Application Brief

Realizing Remote Temperature Sensing and Protection Using TI High-Side Switch Controllers

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System Introduction

With increasing demand for vehicle electrification to meet stringent emission targets, automotive manufacturers are using dual 48V/12V battery systems which can allow engineers to move all power-hungry loads such as air conditioning compressors, electrical power steering, and to on to the 48V battery side while the 12V battery continues to power remaining loads such as lighting, infotainment, and so on. Figure 1 is a typical block diagram for 48V/12V battery system in which High side switch controllers drive external MOSFETs, functioning as battery disconnect and circuit breaker switches. These system designs include DC/DC converter, battery management systems, power distribution box, and so on in dual battery systems.

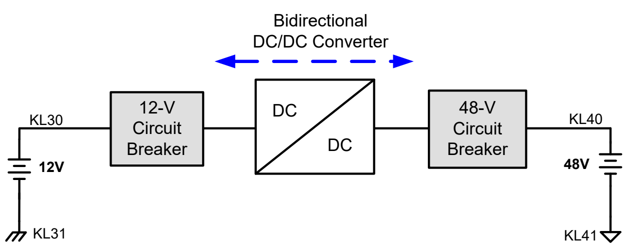

Figure 1. Block Diagram of a Bidirectional 48V to 12V System in Electric Vehicles

In such high power designs, while driving external power MOSFETs, one of the key considerations from power design engineers is to make sure robust thermal protection to prevent overheating and thermal runaway. So, accurate temperature sensing and overtemperature protection is crucial. This application brief covers the design considerations of realizing remote temperature sensing and protection using TI's smart high side switch controller.

TPS4811x-Q1 and TPS1211x-Q1 are TI's smart high side switch controller with protection and diagnostics. These features an integrated remote temperature sensing, protection and dedicated fault output. The remote temperature measurement is done by using external transistor in diode configuration as shown in Figure 2.

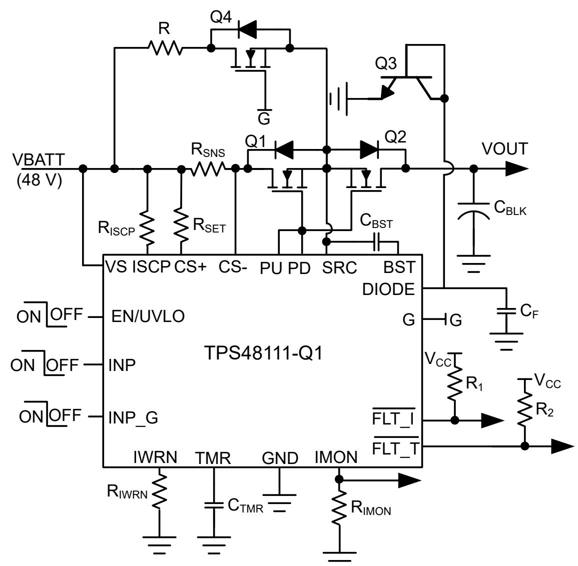

Figure 2. Circuit Breaker for DC-DC Converter

Diode Based Remote Temperature Sensing

A common practice is to use an external NPN Bipolar Junction Transistor (BJT) as a remote temperature sensing element. The NPN transistor is connected in diode mode such that case temperature of device or PCB can be estimated by base emitter forward voltage. The standard Ebers-Moll model gives simplified equation for the collector current as Equation 1.

$$I_C = I_S \times e^{\left(\frac{V_{BE}}{\eta \times V_T}\right)} \quad (1)$$

$$V_T = \frac{kT}{q} \quad (2)$$

where

- I_C is the collector current
- I_S is the reverse saturation current
- V_{BE} is the base emitter forward voltage drop
- V_T is the thermal voltage
- T is the temperature of the transistor in Kelvin degrees

- η is the ideality factor(η-factor), varies from manufacturer to manufacturer
- k is the Boltzmann constant (1.38×10^{-23} J/Kelvin)
- q is the charge of an electron (1.602×10^{-19} C)
- k/q is constant(8.61423×10^{-5})

Solving for temperature results in Equation 3

$$T = \frac{q \times V_{BE}}{\eta \times k \times \ln\left(\frac{I_C}{I_S}\right)} \quad (3)$$

Because η-factor, k, and I_S are constants, the straightforward way to measure temperature is to force collector current, measure voltage and then calculate temperature accordingly. However, the reverse saturation current has process dependencies and varies widely, which significantly impacts the temperature measurement accuracy. To overcome these drawbacks, the two current delta method approach has gained popularity. This method employs two currents such that temperature is determined by the difference of two diode voltage (V_{BE}) measurements, as shown in Equation 6.

