SPOC^{TM}+ 12V

SPI Power Controller

Short Circuit to V_S and Open Load Detection

Application Note

Rev. 1.0, 2013-09-25

Automotive Power

1 Abstract

Note: The following information is given as a hint for the implementation of the device only and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

This Application Note is intended to provide detailed application hints regarding the short circuit to V_S detection of the SPOC™+. Furthermore, an open load in OFF detection can be implemented with the use of an external resistor. General information about the SPI Power Controller can be found in the SPOC™+ data sheets.

2 Introduction

The SPOC™+ is a family of four, five or six channels high-side power switches, which are especially designed to control standard exterior front and rear lighting (either lamps or their LED equivalent) in automotive applications.

Configuration and status diagnosis is done via SPI. Additionally, there is a current sense signal available for each channel that is routed via a multiplexer to one diagnostic pin.

The following table is an overview of all products in SPOC™+ 12V product family.

Table 1 SPOC™+ 12V product family overview

Product	Typical ON State Resistance at T_j = 25 °C ($R_{DS(ON,typ)}$)	Ext. driver capability
BTS54220-LBA	Channel 1, 4: 9 mΩ Channel 2, 3: 27 mΩ	no
BTS54220-LBE	Channel 1, 4: 9 mΩ Channel 2, 3: 27 mΩ	yes
BTS54040-LBA	Channel 1, 2, 3, 4: 39 mΩ	no
BTS54040-LBE	Channel 1, 2, 3, 4: 39 mΩ	yes
BTS55032-LBA	Channel 2, 3, 4: 39 mΩ Channel 1, 5: 110 mΩ	no
BTS56033-LBA	Channel 2, 3, 4: 39 mΩ Channel 1, 5, 6: 110 mΩ	no

This document will show how to use the internal function of the Switch Bypass Monitor (SBM) to detect whether the output is connected via a low resistance to V_S or not. For this short circuit to V_S detection no external hardware is required. For the implementation of an open load in off detection an external resistor is required.

3 Functionality of Switch Bypass Monitor (SBM)

The Switch Bypass Monitor (SBM) is a part of the device logic, which evaluates the V_{DS} voltage of the DMOS. There is only one SBM comparator on the device for all four, five or six channels. Thus, there is an additional multiplexer implemented, which connects the outputs of the channels to the SBM comparator. This multiplexer is also programmed by the current sense multiplexer bits of the diagnosis control register (DCR). For further details please refer to the datasheet.

In case of a short circuit to V_S and $V_{DS} < V_{DS(SB)}$ the bit DCR.SBM indicates the short circuit to V_S. This can be seen for OFF- (**Table 2**) and ON-state (**Table 3**).

Table 2 SBM and Current Sense during OFF-state [1)2)]

Operation mode	Current sense	Bit DCR.SBM
Normal operation	Z	1
Short Circuit to GND	Z	1
Over Temperature	Z	X
Short Circuit to V_S	Z	0
Open Load	Z	X

1) Z = high impedance, potential depends on leakage currents and external circuit. X = undefined.

2) During OFF-state the bit dcr.SBMdepends on the potential at the output pin. The potential of the output pin depends in Open Load case on leakage currents. As a result, the bit DCR.SBM can be set either to “1” or “0” during an Open Load in OFF-state.

Table 3 SBM and Current Sense during ON-state [1)]

Operation mode	Current sense	Bit DCR.SBM
Normal operation	I_L / k_{ILIS}	0
Current limitation	Z	X
Short Circuit to GND	Z	1
Over Temperature	Z	X
Short Circuit to V_S	$< I_L / k_{ILIS}$	0
Open Load	Z	0

1) Z = high impedance, potential depends on leakage currents and external circuit. X = undefined.

3.1 Use of SBM for Short Circuit to V_S Detection

In case of a short circuit between one output pin and V_S supply voltage a major part of the load current will flow through the short circuit. As a result, a lower current compared with the normal operation will flow through the DMOS of the SPOC^{TM}+, which can be recognized at the current sense signal.

In case of a current sense signal below the normal value, a software strategy is required to verify, whether an over temperature failure or a short circuit to V_S leads to the low current sense signal.

