Off-state diagnostics with TLE9563/64

About this document

Scope and purpose

This application note provides information about the off-state diagnostic features of the TLE9563/64.

It should be used in conjunction with the corresponding datasheet, which contains full technical details on the device specification and operation.

Intended audience

Developers working with the TLE956x devices.

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1 Introduction

The Motor System IC family (TLE956x) is a multi-half-bridge MOSFET driver, which combines power, communication and supply.
All devices feature a low-dropout voltage regulator with an output current of 250mA/5V. The communication interface incorporates a CAN FD transceiver up to 5Mbit/s according to ISO 11898-2:2016 (including Partial Networking option) and/or LIN transceiver.
All devices are available in a VQFN-48 (7mm x 7mm) package.

The devices offer a wide range of diagnostic features for the bridge driver both in on-state and in off-state. This application note focuses on the **off-state diagnostic features**.

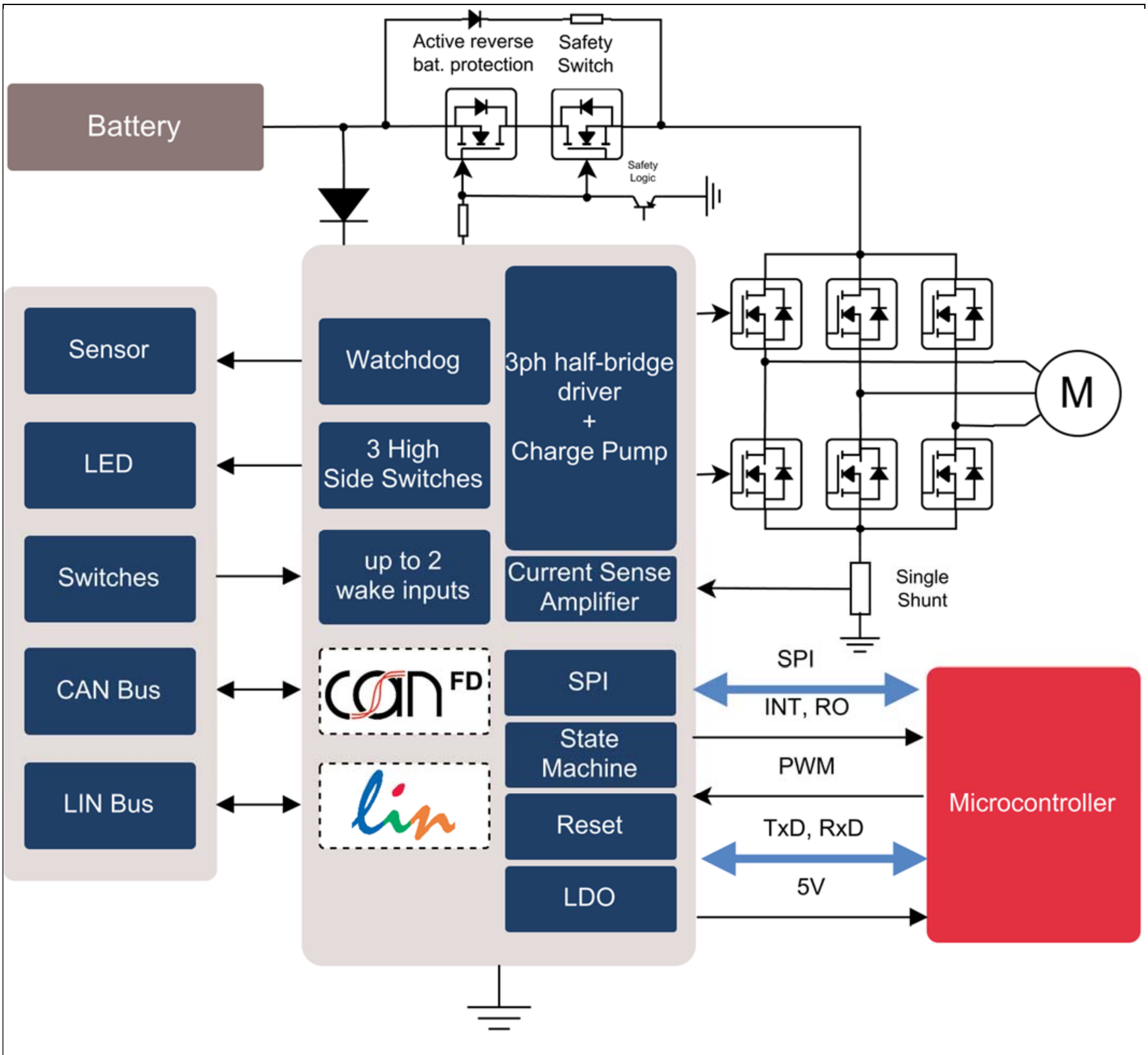

Figure 1 **TLE9563/64 block diagram**

2 Off-state diagnostic general principles

2.1 Benefits

The off-state diagnostic feature (i.e. the MOSFETs are off while the diagnostic is performed) offers several advantages:

- Diagnostic checks can be regularly performed even for loads that are infrequently activated
- MOSFET short circuits are detected without the stress inherent to the on-state diagnostic mode (note that on-state diagnostic is also available TLE956x). For example, the microcontroller can perform an off-state diagnostic right before the activation request. Upon the fault condition, the application software can report the failure and inhibits the load activation, avoiding any stress to the MOSFETs.

2.2 Required settings

The bridge driver is activated and the associated MOSFETs are off:

- The device is in **Normal Mode**
- The bridge driver is in active mode: **CPEN = 1_B** (charge pump enabled)
- The MOSFETs are actively kept off: **HBxMODE[1:0] = 11_B**
- It is highly recommended to set the drain-source overvoltage threshold ($V_{DSMONTH}$) of the diagnosed half-bridge to its maximum value for a robust diagnostic: **HBxVDSTH[2:0] = 111_B**, $V_{DSMONTH}$ = 2 V typ. (datasheet parameter $V_{DSMONTH7\_CPON}$)*.

