Current sense chain accuracy
for the MC20XS4200 dual 24 V high-side switch family

1 Introduction

This application note discusses MC20SX4200 current sense accuracy and covers the corresponding cost reduction opportunities that MC20XS4200 current sense features make possible. The application note also addresses the consistent behavior of MC20XS4200 current sense across the device's voltage and temperature range—a feature that enables efficient single-point calibration.

The MC20XS4200 is an intelligent high-side switch designed for use in 24 V systems such as trucks, busses, and special engines. The device also supports various industrial and 12 V applications. The low $R_{DS(on)}$ channels provide a means of controlling incandescent lamps, LEDs, solenoids, or DC motors. A 16-bit SPI interface offers easy integration into existing applications for control, device configuration, and diagnostics purposes. For a complete feature description, refer to the MC20XS4200 data sheet.

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2 Current sense introduction

The MC20XS4200 eXtreme power switch for 24 V applications provides two current sense ratios that support a range of low-current to high-current applications. The MC20XS4200 current sense is highly accurate by design. In addition, the device also offers features that allow you to enhance current sense accuracy and reduce cost across the current measurement chain.

The following sections review the MC20XS4200 current sense features and discuss the cost reduction and integration opportunities they present.

3 The measurement chain—key factors impacting overall accuracy

Each element in the measurement chain has its own level of accuracy. The accuracy of each of these elements impacts the overall accuracy of the chain. The worst-case accuracy for the measurement chain is the sum of each individual element's worst-case accuracy.

Figure 1 shows a typical measurement chain for a given range of load currents. Notice that the drawing illustrates a basic measurement chain. In practice, some chains may include operational amplifiers and filters, depending on the application.
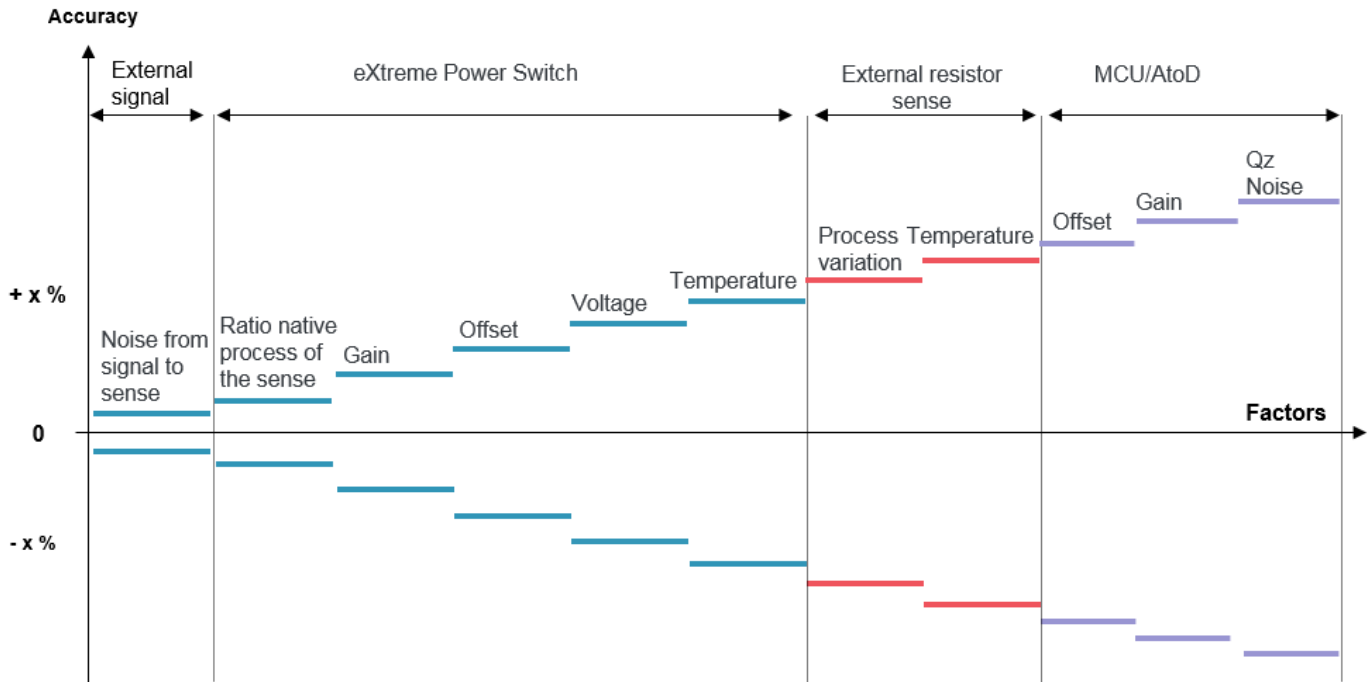

Figure 1. Measurement chain

4 The measurement chain—improving overall accuracy

Random offset refers to an inherent variability in the semiconductor fabrication process that causes key parameters to differ slightly from part to part. Random offset variations are sporadic by nature but can be influenced by supply voltage and device temperature. NXP's eXtreme switches provide a feature that compensates for the affects of random offset.

