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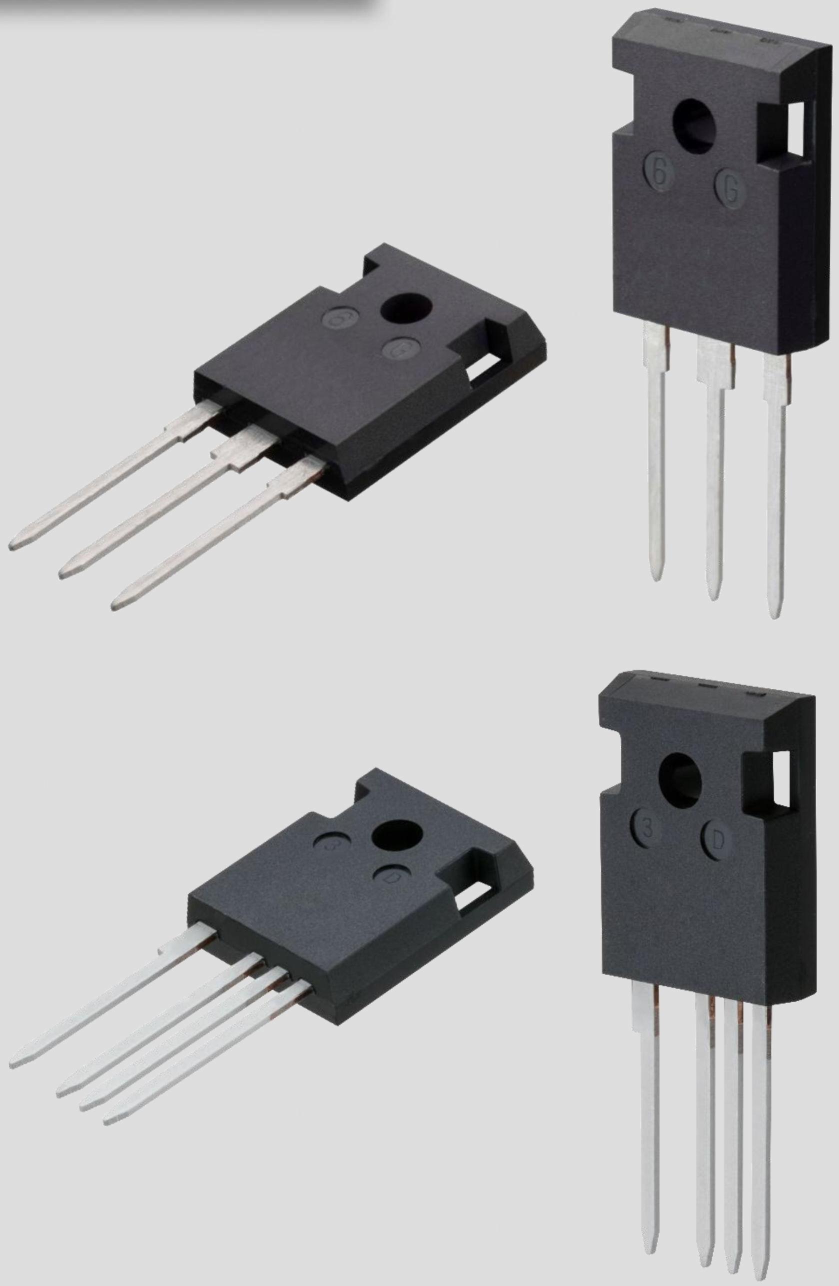

Discrete IGBT

Application Manual

Dec. 2025

Fuji Electric Co.,Ltd.

⚠ Cautions

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Chapter 2 Terms and Characteristics

This chapter describes the terms and characteristics of Discrete IGBTs.

1. Explanation of Terms

Various terms used in the data sheets of XS Series are explained below. Refer to the specifications for details.

Table 2-1 Absolute Maximum Ratings

Term	Symbol	Definitions and explanations (Refer to the specifications of each product for the 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	$I_{C@25}$	Maximum DC collector current of IGBT at T_c=25°C.
	$I_{C@100}$	Maximum DC collector current of IGBT at T_c=100°C.
	I_{CP}	Maximum pulse collector current of IGBT.
Diode forward current	$I_{F@25}$	Maximum DC forward current of FWD at T_c=25°C.
	$I_{F@100}$	Maximum DC forward current of FWD at T_c=100°C.
	I_{FP}	Maximum pulse forward current of FWD.
Collector power dissipation	P_{tot_IGBT}	Maximum power dissipation of IGBT at T_c=25°C.
FWD power dissipation	P_{tot_FWD}	Maximum power dissipation of FWD at T_c=25°C.
Operating virtual junction temperature	T_{vj}	Maximum junction temperature at which the device can operate without abnormalities. (The equipment must be designed so that this value is not exceeded under worst-case conditions.)
Storage temperature	T_{stg}	Temperature range for storage or transportation without being subjected to electrical load.