*It is recommended to restore the setting of $V_{DSMONTH}$ once the off-state diagnostic is performed for an appropriate MOSFET protection in on-state.

2.3 Detectable failures by the off-state diagnostic

The TLE956x enables the detection of the following fault conditions while the MOSFETs are deactivated:

- Short-circuit between SHx and VBAT
- Short-circuit between SHx and GND
- Open load

SHx designates the output of the half-bridge x, VBAT is the battery voltage

2.4 Theory of operation

Figure 2 shows the block diagram of the gate drivers of one half-bridge.

The following integrated components are used to perform the off-state diagnostic:

- Pull-up diagnostic current (I_{PUDIAG})
- Pull-down diagnostic current (I_{PDDIAG})
- Comparator for the high-side drain-source overvoltage

Note: I_{PUDIAG} is a by-product of the drain-source overvoltage monitoring for each high-side MOSFET. It is automatically activated when the bridge driver is in active mode (CPEN = 1_B and the considered half-bridge is actively kept off: HBxMODE[1:0] = 11_B)

Note: I_{PDDIAG} can be individually activated for each half-bridge only if the bridge driver is activated and the considered half-bridge is actively kept off

By design I_{PDDIAG} > 4.25 x I_{PUDIAG}. Typically I_{PUDIAG} = 400 µA, I_{PDDIAG} = 2200 µA.

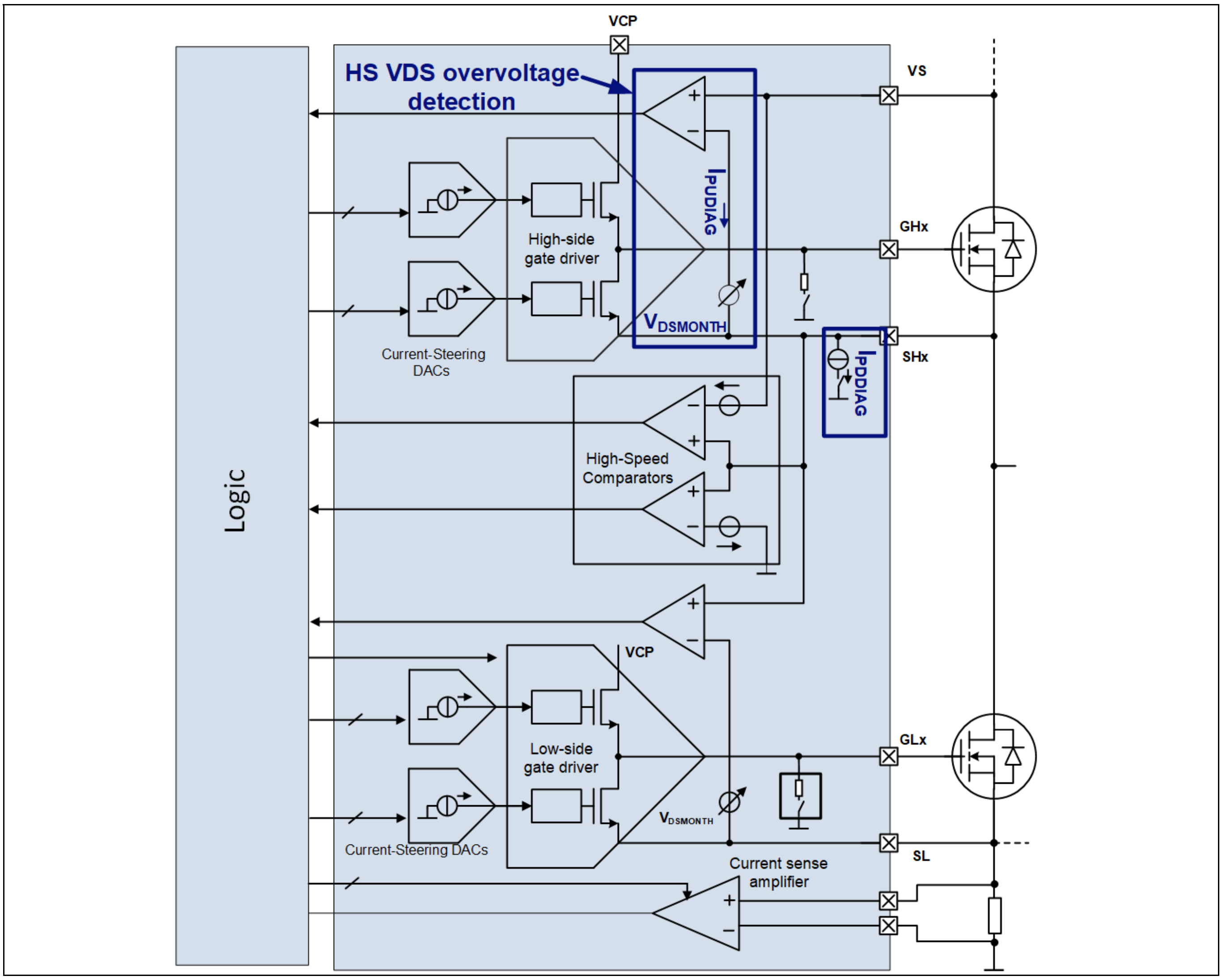

Figure 2 Block diagram of one half-bridge gate driver

The TLE956x determines the voltage at SHx, using the drain-source overvoltage comparators of the high-side MOSFETs. The microcontroller can read the status bits HBxVOUT to determine if V_{SHx} is high or low.

The diagnostic process is controlled by the microcontroller, whose task is:

- To activate and deactivate I_{PDDIAG}, (refer to the control bits HBxIDIAG)
- To read and interpret the status bits HBxVOUT according to the setting of I_{PDDIAG}

2.5 Conventions

The following conditions are equivalent in the rest of this document:

- HBxVOUT = 0: V_{SHx} is low ($V_S - V_{SHx} > V_{DSMONTH}$)
- HBxVOUT = 1: V_{SHx} is high ($V_S - V_{SHx} < V_{DSMONTH}$)

V_S designates the voltage applied to the VS pin. In particular, it is also the drain voltage of the high-side MOSFETs.

