

# TPS2HB50-Q1 40V、50mΩ デュアルチャネル・スマート・ハイサイド・スイッチ

## 1 特長

- 車載アプリケーションに対応
- 下記内容で AEC-Q100 認定済み
  - デバイス温度グレード 1: 動作時周囲温度範囲  $T_A = -40^{\circ}\text{C} \sim 125^{\circ}\text{C}$
  - デバイス HBM ESD 分類レベル 2
  - デバイス CDM ESD 分類レベル C4B
  - 40V の負荷ダンプへの耐性
- 50mΩ  $R_{ON}$  ( $T_J = 25^{\circ}\text{C}$ ) のデュアルチャネル・スマート・ハイサイド・スイッチ
- 可変電流制限によるシステム・レベルの信頼性の向上
  - 電流制限値は 1.6A~18A の範囲で設定可能
- 堅牢な出力保護機能を内蔵
  - 熱保護機能を内蔵
  - グランド/バッテリーへの短絡に対する保護
  - 逆電圧による自動スイッチ・オンを含む **バッテリー逆接続**からの保護
  - バッテリ/グランド喪失が発生した場合に自動シャットオフ
  - 誘導性負荷の逆起電圧の発生を防止する出力クランプを内蔵
  - フォルト処理を設定可能
- アナログ検出出力は、以下を正確に測定するよう設定可能
  - 負荷電流
  - デバイス温度
- SNS ピンによるフォルト通知
  - 開放負荷とバッテリー短絡の検出

## 2 アプリケーション

- インフォテインメント・ディスプレイ
- ADAS モジュール
- 発熱体
  - シート・ヒーター
  - グロー・プラグ
  - タンク・ヒーター
- トランスミッション制御ユニット
- HVAC 温度調節器
- 車体制御モジュール
- 白熱光および LED ライティング

## 3 概要

TPS2HB50-Q1 は 12V 車載システム用のデュアルチャネル・スマート・ハイサイド・スイッチです。堅牢な保護・診断機能を内蔵しているため、車載システムで短絡などの有害な事象が発生しても、出力ポートを確実に保護できます。デバイスの種類に応じて 1.6A~18A に設定できる**信頼性の高い電流制限**により障害を防ぎます。電流制限範囲を小さくすると、大きなピーク電流を必要としない負荷で保護を強化できる一方で、電流制限範囲を大きくすると、大きな過渡電流を必要とする負荷でも使用できます。このデバイスは、さまざまな**負荷プロファイル**を確実に駆動できます。

TPS2HB50-Q1 は高精度のアナログ電流センスも備えているため、優れた負荷診断を実現します。負荷電流とデバイス温度をシステムの MCU に報告することで、予知保全と負荷診断が可能になり、システムの寿命が長くなります。

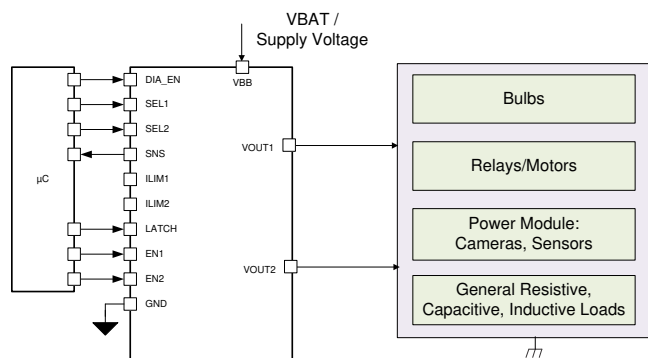
TPS2HB50-Q1 は HTSSOP パッケージで供給されるため、PCB の占有面積も削減できます。

### 製品情報<sup>(1)</sup>

型番	パッケージ	本体サイズ(公称)
TPS2HB50-Q1	HTSSOP (16)	5.00mm x 4.40mm

(1) 提供されているすべてのパッケージについては、巻末の注文情報を参照してください。

### 概略回路図



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## 4 改訂履歴

2018年2月発行のものから更新

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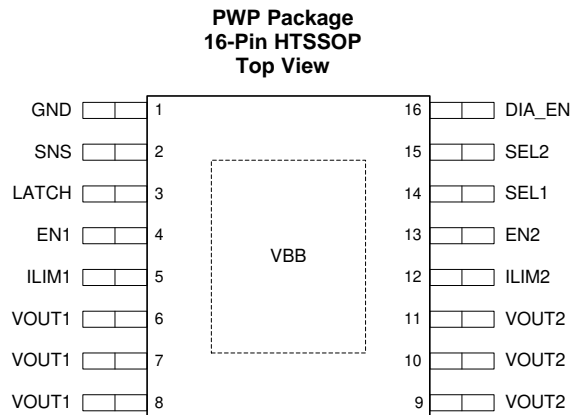
•	データシート全体にわたって変更	1
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## 5 Device Comparison Table

**Table 1. TPS2HB50-Q1 Device Options**

Device Version	Part Number	Current Limit	Current Limit Range	Overcurrent Behavior
A	TPS2HB50A-Q1	Resistor Programmable	1.6 A - 8 A	Disable switch immediately
B	TPS2HB50B-Q1	Resistor Programmable	3.6 A - 18 A	Disable switch immediately

## 6 Pin Configuration and Functions



### Pin Functions

PIN		I/O	DESCRIPTION
NO.	NAME		
1	GND	—	Device ground
2	SNS	O	Sense output
3	LATCH	I	Sets fault handling behavior (latched or auto-retry)
4	EN1	I	Channel 1 control input, active high
5	ILIM1	O	Connect pull-up resistor to $V_{BB}$ to set current-limit threshold on CH1
6-8	VOUT1	O	Channel 1 output
9-11	VOUT2	O	Channel 2 output
12	ILIM2	O	Connect pull-up resistor to $V_{BB}$ to set current-limit threshold on CH2
13	EN2	I	Channel 2 control input, active high
14	SEL1	I	Diagnostics select 1
15	SEL2	I	Diagnostics select 2
16	DIA_EN	I	Diagnostic enable, active high
Exposed pad	VBB	I	Power supply input

## 6.1 Recommended Connections for Unused Pins

The TPS2HB50-Q1 device is designed to provide an enhanced set of diagnostic and protection features. However, if the system design only allows for a limited number of I/O connections, some pins may be considered optional.

**Table 2. Connections for Optional Pins**

PIN NAME	CONNECTION IF NOT USED	IMPACT IF NOT USED
SNS	Ground through 1-kΩ resistor	Analog sense is not available.
LATCH	Float or ground through $R_{\text{PROT}}$ resistor	With LATCH unused, the device will auto-retry after a fault. If latched behavior is desired, but the system describes limited I/O, it is possible to use one microcontroller output to control the latch function of several high-side channels.
ILIM1, ILIM2	Float	If the ILIMx pin is left floating, the device will be set to the default internal current-limit threshold.
SEL1	Float or ground through $R_{\text{PROT}}$ resistor	SEL1 selects the $T_J$ sensing feature. With SEL1 unused, only CH1 and CH2 current sensing and open load detection are available.
SEL2	Ground through $R_{\text{PROT}}$ resistor	With SEL2 = 0 V, CH2 current sensing and CH2 open load detection are not available.
DIA_EN	Float or ground through $R_{\text{PROT}}$ resistor	With DIA_EN unused, the analog sense, open-load, and short-to-battery diagnostics are not available.

$R_{\text{PROT}}$  is used to protect the pins from excess current flow during reverse battery conditions, for more information please see the section on [Reverse Battery](#) protection.

## 7 Specifications

### 7.1 Absolute Maximum Ratings

Over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
Maximum continuous supply voltage, $V_{BB}$			36	V
Load dump voltage, $V_{LD}$	ISO16750-2:2010(E)		40	V
Reverse battery voltage, $V_{Rev}$ , $t \leq 3$ minutes		-18		V
Enable pin voltage, $V_{EN1}$ and $V_{EN2}$		-1	7	V
LATCH pin voltage, $V_{LATCH}$		-1	7	V
Diagnostic Enable pin voltage, $V_{DIA\_EN}$		-1	7	V
Sense pin voltage, $V_{SNS}$		-1	18	V
Select pin voltage, $V_{SEL1}$ and $V_{SEL2}$		-1	7	V
Reverse ground current, $I_{GND}$		$V_{BB} < 0$ V	-50	mA
Energy dissipation during turnoff, $E_{TOFF}$		Single pulse, one channel, $L_{OUT} = 5$ mH, $T_{J,start} = 125^\circ\text{C}$		TBD <sup>(2)</sup> mJ
Energy dissipation during turnoff, $E_{TOFF}$		Repetitive pulse, one channel, $L_{OUT} = 5$ mH, $T_{J,start} = 125^\circ\text{C}$		TBD <sup>(2)</sup> mJ
Maximum junction temperature, $T_J$			150	$^\circ\text{C}$
Maximum junction temperature - limited duration, $T_J$		$t < 100$ hours	170	$^\circ\text{C}$
Storage temperature, $T_{stg}$		-65	150	$^\circ\text{C}$

- (1) Stresses beyond those listed under *Absolute Maximum Ratings* may cause permanent damage to the device. These are stress ratings only, which do not imply functional operation of the device at these or any other conditions beyond those indicated under *Recommended Operating Conditions*. Exposure to absolute maximum rated conditions for extended periods may affect device reliability.
- (2) For further details, see the section regarding switch-off of an inductive load.

### 7.2 ESD Ratings

			VALUE	UNIT
$V_{(ESD)}$	Electrostatic discharge	Human-body model (HBM), per AEC Q100-002 <sup>(1)</sup>	$\pm 2000$	V
			$\pm 4000$	
		Charged-device model (CDM), per AEC Q100-011	$\pm 750$	

- (1) AEC-Q100-002 indicates that HBM stressing shall be in accordance with the ANSI/ESDA/JEDEC JS-001 specifications.

### 7.3 Recommended Operating Conditions

over operating free-air temperature range (unless otherwise noted)<sup>(1)</sup>

		MIN	MAX	UNIT
$V_{BB}$	Nominal supply voltage <sup>(1)</sup>	6	18	V
$V_{BB}$	Extended supply voltage <sup>(2)</sup>	3	28	V
$V_{EN1}$ , $V_{EN2}$	Enable voltage	-1	5.5	V
$V_{LATCH}$	LATCH voltage	-1	5.5	V
$V_{DIA\_EN}$	Diagnostic Enable voltage	-1	5.5	V
$V_{SEL1}$ , $V_{SEL2}$	Select voltage	-1	5.5	V
$V_{SNS}$	Sense voltage	-1	7	V
$T_A$	Operating free-air temperature	-40	125	$^\circ\text{C}$

- (1) All operating voltage conditions are measured with respect to device GND
- (2) Device will function within extended operating range, however some parametric values might not apply

## 7.4 Thermal Information

THERMAL METRIC <sup>(1)(2)</sup>		TPS2HB50-Q1	UNIT
		PWP (HTSSOP)	
		16 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	32.9	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	30.8	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	9.0	°C/W
$\psi_{JT}$	Junction-to-top characterization parameter	1.8	°C/W
$\psi_{JB}$	Junction-to-board characterization parameter	9.2	°C/W
$R_{\theta JC(bot)}$	Junction-to-case (bottom) thermal resistance	2.0	°C/W

(1) For more information about traditional and new thermal metrics, see TI's [SPRA953](#) application report.

(2) The thermal parameters are based on a 4-layer PCB according to the JESD51-5 and JESD51-7 standards.

## 7.5 Electrical Characteristics

$V_{BB} = 6\text{ V to }18\text{ V}$ ,  $T_J = -40^\circ\text{C to }150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>INPUT VOLTAGE AND CURRENT</b>						
$V_{DSCLAMP}$	$V_{DS}$ clamp voltage		38		46	V
$V_{BBCLAMP}$	$V_{BB}$ clamp voltage		58		76	V
$V_{UVLOF}$	$V_{BB}$ undervoltage lockout falling	Measured with respect to the GND pin of the device	2.0		3	V
$V_{UVLOR}$	$V_{BB}$ undervoltage lockout rising	Measured with respect to the GND pin of the device	2.2		3	V
$I_{SB}$	Standby current (total device leakage including both MOSFET channels)	$V_{BB} = 13.5\text{ V}$ , $T_J = 25^\circ\text{C}$ $V_{ENX} = V_{DIA\_EN} = 0\text{ V}$ , $V_{OUT} = 0\text{ V}$			0.5	$\mu\text{A}$
		$V_{BB} = 13.5\text{ V}$ , $T_J = 125^\circ\text{C}$ , $V_{ENX} = V_{DIA\_EN} = 0\text{ V}$ , $V_{OUT} = 0\text{ V}$			4	$\mu\text{A}$
$I_{L\_NOM}$	Continuous load current, per channel	Two channels enabled, $T_{AMB} = 70^\circ\text{C}$		3		A
		One channel enabled, $T_{AMB} = 70^\circ\text{C}$		4.5		A
$I_{OUT(standby)}$	Output leakage current (per channel)	$V_{BB} = 13.5\text{ V}$ , $T_J = 25^\circ\text{C}$ $V_{ENX} = V_{DIA\_EN} = 0\text{ V}$ , $V_{OUT} = 0\text{ V}$		0.01	0.5	$\mu\text{A}$
		$V_{BB} = 13.5\text{ V}$ , $T_J = 125^\circ\text{C}$ $V_{ENX} = V_{DIA\_EN} = 0\text{ V}$ , $V_{OUT} = 0\text{ V}$			1.5	$\mu\text{A}$
$I_{DIA}$	Current consumption in diagnostic mode	$V_{BB} = 13.5\text{ V}$ , $I_{SNS} = 0\text{ mA}$ $V_{ENX} = 0\text{ V}$ , $V_{DIA\_EN} = 5\text{ V}$ , $V_{OUT} = 0\text{ V}$		3	6	mA
$I_Q$	Quiescent current	$V_{BB} = 13.5\text{ V}$ $V_{ENX} = V_{DIA\_EN} = 5\text{ V}$ , $I_{OUTX} = 0\text{ A}$		3	6	mA
$t_{STBY}$	Standby mode delay time	$V_{ENX} = V_{DIA\_EN} = 0\text{ V}$ to standby	12	17	22	ms
<b>RON CHARACTERISTICS</b>						
$R_{ON}$	On-resistance (Includes MOSFET and package)	$T_J = 25^\circ\text{C}$ , $6\text{ V} \leq V_{BB} \leq 28\text{ V}$ , $I_{OUT1} = I_{OUT2} > 1\text{ A}$		50		m $\Omega$
		$T_J = 150^\circ\text{C}$ , $6\text{ V} \leq V_{BB} \leq 28\text{ V}$ , $I_{OUT1} = I_{OUT2} > 1\text{ A}$			100	m $\Omega$
		$T_J = 25^\circ\text{C}$ , $3\text{ V} \leq V_{BB} \leq 6\text{ V}$ , $I_{OUT1} = I_{OUT2} > 1\text{ A}$			75	m $\Omega$
$R_{ON(REV)}$	On-resistance during reverse polarity	$T_J = 25^\circ\text{C}$ , $-18\text{ V} \leq V_{BB} \leq -7\text{ V}$		50		m $\Omega$
		$T_J = 105^\circ\text{C}$ , $-18\text{ V} \leq V_{BB} \leq -7\text{ V}$			100	m $\Omega$
<b>CURRENT SENSE CHARACTERISTICS</b>						
$K_{SNS}$	Current sense ratio $I_{OUTX} / I_{SNS}$	$I_{OUTX} = 1\text{ A}$		1500		

