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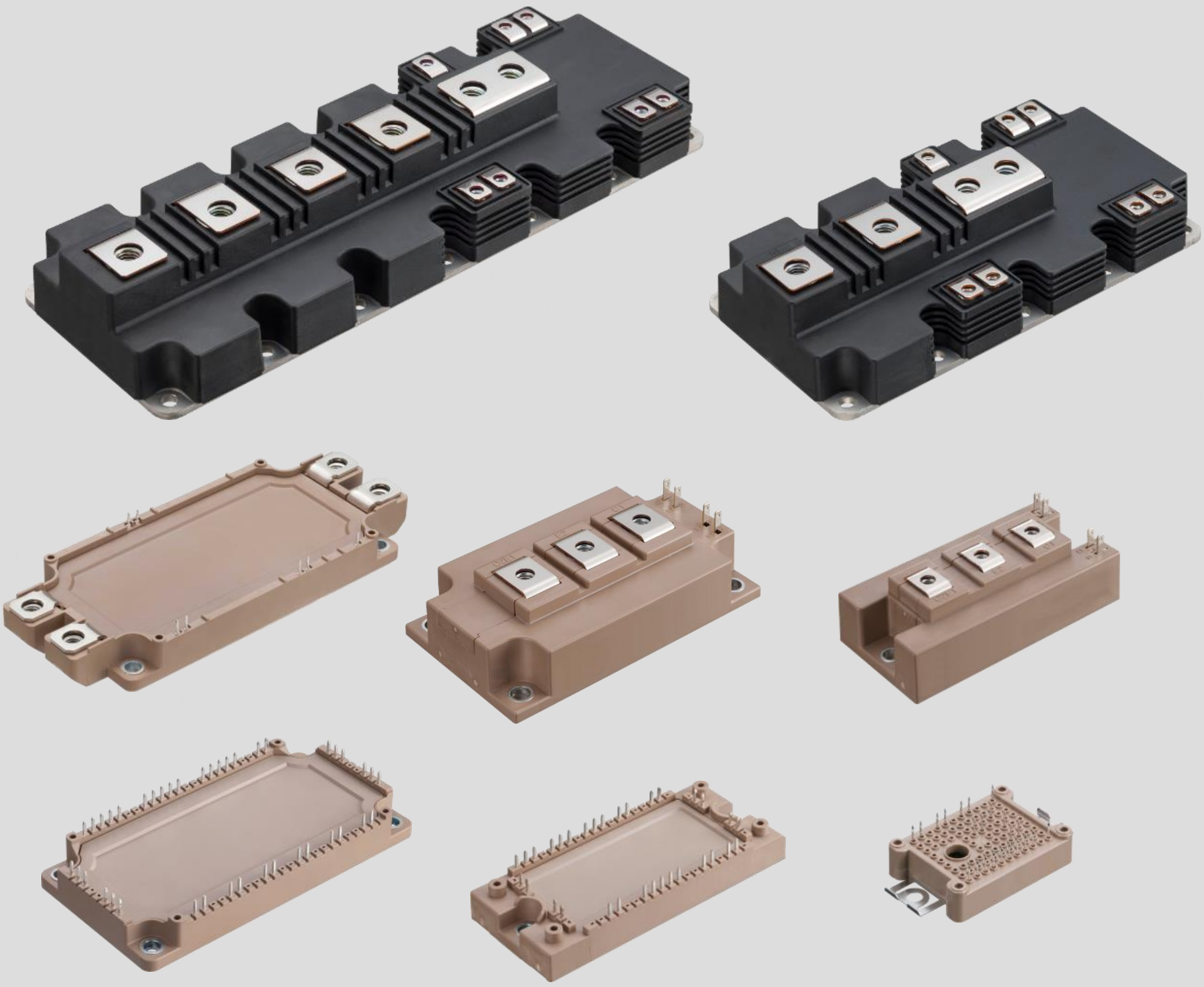

Fuji IGBT Module

Application Manual

March, 2023

Fuji Electric Co., Ltd.

⚠Cautions

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Chapter 2 Terms and Characteristics

This chapter describes the terms and characteristics of IGBT modules.

1. Explanation of Terms

Various terms used in the specifications are explained below.