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 Static electrical characteristics

Term	Symbol	Definitions and explanations (Refer to the specifications of each product for the conditions
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.

Table 2-3 Dynamic electrical characteristics

Term	Symbol	Definitions and explanations (Refer to the specifications of each product for the conditions
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.
Gate charge	Q_G	Amount of charge required to turn-on the IGBT.
Turn-on delay time	$t_{d(on)}$	The time during IGBT turn-on when V_{GE} reaches 10% of its maximum value until collector current reaches 10% of its maximum value. (see Fig. 2-3)
Rise time	t_r	The time during IGBT turn-on when collector current rises from 10% to 90% of its maximum value. (see Fig.2-3)
Turn-off delay time	$t_{d(off)}$	The time during IGBT turn-off when V_{GE} drops from 90% of its maximum value until collector current drops to 90% of its maximum value. (see Fig. 2-3)
Fall time	t_f	The time during IGBT turn-off when collector current drops from 90% to 10% of its maximum value. (see Fig. 2-3)
Turn-on loss	E_{on}	Switching loss generated during IGBT turn-on. (see Fig. 2-3)
Turn-off loss	E_{off}	Switching loss generated during IGBT turn-off. (see Fig. 2-3)

Table 2-4 FWD characteristics

Term	Symbol	Definitions and explanations (Refer to the specifications of each product for the conditions
Forward voltage	V_F	Forward voltage of FWD at a specified forward current.
Diode reverse recovery time	t_{rr}	The time during FWD turn-off when the reverse recovery current crosses 0A until it recovers to 10% of the reverse recovery peak current. (see Fig. 2-4)
Diode reverse recovery charge	Q_{rr}	Amount of charges calculated as the time integral value of the reverse recovery current of FWD.

Table 2-5 Thermal resistance characteristics

Term	Symbol	Definitions and explanations (Refer to the specifications of each product for the conditions
Thermal resistance, junction to ambient	$R_{th(j-a)}$	Thermal resistance between the chip (junction) and ambient without heat sink attached and windless.
Thermal resistance, IGBT junction to case	$R_{th(j-c)\_IGBT}$	Thermal resistance between the chip (junction) and case of IGBT.
Thermal resistance, FWD junction to case	$R_{th(j-c)\_FWD}$	Thermal resistance between the chip (junction) and case of FWD.