When activated, the compensation feature factors in random offsets in temperature and voltage, thereby yielding greater accuracy across the measurement chain.
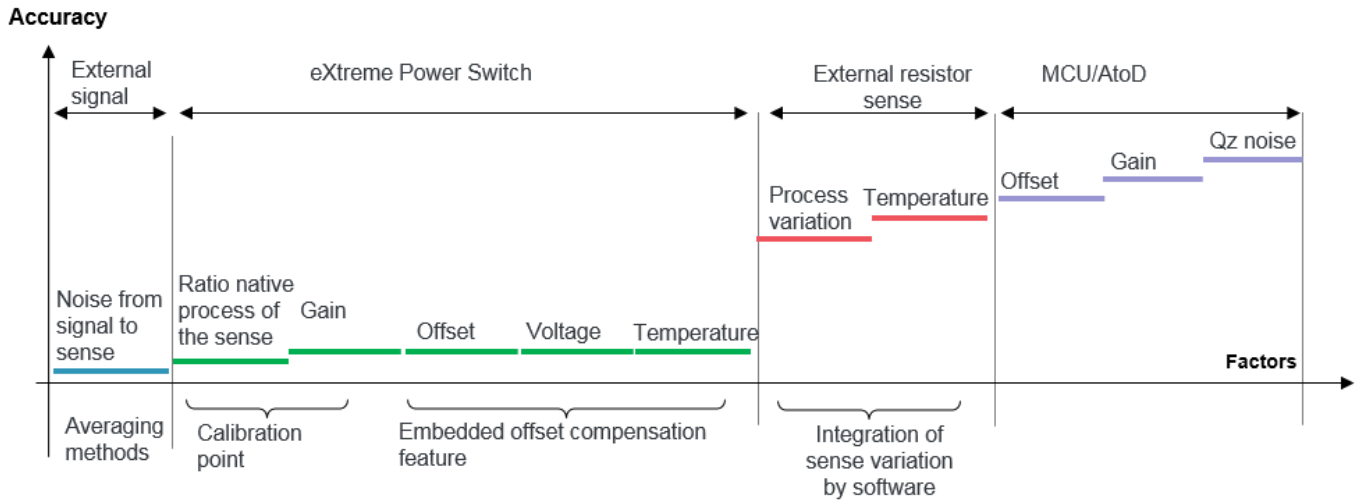
Figure 2. Addressing current sense accuracy

5   Reducing BOM cost with eXtreme switches

Figure 3 shows the external sense accuracy of a regular power switch with no compensation or calibration applied. The sense must be as accurate as possible to eliminate any impact on the current measurement chain.
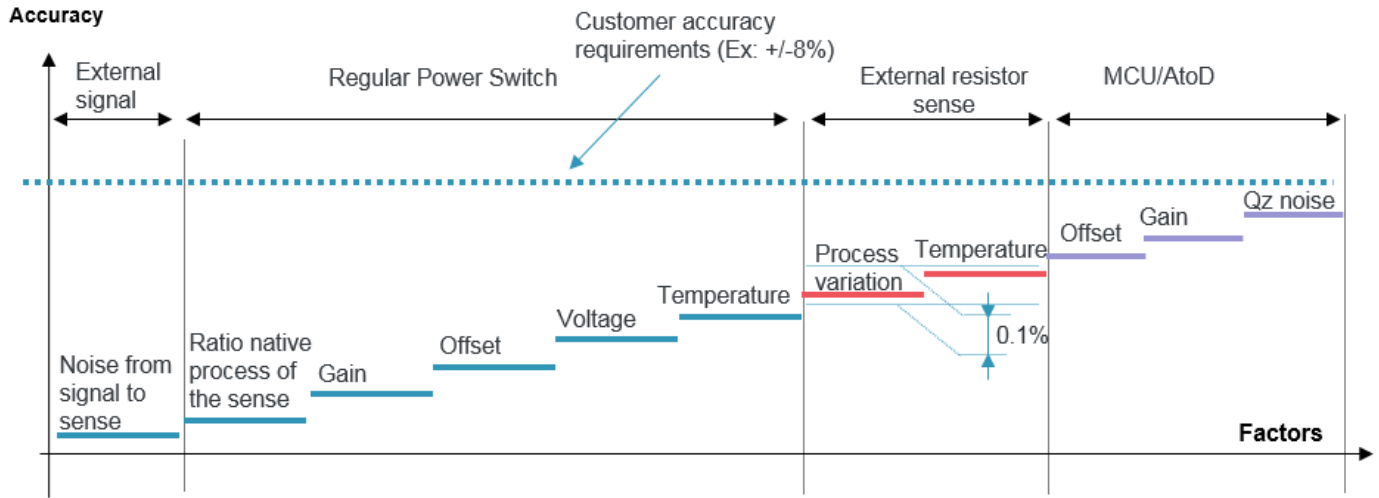

Figure 3. External sense accuracy with no compensation or calibration

Figure 4 shows the external sense accuracy of an MC20XS4200 device (20 mΩ.) The maximum accuracy is ±5.5% using the compensation feature. (Calibration was not performed, in this example.)