**Electrical Characteristics (continued)**
 $V_{BB} = 6\text{ V to }18\text{ V}$ ,  $T_J = -40^\circ\text{C to }150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
$I_{SNSI}$	Current sense current and accuracy	$V_{EN} = V_{DIA\_EN} = 5\text{ V}$ , $V_{SEL1} = 0\text{ V}$ , $V_{SEL2} = X$	$I_{OUT} = 6\text{ A}$		4.000		mA
					-4%	4%	%
			$I_{OUT} = 3\text{ A}$		2.000		mA
					-4%	4%	%
			$I_{OUT} = 1\text{ A}$		0.667		mA
					-4%	4%	%
			$I_{OUT} = 300\text{ mA}$		0.2		mA
	-10%	10%		%			
$I_{OUT} = 100\text{ mA}$		0.067		mA			
		-25%	25%	%			
$I_{OUT} = 50\text{ mA}$		0.033		mA			
		-35%	35%	%			
<b>TJ SENSE CHARACTERISTICS</b>							
$I_{SNSST}$	Temperature sense current	$V_{DIA\_EN} = 5\text{ V}$ , $V_{SEL1} = 5\text{ V}$ , $V_{SEL2} = 0\text{ V}$	$T_J = -40^\circ\text{C}$	0.00	0.12	0.29	mA
			$T_J = 25^\circ\text{C}$	0.68	0.85	1.02	mA
			$T_J = 85^\circ\text{C}$	1.25	1.52	1.79	mA
			$T_J = 125^\circ\text{C}$	1.61	1.96	2.31	mA
			$T_J = 150^\circ\text{C}$	1.80	2.25	2.70	mA
$dI_{SNSST}/dT$	Coefficient			0.011			mA/°C
<b>SNS CHARACTERISTICS</b>							
$I_{SNSFH}$	$I_{SNS}$ fault high-level	$V_{DIA\_EN} = 5\text{ V}$ , $V_{SEL1} = 0\text{ V}$ , $V_{SEL2} = X$		4	4.5	5.3	mA
$I_{SNSleak}$	$I_{SNS}$ leakage	$V_{DIA\_EN} = 0\text{ V}$				1	µA
<b>CURRENT LIMIT CHARACTERISTICS</b>							
$I_{CL}$	Current Limit Threshold	Device Version A, $T_J = -40^\circ\text{C to }150^\circ\text{C}$	$R_{LIM} = \text{GND, open, or out of range}$		11.8		A
			$R_{LIM} = 5\text{ k}\Omega$	6.2	8	9.36	A
			$R_{LIM} = 25\text{ k}\Omega$	1.4	1.6	2.28	A
		Device Version B, $T_J = -40^\circ\text{C to }150^\circ\text{C}$	$R_{LIM} = \text{GND, open, or out of range}$		27		A
			$R_{LIM} = 5\text{ k}\Omega$	13.68	18	21.6	A
			$R_{LIM} = 25\text{ k}\Omega$	2.96	3.6	4.44	A
$K_{CL}$	Current Limit Ratio	Version A		31	40	57	A * kΩ
		Version B		68.4	90	111	A * kΩ
<b>FAULT CHARACTERISTICS</b>							
$V_{OL}$	Open-load (OL) detection voltage	$V_{ENx} = 0\text{ V}$ , $V_{DIA\_EN} = 5\text{ V}$		2	3	4	V
$t_{OL1}$	OL and STB indication-time from ENx falling	$V_{ENx} = 5\text{ V to }0\text{ V}$ , $V_{DIA\_EN} = 5\text{ V}$ , $V_{SEL1} = 0\text{ V}^{(1)}$ $I_{OUT} = 0\text{ mA}$ , $V_{OUTx} = 4\text{ V}$		300	500	700	µs
$t_{OL2}$	OL and STB indication-time from DIA_EN rising	$V_{ENx} = 0\text{ V}$ , $V_{DIA\_EN} = 0\text{ V to }5\text{ V}$ , $V_{SEL1} = 0\text{ V}^{(1)}$ $I_{OUT} = 0\text{ mA}$ , $V_{OUTx} = 4\text{ V}$				50	µs
$t_{OL3}$	OL and STB indication-time from V_OUT rising	$V_{ENx} = 0\text{ V}$ , $V_{DIA\_EN} = 5\text{ V}$ , $V_{SEL1} = 0\text{ V}^{(1)}$ $I_{OUT} = 0\text{ mA}$ , $V_{OUTx} = 0\text{ V to }4\text{ V}$				50	µs
$T_{ABS}$	Thermal shutdown			150			°C
$T_{REL}$	Relative thermal shutdown				50		°C
$T_{HYS}$	Thermal shutdown hysteresis				28		°C

(1) SELx must be set to select the relevant channel. Diagnostics are performed on Channel 1 when SELx = 00 and diagnostics are performed on channel 2 when SELx = 01



## Electrical Characteristics (continued)

 $V_{BB} = 6\text{ V to }18\text{ V}$ ,  $T_J = -40^\circ\text{C to }150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{\text{FAULT}}$	Fault shutdown indication-time	$V_{\text{DIA\_EN}} = 5\text{ V}$ Time between switch shutdown and $I_{\text{SNS}}$ settling at $I_{\text{SNSFH}}$			50	$\mu\text{s}$
$t_{\text{RETRY}}$	Retry time	Time from fault shutdown until switch re-enable (thermal shutdown or current limit).	1	2	3	ms
<b>EN1 AND EN2 PIN CHARACTERISTICS<sup>(2)</sup></b>						
$V_{\text{IL\_ENx}}$	Input voltage low-level	No GND network diode			0.8	V
$V_{\text{IH\_ENx}}$	Input voltage high-level	No GND network diode	2			V
$V_{\text{IHYS\_ENx}}$	Input voltage hysteresis			350		mV
$R_{\text{ENx}}$	Internal pulldown resistor		0.5	1	2	$\text{M}\Omega$
$I_{\text{IL\_EN}}$	Input current low-level	$V_{\text{EN}} = 0.8\text{ V}$		0.8		$\mu\text{A}$
$I_{\text{IH\_EN}}$	Input current high-level	$V_{\text{EN}} = 5\text{ V}$		5		$\mu\text{A}$
<b>DIA_EN PIN CHARACTERISTICS<sup>(2)</sup></b>						
$V_{\text{IL\_DIA\_EN}}$	Input voltage low-level	No GND network diode			0.8	V
$V_{\text{IH\_DIA\_EN}}$	Input voltage high-level	No GND network diode	2.0			V
$V_{\text{IHYS\_DIA\_EN}}$	Input voltage hysteresis		200	350	530	mV
$R_{\text{DIA\_EN}}$	Internal pulldown resistor		0.5	1	2	$\text{M}\Omega$
$I_{\text{IL\_DIA\_EN}}$	Input current low-level	$V_{\text{DIA\_EN}} = 0.8\text{ V}$		0.8		$\mu\text{A}$
$I_{\text{IH\_DIA\_EN}}$	Input current high-level	$V_{\text{DIA\_EN}} = 5\text{ V}$		5		$\mu\text{A}$
<b>SEL1 AND SEL2 PIN Characteristics</b>						
$V_{\text{IL\_SELx}}$	Input voltage low-level	No GND network diode			0.8	V
$V_{\text{IH\_SELx}}$	Input voltage high-level	No GND network diode	2			V
$V_{\text{IHYS\_SELx}}$	Input voltage hysteresis			350		mV
$R_{\text{SELx}}$	Internal pulldown resistor		0.5	1	2	$\text{M}\Omega$
$I_{\text{IL\_SELx}}$	Input current low-level	$V_{\text{SELx}} = 0.8\text{ V}$		0.8		$\mu\text{A}$
$I_{\text{IH\_SELx}}$	Input current high-level	$V_{\text{SELx}} = 5\text{ V}$		5		$\mu\text{A}$
<b>LATCH PIN CHARACTERISTICS<sup>(2)</sup></b>						
$V_{\text{IL\_LATCH}}$	Input voltage low-level	No GND network diode			0.8	V
$V_{\text{IH\_LATCH}}$	Input voltage high-level	No GND network diode	2			V
$V_{\text{IHYS\_LATCH}}$	Input voltage hysteresis		200	350	530	mV
$R_{\text{LATCH}}$	Internal pulldown resistor		0.5	1	2	$\text{M}\Omega$
$I_{\text{IL\_LATCH}}$	Input current low-level	$V_{\text{LATCH}} = 0.8\text{ V}$		0.8		$\mu\text{A}$
$I_{\text{IH\_LATCH}}$	Input current high-level	$V_{\text{LATCH}} = 5\text{ V}$		5		$\mu\text{A}$

(2)  $V_{BB} = 3\text{ V to }28\text{ V}$ 

## 7.6 SNS Timing Characteristics

 $V_{BB} = 6\text{ V to }18\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
<b>SNS TIMING - CURRENT SENSE</b>						
$t_{\text{SNSION1}}$	Settling time from rising edge of DIA_EN	$V_{\text{ENx}} = 5\text{ V}$ , $V_{\text{DIA\_EN}} = 0\text{ V to }5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			40	$\mu\text{s}$
$t_{\text{SNSION2}}$	Settling time from rising edge of ENx and DIA_EN	$V_{\text{ENx}} = V_{\text{DIA\_EN}} = 0\text{ V to }5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			165	$\mu\text{s}$
$t_{\text{SNSION3}}$	Settling time from rising edge of ENx	$V_{\text{ENx}} = 0\text{ V to }5\text{ V}$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			165	$\mu\text{s}$

### SNS Timing Characteristics (continued)

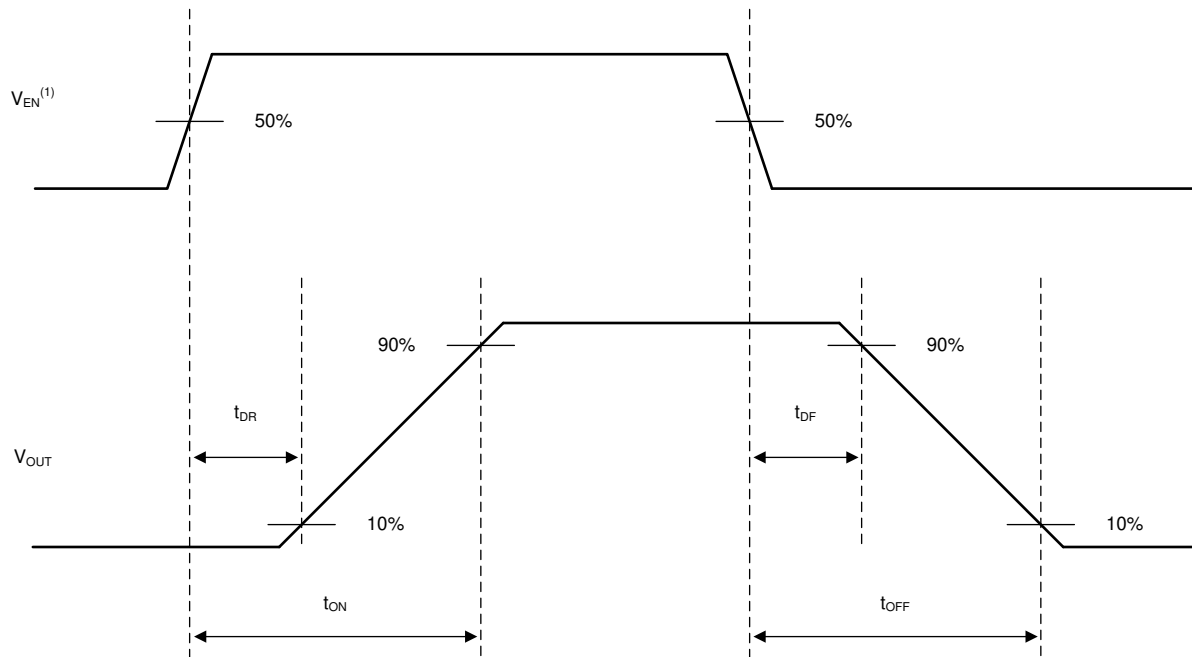
$V_{BB} = 6\text{ V to }18\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{\text{SNSIOFF1}}$	Settling time from falling edge of DIA_EN	$V_{\text{ENx}} = 5\text{ V}$ , $V_{\text{DIA\_EN}} = 5\text{ V to }0\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			20	$\mu\text{s}$
$t_{\text{SETTLEH}}$	Settling time from rising edge of load step	$V_{\text{EN1}} = 5\text{ V}$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $I_{\text{OUT}} = 5\text{ A to }1\text{ A}$			20	$\mu\text{s}$
$t_{\text{SETTLEL}}$	Settling time from falling edge of load step	$V_{\text{ENx}} = 5\text{ V}$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $I_{\text{OUT}} = 5\text{ A to }1\text{ A}$			20	$\mu\text{s}$
<b>SNS TIMING - TEMPERATURE SENSE</b>						
$t_{\text{SNSTON1}}$	Settling time from rising edge of DIA_EN	$V_{\text{ENx}} = 5\text{ V}$ , $V_{\text{DIA\_EN}} = 0\text{ V to }5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$			40	$\mu\text{s}$
$t_{\text{SNSTON2}}$	Settling time from rising edge of DIA_EN	$V_{\text{ENx}} = 0\text{ V}$ , $V_{\text{DIA\_EN}} = 0\text{ V to }5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$			70	$\mu\text{s}$
$t_{\text{SNSTOFF}}$	Settling time from falling edge of DIA_EN	$V_{\text{ENx}} = X$ , $V_{\text{DIA\_EN}} = 5\text{ V to }0\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$			20	$\mu\text{s}$
<b>SNS TIMING - MULTIPLEXER</b>						
$t_{\text{MUX}}$	Settling time from temperature sense to current sense	$V_{\text{ENx}} = X$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $V_{\text{SEL1}} = 5\text{ V to }0\text{ V}$ , $V_{\text{SEL2}} = X$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			60	$\mu\text{s}$
	Settling time from current sense on CHx to CHy	$V_{\text{ENx}} = X$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $V_{\text{SEL1}} = 0\text{ V}$ , $V_{\text{SEL2}} = 0\text{ V to }5\text{ V}$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $I_{\text{OUT1}} = 2\text{ A}$ , $I_{\text{OUT2}} = 4\text{ A}$			20	$\mu\text{s}$
	Settling time from current sense to temperature sense	$V_{\text{ENx}} = X$ , $V_{\text{DIA\_EN}} = 5\text{ V}$ $V_{\text{SEL1}} = 0\text{ V to }5\text{ V}$ , $V_{\text{SEL2}} = X$ $R_{\text{SNS}} = 1\text{ k}\Omega$ , $R_L \leq 6\ \Omega$			60	$\mu\text{s}$