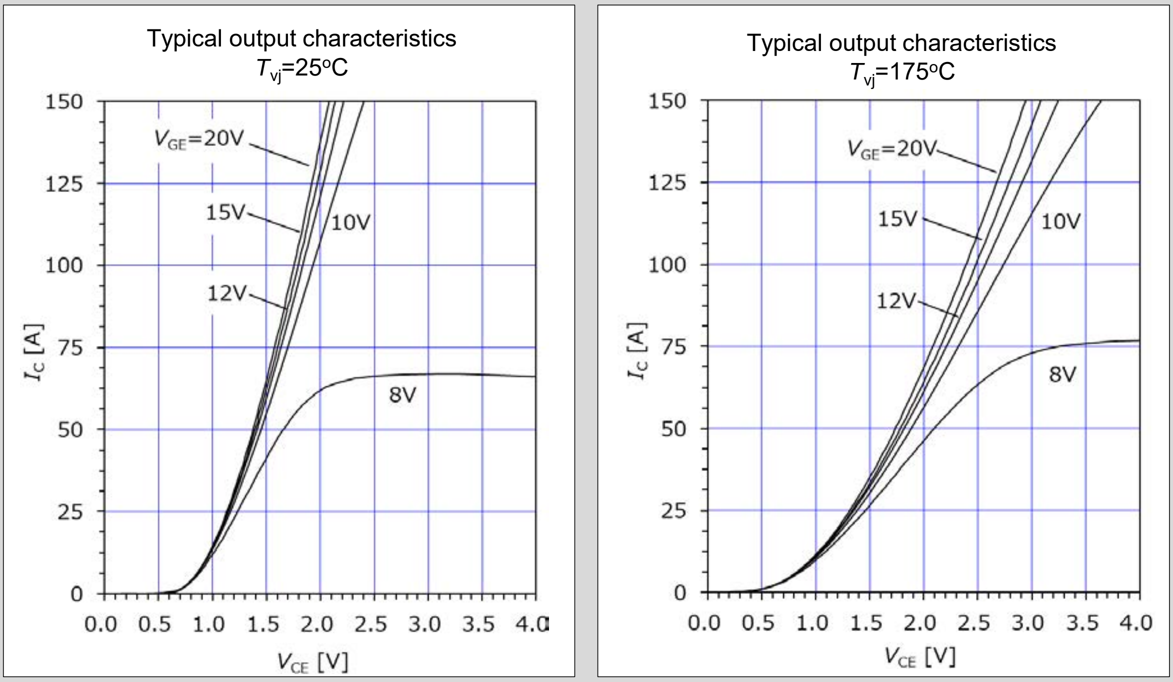
2. Characteristics of IGBT and FWD

Discrete IGBT products are available in two types: products with antiparallel FWD, and products with only IGBT. Using FGZ75XS120C (1200V/75A device) as an example, the various characteristics of IGBT and FWD described in the specifications are explained below.

2.1 Static characteristics

Fig. 2-1 shows the V_{GE} dependence of V_{CE} - I_C characteristics (output characteristics). These curves show the relationship between V_{CE} and I_C when the IGBT is on, and it directly relates to the on-state power loss in the IGBT. Accordingly, the lower the V_{CE}, the smaller the power loss. Because this characteristic varies with virtual junction temperature T_{vj} and gate-emitter voltage V_{GE}, it is necessary to take both into account when designing your equipment.

As a general guideline, we recommend to operate the IGBT at V_{GE}=15V, and the equipment's maximum output peak current lower than the device's rated current.



(a) T_{vj}=25^{o}C

(b) T_{vj}=175^{o}C

Fig. 2-1 V_{CE} - I_C characteristics

2.2 Switching characteristics

Since IGBTs are generally used in switching applications, it is important to thoroughly understand their turn-on and turn-off switching characteristics. Because these characteristics vary with a number of parameters, it is necessary to take them into account when designing your system.

Switching characteristics can be broadly divided into switching times and switching loss. These characteristics are measured using the test circuit shown in Fig. 2-2.

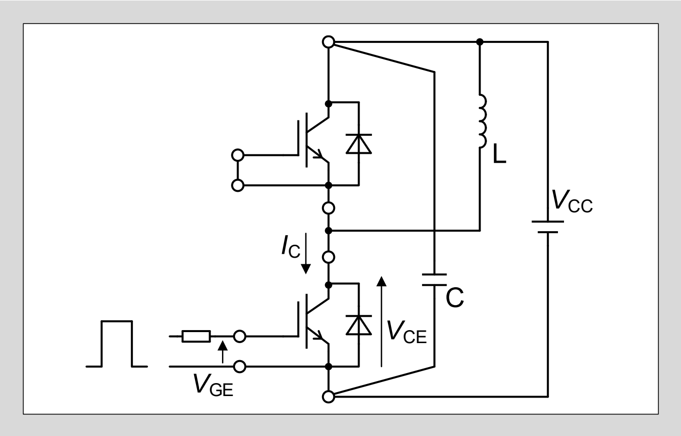


Fig. 2-2 Switching characteristics measuring circuit

Fig. 2-3 and Fig. 2-4 show the definitions of the characteristics $t_{d(on)}$, t_r, $t_{d(off)}$, t_f, E_{on}, E_{off}, and t_{rr} in Table 2-3 and Table 2-4, as well as the definitions of E_{rr} and I_{rr}.