Table 2-1 Maximum ratings

Term	Symbol	Definition explanation (Refer to specifications for test conditions)
Collector-Emitter voltage	V_{CES}	Maximum Collector-Emitter (hereinafter referred to as C-E) voltage with Gate-Emitter (G-E) shorted.
Gate-Emitter voltage	V_{GES}	Maximum G-E voltage with C-E shorted.
Collector current	I_C	Maximum DC collector current of IGBT.
	I_{CRM} I_C pulse	Maximum pulse collector current of IGBT.
Forward current	$-I_C$	Maximum DC forward current of FWD.
	I_{FRM} $-I_C$ pulse	Maximum pulse forward current of FWD.
Total power dissipation	P_{tot} P_C	Maximum power dissipation per IGBT.
Virtual junction temperature	T_{vj} T_j	Maximum junction temperature at which normal operation is possible. You must not exceed this temperature under the worst condition.
Operating virtual junction temperature	$T_{vj(op)}$ T_{vjop}	Junction temperature during continuous operation.
Case temperature	T_C	Case temperature directly below the IGBT chip or FWD chip that generates the most heat inside the IGBT module. (refer to Chapter 6 for details.)
Storage temperature	T_{stg}	Temperature range allowing storage or transportation without being subjected to electrical load.
FWD I^2t	I^2t	Joule-integral value of overcurrent allowed that does not result in diode destruction. The overcurrent is defined by a line frequency half sine wave (50, 60Hz) at one cycle.
FWD surge forward current	I_{FSM}	The maximum value of overcurrent allowed that does not result in diode destruction. The overcurrent is defined by a line frequency half sine wave (50, 60Hz).
Isolation voltage	V_{iso}	Maximum sinusoidal voltage RMS value allowed between all shorted terminals and the heat sink mounting surface.
Screw torque	Mounting	Maximum allowable torque value when mounting the IGBT module on a heat sink with the specified screws
	Terminal	Maximum allowable torque value when connecting external busbar or wires to the terminals with the specified screws

Note 1: Values at T_C = 25 °C unless otherwise specified
Note 2: The values listed as maximum ratings should not be exceeded under any circumstances.

Table 2-2 Electrical characteristics

	Term	Symbol	Definition explanation (Refer to specifications for test conditions)
Static characteristics	Zero gate voltage collector current	I_{CES}	Collector current when a specific voltage is applied between C-E with G-E shorted.
	Gate-Emitter leakage current	I_{GES}	Gate current when a specific voltage is applied between G-E with C-E shorted.
	Gate-Emitter threshold voltage	$V_{GE(th)}$	G-E voltage (V_{GE}) at a specified I_C and C-E voltage.
	Collector-Emitter saturation voltage	$V_{CE(sat)}$	C-E voltage at a specified collector current and G-E voltage.
	Input capacitance	C_{ies}	G-E capacitance when a specified voltage is applied between G-E and C-E while C-E is shorted in AC.
	Output capacitance	C_{oes}	C-E capacitance when a specified voltage is applied between G-E and C-E while G-E is shorted in AC.
	Reverse transfer capacitance	C_{res}	C-G capacitance when a specified voltage is applied between G-E and C-E while G-E and C-E are shorted in AC.
	Forward voltage	V_F	Forward voltage of FWD at a specified forward current.
Dynamic characteristics	Turn-on time	t_{on}	The time during IGBT turn-on when V_{GE} rises from 10% of the maximum value until collector current rises to 90% of the maximum value.
	Rise time	t_r	The time during IGBT turn-on when the collector current rises from 10% to 90% of the maximum value.
	Turn-off time	t_{off}	The time during IGBT turn-off when V_{GE} drops from 10% of the maximum value until collector current drops to 10% of the maximum value.
	Fall time	t_f	The time during IGBT turn-off when the collector current drops from 90% to 10% of the maximum value.
	Turn-on loss	E_{on}	Loss generated during IGBT turn-on.
	Turn-off loss	E_{off}	Loss generated during IGBT turn-off.
	Reverse recovery loss	E_{rr}	Loss generated during FWD reverse recovery.
	Reverse recovery time	t_{rr}	Time required for FWD reverse recovery current to disappear.
	Reverse recovery current	I_{rr} (I_{rp})	Peak reverse current during reverse recovery.
Reverse bias safe operating area		RBSOA	Current and voltage range where IGBT can be turned off safely under specified conditions.
Internal gate resistance		r_g $R_{g(int)}$	Built-in gate series resistance.
Gate charge		Q_g	Amount of charge required to turn-on the IGBT.

