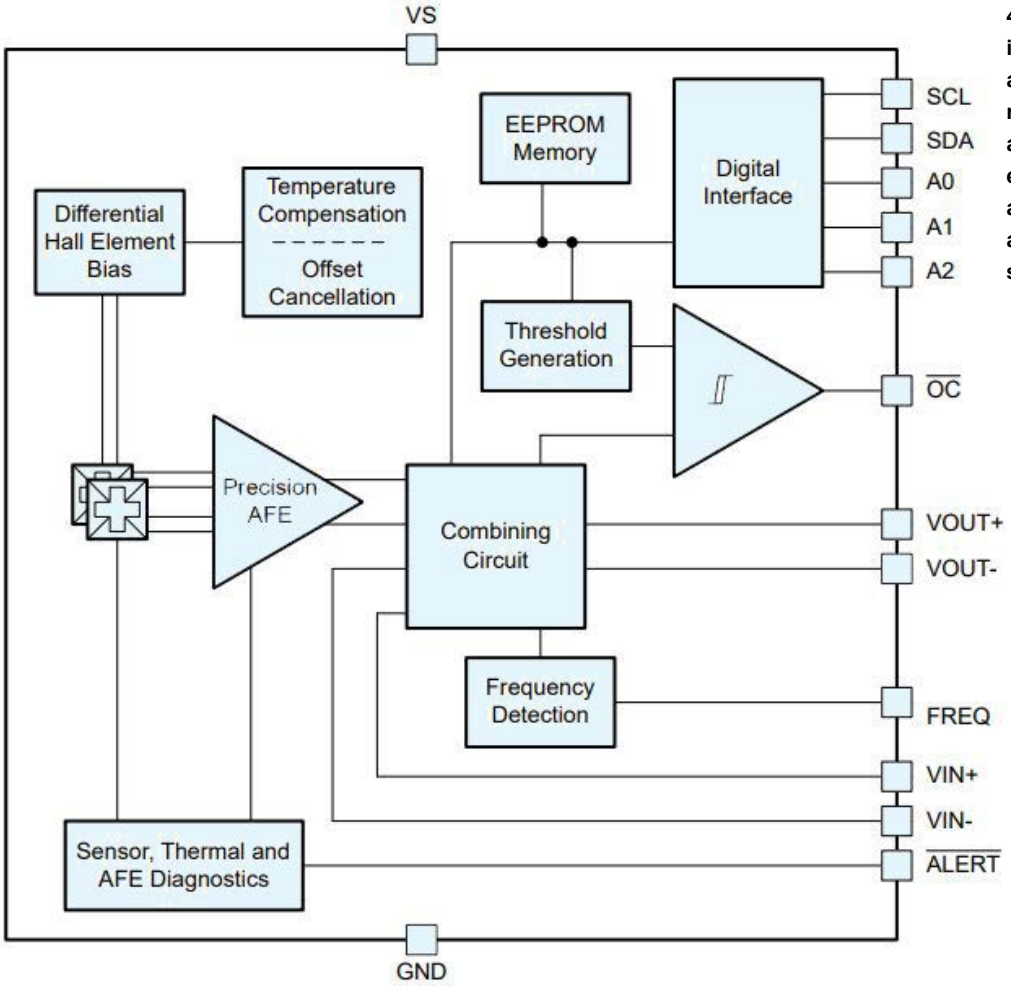
Figure 4 shows a block diagram of the device, available in a 14-pin thin-shrink small-outline package (TSSOP). In addition to the power-supply and ground pins, the device includes, from the top right, an I2C clock input, a bidirectional I2C serial-data pin, three I2C address pins, an overcurrent signal, the differential output signals, a frequency indicator, differential voltage input signals, and a diagnostic alert signal.

The TMCS2100-Q1 comes in three magnetic-field ranges: ±10.6 to ±84.4 mT, ±5.3 to ±42.2 mT, and ±2.6 to ±21.2 mT. It's AEC-Q100 qualified for automotive applications, and TI classifies the device as "functional safety-capable."