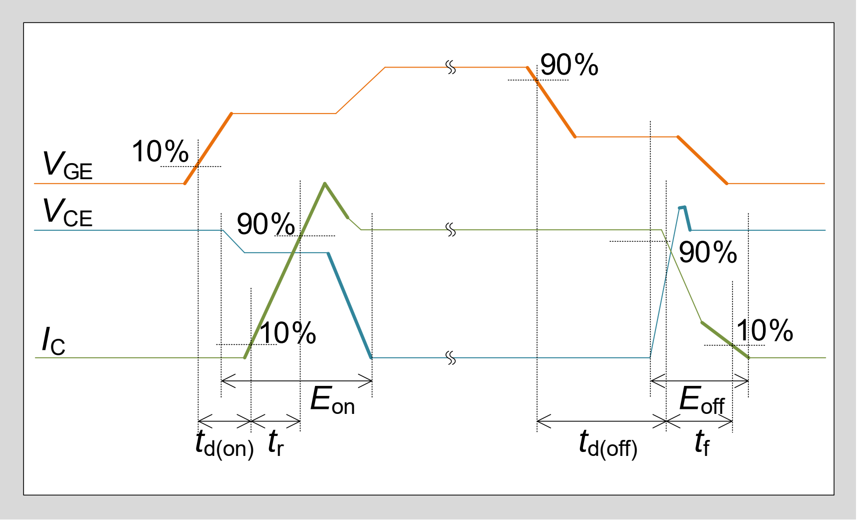


Fig. 2-3 Definition of switching time (turn-on and turn-off waveforms)

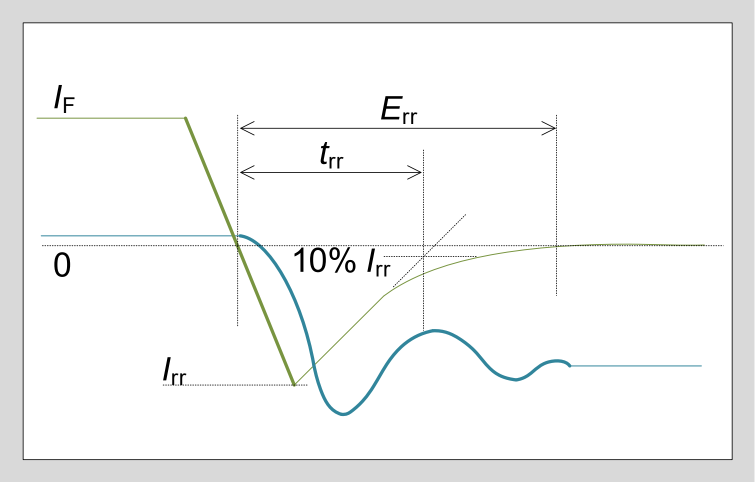


Fig. 2-4 Definition of switching time (reverse-recovery waveform)

Fig. 2-5 shows the relationship between these switching times and the collector current I_C. Fig. 2-6 shows how the switching times vary with gate resistance R_G. Because switching times varies depending on I_C, virtual junction temperature T_{vj} and R_G, it is necessary to take these parameters into account when designing your equipment.

For example, when operating under conditions that increase switching times such as $t_{d(off)}$ or t_f, insufficient dead time can lead to series arm short circuit (refer to Chapter 4 for details), potentially destroying the device. Conversely, if switching times such as t_f is too short, the transient current change rate dI_C/dt will becomes high, causing an excessive surge voltage ($=L_S \cdot dI_C/dt$) from the circuit stray inductance. Since this surge voltage is superimposed on the applied voltage, it can push the device beyond its RBSOA (refer to Chapters 2 and 4 for details), risking device failure.