- HBxIDIAG = 0: I_{PDDIAG} of HBx is off
- HBxIDIAG = 1: I_{PDDIAG} of HBx is on

3 Off-state diagnostic

The proposed principle consists in analyzing V_{SHx} in the different load conditions, when all pull-down diagnostic currents are deactivated, and when two out of three pull-down diagnostic currents are activated.

Note: An off-state diagnostic activating one pull-down out of three is also possible, considering that $I_{PDDIAG} > 4.25 \times I_{PUDIAG}$. Consequently, one single pull-down is stronger than the sum of the three pull-ups. However, the net pull-down current in normal conditions is $I_{PDDIAG} - 3 \times I_{PUDIAG}$ (compared to $2 \times I_{PDDIAG} - 3 \times I_{PUDIAG}$ when two pull-down currents are activated). Therefore the net discharge current is lower and the settling time for discharging output capacitors is longer.

Table 1 Configurations of the pull-down diagnostic currents

Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3
Configuration 1	OFF	OFF	OFF
Configuration 2	ON	ON	OFF
Configuration 3	OFF	ON	ON
Configuration 4	ON	OFF	ON

3.1 Normal condition

It is assumed that the motor is correctly connected without any short circuit between SHx and VBAT or GND.

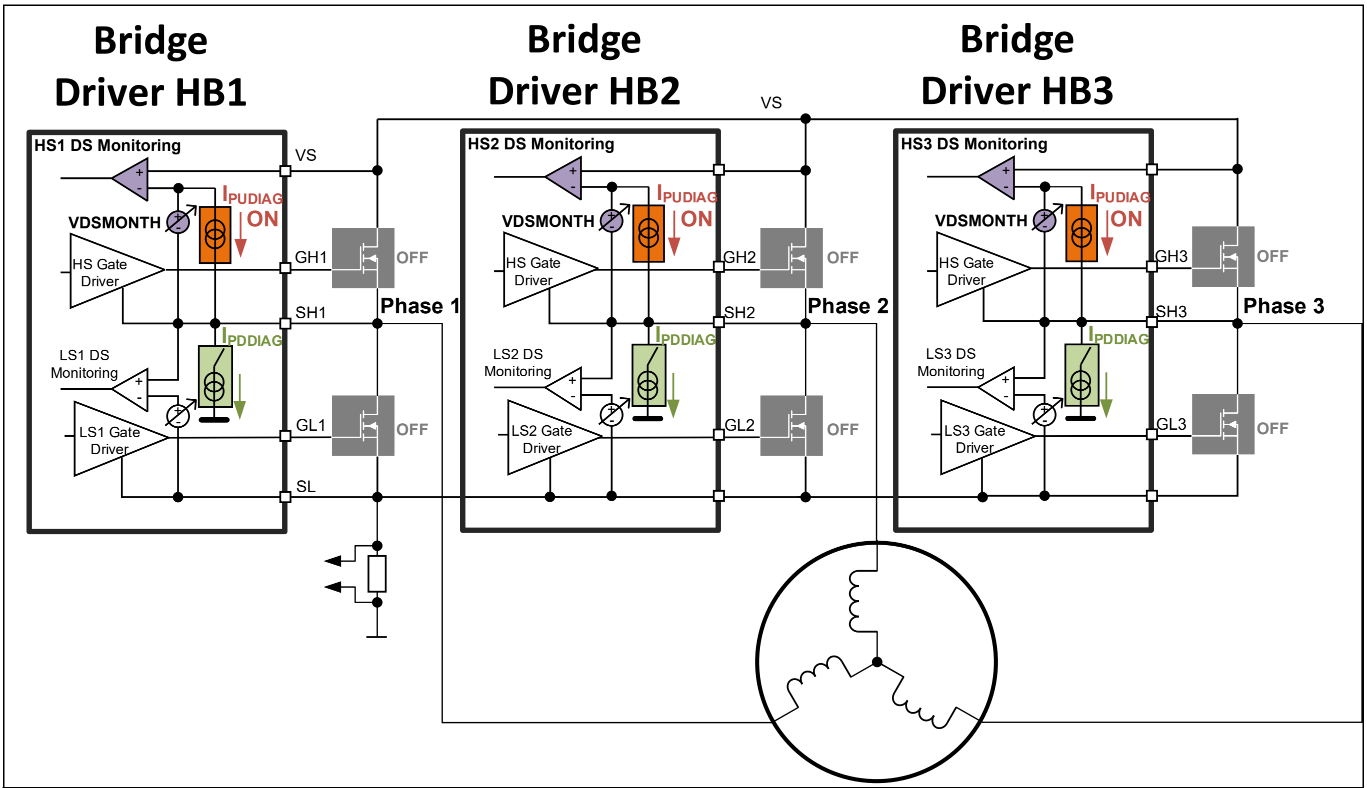

Figure 3 Off-state diagnostic in normal load conditions, CPEN = 1, HBxMODE[1:0] = 11_B

Condition 1: I_{PDDIAG} HB1 OFF, I_{PDDIAG} HB2 OFF, I_{PDDIAG} HB3 OFF

No pull-down is activated. Therefore SH1, SH2 and SH3 are pulled up by the I_{PUDIAG} of each half-bridges. Refer to Figure 4.