### 7.7 Switching Characteristics

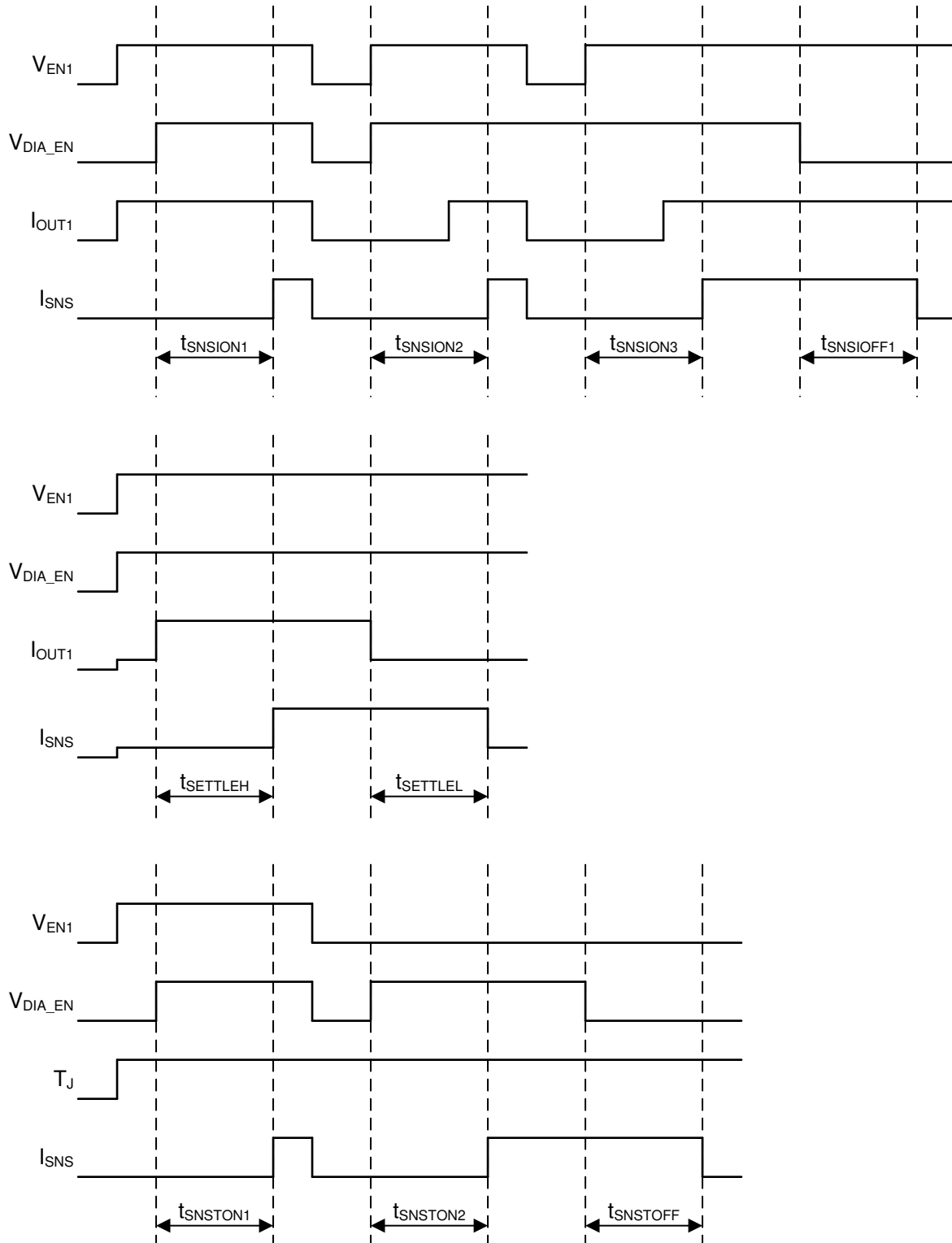
$V_{BB} = 13.5\text{ V}$ ,  $T_J = -40^\circ\text{C to }+150^\circ\text{C}$  (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
$t_{\text{DR}}$	Turnon delay time	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$ , 50% EN rising to 10% $V_{\text{OUT}}$ rising	20	60	100	$\mu\text{s}$
$t_{\text{DF}}$	Turnoff delay time	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$ , 50% EN falling to 90% $V_{\text{OUT}}$ Falling	20	60	100	$\mu\text{s}$
$\text{SR}_R$	$V_{\text{OUTx}}$ rising slew rate	$V_{\text{BB}} = 13.5\text{ V}$ , 20% to 80% of $V_{\text{OUT}}$ , $R_L \leq 6\ \Omega$	0.1	0.4	0.7	$\text{V}/\mu\text{s}$
$\text{SR}_F$	$V_{\text{OUTx}}$ falling slew rate	$V_{\text{BB}} = 13.5\text{ V}$ , 80% to 20% of $V_{\text{OUT}}$ , $R_L \leq 6\ \Omega$	0.1	0.4	0.7	$\text{V}/\mu\text{s}$
$t_{\text{ON}}$	Turnon time	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$ , 50% EN rising to 80% $V_{\text{OUT}}$ rising	39	87	145	$\mu\text{s}$
$t_{\text{OFF}}$	Turnoff time	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$ , 50% EN rising to 80% $V_{\text{OUT}}$ rising	39	87	147	$\mu\text{s}$
$t_{\text{ON}} - t_{\text{OFF}}$	Turnon and turnoff matching	200- $\mu\text{s}$ enable pulse	-50	0	50	$\mu\text{s}$
$E_{\text{ON}}$	Switching energy losses during turnon	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$		0.4		mJ
$E_{\text{OFF}}$	Switching energy losses during turnoff	$V_{\text{BB}} = 13.5\text{ V}$ , $R_L \leq 6\ \Omega$		0.4		mJ



(1) Rise and fall time of  $V_{ENx}$  is 100 ns.

**1. Switching Characteristics Definitions**

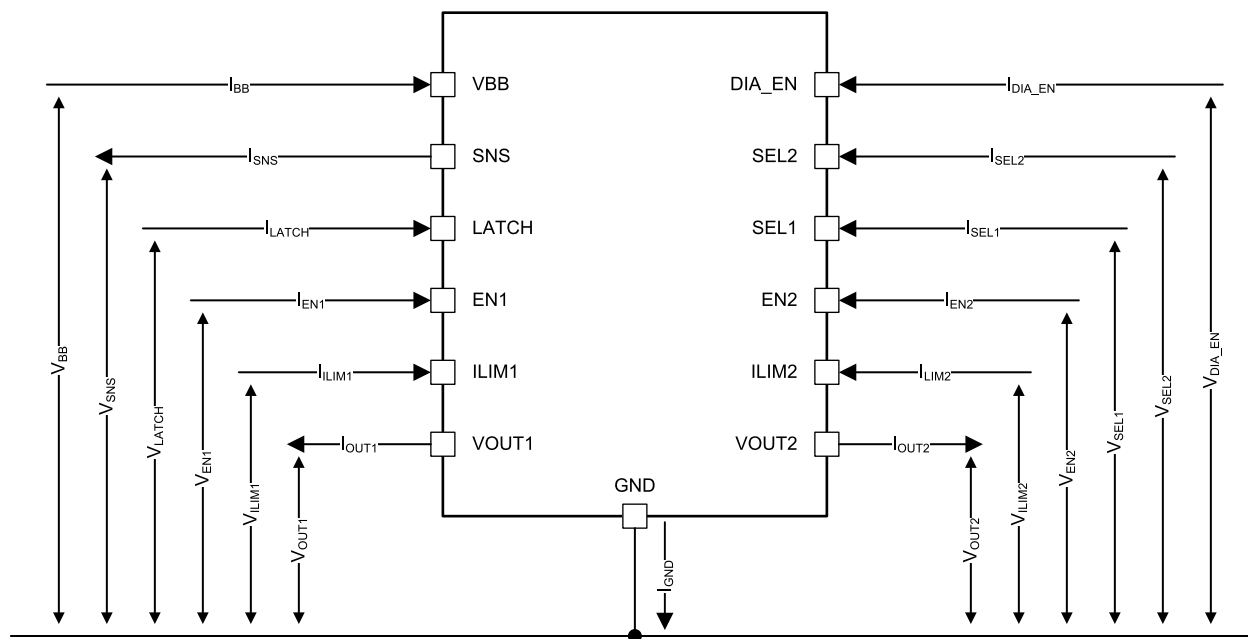


NOTE1: Rise and fall times of control signals are 100 ns. Control signals include: EN1, EN2, DIA\_EN, SEL1, SEL2.

NOTE2: SEL1 and SEL2 must be set to the appropriate values.

**2. SNS Timing Characteristics Definitions**

## 8 Parameter Measurement Information



3. Parameter Definitions

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## 9 Detailed Description

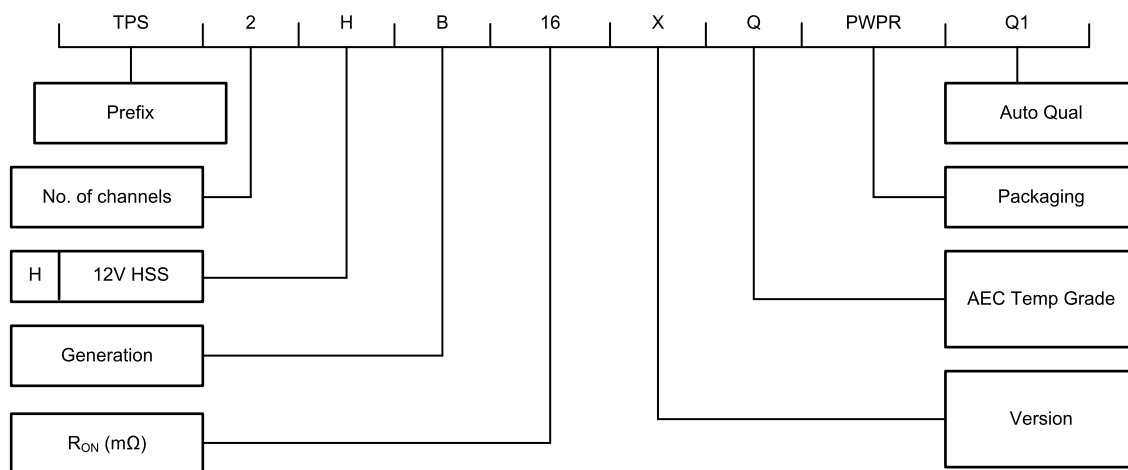
### 9.1 Overview

The TPS2HB50-Q1 device is a dual-channel smart high-side switch intended for use with 12-V automotive batteries. Many protection and diagnostic features are integrated in the device.

Diagnostics features include the analog SNS output that is capable of providing a signal that is proportional to load current or device temperature. The high-accuracy load current sense allows for diagnostics of complex loads.

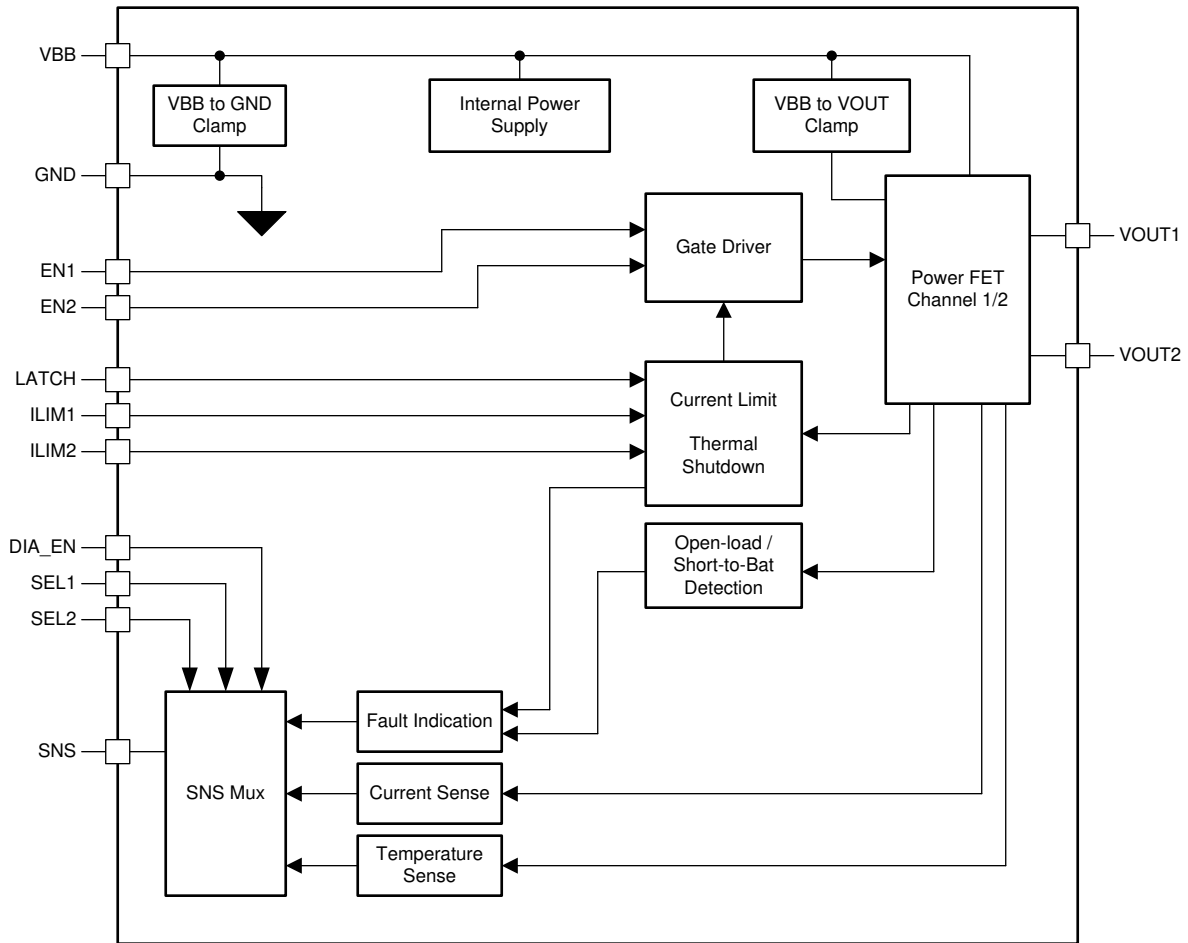
This device includes protection through thermal shutdown, current limiting, transient withstand, and reverse battery operation. For more details on the protection features, refer to the [Feature Description](#) and [Application Information](#) sections of the document.

The TPS2HB50-Q1 is one device in a family of TI high side switches. For each device, the part number indicates elements of the device behavior. [Figure 4](#) gives an example of the device nomenclature.



**Figure 4. Naming Convention**

## 9.2 Functional Block Diagram



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## 9.3 Feature Description

### 9.3.1 Protection Mechanisms

The TPS2HB50-Q1 is designed to operate in the automotive environment. The protection mechanisms allow the device to be robust against many system-level events such as load dump, reverse battery, short-to-ground, and more.