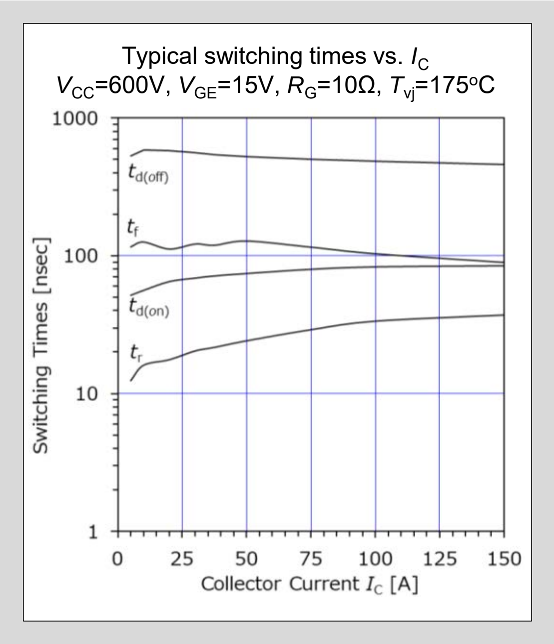


Fig. 2-5 Switching time - I_C characteristics

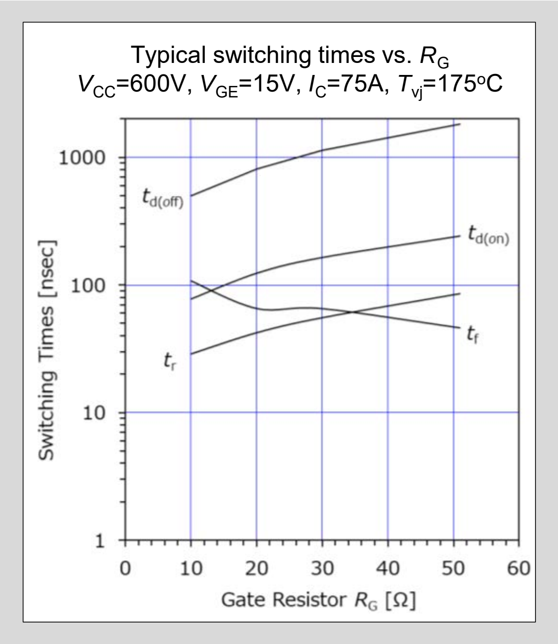


Fig. 2-6 Switching time - R_G characteristics

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. 2-7, 2-8 and 2-9, 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.

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.

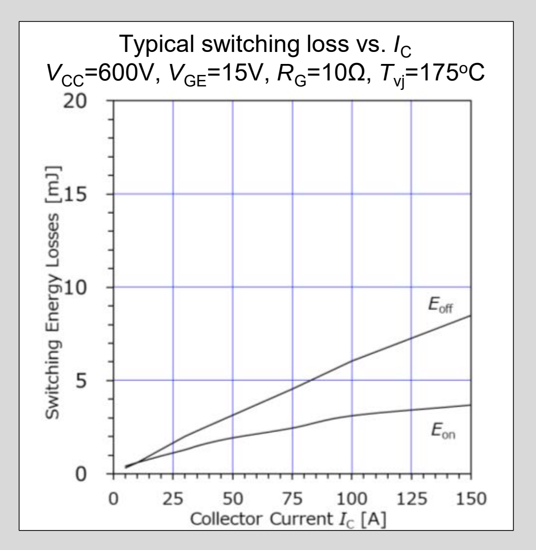


Fig. 2-7 E_{on}, E_{off} – I_C characteristics

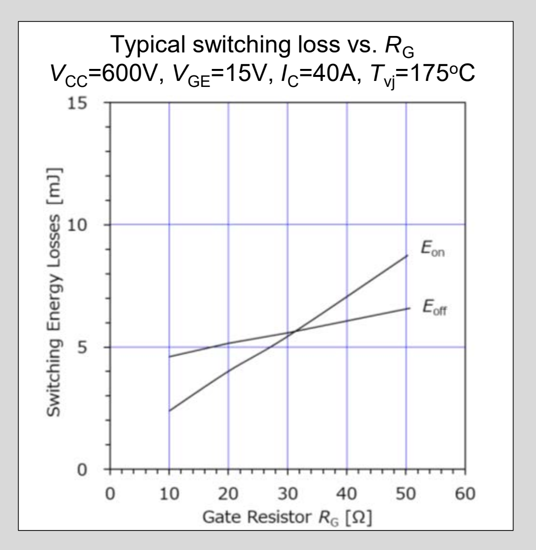


Fig. 2-8 E_{on}, E_{off} – R_G characteristics

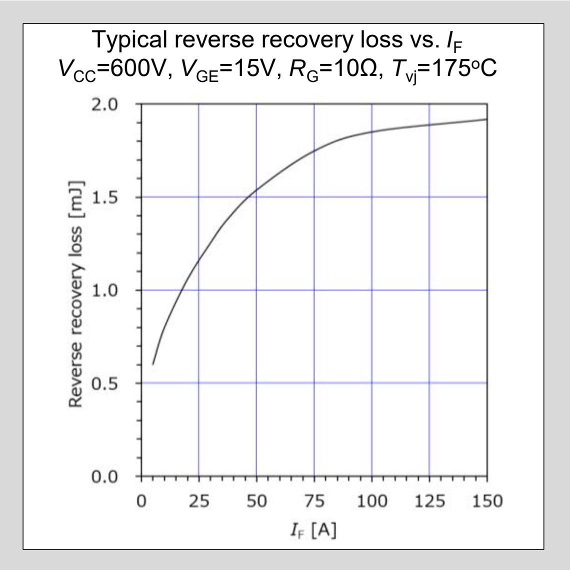


Fig. 2-9 E_{rr} – I_F characteristics

2.3 Capacitance characteristics

Fig. 2-10 shows the characteristics of gate charge Q_g. This characteristic shows the change of V_{GE} with respect to Q_g. An increase in Q_G corresponds to charging the G-E capacitance of the IGBT; as Q_G rises, V_{GE} (= Q_G divided by the G–E capacitance) increases until the IGBT turns on. Once on, V_{CE} falls to the saturation voltage. In this way, Q_G indicates the total charge required to drive the IGBT. Use this characteristic when determining the power supply capacity of the gate-drive circuit.

