Off-state diagnostics with TLE92108-231/232QX

About this document

Scope and purpose

This application note provides information about the off-state diagnostic features of the TLE92108-231/232QX. It should be used in conjunction with the TLE92108-231/232QX datasheet, which contains full technical details on the device specification and operation.

Intended audience

Developers working with the TLE92108-231/232QX.

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1 Introduction

The TLE92108-231/232QX are multiple MOSFET drivers, dedicated to control up to sixteen n-channel MOSFETs. They integrate eight half-bridge drivers for DC motor control applications such as automotive power seats, power lift gates, cargo cover, sunroof, door lock etc…

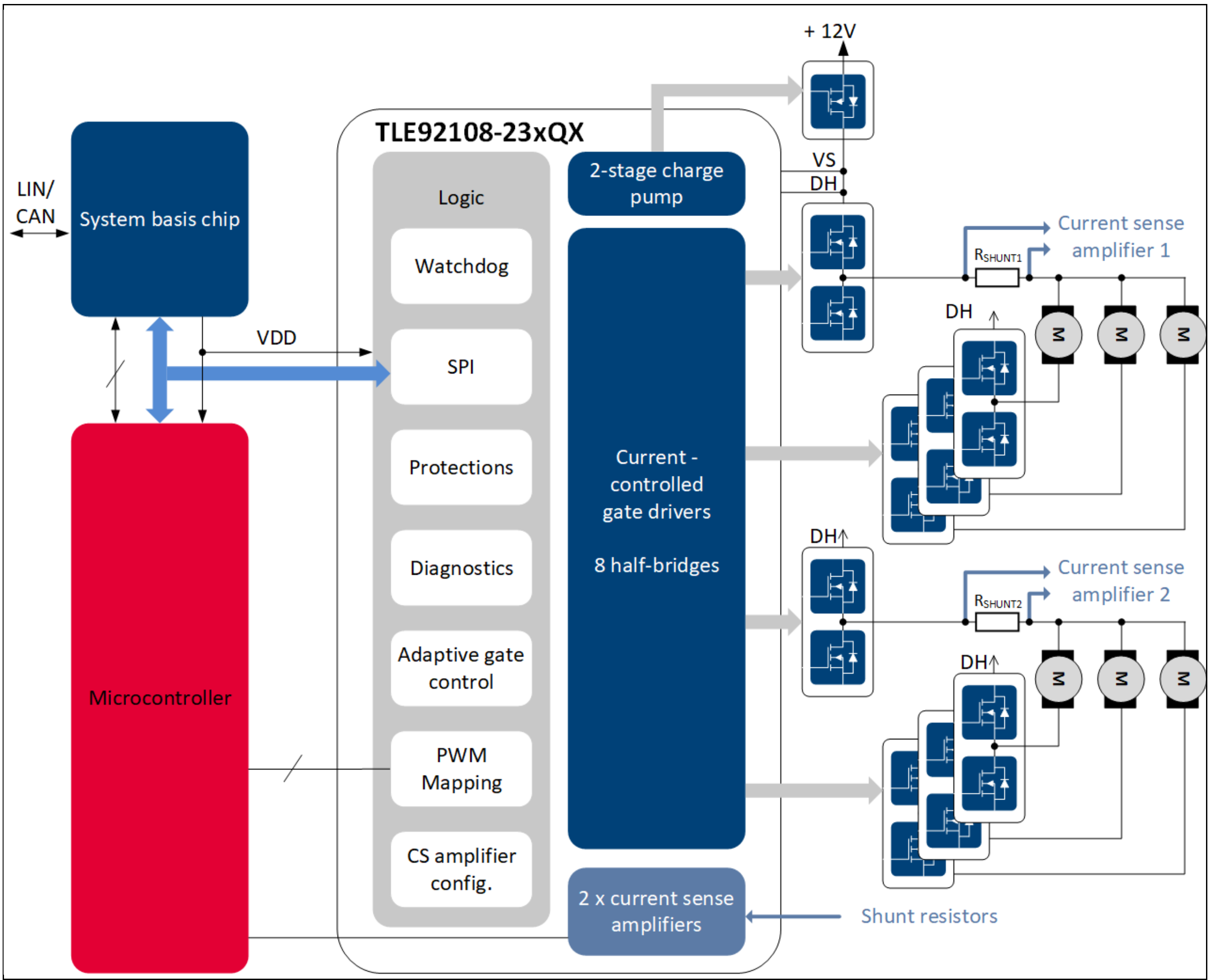


Figure 1 TLE92108-231/232QX block diagram in one of the possible half-bridge configurations

The devices offer a wide range of diagnostic features for the bridge driver both in on-state and in off-state. Refer to the corresponding datasheet for detailed information.

This application note focuses on the off-state diagnostic features of the half-bridge.

2 Off-state diagnostic general principles

2.1 Benefits

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

- Diagnostic checks can be performed for loads that are infrequently activated
- MOSFET short circuit conditions are detected without the stress inherent to on-state diagnostic mode (also available in the TLE92108-231/232QX). For example, the microcontroller can perform an off-state diagnostic right before the activation request of the load. 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 bridge driver is in active mode: EN = High and BD_PASS = 0
- The corresponding MOSFETs are off: HBxMODE[1:0] =00_B
- The device is operating operates in normal mode:
  - VS and VDD are in the normal operating range
  - No watchdog failure
- 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: If HBxVDSTH[2:0] = 111_B , x = 1 ..8, then $V_{DSMONTH}$ = 2 V typ. (datasheet parameter $V_{DSMONTH7}$)*.

*It it is highly 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 TLE92108-231/232QX enables the detection of the following fault conditions while the MOSFETs are deactivated:

- SHx is shorted to VBAT
- SHx is shorted to GND
- Open load

SHx designates the output of the half-bridge x (x = 1 … 8), VBAT is the battery voltage

2.4 Theory of operation

Figure 2 and Figure 3 show the block diagram of the gate drivers the half-bridges.

