Technical Article

How to differentiate between open-load and short-to-battery faults in high-side switches

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Abstract

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In automotive applications, high-side switches tend to supply power to different loads, requiring system setups to differentiate between different load faults, especially for short and open circuit faults. Reliable fault alerts are required. This article enables the distinction between open-load and short-to-battery faults with minimal external circuit design through high-accuracy current sensing circuits integrated inside TI high-side switches so as to help engineers differentiate between faults in functional design.

Open-load and short-to-battery diagnostic mechanisms for high-side switches

TI's high-side switch products integrate a high-accuracy current sensing circuits and fault diagnosis circuits, enabling them to detect faults such as a short circuit between the load and the battery or an open-load fault. The following section outlines the diagnostic mechanism of TI's high-side switches.

EN=High

TI's TPSxHxxx family products of high-side switches integrate current sensing circuits internally and they have very high current sensing accuracy. For example, TPS1HB08-Q1 has ±5% accuracy at loads > 1A.

After EN pin of the high-side switch is enabled, SNS output is selected to sense the load current. The current sensing circuit will output a current I_{SNSI} that passes through Power MOSFET current I_{OUT} and is proportional to the current K_{SNS}. Input this current into an external resistor R_{SNS} and a voltage proportional to the load current can be generated as shown in Figure 1. This voltage can be measured by ADC to determine the load fault type, as shown in Table 1.

