NXP Semiconductors
Application Note

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Repetitive short-circuit performances

Featuring the MC12XS6 IC's family

1 Introduction

This application note relates to the robustness of devices of the eXtreme Switch MC12XS6 device family in cases of various repetitive short-circuit conditions.

The MC12XS6 family is the latest achievement in term of low-voltage lighting applications. It is an evolution of the successful generation of MC12XS3 eXtreme switches. This family is composed of nine different devices. Those dual, triple, quad, and penta outputs devices are footprint and software compatible, with a wide panel of low $R_{DS(on)}$ MOSFETs fitting the various types of automotive and industrial bulbs.

Programming, control, and diagnostics are accomplished using a 16-bit SPI interface, which provides a large panel of configurations, analog and digital information related to the device in its application, and a full set of protection features to ensure its safety. All information provided by this SMARTMOS device through the SPI gives the MCU all the key information to reflect device and output status. This device also provides a wide flexibility of configurations in addition to highly sophisticated fault and failure mode handling.

For feature information, refer to the individual device data sheets.

Contents

2 Short-circuit protection strategy

The MC12XS6 devices include up to five self-protected high-side switches, with its extended protection and diagnostics, to detect bulb outage and short-circuit fault conditions. Additionally, this device incorporates a pulse width modulation control module, to improve lamp lifetime with bulb power regulation at no less than 25 Hz, and address the dimming application (daytime running light).

The MC12XS6 family proposes different load protection features:

- latched overcurrent protection,
- severe short-circuit protection.
- overcurrent in the On state

Those protections are preferred to conventional current limitations, to minimize the thermal overstress within the device in cases of overload conditions. The delta (T) is drastically reduced to a value which does not affect the device's reliability.

2.1 Transient overcurrent protection

MC12XS6 includes a transient overcurrent protection at each Turn On command. This profile, represented in Figure 1, is configurable through the SPI:

- OCHI1 can be decreased by 15% or 50%, depending on the dynamic output voltage at Turn On or ambient temperature
- OCHI1…3 can be adjusted from 37 ms (Short OCHI feature) to 130 ms (NO HID feature)
- OCLO threshold has three selectable values and a range from 2.0 A to 22 A over the family
- OCHI1/2/3 profile could also be disabled during turn On, in case of a resistive load (NO OCHI feature)
- MC12XS6 offers the possibility to start another transient overcurrent profile in the On state when the output current exceeds OCLO (OCHI OD feature)

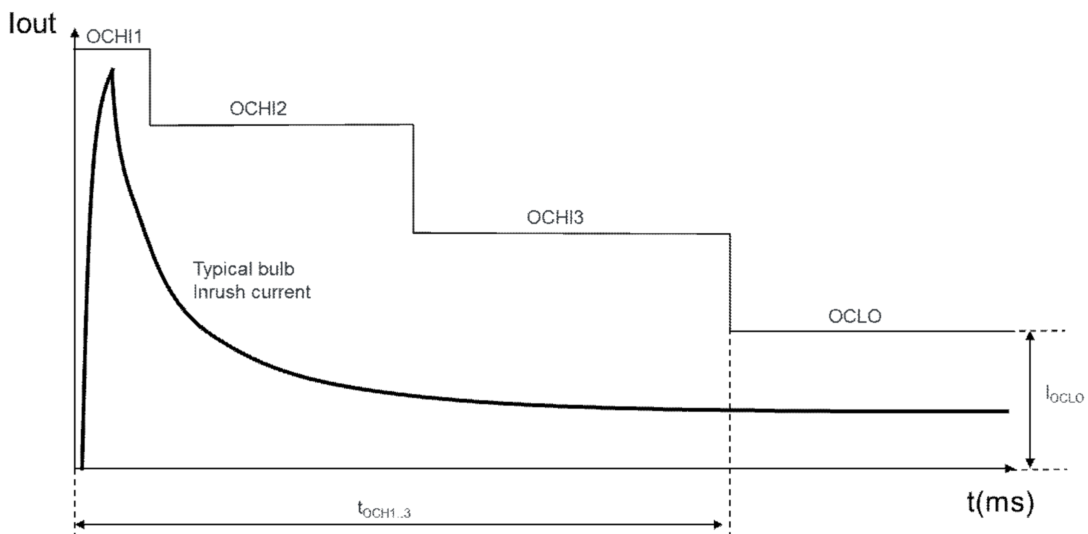

Figure 1. Multi-step transient overcurrent protection

2.2 Severe short-circuit protection

In addition to latched overcurrent protection, a severe short-circuit detection is available during lamp switching to immediately turn off the output in cases of an extremely low short-circuit event. This feature lowers the junction temperature in this extreme condition where the high-side MOSFET is not yet in the $R_{DS(on)}$ state.