There are two protection features which, if triggered, will cause the switch to automatically disable:

- Thermal Shutdown
- Current Limit

When any of these protections are triggered, the device will enter the FAULT state. In the FAULT state, the fault indication will be available on the SNS pin (see the [Diagnostic Mechanisms](#) section of the data sheet for more details).

The switch is no longer held off and the fault indication is reset when all of the below conditions are met:

- LATCH pin is low
- $t_{\text{RETRY}}$  has expired
- All faults are cleared (thermal shutdown, current limit)

---

注

CH1 and CH2 operate independently. If there is a fault on one channel, the other channel is not affected.

---

#### 9.3.1.1 Thermal Shutdown

The device includes a temperature sensor on each power FET and also within the controller portion of the device. There are two cases that the device will consider to be a thermal shutdown fault:

- $T_{\text{J,FET}} > T_{\text{ABS}}$
- $(T_{\text{J,FET}} - T_{\text{J,controller}}) > T_{\text{REL}}$

After the fault is detected, the relevant switch will turn off. Each channel is turned off based on the measurement of temperature sensor for that channel. Therefore, if the thermal fault is detected on only one channel, the other channel continues operation. If  $T_{\text{J,FET}}$  passes  $T_{\text{ABS}}$ , the fault is cleared when the switch temperature decreases by the hysteresis value,  $T_{\text{HYS}}$ . If instead the  $T_{\text{REL}}$  threshold is exceeded, the fault is cleared after  $T_{\text{RETRY}}$  passes.

#### 9.3.1.2 Current Limit

When  $I_{\text{OUT}}$  reaches the current limit threshold,  $I_{\text{CL}}$ , the channel will switch off immediately. The  $I_{\text{CL}}$  value will vary with slew rate and a fast current increase that occurs during a powered-on short circuit can temporarily go above the specified  $I_{\text{CL}}$  value. When the switch is in the FAULT state it will output an output current  $I_{\text{SNSFH}}$  on the SNS pin.

During a short circuit event, the device will hit the  $I_{\text{CL}}$  value that is listed in the Electrical Characteristics table (for the given device version and  $R_{\text{ILIM}}$ ) and then turn the output off to protect the device. The device will register a short circuit event when the output current exceeds  $I_{\text{CL}}$ , however the measured maximum current may exceed the  $I_{\text{CL}}$  value due to the TPS2HB50-Q1 deglitch filter and turn-off time. The device is guaranteed to protect itself during a short circuit event up to 24 V at 125°C.

##### 9.3.1.2.1 Current Limit Foldback

Version B of the TPS2HB50-Q1 implements a current limit foldback feature that is designed to protect the device in the case of a long-term fault condition. If the device undergoes fault shutdown events (either of thermal shutdown or current limit) seven consecutive times, the current limit will be reduced to half of the original value. The device will revert back to the original current limit threshold if either of the following occurs:

- The device goes to standby mode.
- The switch turns on and turns off without any fault occurring.

Version A does not implement the current limit foldback due to the lower current limit causing less harm during repetitive long-term faults.



## Feature Description (continued)

### 9.3.1.2.2 Programmable Current Limit

The TPS2HB50-Q1 includes an adjustable current limit. Some applications (for example, incandescent bulbs) will require a high current limit. Other applications can benefit from a lower current limit threshold. In general, wherever possible a lower current limit is recommended due to allowing system advantages through:

- Reduced size and cost in current carrying components such as PCB traces and module connectors
- Less disturbance at the power supply ( $V_{BB}$  pin) during a short circuit event
- Improved protection of the downstream load

To set the current limit threshold, connect a resistor from  $I_{LIM}$  to  $V_{BB}$ . The current limit threshold is determined by [Equation 1](#) ( $R_{ILIM}$  in  $k\Omega$ ):

$$I_{CL} = K_{CL} / R_{ILIM} \quad (1)$$

The  $R_{ILIM}$  range is between 5  $k\Omega$  and 25  $k\Omega$ . An  $R_{ILIM}$  resistor is required, however in the fault case where the pin is floating, grounded, or outside of this range the current limit will default to an internal level that is defined in the [Specifications](#) section of this document.

#### 注

Capacitance on the  $I_{LIM}$  pin can cause  $I_{LIM}$  to go out of range during short circuit events. For accurate current limiting, place  $R_{ILIM}$  near to the device with short traces to ensure <5 pF capacitance to GND on the  $I_{LIM}$  pin.

### 9.3.1.2.3 Undervoltage Lockout (UVLO)

The device monitors the supply voltage  $V_{BB}$  to prevent unpredicted behaviors in the event that the supply voltage is too low. When the supply voltage falls down to  $V_{UVLOF}$ , the output stage is shut down automatically. When the supply rises up to  $V_{UVLOR}$ , the device turns back on.

During an initial ramp of  $V_{BB}$  from 0 V at a ramp rate slower than 1 V/ms,  $V_{EN}$  pin will have to be  $V_{BB}$  held low until  $V_{BB}$  is above UVLO threshold (with respect to board ground) and the supply voltage to the device has reliably reached above the UVLO condition. For best operation, ensure that  $V$  has risen above UVLO before setting the  $V_{EN}$  pin to high.

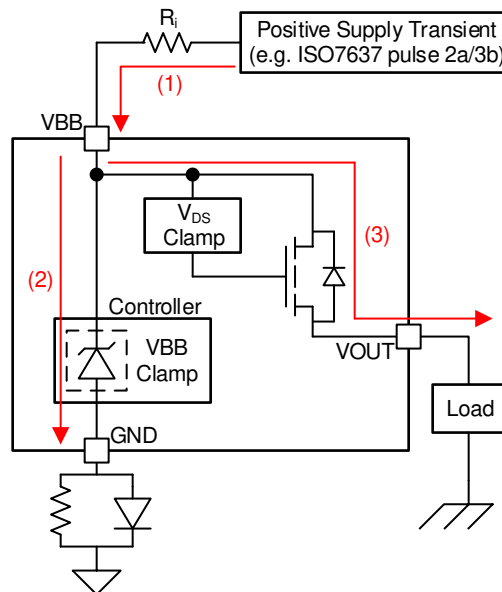
### 9.3.1.2.4 $V_{BB}$ During Short-to-Ground

When  $V_{OUT}$  is shorted to ground, the module power supply ( $V_{BB}$ ) can have a transient decrease. This is caused by the sudden increase in current flowing through the wiring harness cables. To achieve ideal system behavior, it is recommended that the module maintain  $V_{BB} > 3$  V (above the maximum  $V_{UVLOF}$ ) during  $V_{OUT}$  short-to-ground. This is typically accomplished by placing bulk capacitance on the power supply node.

### 9.3.1.3 Voltage Transients

The TPS2HB50-Q1 device describes two types of voltage clamps which protect the FET against system-level voltage transients. The two different clamps are shown in [Figure 5](#).

The clamp from  $V_{BB}$  to GND is primarily used to protect the controller from positive transients on the supply line (for example, ISO7637-2). The clamp from  $V_{BB}$  to  $V_{OUT}$  is primarily used to limit the voltage across the FET when switching off an inductive load. If the voltage potential from  $V_{BB}$  to GND exceeds the  $V_{BB}$  clamp level, the clamp will allow current to flow through the device from  $V_{BB}$  to GND (Path 2). If the voltage potential from  $V_{BB}$  to  $V_{OUT}$  exceeds the clamping voltage, the power FET will allow current to flow from  $V_{BB}$  to  $V_{OUT}$  (Path 3). Additional capacitance from  $V_{BB}$  to GND can increase the reliability of the system during ISO 7637 pulse 2A testing.

**Feature Description (continued)**

**图 5. Current Path During Supply Voltage Transient**
**9.3.1.3.1 Load Dump**

The TPS2HB50-Q1 device is tested according to ISO 16750-2:2010(E) suppressed load dump pulse. The device supports up to 40-V load dump transient and will maintain normal operation during the load dump pulse. If the switch is enabled, it will stay enabled and if the switch is disabled, it will stay disabled.

**9.3.1.4 Driving Inductive Loads**

When switching off an inductive load, the inductor may impose a negative voltage on the output of the switch. The TPS2HB50-Q1 includes a voltage clamp to limit voltage across the FET. The maximum acceptable load inductance is a function of the device robustness.

For more information on driving inductive loads, refer to TI's [How To Drive Inductive, Capacitive, and Lighting Loads with Smart High Side Switches](#) application report.

**9.3.1.5 Reverse Battery**

In the reverse battery condition, the switch will automatically be enabled regardless of the state of EN1/EN2 to prevent excess power dissipation inside the MOSFET body diode. In many applications (for example, resistive loads), the full load current may be present during reverse battery. In order to activate the automatic switch on feature, the SEL2 pin must have a path to module ground. This may be path 1 as shown in [图 6](#), or if the SEL2 pin is unused, the path may be through  $R_{PROT}$  to module ground.

Protection features like thermal shutdown are not available during a reverse battery event. Care must be taken to ensure that excessive power is not dissipated in the switch during the reverse battery condition.

There are two options for blocking reverse current in the system. The first option is to place a blocking device (FET or diode) in series with the battery supply, blocking all current paths. The second option is to place a blocking diode in series with the GND node of the high-side switch. This method will protect the controller portion of the switch (path 2), but it will not prevent current from flowing through the load (path 3). The diode used for the second option may be shared amongst multiple high-side switches.

Path 1 shown in [图 6](#) is blocked inside of the device.

Feature Description (continued)

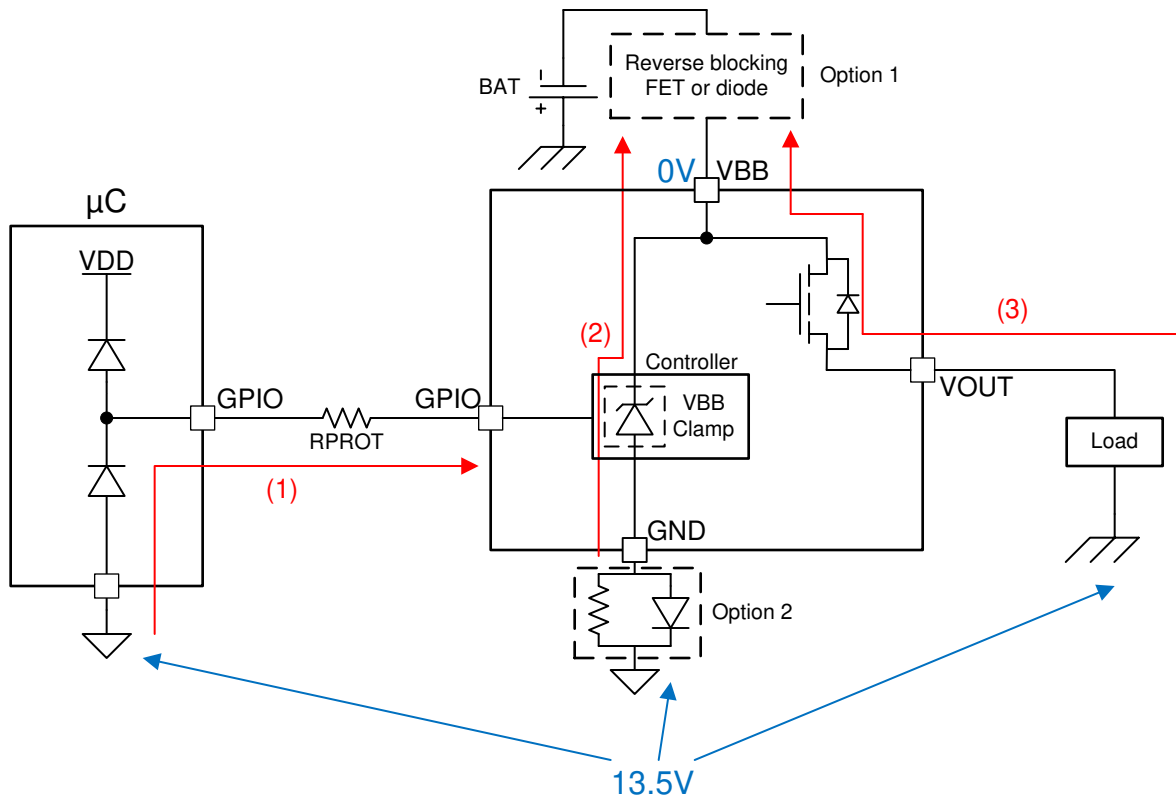


图 6. Current Path During Reverse Battery

9.3.1.6 Fault Event – Timing Diagrams

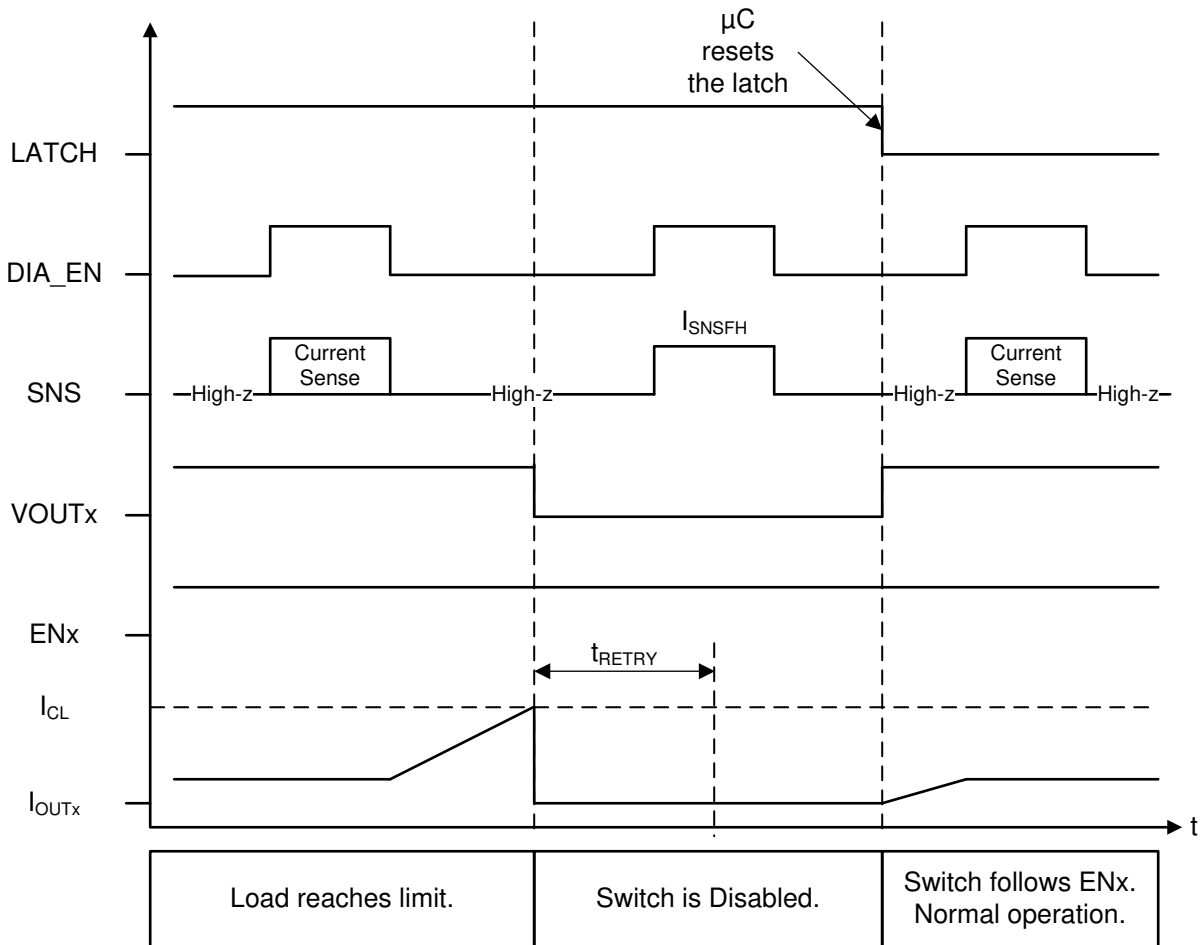
注

All timing diagrams assume that the SELx pins are set to select the relevant channel. The LATCH, DIA\_EN, and ENx pins are controlled by the user. The timing diagrams represent a possible use-case.