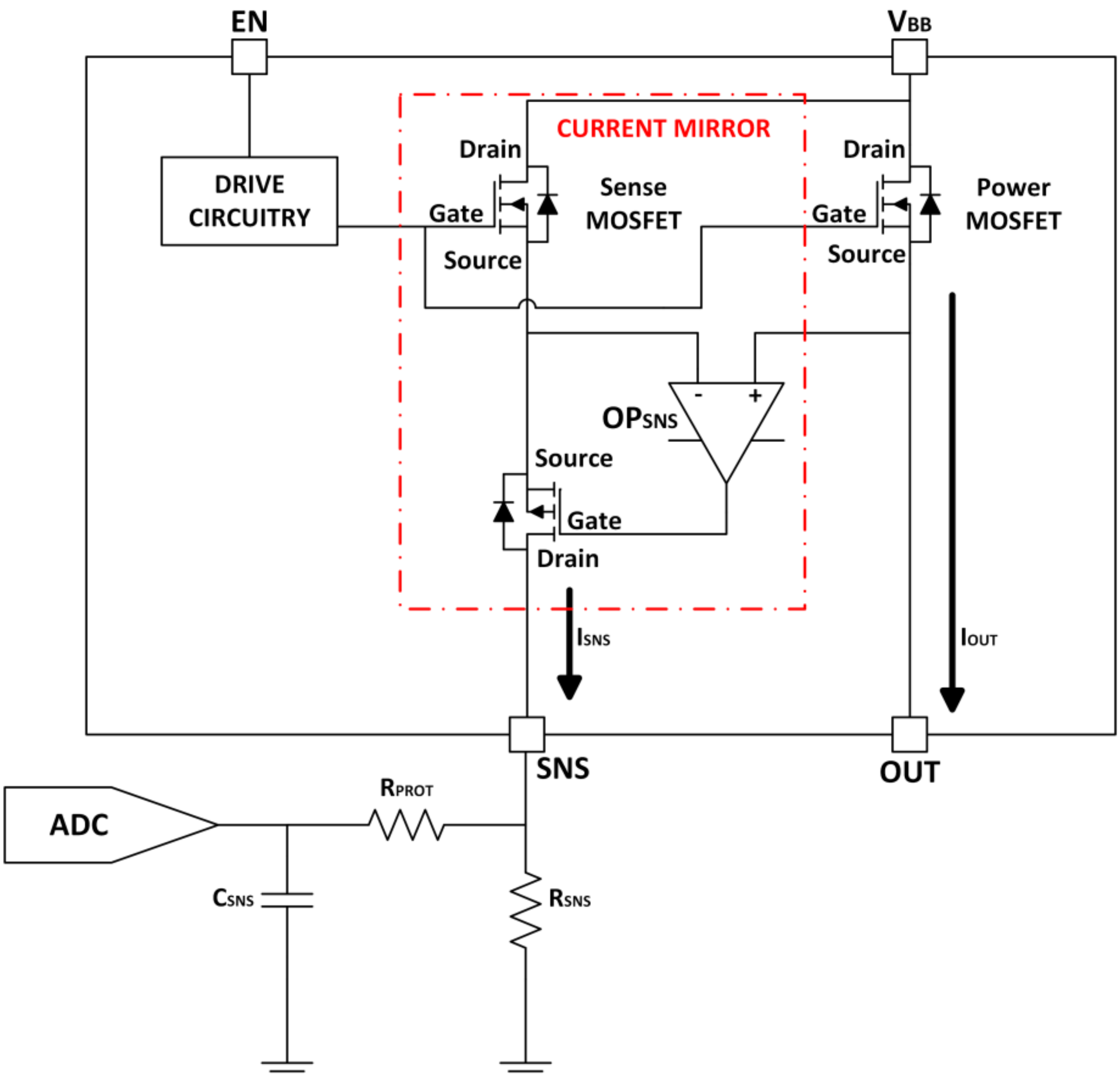

Figure 1. TPSxHxxx Current Sensing Circuit

Since no current flows through the internal Power MOSFET of the high-side switch at open-load and short-to-battery. The load current measured through SNS pin is much lower than expected one in the case of OUT shorted to battery or open-load.

Table 1. EN=High Diagnostic Summary

Load conditions	I_{SNSI} current/A
Normal	I_{OUT} / K_{SNS}
Open-circuit	0
Short-to-battery	0

As mentioned above, TI's high-side switch products are capable of detecting OUT shorted to battery or open-load faults at EN=High, but cannot distinguish the two faults.

EN=Low

When EN=Low, the high-side switch is disabled for output, the internal comparator detects the status of OUT for fault diagnosis. The mechanism is that the Power MOSFET has a pull-up MOS and 1MΩ resistor in parallel. If DIA_EN=High, the pull-up MOS is turned on and V_{OUT} is connected to V_{BAT} through 1MΩ resistor. In case of open-load or short-to-battery, V_{OUT} voltage will be much higher than the open threshold V_{OL}, and SNS pin will output a fault current I_{SNSFH}. The current inputs into an external resistor R_{SNS} to generate a fault voltage to indicate a fault, as shown in Figure 2. V_{OL} and I_{SNSFH} are described in the Electrical Characteristics section of the data sheet, as shown in Table 2.

Table 2. TPS1HB08-Q1 V_{OL} and I_{SNSFH} parameters

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
V_{OL}	Open-load (OL) detection voltage	VEN = 0V, VDIA_en = 5V, VSEL1 = 0V	2	3	4	V
I_{SNSFH}	ISNS fault high-level	VDIA_en = 5V, VSEL1 = 0V	4	4.5	5.3	mA