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 voltage (HS VDS) monitoring

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 (BD_PASS = 0 or one MOSFET is on: HBxMODE[1:0] = 01_B or 10_B)*

Note: *I_{PDDIAG} can be activated for each half-bridge only if the bridge driver is in active mode as set by the control bits HBxIDIAG, x = 1… 8*

By design $I_{PDDIAG} > 2 \times I_{PUDIAG}$ in order to allow the off-state diagnostic. Typically I_{PUDIAG} = 450 µA, I_{PDDIAG} = 1250 µA. Background information for this ratio is given in examples of chapter 3 and chapter 4.

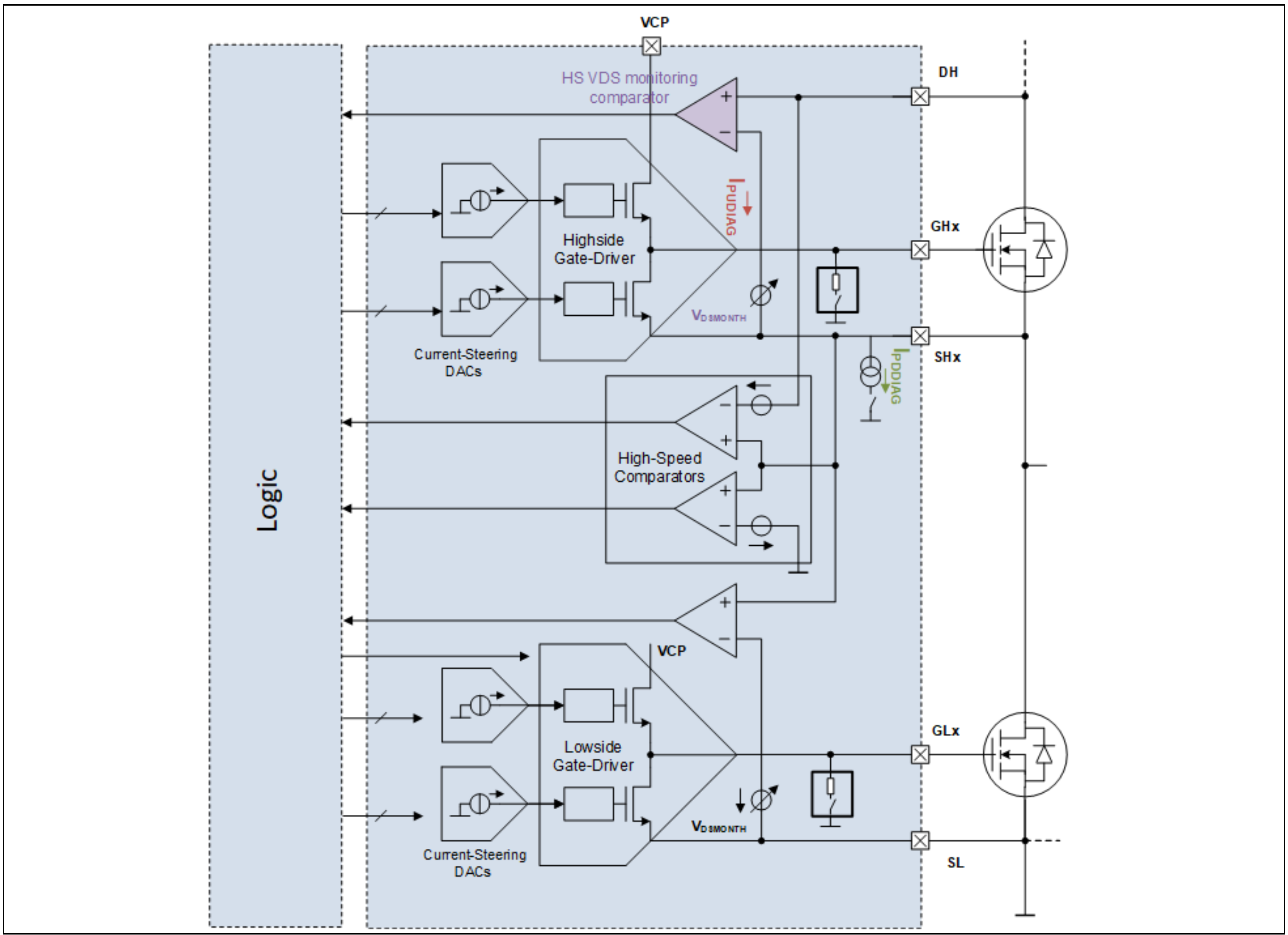


Figure 2 Block diagram of one half-bridge gate driver

The TLE92108-232/231 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 activates and deactivates I_{PDDIAG}, controlled by the control bits HBxIDIAG
- To read and interpret the status bits HBxVOUT while I_{PDDIAG} are on/off

2.5 Conventions

The following conditions are equivalent in the rest of this document

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

V_{DRAIN_HSx} designates the drain-source voltage of the high-side MOSFET x, x = 1 … 8

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

3 Off-state diagnostic with one DC motor

This chapter provides examples of off-state diagnostic for a single DC motor configuration.

3.1 Example with a DC motor controlled by two half-bridges

This section gives an example of off-state diagnostic with one DC motor controlled by the half-bridges 1 and 2 (HB1 and HB2).

Note: The high-side drains of the considered half-bridges can be connected to the DH pin or to CSIN1. The control bits HBxD, x = 1 … 8 must be configured accordingly. Refer to the datasheet.