图 7 shows the immediate current limit switch off and the retry behavior of versions A and B of the device. As shown, the switch will remain latched off until the LATCH pin is low.

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**Feature Description (continued)**



**Figure 7. Current Limit – Version A and B - Latched Behavior**

Figure 8 shows the immediate current limit switch off behavior of versions A and B. In this example, LATCH is tied to GND; hence, the switch will retry after the fault is cleared and  $t_{\text{RETRY}}$  has expired.

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Feature Description (continued)

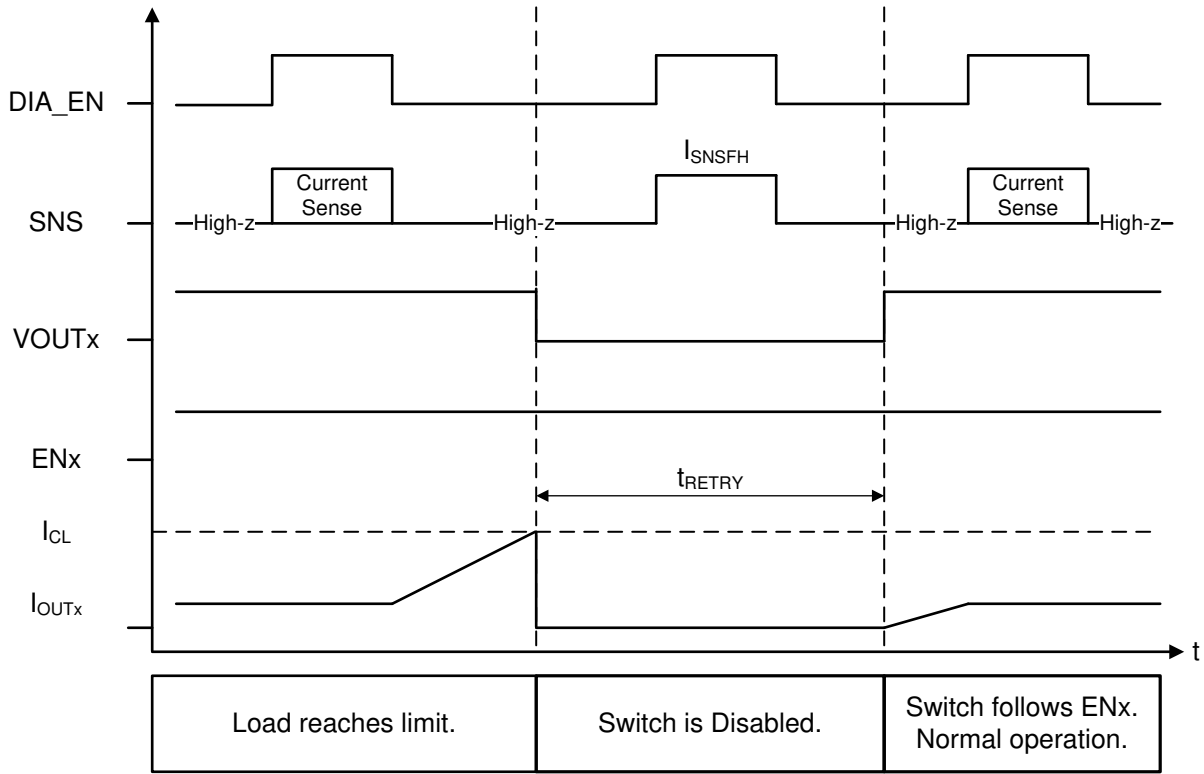


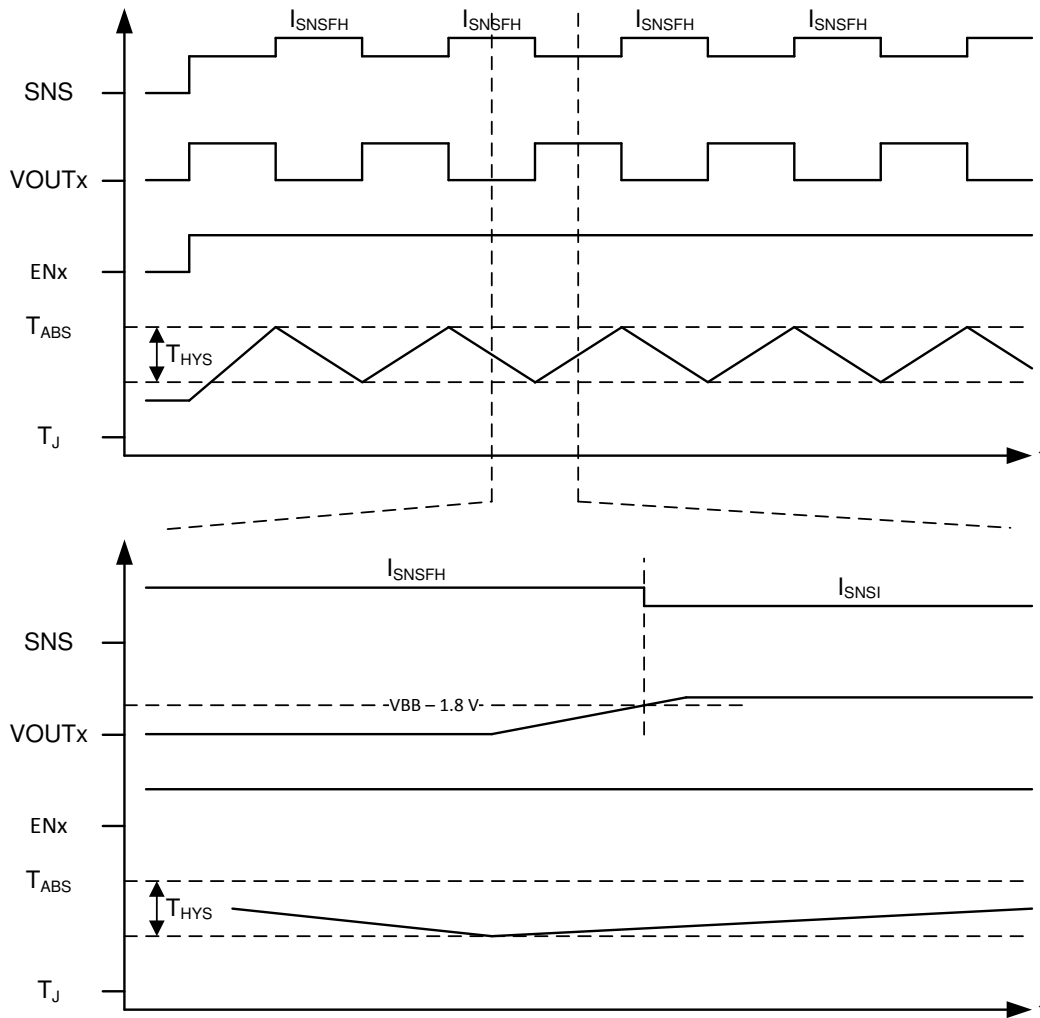
图 8. Current Limit – Version A and B - LATCH = 0

图 9 illustrates auto-retry behavior and provides a zoomed-in view of the fault indication during retry. When the switch retries after a shutdown event, the SNS fault indication will remain at the fault state until  $V_{OUT}$  has risen to  $V_{BB} - 1.8\text{ V}$ . Once  $V_{OUT}$  has risen, the SNS fault indication is reset and current sensing is available. If there is a short-to-ground and  $V_{OUT}$  cannot rise, the SNS fault indication will remain indefinitely.

注

图 9 assumes that  $t_{RETRY}$  has expired by the time that  $T_J$  reaches the hysteresis threshold.  
LATCH = 0 V and DIA\_EN = 5 V

**Feature Description (continued)**



**9. Fault Indication During Retry**

**9.3.2 Diagnostic Mechanisms**

**9.3.2.1 *VOUTx* Short-to-Battery and Open-Load**

The TPS2HB50-Q1 is capable of detecting short-to-battery and open-load events regardless of whether the switch is turned on or off, however the two conditions use different methods.

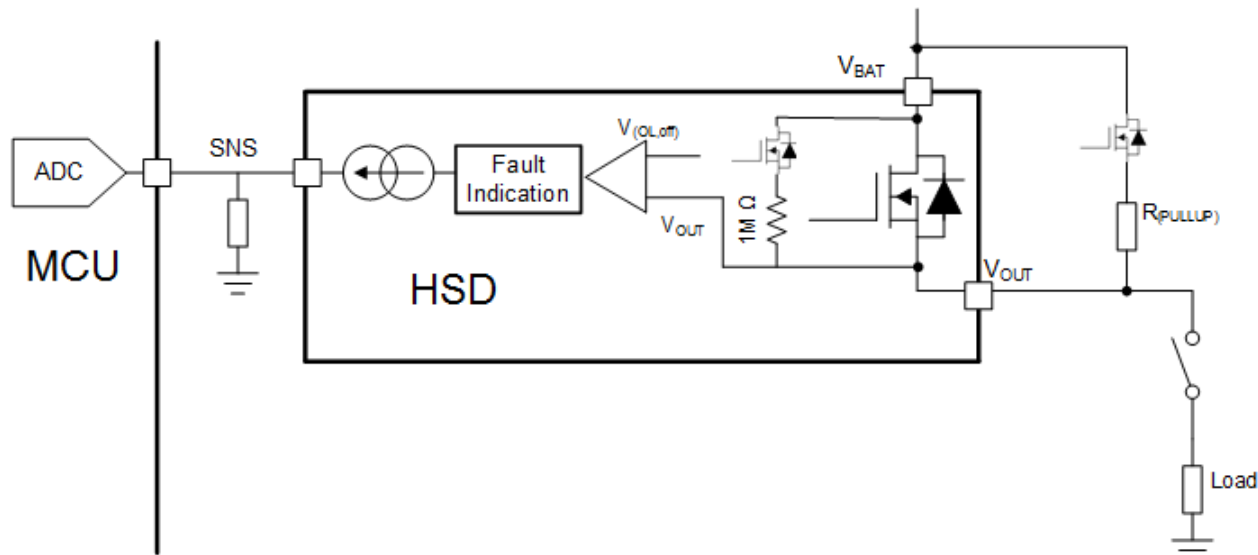
**9.3.2.1.1 Detection With Switch Enabled**

When the switch is enabled, the  $VOUTx$  short-to-battery and open-load conditions can be detected by the current sense feature. In both cases, the load current will be measured through the SNS pin as below the expected value.

## Feature Description (continued)

### 9.3.2.1.2 Detection With Switch Disabled

While the switch is disabled, if DIA\_EN is high, an internal comparator will detect the condition of  $V_{OUT}$ . If the load is disconnected (open load condition) or there is a short to battery the  $V_{OUT}$  voltage will be higher than the open load threshold ( $V_{OL,off}$ ) and a fault is indicated on the SNS pin. An internal pull-up of  $1\text{ M}\Omega$  is in series with an internal MOSFET switch, so no external component is required if only a completely open load must be detected. However, if there is significant leakage or other current draw even when the load is disconnected, a lower value pull-up resistor and switch can be added externally to set the  $V_{OUT}$  voltage above the  $V_{OL,off}$  during open load conditions.



- (1) This figure assumes that the device ground and the load ground are at the same potential. In a real system, there may be a ground shift voltage of 1 V to 2 V.

FIG 10. Short to Battery and Open Load Detection

The detection circuitry is only enabled when DIA\_EN = HIGH and EN = LOW. If  $V_{OUT} > V_{OL}$ , the SNS pin will go to the fault level, but if  $V_{OUT} < V_{OL}$  there will be no fault indication. The fault indication will only occur if the SEL1 pin is set to diagnose the respective channel.

While the switch is disabled and DIA\_EN is high, the fault indication mechanisms will continuously represent the present status. For example, if  $V_{OUT}$  decreases from greater than  $V_{OL}$  to less than  $V_{OL}$ , the fault indication is reset. Additionally, the fault indication is reset upon the falling edge of DIA\_EN or the rising edge of EN.