$V_{SH1} = V_{SH2} = V_{SH3}$ = High

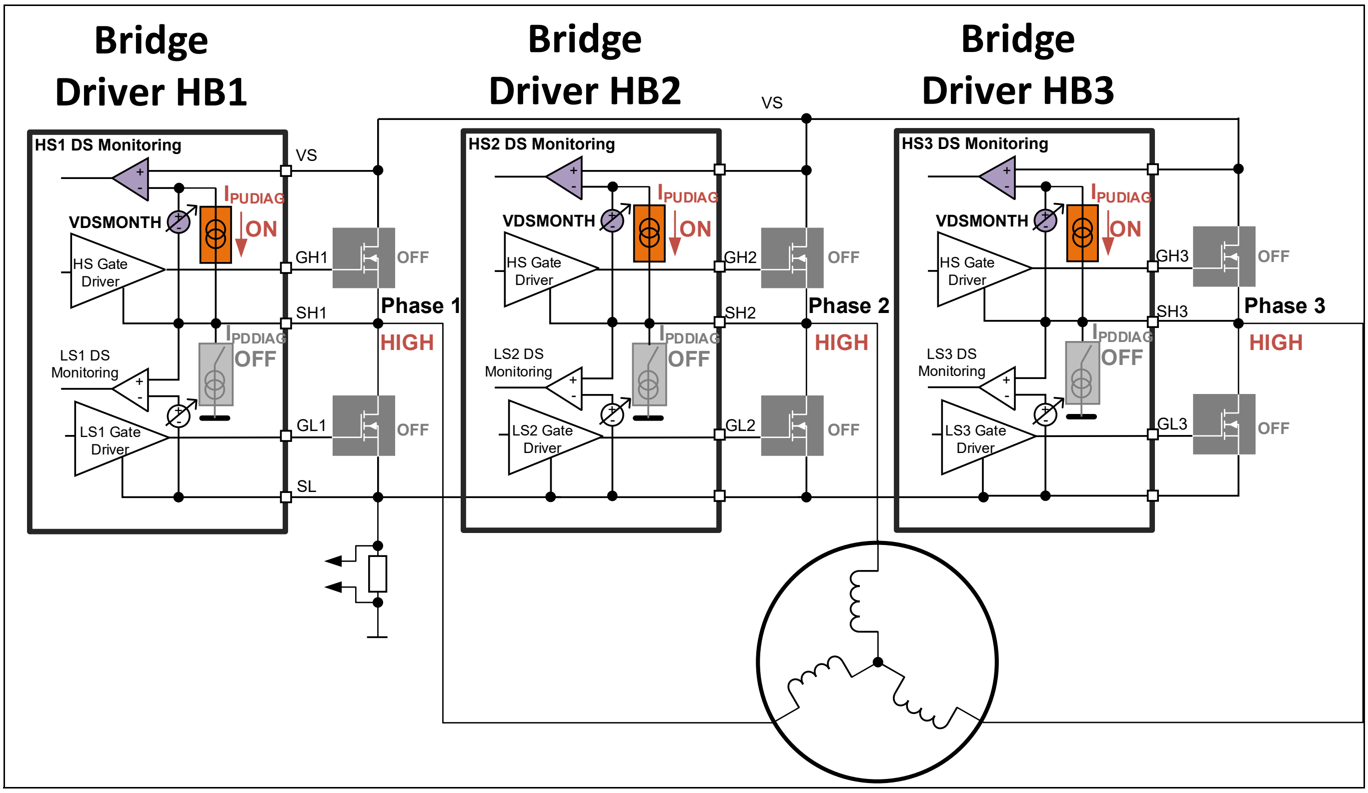

Figure 4 **Normal load conditions in Configuration 1**

Configuration 2: I_{PDDIAG} HB1 ON, I_{PDDIAG} HB2 ON, I_{PDDIAG} HB3 OFF

By design I_{PDDIAG} > 4.25 x I_{PUDIAG}. When the pull-down and pull-up diagnostic currents of a half-bridge are activated (like for HB1 and HB2 in Configuration 2), it results in a net pull-down current in the considered half-bridge equal to I_{PDDIAG} - I_{PUDIAG}.

The net pull-down current in Configuration 2 is 2 x I_{PDDIAG} - 3 x I_{PUDIAG}, therefore **V_{SH1} = V_{SH2} = V_{SH3} = low**.

*Note: SH3 is also pulled to GND by I_{PDDIAG} of HB1 and HB2 through the motor windings → **V_{SH3} = low**.*

