Application Note

How TPSI3133 DESAT Can Protect Your Expensive SiC MOSFETs and IGBTs

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ABSTRACT

Protecting power semiconductors like SiC MOSFETs and IGBTs from damage due to oversaturation is critical in power electronics design. When these devices perform beyond their intended operating region, excessive power dissipation can lead to thermal stress and failure.

Desaturation (DESAT) protection circuits offer cost-effective protection by monitoring the voltage across the semiconductor and shutting it down during an overcurrent event. This article explores how DESAT protection works, key circuit components, and how to design a DESAT circuit with the TPSI3133 isolated switch driver.

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Trademarks

1 Why DESAT Protection Is Needed

Power semiconductors like MOSFETs and IGBTs ideally operate in a fully saturated state: ohmic region for MOSFETs and saturation region for IGBTs. The voltage across, V_{DS} for MOSFETs or V_{CE} for IGBTs, remains low to minimize power dissipation. However, when these devices enter an oversaturated state as shown in Figure 1-1, small increases in current cause large voltage increases, leading to excessive power dissipation and potential damage.

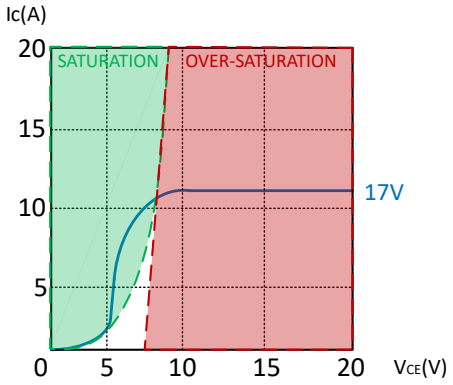

Figure 1-1. Example IGBT I-V Curve

Some isolated switch drivers include a desaturation (DESAT) protection feature that monitors V_{DS} or V_{CE} and quickly shuts down the semiconductor during an overcurrent event. The TPSI31xx is a family of fully integrated isolated switch drivers, which when combined with an external power switch, forms a complete isolated solid-state relay solution.

The TPSI3133, as shown in Figure 1-2, is a variant specifically intended for DESAT due to its internal pulldown MOSFET on the fault comparator input. This internal MOSFET prevents false positives while the IGBT/SiC MOSFET is off by pulling down the fault comparator input and keeping it pulled down for an additional 100ns after EN goes high, allowing the IGBT/SiC MOSFET to fully turn on.

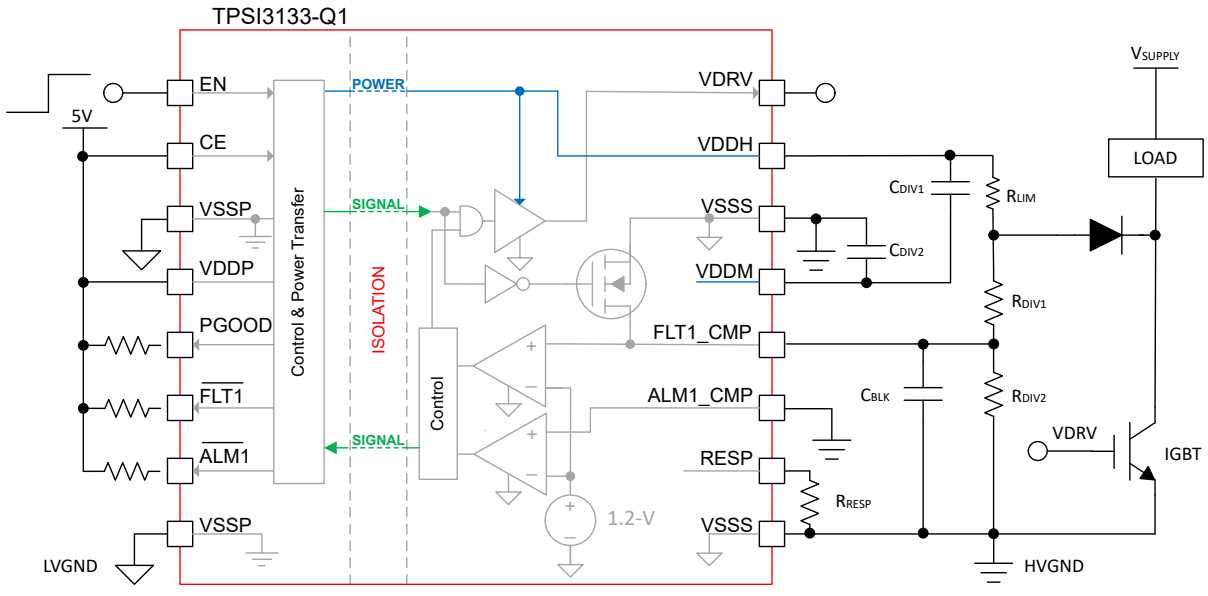

Figure 1-2. DESAT With TPSI3133

1.1 Key Considerations for DESAT Protection

DESAT protection circuits are typically configured with IGBTs because IGBTs show distinct voltages (V_{CE}) across current (I_C) in the saturation region which makes detection easier, have sharper transitions into the active region, and generally able to handle more power due to larger die size (many have a short circuit withstand rating).