This sub-chapter analyzes the voltage at SH1/SH2 (noted V_{SH1}/V_{SH2}) in the following test configurations:

- Configuration 1: I_{PDDIAG} HB1 OFF, I_{PDDIAG} HB2 OFF
- Configuration 2: I_{PDDIAG} HB1 ON, I_{PDDIAG} HB2 OFF
- Configuration 3: I_{PDDIAG} HB1 OFF, I_{PDDIAG} HB2 ON

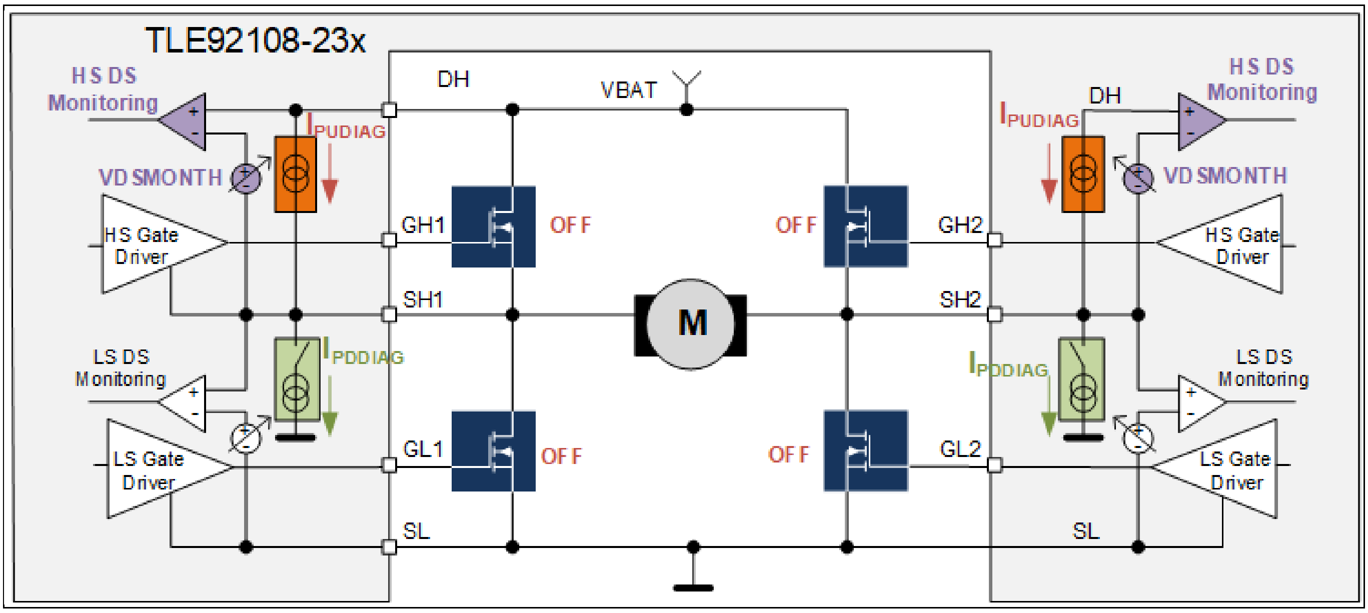


Figure 3 Simplified block diagram with one DC motor controlled by two half-bridges

3.2 Normal load conditions

Configuration 1:

- **I_{PDDIAG} HB1 OFF (HB1IDIAG=0)**
- **I_{PDDIAG} HB2 OFF (HB2IDIAG = 0)**

In normal conditions, the motor is connected between SH1 and SH2 without any short circuit.

If I_{PDDIAG} of HB1 and HB2 are off, then SH1 and SH2 are pulled up by I_{PUDIAG} of HB1 and HB2 (Figure 4).

V_{SH1} = V_{SH2} = High.

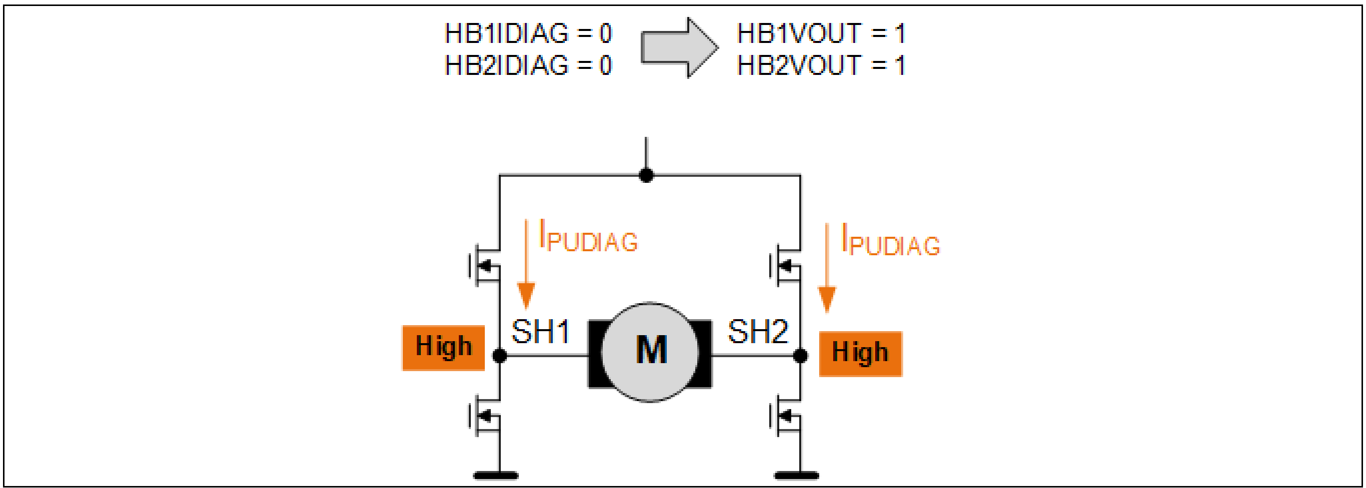


Figure 4 **One motor in normal conditions, I_{PDDIAG} HB1/HB2 OFF with normal load**

Configuration 2:

- **I_{PDDIAG} HB1 ON (HB1IDIAG=1)**
- **I_{PDDIAG} HB2 OFF (HB2IDIAG=0)**

By design I_{PDDIAG} > 2.5 x I_{PUDIAG}, therefore SH1 is pulled to GND → **V_{SH1} = low**. Refer to Figure 5, left picture.

SH2 is also pulled to GND by I_{PDDIAG} of HB1 via the motor → **V_{SH2} = low**.