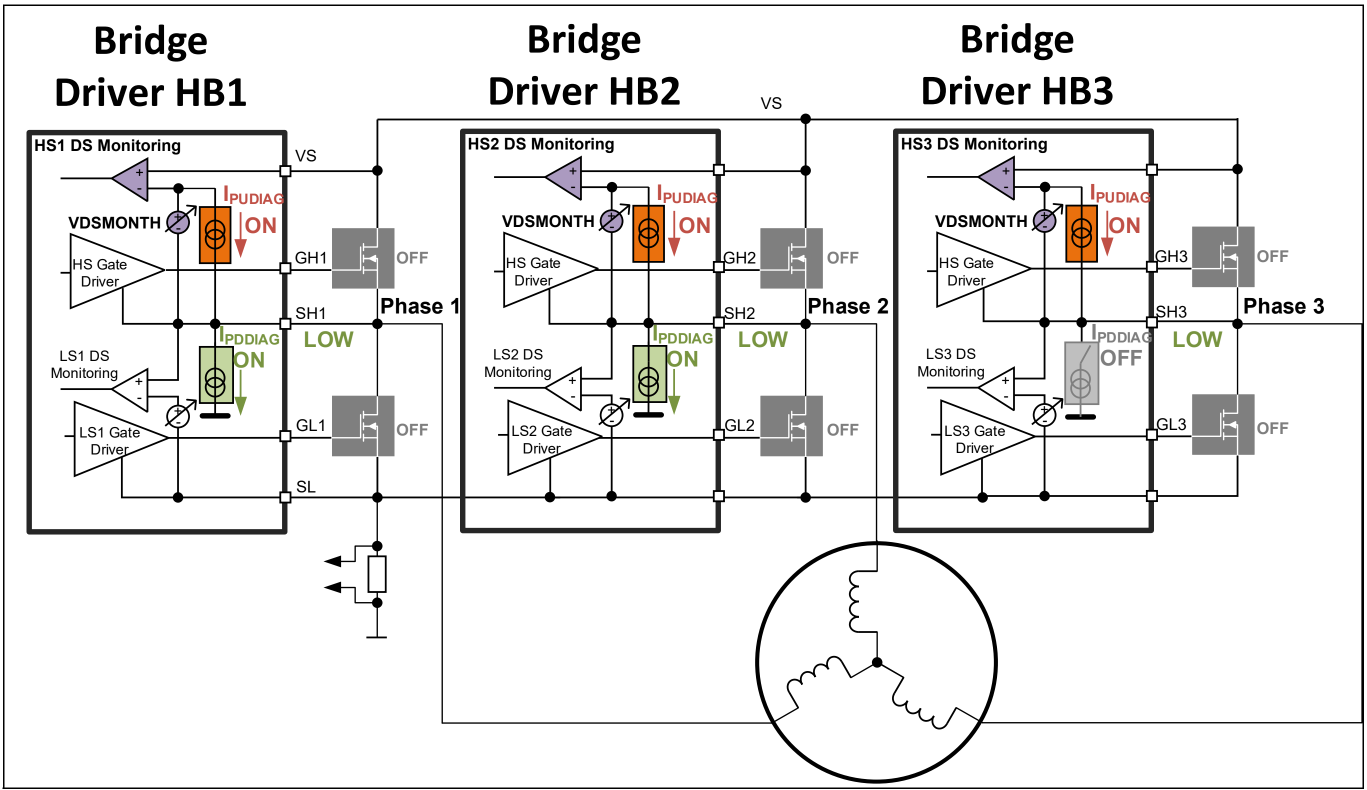

Figure 5 **Normal load conditions in Configuration 2**

Note: When capacitors are connected to SHx (e.g. ESD capacitors placed on the PCB, or filter capacitors located in the motors), these capacitors are charged / discharged by the sum of the diagnostic currents of each half-bridge. Therefore, the application must take into consideration this charge / discharge times for a valid determination of the voltage level at the SHx pins

Configuration 3 and Configuration 4:
Likewise **V_{SH1} = V_{SH2} = V_{SH3} = low** in Configuration 3 and Configuration 4

Table 2 summarizes the results obtained in normal conditions.

Table 2 **Truth table with normal load conditions**

Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
Configuration 1	OFF	OFF	OFF	High	High	High
Configuration 2	ON	ON	OFF	Low	Low	Low
Configuration 3	OFF	ON	ON	Low	Low	Low
Configuration 4	ON	OFF	ON	Low	Low	Low

3.2 Short circuit to VBAT

A short circuit between one of the phases and VBAT results in **V_{SH1} = V_{SH2} = V_{SH3} = high**, independently from the activation of I_{PDDIAG}.

Table 3 summarizes the results obtained with a short circuit of one phase to VBAT.

Table 3 Truth table with a short circuit to VBAT

Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
Configuration 1	OFF	OFF	OFF	High	High	High
Configuration 2	ON	ON	OFF	High	High	High
Configuration 3	OFF	ON	ON	High	High	High
Configuration 4	ON	OFF	ON	High	High	High

3.3 Short circuit to GND

A short circuit between one of the phases and GND results in **V_{SH1} = V_{SH2} = V_{SH3} = Low**, even if some I_{PDDIAG} are activated.

Table 4 summarizes the results obtained with a short circuit of one phase to GND.

Table 4 Truth table with a short circuit to GND

Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
Configuration 1	OFF	OFF	OFF	Low	Low	Low
Configuration 2	ON	ON	OFF	Low	Low	Low
Configuration 3	OFF	ON	ON	Low	Low	Low
Configuration 4	ON	OFF	ON	Low	Low	Low

3.4 Open load conditions

This chapter describes a method to detect open load failures.

3.4.1 Disconnected phase at SH3

This section proposes to detect an open load failure at SH3, by analyzing the VSHx levels in the different pull-down configurations.

Configuration 1: I_{PDDIAG} HB1 OFF, I_{PDDIAG} HB2 OFF, I_{PDDIAG} HB3 OFF

SH1, SH2 and SH3 are pulled up by their pull-up diagnostic currents: $V_{SH1} = V_{SH2} = V_{SH3}$ = **High**