Feature Description (continued)

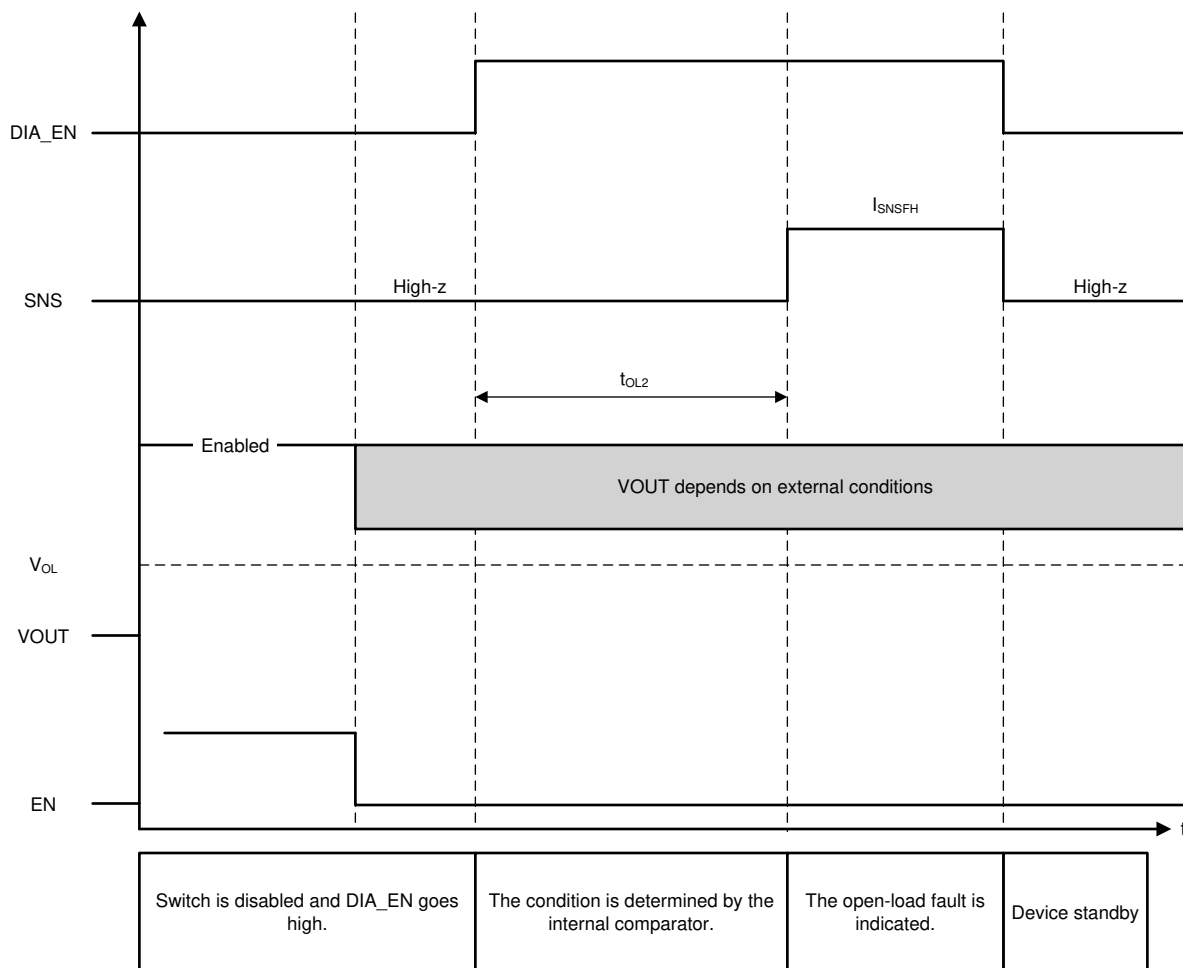


图 11. Open Load

9.3.2.2 SNS Output

The SNS output may be used to sense the load current or device temperature. The SELx pins will select the desired sense signal. The sense circuit will provide a current that is proportional to the selected parameter. This current will be sourced into an external resistor to create a voltage that is proportional to the selected parameter. This voltage may be measured by an ADC or comparator.

To ensure accurate sensing measurement, the sensing resistor should be connected to the same ground potential as the  $\mu$ C ADC.

表 3. Analog Sense Transfer Function

PARAMETER	TRANSFER FUNCTION
Load current	$I_{SNSI} = I_{OUT} / K_{SNS}$ (1500)
Device temperature	$I_{SNST} = (T_J - 25^\circ\text{C}) \times dI_{SNST} / dT + 0.85$

The SNS output will also be used to indicate system faults.  $I_{SNS}$  will go to the predefined level,  $I_{SNSFH}$ , when there is a fault.  $I_{SNSFH}$ ,  $dI_{SNST}/dT$ , and  $K_{SNS}$  are defined in the [Specifications](#) section.

9.3.2.2.1 R<sub>SNS</sub> Value

The following factors should be considered when selecting the R<sub>SNS</sub> value:

- Current sense ratio ( $K_{SNS}$ )

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- Largest and smallest diagnosable load current required for application operation
- Full-scale voltage of the ADC
- Resolution of the ADC

For an example of selecting  $R_{SNS}$  value, reference [Selecting the  \$R\_{SNS}\$  Value](#) in the applications section of this datasheet.

#### 9.3.2.2.1.1 High Accuracy Load Current Sense

In many automotive modules, it is required that the high-side switch provide diagnostic information about the downstream load. With more complex loads, high accuracy sensing is required. A few examples follow:

- **LED lighting:** In many architectures, the body control module (BCM) must be compatible with both incandescent bulbs and also LED modules. The bulb may be relatively simple to diagnose. However, the LED module will consume less current and also can include multiple LED strings in parallel. The same BCM is used in both cases, so the high-side switch can accurately diagnose both load types.
- **Solenoid protection:** Often solenoids are precisely controlled by low-side switches. However, in a fault event, the low-side switch cannot disconnect the solenoid from the power supply. A high-side switch can be used to continuously monitor several solenoids. If the system current becomes higher than expected, the high-side switch can disable the module.

#### 9.3.2.2.1.2 SNS Output Filter

To achieve the most accurate current sense value, it is recommended to filter the SNS output. There are two methods of filtering:

- Low-Pass RC filter between the SNS pin and the ADC input. This filter is illustrated in [Figure 15](#) with typical values for the resistor and capacitor. The designer should select a  $C_{SNS}$  capacitor value based on system requirements. A larger value will provide improved filtering but a smaller value will allow for faster transient response.
- The ADC and microcontroller can also be used for filtering. It is recommended that the ADC collects several measurements of the SNS output. The median value of this data set should be considered as the most accurate result. By performing this median calculation, the microcontroller can filter out any noise or outlier data.

#### 9.3.2.3 Fault Indication and SNS Mux

The following faults will be communicated through the SNS output:

- Switch shutdown, due to:
  - Thermal Shutdown
  - Current limit
- Open-Load /  $V_{OUT}$  shorted-to-battery

Open-load / Short-to-battery are not indicated while the switch is enabled, although these conditions can still be detected through the sense current. Hence, if there is a fault indication corresponding to an enabled channel, then it must be either due to an over-current or over-temperature event.

The SNS pin will only indicate the fault if the SELx pins are selecting the relevant channel. When the device is set to measure temperature, the pin will be measuring the temperature of whichever channel is at a higher temperature.

**表 4. Version A/B SNS Mux**

INPUTS				OUTPUTS
DIA_EN	SEL1	SEL2	FAULT DETECT <sup>(1)</sup>	SNS
0	X	X	X	High-Z
1	0	0	0	CH1 current
1	0	1	0	CH2 current
1	1	0	0	Device temperature

- (1) Fault Detect encompasses multiple conditions:  
 (a) Switch shutdown and waiting for retry  
 (b) Open Load / Short To Battery

表 4. Version A/B SNS Mux (continued)

INPUTS				OUTPUTS
DIA_EN	SEL1	SEL2	FAULT DETECT <sup>(1)</sup>	SNS
1	1	1	0	N/A
1	0	0	1	I <sub>SNSFH</sub>
1	0	1	1	I <sub>SNSFH</sub>
1	1	0	1	Device temperature
1	1	1	1	N/A

9.3.2.4 Resistor Sharing

Multiple high-side channels may use the same SNS resistor as shown in the figure below. This reduces the total number of passive components in the system and the number of ADC terminals that are required of the microcontroller.

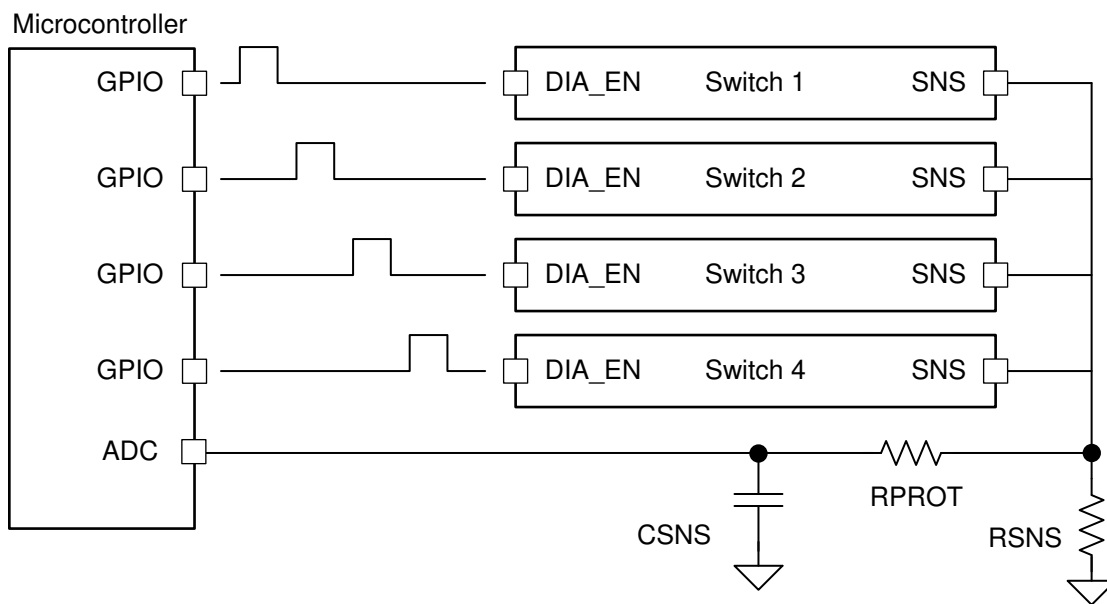
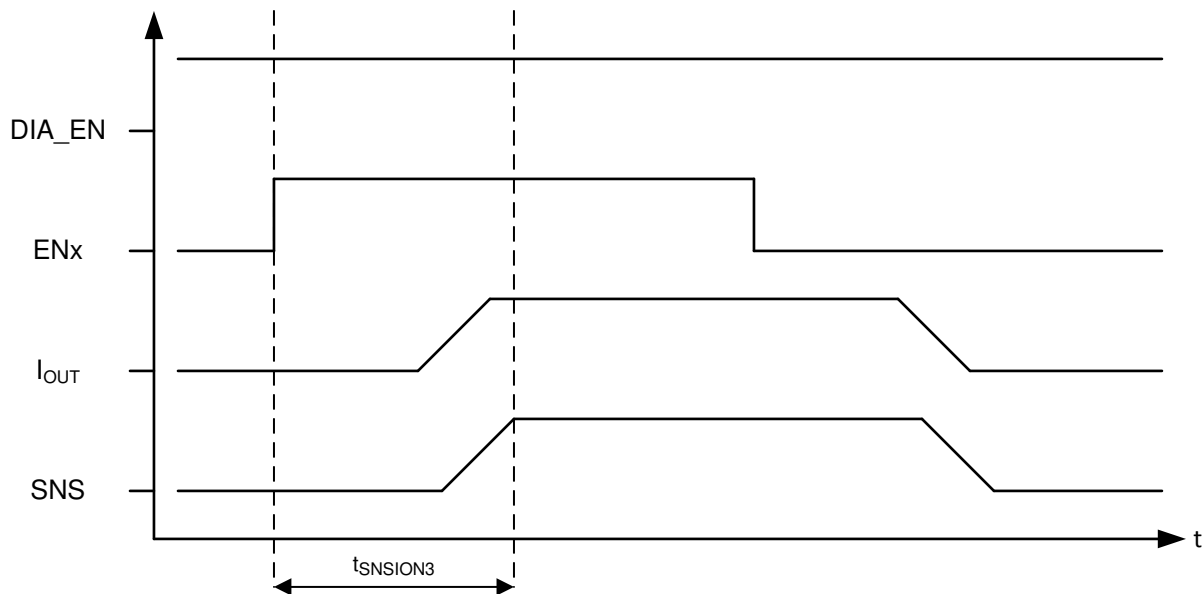


图 12. Sharing R<sub>SNS</sub> Among Multiple Devices

9.3.2.5 High-Frequency, Low Duty-Cycle Current Sensing

Some applications will operate with a high-frequency, low duty-cycle PWM or require fast settling of the SNS output. For example, a 250 Hz, 5% duty cycle PWM will have an on-time of only 200 μs that must be accommodated. The micro-controller ADC may sample the SNS signal after the defined settling time t<sub>SNSION3</sub>.

ADVANCE INFORMATION



13. Current Sensing in Low-Duty Cycle Applications

## 9.4 Device Functional Modes

During typical operation, the TPS2HB50-Q1 can operate in a number of states that are described below and shown as a state diagram in 14.

### 9.4.1 Off

Off state occurs when the device is not powered.

### 9.4.2 Standby

Standby state is a low-power mode used to reduce power consumption to the lowest level. Diagnostic capabilities are not available in Standby mode.

### 9.4.3 Diagnostic

Diagnostic state may be used to perform diagnostics while the switches are disabled.

### 9.4.4 Standby Delay

The Standby Delay state is entered when EN1, EN2, and DIA\_EN are low. After  $t_{STBY}$ , if the ENx and DIA\_EN pins are still low, the device will go to Standby State.

### 9.4.5 Active

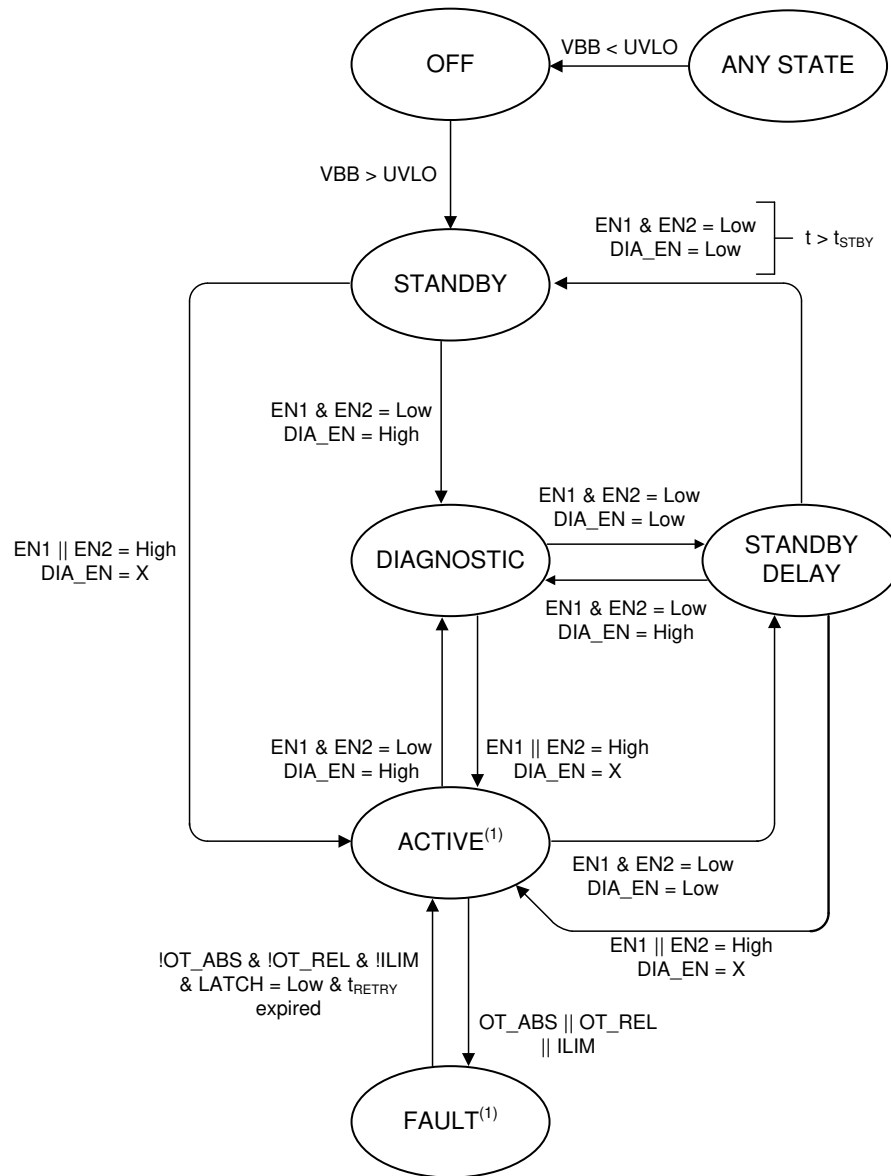
In Active state, one or more of the switches are enabled. The diagnostic functions may be turned on or off during Active state.

