IGBT

On-chip and Off-chip sensor comparison for protection

About this document

This document will discuss about of On-chip and Off-chip sensor technique comparison for over current protection in IGBT.

Target Device

IGBT

Contents

1. Introduction

Overcurrent protection for IGBTs and their modules is a critical consideration in various industrial applications. Overcurrent can result from short circuits or overload faults, with the current levels influenced by the impedance of the fault current path. Effective overcurrent protection for IGBTs limits the short-circuit current and maintains the current-voltage characteristics within a safe operating range during a fault. This mechanism ensures that the IGBT switches off before sustaining any damage, thereby protecting the device from potential harm.

2. Short-circuit breakdown protection

Short-circuit breakdown protection is a critical aspect of electrical and electronic system design, aimed at safeguarding circuits from the potentially destructive effects of short circuits. A short circuit occurs when a low-resistance pathway is created, allowing excessive current to flow, which can lead to overheating, component damage, and even fire hazards. As modern systems become increasingly complex and integrated, ensuring reliable protection mechanisms is essential for enhancing safety, improving system longevity, and maintaining operational integrity.

Effective short-circuit protection involves a combination of techniques and devices designed to detect abnormal current conditions and respond swiftly to mitigate damage. These can include fuses, circuit breakers, current sensing devices, and advanced protective relays, each tailored to specific application requirements. By implementing robust short-circuit protection strategies, engineers can ensure that electrical systems operate safely and efficiently, while also complying with industry standards and regulations. In the next section, two common protection topology methods will be discussed.

2.1 Desaturation (DESAT) method

DESAT (Desaturation) is a well-known short-circuit and overcurrent detection topology used to detect the desaturation of an IGBT. Commonly implemented by other competitors, it detects when an IGBT leaves its optimal saturation region and helps protect the device by turning it off during a short circuit. The design is simple by using driver IC which can monitor IGBT’s ICE pin voltage as shown in below Figure 2-1. In Figure 2-2 shows the example operation waveforms.