Note 1: The definition of dynamic characteristics differs between series. For details, refer to the specifications of each product.

Table 2-3 Thermal resistance characteristics

Term	Symbol	Definition explanation (Refer to specifications for test conditions)
Thermal resistance	$R_{th(j-c)}$	Thermal resistance between the chip (junction)and case of IGBT or FWD.
	$R_{th(c-s)}$	Thermal resistance between the case and heat sink when the IGBT module is mounted on a heat sink with the recommended torque and thermal grease.

Table 2-4 Thermistor characteristics

Term	Symbol	Definition explanation (Refer to specifications for test conditions)
Thermistor resistance	R	Thermistor resistance at specified temperature
B value	B	Value indicating the magnitude of thermistor resistance change between any two temperatures in resistance-temperature characteristics.

2. Characteristics of IGBT and FWD

Using the 6MBI100VB-120-50 (1200V/100A, 6th generation IGBT module) as an example, the various characteristics of the IGBT described in the specifications are explained below.

2.1 Static characteristics

Fig. 2-1 and Fig. 2-2 show the V_{GE} dependence of V_{CE}-I_C characteristics (output characteristics). While the IGBT is on, V_{CE} changes in accordance with I_C, V_{GE}, and T_{vj}. V_{CE} represents the C-E voltage drop during the ON state, and is used to calculate the power dissipation loss of the IGBT. The smaller the V_{CE} value, the lower the power dissipation loss.

It is generally recommended to operate at V_{GE}=15V, and the collector current lower than the module current rating.

Fig. 2-3 shows the data in Fig. 2-1 as I_C dependence of V_{CE}-V_{GE} characteristics. From the graph, the V_{GE} value limit where V_{CE} suddenly increases can be read.

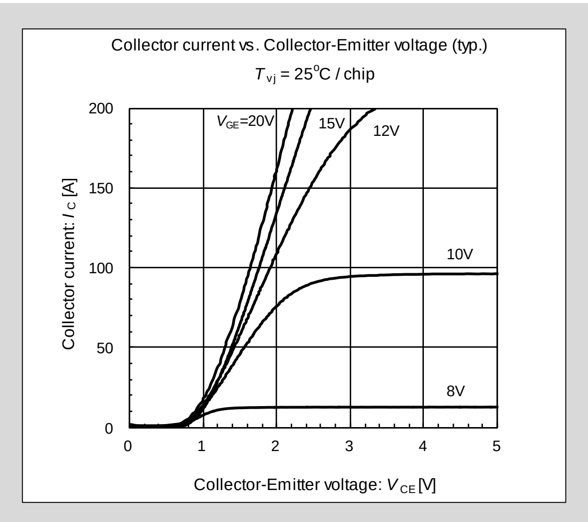

Fig. 2-1 $V_{CE(sat)}$ - I_C characteristics (T_{vj}=25°C)

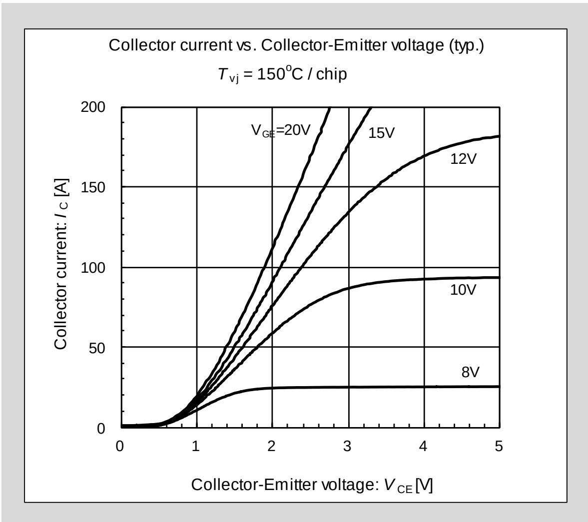

Fig. 2-2 $V_{CE(sat)}$ - I_C characteristics (T_{vj}=150°C)