The following flow chart shows a possible way to implement a software strategy (see **Table 4** for the SPI commands required by this sequence):

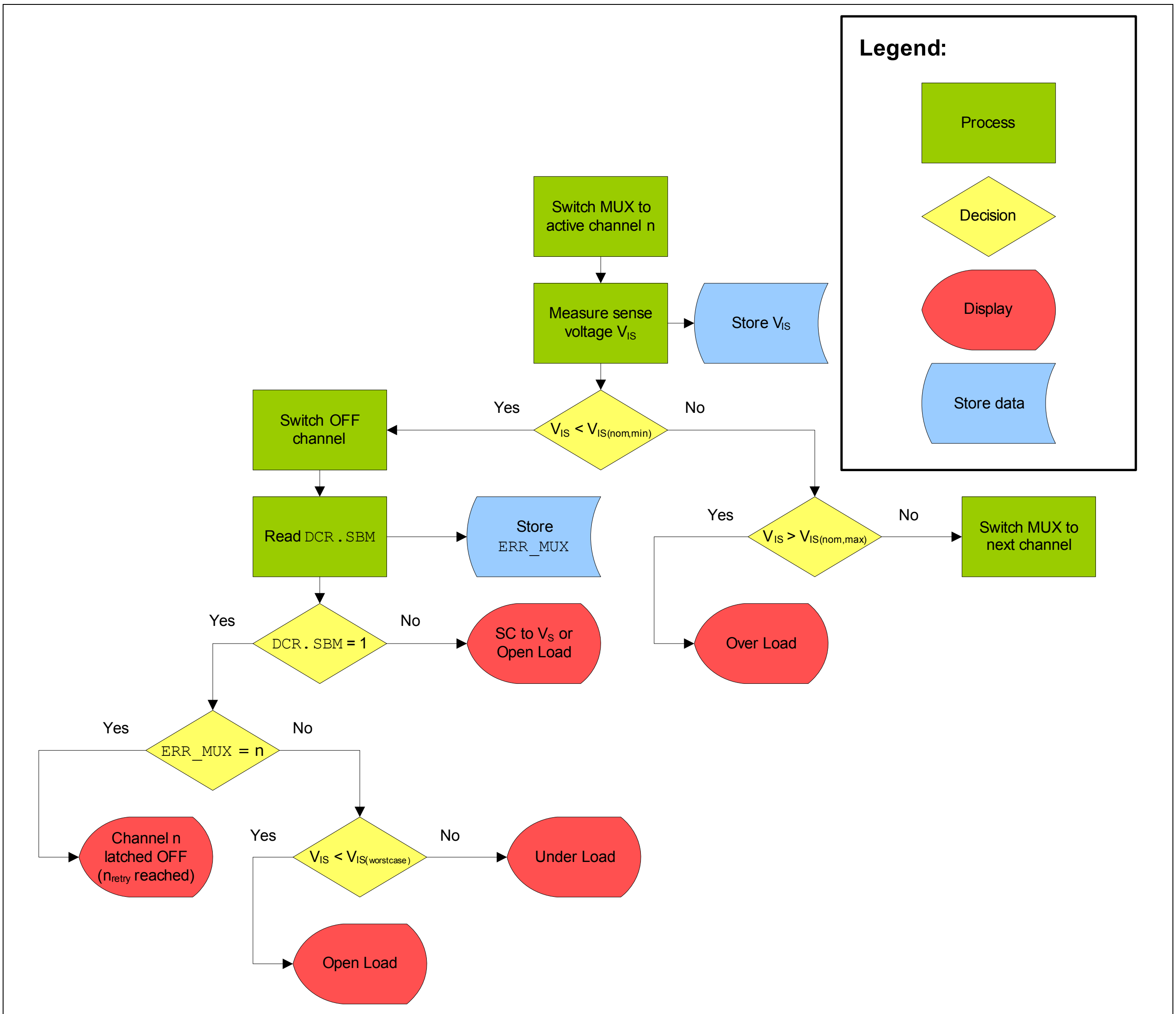

Figure 1 Decision flow chart to detect a Short Circuit to V_S or a Channel Latch OFF (n_{retry} reached)

With this software routine it is possible to distinguish between short circuit to V_S and over temperature. A complete differentiation between short circuit to V_S and open load is not possible, because during open load the output potential depends on leakage currents. This can also cause a V_{DS} voltage below $V_{DS(SB)}$. Therefore, the open load case may behave like a short circuit to V_S.

