NXP Semiconductors
Application Note

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Output current sensing

For the MC12XS6 eXtreme switch device family

1 Introduction

This application note describes current sense performances for SMARTMOS eXtreme switch devices belonging to the MC12XS6 family.

The application note covers

- the enhanced current sense mode dedicated to low current loads, such as light emitting diodes (LED)
- current sense accuracy
- the practical implementation of a calibration procedure to get optimized results

This document does not address errors linked to MCU and the external resistor connected to the CSNS pin.

Contents

2 Scope

The eXtreme switch MC12XS6 family is the latest achievement in automotive lighting drivers. It consists of a scalable family of devices compatible in software, MCU interface, and footprint. This product family is designed for low-voltage automotive and industrial lighting applications, and is composed of nine devices with various $R_{DS(on)}$ values and number of outputs to best fit various load and applications. All devices of this family are footprint and software compatible.

Table 1. MC12XS6 family

Part number	Type	Datasheet	OUT1	OUT2	OUT3	OUT4	OUT5
MC07XS6517BEK	Penta	MC12XS6D1	17 mΩ	17 mΩ	7.0 mΩ	7.0 mΩ	7.0 mΩ
MC17XS6500BEK	Penta		17 mΩ	17 mΩ	17 mΩ	17 mΩ	17 mΩ
MC17XS6400EK	Quad		17 mΩ	17 mΩ	17 mΩ	17 mΩ	NC
MC25XS6300EK	Triple	MC12XS6D2	25 mΩ	25 mΩ	25 mΩ	NC	NC
MC10XS6325EK	Triple		25 mΩ	NC	10 mΩ	10 mΩ	NC
MC10XS6200EK	Dual		NC	NC	10 mΩ	10 mΩ	NC
MC10XS6225EK	Dual		25 mΩ	NC	10 mΩ	NC	NC
MC40XS6500EK	Penta	MC12XS6D3	40 mΩ	40 mΩ	40 mΩ	40 mΩ	40 mΩ
MC08XS6421EK	Quad	MC12XS6D4	21 mΩ	21 mΩ	8.0 mΩ	8.0 mΩ	NC

This application note refers to the enhanced analog feedback provided by the device with its CSNS pin. This output pin of the IC is dedicated for battery voltage, IC's temperature or current sensing.

The family of eXtreme switches include an Advanced Current Sensing mode (ACM) giving an optimized accuracy of the output current from each channel. In this mode, the error amplifier offset contribution to the CSNS error can be eliminated from the measurement result by averaging each of two sequential current sense measurements.