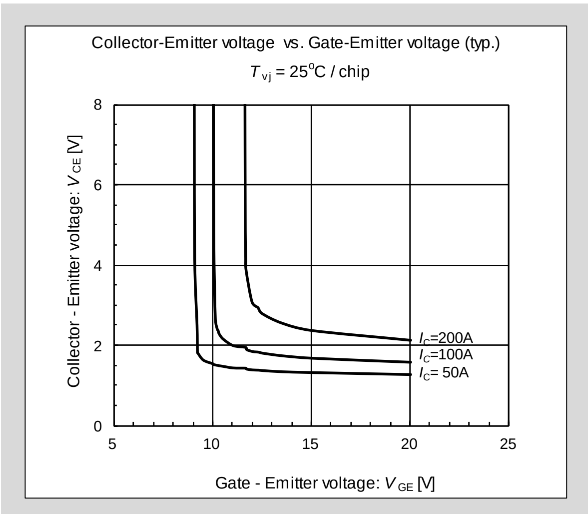

Fig. 2-3 V_{CE} - V_{GE} characteristics (T_{vj}=25°C)

2.2 Switching characteristics

As the IGBT is generally used for switching applications, it is important to fully understand the turn-on and turn-off switching characteristics. Since these characteristics are affected by various parameters, it is necessary to take these into consideration when determining operating conditions.

Switching characteristics can be divided into switching time and switching loss. These switching characteristics can be measured by the chopper circuit shown in Fig. 2-4.

The definitions of switching times are shown in Fig. 2-5.

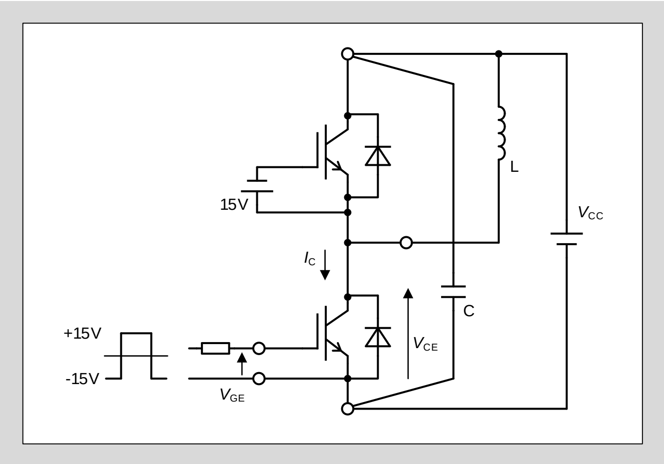

Fig. 2-4 Switching characteristics measuring circuit

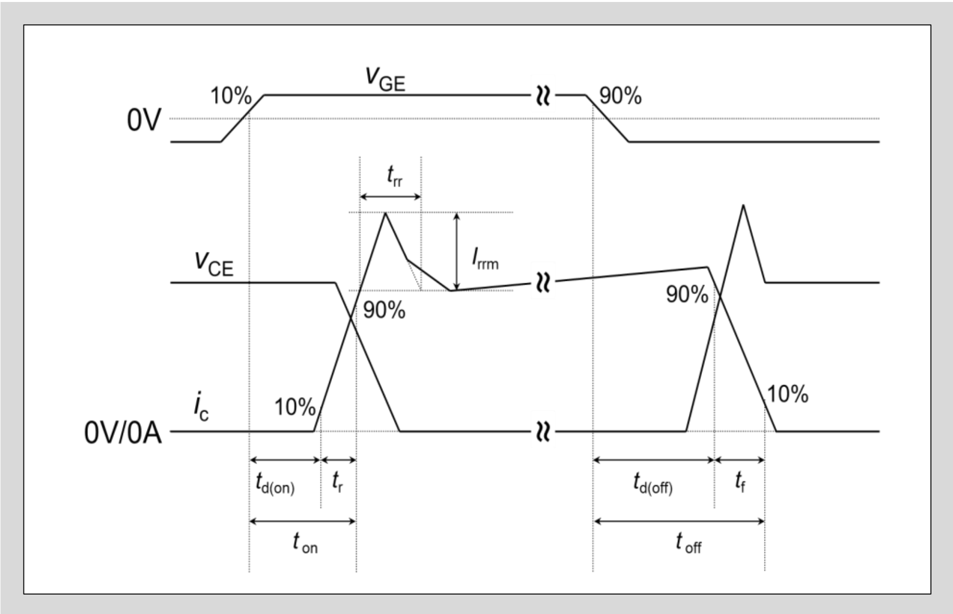

Fig. 2-5 Definition of switching time

The relationship between switching time and collector current I_C is shown in Fig. 2-6 and Fig. 2-7. Fig. 2-8 shows the relationship between switching time and gate resistance R_G. As shown in these figures, the switching time varies depending on I_C, T_{vj}, and R_G, so please take this into consideration when designing equipment.