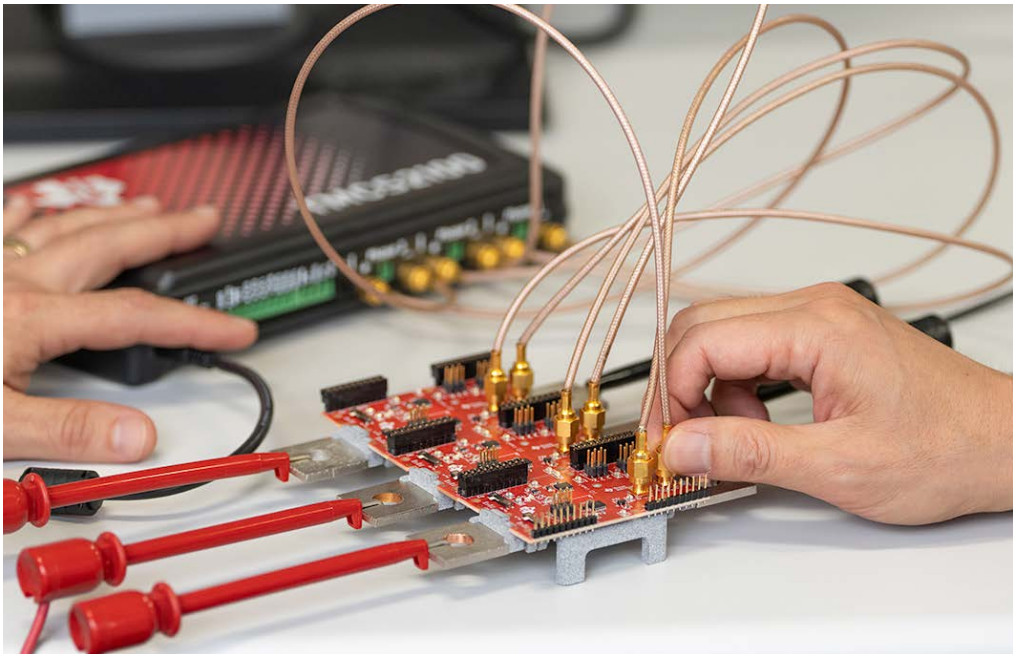
To facilitate functional-safety-compliant system design, the company can provide documentation regarding the device's functional-safety failure-in-time (FIT) rates, component failure modes and distribution (FMD), and pin failure-mode analysis (FMA) in accordance with the ISO 26262 international automotive functional-safety standard and other relevant standards.



3. Six TMCS2100-Q1 programmable, coreless, high-precision, Hall-effect current-sensing devices can accurately measure three-phase currents.



4. The TMCS2100-Q1 includes serial clock and data lines, overcurrent and diagnostic alert signals, differential voltage input and output pins, and a frequency-detection signal.



5. A designer uses TMCS2100EVM and TMCS2100CHA-REVM boards to evaluate and characterize TMCS2100 devices in a three-phase current-measurement setup.

To help you get started with TMCS2100-Q1 designs, TI offers the TMCS2100EVM evaluation module *(Fig. 5)*, which includes headers that provide convenient access to device pins, switches to address individual devices on the board, and a nickel-plated busbar that facilitates connection to a test current source.

You can add the TMCS2100CHAREVM characterization module to characterize the magnetic environment of your measurement setup as well as calculate the coefficients that can be uploaded to each device used within the same magnetic environment. Subsequently, at end-of-line production, a quick and simple gain and offset calibration will compensate for assembly variations and individual device tolerances.

Conclusion

TI's TMCS2100-Q1 multi-axial Hall-effect current-sensing device can measure horizontal and vertical magnetic fields simultaneously to minimize crosstalk and movement error. The coreless device enables a compact, lightweight measurement solution that fits easily within the confines of an EV traction inverter.

The company offers an evaluation board that helps you get started on successful TMCS2100-Q1 projects. Furthermore, an additional board helps characterize your magnetic environment and develop the coefficients that you can upload to each device.