For the determination of $V_{IS(nom,min)}$ and $V_{IS(nom,max)}$ please refer to the following two equations.

$$V_{IS(nom,\min)} = \frac{I_{nom,\min}}{k_{ILIS,\max}} \cdot R_{IS,\min} \tag{1}$$

$$V_{IS(nom,\max)} = \frac{I_{nom,\max}}{k_{ILIS,\min}} \cdot R_{IS,\max} \tag{2}$$

For the determination of $V_{IS(worstcase)}$ please refer to the following calculation.

For example: The nominal load of channel 0 is a 21 W bulb. But it is also possible to put a 10 W or 5 W bulb into the socket of the 21 W load. Therefore, it might be interesting to recognize, if there is an open load or only a wrong bulb connected. The implementation of a V_{IS} threshold with a value of 0.25 V for a sense resistor R_{IS} = 2.7 kΩ is recommended. So, if the V_{IS} voltage is below this threshold, then an Open Load failure is detected, otherwise a Under Load current caused the failure.

The following calculation shows an example with typical values in bulb-mode, how the minimum sense voltage can be calculated. For channels with LED-mode higher accuracies can be achieved by switching into LED-mode. The switch into LED-mode can be done dynamically also when the channel is switched ON.

Nominal current of a 10 W bulb: $I_{nom,10W}$ = 0.74 A

Typical k_{ILIS} ratio for channel 2 in bulb-mode: k_{ILIS} = 2000

Typical sense resistor: R_{IS} = 2.7 kΩ

$$V_{IS} = \frac{I_{nom,10W}}{k_{ILIS}} \cdot R_{IS} = \frac{0.74}{2000} \cdot 2700 = 1 \tag{3}$$

For the worst case calculation the following formula should be used:

$$V_{IS(worstcase)} = \frac{I_{nom,10W\ \min}}{k_{ILIS,\max}} \cdot R_{IS,\min} \tag{4}$$

The implemented threshold should be below this value.

3.2 Use of SBM for Differentiation between Short Circuit to VS and Open Load

If a short circuit to V_S should be distinguished from an open load (e.g. broken bulb) an external output pull down resistor is required. The following figure shows the circuit with the additional output pull down resistor R_{OUT_pd}:

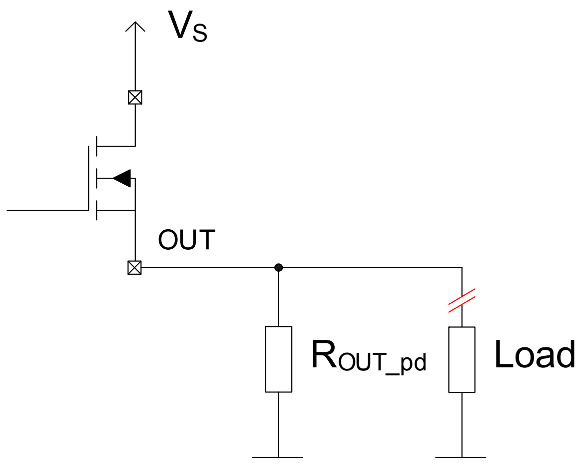

Figure 2 External Circuit for Open Load Detection in OFF state

With the following formula the output pull down resistor R_{OUT_pd} can be calculated to ensure during open load condition that device and system leakage currents do not cause the bit `DCR.SBM` to transition to a logic 0.

$$R_{OUT\_pd} < \frac{V_S - V_{DS(SB),\max}}{I_{L(OFF),\max} + I_{SystemLeakage}} \tag{5}$$

Taking V_S = 9 V, $V_{DS(SB),max}$ = 4.5 V, $I_{L(OFF),max}$ = 50 µA and neglecting system leakages for the moment, the resulting R_{OUT_pd} should be smaller than 90 kΩ.

