Thermal resistance junction to case R_{thjc} per diode

The thermal resistance junction to case R_{thjc} describes the passage of heat between diode chips (index j) and module base plate (index c).

2.3.3 Diagrams

Following the sequence of the datasheets, this chapter will give some hints concerning IGBT datasheet diagrams. In cases where the diagram concerned is detailed in other chapters, this will be referred to.

Maximum total power dissipation P_{tot} of IGBT module versus case temperature T_{case}

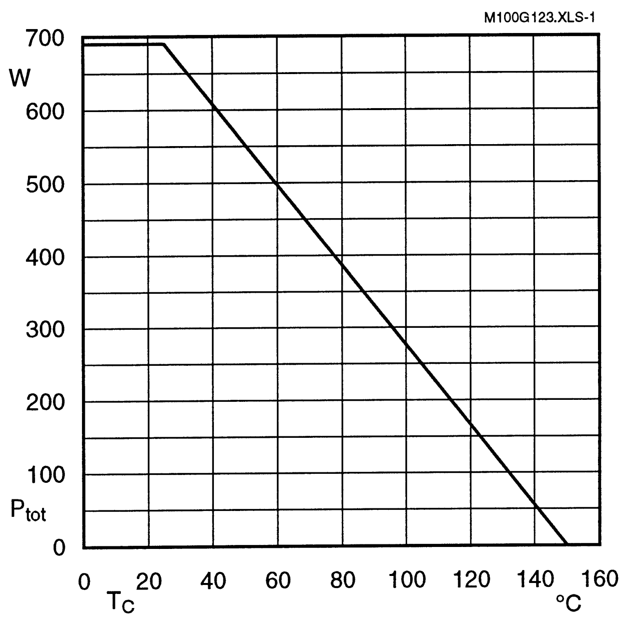


Figure 2.12 Maximum total power dissipation

Based on the maximum total power dissipation per IGBT (or per free-wheeling diode) $P_{tot(25°C)} = (T_{jmax} - 25°C)/R_{thjc}$ which is limited to T_{case} = 25°C per definition, the function depicted in the diagram describes derating at a higher case temperature.

Turn-on/ turn-off energy E_{on}, E_{off} per pulse of an IGBT as function of the collector current I_C

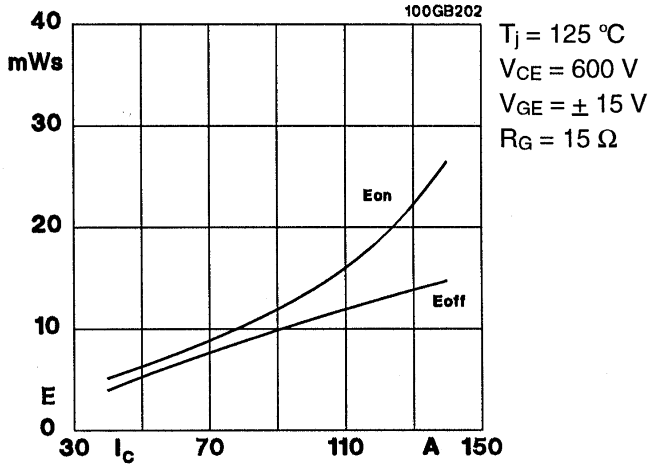


Figure 2.13 Turn-on/ -off energy dissipation as function of I_C

The turn-on/-off energies E_{on}, E_{off} determined from a measuring circuit under ohmic-inductive load are indicated versus different collector currents I_C (e.g. chip temperature T_j = 125°C, collector-emitter supply voltage V_{CC} = 600 V) with specified control parameters.
Switching losses may be determined by multiplying dissipation energy and switching frequency f:

$P_{on} = f * E_{on}$ $P_{off} = f * E_{off}$.

E_{on} and E_{off} are indicated for IGBT at rated current (I_c@ T_{case} = 80°C) in the characteristic values of the datasheet.

Turn-on and turn-off energy E_{on}, E_{off} per pulse of an IGBT as function of the gate series resistors R_G (R_{Gon}, R_{Goff})

see chapter 3.5.2

Maximum safe operating area during switch operation (SOA)

As explained in chapter 1.2.3 the IGBT has to manage an almost rectangular characteristic i = f(u) between V_{CC} and I_L in case of hard switching.
The SOA (**S**afe **O**perating **A**rea)-diagrams indicate to what extent this may be realized during different operations without risk of destruction:

- SOA for switching, on-state and single pulse operation
- RBSOA (Reverse Biased SOA) for periodic turn-off
- SCSOA (Short Circuit SOA) for non-perdiodic turn-off of short circuits (chapter 3.6.2)

The SOA is limited by the following parameters:

- maximum collector current (horizontal limit);
- maximum collector-emitter voltage (vertical limit);
- maximum power dissipation or chip temperature (diagonal limits) see Figure 2.14;

Maximum safe operating area during pulse operation (SOA)

Figure 2.14 shows the maximum curve $I_C = f(V_{CE})$ during switching and on-state for different pulse durations t_p at a double logarithmic scale.

