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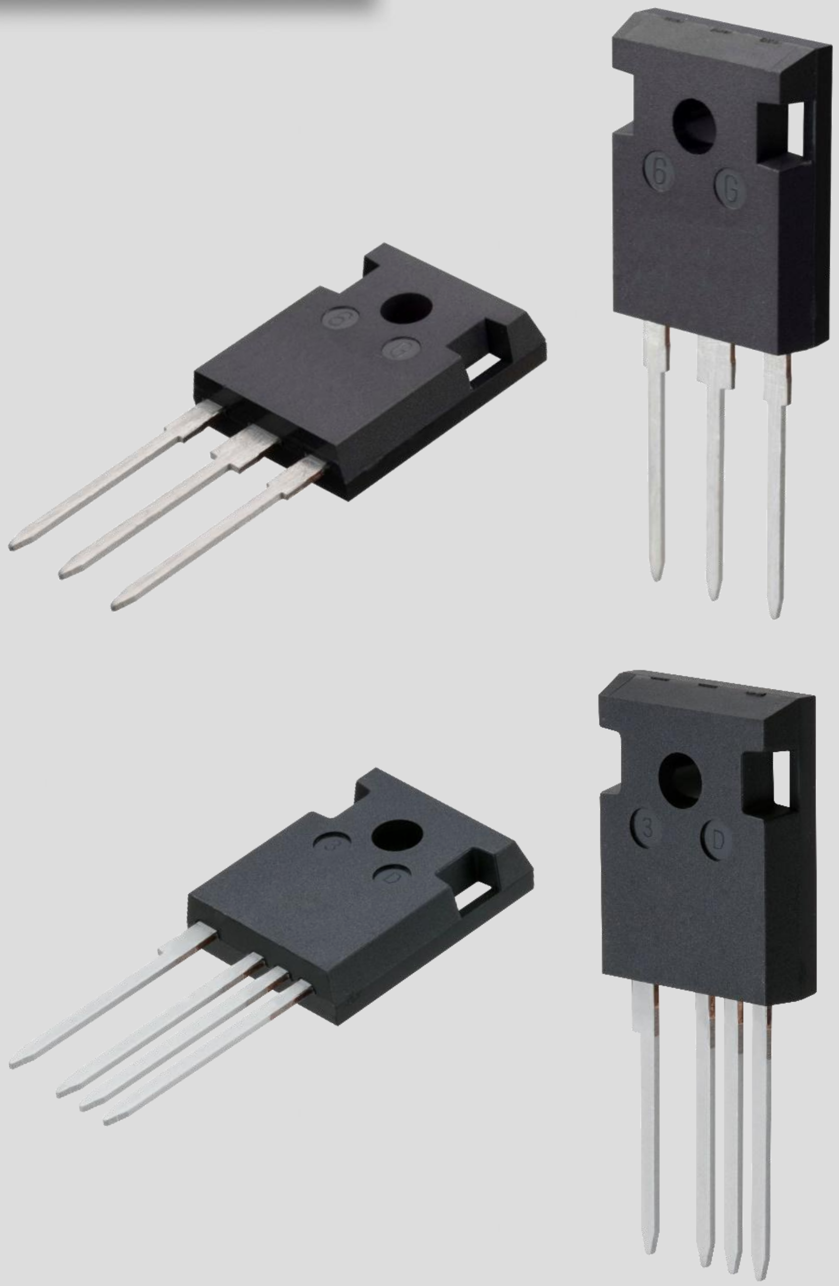

Discrete IGBT

Application Manual

Dec. 2025

Fuji Electric Co.,Ltd.

⚠ Cautions

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Chapter 9 Evaluation and Measurement

This chapter describes how to evaluate the characteristics of discrete IGBT, and the methods for measuring voltage and current.

1. Evaluation and Measurement Methods

During development of power electronics equipment, it is necessary to evaluate the characteristics and measure the load of the IGBT modules while they are installed in the equipment. An overview of the evaluation items and measurement methods is shown in Table 9-1.