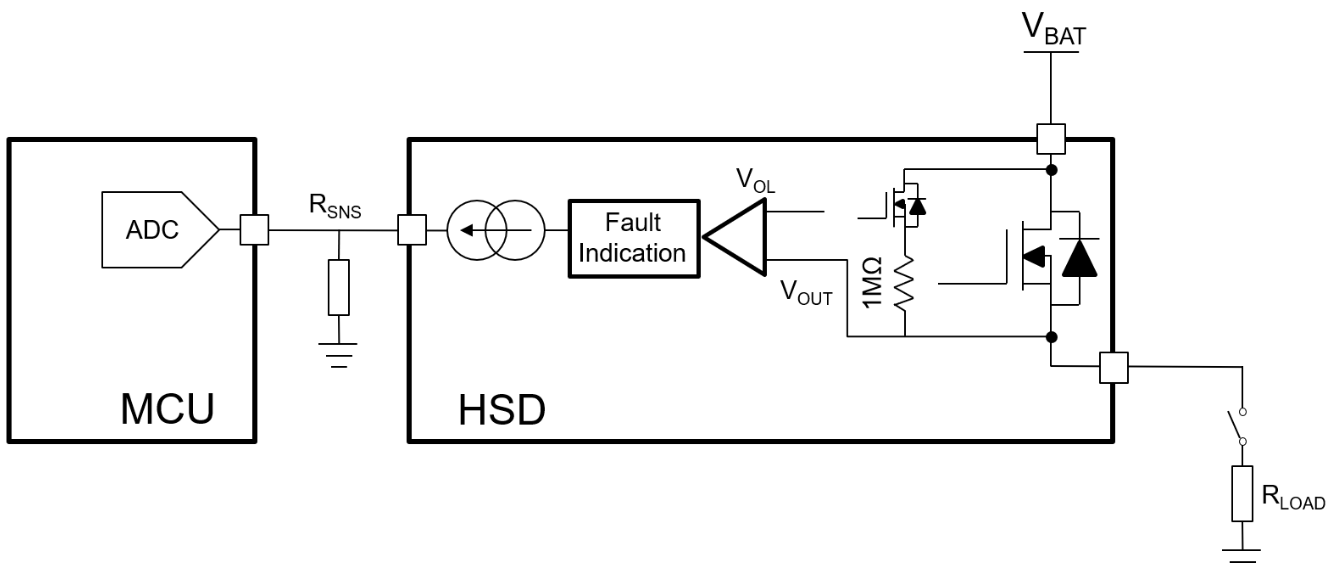

Figure 2. Open-load and short-to-battery diagnostic circuit

As mentioned above, when DIA_EN=HIGH and EN=Low, TI's high-side switch products are capable of detecting both OUT shorted to battery and open load faults; however, in both cases, V_{OUT} voltage will be significantly higher than the open-circuit threshold V_{OL} and SNS pin will output the same fault I_{SNSFH}. It remains impossible to distinguish between these two faults.

Differentiate between open-load and short-to-battery faults in high-side switches

From the analysis above, the reader will find that it is not possible to distinguish between open-load and short-to-battery faults under the existing mechanisms. TPSxHxxx-Q1 family of products can indicate fault information with a high-accuracy current sensing circuit and fault diagnostic circuit. Based on this feature, additional external components can be designed to differentiate between open-load and short-to-battery faults.

