

Keysight Technologies

IGBT Sense Emitter Current Measurement Using the Keysight B1505A

Application Note



Introduction

Insulated gate bipolar transistors (IGBTs) have become the key energy-saving devices for use in switching applications such as switching convertors and invertors. However, IGBTs used in circuits that drive inductive loads (such as induction motors or igniters) risk damage due to excessive currents caused by a motor jamming or a short in the igniter circuit.

To detect overcurrents and prevent damage, some IGBTs have a second emitter terminal known as a sense emitter. The ratio of sense emitter current to emitter current is very small (one part to several thousand or several tens of thousands). The sense emitter current is monitored using a shunt resistor; the voltage across the shunt resistor in-turn feeds into an overcurrent protection circuit. When the overcurrent detector circuit senses the voltage exceeding a specified limit, it turns off the IGBT (Figure 1).

Power devices such as IGBTs consist of tens of thousands of small cells connected in parallel, and the sense emitter uses some of these cells. Since the individual IGBT cells vary in size and characteristics, the sense emitter current to emitter current ratio also varies. In addition, the sense emitter current to emitter current ratio depends on the emitter current level. This is due to the effects of both the voltage across the shunt resistor and the residual resistances inherent in each device.

For these reasons, it is necessary to measure the sense emitter to emitter current ratio under actual use conditions to determine the correct overcurrent limit.

The Keysight Technologies, Inc. B1505A Power Device Analyzer/Curve Tracer has a wide measurement range (1500 A/10 kV), making it a powerful tool to characterize IGBTs. It also has a modular architecture that allows you to have multiple measurement channels, which enables the simultaneous measurement of both the sense emitter current and the emitter current.

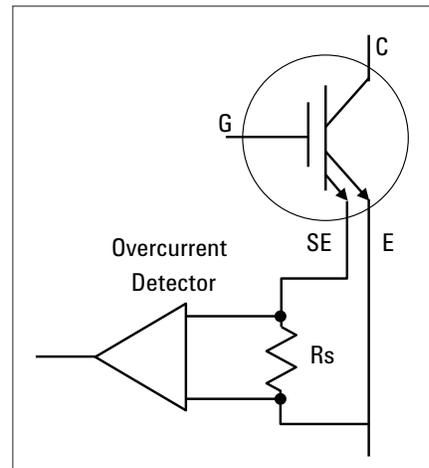


FIGURE 1. Overcurrent protection using sense emitter

The basic measurement resource of the B1505A is the SMU (Source Measure Unit). It integrates four measurement functions (voltage sourcing, current sourcing, current measurement and voltage measurement) into a single module. An SMU can function as a voltage meter by putting it into force current/measure voltage mode with a zero current output. Similarly, it can act as a current meter by putting it into force voltage/measure current mode with a zero voltage output. Figure 2 (a) shows a simplified circuit diagram using an SMU as a voltage meter to measure the voltage across a shunt resistor. Figure 2 (b) shows the corresponding circuit diagram using the SMU as a current meter. Note that when using the SMU as a current meter the sense emitter current can be measured directly without using an external shunt resistor.