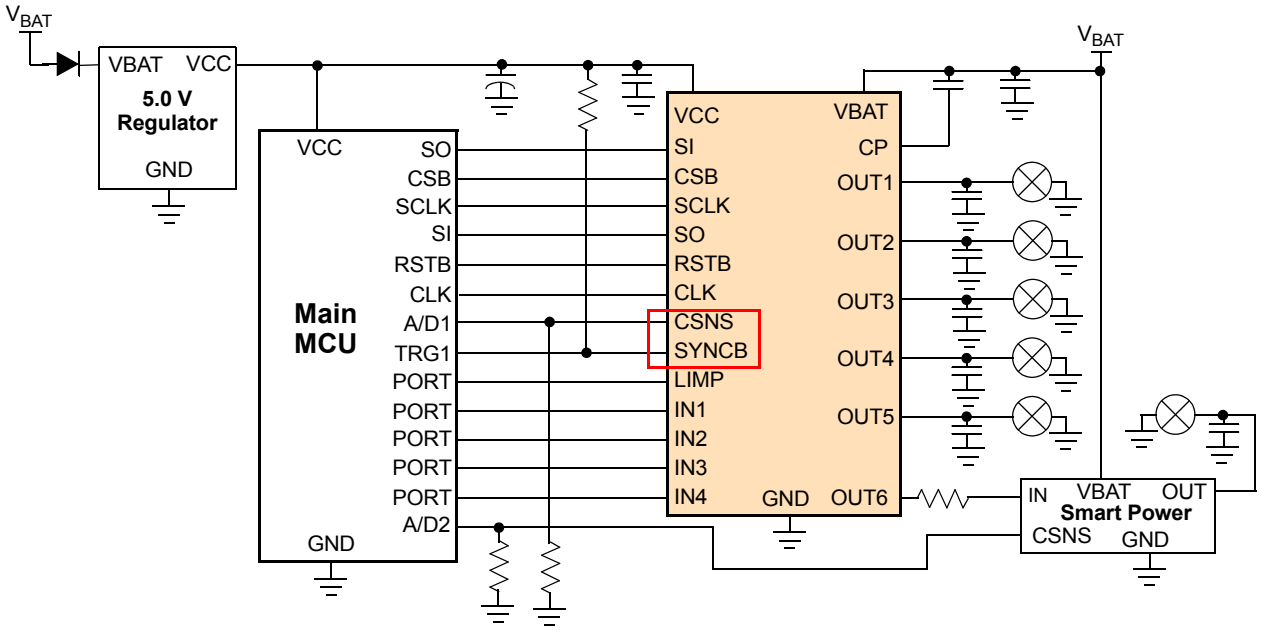


Figure 1. Typical application diagram

3 Selectable current sensing overview

3.1 Current sense definition

The CSNS output pin of the device provides ratio metric feedback of the output current of each channel (multiplexed by the SPI). The maximum current reported by the CSNS pin (1.0 mA) corresponds to the maximum current allowed on the corresponding channel. This maximum current varies along the $R_{DS(on)}$ type and the SPI configuration (full scale range).

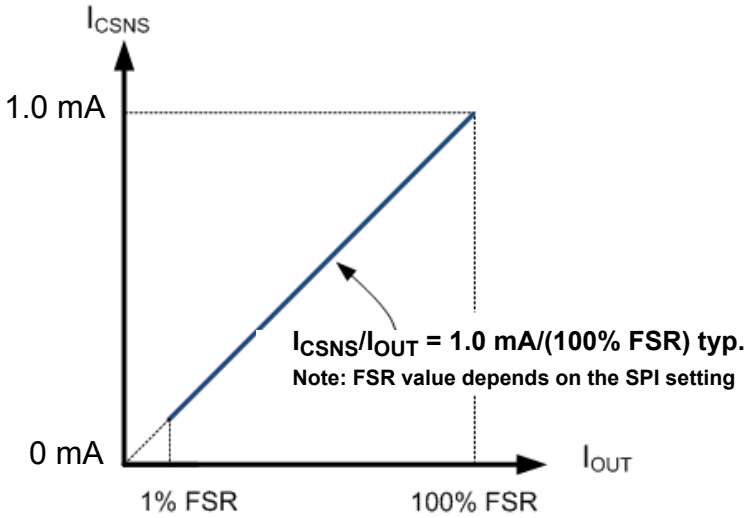
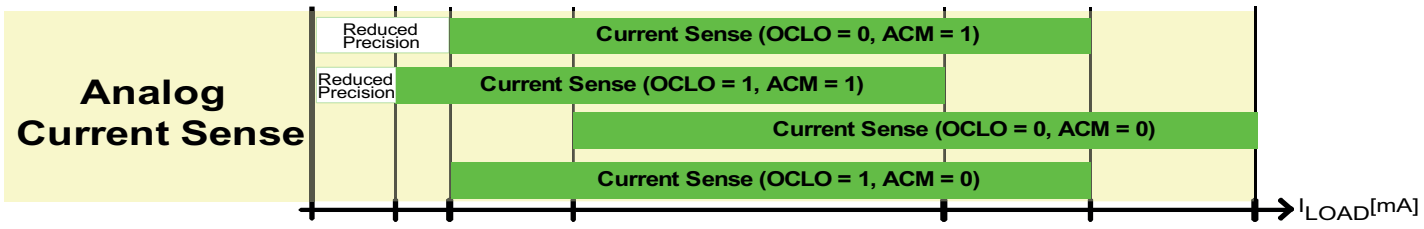


Figure 2. Current sense interpretation

The current sensing can be adjusted according to the intended lamp wattage and operation mode. An overcurrent active low signal can be configured for each channel corresponding to the full scale range (FSR) current of the affected channel. There are two bits available on the SPI register to set the correct FSR related to selected application. A default FSR value (OCLO bit = ACM bit = 0) can be divided by two or four, depending on this configuration.

Figure 3 shows FSR (right side) and accuracy (left side) for all $R_{DS(on)}$ values composed by the family vs. the SPI register configuration: overcurrent low (OCLO) and Advanced Current Sensing mode (ACM).