For example, when the IGBT is used under the condition that t_{off} is too long, it may exceed the dead time and cause a series arm short-circuit.

It is also important to be aware that if the switching time, such as t_f is too short, the transient current change rate dI_c/dt will increase and may cause a high turn-off surge voltage ($=L_S \cdot dI_C/dt$). Since this surge voltage is superimposed on the applied voltage, the resulting voltage might exceed RBSOA and destroy the IGBT (refer to Chapter 2 and 4 for details).

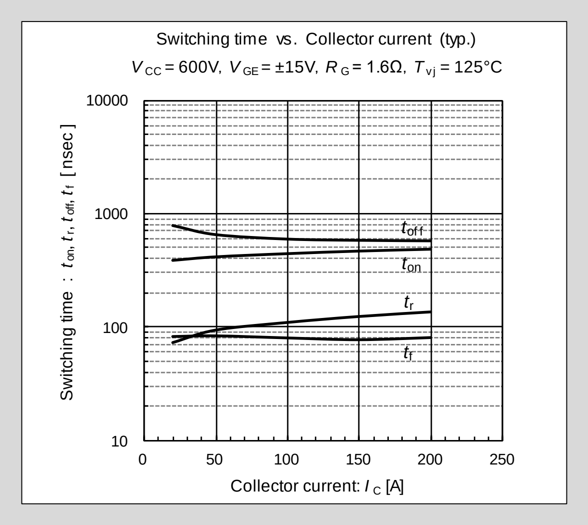

Fig. 2-6 Switching time - I_C characteristics (T_{vj}=125°C)

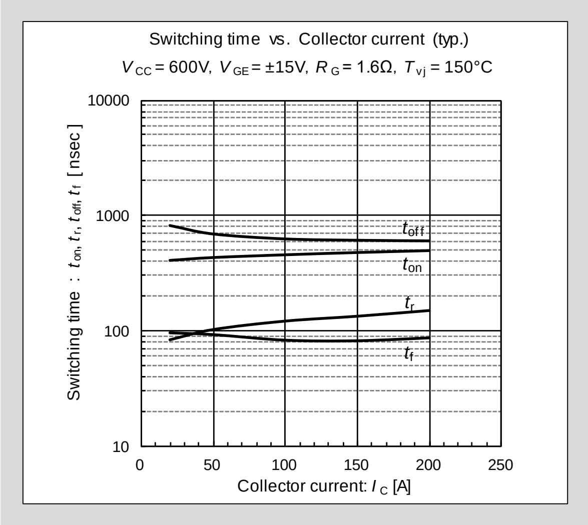

Fig. 2-7 Switching time - I_C characteristics (T_{vj}=150°C)

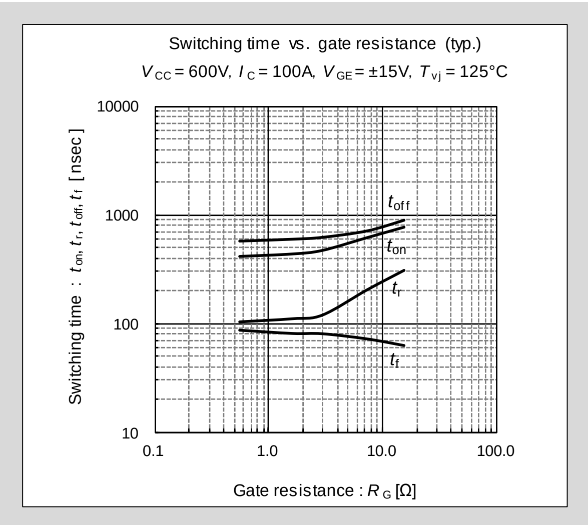

Fig. 2-8 Switching time - R_G characteristics (T_{vj}=125°C)

Switching loss (E_{on}, E_{off}, E_{rr}) occurs every time an IGBT is turned on or off, therefore it is important to minimize this loss as much as possible. As shown in Fig. 2-9 and 2-10, switching loss changes in accordance with I_C, T_{vj}, and R_G. In particular, the selection of R_G is important. If it is too large, the switching loss will increase, and series arm short circuit due to the aforementioned insufficient dead time will easily occur. Conversely, if R_G is reduced to reduce switching loss, the aforementioned excessive surge voltage ($=L_S \cdot dI_C/dt$) may occur.