For applications requiring ±8% for the measurement chain, use higher valued resistors (<1%.)
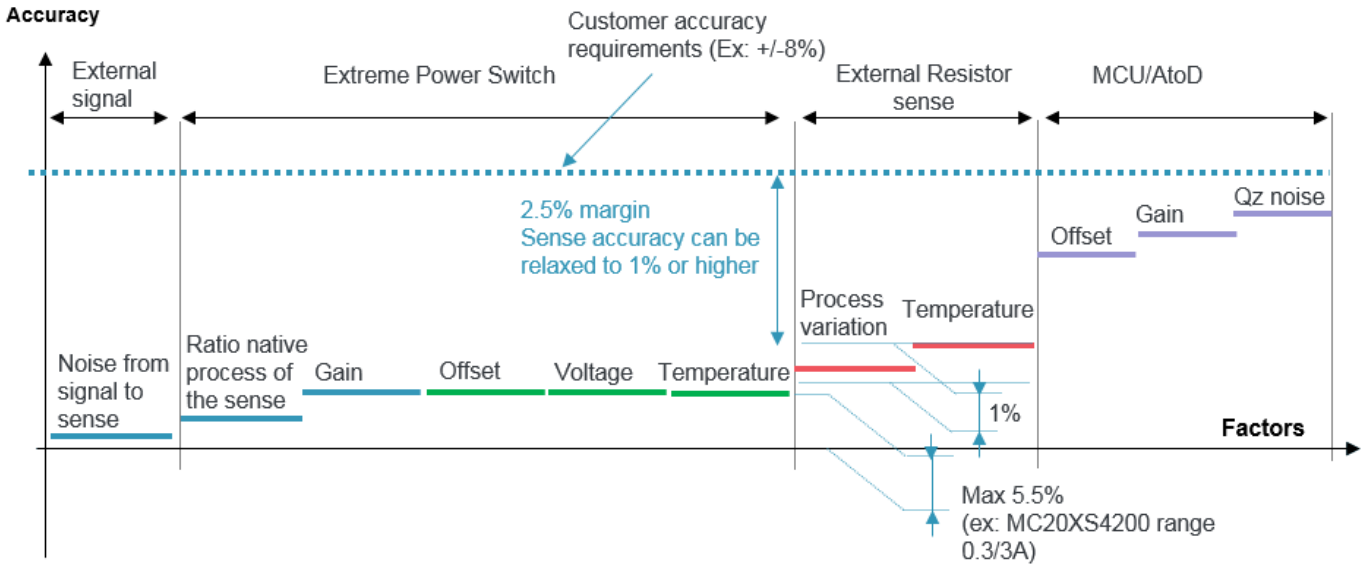

Figure 4. External sense accuracy with MC20XS4200

6 MC20XS4200 current sense accuracies with compensation over a range of temperatures and supply voltages

6.1 MC20XS4200 current sense accuracy +125 °C

Figure 5 and Figure 6 show the current sense accuracy of an MC20XS4200 with the compensation feature activated, but with no calibration applied. At 125 °C, accuracy remains at ±5.5% across the supply voltage range. Below 0.75 A, change the current sense mode from high current mode (CSNS=0) to low current mode (CSNS=1) to assure that accuracy remains in the ±5.5% range.

In Figure 5, the bar graph to the right of the chart illustrates the expected distribution for accuracy within the defined limits (Average = ±3 σ.) This distribution applies under all conditions (voltage or temperature and current sense ratio.)
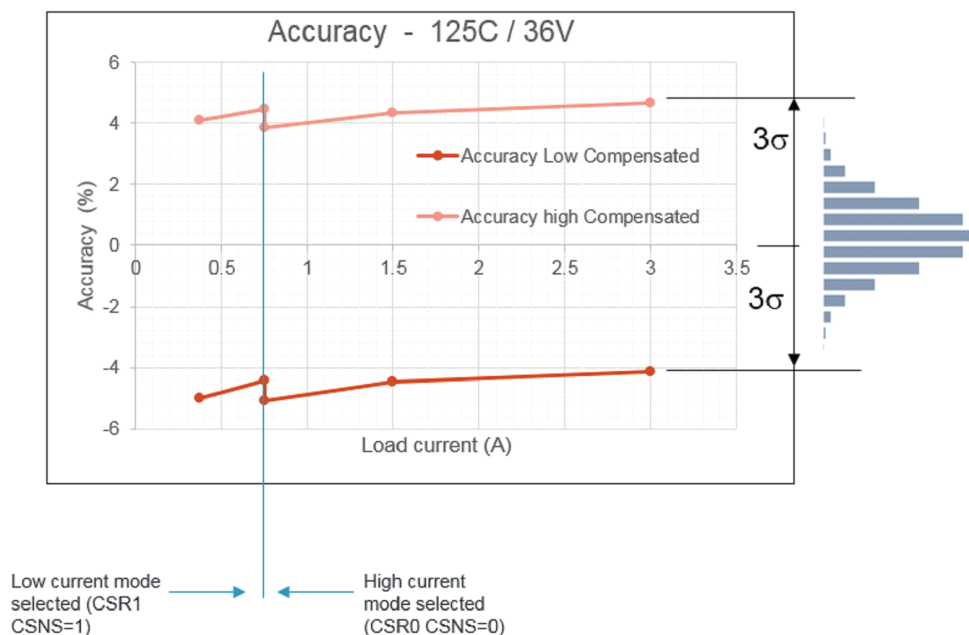

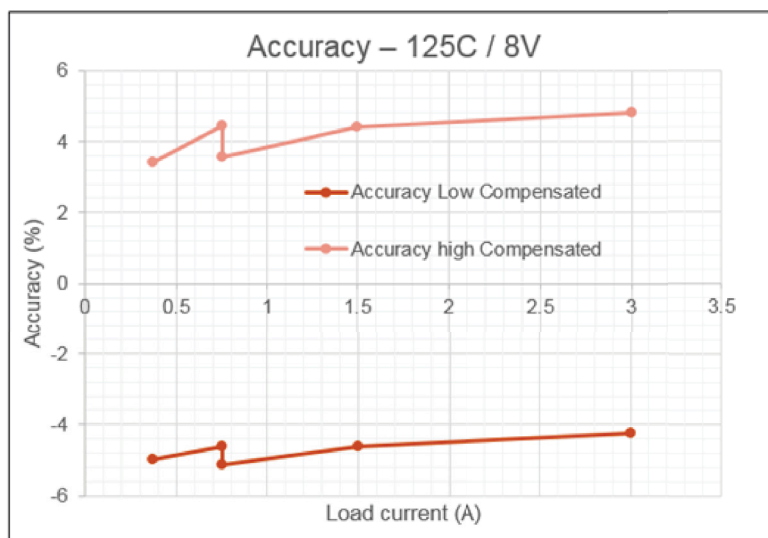Figure 5. MC20XS4200 current sense accuracy—125 °C / 36 V

