Application Note

Optimizing Low-Side Current Sensing with DRV8376: Mitigating Gain Error and Temperature Drift

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ABSTRACT

The DRV8376, a three-phase motor driver with integrated low-side current-sense amplifiers, enables efficient current monitoring for BLDC motor applications, supporting overcurrent protection, torque control, and commutation. However, gain error and temperature drift can reduce measurement accuracy, affecting motor performance. This application note examines the DRV8376's current-sense amplifier architecture and error sources, proposing practical calibration methods, including room-temperature, multi-temperature, self-calibration, and software-based compensation, to verify precision across a wide temperature range.This application note offers engineers straightforward strategies to optimize current sensing with the DRV8376.

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1 Introduction

The DRV8376 provides a gate drive and power stage for driving a 4.5V to 65V brushless-DC motors. The DRV8376 integrates three 1/2-H bridges with 70V absolute maximum capability and a very low RDS(ON) of 400mΩ (high-side plus low-side) to enable high power drive capability. Current is sensed using an integrated current sensing feature eliminating the need for external sense resistors. Power management features with integrated LDO generate the necessary voltage rails for the device and can be used to power external circuits. DRV8376 implements a 6x or 3x PWM control scheme which can be used to implement sensored or sensorless field-oriented control (FOC), sinusoidal control, or trapezoid control using an external microcontroller. The DRV8376 is capable of driving a PWM frequency up to 100kHz. The control scheme is highly configurable through hardware pins or register settings ranging from motor current limiting behavior to fault response.

The DRV8376 integrates three, high-performance low-side current sense amplifiers for current measurements using built-in current sensing. Low-side current measurements are commonly used to implement overcurrent protection, external torque control, or brushless-DC commutation with an external controller. All three amplifiers can be used to sense the current in each of the half-bridge legs (low-side FETs). The current sense amplifiers include features such as programmable gain and external reference is provided on a voltage reference pin (VREF).

2 Advantages and Challenges of Low-Side Current Sensing with DRV8376

Low-side current sensing, as implemented in the DRV8376 integrated current-sense amplifier (CSAs), is a widely adopted approach for monitoring phase currents in brushless DC (BLDC) motor drives. This configuration uses an integrated sense FET based method, offering distinct advantages for cost-sensitive and high-performance motor control applications. However, the application is also susceptible to specific error sources, notably gain error and temperature drift, which must be addressed to verify precision. This section outlines the key benefits of low-side sensing with the DRV8376 and the challenges that require careful calibration methods.

2.1 Advantages of Low Side Current Sensing

2.1.1 Low Common Mode Voltage

In low-side sensing, the voltage across the sense element is near ground potential, resulting in a low common-mode voltage (typically < 1V). This eliminates the need for high common-mode rejection ratio (CMRR) amplifiers, which are essential in high-side sensing where common-mode voltages can reach the motor supply (for example, 24V or 48V). The DRV837x's internal CSAs are optimized for this low common-mode environment, enabling the use of simpler, lower-cost amplifier designs with high accuracy, as the SOx outputs (V_SOx = I_SENSE × G_CSA + VREF/2) are referenced to a stable VREF pin.

2.1.2 Cost Effectiveness

Low-side current sensing is inherently economical, as this eliminates the need for high-voltage, isolated sensing components required in high-side configurations. The integrated sense FET of the DRV8376 further reduces costs by removing the requirement for external shunt resistors, which can range from $0.50 to $2.00 for precision, low temperature options. This integration simplifies the bill of materials (BOM) and reduces PCB space, making the DRV8376 an attractive choice for cost-sensitive applications such as consumer appliances or entry-level automotive systems.

2.2 Challenges of Low side Current Sensing

Despite advantages, low-side current sensing is susceptible to error sources that can degrade measurement accuracy, particularly in precision BLDC motor control applications. The primary challenges are gain error and temperature drift, which directly impact the ability of the device to deliver reliable current measurements for torque control, overcurrent protection, and commutation

2.2.1 Gain Error

Gain error arises from mismatches in the internal gain-setting resistors of the DRV8376 and mismatch between the power stage FET and senseFET. For example, a 1% mismatch in the gain network of the CSA (for example, G_CSA = 0.4V/A) can introduce a corresponding 1% error in the SOx output voltage, affecting current measurement accuracy. In motor drives, this error can lead to imprecise torque control or incorrect commutation timing, reducing efficiency and performance.