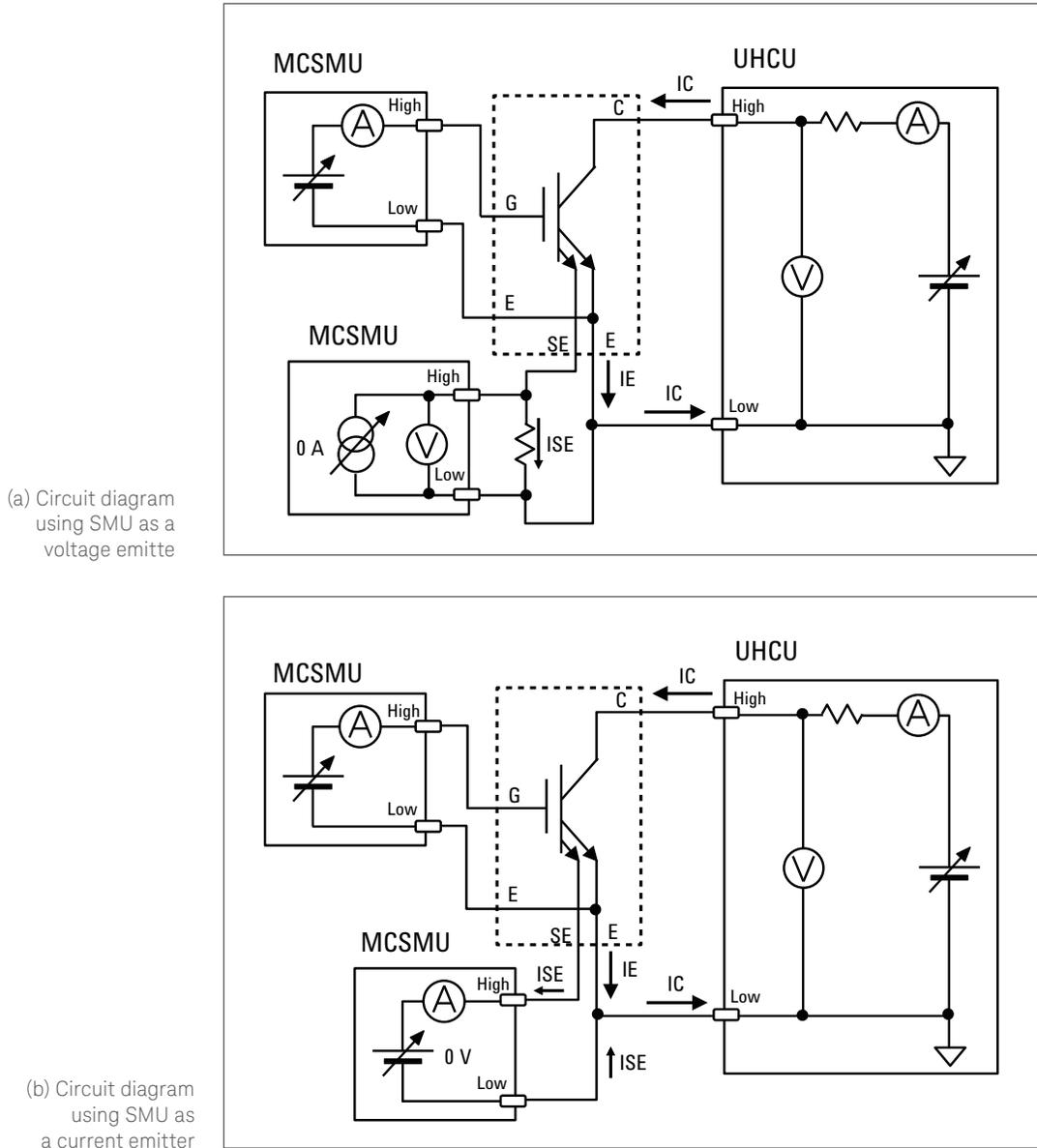


FIGURE 2. Connection diagram to measure sense emitter current

Floating SMUs do not have a hard-wired connection to any internal ground reference. In the B1505A both the medium current SMUs (MCSMUs) and high current SMUs (HCSMUs) are floating SMUs. The floating SMU feature makes it easy to measure the differential voltage across the shunt resistor, as well as the ratio of the current flowing through the sense emitter sense to that flowing through the regular emitter. Note: In these diagrams “UHCU” refers to the B1505A’s ultrahigh current unit, which can source and measure currents up to 1500 A.

Measurement Examples

Figure 3 shows plots of emitter current (IE) and sense emitter current (ISE) versus collector voltage (VCE) both with and without a shunt resistor. Note that the scales of the IE axis and the ISE axis differ by a factor of 10,000.