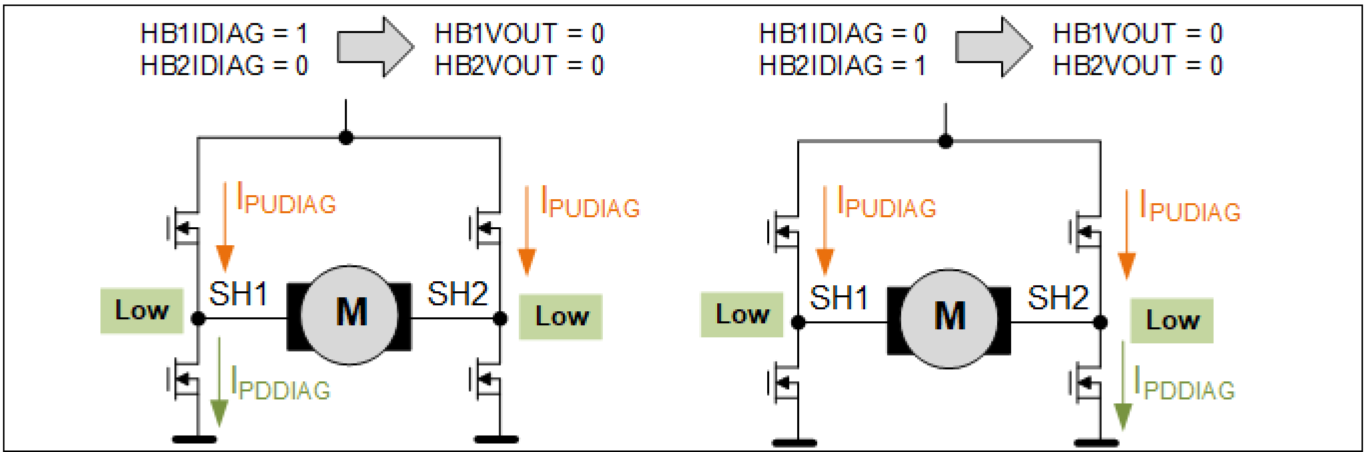


Figure 5 **One motor in normal conditions with one pull down diagnostic current on**

Configuration 3:

- **I_{PDDIAG} HB1 OFF (HB1IDIAG=0)**
- **I_{PDDIAG} HB2 ON (HB2IDIAG=1)**

This configuration is equivalent to Configuration 2, with HB2 pull-down activated instead of HB1.

By design I_{PDDIAG} > 2.5 x I_{PUDIAG}, therefore SH2 is pulled to GND → **V_{SH2} = low**. Refer to Figure 5, right picture.

SH1 is pulled down by I_{PDDIAG} of HB2 via the motor → **V_{SH1} = low**.

Table 1 summarizes the results obtained in normal conditions.

Table 1 Truth table with normal load conditions

Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	V_{SH1}	V_{SH2}
1	OFF	OFF	HIGH	HIGH
2	ON	OFF	LOW	LOW
3	OFF	ON	LOW	LOW

3.3 Short circuit to VBAT

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

SH2 is pulled up by the short circuit via the motor: **V_{SH2} = high**.

Similarly, a short circuit of SH2 to VBAT results in **V_{SH1} = V_{SH2} = high**, independently from the activation of I_{PDDIAG}.

Table 2 and Figure 6 summarize the results obtained with a short circuit of one output to VBAT.

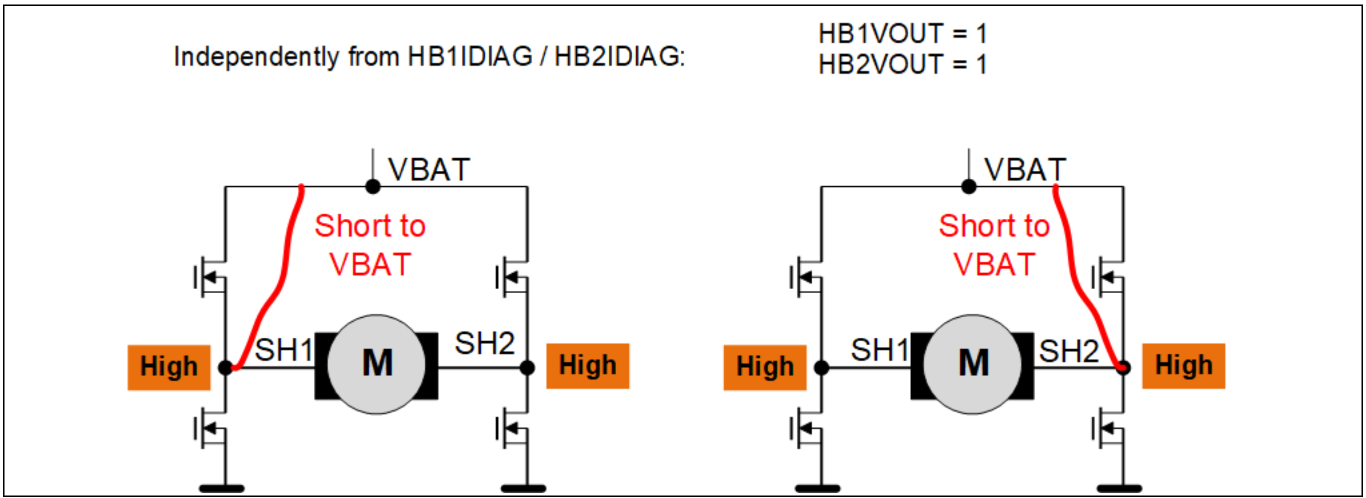


Figure 6 Short circuit to VBAT

Table 2 Truth table with a short circuit to VBAT

Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	V_{SH1}	V_{SH2}
1	OFF	OFF	HIGH	HIGH
2	ON	OFF	HIGH	HIGH
3	OFF	ON	HIGH	HIGH

3.4 Short circuit to GND

A short circuit between SH1 and GND results in **V_{SH1} = low** even if I_{PDDIAG} are deactivated.

SH2 is pulled down by the short circuit via the motor winding. **V_{SH2} = low**.

Similarly, a short circuit of SH2 to GND results in **V_{SH1} = V_{SH2} = low**, independently from the state of I_{PDDIAG}.