2.3 Short-circuit in the on state

The configurable OCLO threshold is triggered once the OCHI1/2/3 profile is passed and available for as long as the output stays on. It acts as a fuse with configurable values and protects the output once the transient trip is gone. However, the device could allow transient events while in the On state during user demands, with the OCHI OD feature.

2.4 Digital diagnostics

For each of those previous listed undesirable events, the type of fault can be distinguished through a specific SPI register, dedicated per output.

Table 1. Output channel status

Register	SO address					SO Data											
	#	D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Ch 1…5 status	2…0	0	x	x	x	Fm	DSF	OVLF	OLF	res	OTSx	OTWx	OC2x	OC1x	OC0x	OLONx	OLOFFx

The SO output register provides a detailed diagnostic for each channel where Open Load or Thermal diagnostics are listed, alongside the type of overcurrent event (bits OC[0…2]x). Figure 2 shows the various type of event that are reported into the channel status SPI register.

#2~#6

OC2x	*OC1x*	*OC0x*	*over current status*
0	*0*	*0*	*no overcurrent*
0	*0*	*1*	*OCHI1*
0	*1*	*0*	*OCHI2*
0	*1*	*1*	*OCHI3*
1	*0*	*0*	*OCLO*
1	*0*	*1*	*OCHIOD*
1	*1*	*0*	*SSC*
1	*1*	*1*	*not used*

Figure 2. Overcurrent status flags

3 Repetitive short-circuit test setup

The repetitive short-circuit tests were performed in accordance with Chapter 12 of AEC-Q100 specification, published by the Automotive Electronics Council (last revision September14, 2006). The goal is to force the device to switch “On” and “Off” cyclically in a short-circuit condition to accelerate silicon device fatigue. In addition, NXP performed its own tests adapted to the device's protections, to fulfill the different use cases in an application.

3.1 Short-circuit conditions

Some test cases are defined in the AEC specification:

- Hot Repetitive Short-circuit Test: an infinite “on” command where the temperature does NOT return to operating temperature (T_{AMB}) between each pulse
- Cold Repetitive Short-circuit Test - Short Pulse: a repetitive turn-on command of 10 ms periods where the temperature returns to operating temperature (T_{AMB}) between each pulse
- Cold Repetitive Short-circuit Test - Long Pulse: a repetitive turn-on command of 300 ms periods where the temperature returns to operating temperature (T_{AMB}) between each pulse

The short-circuit case applied to the Smart Power Switch is dependent of its failure handling during short-circuit events.