DESAT can also work with SiC MOSFETs. The problem with low voltage MOSFETs is since the overcurrent threshold is typically set well above normal operation to avoid false positives, a low voltage MOSFET may be damaged by overheating well before the circuit even detects an overcurrent event.

By implementing DESAT protection, engineers can ensure power semiconductors stay within safe operating area.

2 Key DESAT Circuit Components

1. Blocking diode: Protects the circuit from high voltage while the IGBT/SiC MOSFET is off.
2. Current limiting resistor (R_{LIM}) to limit diode forward current.
3. DESAT threshold detection (R_{DIV1}, R_{DIV2}): Defines the voltage threshold for detecting oversaturation.
4. Blanking capacitance (C_{BLK}): Filters noise and prevents false triggering. While blanking capacitance helps avoid false positives, it may also extend stress time on the IGBT/SiC MOSFET during overcurrent events.

2.1 Circuit Startup Behavior

At power-up while EN is low, TPSI3133 receives power and begins to transfer power to its secondary rails (VDDM and VDDH). The internal MOSFET pulls down the comparator input to avoid a false trigger. Once EN goes high, the two current paths (paths 1 and 2) compete to set the comparator input voltage as shown in Figure 2-1. Since Path 1 normally would be faster than path 2 due to IGBT turn-on delay, once EN goes high, the TPSI3133 keeps the comparator input pulled down for an additional 100ns, allowing the IGBT to fully turn on before fault detection. Adding blanking capacitance (C_{BLK}) can provide additional delay but must be carefully selected in order to minimize stress time. During an overload condition, the IGBT V_{CE} rises, which brings up the voltage at the HV diode anode, trips the fault comparator threshold. Once the TPSI3133 detects the fault, it shuts off the driver which turns off the IGBT, protecting the system.

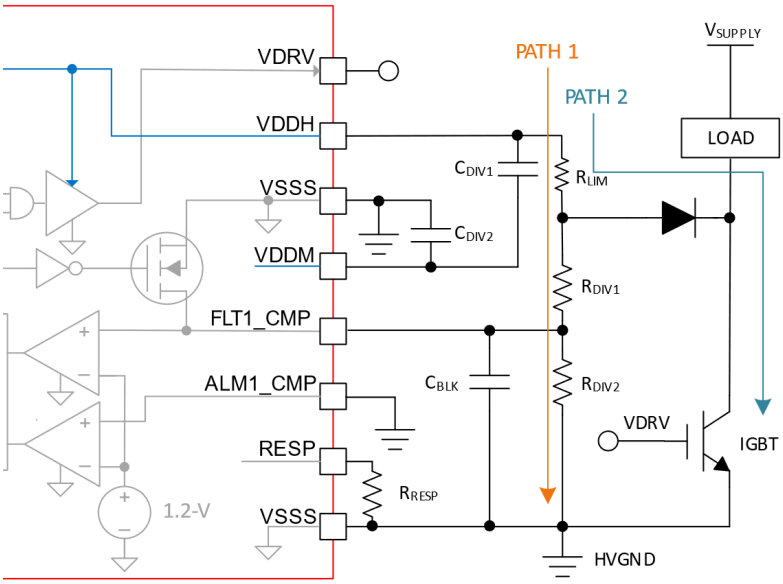

Figure 2-1. DESAT KVL Paths

3 Design Example

3.1 Design Requirements

Table 3-1 lists the requirements for an example DESAT design.

Table 3-1. Example Design Requirements

PARAMETER	VALUE
Overcurrent Threshold	10A
Maximum Response Time	10µs

3.2 Threshold Equations

Selecting appropriate resistance values ensures that the blocking diode becomes forward biased while the IGBT is on, allowing proper voltage sensing.