Solution 1

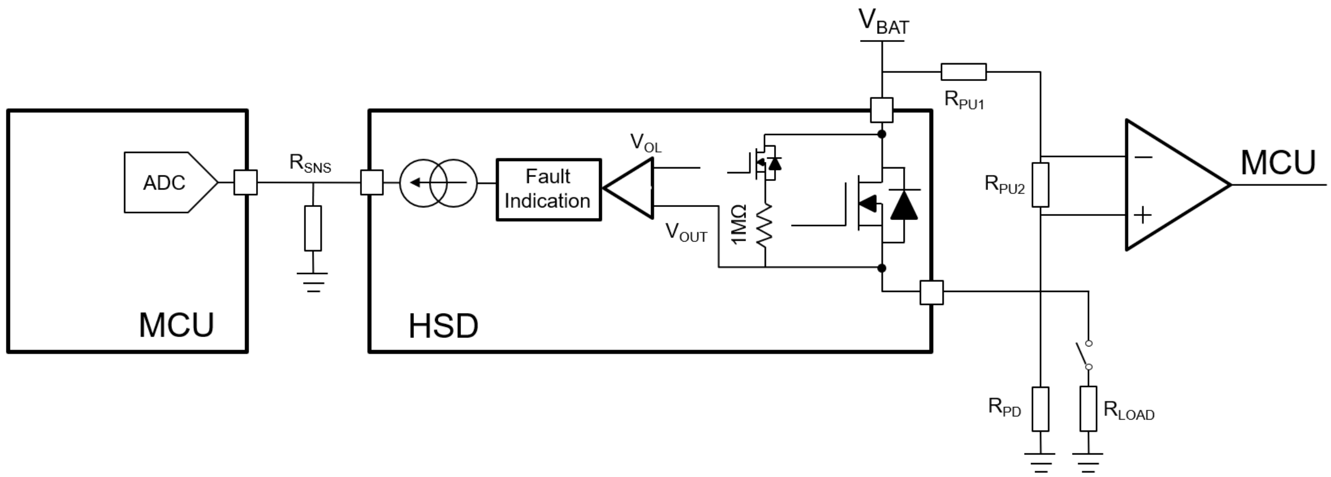

Figure 3. Solution 1 - Implement a diagnostic circuit that differentiates between open-load and short-to-battery

If EN=H and DIAG_EN=H, the current value of SNS can be read to determine the fault type:

- Normal: $I_L=V_{BAT}/(R_{DS\_ON}+R_{PD}//R_{LOAD})$
- Open Load: $I_L=V_{BAT}/(R_{DS\_ON}+R_{PD})$
- Short to Battery: $V_{BAT}≈V_{OUT}$, $I_L=0A$

Note: I_L refers to the current through the internal MOS of the high-side switch.

If EN=L and DIAG_EN=H, the output of the op amp can be read to determine the fault type:

- Normal: SNS will be Hi-Z (Do not report fault). Since the internal diagnostic MOS has a 1MΩ in series, the pull-down capability of a load-equivalent pull-down resistor is stronger than that of the internal pull-up, V_{OUT} will be less than V_{OL}. The comparator output will be low because V-> V+.
- Open Load: $V_{OUT}=V_{BAT}> V_{OL}$ so SNS will output a fault but the comparator will output a low because of V-> V+.
- Short to Battery: $V_{OUT}=V_{BAT}> V_{OL}$ so SNS will output a fault. The comparator will output a high because $V_{OUT}=V_{BAT}$ =V+ > V-.

Table 3. A diagnostic summary to differentiate between open-load and short-to-battery faults

EN PIN	Load conditions	I_{SNSI} current/A.	
High	Normal	$[V_{BAT}/(R_{ON}+R_{PD}//R_{LOAD})]/K_{SNS}$	
	Open-circuit	$[V_{BAT}/(R_{ON}+R_{PD})]/K_{SNS}$	
	Short-to-battery	0	
EN PIN	Load conditions	I_{SNSI} current/A.	Comparator output
Low	Normal	0	Low
	Open-circuit	I_{SNSFH}	Low
	Short-to-battery	I_{SNSFH}	High