As can be seen from this, the value of main circuit inductance L_S has great influence on R_G selection. The smaller the value is, the smaller the surge voltage will be, making it easier to consider R_G selection. Therefore, it is recommended to design the L_S value as small as possible.

When selecting R_G, it is also necessary to consider matching with the capacitance of the IGBT drive circuit. Therefore, please select the R_G after careful consideration using the capacitance characteristics as shown in Chapter 2.3.

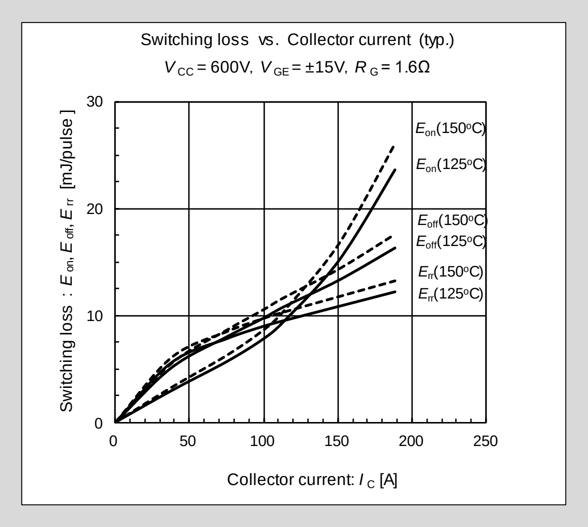

Fig. 2-9 Switching loss - I_C characteristics

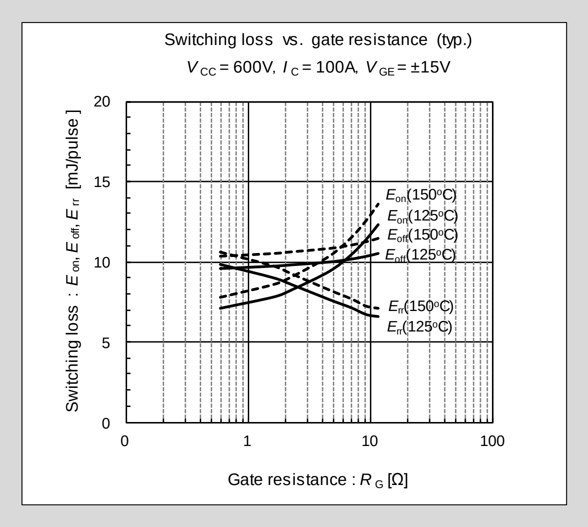

Fig. 2-10 Switching loss - R_G characteristics

2.3 Capacitance characteristics

Fig. 2-11 shows the characteristics of Q_g. This characteristic shows the change of V_{CE}, V_{GE} with respect to Q_g. 'Q_g increases' means 'charging the G-E capacitance of the IGBT', so when Q_g increases, V_{GE} (=Q_g / G-E capacitance) rises and the IGBT turns on. When the IGBT turns on, V_{CE} drops to the saturation voltage. Thus, Q_g indicates the amount of charge required to drive the IGBT. Use this characteristic when determining the power supply capacity of the drive circuit.

Fig. 2-12 shows the IGBT junction capacitance characteristics. Fig. 2-13 shows the junction capacitance C_{ies}, C_{oes} and C_{res}. Use these characteristics along with Q_g to design your drive circuit.