Figure 6. MC20XS4200 current sense accuracy—125 °C / 8 V

6.2   MC20XS4200 current sense accuracy -40 °C

At -40 °C, current sense accuracy remains within ±5.5% across the supply voltage range. Below 0.75 A, change the current sense mode from high current mode (CSNS=0) to low current mode (CSNS=1) to assure that accuracy remains in the ±5.5% range.

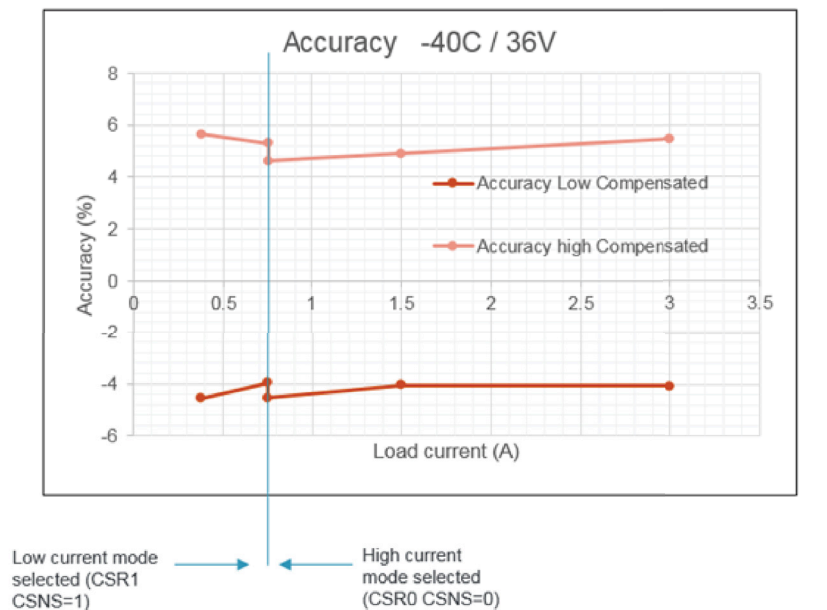Figure 7 and Figure 8 illustrate the current sense accuracy at -40 °C.

Figure 7. MC20XS4200 current sense accuracy at –40 °C / 36 V
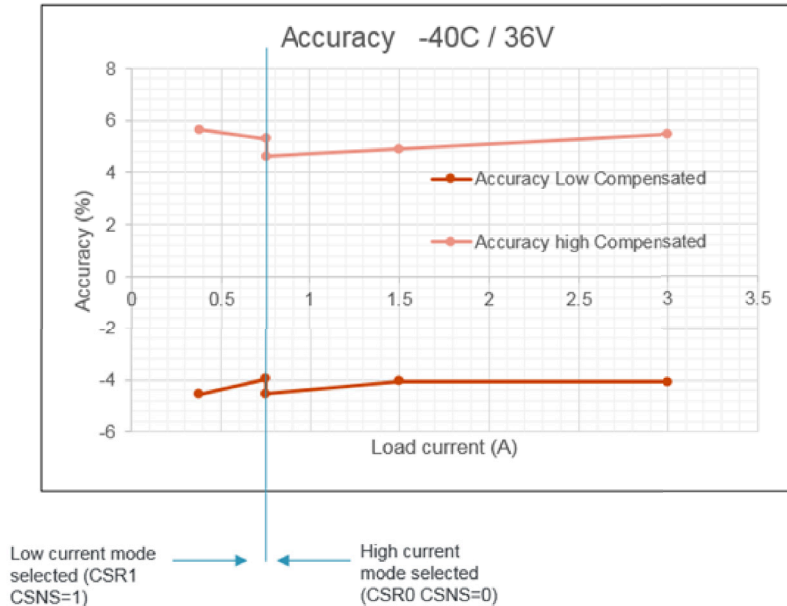
Figure 8. MC20XS4200 current sense accuracy at –40 °C / 8 V

7   Current sense operation

The MC20SX4200 has two load current sensing modes: synchronous mode and track & hold mode.

In synchronous mode, the load current is duplicated at the current sense pin and is therefore synchronous with it. However, after Turn-OFF, the current sense pin does not retain the load current value. In track & hold mode, the current sense pin retains the load current value present at Turn-OFF.

Synchronous mode is activated by setting the T_H_en bit to 0; Track & Hold mode is activated by setting the T_H_en bit to 1

To synchronize current sensing with an external process, connect the SYNC signal to the digital input of an external MCU. SYNC is asserted logic low when the current sense signal is accurate and ready to be read.