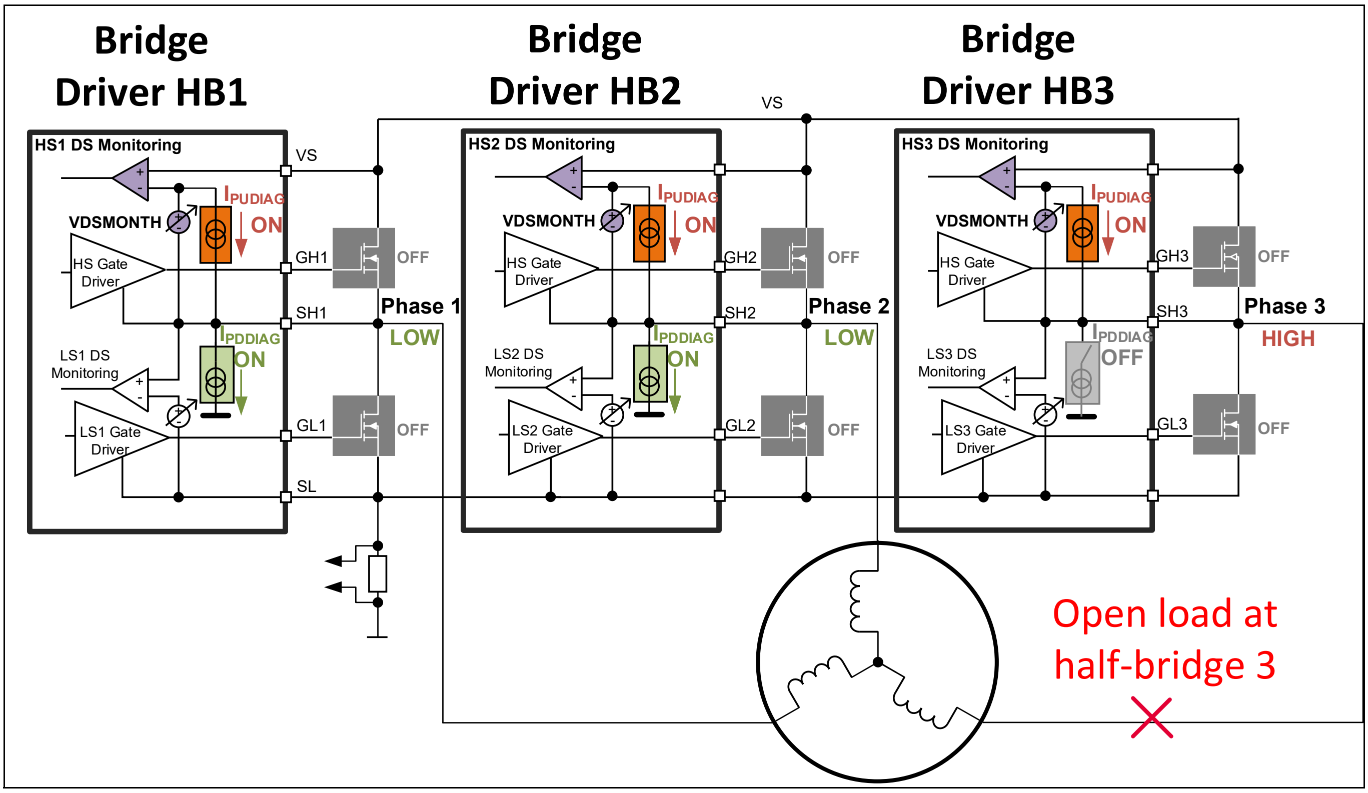

Figure 6 Open load conditions at SH3 in Configuration 1

Configuration 2: I_{PDDIAG} HB1 ON, I_{PDDIAG} HB2 ON, I_{PDDIAG} HB3 OFF

SH1 and SH2 are pulled down by the net pull-down current 2 x I_{PDDIAG} - 2 x I_{PUDIAG}: **V_{SH1} = V_{SH2} = low**

Due to the disconnection at the phase 3, SH3 is pulled up by I_{PUDIAG} of HB3: **V_{SH3} = high**

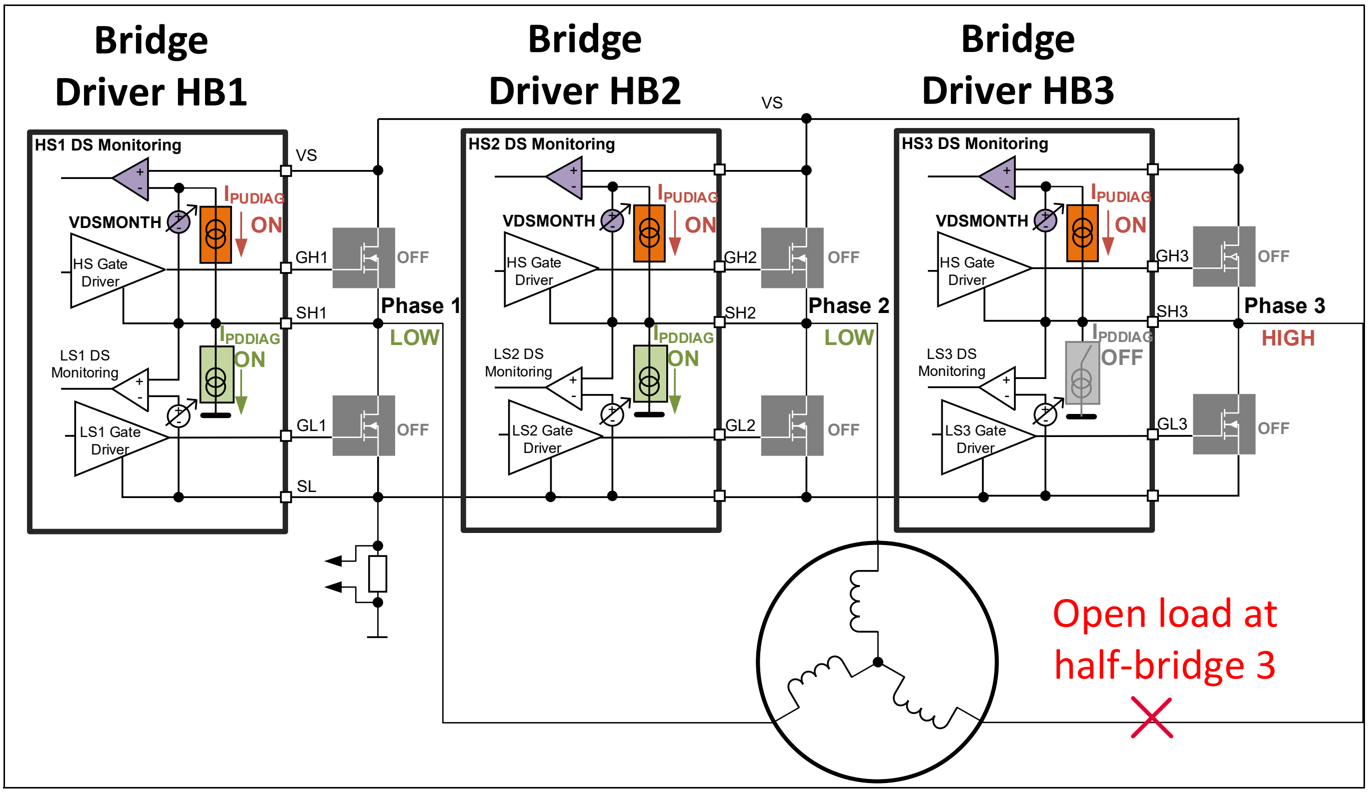

Figure 7 **Open load conditions at SH3 in Configuration 2**

Configuration 3: I_{PDDIAG} HB1 OFF, I_{PDDIAG} HB2 ON, I_{PDDIAG} HB3 ON

SH1 and SH2 are pulled down by the net pull-down current I_{PDDIAG} - 2 x I_{PUDIAG}: **V_{SH1} = V_{SH2} = low**