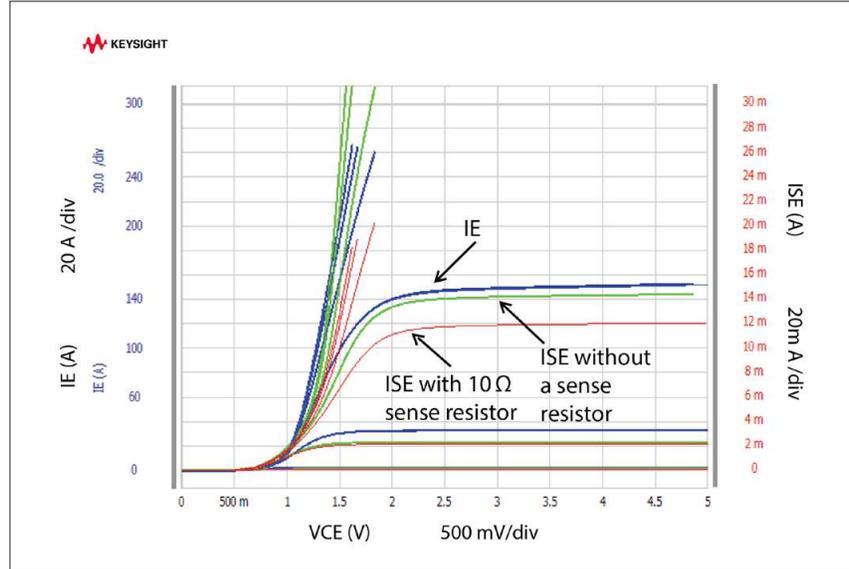


FIGURE 3. Plot of IE/ISE-VCE characteristics

The slope of ISE increases rapidly with increasing emitter current. This means that the IE/ISE ratio decreases with increasing IE as shown in figure 4.

Figure 4 shows the dependency of the IE to ISE ratio as a function of emitter current. Note: The gate voltage for the curves shown in figure 4 was large enough to turn on the IGBT (maximum allowable gate voltage, VGES). As can be seen, the ratio reaches a maximum value quickly and then decreases with increasing IE. The ratio is also larger with a shunt resistor present.

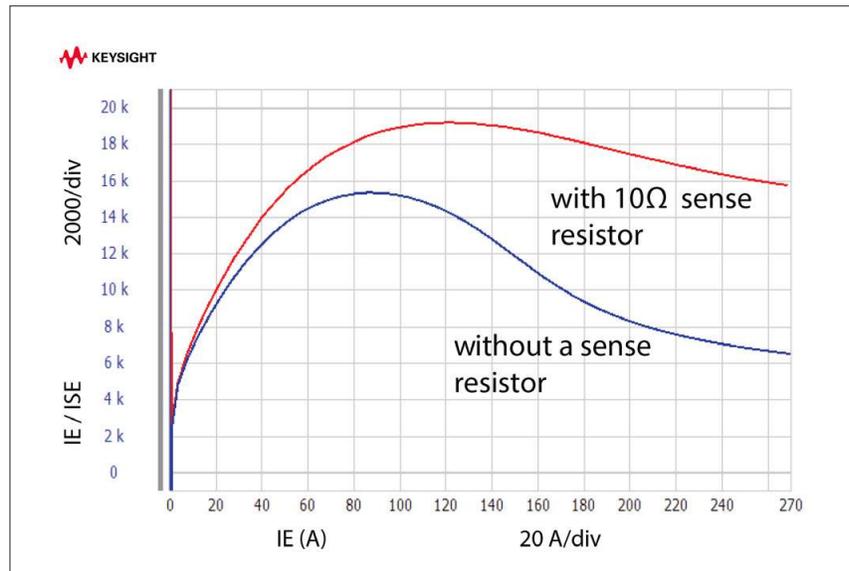


FIGURE 4. IE/IES dependency as a function of IE

The decrease of the IE to ISE ratio and the effect of the shunt resistor can be explained by considering the voltage drop across the interconnect resistances inside the IGBT.

Measurement Examples

continued

Figure 5 shows a circuit schematic that helps to explain this effect.

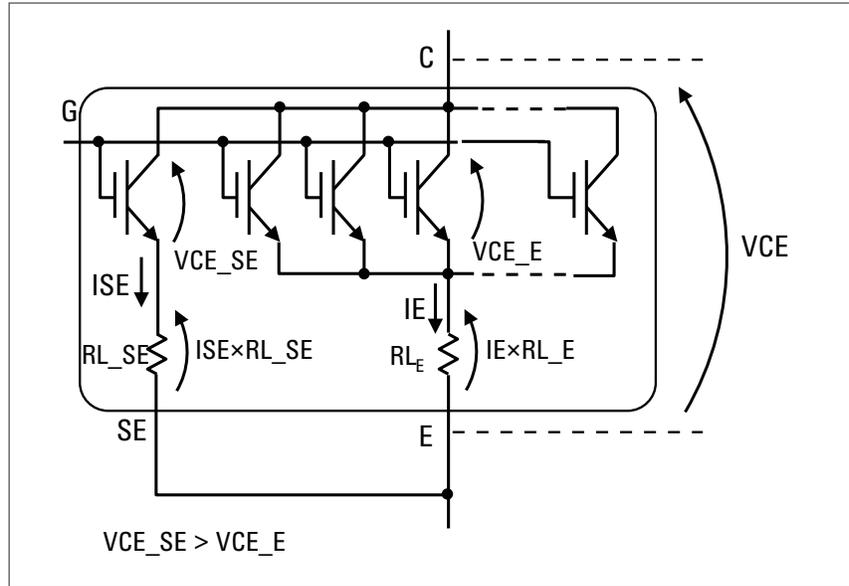


FIGURE 5. Schematic showing the influence of residual resistance voltage drops inside the device