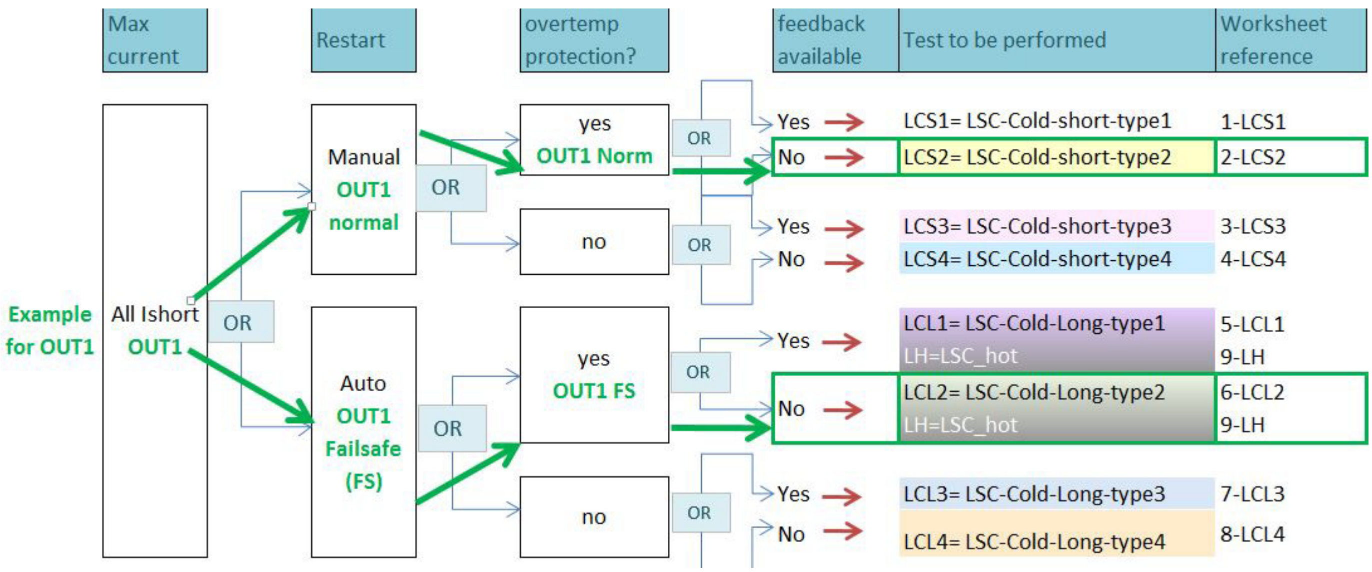

Figure 3. AECQ100-12 decision tree

Based on the decision tree, NXP performs its robustness assessment in cold repetitive short-circuit short pulse conditions. Figure 4 illustrates the typical hardware used for the assessment.

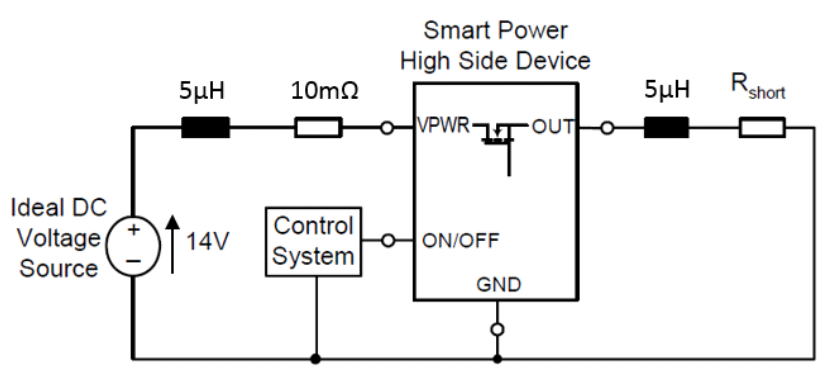

Figure 4. AECQ100-12 short-circuit test setup

Tests applied for the MC12XS6 devices were based on specific short-circuit conditions, activating each overload protection feature, as described in Table 2. and Figure 5.

Table 2. Short-circuit test types

Test # [2]	Description	
1	Terminal short-circuit of 20 mΩ (R_{SHORT})	AECQ100-12 and NXP Test
2	Load short-circuit of 50 mΩ or 100 mΩ (R_{SHORT}) [1]	AECQ100-12 and NXP Test
3	Overload condition exceeding the nominal current	NXP Test
4	Overcurrent in the On-state (applied after Transient overcurrent profile)	NXP Test

Notes

1. R_{SHORT} is choosen depending on I_{SHORT} (R_{SHORT} = 50 mΩ if I_{SHORT} > 100 A)
2. These test numbers refers to those identified in Figure 5.