Table 9-1 Overview of evaluation items and measurement methods

No.	Evaluation item	Measurement item	Measurement methods	Measuring instrument
1	Collector-Emitter voltage	Voltage	With G-E shorted, apply test voltage to C-E. *If there is possibility that the test voltage may exceed the rating of the components connected to C-E, disconnect those components first.	Curve tracer
2	Collector-Emitter saturation voltage		Measure by connecting a voltage clamping circuit between C-E so that the built-in amplifier of the oscilloscope does not saturate. *Static characteristics can be measured with a curve tracer or pulse h_{FE} meter	Oscilloscope
3	Turn-off surge voltage	Voltage	Measure the C-E voltage directly at the device terminals.	Oscilloscope
4	Switching time	Voltage Current	Measure the required voltage and current waveforms according to the switching time definition.	Oscilloscope
5	Current sharing (parallel connection)	Current	Measure the current flowing through each device.	Oscilloscope
6	Switching loss	Voltage Current	The product of the current and voltage is integrated over a specified period. (1) Calculate from voltage & current waveforms (2) Use a measuring instrument with math function	Oscilloscope
7	Operation locus		Plot the voltage & current during switching in current-voltage graph.	Oscilloscope
8	Case temperature	Temperature	Measure the temperature of the lead frame surface directly beneath the IGBT chip.	Thermocouple
9	Junction temperature		Create a calibration curve for the junction temperature and device characteristics with temperature dependence characteristics (for example, saturation voltage), and measure the characteristics of the device during operation to estimate the junction temperature.	-

2. Voltage Measurement

Note that voltage measurement during IGBT operation is susceptible to noise caused by high-amplitude, high-speed switching operation.

2.1 Measuring instrument and calibration

Both the waveform and the target voltage value are important. Normally, an oscilloscope is used as the measuring instrument, and a voltage probe is used for voltage measurement. The time constant of the voltage divider RC of the probe/oscilloscope vary depending on the oscilloscope/probe combination. Therefore, before using the probe, carry out probe compensation to achieve uniform attenuation across all frequency range by connecting it to the calibration terminal of the oscilloscope.

Set the appropriate sensitivity (generally, 3 to 4 division amplitude on the display screen) and set the input coupling to DC. Exercise caution in selecting the probe, because the adjustment capacitance of the probe and the input capacitance of the oscilloscope must match to enable adjustment.

2.2 Saturation voltage measurement

Generally, while the circuit voltage using IGBT is as high as several hundred volts, the IGBT saturation voltage is as low as several volts. Because the size of the screen of the oscilloscope is limited, increasing the voltage sensitivity in an effort to measure the saturation voltage accurately will result in the display of a waveform that is different from the actual waveform due to effect such as saturation of the oscilloscope built-in amplifier. Therefore, the IGBT saturation voltage during switching operation cannot be measured by directly measuring the C-E voltage of the IGBT with an oscilloscope. The method to measure the saturation voltage is by adding a voltage clipping circuit as shown in Fig. 9-1, and measure $V_{CE(sat)}$ through that circuit.

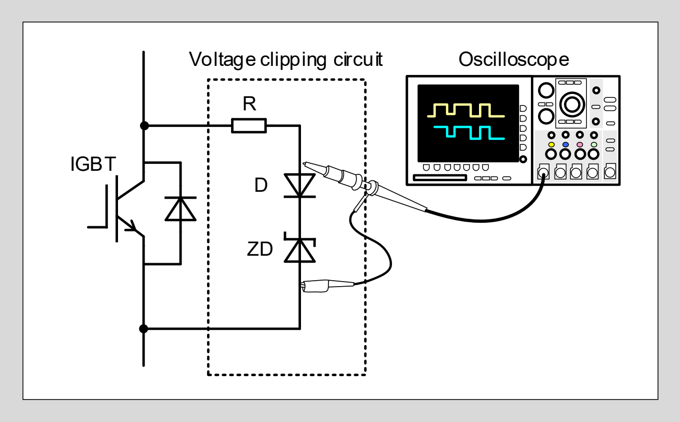


Fig. 9-1 Measurement method of saturation voltage

In Fig. 9-1, the Zener diode (ZD) limits the high voltage when the IGBT is turned off. Generally, a Zener diode with Zener voltage of 10V or less is used. R is a current-limiting resistor. Because most of the circuit voltage is applied to this resistor when the IGBT is turned off, the resistor must have a relatively large capacity. The diode (D) prevents the charges built in the junction capacitance of the Zener diode from discharging, and also prevents a RC filter from being formed by the junction capacitance and the current-limiting resistance.

