Application Brief

Low-Drift, Precision, In-Line Isolated Magnetic Motor Current Measurements

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The demand for higher efficiency systems continues to increase, leading to direct pressure for improvement in motor operating efficiency and control. This focus applies to nearly all classes of electric motors, including those used in:

- White goods
- Industrial drives
- Automation
- Automotive applications

This is especially true in higher-power systems with elevated operating voltages. Operational characteristics of the motor that is fed back into the control algorithm are critical to make sure the motor is operating at peak efficiency and performance. Phase current is one of these critical diagnostic feedback elements used by the system controller to enable designed for motor performance.

Due to the continuity of the measurement signal and direct correlation to the phase currents, Figure 1 shows a location to measure the motor current is directly in-line with each phase. Measuring current in other locations, such as the low-side of each phase, requires recombination and processing before meaningful data can be used by the control algorithm.

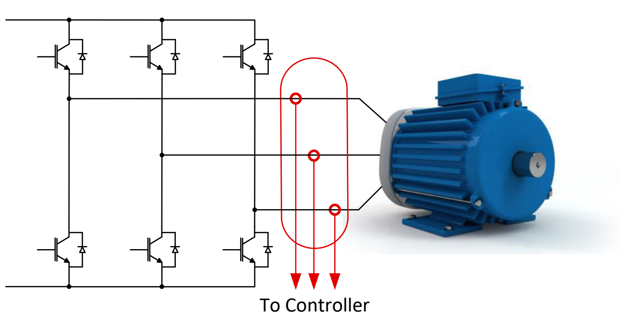

Figure 1. In-Line Current Sensing

The drive circuitry for the motor generates pulse width modulated (PWM) signals to control the operation of the motor. These modulated signals subject the measurement circuitry placed in-line with each motor phase to large voltage transients that switch between the positive and negative power rails every cycle. A current sensor has the ability to completely reject the common-mode voltage component of the measurement, and only measure the current of interest. In-package magnetic current sensors like the TMCS1123 or TMCS1100 pass the phase current through a package leadframe, which creates an internal magnetic field. A galvanically isolated sensor then measures the magnetic field, providing a measurement of the current without any direct electrical connection between the sensor IC and the isolated phase current. By measuring only the magnetic field, the sensor provides isolation to high common-mode voltages, as well as excellent immunity to PWM switching transients. This results in excellent motor phase current measurements without unwanted disturbances at the sensor output due to large, PWM-driven input voltage steps. Figure 2 illustrates an RC-filtered TMCS1100 output waveform, along with the motor phase voltage and current waveforms. Only minor PWM-coupling due to measurement parasitics are observable, and the TMCS1100 output tracks the motor phase current with no significant output transients due to the 300-V switching events.

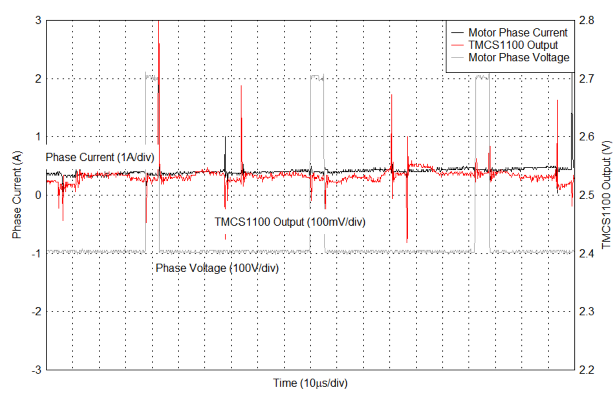

Figure 2. Motor Phase Current Measurement with High Transient Immunity

The unique characteristics of an in-package magnetic current sensor eliminate many of the challenges faced by alternative designs for measuring motor phase currents. The inherent galvanic isolation provides capability to withstand high voltage, and the high transient immunity of the output reduces output noise due to switching events. Current sensing implementations without this immunity require higher bandwidth to improve output glitch settling time; a magnetic sensor can use a lower-bandwidth signal chain without sacrificing transient immunity performance. In-package magnetic current sensors also provide a reduction in total design cost and design complexity due to no requirement for external resistive shunts, passive filtering, or isolated power supplies relative to the high voltage input.