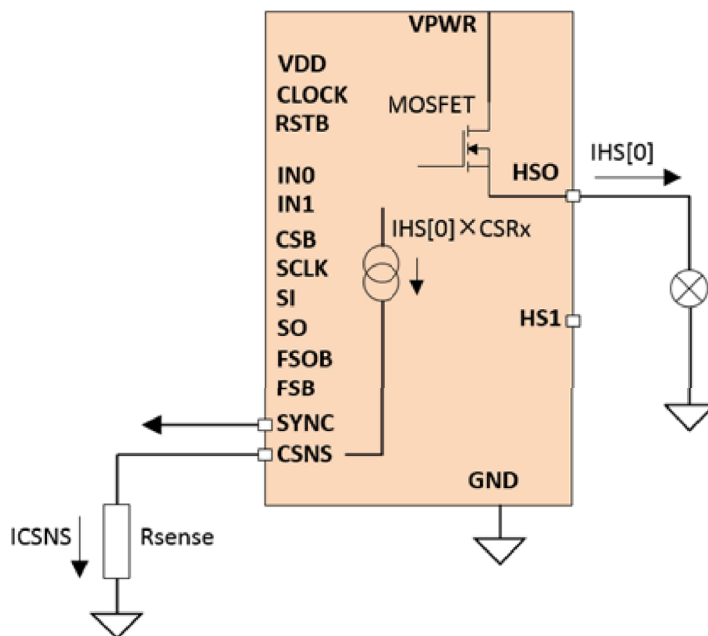Note: Refer to the MC20XS4200 data sheet for timing information.

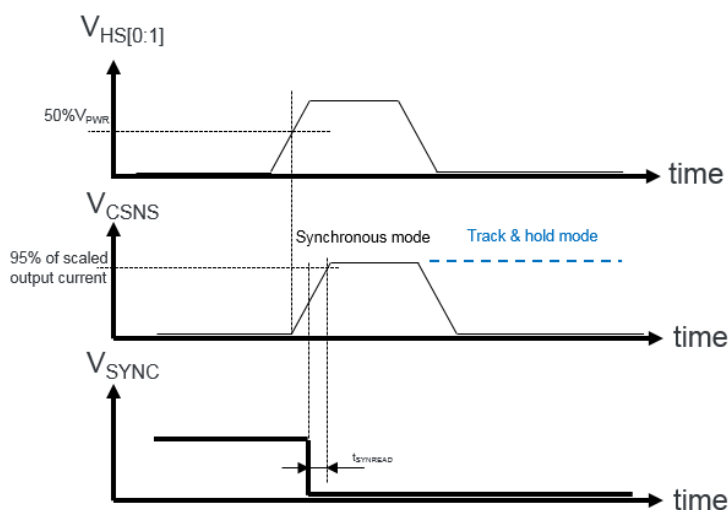**Figure 9. Current sense connections**

Figure 10. Synchronous and track-and-hold current sensing modes: associated delay and settling times

7.1 Current sense definition and errors

7.1.1 Current sense ratio selection

The CSNS_ratio bit in the OCR register selects the sense ratio of the load current at the CSNS pin. For optimal accuracy at low current levels, select the lower current sensing ratio (CSR1).

7.1.2 Current sensing errors

$$I_{CSNS} = (I_{HSx} + I_{LOAD\_ERR\_SYS} + I_{LOAD\_ERR\_RAND}) \times C_{SRX}$$

where:

I_{HSx}	=	current in the load
$I_{LOAD\_ERR\_SYS}$	=	systematic error due to process, voltage and temperature (value available in the datasheet)
$I_{LOAD\_ERR\_RAND}$	=	random offset error, randomly distributed with an average of zero. This error can be identified with the compensation technique. (See Section 7.1.3 "Current activation and use of offset compensation")

$$C_{SRO} = 1/1500 + \varepsilon_{GAIN0}$$
$$C_{SR1} = 1/500 + \varepsilon_{GAIN1}$$

where:

$\varepsilon_{GAIN0} + \varepsilon_{GAIN1}$	=	Gain errors. Can be reduced by a calibration point in the range of interest
CSR0	=	High current ratio
CSR1	=	Low current ratio
1/1500	=	High current ratio CSR0 for MC20XS4200
1/500	=	Low current ratio CSR1 for MC20XS4200

7.1.3 Current activation and use of offset compensation

An embedded feature in the MC20XS4200 provides a means of generating the opposite value of the random offset. Enabling the bit OFP_s in the RETRY register causes the MC20XS4200 to generate an opposite value on the next current measurement.

Two measurements are needed: I_{CSNS1} (initial current value) and I_{CSNS2} (current value with opposite random offset.) (See Figure 11).

$$I_{CSNS1} = (I_{HSx} + I_{LOAD\_ERR\_SYS} + I_{LOAD\_ERR\_RAND}) \times C_{SRx}$$
$$I_{CSNS2} = (I_{HSx} + I_{LOAD\_ERR\_SYS} - I_{LOAD\_ERR\_RAND}) \times C_{SRx}$$
$$I_{LOAD\_ERR\_RAND} = (I_{CSNS1} - I_{CSNS2}) / (2 \times C_{SRx})$$

Therefore:

$$I_{CSNS\_COMPENSATED} = (I_{CSNS1} + I_{CSNS2}) / 2$$
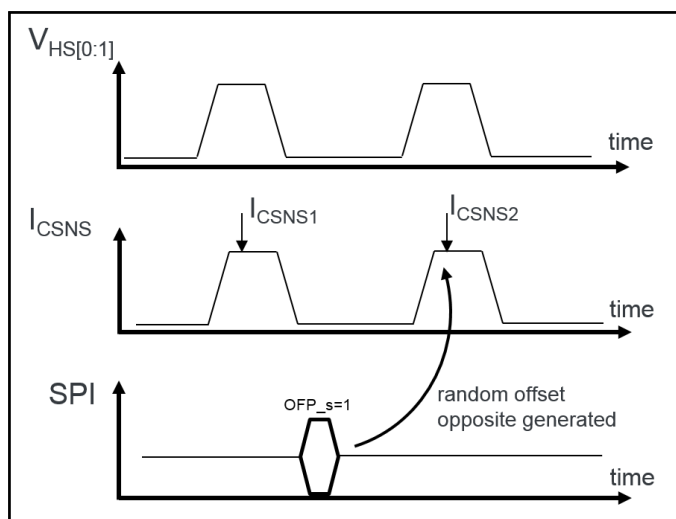$$I_{HS[0:1]} = (I_{CSNS\_COMPENSATED} / C_{SRx}) - I_{LOAD\_ERR\_SYS}$$

Figure 11. Sequence for current measurement for compensation

The MC20XS4200's random offset feature provides a means of achieving a high level of accuracy, especially under low current conditions. A major advantage of this feature is that the computation can be easily embedded in software, because ILOAD_ERR_SYS is the same for all devices.