RL_E is the residual resistance of the emitter terminal (including the package leads). Similarly, RL_{SE} is the residual resistance of the sense emitter terminal. Unlike the small ratio of the I_{SE} to I_E currents, the ratio of RL_E to RL_{SE} is not as extreme because it is dominated by the resistance of the interconnects and leads. Since the resistors are comparable in value, the voltage drop across RL_E is larger than that across RL_{SE} at higher emitter currents. This larger voltage drop across RL_E causes the effective emitter to collector voltage at the IGBT cells that comprise the emitter to be less than that experienced by the IGBT cells that comprise the sense emitter.

When a shunt resistor is used, the voltage drop across the shunt resistor partially cancels the voltage drop difference of the residual lead resistances. This acts to increase the ratio of I_E to I_{SE} even under high emitter current conditions.

Obviously, the higher I_{SE} to I_E ratio at low-levels of emitter current cannot be explained through residual resistances. Instead, for low emitter currents the suspected cause is variation in the IGBT cells forming the emitter and sense emitter.

Time Response

Figure 6 shows VCE, IC and ISE waveforms captured using the B1505A's Oscilloscope View function. The B1505A's measurement modules can monitor voltage and current waveforms with 2 μs timing resolution. In this example a 10 Ω shunt resistor is being used, and ISE is calculated using the differential voltage measured across the resistor. VGE is kept at the same value as VGES to ensure that the device is completely on.

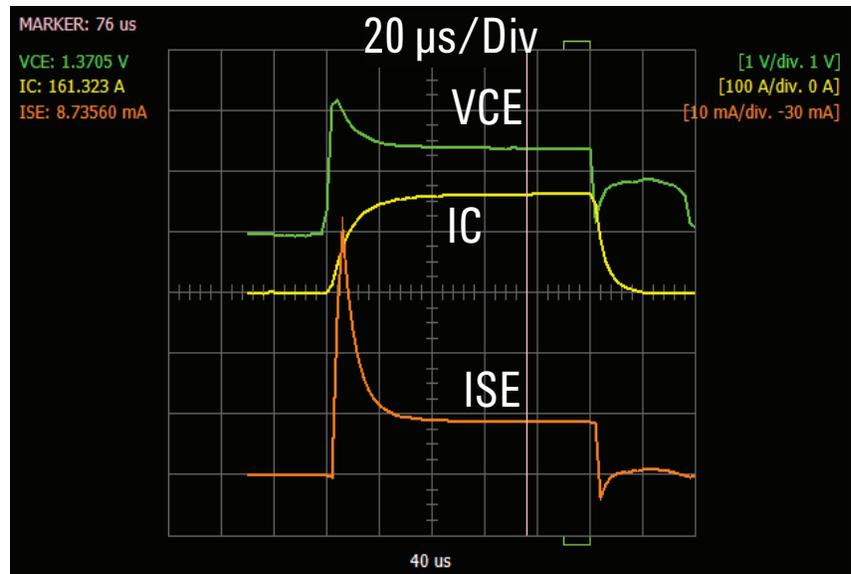


FIGURE 6. Waveform of VCE, IC and ISE with a 10 Ω shunt resistor

Although you would expect the collector and emitter current waveforms to have similar shapes, in this example the IC and ISE waveforms are clearly different. ISE shows a significant overshoot at the beginning of the pulse.

This discrepancy can be explained by considering the residual inductances of the wires at the emitter and sense emitter terminals (including the measurement cables). The residual inductances of the wires at the emitter (LE) and the sense emitter (LSE) terminals shown in figure 7 are roughly comparable, because wiring inductance is primarily determined by the total wire length.