$$\Delta V_{BE} = V_{BE2} - V_{BE1} \quad (4)$$

$$\Delta V_{BE} = \frac{\eta k T}{q}\ln\left(\frac{I_2}{I_S}\right) - \frac{\eta k T}{q}\ln\left(\frac{I_1}{I_S}\right) = \frac{\eta k T}{q}\ln\left(\frac{I_2}{I_1}\right) \quad (5)$$

$$T = \frac{q \times \Delta V_{BE}}{\eta \times k \times \ln\left(\frac{I_2}{I_1}\right)} \quad (6)$$

By maintaining precise current ratio of (I_2/I_1), this approach cancels out the process variation effects of reverse saturation current (I_S) making the temperature measurement dependence only on the η-factor, which is relatively stable compared to I_S and can be obtained from the transistor manufacturer.

Overtemperature Protection using TI High Side Switch Controllers

The TPS4811x-Q1/ TPS1211x-Q1 controller forces two currents 10µA(I_1) to 160µA(I_2) in to external transistor and measures change in V_{BE} voltage (ΔV_{BE}) to detect over temperature and trigger thermal shutdown to turn-off the external MOSFET under any fault conditions. The device has also features a dedicated fault($\overline{FLT\_T}$) pin which asserts low when overtemperature fault is detected. The simplified block diagram of DIODE based remote temperature sensing scheme in TPS4811x-Q1 is shown in Figure 3.

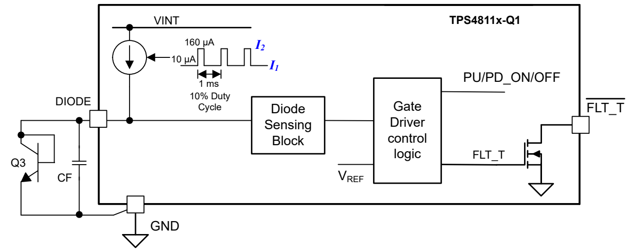

Figure 3. DIODE Based Remote Temperature Sensing in TPS4811x-Q1

As the PCB temperature increases, ΔV_{BE} increases accordingly and at 150°C, ΔV_{BE} approaches 101.5mV which is set as internal threshold for TPS4811x-Q1 to trigger overtemperature protection. Figure 4 shows timing diagram of overtemperature protection scheme.

- In TPS48110-Q1, once the sensed temperature reaches approximately 150°C, the device pulls PD(Gate driver Pull-Down) to SRC(Source of MOSFET), turning off the external MOSFET and also asserts $\overline{FLT\_T}$ low. After the temperature reduces to 135°C, an internally fixed auto-retry cycle of 512ms commences. The device turns on the external MOSFET and $\overline{FLT\_T}$ also de-asserts after the retry duration of 512ms is lapsed.
- In TPS48111-Q1,once the sensed temperature crosses 150°C, the device turns off the external FET and device remains in latched state. The latch gets reset by toggling $V_{EN/UVLO}$ below $V_{(ENF)}$ or by power cycling V_S below $V_{(VS\_PORF)}$.

Figure 5 and Figure 6 shows diode pin voltage profile at room temperature and at the instant of overtemperature shutdown.