### 9.4.6 Fault

The Fault state is entered if a fault shutdown occurs (thermal shutdown or current limit). After all faults are cleared, the LATCH pin is low, and the retry timer has expired, the device will transition out of Fault state. If the relevant ENx pin is high, the switch will re-enable. If the relevant ENx pin is low, the switch will remain off.

Device Functional Modes (continued)

ADVANCE INFORMATION



(1) CH1 and CH2 operate independently. Each channel is enabled/disabled independently. Also, if there is a fault on one channel, the other channel is not affected.

14. State Diagram

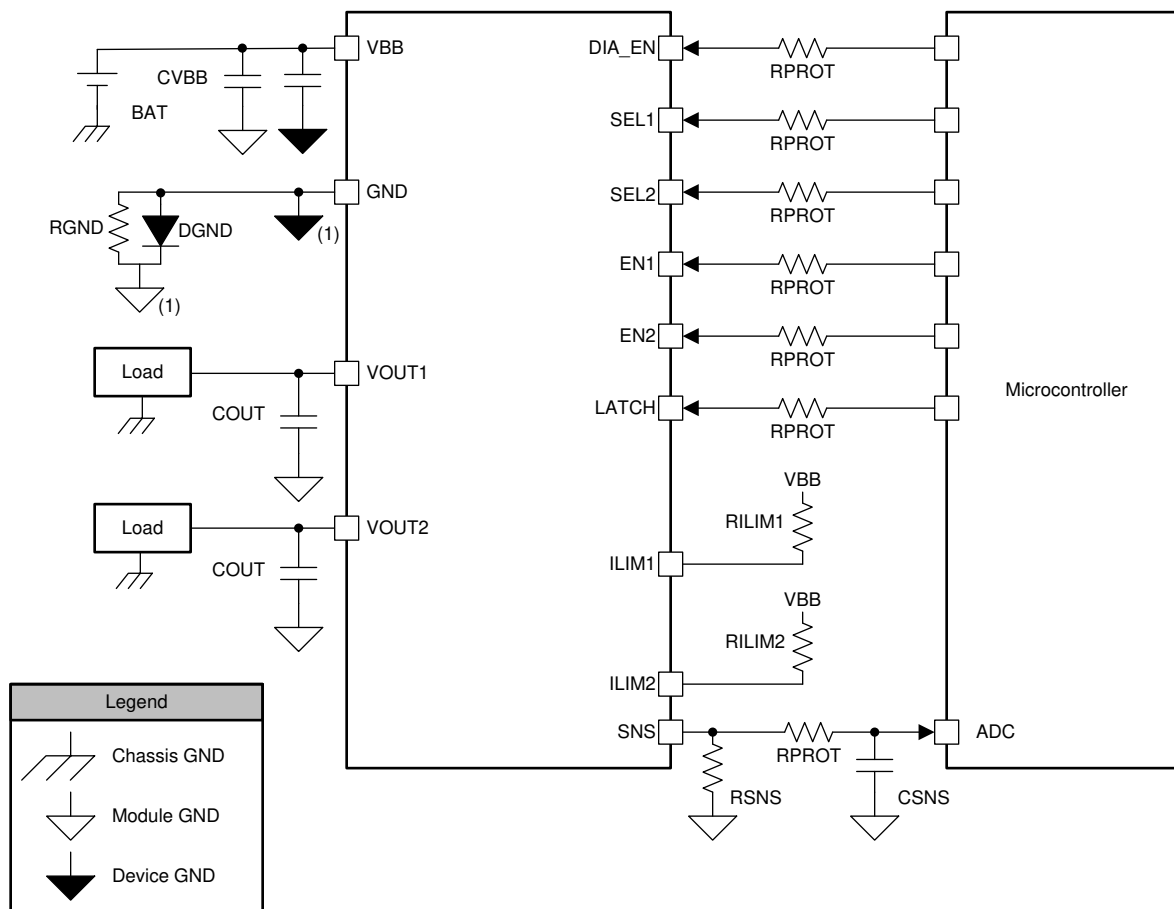
## 10 Application and Implementation

### 注

Information in the following applications sections is not part of the TI component specification, and TI does not warrant its accuracy or completeness. TI's customers are responsible for determining suitability of components for their purposes. Customers should validate and test their design implementation to confirm system functionality.

### 10.1 Application Information

Figure 15 shows the schematic of a typical application for the TPS2HB50-Q1. It includes all standard external components. This section of the datasheet discusses the considerations in implementing commonly required application functionality.



(1) With the ground protection network, the device ground will be offset relative to the microcontroller ground.

Figure 15. System Diagram

Table 5. Recommended External Components

COMPONENT	TYPICAL VALUE	PURPOSE
R <sub>PROT</sub>	15 kΩ	Protect microcontroller and device I/O pins
R <sub>SNS</sub>	1 kΩ	Translate the sense current into sense voltage
C <sub>SNS</sub>	100 pF - 10 nF	Low-pass filter for the ADC input
R <sub>GND</sub>	4.7 kΩ	Stabilize GND potential during turn-off of inductive load
D <sub>GND</sub>	BAS21 Diode	Protects device during reverse battery

**Application Information (continued)**
**表 5. Recommended External Components (continued)**

COMPONENT	TYPICAL VALUE	PURPOSE
R <sub>LIM</sub>	5 kΩ - 25 kΩ	Set current limit threshold
C <sub>VBB</sub>	220 nF to Device GND	Filtering of voltage transients (for example, ESD, ISO7637-2) and improved emissions
	100 nF to Module GND	Stabilize the input supply and filter out low frequency noise.
C <sub>OUT</sub>	22 nF	Filtering of voltage transients (for example, ESD, ISO7637-2)
C <sub>GND</sub>	1 μF from Device GND to Module GND	Optional capacitance to help with RF immunity.

**10.1.1 Ground Protection Network**

As discussed in the [Reverse Battery](#) section, D<sub>GND</sub> may be used to prevent excessive reverse current from flowing into the device during a reverse battery event. Additionally, R<sub>GND</sub> is placed in parallel with D<sub>GND</sub> if the switch is used to drive an inductive load. The ground protection network (D<sub>GND</sub> and R<sub>GND</sub>) may be shared amongst multiple high-side switches.

A minimum value for R<sub>GND</sub> may be calculated by using the absolute maximum rating for I<sub>GND</sub>. During the reverse battery condition, I<sub>GND</sub> = V<sub>BB</sub> / R<sub>GND</sub>:

$$R_{GND} \geq V_{BB} / I_{GND}$$

- Set V<sub>BB</sub> = -13.5 V
- Set I<sub>GND</sub> = -50 mA (absolute maximum rating)

$$R_{GND} \geq -13.5 \text{ V} / -50 \text{ mA} = 270 \ \Omega \quad (2)$$

In this example, it is found that R<sub>GND</sub> must be at least 270 Ω. It is also necessary to consider the power dissipation in R<sub>GND</sub> during the reverse battery event:

$$P_{RGND} = V_{BB}^2 / R_{GND} \quad (3)$$

$$P_{RGND} = (13.5 \text{ V})^2 / 270 \ \Omega = 0.675 \text{ W}$$

In practice, R<sub>GND</sub> may not be rated for such a high power. In this case, a larger resistor value should be selected.

**10.1.2 Interface With Microcontroller**

The ground protection network will cause the device ground to be at a higher potential than the module ground (and microcontroller ground). This offset will impact the interface between the device and the microcontroller.

Logic pin voltage will be offset by the forward voltage of the diode. For input pins (for example, EN1), the designer must consider the V<sub>IH</sub> specification of the switch and the V<sub>OH</sub> specification of the microcontroller. For a system that *does not* include D<sub>GND</sub>, it is required that V<sub>OH</sub> > V<sub>IH</sub>. For a system that *does* include D<sub>GND</sub>, it is required that V<sub>OH</sub> > (V<sub>IH</sub> + V<sub>F</sub>). V<sub>F</sub> is the forward voltage of D<sub>GND</sub>.

The sense resistor, R<sub>SNS</sub>, should be terminated to the microcontroller ground. In this case, the ADC can accurately measure the SNS signal even if there is an offset between the microcontroller ground and the device ground.

**10.1.3 I/O Protection**

R<sub>PROT</sub> is used to protect the microcontroller I/O pins during system-level voltage transients such as ISO pulses or reverse battery. The SNS pin voltage can exceed the ADC input pin maximum voltage if the fault or saturation current causes a high enough voltage drop across the sense resistor. If that can occur in the design (for example, by switching to a high value R<sub>SNS</sub> to improve ADC input level), then an appropriate external clamp has to be designed to prevent a high voltage at the SNS output and the ADC input.

**10.1.4 Inverse Current**

Inverse current occurs when 0 V < V<sub>BB</sub> < V<sub>OUTX</sub>. In this case, current may flow from V<sub>OUTX</sub> to V<sub>BB</sub>. Inverse current cannot be caused by a purely resistive load. However, a capacitive or inductive load can cause inverse current. For example, if there is a significant amount of load capacitance and the V<sub>BB</sub> node has a transient droop, V<sub>OUTX</sub> may be greater than V<sub>BB</sub>.

The TPS2HB50-Q1 will not detect inverse current. When the switch is enabled, inverse current will pass through the switch. When the switch is disabled, inverse current may pass through the MOSFET body diode. The device will continue operating in the normal manner during an inverse current event.

### 10.1.5 Loss of GND

The ground connection may be lost either on the device level or on the module level. If the ground connection is lost, both switches will be disabled. If the switch was already disabled when the ground connection was lost, the switch will remain disabled. When the ground is reconnected, normal operation will resume.

### 10.1.6 Automotive Standards

The TPS2HB50-Q1 is designed to be protected against all relevant automotive standards to ensure reliable operations when connected to a 12-V automotive battery.

#### 10.1.6.1 ISO7637-2

The TPS2HB50-Q1 is tested according to the ISO7637-2:2011 (E) standard. The test pulses are applied both with the switches enabled and disabled. The test setup includes only the DUT and minimal external components:  $C_{VBB}$ ,  $C_{OUT}$ ,  $D_{GND}$ , and  $R_{GND}$ .

Status II is defined in ISO 7637-1 Function Performance Status Classification (FPSC) as: “The function does not perform as designed during the test but returns automatically to normal operation after the test”. See 表 6 for ISO7637-2:2011 (E) expected results.

表 6. ISO7637-2:2011 (E) Results

TEST PULSE	TEST PULSE SEVERITY LEVEL WITH STATUS II FUNCTIONAL PERFORMANCE		MINIMUM NUMBER OF PULSES OR TEST TIME	BURST CYCLE / PULSE REPETITION TIME	
	LEVEL	US		MIN	MAX
1	III	-112 V	500 pulses	0.5 s	--
2a <sup>(1)</sup>	III	+55 V	500 pulses	0.20	5 s
2b	IV	+10 V	10 pulses	0.5 s	5 s
3a	IV	-220 V	1 hour	90 ms	100 ms
3b	IV	+150 V	1 hour	90 ms	100 ms

(1) 1  $\mu$ F capacitance on  $C_{VBB}$  is required for passing level 3 ISO7637 pulse 2A.

#### 10.1.6.2 AEC – Q100-012 Short Circuit Reliability

The TPS2HB50-Q1 is tested according to the AEC-Q100-012 Short Circuit Reliability standard. This test is performed to demonstrate the robustness of the device against  $V_{OUT}$  short-to-ground events. Test conditions and test procedures are summarized in 表 7. For further details, refer to the AEC - Q100-012 standard document.

Test conditions:

- LATCH = 0 V
- $I_{LIM} = 5 \text{ k}\Omega$
- 10 units from 3 separate lots for a total of 30 units.
- $L_{supply} = 5 \mu\text{H}$ ,  $R_{supply} = 10 \text{ m}\Omega$
- $V_{BB} = 14 \text{ V}$

Test procedure:

- Parametric data is collected on each unit pre-stress
- Each unit is enabled into a short-circuit with the required short circuit cycles or duration as specified
- Functional testing is performed on each unit post-stress to verify that the part still operates as expected

The cold repetitive test is run at 85°C which is the worst case condition for the device to sustain a short circuit. The cold repetitive test refers to the device being given time to cool down between pulses, rather than being run at a cold temperature. The load short circuit is the worst case situation, since the energy stored in the cable inductance can cause additional harm. The fast response of the device ensures current limiting occurs quickly and at a current close to the load short condition. In addition, the hot repetitive test is performed as well.

表 7. AEC - Q100-012 Test Results

TEST	LOCATION OF SHORT	DEVICE VERSION	NO. OF CYCLES / DURATION	NO. OF UNITS	NO. OF FAILS
Cold Repetitive - Long Pulse	Load Short Circuit, $L_{short} = 5 \mu\text{H}$ , $R_{short} = 100 \text{ m}\Omega$ , $T_A = 85^\circ\text{C}$	B	100 k cycles	30	0
Hot Repetitive - Long Pulse	Load Short Circuit, $L_{short} = 5 \mu\text{H}$ , $R_{short} = 100 \text{ m}\Omega$ , $T_A = 25^\circ\text{C}$	B	100 hours	30	0

### 10.2 Typical Application

This application example demonstrates how the TPS2HB50-Q1 device can be used to power resistive heater loads in automotive seats. In this example, we consider dual heater loads that are powered independently by the two channels of the device. A dual-channel device is the ideal solution as it will yield a smaller solution size relative to two single-channel devices.