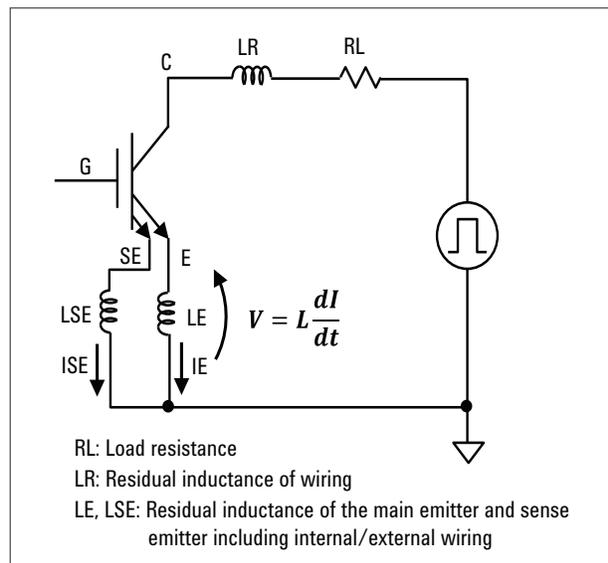


FIGURE 7. Residual inductances at each terminal

Time Response continued

Since the emitter current is significantly larger than the sense emitter current, the inductive voltage spike across LE on the rising edge of the emitter current pulse is significantly larger than that across LSE. This large voltage spike acts to limit large increases in the emitter current.

Since VCE is primarily determined by the combination of the voltage being applied by the voltage source and the voltage drop at the load resistance (RL), the VCE waveform has an inverse relationship with respect to IC.

Conversely, since ISE is significantly smaller than the emitter current (IE), the voltage drop across LSE due to the current pulse is not significant. The sense emitter therefore experiences a large voltage increase and the ISE displays a sharper rising edge and overshoot proportional to the collector voltage pulse. Of course, once the collector current stabilizes the voltage drop across the residual inductances becomes negligible.

Temperature Sensor Measurement

The IGBTs used in DC/AC inverters typically have built-in temperature sensors to protect against over-heating. Using an additional SMU, the B1505A can measure this temperature sensor to monitor the IGBT's internal temperature. Figure 8 shows a plot of the internal temperature and the sense emitter current versus time made using the B1505A after applying a constant current pulse of 200 A.

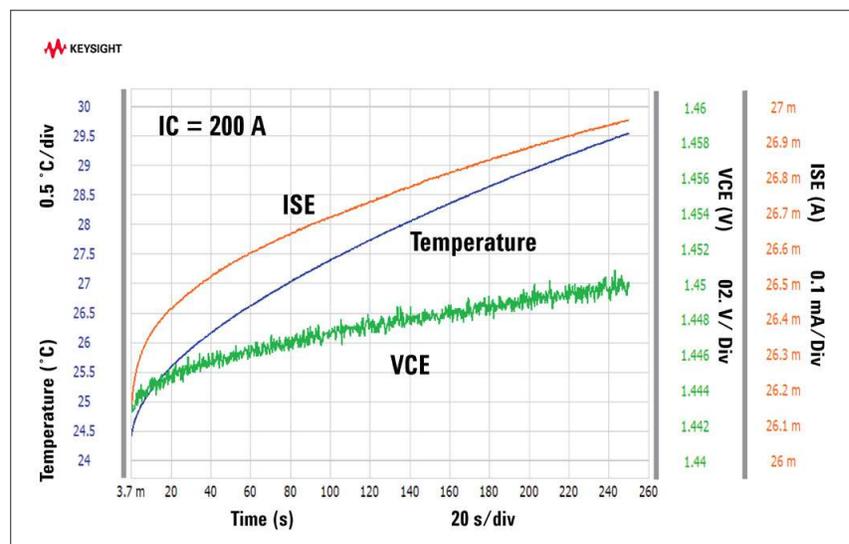


FIGURE 8. Sense emitter current temperature dependency

The sense emitter current increases with increasing temperature. This is attributed to the temperature difference between the IGBT cells comprising the emitter and those comprising the sense emitter. The temperature sensor is normally placed near the center of the device. This means that if the IGBT sense emitter cells are located at the ends of the device, the average temperature of the IGBT emitter cells will be higher than that of the sense emitter cells.

Conclusion

This application note has shown how the ISE to IE ratio of IGBT sense emitter currents can be influenced by currents and voltages both inside and outside of the device. In addition, the load resistance and residual inductances of the total system can affect the transient responses of both the collector current and the sense emitter current.

Besides being influenced by voltage and current, the ISE to IE ratio also depends on the IGBT's internal temperature.

The B1505A's modular architecture allows you to measure the sense emitter current and emitter current simultaneously up to 1500 A. It also makes it possible to measure the temperature dependency of the sense emitter current using an SMU to monitor the built-in temperature sensor.

The Oscilloscope View feature is also useful to observe the different transient responses of the collector current and the sense emitter current.

All of these B1505A features significantly improve efficiency when characterizing the sense emitter current of an IGBT under actual use conditions.

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