	1% FSR values vs. selected mode			100% FSR values vs.selected mode		
7.0 & 8.0 mΩ channel:	55	110	220	5500	11000	22000
10 mΩ channel:	45	90	180	4500	9000	18000
17 & 21 mΩ channel:	27.5	55	110	2750	5500	11000
25 mΩ channel:	24	48	96	2400	4800	9600
40 mΩ channel:	19.5	39	78	1950	3900	7800

Figure 3. Current sense performances vs. SPI register configuration

As an example, if the 7.0 mΩ output is configured with OCLO = 1 and ACM = 0, then FSR = 11 A. With an output current of 5.5 A, the CSNS pin provides 500 µA.

3.2 Current sense performances at low current

The current sense is unique in the market for its high reliability to diagnose either low or high current with an enhanced accuracy. Table 2 shows the minimum current sense reporting accuracy for both extreme $R_{DS(on)}$ values along the family: MC07XS6517B for 7.0 mΩ and 17 mΩ, and MC40XS6500 for 40 mΩ channel performance.

Values displayed are based on the statistical analysis of three different lots for each device with 3-Sigma (these are not the limits from the specification). It shows the default accuracy (No Calibration) as well as with 1 or 2 points calibration.

Extracted values come from the configuration OCLO bit = 1 and ACM bit = 0.

Table 2. Minimum current sense accuracy in OCLO = 1 (no ACM) for 7.0, 17, and 40 mΩ channels

	07XS6517B (OCLO = 1 / ACM = 0) - FSR = 5.5/11A								40XS6500 (OCLO = 1 / ACM = 0) - FSR = 3.9A							
	% FSR	Absolute Current	Min/Max precision								Min/Max precision					
			No calibration		1pt offset calibration		2pts calibration				No calibration		1pt offset calibration		2pts calibration	
			Min	Max	Min	Max	Min	Max			Min	Max	Min	Max	Min	Max
OUT1 (17 mΩ)	1%	55.0 mA	-42%	59%	-40%	50%	-40%	50%	**OUT1** (40 mΩ)	1%	39.0 mA	-30%	36%	-28%	31%	-28%	31%
OUT2 (17 mΩ)	1%	55.0 mA	-46%	49%	-44%	39%	-43%	39%	**OUT2** (40 mΩ)	1%	39.0 mA	-33%	32%	-29%	26%	-28%	25%
OUT3 (7.0 mΩ)	1%	110.0 mA	-62%	66%	-57%	56%	-57%	56%	**OUT3** (40 mΩ)	1%	39.0 mA	-37%	32%	-34%	23%	-34%	23%
OUT4 (7.0 mΩ)	1%	110.0 mA	-64%	61%	-59%	50%	-59%	50%	**OUT4** (40 mΩ)	1%	39.0 mA	-41%	32%	-38%	23%	-38%	22%
OUT5 (7.0 mΩ)	1%	110.0 mA	-68%	56%	-61%	50%	-61%	49%	**OUT5** (40 mΩ)	1%	39.0 mA	-38%	40%	-31%	22%	-32%	23%

ACM mode helps to significantly improve the accuracy at low output current as shown in Table 3.

Table 3. Minimum current sense accuracy in OCLO = 1 and ACM mode = 1 for 7.0, 17, and 40mΩ channels

	07XS6517B (OCLO = 1 / ACM = 1) - FSR = 2.75/5.5A								40XS6500 (OCLO = 1 / ACM = 1) - FSR = 1.95A							
	% FSR	Absolute Current	Min/Max precision								Min/Max precision					
			No calibration		1pt offset calibration		2pts calibration				No calibration		1pt offset calibration		2pts calibration	
			Min	Max	Min	Max	Min	Max			Min	Max	Min	Max	Min	Max
OUT1 (17 mΩ)	1%	27.5 mA	-22%	21%	-12%	13%	-11%	12%	**OUT1** (40 mΩ)	1%	19.5 mA	-20%	11%	-9%	9%	-8%	8%
OUT2 (17 mΩ)	1%	27.5 mA	-20%	22%	-11%	13%	-10%	13%	**OUT2** (40 mΩ)	1%	19.5 mA	-19%	13%	-7%	9%	-6%	8%
OUT3 (7.0 mΩ)	1%	55.0 mA	-36%	30%	-25%	17%	-25%	17%	**OUT3** (40 mΩ)	1%	19.5 mA	-15%	16%	-9%	9%	-8%	9%
OUT4 (7.0 mΩ)	1%	55.0 mA	-34%	30%	-25%	17%	-24%	17%	**OUT4** (40 mΩ)	1%	19.5 mA	-17%	19%	-11%	10%	-10%	9%
OUT5 (7.0 mΩ)	1%	55.0 mA	-44%	24%	-27%	18%	-26%	18%	**OUT5** (40 mΩ)	1%	19.5 mA	-14%	21%	-9%	10%	-8%	10%

The following pages show the current sense precision for the power output channels 7.0, 10, 17, 25, and 40 mΩ of the 07XS6517B, 17XS6500B, 17XS6400, 10XS6225, 10XS6200, 10XS6325, 25XS6300, and 40XS6500[(1)].