2.3 Surge voltage measurement (Collector-emitter voltage measurement)

While IGBTs offer the benefit of fast switching, the current change rate (-d*i*/d*t*) at turn-off is large, inducing a high voltage in the main circuit wiring inductance (L_S) of the equipment. This voltage is superimposed over the DC circuit voltage and cause a spike voltage to be applied to the device. This voltage is called surge voltage, and it is necessary to confirm that the voltage is within a predetermined voltage margin with respect to the maximum rating of the device.

The surge voltage can be measured at the device terminals with an oscilloscope and directly reading the value on the oscilloscope screen. Note the following precautions during measurement.

- Use a probe and an oscilloscope with sufficient frequency bandwidth.
- Adjust the oscilloscope sensitivity and calibrate the probe.
- Connect the measurement probe directly to the device terminals.

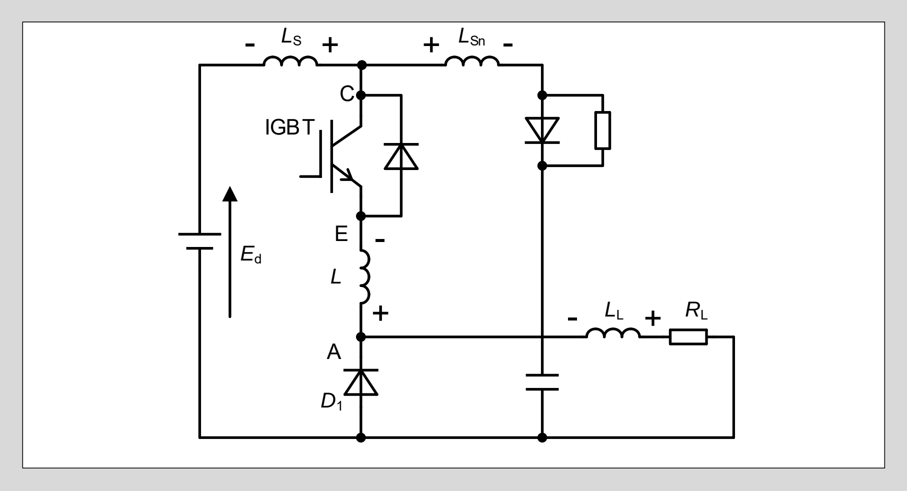


Fig. 9-2 Example of surge voltage measurement circuit

During IGBT turn-off, voltages of the polarity shown in Fig. 9-2 are induced in the circuit inductances of each part of the circuit. Note that in the case where V_{CA} is measured instead of V_{CE}, then a voltage lower than V_{CE} by $-L \cdot di/dt$ will be erroneously measured. Therefore, when measuring the surge voltage of the IGBT, it is necessary to measure it in a state where the influence of the wiring inductance L is minimized, such as by connecting the voltage probe directly to the module terminal.

- Keep the probe measurement leads as short as possible.
- Keep probe leads away from high d*i*/d*t* areas so that noise interferences are minimized.

When the voltage probe is connected to the switching circuit, the reference potential of the oscilloscope would equal the switching circuit. If there is a large ground potential fluctuation in the switching circuit, common-mode current would flow through the power line of the oscilloscope, which may cause the internal circuit to malfunction. Noise interferences can be verified by the following methods.

- Consider whether the measured waveform can be logically explained.
- Comparing with waveforms measured on a battery-powered oscilloscope that is less susceptible to noise interferences.

2.4 Gate voltage measurement (Gate-emitter voltage measurement)

The V_{GE} can be directly measured with an oscilloscope similar to the surge voltage. However, since the IGBT gate is a capacitive load and the voltage probe also has capacitive impedance, do not attach or detach the voltage probe during measurement. The same precautions as for the surge voltage measurement are required.

3. Current Measurement

Current probes are used for current measurement. However, in practical equipment, the main circuit is compact in order to reduce wiring inductances L_S and simplify the structure. Thus, the wiring needs to be extended to measure the device current. A current transformer can be used to minimize the wiring extension. In addition, the use of current transformers is also necessary due to the limited measuring capacity of the current probe.