1. Condition for sensing voltage, allows the blocking diode to become forward biased when IGBT is on:

$$\left(V_{CE(DESAT)} + V_{F(DIODE)}\right) < \frac{R_{DIV1} + R_{DIV2}}{R_{DIV2} + R_{DIV1} + R_{LIM}} \times VDDH \quad (1)$$

2. Overcurrent threshold equation, select the desired voltage threshold ($V_{CE\ (DESAT)}$) to trip the comparator (V_{REF+}):

$$V_{REF+} < \frac{R_{DIV2}}{R_{DIV2} + R_{DIV1}} \times \left(V_{CE(DESAT)} + V_{F(DIODE)}\right) \quad (2)$$

Using the example IGBT I-V curve from earlier, it looks like I_C = 10 A at V_{CE} = 7.5V. With this overcurrent threshold value, solve for the resistances. Please keep in mind that I-V curves are typical and devices may individually have variation.

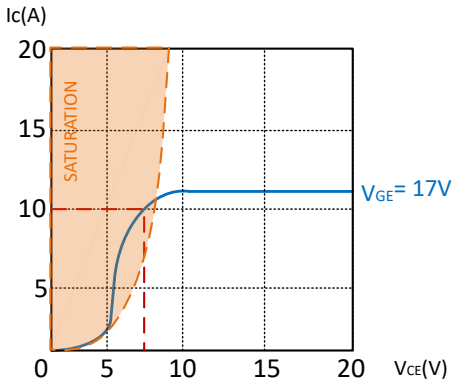

Figure 3-1. DESAT Selection V_{CE} Threshold

3.3 Given Parameters

Select R_{LIM} to limit diode forward current. Given the example HV diode I-V curve in Figure 3-2, selecting 54.9kΩ would limit V_F to 0.7V. Please keep in mind that the TPSI3100 family has 25mW available for powering auxiliary circuitry, R_{LIM} = 54.9kΩ consumes up to 5.26mW.

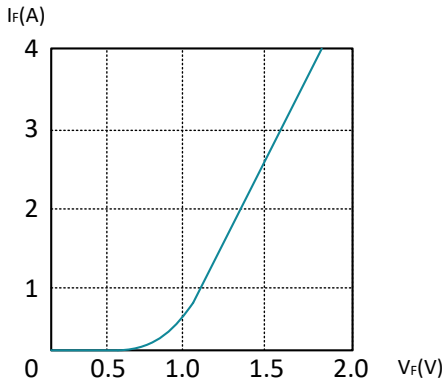

Figure 3-2. Example HV Diode I-V Curve

Table 3-2. Given Design Parameter Values

PARAMETER	VALUE
$V_{CE\ (DESAT)}$	7.5V
$V_{F\ (DIODE)}$	0.7V
V_{REF+}	1.23V
R_{LIM}	54.9kΩ

3.4 Inserting Given Parameters into Equations

1. $\left(7.5V + 0.7V\right) \times 1.2_{(20\%margin)} < \frac{R_{DIV1} + R_{DIV2}}{R_{DIV2} + R_{DIV1} + 54.9e3} \times 17V$
2. $\frac{R_{DIV2}}{R_{DIV2} + R_{DIV1}} \times (7.5V + 0.7V) > 1.23V{*}1.2_{(20\%margin)}$

3.5 Solving Equations for Unknowns

1. $R_{DIV1} > -\frac{41}{50}$
2. $R_{DIV2} > \frac{1}{73}(5325300 - 73 \times R_{DIV1})$

3.6 Selecting Resistances to Satisfy Equations

Table 3-3. Selected Design Resistances

PARAMETER	VALUE
R_{DIV1}	23.9kΩ
R_{DIV2}	11.5kΩ

3.7 Determining Blanking Capacitance

Select a C_{BLK} value based on the 10µs maximum delay requirement, starting with the general RC equation. If we use R_{RESP} < 10kΩ, propagation delay time can be as long as 460ns and needs to be accounted for. Use Thevenin/Norton equivalent to determine the equivalent resistance seen by C_{BLK}.

$$V_C = V_S \times \left(1 - e^{-\frac{t}{RC}}\right) \tag{3}$$

$$V_{REF+} < VDDH \times \left(1 - e^{\frac{-(t_{MAXDELAY} - t_{RESP}) \times (R_{LIM} + R_{DIV1} + R_{DIV2})}{(R_{LIM} + R_{DIV1}) \times R_{DIV2} \times C_{BLK}}}\right) \tag{4}$$

$$1.23 < 17 \times \left(1 - e^{\frac{-(10\mu - 460n) \times (54.9e3 + 23.9e3 + 11.5e3)}{(54.9e3 + 23.9e3) \times 11.5e3 \times C_{BLK}}}\right) \tag{5}$$

$$0 < C_{BLK} < 12.66nF \quad (6)$$

3.8 Final Component Values

With these selected values, the design prevents oversaturation and meets the desired delay time specified by the initial requirements.