Table 3 and Figure 7 summarize the results obtained with a short circuit of one output to GND.

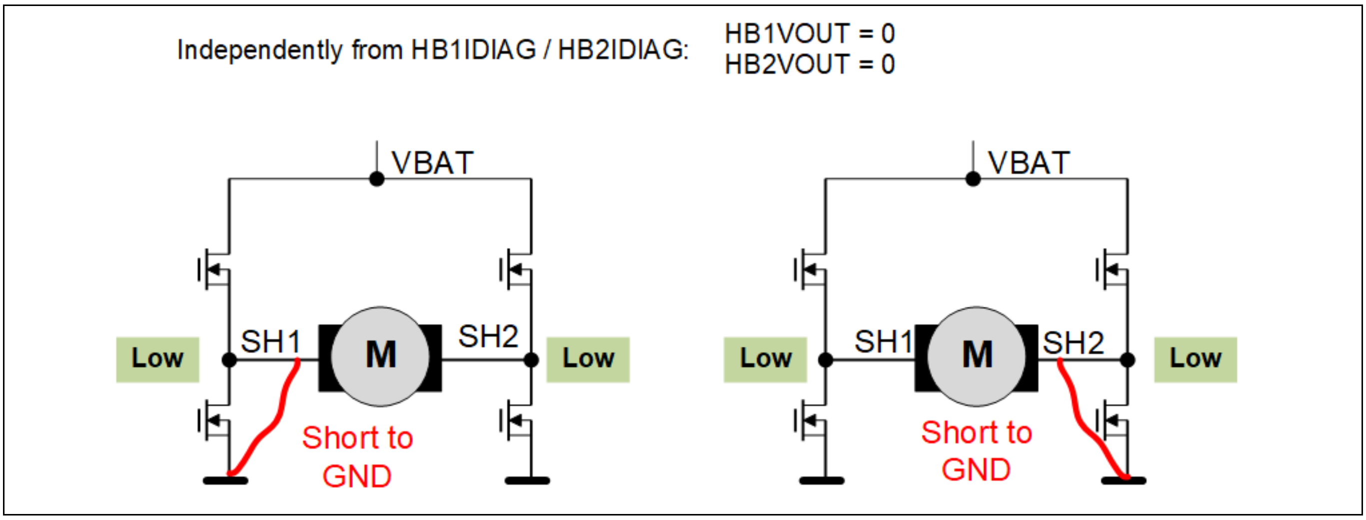


Figure 7 Short circuit to GND

Table 3 Truth table with a short circuit to GND

Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	V_{SH1}	V_{SH2}
1	OFF	OFF	LOW	LOW
2	ON	OFF	LOW	LOW
3	OFF	ON	LOW	LOW

3.5 Open load – SH1 is disconnected

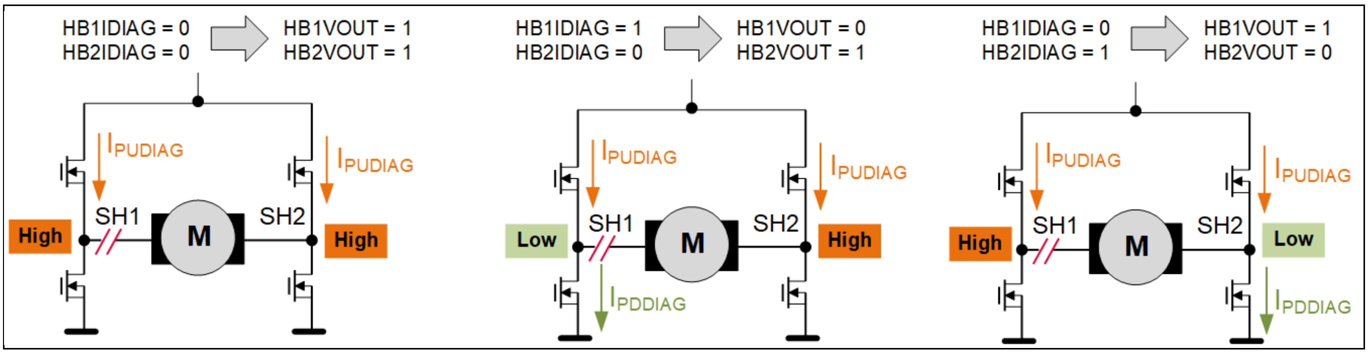


Figure 8 One motor – Diagnostic result with an open load at SH1

Configuration 1: I_{PDDIAG} HB1 OFF (HB1IDIAG=0), I_{PDDIAG} HB2 OFF (HB2IDIAG = 0)

SH1 and SH2 are pulled up by their respective pull-up diagnostic current: **V_{SH1} = V_{SH2} = High**

Configuration 2: I_{PDDIAG} HB1 ON (HB1IDIAG=1), I_{PDDIAG} HB2 OFF (HB2IDIAG=0)

SH1 is pulled down by I_{PDDIAG} HB1: **V_{SH1} = low**

Due to the motor disconnection at SH1, SH2 is pulled up by I_{PUDIAG} HB2: **V_{SH2} = high**

Configuration 3: I_{PDDIAG} HB1 OFF (HB1IDIAG=0), I_{PDDIAG} HB2 ON (HB2IDIAG=1)