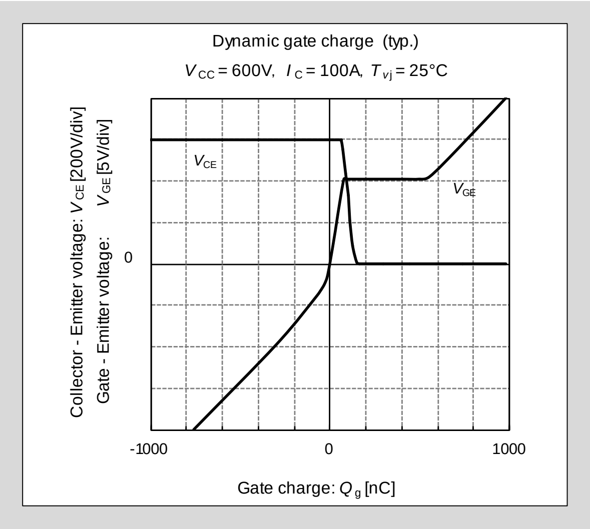

Fig. 2-11 V_{CE}, V_{GE} - Q_g characteristics

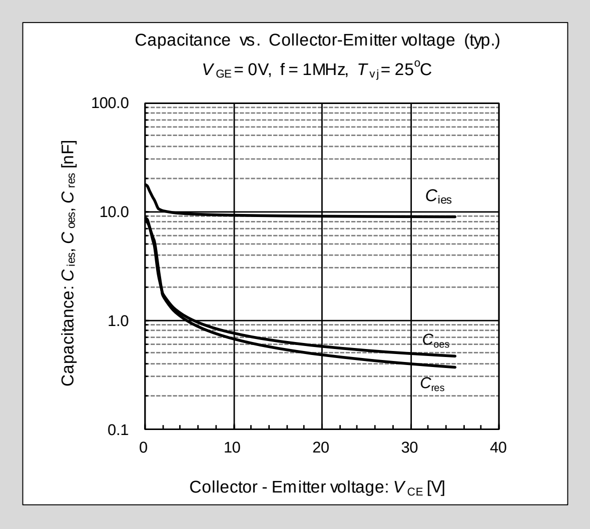

Fig. 2-12 Junction capacitance characteristic

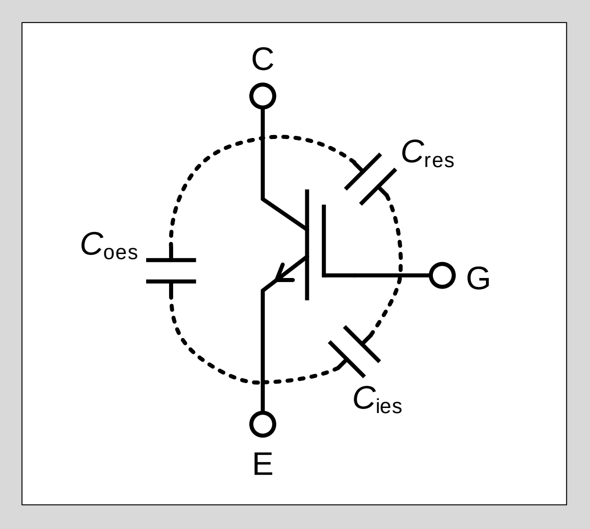

Fig. 2-13 Junction capacitance

2.4 Reverse biased safe operating area

During turn-off, IGBT has a safe operating area defined by V_{CE} an I_C called RBSOA (Reverse Bias Safe Operating Area). Fig. 2-14 shows the area of 1200V/100A IGBT as an example.

It is important to design the snubber circuit that will keep V_{CE} and I_C within the region of RBSOA when the IGBT is turned off. In the case of a short circuit (non-repetitive), the IGBT safe operating area defined by V_{CE} an I_C is called SCSOA (Short Circuit Safe Operating Area). SCSOA is different for each IGBT series, thus refer to the technical data of each series for details.

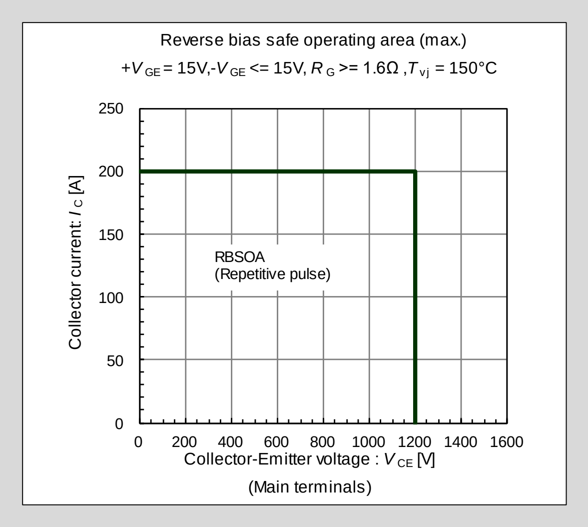

Fig. 2-14 RBSOA

2.5 FWD characteristics

The IGBT module has built-in anti-parallel FWD. Fig. 2-15 shows the FWD V_F-I_F characteristic, and Fig. 2-16 shows the reverse recovery characteristic (t_{rr}, I_{rr}). E_{rr} characteristics are shown in Fig. 2-9 and 2-10. Use these characteristics to calculate the power loss of FWD as well as the IGBT. Note that these characteristics change in accordance with I_F, T_{vj}, and R_G.