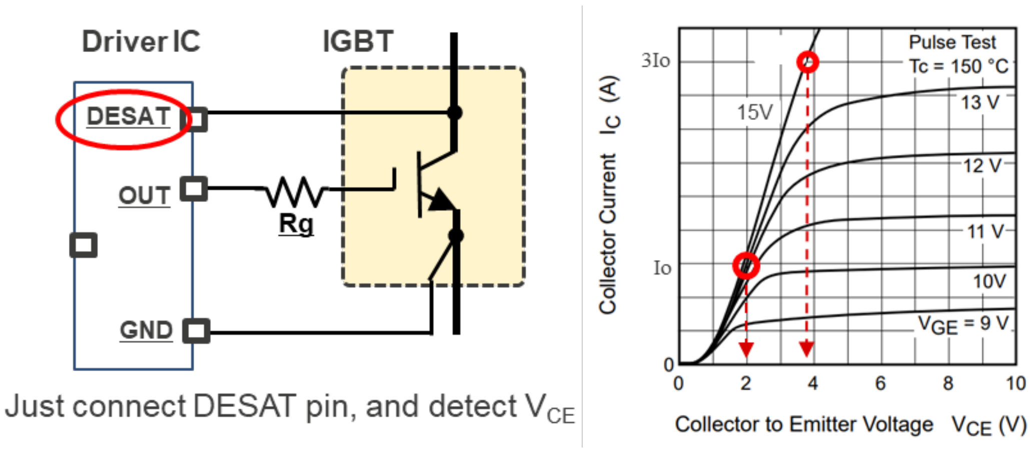


Figure 2-1 DESAT circuit diagram and VCE example value

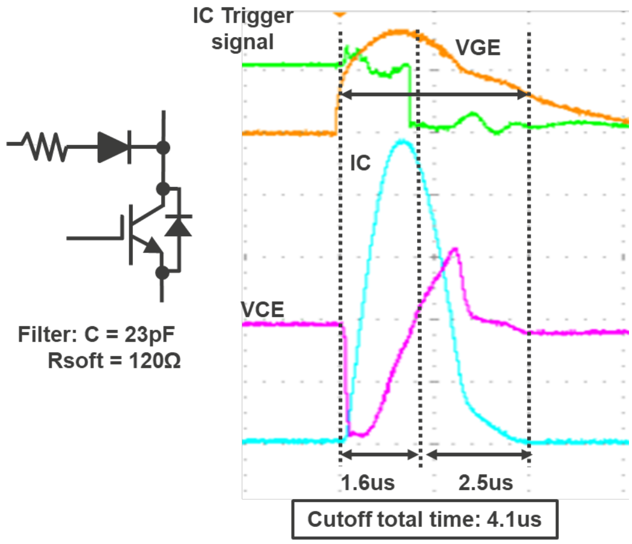


Figure 2-2 DESAT Operation

2.2 Current sense detection method

Sensing current is another one method to apply short-circuit and overcurrent detection topology. It can be done by using shunt resistor current sensing or sense IGBT. Although using shunt resistor has advantages such as simplicity and cost effectiveness, it also has disadvantages in power loss and heat issues. Therefore, it has a limitation for a very high currents design, shunt resistors can be impractical due to heat dissipation. Using the sense IGBT for current sensing will be able to achieve an integrated solutions because some IGBTs have built-in current sensing features which can simplify design.

IGBTs are capable of handling high currents efficiently, avoiding the heat problems associated with shunt resistors, and they also lead to lower power losses. They offer a reduced voltage drop in the circuit compared to shunt resistors. However, there are some drawbacks, including more complex designs and higher costs than shunt resistors. Ultimately, the choice between IGBTs and shunt resistors depends on various factors, such as the current range, desired accuracy, budget limitations, and thermal management requirements.

The current sensing design as below figure uses two emitters which's mirror emitter terminal and kelvin emitter terminal, which can detect the current in the sense IGBT. This helps achieve high-speed shutdown, providing fast short-circuit protection that improves IGBT performance and enhances design reliability. For high-speed short circuit protection improves IGBT performance and realizes a more reliable design.

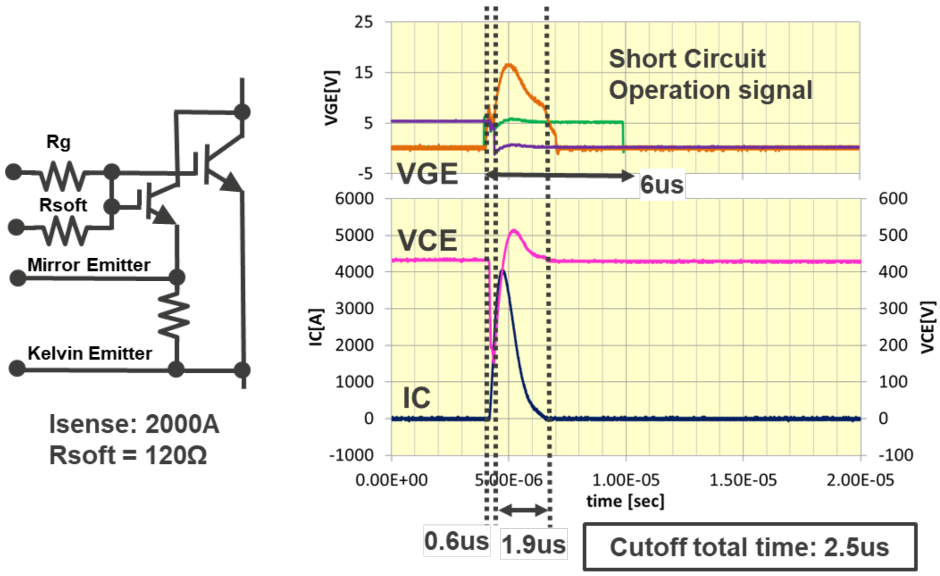


Figure 2-3 Current Sensing Operation

3. Temperature Shutdown Function

IGBTs typically operate in applications that have switching frequencies of less than 30kHz, power consumption greater than 5 kW, and operating temperatures exceeding 125℃. Thus, IGBTs require thermal monitoring and protection to ensure the safety and reliability of the system. There are two methods for monitoring the temperature changes in an IGBT module: using thermistors mounted within the module or an on-chip temperature-sensing diode built in the IGBT device.

3.1 Thermistor sensing

Thermistors operate by varying their resistance based on temperature changes. They are commonly utilized in circuits for temperature measurement because their resistance can be easily translated into temperature readings. In a typical setup, thermistors are arranged in series with a fixed resistor and a voltage source to form a voltage divider circuit. The voltage across the thermistor is measured to calculate the temperature. As the temperature rises, the resistance of the thermistor decreases, resulting in a corresponding change in voltage across it. This voltage variation is directly proportional to the temperature change.

Below Figure 3-1 shows the thermistor placement in an IGBT module for temperature sensing.