Table 3-4. Final Design Component Values

COMPONENT	VALUE
R_{LIM}	54.9kΩ
R_{DIV1}	23.9kΩ
R_{DIV2}	11.5kΩ
C_{BLK}	<12.66nF

3.9 Lab Testing

The waveform below shows the DESAT circuit in action, confirming its ability to detect overcurrent conditions and shut down the IGBT before damage occurs.

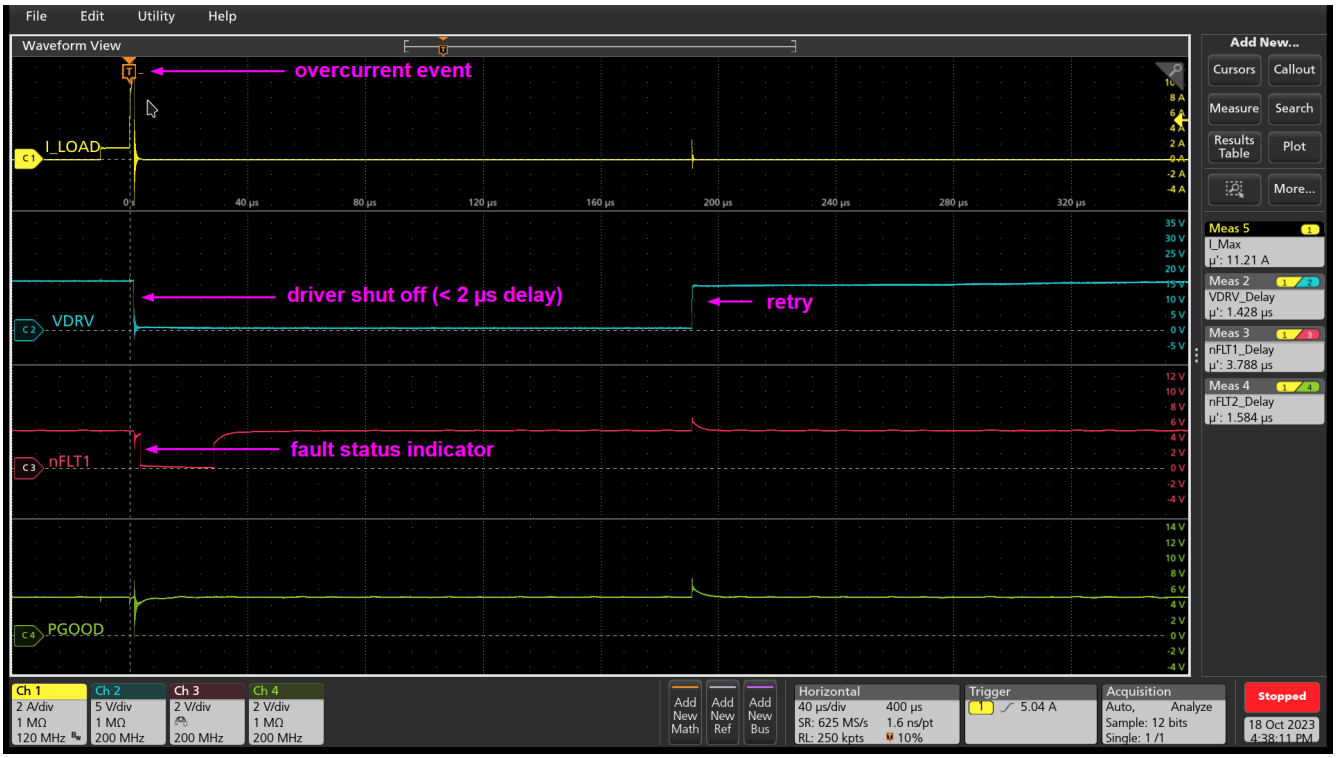

Figure 3-3. DESAT Circuit Waveform

4 Closing

Proper implementation of DESAT protection enhances the reliability and lifespan of SiC MOSFETs and IGBTs by preventing destructive oversaturation. By carefully selecting an isolated gate driver like TPSI3133 with DESAT protection and calculating component values, designers can optimize around speed while also preventing false positives. The article walks through an example of how to select components to meet specific DESAT design requirements. Engineers can use DESAT protection for their power semiconductors against overcurrent events, ensuring efficiency and long-term performance in high-power applications.

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