SH3 is pulled down by I_{PDDIAG} of HB3 (the net pull-down current is I_{PDDIAG} - I_{PUDIAG}): **V_{SH3} = low**

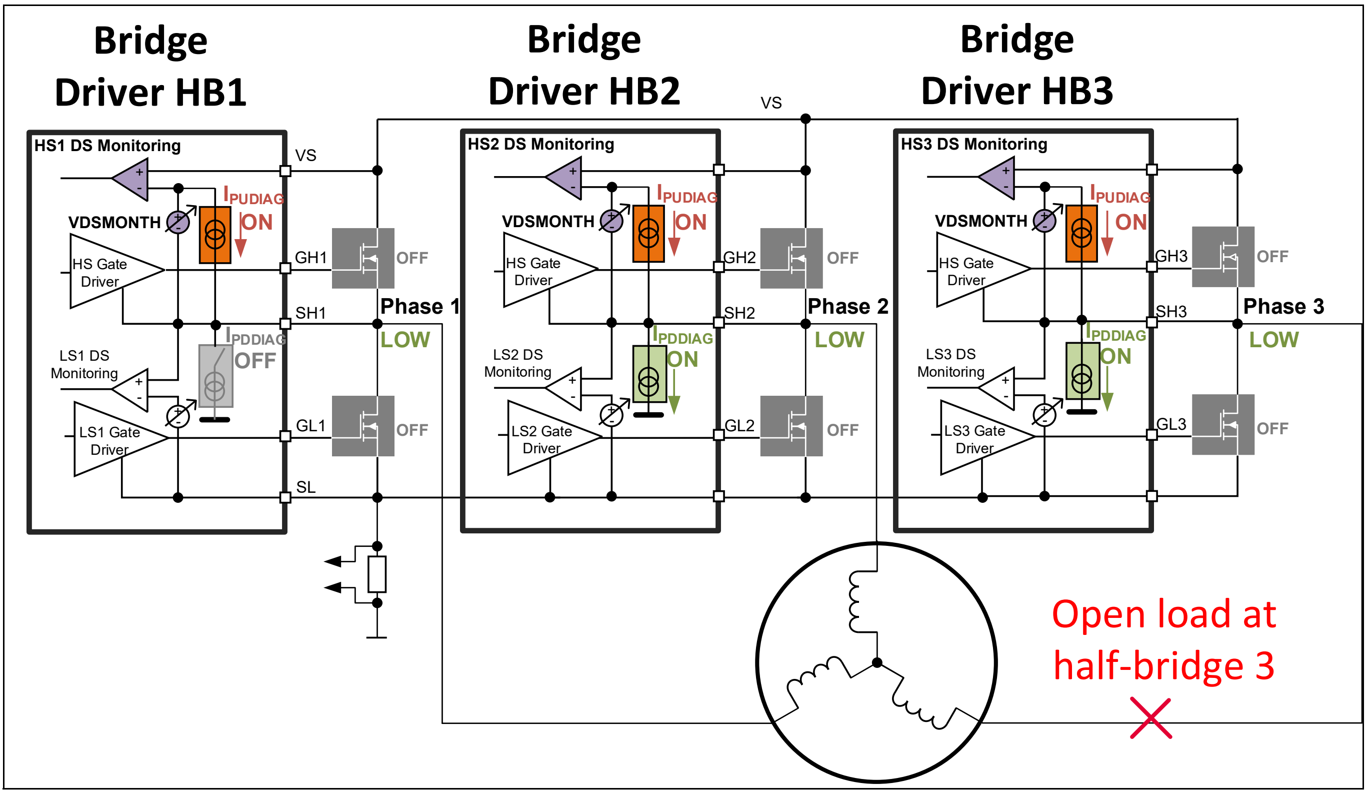

Figure 8 **Open load conditions at SH3 in Configuration 3**

Configuration 4: I_{PDDIAG} HB1 ON, I_{PDDIAG} HB2 OFF, I_{PDDIAG} HB3 ON

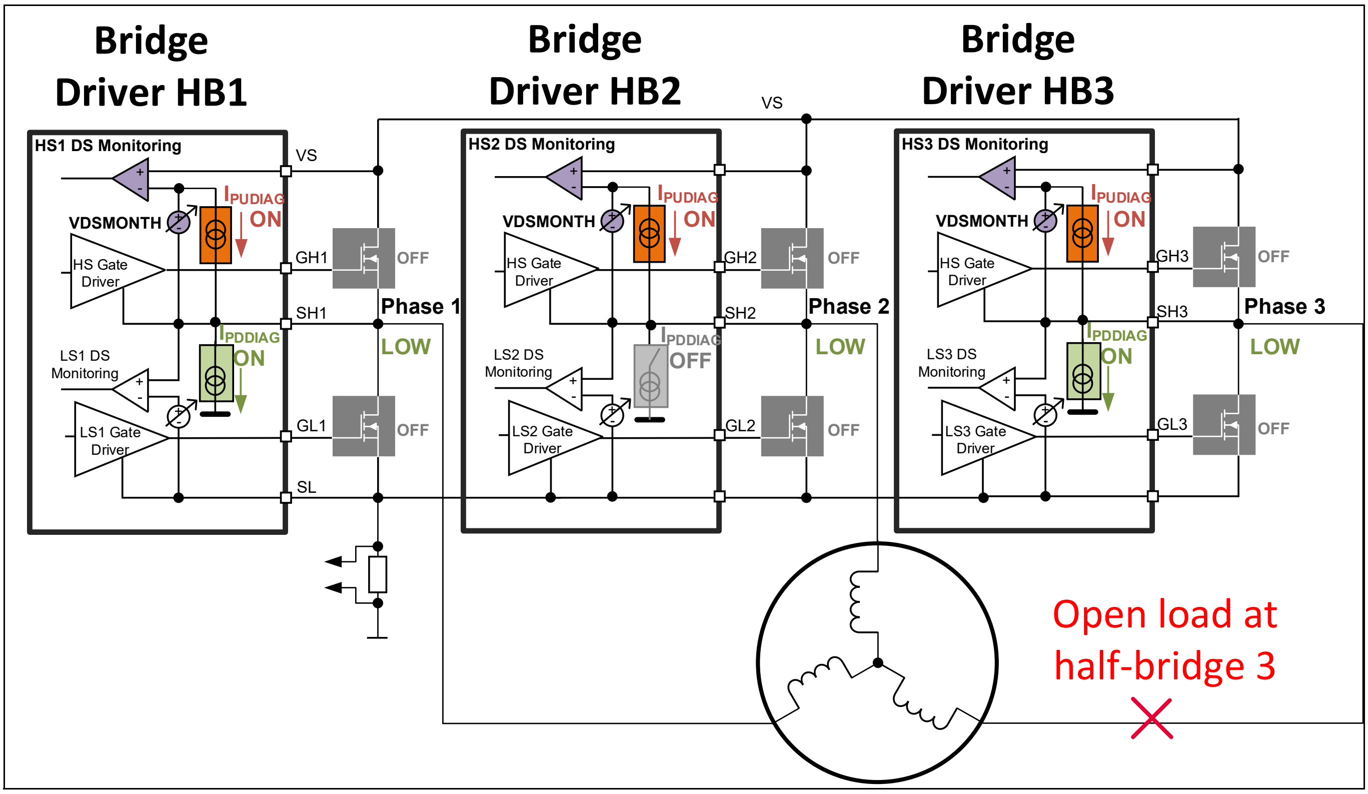

Figure 9 Open load conditions at SH3 in Configuration 4

Table 5 summarizes the results obtained in case of an open load failure at SH3

Table 5 Truth table – Open load at SH3

Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
Configuration 1	OFF	OFF	OFF	High	High	High
Configuration 2	ON	ON	OFF	Low	Low	High
Configuration 3	OFF	ON	ON	Low	Low	Low
Configuration 4	ON	OFF	ON	Low	Low	Low

3.4.2 Summary of the off-state diagnostic with open load conditions

Table 6 summarizes the analysis done in 3.4.1 and extends the truth table to open load failures at SH1 and SH2 with the pull-down configurations shown in Table 1.

Table 6 Truth table – Open load at SH1, SH2 and SH3 using the pull-down configurations 1 o 4

Load conditions	Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
OL* at SH1	Configuration 1	OFF	OFF	OFF	High	High	High
	Configuration 2	ON	ON	OFF	Low	Low	Low
	Configuration 3	OFF	ON	ON	High	Low	Low
	Configuration 4	ON	OFF	ON	Low	Low	Low
OL* at SH2	Configuration 1	OFF	OFF	OFF	High	High	High
	Configuration 2	ON	ON	OFF	Low	Low	Low
	Configuration 3	OFF	ON	ON	Low	Low	Low
	Configuration 4	ON	OFF	ON	Low	High	Low
OL* at SH3	Configuration 1	OFF	OFF	OFF	High	High	High
	Configuration 2	ON	ON	OFF	Low	Low	High
	Configuration 3	OFF	ON	ON	Low	Low	Low
	Configuration 4	ON	OFF	ON	Low	Low	Low

*OL: Open Load

Table 7 shows the diagnostic results of an open load failure when one single pull-down is activated at a time.

Table 7 Truth table – Open load at SH1, SH2 and SH3. One pull-down is activated at a time