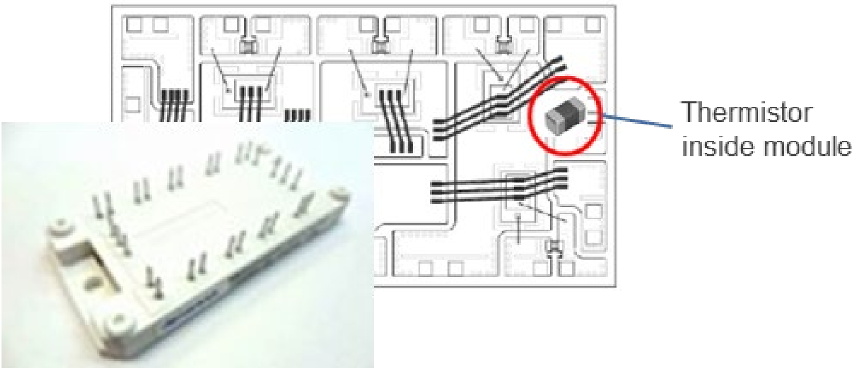


Figure 3-1 Thermistor location in IGBT module

3.2 Temperature sense diode

Unlike thermistor temperature monitoring, an on-chip temperature-sensing diode enables a real-time IGBT junction temperature monitoring in the power module. This diode provides high precision in temperature sensitivity due to changes in the forward voltage (VF), allowing the system to react and shut down the IGBT promptly.

The figure below shows the temperature trend in two different areas: Area A (0-5 seconds) and Area B (after 5 seconds). This illustrates the capabilities of the two monitoring solutions. In Area A, it is difficult for a thermistor to detect the temperature of the IGBT chip because of the slow response time and low temperature change. In Area B, while the temperature has reached saturation, there is still a significant detection gap between the two methods.

With temperature-sensing diode, the IGBT temperature can be detected as quickly as 1ms and is more sensitive to temperature changes over a shorter period.

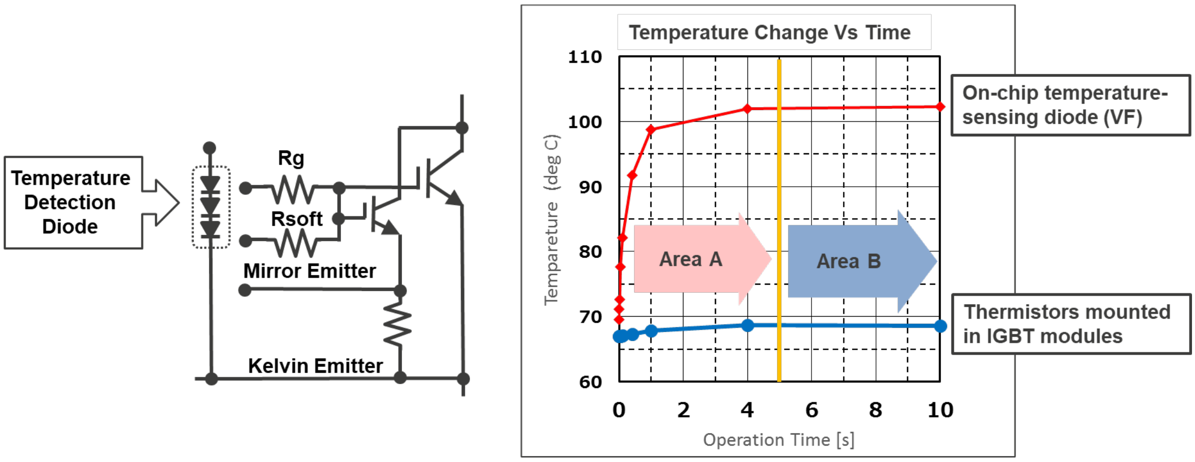
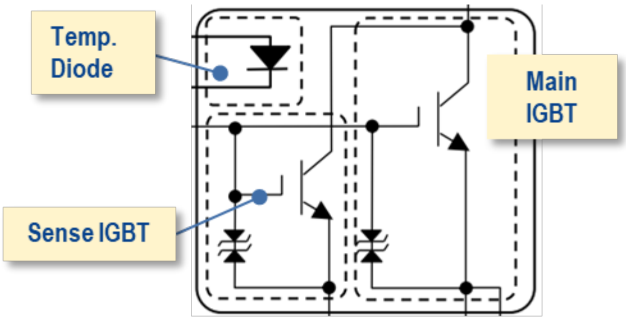


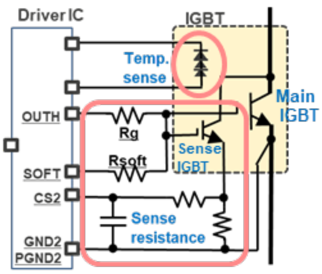
Figure 3-2 Temperature monitoring on different solution

4. On-chip solution for IGBT

Off-chip solutions involve the use of external components that are not integrated into the primary semiconductor chip. Whereas On-chip solution IGBT equipped with built-in over-current and junction temperature sensors in chip level, which provide fast response to over-current conditions by monitoring the IGBT emitter and enable accurate junction temperature (Tj) monitoring, thereby enhancing the device's performance and reliability for system thermal design.