NOTE

For any computation of the compensated current, the OFP bit must be toggled between the two measurements.

7.1.4   Offset compensation using software

Figure 12 illustrates the sequence of steps required to implement the MC20SX4200's compensation feature in software.
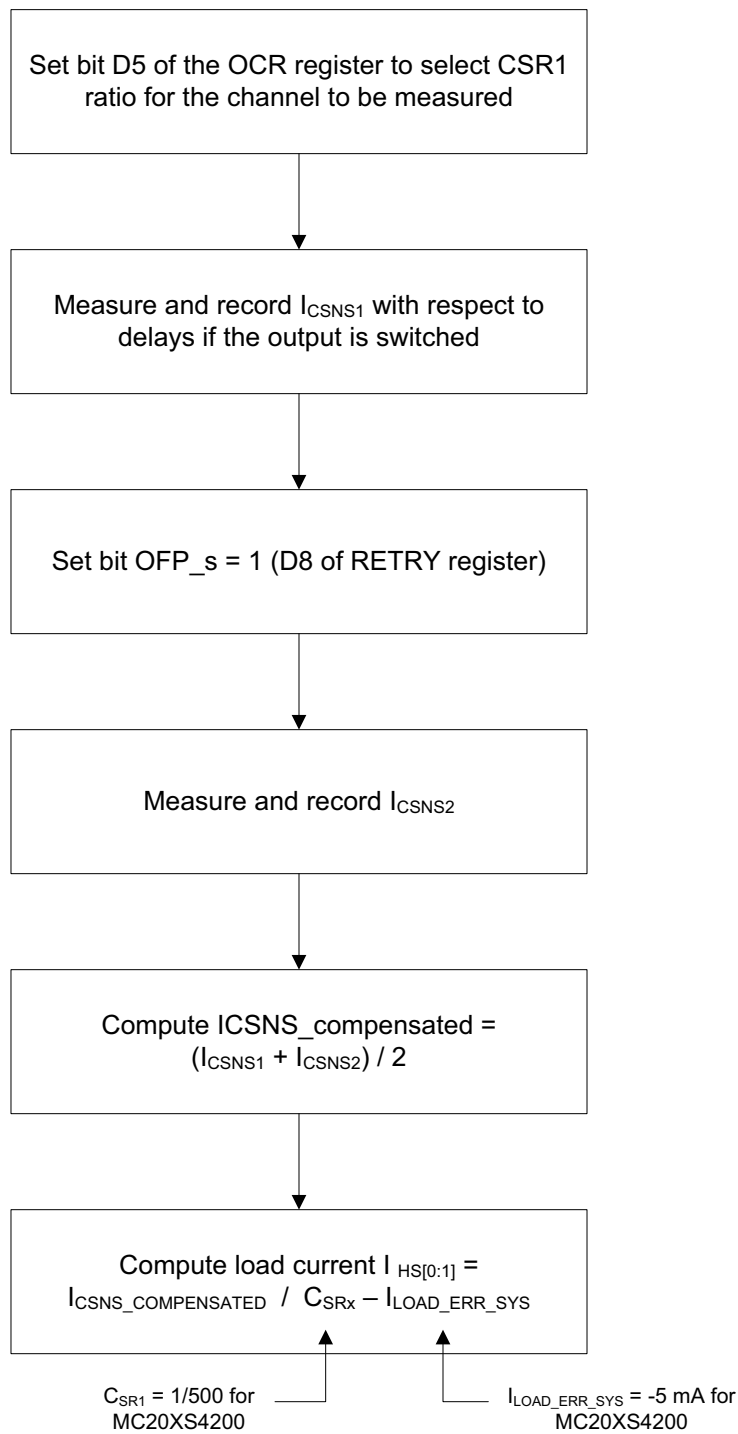
Set bit D5 of the OCR register to select CSR1
ratio for the channel to be measured

↓

Measure and record I_{CSNS1} with respect to
delays if the output is switched

↓

Set bit OFP_s = 1 (D8 of RETRY register)

↓

Measure and record I_{CSNS2}

↓

Compute ICSNS_compensated =
$(I_{CSNS1} + I_{CSNS2}) / 2$

↓

Compute load current $I_{HS[0:1]} =$
$I_{CSNS\_COMPENSATED} / C_{SRx} - I_{LOAD\_ERR\_SYS}$