SH1 is up down by I_{PUDIAG} HB1: **V_{SH1} = high**

SH2 is pulled down by I_{PDDIAG} HB2: **V_{SH2} = low**

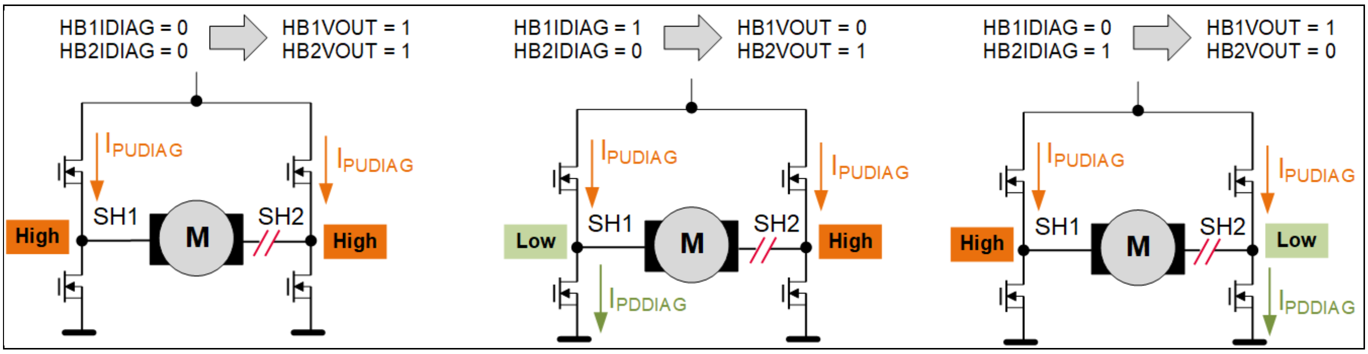
Table 4 summarizes the results obtained with a short circuit of one output to VBAT.

Table 4 Truth table open load - SH1 is disconnected

Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	V_{SH1}	V_{SH2}
1	OFF	OFF	HIGH	HIGH
2	ON	OFF	LOW	HIGH
3	OFF	ON	HIGH	LOW

3.6 Open load – SH2 is disconnected

Similarly a motor disconnection at SH2 shows the same result as for a motor disconnection at SH1. Refer to Figure 9. Therefore, Table 4 is valid for an open load, independently from the location of the disconnection.



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3.7 Summary of the off-state diagnostic

Compiling the results from Table 1, Table 2, Table 3 and Table 4, we see that the test configuration 1 and the test configuration 2 are sufficient to detect and distinguish between a normal load condition, a short circuit to VBAT/GND, and an open load. Refer to Figure 10:

- **V_{SH1} and V_{SH2} = high in Configuration 2 is characteristic for a short circuit of one of the outputs to VBAT**. The short circuit to VBAT prevents the pull-down diagnostic current to pull SH1/SH2 to GND.
- **V_{SH1} and V_{SH2} = low in Configuration 1 is characteristic for a short circuit of one of the outputs to GND**. The short circuit to GND prevents the pull-up diagnostic currents to pull SH1/SH2 to VBAT.
- **V_{SH1} = Low and V_{SH2} = high in Configuration 2 is characteristic for an open load condition**. The motor disconnection prevents the pull-down diagnostic current to pull both SH1 and SH2 to GND

Load conditions	Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	V_{SH1}	V_{SH2}	
Normal conditions	1	OFF	OFF	HIGH	HIGH	
	2	ON	OFF	LOW	LOW	
Short to VBAT	1	OFF	OFF	HIGH	HIGH	
	2	ON	OFF	HIGH	HIGH	→ Short to VBAT
Short to GND	1	OFF	OFF	LOW	LOW	→ Short to GND
	2	ON	OFF	LOW	LOW	
Open load	1	OFF	OFF	HIGH	HIGH	
	2	ON	OFF	LOW	HIGH	→ Open load

Figure 10 Differentiation between normal load, short to VBAT, short to GND and open load with one motor

4 Off-state diagnostic with two cascaded motors

This chapter provides hints about the off-state diagnostic with two cascaded motors controlled by three half-bridges (Figure 11).

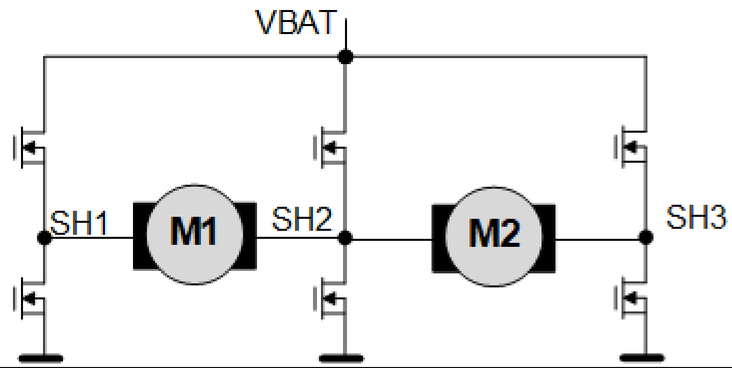

Figure 11 Two cascaded DC motors Summary of the off-state diagnostic

The proposed principle for the off-state diagnostic consists of analyzing V_{SHx} when all pull-down diagnostic currents are deactivated, and when two out of three pull-down diagnostic currents are activated.

The results are summarized in Figure 12.

Load conditions	Configuration	I_{PDDIAG} HB1	I_{PDDIAG} HB2	I_{PDDIAG} HB3	V_{SH1}	V_{SH2}	V_{SH3}	
Normal conditions	1	OFF	OFF	OFF	HIGH	HIGH	HIGH	
	2	ON	ON	OFF	LOW	LOW	LOW	
	3	OFF	ON	ON	LOW	LOW	LOW	
	4	ON	OFF	ON	LOW	LOW	LOW	
Short to VBAT	1	OFF	OFF	OFF	HIGH	HIGH	HIGH	
	2	ON	ON	OFF	HIGH	HIGH	HIGH	
	3	OFF	ON	ON	HIGH	HIGH	HIGH	Short to VBAT
	4	ON	OFF	ON	HIGH	HIGH	HIGH	
Short to GND	1	OFF	OFF	OFF	LOW	LOW	LOW	Short to GND
	2	ON	ON	OFF	LOW	LOW	LOW	
	3	OFF	ON	ON	LOW	LOW	LOW	
	4	ON	OFF	ON	LOW	LOW	LOW	
Open load MOTOR1	1	OFF	OFF	OFF	HIGH	HIGH	HIGH	
	2	ON	ON	OFF	LOW	LOW	LOW	
	3	OFF	ON	ON	HIGH	LOW	LOW	Open load Motor 1
	4	ON	OFF	ON	LOW	LOW	LOW	
Open load MOTOR2	1	OFF	OFF	OFF	HIGH	HIGH	HIGH	
	2	ON	ON	OFF	LOW	LOW	HIGH	
	3	OFF	ON	ON	LOW	LOW	LOW	Open load Motor 2
	4	ON	OFF	ON	LOW	LOW	LOW	
Open load MOTOR1 and MOTOR2	1	OFF	OFF	OFF	HIGH	HIGH	HIGH	
	2	ON	ON	OFF	LOW	LOW	HIGH	
	3	OFF	ON	ON	HIGH	LOW	LOW	
	4	ON	OFF	ON	LOW	HIGH	LOW	Open load Motor 1 and Motor 2

Figure 12 Differentiation between normal load, short to VBAT, short to GND and open load with two cascaded motors

The test configurations 1, 2, 3 are sufficient to differentiate a normal load condition from the considered failures.