2.2.2 Temperature Drift

Temperature variations exacerbate gain error through the temperature coefficient of the internal gain network of the CSA (typically 20ppm/°C) and external components, such as PCB traces or shunt resistors (50–200ppm/°C). Over the operating range of -40°C to +150°C of the DRV8376, even a low temperature coefficient can result in noticeable drift. For instance, a 20ppm/°C drift over a 100°C range causes a 0.2% gain error, which can translate to measurable errors in the SOx output, impacting system reliability in harsh environments such as automotive or industrial settings.

3 DRV8376 Current Sense Amplifier (CSA) Architecture

DRV8376 implements a senseFET based low side current sense architecture for the current sense amplifier (CSA) with adaptive offset calibration to mitigate the errors associated with offset error of the final stage amplifier. Figure below shows the simplified block diagram of the CSA.

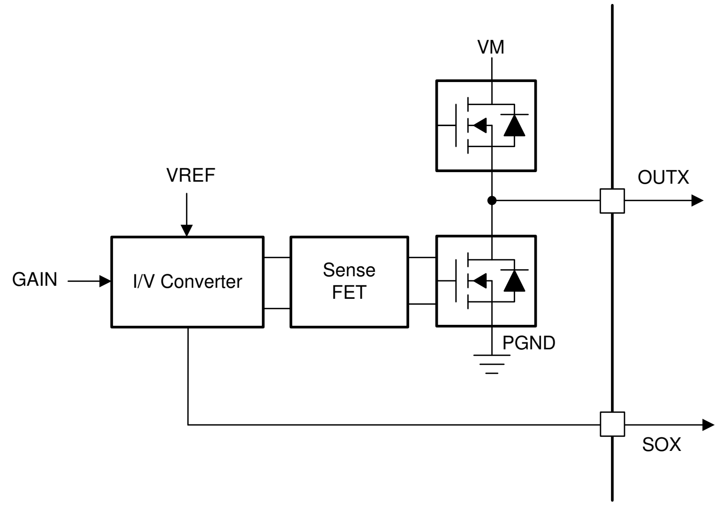

Figure 3-1. Current Sense Amplifier Architecture

The SOx pin on the DRV8376 outputs an analog voltage proportional to the current flowing in the low-side FETs multiplied by the gain setting (G_{CSA}). The gain setting is adjustable between four different levels which can be set by the GAIN pin (in the hardware device variant) or the GAIN bits (in the SPI device variant).The current sense is implemented with the sense FET on each low-side FET of the DRV8376 device. This current information is fed to the internal I/V converter, which generates the CSA output voltage on the SOx pin based on the voltage on the VREF pin and the Gain setting. The CSA output voltage can be calculated as:

$$SOX = \left({}^{V_{REF}}/_{2}\right) \pm GAIN \times I_{OUTX} \tag{1}$$

3.1 Gain Error vs Temperature

Gain error refers to the deviation of the actual gain from the nominal gain value, often influenced by temperature variations. In the context of a three-phase motor driver such as the DRV8376, gain typically exhibits a linear dependence across a temperature range of -40°C to +125°C, impacting the accuracy of current sense amplifiers or PWM outputs. Figure 3-2 shows the gain error of DRV8376 at two different motor voltages 24V and 48V respectively.