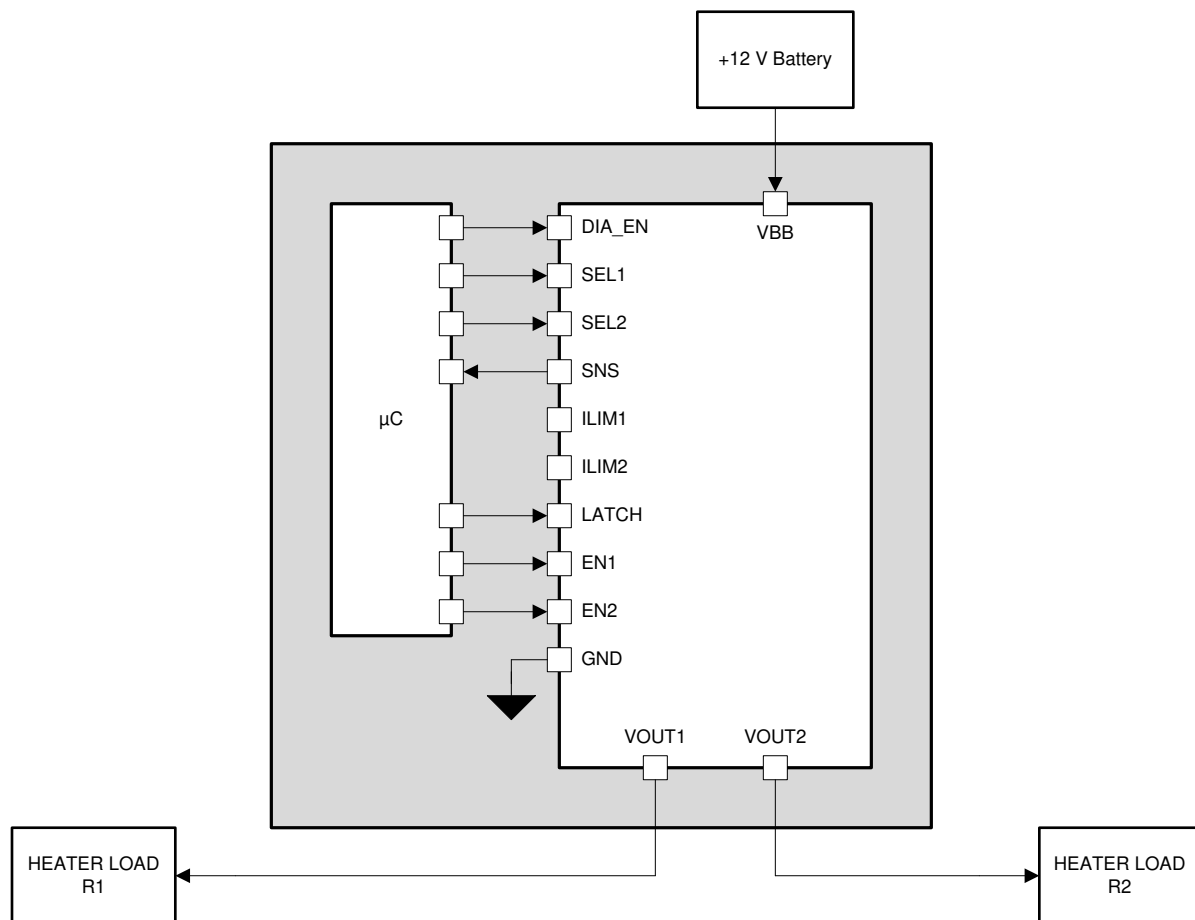


图 16. Block Diagram for Powering Dual Heater Loads

#### 10.2.1 Design Requirements

For this design example, use the input parameters shown in 表 8.

表 8. Design Parameters

DESIGN PARAMETER	EXAMPLE VALUE
$V_{BB}$	13.5 V
Load Ch1 - Heater 1	32 W max
Load Ch2 - Heater 2	32 W max



**表 8. Design Parameters (continued)**

DESIGN PARAMETER	EXAMPLE VALUE
Load Current Sense	30 mA to 6 A
$I_{LIM}$	4 A
Ambient temperature	70°C
$R_{\theta JA}$	32.5°C/W (depending on PCB)
Device Version	A

## 10.2.2 Detailed Design Procedure

### 10.2.2.1 Thermal Considerations

The DC current in each channel under maximum load power condition will be around 2.4 A. Both heater loads can be ON at the same time, so the case where both channels are enabled simultaneously is considered to assume worst case heating.

Power dissipation in the switch is calculated in 式 4.  $R_{ON}$  is assumed to be 100 mΩ because this is the maximum specification at high temperature. In practice,  $R_{ON}$  will almost always be lower.

$$P_{FET} = I^2 \times R_{ON} \quad (4)$$

$$P_{FET} = (2.4 \text{ A})^2 \times 100 \text{ m}\Omega = 0.58 \text{ W} \quad (5)$$

If both channels are enabled, then the total power dissipation is 1.15 W. The junction temperature of the device can be calculated using 式 6 and the  $R_{\theta JA}$  value from the [Specifications](#) section.

$$T_J = T_A + R_{\theta JA} \times P_{FET} \quad (6)$$

$$T_J = 70^\circ\text{C} + 32.5^\circ\text{C/W} \times 1.15 \text{ W} = 107.5^\circ\text{C}$$

The maximum junction temperature rating for the TPS2HB50-Q1 device is  $T_J = 150^\circ\text{C}$ . Based on the above example calculation, the device temperature will stay below the maximum rating.

### 10.2.2.2 $R_{ILIM}$ Calculation

In this application, the TPS2HB50-Q1 must allow for the maximum 2.4 A current with margin but minimize the energy in the switch during a fault condition by minimizing the current limit. For this application, the best  $I_{LIM}$  set point is approximately 4 A. 式 7 allows you to calculate the  $R_{ILIM}$  value that is placed from the  $I_{LIMX}$  pins to  $V_{BB}$ .  $R_{ILIM}$  is calculated in kΩ.

$$R_{ILIM} = K_{CL} / I_{CL} \quad (7)$$

Because this device is version A, the  $K_{CL}$  value in the [Specifications](#) section is 40 A × kΩ.

$$R_{ILIM} = 40 \text{ A} \times \text{k}\Omega / 4 \text{ A} = 10 \text{ k}\Omega \quad (8)$$

For a  $I_{LIM}$  of 4 A, the  $R_{ILIM}$  value should be set at approximately 10 kΩ.

### 10.2.2.3 Diagnostics

If the resistive heating load is disconnected (heater malfunction), an alert is desired. Open-load detection can be performed in the switch-enabled state with the current sense feature of the TPS2HB50-Q1 device. Under open load condition, the current in the SNS pin will be the fault current and the can be detected from the sense voltage measurement.

#### 10.2.2.3.1 Selecting the $R_{SNS}$ Value

表 9 shows the requirements for the load current sense in this application. The  $K_{SNS}$  value is specified for the device and can be found in the [Specifications](#) section.

**表 9.  $R_{SNS}$  Calculation Parameters**

PARAMETER	EXAMPLE VALUE
Current Sense Ratio ( $K_{SNS}$ )	1500
Largest diagnosable load current	6 A
Smallest diagnosable load current	30 mA
Full-scale ADC voltage	5-V

**表 9.  $R_{SNS}$  Calculation Parameters (continued)**

PARAMETER	EXAMPLE VALUE
ADC resolution	10-bit

The load current measurement requirements of 6 A ensures that even in the event of a overcurrent surpassing the device internal 4 A limit, the MCU can register and react by shutting down the TPS2HB50-Q1, while the low level of 30 mA allows for accurate measurement of low load currents.

The  $R_{SNS}$  resistor value should be selected such that the largest diagnosable load current puts  $V_{SNS}$  at about 95% of the ADC full-scale. With this design, any ADC value above 95% can be considered a fault. Additionally, the  $R_{SNS}$  resistor value should ensure that the smallest diagnosable load current does not cause  $V_{SNS}$  to fall below 1 LSB of the ADC. With the given example values, a 1.2 k $\Omega$  sense resistor satisfies both requirements shown in 表 10.

**表 10.  $V_{SNS}$  Calculation**

LOAD (A)	SENSE RATIO	$I_{SNS}$ (mA)	$R_{SNS}$ ( $\Omega$ )	$V_{SNS}$ (V)	% of 5-V ADC
0.030	1500	0.02	1200	0.024	0.5%
6	1500	4	1200	4.800	96.0%

## 11 Power Supply Recommendations

The TPS2HB50-Q1 device is designed to operate in a 12-V automotive system. The nominal supply voltage range is 6 V to 18 V as measured at the  $V_{BB}$  pin with respect to the GND pin of the device. In this range the device meets full parametric specifications as listed in the Electrical Characteristics table. The device is also designed to withstand voltage transients beyond this range. When operating outside of the nominal voltage range but within the operating voltage range, the device will exhibit normal functional behavior. However, parametric specifications may not be specified outside the nominal supply voltage range.

**表 11. Operating Voltage Range**

$V_{BB}$ Voltage Range	Note
3 V to 6 V	Transients such as cold crank and start-stop, functional operation are specified but some parametric specifications may not apply. The device is completely short-circuit protected up to 125°C
6 V to 18 V	Nominal supply voltage, all parametric specifications apply. The device is completely short-circuit protected up to 125°C
18 V to 24 V	Transients such as jump-start and load-dump, functional operation specified but some parametric specifications may not apply. The device is completely short-circuit protected up to 125°C
18 V to 40 V	Transients such as jump-start and load-dump, functional operation specified but some parametric specifications may not apply.

## 12 Layout

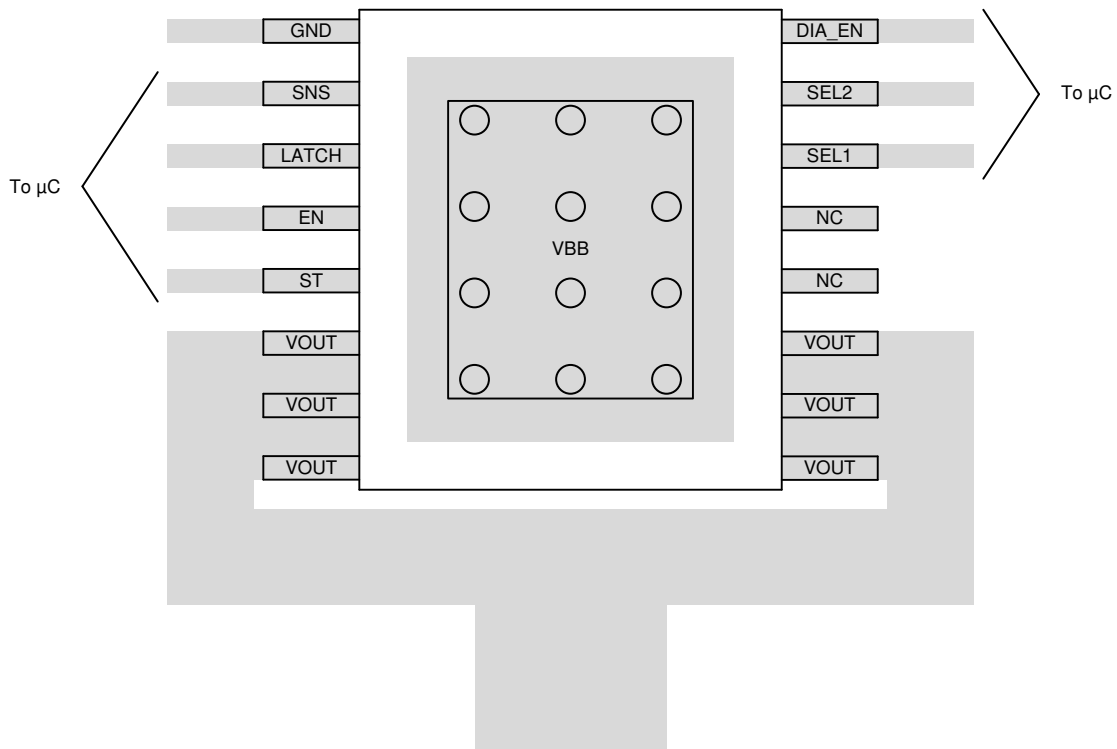
### 12.1 Layout Guidelines

To achieve optimal thermal performance, connect the exposed pad to a large copper pour. On the top PCB layer, the pour may extend beyond the package dimensions as shown in the example below. In addition to this, it is recommended to also have a  $V_{BB}$  plane either on one of the internal PCB layers or on the bottom layer.

Vias should connect this plane to the top  $V_{BB}$  pour.

Ensure that all external components are placed close to the pins. Device current limiting performance can be harmed if the  $R_{ILIM}$  is far from the pins and extra parasitics are introduced.

## 12.2 Layout Example



☒ 17. PWP Layout Example

## 13 デバイスおよびドキュメントのサポート

### 13.1 ドキュメントのサポート

#### 13.1.1 関連資料

関連資料については、以下を参照してください。

- テキサス・インスツルメンツ、『[How To Drive Inductive, Capacitive, and Lighting Loads With Smart High Side Switches](#)』(英語)
- テキサス・インスツルメンツ、『[Short Circuit Reliability Test for Smart Power Switch](#)』(英語)
- テキサス・インスツルメンツ、『[Adjustable Current Limit of Smart Power Switches](#)』(英語)
- テキサス・インスツルメンツ、『[TPS2HB35-Q1 40-V, 35-mΩ Dual-Channel Smart High-Side Switch](#)』(英語)
- テキサス・インスツルメンツ、『[Improved Automotive Short Circuit Reliability with Adjustable Current Limiting](#)』(英語)

#### 13.2 ドキュメントの更新通知を受け取る方法

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#### 13.3 コミュニティ・リソース

The following links connect to TI community resources. Linked contents are provided "AS IS" by the respective contributors. They do not constitute TI specifications and do not necessarily reflect TI's views; see TI's [Terms of Use](#).

**TI E2E™ Online Community** *TI's Engineer-to-Engineer (E2E) Community*. Created to foster collaboration among engineers. At [e2e.ti.com](#), you can ask questions, share knowledge, explore ideas and help solve problems with fellow engineers.

**Design Support** *TI's Design Support* Quickly find helpful E2E forums along with design support tools and contact information for technical support.

#### 13.4 商標

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#### 13.5 静電気放電に関する注意事項



すべての集積回路は、適切なESD保護方法を用いて、取扱いと保存を行うようにして下さい。

静電気放電はわずかな性能の低下から完全なデバイスの故障に至るまで、様々な損傷を与えます。高精度の集積回路は、損傷に対して敏感であり、極めてわずかなパラメータの変化により、デバイスに規定された仕様に適合しなくなる場合があります。

#### 13.6 Glossary



[SLYZ022](#) — *TI Glossary*.

This glossary lists and explains terms, acronyms, and definitions.

## 14 メカニカル、パッケージ、および注文情報

以降のページには、メカニカル、パッケージ、および注文に関する情報が記載されています。この情報は、そのデバイスについて利用可能な最新のデータです。このデータは予告なく変更されることがあり、ドキュメントが改訂される場合もあります。本データシートのブラウザ版を使用されている場合は、画面左側の説明をご覧ください。

**PACKAGING INFORMATION**

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TPS2HB50AQPWPRQ1	ACTIVE	HTSSOP	PWP	16	3000	RoHS-Exempt & Green	NIPDAU	Level-3-260C-168HRS	-40 to 125	2HB50AQ	
TPS2HB50BQPWPRQ1	ACTIVE	HTSSOP	PWP	16	3000	RoHS-Exempt & Green	NIPDAU	Level-3-260C-168HRS	-40 to 125	2HB50BQ	

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

**RoHS Exempt:** TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

**Green:** TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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**TAPE AND REEL INFORMATION**

**QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TPS2HB50AQPWPRQ1	HTSSOP	PWP	16	3000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1
TPS2HB50BQPWPRQ1	HTSSOP	PWP	16	3000	330.0	12.4	6.9	5.6	1.6	8.0	12.0	Q1

**TAPE AND REEL BOX DIMENSIONS**


\*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TPS2HB50AQPWRQ1	HTSSOP	PWP	16	3000	350.0	350.0	43.0
TPS2HB50BQPWRQ1	HTSSOP	PWP	16	3000	350.0	350.0	43.0





Images above are just a representation of the package family, actual package may vary.  
Refer to the product data sheet for package details.

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