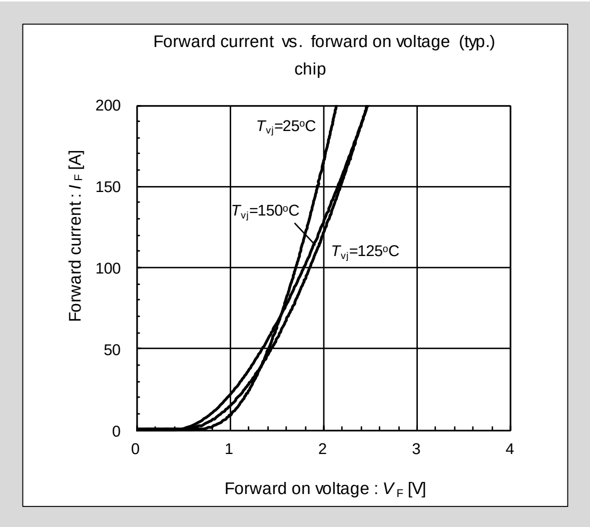

Fig. 2-15 V_F - I_F characteristics

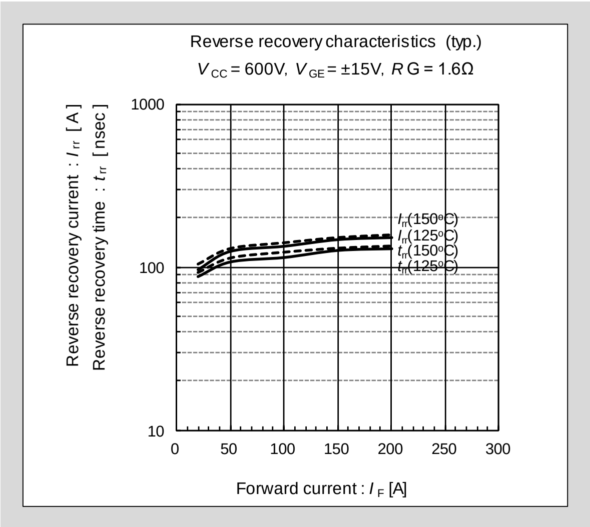

Fig. 2-16 t_{rr}, I_{rr} - I_F characteristics

2.6 Transient thermal resistance characteristics

Fig. 2-17 shows the transient thermal resistance characteristics used for temperature rise calculation and heat sink design (this characteristic is for one arm for both IGBT and FWD).

This thermal resistance is a characteristic often used in thermal analysis, and the formula is very similar to Ohm's law of electrical resistance. It is defined as:

Temperature difference ΔT [°C] = Thermal resistance R_{th} [°C / W] x Energy E (loss) [W]

In the IGBT module, the thermal resistance is used when calculating the T_{vj} of the IGBT and FWD. (For details, refer to Chapter 6 'Cooling Design')

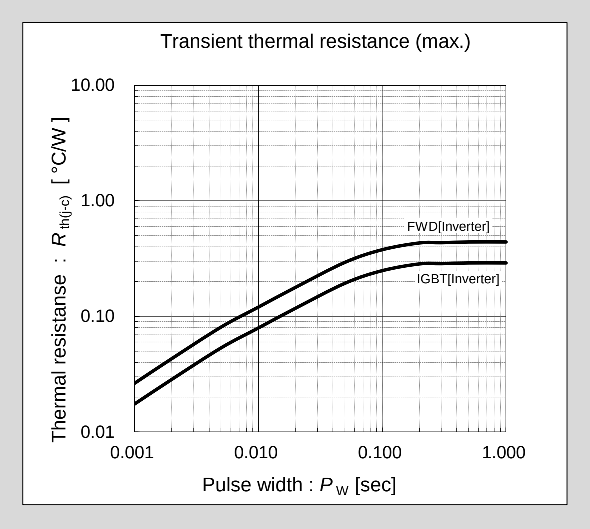

Fig. 2-17 Transient thermal resistance