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The detailed analysis of the V_{SHx} in the different load conditions are shown in Figure 13, Figure 14, Figure 15, Figure 15 and Figure 16.

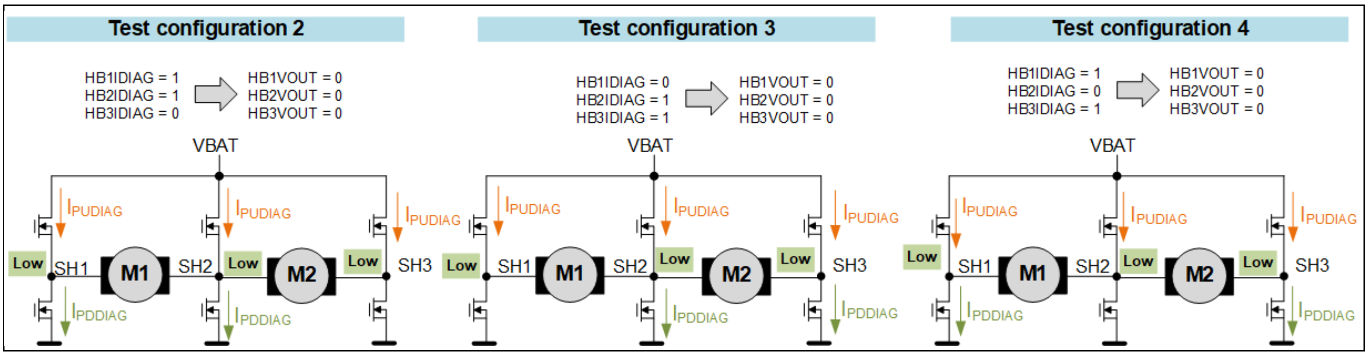

Figure 13 Diagnostic result with two cascaded motors with normal load conditions

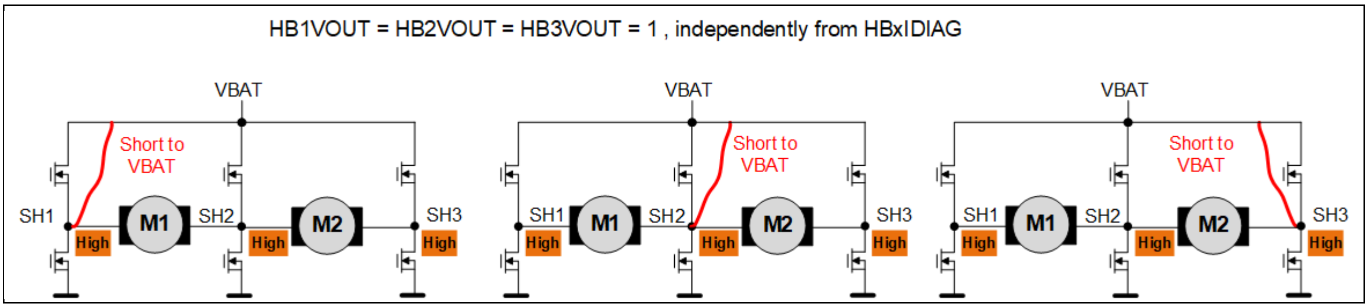

Figure 14 Diagnostic result with two cascaded motors with a short circuit to VBAT