Solution 2

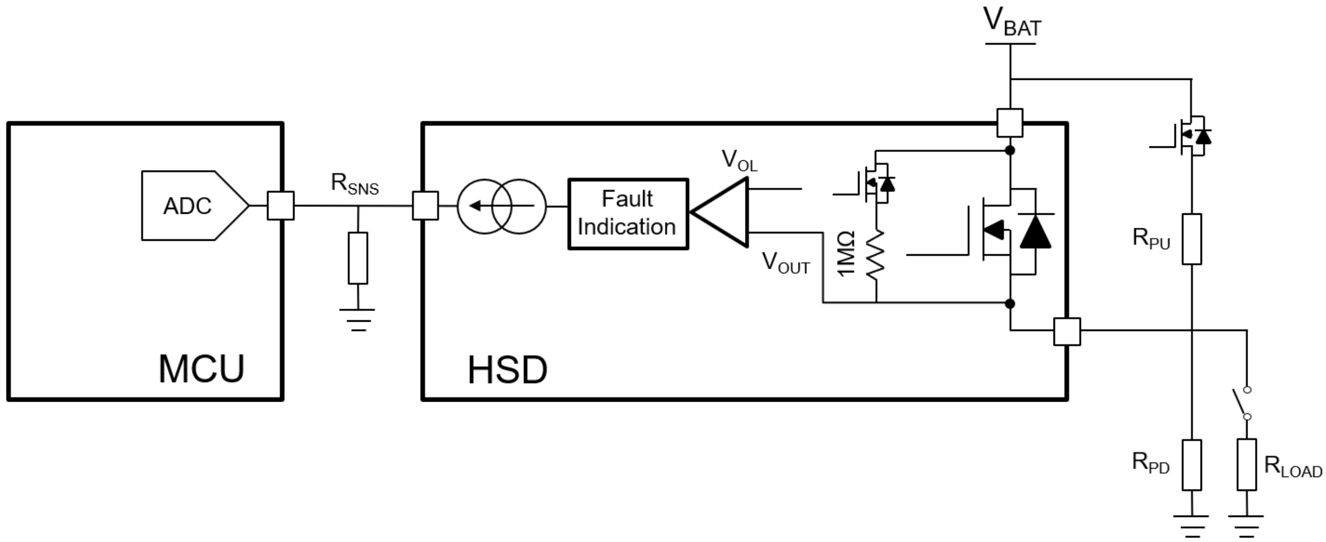

Figure 4. Solution 2 - Implement a diagnostic circuit that differentiates between open-load and short-to-battery

If EN=H and DIAG_EN=H, the current value of SNS can be read to determine the fault type:

- Normal: $I_L=V_{BAT}/(R_{DS\_ON}+R_{PD}//R_{LOAD})$
- Open Load: $I_L=V_{BAT}/(R_{DS\_ON}+R_{PD})$
- Short to Battery: $V_{BAT}\approx V_{OUT}$, current does not pass through the device, I_L=0A

If EN=L and DIAG_EN=H, open load can be distinguished from short-to-battery:

- Normal: SNS will be Hi-Z (Do not report fault) regardless of FET/BJT status
- Open Load: SNS will not report a fault when FET/BJT is disabled. It will only show a fault when the FET/BJT is turned on, then the fault type can be determined by toggling FET/BJT and seeing if SNS voltage changes. (When EN=L and DIAG_EN=H and it is necessary to configure the values of R_{PU} and R_{PD} to disable FET/BJT, $V_{OUT}=V_{BAT}> V_{OL}$. When FET/BJT is turned on, $V_{OUT} < V_{OL}$)
- Short to Battery: $V_{OUT}=V_{BAT}> V_{OL}$, SNS reports a fault regardless of FET/BJT status.

Table 4. A diagnostic summary to differentiate between open-load and short-to-battery faults

EN PIN	MCU_GPIO	Load conditions	I_{SNSI} current/A
High	Low	Normal	$[V_{BAT}/(R_{DS\_ON}+R_{PD}//R_{LOAD})]/K_{SNS}$
	Low	Open-circuit	$[V_{BAT}/(R_{DS\_ON}+R_{PD})]/K_{SNS}$
	Low	Short-to-battery	0
Low	Low/High	Normal	0
	Low	Open-circuit	0
	High	Open-circuit	I_{SNSFH}
	Low/High	Short-to-battery	I_{SNSFH}

Summary

Two solutions are described above to differentiate between open-load and short-to-battery faults when not driving loads, and engineers can choose one to design based on their needs. For applications that do not require offline diagnostics, diagnostics can be performed at EN=High, which eliminates the need for external circuit design.

References

1. Datasheet "TPS1HB08-Q1 40-V, 8-mΩ Single-Channel Smart High-Side Switch datasheet (Rev. C)"
2. Application note "High Accuracy Current Sense of Smart High Side Switches"