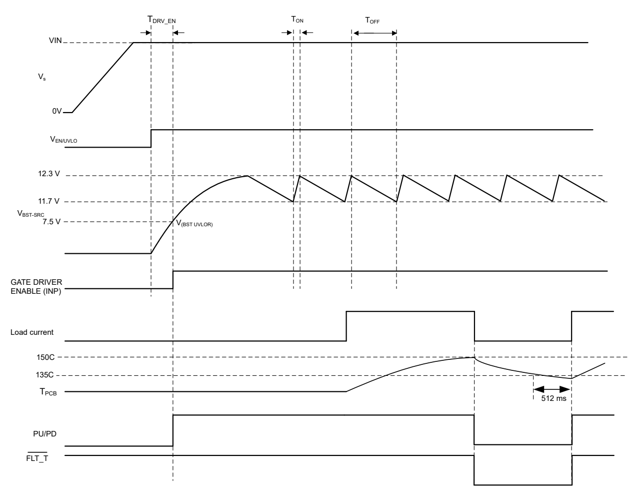

Figure 4. Timing Diagram of Overtemperature Protection Scheme

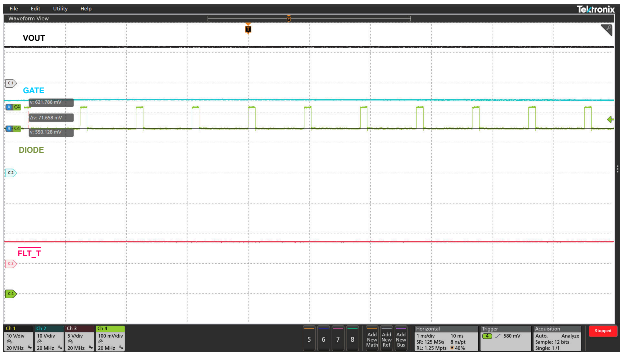

Figure 5. Diode Pin Voltage Profile at 25°C

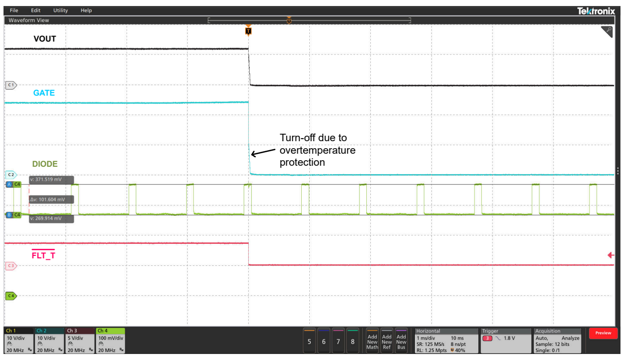

Figure 6. Diode Pin Voltage Profile at 150°C

Design and Layout Guidelines

Accurate overtemperature protection depends on proper NPN selection and good layout. A simple set of design and layout rules can prevent a lot of problems during system operation and help to achieve overtemperature protection within 150±10°C.

- The overtemperature protection threshold depends on the ideality factor (η) which can vary widely from one transistor type to another. TI recommends BJT MMBT3904 to use as a remote temperature sense element (Q3). Any 3904 manufacturer with ideality factor close to 1.004 is preferred as mentioned in Table 1.

Table 1. Details of Ideality Factor from Suitable Vendors

3904 Manufacturer	Typical Ideality Factor (η-factor)
Diodes Inc.	1.0044
Philips	1.0049
ST Micro	1.0045
On Semi	1.0045
Infineon	1.0044

- Place a small filter capacitor(CF) of 1000pF near controller between DIODE and GND pins to reduce/mitigate the effects of noise.
- Place transistor (Q3) adjacent to pass MOSFET or in between the MOSFETs in parallel configuration.
- Route a differential pair connection from the transistor (Q3) to the controller with minimum spacing as shown in Figure 7. Connect return path directly to the GND pin and eliminate shared ground path.
- High PCB trace resistance from Q3 to the controller can cause temperature offset. So, use thicker traces to minimize the parasitic resistance.
- Keep the trace length short as much as possible as longer trace run offers more opportunity to pick up noise due to trace inductance.
- Avoid routing near noise generators such as fast clock, switching nodes, large current traces, and so on.

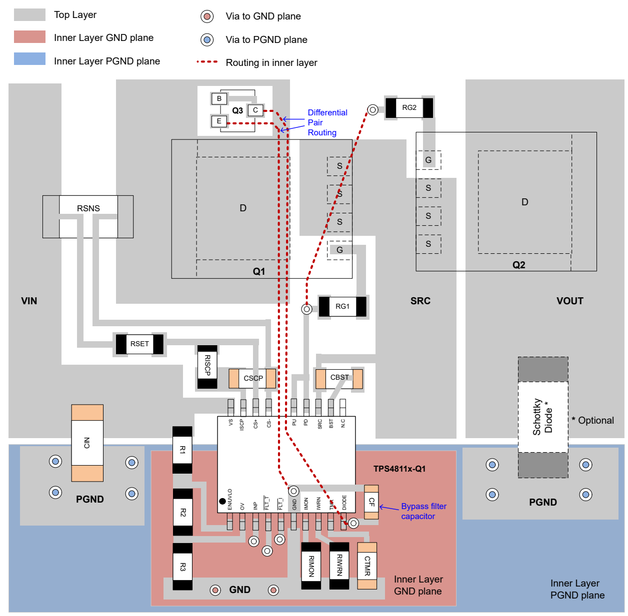

Figure 7. Layout and Placement Recommendation for the Temperature Sense Diode (Q3)

Conclusion

The TPS4811x-Q1 features an integrated remote temperature sensing and overtemperature protection to prevent overheating and thermal runaway in high power system designs. Proper selection of NPN transistor and layout techniques such as differential pair routing discussed in this application brief are essential to make sure overtemperature protection at the correct threshold point.

References

1. Texas Instruments, *Optimizing Remote Temperature Sensor Design*, application report.
2. Texas Instruments, *TPS4811-Q1 100V Automotive Smart High-Side Driver With Protection and Diagnostics*, data sheet.