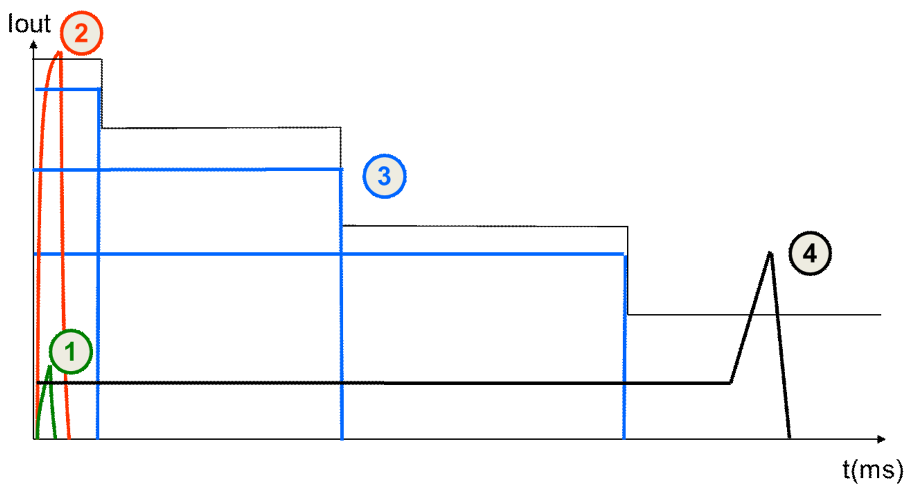

Figure 5. Repetitive short-circuit tests modes

3.2 Hardware environment for short-circuit tests

According to the conditions outlined in the previous section, the available hardware fulfills the following requirements:

- Fixed input and output inductance value
- Variable input and output resistance values
- Configurable ambient temperature
- High sample quantity capability
- Continuous individual SPI monitoring to record the exact number of cycles to failure

Devices are mounted on 4 layer PCBs, with layout and construction reflecting the application conditions. Each PCB is inserted into sockets that are on a common Burn-in-board (10 PCBs per Burn-in-board). The line impedance represents the wire harness put on each Input/output of each PCB. Burn-in-boards are loaded in a thermally controlled oven with outside connections for power and logic. Permanent monitoring performed by the supervision can digitally trace the different failures reported by each device.

4 Repetitive short-circuit test results

Table 3. presents the summary of repetitive test results for all devices from the MC12XS6 family in AECQ100-12 test conditions. Tests have been performed for load short-circuit condition, and for each device:

Table 3. AECQ100-12 reliability test results at T_{AMB} = 85 °C and voltage = 14 V

Short-circuit case [(3)]	Supply line	Load line	AECQ100-12 grade
Terminal short-circuit on 7.0 mΩ, 8.0 mΩ, and 10 mΩ outputs (test 1)	5.0 µH/10 mΩ	5.0 µH/20 mΩ	A
Terminal short-circuit on 17 mΩ, 21 mΩ, 25 mΩ, and 40 mΩ outputs (test 1)			A
Load short-circuit on 7.0 mΩ, 8.0 mΩ, and 10 mΩ outputs (test 2)		5.0 µH/100 mΩ	D
Load short-circuit on 17 mΩ, 21 mΩ, 25 mΩ, and 40 mΩ outputs (test 2)		5.0 µH/50 mΩ	D

Notes
3.These test numbers refers to those identified in Figure 5.

Table 4. shows the summary of repetitive short-circuit tests in custom conditions. Those results are extracted from performances of three devices over the family: MC07XS6517, MC17XS6500, and MC17XS6400, and done on all output types. Tests were voluntary stopped at 500 k cycles.

Table 4. NXP repetitive short-circuit test results at T_{AMB} = 70 °C

Short-circuit case	Battery voltage	Supply line	Load line	Fault triggered	Output cycle without failure
Turn On into short-circuit condition (tests 1 and 2)	16 V	0.3 m/2.5 mm^2	5.0 m/1.0 mm^2	OCHI1 (test 2) [(4)]	> 500 k
			0.3 m/1.0 mm^2	SSC (test 1) [(4)]	> 500 k
		5.0 m/2.5 mm^2		Undervoltage	> 500 k
Short-circuit in On state (test 4)	14 V	0.3 m/2.5 mm^2	5.0 m/1.0 mm^2	OCLO	> 500 k
			0.3 m/1.0 mm^2		> 500 k
		5.0 m/2.5 mm^2			> 500 k
On state overload 95% of OCHI1/2/3 level (test 3)	16 V	0.3 m/6.0 mm^2	0.3 m/6.0 mm^2	OCHI1/2/3	> 1.0 M

Notes
4.These test numbers refers to those identified in Figure 5.

5 Engineering evaluations

The device's level of robustness is a function of ambient temperature. With the default device's configuration, the number of cycles to failure decreases above 50 °C. Several features embedded in the device help maximize the device robustness in different application cases.