Current probe can measure current while maintaining insulation from the conductive part, but in addition to being an electromagnetic induction-based detector, the signal level is low that it is susceptible to induction caused noise interferences. Care should be taken against noise interferences.

3.1 Current probe sensitivity check

Before making any measurements, it is necessary to check the probe sensitivity.

Current probe can be calibrated using the oscilloscope calibrator output or using an oscillator as shown in Fig. 9-3. The measurement method in Fig. 9-3 uses a known resistance *R* (non-inductive) to measure the voltage *e* across *R* to obtain the current *i*. Compare the current *i* and the waveform of the current probe to calibrate. If the current *i* is too small, sensitivity can be increased by increasing the number of primary winding of the current probe.

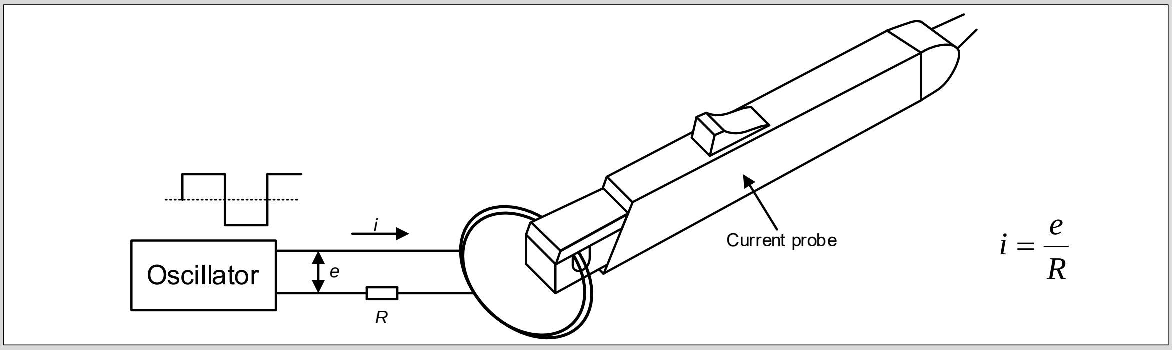


Fig. 9-3 Current probe calibration method

3.2 Current measurement method

Using a two parallel connection as example, Fig. 9-4 shows where current transformers (CT) are inserted to measure the current. When measuring the current on the positive side of T_{11}, measure the secondary side current of CT_1 with a current probe. For T_{12}, measure the secondary side current. The total current on the positive side (sum of T_{11} current and T_{12} current) can be measured with the same current probe by aligning the directions of the secondary side currents of CT_1 and CT_2 and measuring them at once.