Fig. 2-11 shows the characteristics of the IGBT's junction capacitances. The specific capacitances C_{ies}, C_{oes} and C_{res} are shown in Fig. 2-12. Use these capacitance characteristics together with the Q_G characteristic when designing your gate drive circuit.

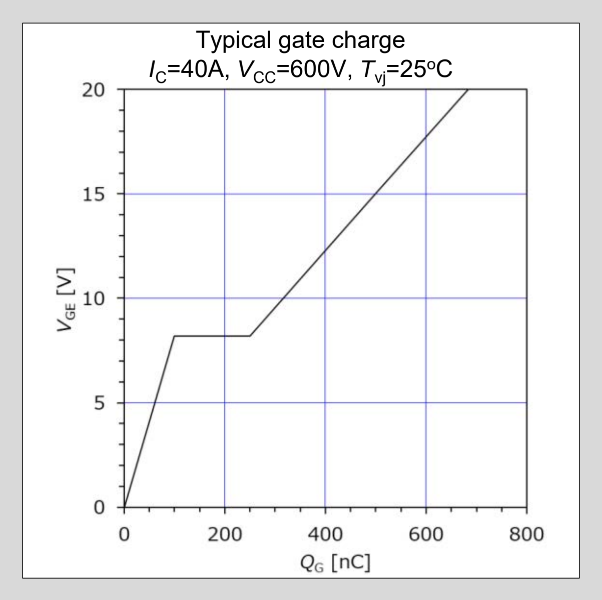


Fig. 2-10 V_{GE} - Q_g characteristics

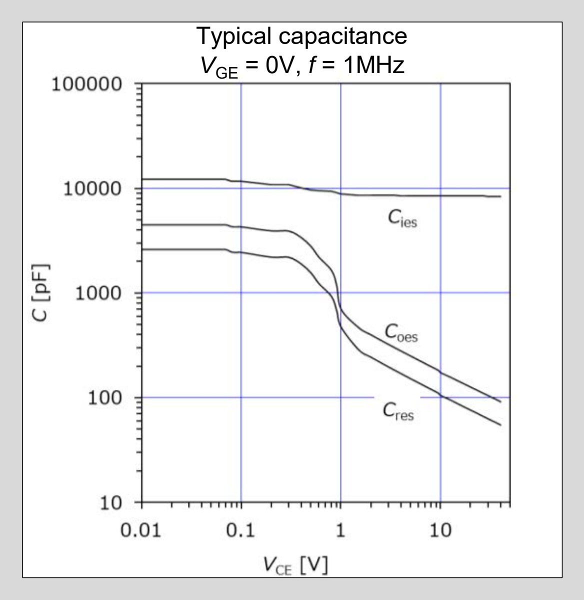


Fig. 2-11 Junction capacitance characteristic

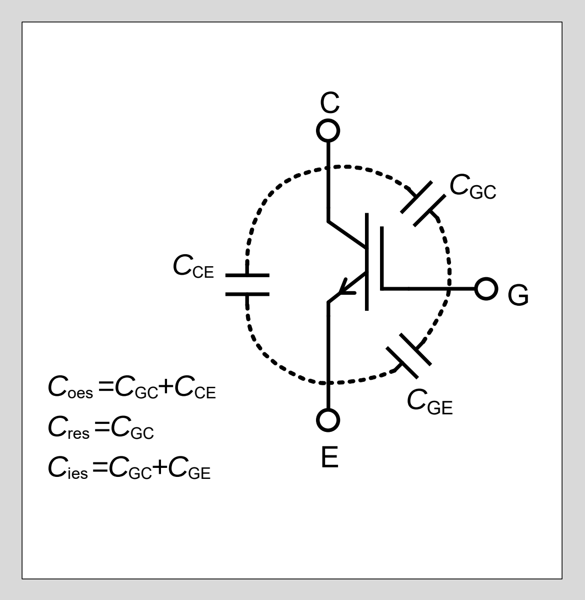


Fig. 2-12 Junction capacitance

2.4 Reverse bias safe operating area

During turn-off, IGBT has a safe operating area defined by V_{CE} and I_C called RBSOA (Reverse Bias Safe Operating Area). Fig. 2-14 shows the area of RBSOA. The operating locus of V_{CE} - I_C at turn-off must be designed to fall within this RBSOA area.