$C_{SR1} = 1/500$ for
MC20XS4200

$I_{LOAD\_ERR\_SYS} = -5$ mA for
MC20XS4200

Figure 12. Software sequence for compensation current measurement

7.1.5   Current sense calibration

A calibration can be performed to improve measurement chain accuracy. To do so, you must record—during end of line testing—the difference between the theoretical measurement chain accuracy and the actual measured value. Then use the extracted delta current to adjust all future measurements.
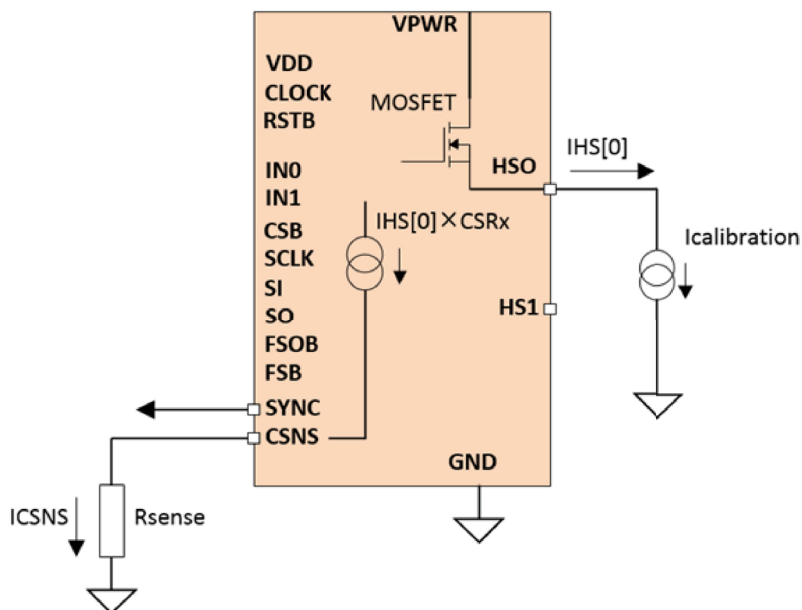
Figure 13. Current calibration

This calibration incorporates the sense ratio and the internal conversion stage, thereby addressing the gain error (ε_{GAIN0}). The calibration can be done at ambient temperature using the application's targeted supply voltage.

With eXtreme switch, all devices behave consistently across their temperature and supply voltage range. Each device may exhibit its own unique performance characteristics within the normal distribution for similar devices. However, those individual characteristics remain stable at different temperatures and voltages because the MC20SX4200's compensation feature minimizes the affect of temperature and voltage variations. Therefore, the calibration can be performed at room temperature using a single voltage (see Figure 14 for an MC20XS4200 in the 300 mA-3 A range.)
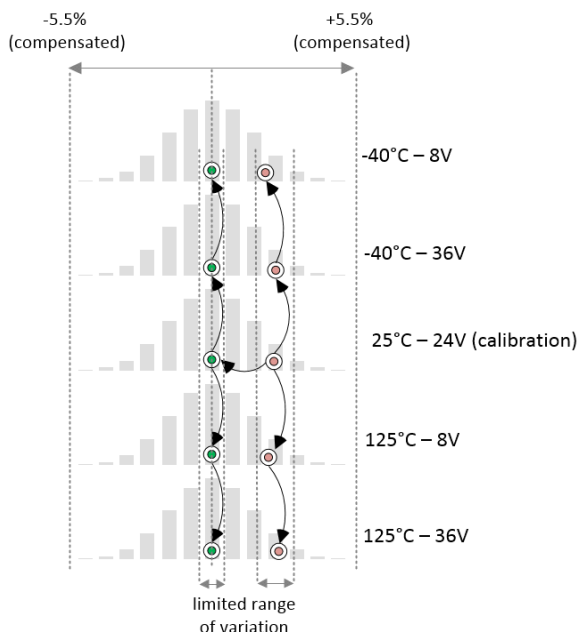
Figure 14. Consistency of current measurement across voltage and temperature