Accuracy is displayed for the worst case output of each $R_{DS(on)}$ value. All graphs present the data with:

X-axis = Full Scale Range/Y-axis = min/max% error on the value read on the CSNS pin.

Notes

1. Device 08XS6421 shares the same performances as the 07XS6517B and is not shown on the following pages.

The data presented are valid within the temperature range -40 °C < T_{AMB} < 125 °C and voltage range 9.0 V < Voltage < 18 V

The following "trumpet curves" represent the following configurations:

Current sense precision without calibration:

1. Devices performances in non-ACM configuration and OCLO = 1
2. Devices performances in ACM configuration and OCLO = 1

Current sense precision with calibration:

1. Devices performances in ACM and OCLO = 1 - 1 point Offset calibration
2. Devices performances in ACM and OCLO = 1 - 2 points Offset calibration

4 Device performance without calibration

4.1 Device performances in non-ACM configuration and OCLO = 1

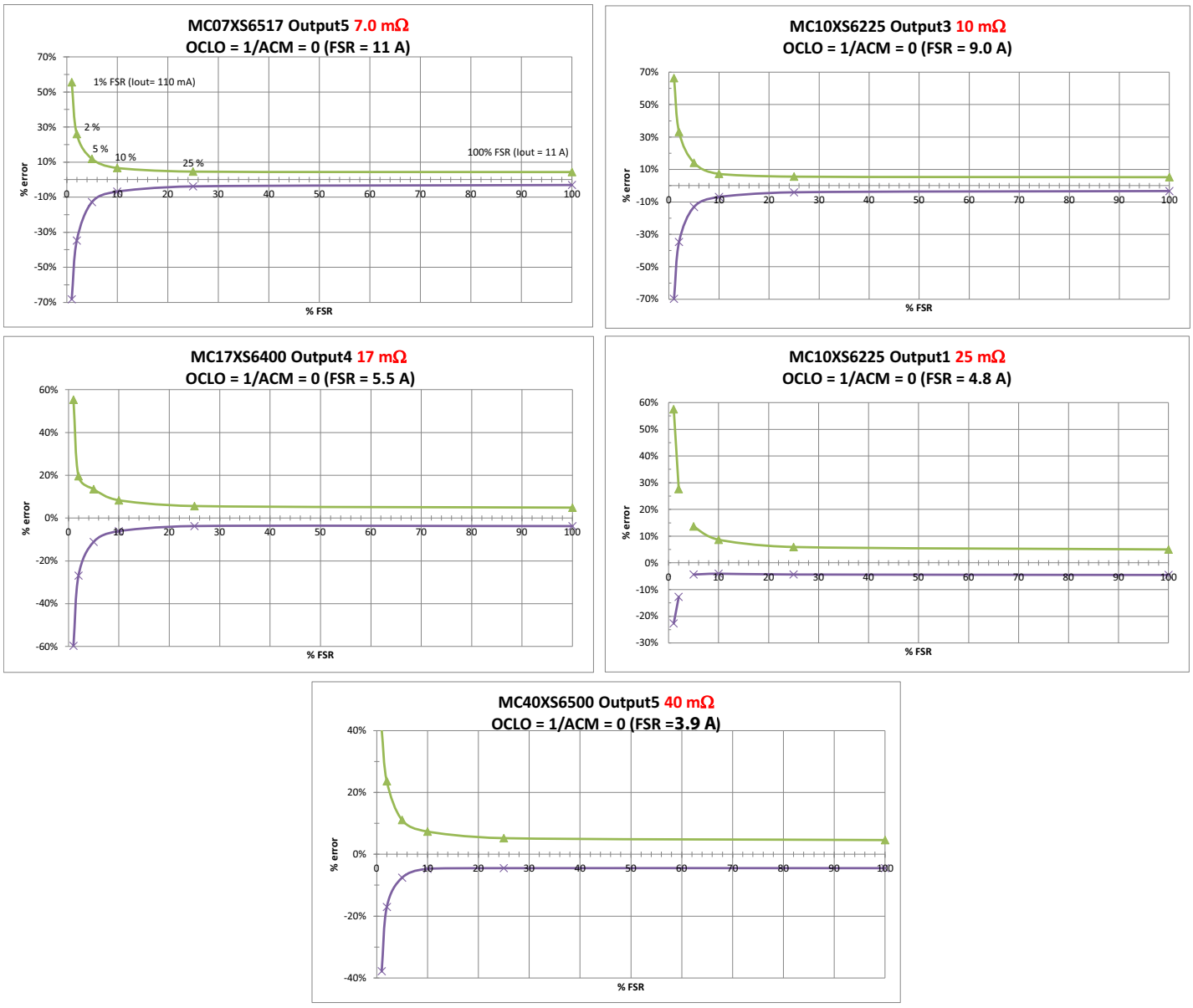


Figure 4. Devices in configuration OCLO bit = 1; ACM bit = 0

4.2 Device performances in ACM configuration and OCLO = 1

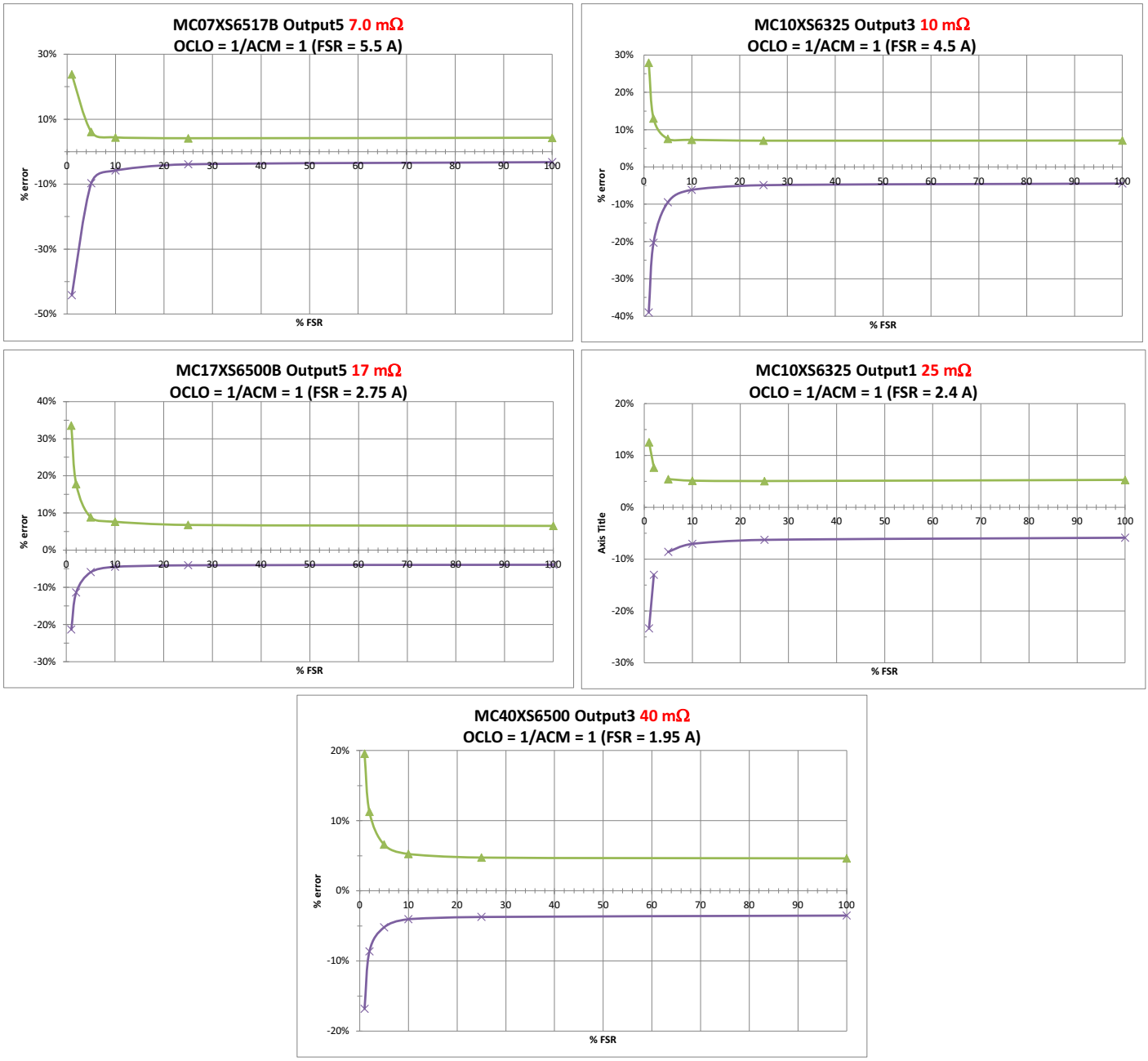


Figure 5. Devices in configuration OCLO bit = 1; ACM bit = 1

5 Device performance with calibration

The accuracy of the current sensing depends on the following contributors:

1. Device-to-device variation due to manufacturing
2. Output current vs. selected full scale range
3. Ambient temperature range -40 °C to 125 °C
4. Battery voltage range 9.0 V to 18 V

With a calibration strategy, the precision of current sensing can be improved significantly. It helps to remove the device-to-device effect or the offset error at low output current. Calibration is the process which determines the exact gain and offset values for specific parts. The onboard microcontroller calculates I_{OUT} according to the formula:

$$I_{OUT} = (I_{CSNS}*GAIN) + OFFSET$$

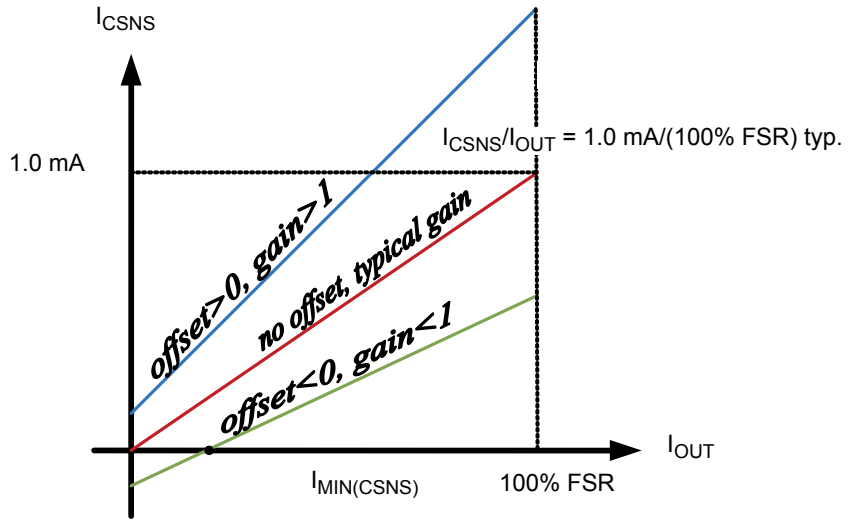


Figure 6. Output current sensing

Notes

2. FSR value depends on the SPI setting, as described in Section 3,"Selectable current sensing overview".

Two different calibration strategies are proposed:

- One calibration point - Offset calibration
  - T_{AMB} = 25 °C/V_{BAT} = 14 V
  - I_{OUT} = 2.0% FSR
- Two calibration points (ACC ICSNS 2 CAL) - Offset and Gain calibration
  - T_{AMB} = 25 °C/V_{BAT} = 14 V
  - I_{OUT} = 2.0% FSR (Offset calibration) and I_{OUT} = 50% FSR (Gain calibration)

These calibration procedures help to improve current sense precision for a voltage range between 9.0 V and 18 V, and the ambient temperature range -40 °C < T_A < 125 °C.

The following pages show the current sense accuracy with 1 point offset or 2 points gain + offset calibration at 14 V. Pictures are shown for the worst case output of each $R_{DS(on)}$ in ACM mode. For 1 point Gain calibration performances, refer to the specification in Section 6,"References".