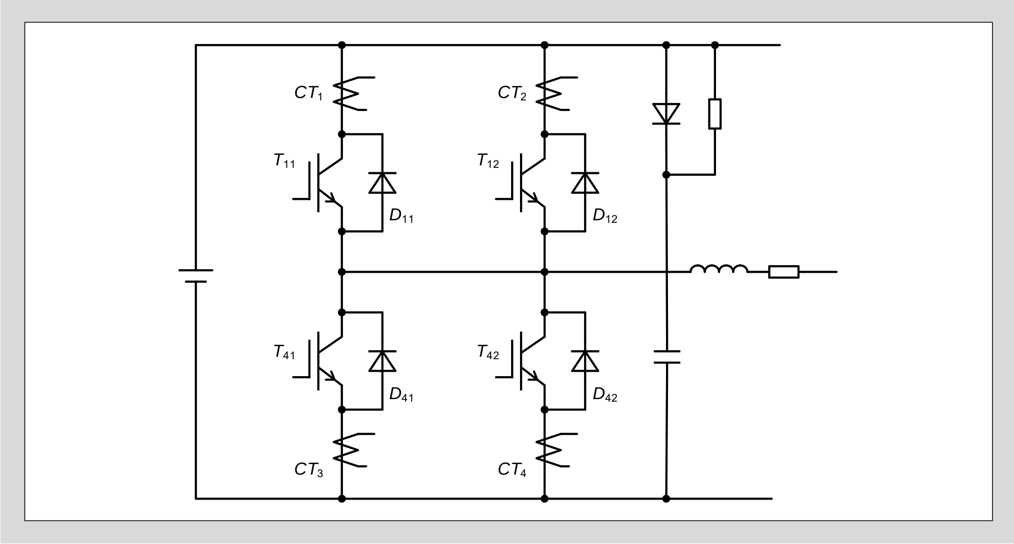


Fig. 9-4 CT insert position and current measurement method

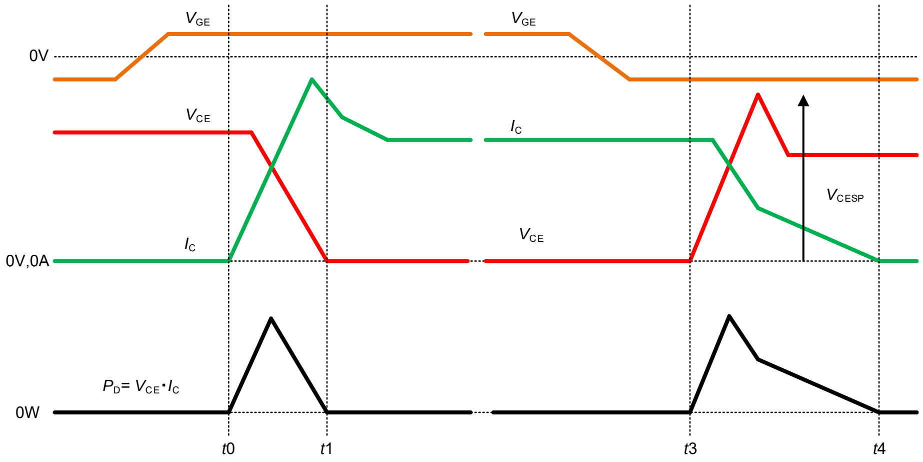
3.3 Switching loss measurement

Switching loss is the loss generated during the period from the start of switching to the end of switching operation and reaching a steady-state. For example, the turn-on loss is the loss that is generated from V_{GE} is above 0V until V_{CE} reaches the saturation voltage.

The switching loss is generally expressed in terms of energy generated per instance of switching.

Fig. 9-5 shows example of switching waveform and switching loss. To measure switching loss, the current and voltage waveforms must be measured correctly. Note that when current and voltage are measured simultaneously, the common-mode current flowing from the voltage probe may cause the current waveform to be distorted. The presence or absence of this common-mode effect can be determined by comparing the current waveforms before and after the voltage probe is connected. If the current waveform is distorted, inserting a common-mode choke into the voltage probe cable and the oscilloscope power cable (by winding the cable around a core with excellent high frequency characteristics) as shown in Fig. 9-6 will reduce the waveform distortion.

In addition, the settings of reference 0V and 0A is important. Note that when using an AC current probe, the position of 0A varies depending on the current value and the conduction ratio.



$$E_{\text{on}} = \int_{t0}^{t1} V_{\text{CE}} \cdot I_{\text{C}} \cdot dt \qquad E_{\text{off}} = \int_{t2}^{t3} V_{\text{CE}} \cdot I_{\text{C}} \cdot dt$$

Fig. 9-5 Switching loss

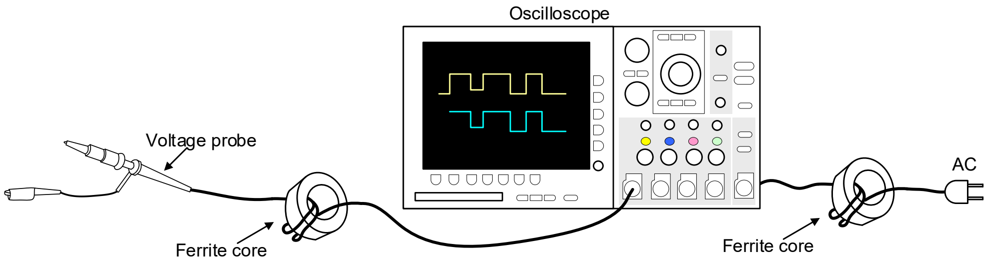


Fig. 9-6 Inserting common mode choke