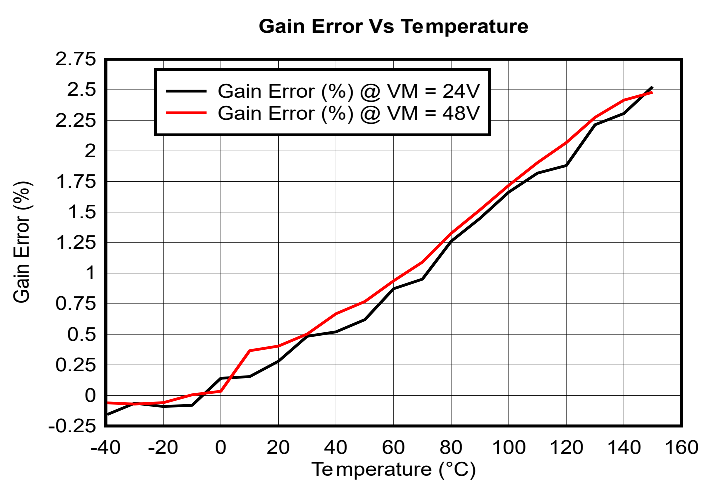

Figure 3-2. Uncalibrated Gain Error

3.2 Calibration Methods

The following calibration methods can be used to address gain errors in the DRV8376. Room temperature calibration measures the gain error of the DRV8376 current-sense amplifiers at a single temperature, typically 25°C, and applies a fixed correction factor to adjust the measured gain to the nominal value, but this approach fails to account for temperature-induced drift, resulting in errors at -40°C and +125°C. Multitemperature calibration collects gain error measurements at multiple temperatures, such as -40°C, 25°C, and 125°C, to fit a linear model y = mx+c to the gain error data, correcting the measured gain by normalizing gain error to the nominal gain, achieving near-zero errors across the temperature range. Software-based compensation scheme to store pre-calibrated parameters (slope (m), intercept (c)) in firmware, applying real-time corrections to the measured gain using the formula.

$$G_c\left(T\right) = {G_m(T)}\Big/{1 + \frac{(m^*T\ +\ c)}{100}} \quad (2)$$

The method fits the gain error data to the linear model:

$$G(T) = G0 \cdot (1 + \alpha \cdot (T - T0)) \quad (3)$$

to

$$E(T) = m \cdot T + c \quad (4)$$

1. E(T): Gain error (%).
2. m : Slope (%/°C).
3. c : Intercept (%)

The method assumes the measured gain is:

$$Gmeasured(T) = Gnominal \cdot (1 + E(T)/100) \quad (5)$$

Calibration corrects the gain to the nominal value:

$$Gcorrected(T) = Gmeasured(T)1 + (m \cdot T + c)/100 \quad (6)$$

The corrected gain error is:

$$\text{Ecorrected}\left(\text{T}\right) = \frac{\text{Gcorrected(T)} - \text{Gnominal}}{\text{Gnominal}} {*}100 \quad (7)$$

Figure 3-3 shows the calibrated gain error of DRV8376 at 24V and 48V supplies using the previous methods.

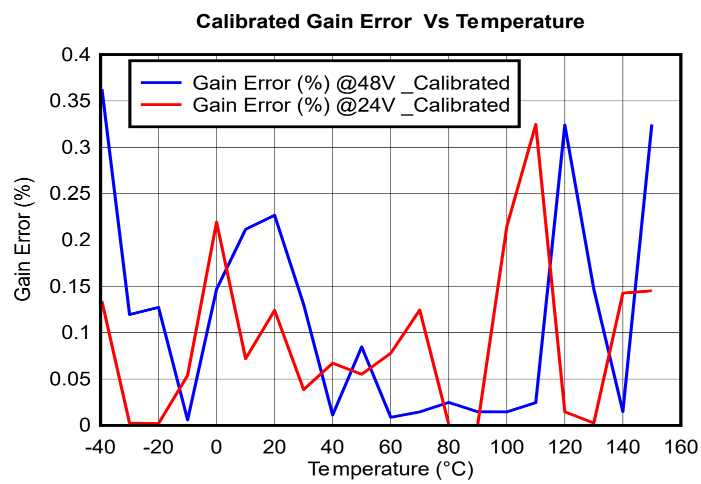

Figure 3-3. Calibrated Gain Error

4 Summary

The DRV8376 integrated low-side current-sense amplifiers provide a design for precise current monitoring in BLDC motor applications, enabling robust overcurrent protection, torque control, and commutation. By addressing challenges such as gain error and temperature drift through calibration methods such as room-temperature, multi-temperature, self-calibration, and software-based compensation, engineers can achieve high measurement accuracy across a wide temperature range. The senseFET-based architecture, combined with adaptive offset calibration and programmable gain, enhances performance while reducing BOM costs and PCB space. Implementing the recommended firmware and PCB layout strategies is designed for operation in demanding environments such as automotive and industrial systems. This application note equips engineers with practical tools to maximize the potential of the DRV8376 for precision motor control applications.

5 References

- Texas Instruments, *DRV8376 Three-Phase Integrated FET Motor Driver*, data sheet.

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