Load conditions	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
OL at SH1	OFF	OFF	OFF	High	High	High
	ON	OFF	OFF	Low	High	High
	OFF	ON	OFF	High	Low	Low
	OFF	OFF	ON	High	Low	Low
OL at SH2	OFF	OFF	OFF	High	High	High
	ON	OFF	OFF	Low	High	Low
	OFF	ON	OFF	High	Low	High
	OFF	OFF	ON	Low	High	Low
OL at SH3	OFF	OFF	OFF	High	High	High
	ON	OFF	OFF	Low	Low	High
	OFF	ON	OFF	Low	Low	High
	OFF	OFF	ON	High	High	Low

3.5 Summary of the off-state diagnostic

Table 8 shows the diagnostic results with the different loads conditions.

We can see that each load condition have a different signature. It enables a distinction between a normal load condition, from a short circuit to GND / VBAT and an open load failure.

Table 8

Load conditions	Pull-down configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH2}
Normal load	Config 1	OFF	OFF	OFF	High	High	High
	Config 2	ON	ON	OFF	Low	Low	Low
	Config 3	OFF	ON	ON	Low	Low	Low
	Config 4	ON	OFF	ON	Low	Low	Low
Short-circuit to VBAT	Config 1	OFF	OFF	OFF	High	High	High
	Config 2	ON	ON	OFF	High	High	High
	Config 3	OFF	ON	ON	High	High	High
	Config 4	ON	OFF	ON	High	High	High
Short-circuit to GND	Config 1	OFF	OFF	OFF	Low	Low	Low
	Config 2	ON	ON	OFF	Low	Low	Low
	Config 3	OFF	ON	ON	Low	Low	Low
	Config 4	ON	OFF	ON	Low	Low	Low
OL at SH1	Config 1	OFF	OFF	OFF	High	High	High
	Config 2	ON	ON	OFF	Low	Low	Low
	Config 3	OFF	ON	ON	High	Low	Low
	Config 4	ON	OFF	ON	Low	Low	Low
OL at SH2	Config 1	OFF	OFF	OFF	High	High	High
	Config 2	ON	ON	OFF	Low	Low	Low
	Config 3	OFF	ON	ON	Low	Low	Low
	Config 4	ON	OFF	ON	Low	High	Low
OL at SH3	Config 1	OFF	OFF	OFF	High	High	High
	Config 2	ON	ON	OFF	Low	Low	High
	Config 3	OFF	ON	ON	Low	Low	Low
	Config 4	ON	OFF	ON	Low	Low	Low

Revision history

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1.0	2020-05-08	First release

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