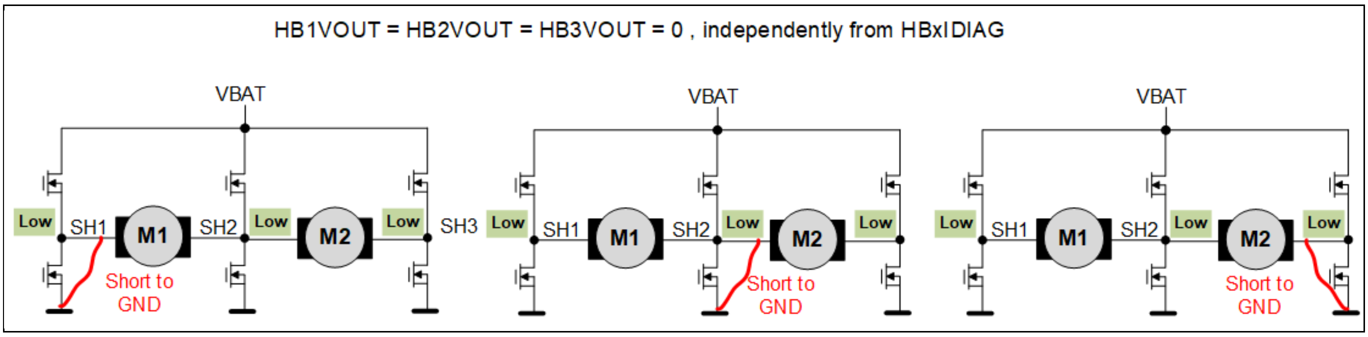

Figure 15 Diagnostic result with two cascaded motors with a short circuit to GND

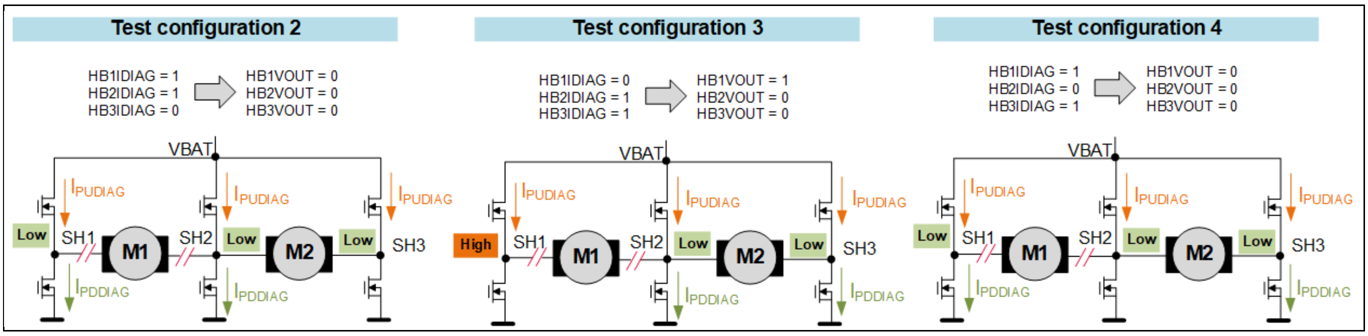

Figure 16 Diagnostic result with two cascaded motors – Open load for motor 1

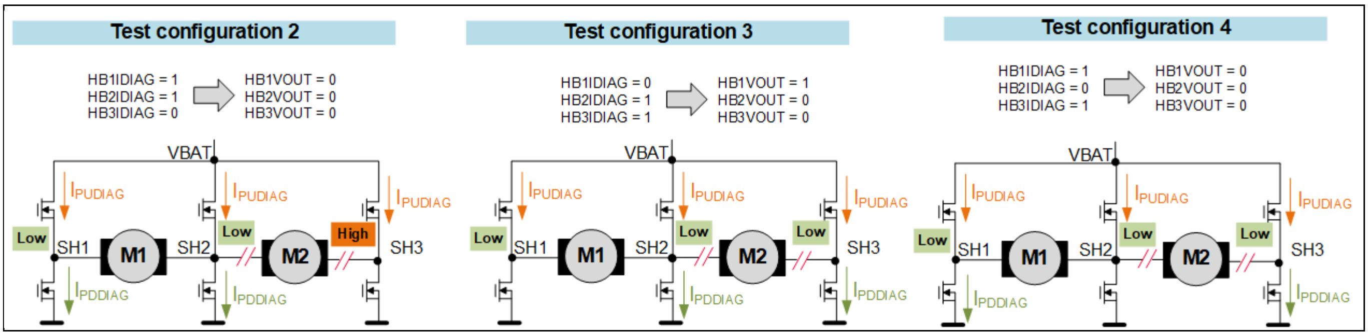

Figure 17 Diagnostic result with two cascaded motors – Open load for motor 2

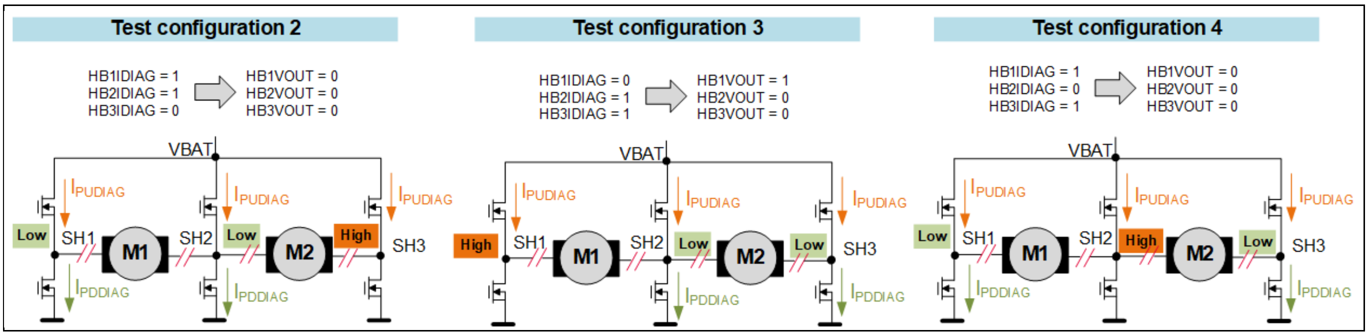

Figure 18 Diagnostic result with two cascaded motors – Open load for motor 1 and motor 2

5 Current sense placed in series with the motor

If a shunt resistor is placed in series to the motor, then the corresponding current sense amplifier must be turned off, in order to allow a proper off-state diagnostic.

When activated, the current sense amplifier sinks current through its inputs (CSIP1/2, CSIN1/2), preventing the pull-up diagnostic current from pulling up the corresponding SHx pin to high. Refer to Figure 19.

In the example shown in Figure 19, a correct off-state diagnostic is possible only if the current sense amplifier 1 is turned off (CSA1_OFF = 1).

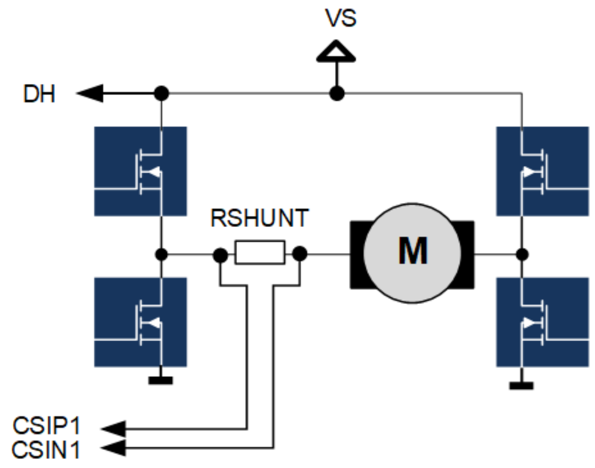

Figure 19 Shunt resistor in series placed between the output and the motor

Revision history

Document version	Date of release	Description of changes
1.0	2019-08-27	First release

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Edition 2019-08-27

Published by

Infineon Technologies AG

81726 Munich, Germany

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Document reference