- Feature OCHI-15%: once the embedded thermal sensor detects an ambient temperature above 63 °C, the robustness of the device is improved, thanks to a lower power dissipation during short-circuit conditions
- Overtemperature shutdown (OTS): With a high ambient temperature (> 110 °C) the device may shutdown with the OTS feature, at a lower current peak, resulting in a lower power dissipation during a short-circuit
- NO OCHI: Depending on the application and ambient temperature, which eliminates the lamp inrush, the OCHI window can be disabled during turn on, significantly minimizing the thermal increase during a short-circuit
- When a PWM is applied to the lamps by the SPI, the OCHI window is disabled for each commutation except the 1st one

Based on these statements and engineering studies done internally, Figure 6 shows the derating results over the ambient temperature in the AECQ100-12 conditions.

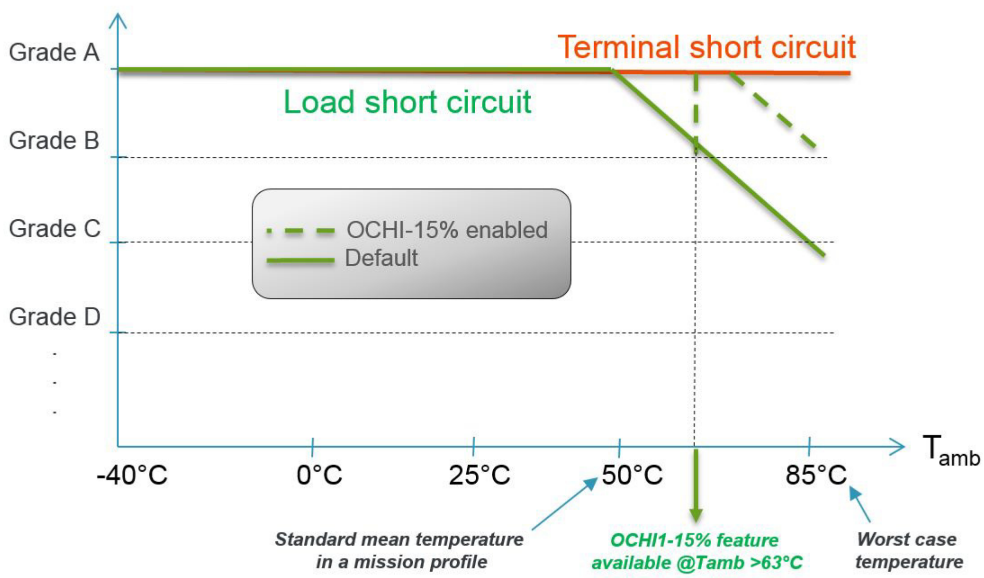

Figure 6. AECQ100-12 results over ambient temperature

Grades mentioned on Table 3. and Figure 6 pertain to Table 5. which are extractions from the AECQ100-12 reliability standard.

Table 5. AECQ100-12 reliability standards

Grade	# Cycles	Lots/samples per lot	# Fails
A	> 1,000,000	3/10	0
B	> 300,000 — 1,000,000	3/10	0
C	> 100,000 — 300,000	3/10	0
D	> 30,000 — 100,000	3/10	0
E	> 10,000 — 30,000	3/10	0
F	> 3000 — 10,000	3/10	0
G	> 1000 — 3000	3/10	0
H	300 — 1000	3/10	0
O	< 300	3/10	0

6 References

Document number and description		URL
MC12XS6D3	Data Sheet	http://cache.nxp.com/files/analog/doc/data_sheet/MC12XS6D1.pdf
MC12XS6D3		http://cache.nxp.com/files/analog/doc/data_sheet/MC12XS6D3.pdf
MC12XS6D4		http://cache.nxp.com/files/analog/doc/data_sheet/MC12XS6D4.pdf
Support pages		**URL**
MC12XS6 Product Summary Page		http://www.nxp.com/webapp/sps/site/prod_summary.jsp
Power Management Home Page		http://www.nxp.com/webapp/sps/site/homepage.jsp?code=POWERMGTHOME
Analog Home Page		http://www.nxp.com/analog

7 Revision history

Revision	Date	Description of Changes
1.0	1/2015	Initial release
	7/2016	Updated to NXP document form and style

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