On-chip IGBT solution with built-in temperature diode & Sense IGBT



On-chip sensor IGBT with gate driver application example

Figure 4-1 IGBT On-chip solution with application example

5. Comparison of On-chip Sensors and Off-chip Sensors

Below table shows the merit and demerit of using conventional method which consider as off-chip sensor method and with the advanced technology which integrated the use of IGBT sense with diode temperature sensor into on-chip solution.

Table 5-1 Merit and demerit of both on-chip and off-chip methods

	On-chip Sensor		Off-chip Sensor Method	Merit	Demerit
Over current Protection	On-chip Sense IGBT	→	DESAT protection in Gate Driver	Simple solution	Nil. (Not detected IGBT current itself, but monitor VCE)
Over Temp. Protection	On-chip Temp. Diode	→	Thermistor (in module)	Low-cost solution	Temperature detection delay due to distance from thermistor to exact die, need to tune by MCU

Below Figure 5-1 is an illustrative circuit block diagram for both solutions.

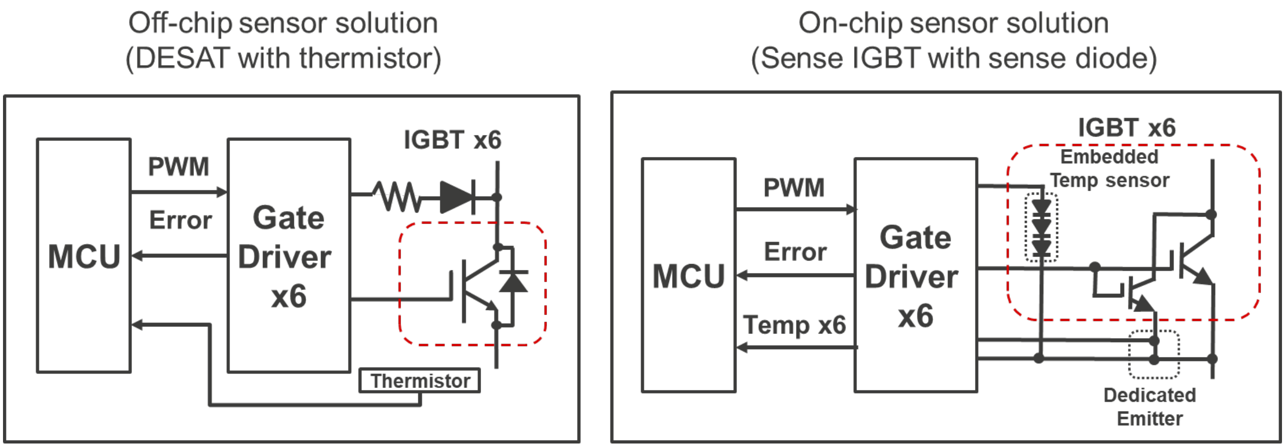


Figure 5-1 Comparison of On-chip sensor vs Off-chip sensor

The on-chip solution clearly helps to minimize the design layout and provides an optimal design. The off-chip solution uses a thermistor to detect the temperature, which has a slow response time and low accuracy when monitoring 6 units of IGBTs. This method requires a large temperature margin to prevent potential damage. Additionally, the short-circuit capability has a slow response due to the chip characteristics that suppress short-circuit current, making it challenging to reduce losses.

In contrast, the on-chip solution utilizes an integrated temperature-sensing diode that provides fast response times and accurate temperature measurements for each IGBT. This feature eliminates the need for extra margins and allows users to set precise limits based on actual data. The short-circuit capability also responds quickly, increasing the energization capacity and further reducing losses.

6. Conclusion

With the introduction of the above solution, application engineers can select either one of the solutions for their design. As mentioned, Renesas can offer an on-chip solution to users who prefer a superior solution which minimizes the need for additional safety margins and reduces losses in the design.

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	25/10/2024	-	First edition

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