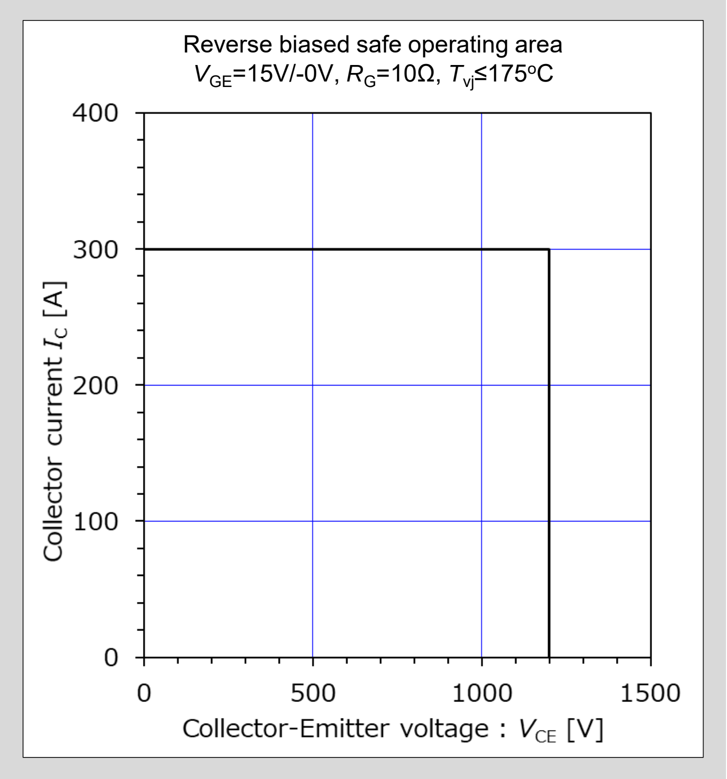


Fig. 2-13 RBSOA

2.5 FWD characteristics

In discrete IGBTs with built-in antiparallel FWD, the FWD has V_F – I_F characteristic shown in Fig. 2-14, the reverse-recovery characteristic (t_{rr}, Q_{rr}) shown in Fig. 2-15, and the E_{rr} characteristic shown in Fig. 2-9. Use these characteristics to calculate the power loss of the FWD as well as the IGBT. Note that FWD characteristics vary in accordance with I_F, T_{vj}, R_G, etc.