The following figure shows the flow chart for the software strategy to distinguish between an Open Load and a short circuit to V_S failure:

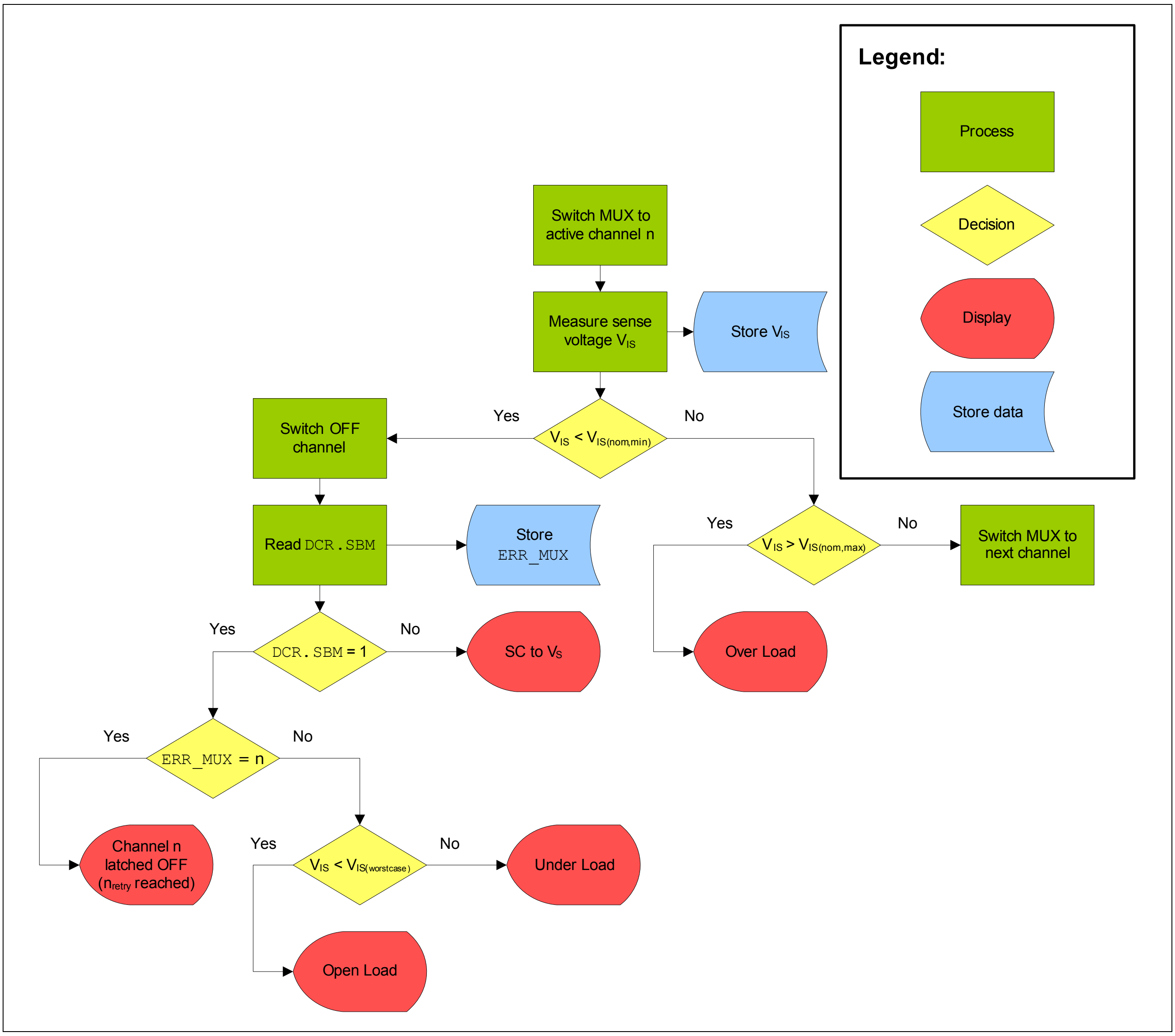

Figure 3 Decision flow chart to detect a Short Circuit to V_S, a Channel Latch OFF (n_{retry} reached) or an Open Load

In the figure above a the differentiation between open load and a too low load current can be done by the implementation of a V_{IS} threshold voltage as described in the **Chapter 3.1**

3.3 Detection and Reaction strategies

The software procedures shown in **Chapter 3.1** and **Chapter 3.2** can be used for "single event detection", meaning that each procedure execution will determined whether there is an Open Load, a Short Circuit to V_S, or a channel latched OFF (which would be a clear indication of Short Circuit to Ground) at the time of execution. In Automotive enviroment such failure conditions can be also intermittent. In such case a "single event detection" strategy represents a too high risk for the application. For this reason OEMs usually implement a "multiple event detection" strategy. Some possible examples are:

- "n" events detected in a row (this is the simplest approach - n = 3 or 5 for loads where a fast detection is preferable to wrong detectiona)
  – this is the simplest approach
  – n = 3 or 5 for loads where a fast detection is preferable to a wrong detection (Turning lights, Stop lights)
  – n = 10 or more if the loads are less critical
- "n" events detected out of "m" load activation cycles (where n < m)
- "n" events within a given timeframe (for instance, the time between two ingnition key activations)
- "n" events detected in a row, with increased time delay between load activation attempts

While it is possible to detect an Open Load or a Short Circuit to V_S when the load is OFF, the detection of a Short Circuit to Ground requires at least one activation (in other words, an ON phase). In modern automotive applications hardly this represents a problem. In general many lamps or LED are operated in PWM, with frequency range from 80 Hz to 200 Hz. In this way each load can have a diagnosis in ON and one in OFF within a short (12 ms for 80 Hz) timeframe.

When the multiple event detection condition is reached, the microcontroller reacts accordingly. Both Detection and Reaction strategies can be different from OEM to OEM, although some elements are common because fixed by law. For example a malfunction (Open Load, Short Circuit to Ground, Short Circuit to V_S) detected at one lamp or LED used for as Turning light forces a double intermittance frequency on the others Turning lights.

The general response to a detection (valid for any malfunction) can include:

- load deactivation
- blinking at double frequency for the other loads with the same function (Turning lights)
- warning lamp on the dashboard or a warning message displayed on the board computer (optional, normally reserved to premium cars)

A simplified general strategy for Detection and Reaction can be the following:

1. Perform diagnostic procedure on every PWM cycles
   – In case of many loads with different PWM frequency, the slowest one (the one with the lowest frequency) should be taken as reference
   – Diagnostic in ON state and in OFF state should be done at least once for every PWM cycle of the reference load
2. Perform a "multiple event detection"
   – Turning lights: 3 events in a row, or 4 events in 6 diagnosis cycles
   – Stop lights: 5 events in a row, or 7 events in 10 diagnosis cycles
   – Other lights (Head Lamp, Tail Lamp, etc.): 10 events in a row, where the first activation is driven by the user and the other 9 are controlled by the microcontroller to attempt an error recovery
3. Adapt the reaction to the load type
   – Turning lights: load deactivated - other Turning lights blinking at double frequency
   – Stop lights: load deactivated
   – Other lights (Head Lamp, Tail Lamp, etc.): load deactivated

4 Conclusion

By the use of the Switch Bypass Monitor it is possible to distinguish between the operation modes described in **Chapter 2**. Therefore, a sophisticated software strategy is required.

Summary:

- Without any external hardware it is possible to distinguish between short circuit to V_S, channel latched OFF and an Under Load. A complete differentiation between short circuit to V_S and Open Load is not possible.
- By using an external output pull down resistor it is possible to distinguish between short circuit to V_S, Open Load, channel latched OFF and Under Load conditions.

5 Additional Information

The following table shows the corresponding SPI commands needed for the flow charts showed in **Figure 1** and **Figure 3**. Further information about SPOC™+ 12V SPI protocol are available in product datasheets.

Table 4 SPI commands for flow chart "processes"

Requested Operation	Frame sent to SPOC+ (SI pin)	Frame received from SPOC+ (SO pin) with the next command
Switch MUX to active channel "n"	`11110aaa`$_B$ where "`aaa`$_B$" = n - 1 in binary example: when MUX must be set to channel 3 the corresponding command is `11110010`$_B$ (3 - 1 = 2 → 010 in binary)	`0aaaaaaa`$_B$ (Standard Diagnosis)
Switch OFF channel "n"	`10aaaaaa`$_B$ where "`aaaaaa`$_B$" is the content that needs to be written in the Output Configuration Register OUT. The number of bits that can be written depends on the SPOC™+ 12V product used.	`0aaaaaaa`$_B$ (Standard Diagnosis)
Read `DCR.SBM` bit	`01110000`$_B$	`1111abbb`$_B$ where: "`a`$_B$" = `DCR.SBM` status "`bbb`$_B$" = `DCR.MUX` status

6 Revision History

Revision	Date	Changes
Rev. 1.0	2013-09-25	Application Note released

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