7.1.6   Compensation and calibration example with high current mode

Figure 15 illustrates how to proceed with both compensation and calibration. In the example, the current sense mode is CSR0 (high current e.g CSNS_ratio_s = 0). The load is a 25 Ω resistor. ILOAD_ERR_SYS is not embedded in the computation. The calibration will embed the systematic error. The percentage in brackets represents accuracy with respect to the target.
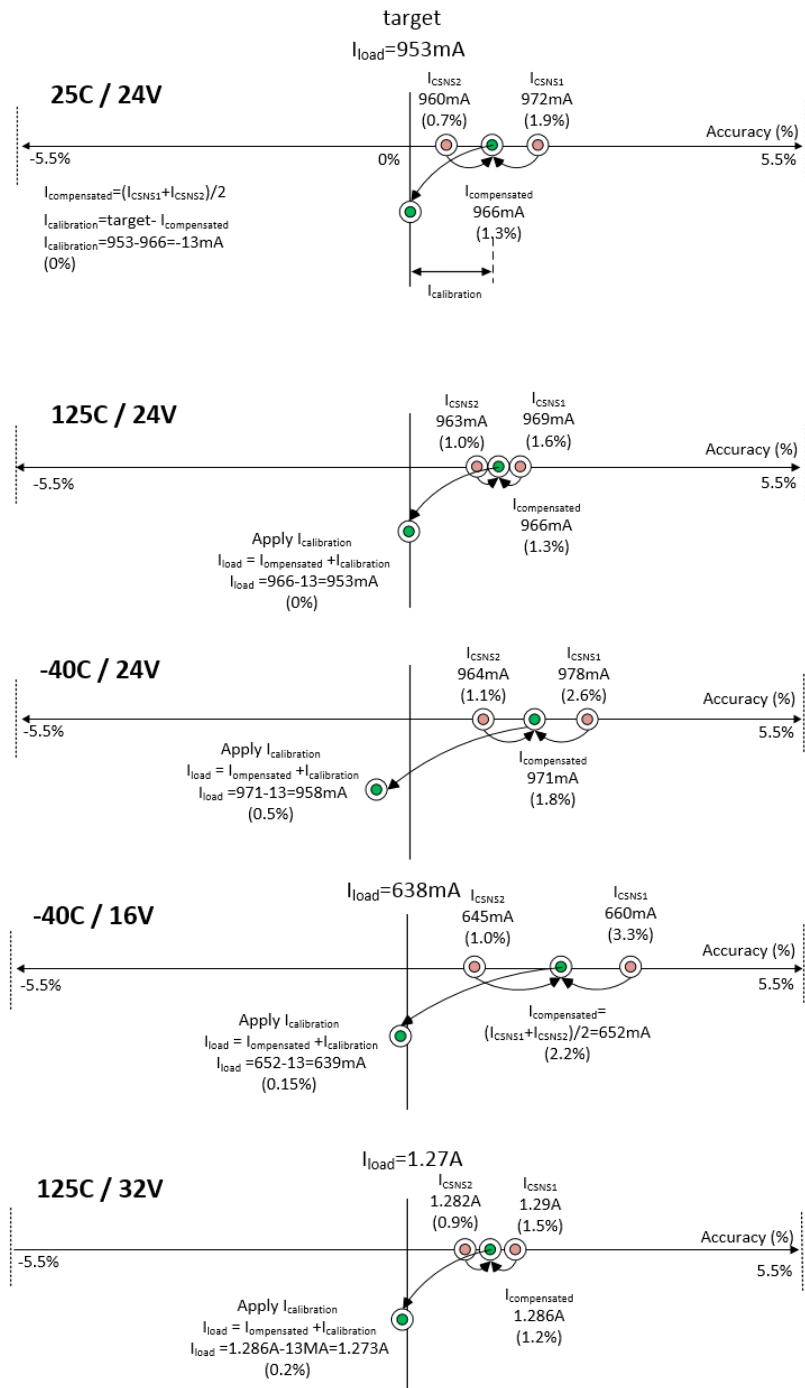

Figure 15. Calibration and compensation example using high current sensing accuracy (CSR0)

7.1.7 Compensation and calibration example with low current mode

Figure 16 provides another example of how to proceed with both compensation and calibration. In the example, the current sense mode is CSR1 (e.g CSNS_ratio_s = 1) for very low current. The load is a 270 Ω resistor. ILOAD_ERR_SYS is not embedded in the computation. The calibration will embed the systematic error. The percentage in brackets represents accuracy with respect to the target.

For a single point of calibration, worst case accuracy remains within 2% for current (35 times lower than nominal current.)
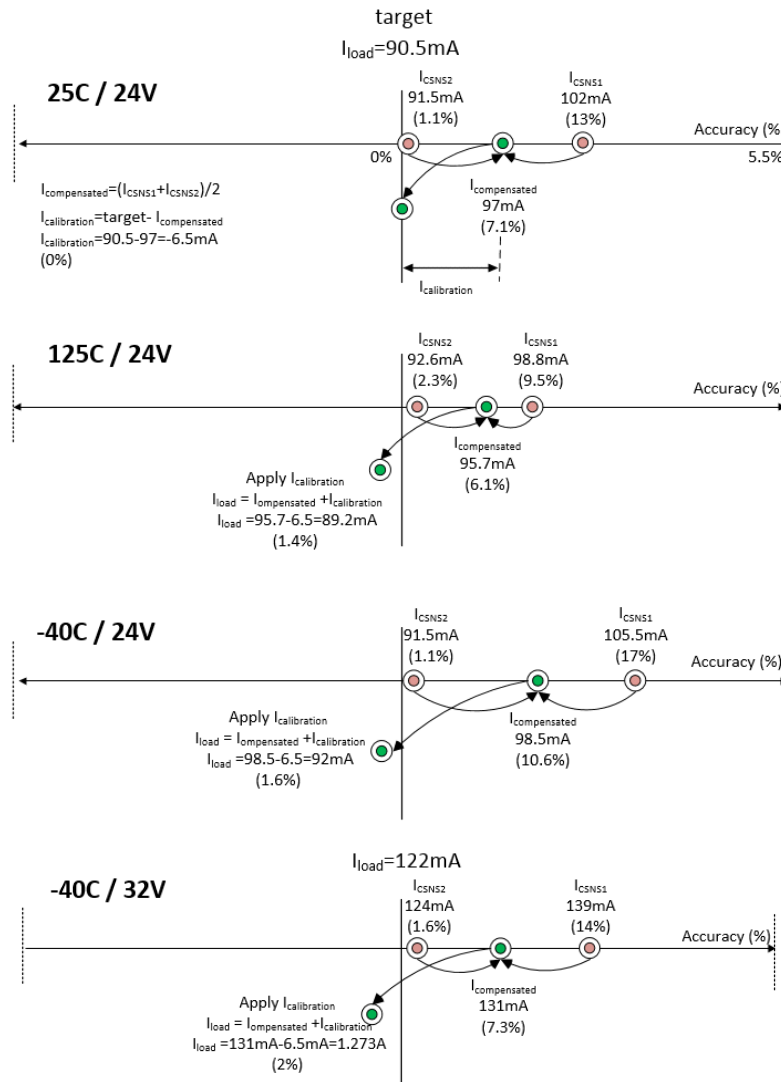
Figure 16. Calibration and compensation example using low current sensing accuracy (CSR1)

8   Revision history

Revision	Date	Description
1.0	6/2015	• Initial release
	7/2016	• Updated to NXP document form and style

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