5.1 Device performances in ACM and OCLO = 1 with 1 point offset calibration

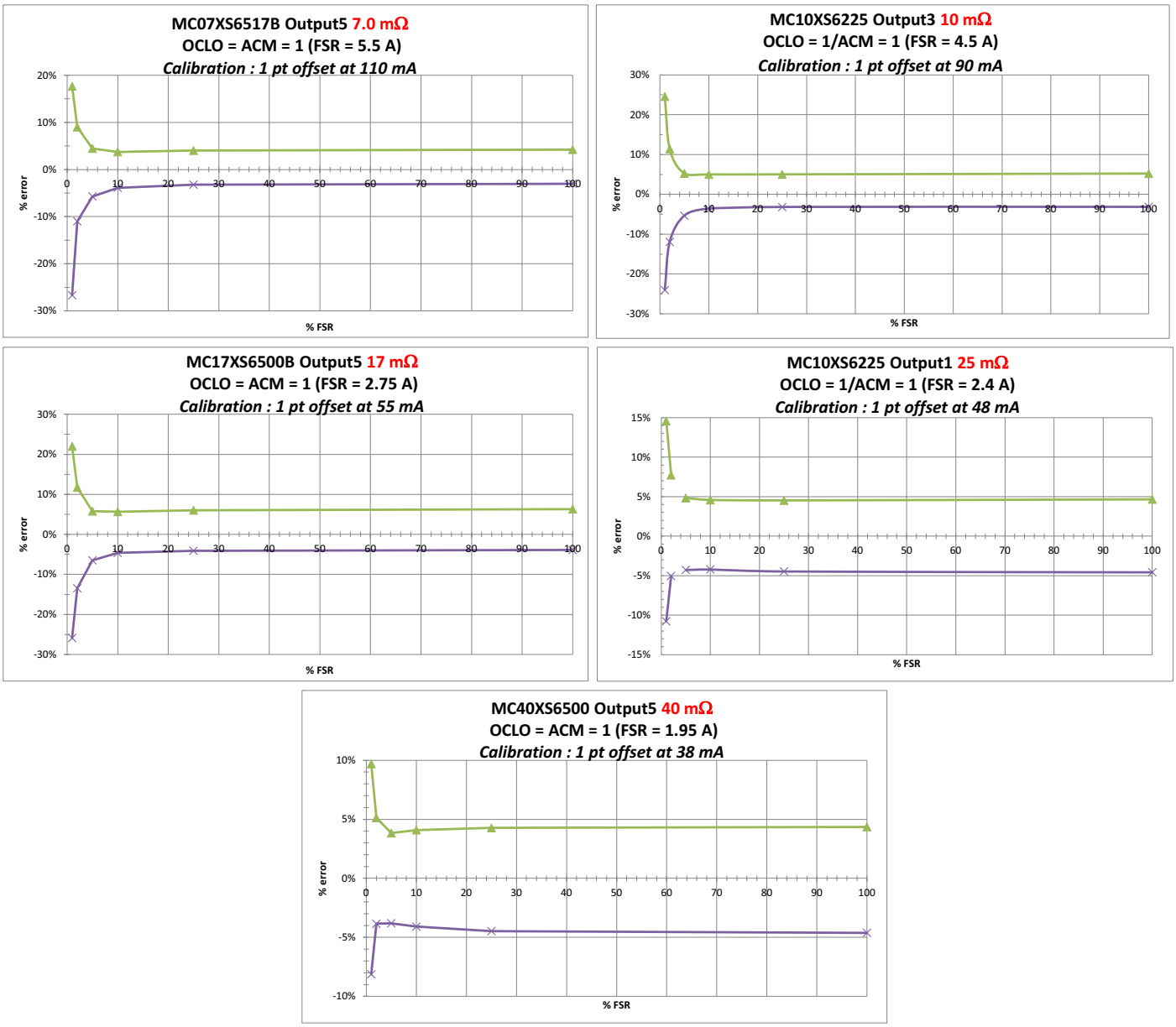


Figure 7. Devices in configuration OCLO bit = 1; ACM bit = 1; calibration = 1 point offset (2%FSR)/voltage = 14 V