For applications where phase current measurements provide over-current protection or diagnostics, the high transient rejection of a magnetic current sensor prevents false overcurrent indications due to output glitches. In motor systems where closed loop motor control algorithms are used, precise phase current measurements are required to optimize motor performance. Historically, Hall-based current sensors have suffered from large temperature, lifetime, and hysteresis errors that degrade motor efficiency, dynamic response, and cause errors such as torque ripple. Common system-level calibration techniques can improve accuracy at room temperature, but accounting for temperature drift in parameters, such as sensitivity and offset, is challenging.

Magnetic current sensing products from Texas Instruments improve system-level performance by incorporating patented linearization techniques and zero-drift architectures that provide stable, precise current measurements across temperature. A high-precision sensor tightly controls phase-to-phase current measurement errors, maintaining accurate feedback control and delivering a seamless user experience.

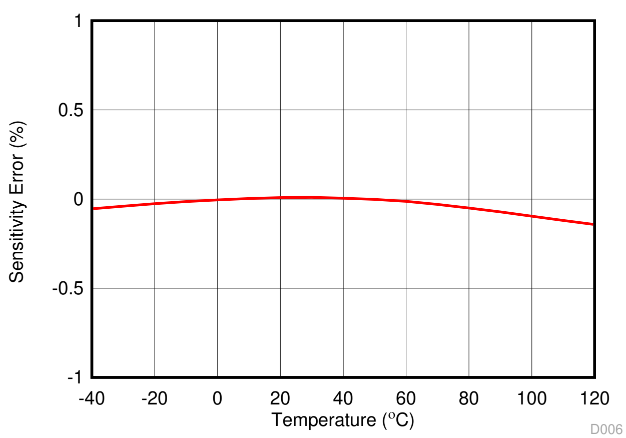

Figure 3. TMCS1100 Typical Sensitivity Error Across Temperature

The TMCS1100 features less than 0.3% typical sensitivity error at room temperature, and less than 0.85% maximum sensitivity error across the entire temperature range from –40°C to 125°C. This stability across temperature, shown in Figure 3, provides excellent phase-to-phase matching by minimizing the temperature drift of the sensor. In addition to high-sensitivity accuracy, the device has less than 2 mV of output offset drift, shown in Figure 4, which greatly improves measurement dynamic range, and allows for precise feedback control even at light loads.

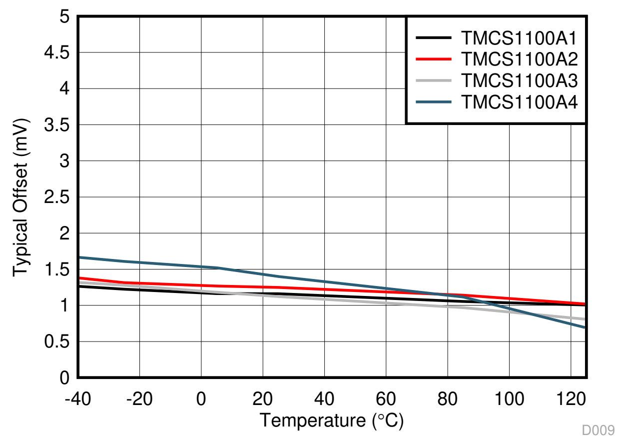

Figure 4. TMCS1100 Typical Output Offset Across Temperature

Combining high-sensitivity stability and a low offset results in an industry-leading isolated current sensing design with < 1% total error across the full temperature range of the device. A 600-V working voltage and 3 kV isolation barrier allows the device to fit into a wide array of high voltage systems. Combining measurement temperature stability, galvanic isolation, and transient PWM input rejection, the TMCS1100 is designed for PWM-driven applications, such as motor phase current measurements, where accurate and reliable measurements are required for precisely controlled performance.

Table 1. Alternate Device Recommendations

Device	Optimized Parameter	Performance Trade-Off
TMCS1123	Ambient Field Rejection, 75 A_{RMS} at 25C, and 1.1-kV reinforced isolation	Lower precision, PSRR
TMCS1101	Magnetic Current Sensor with Internal Reference	Lower precision, PSRR
AMC1300	Reinforced Isolation Shunt Amplifier	Design size, complexity
INA241	Precision Shunt Amplifier with PWM Rejection	110-V operation

Table 2. Related TI Application Briefs

Lit #	Title
SBOA340	*Ratiometric Versus Non-Ratiometric Magnetic Signal Chains*
SBOA160	*Low-Drift, Precision, In-Line Motor Current Measurements With PWM Rejection*
SBOA161	*Low-Drift, Low-Side Current Measurements for Three-Phase Systems*
SBOA163	*High-Side Motor Current Monitoring for Over-Current Protection*

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