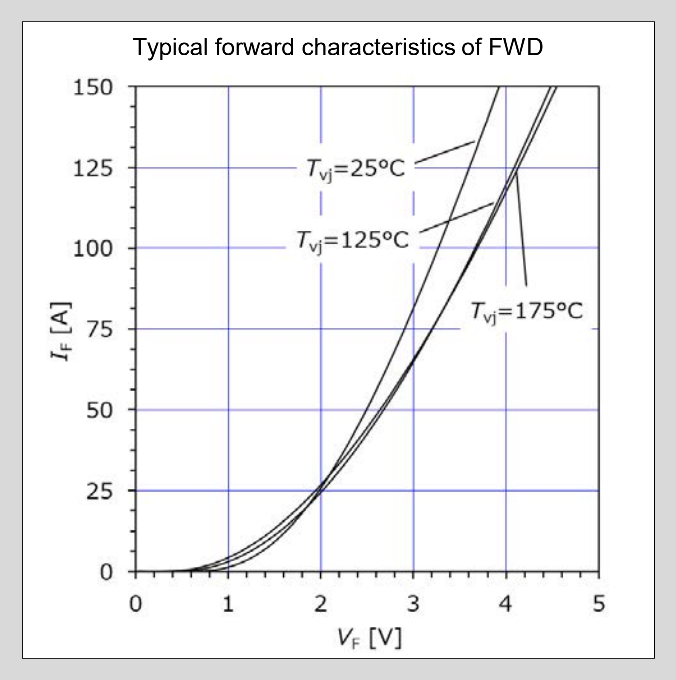


Fig. 2-14 V_F - I_F characteristics

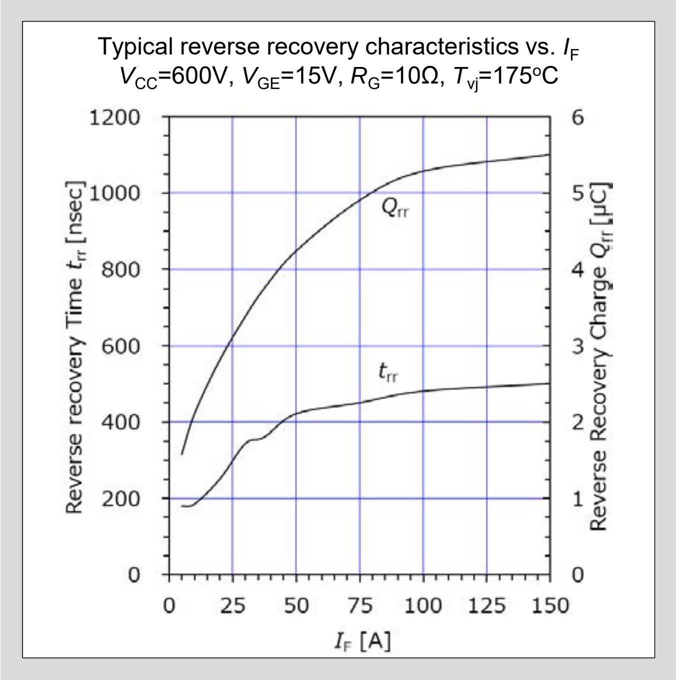
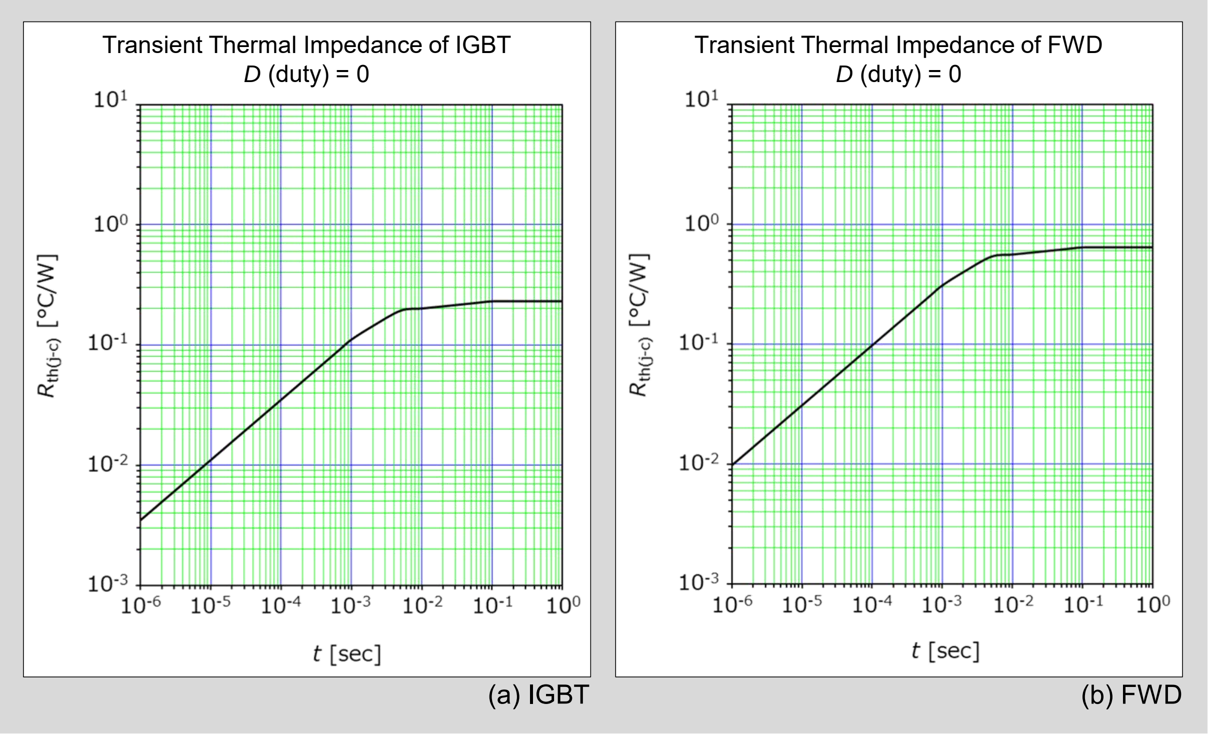


Fig. 2-15 t_{rr}, Q_{rr} characteristics

2.6 Transient thermal impedance characteristics

Fig. 2-16 shows the transient thermal impedance characteristics used for calculating temperature rise and designing the heat sink. These transient thermal impedance characteristics are used to calculate the T_{vj} of IGBTs and FWDs. (For details, refer to Chapter 6, “Cooling Design”)



(a) IGBT (b) FWD

Fig. 2-16 Transient thermal impedance characteristics