5.2 Devices performances in ACM and OCLO = 1 with 2 points offset calibration

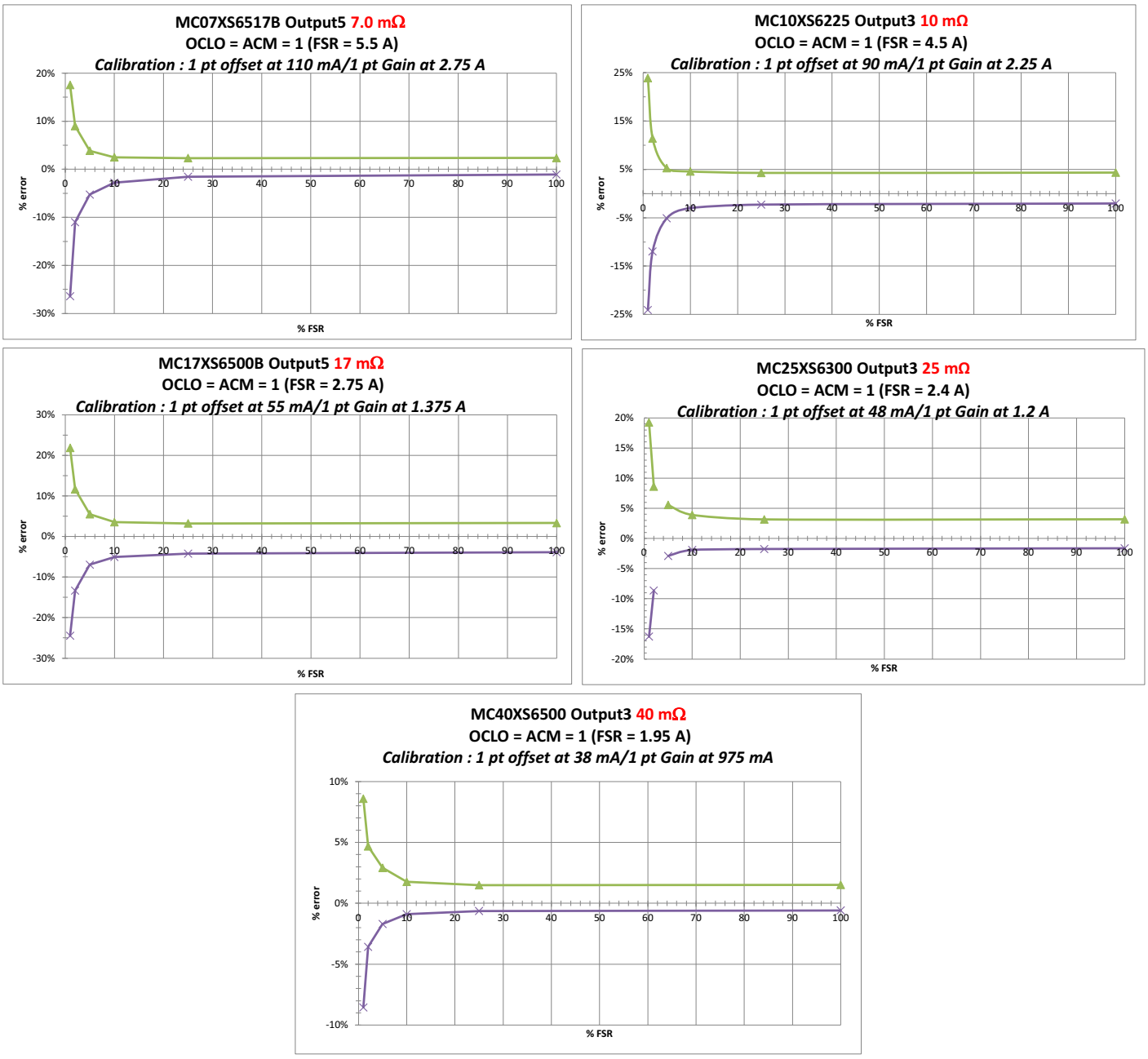


Figure 8. Devices in configuration OCLO bit = 1; ACM bit = 1; calibration = 1 point offset (2%FSR)/1 point gain (50%FSR)/voltage = 14 V

6 References

Following are URLs where you can obtain information on related NXP products and application solutions:

Document number	Description	URL
MC12XS6	Product Summary Page	http://www.nxp.com/webapp/sps/site/prod_summary.jsp?code=MC12XS6
Analog Home Page	Home Page	http://www.nxp.com/analog

7 Revision history

Revision	Date	Description
1.0	2/2014	• Initial release
2.0	5/2014	• Version pass 1p4 added for this AN • Current Sense Performances vs. SPI Register Configuration figure updated • Minimum Current Sense Reporting in ACM Mode and OCLO = 1 figure added • Chapters 4 & 5 reworked. Adapted format to display trumpet curves for all channels in OCLO = 1, ACM or non-ACM, without calibration (Device performance without calibration), and 1 or 2 points with calibration (Devices performances in ACM and OCLO = 1 with 2 points offset calibration)
3.0	5/2015	• Scope completed with additional explanation on current sense • Results adapted for version B of the 07XS6517 and 17XS6500 • Curves removed to simplify the document • Performances of all 12XS6 devices integrated in the document
	7/2016	• Updated to NXP document form and style

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