It is important that the maximum ratings are valid at a case temperature T_c = 25°C and for single pulses, which will not heat the IGBT over the maximum chip temperature T_j = 150°.
Although the lowest of the depicted diagonals represents the hyperbola of the maximum stationary power losses P_{tot}, IGBT modules may only touch the linear characteristic area with approximately V_{CE} > 20 V or V_{GE} < 9 V during switching operation. Analogous operation over a longer period of time is not permitted, since asymmetries due to variation among the chips as well as negative temperature coefficients of the threshold voltages might cause thermal instability.

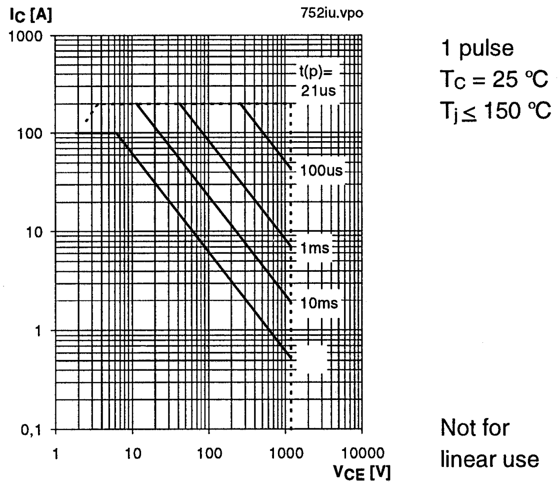


Figure 2.14 Maximum safe operating area $I_C = f(V_{CE})$ during pulse operation (SOA)

Turn-off safe operating area

Figure 2.15 shows the turn-off safe operating area of an IGBT.

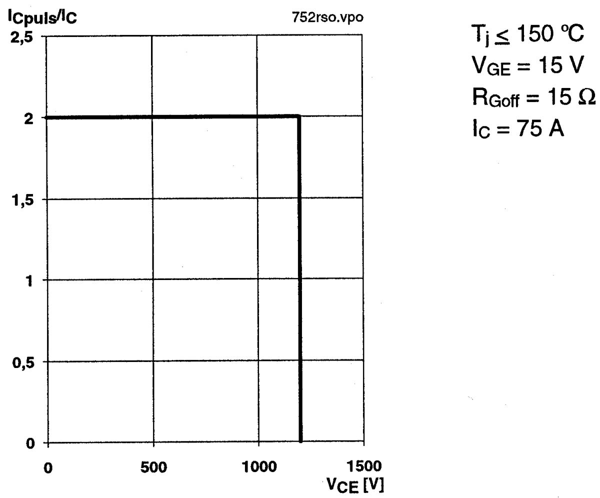


Figure 2.15 Turn-off safe operating area (RBSOA)

During periodic turn-off the IGBT may effect a hard turn-off of I_{CM}@80°C = T_C for T_{jmax} and defined driver parameters, provided that v_{CE} (chip) has reached V_{CES}-level (influence of parasitic inductances and driver parameters, see chapters 3.4.1 and 3.5.2).

Safe operating area at short circuit

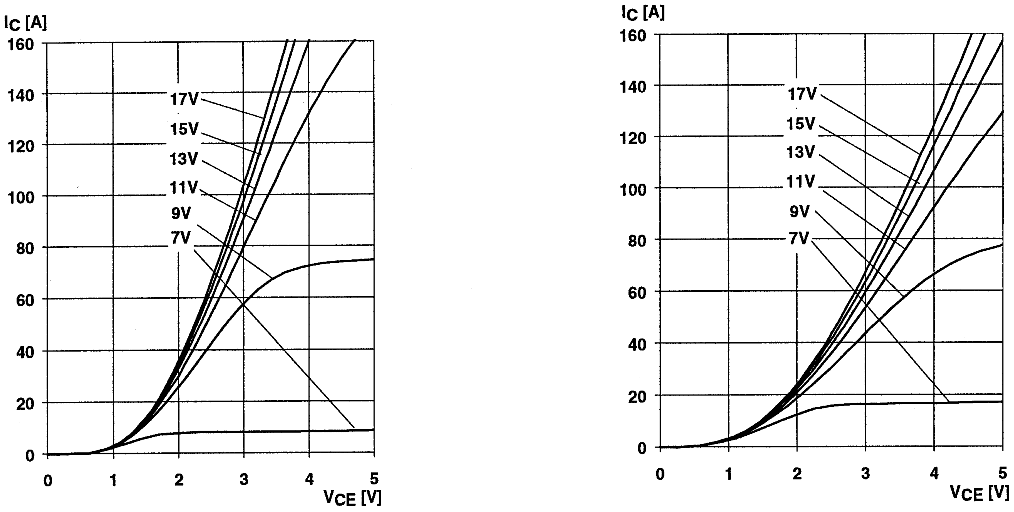
see chapter 3.6.2

Derating of collector current versus case temperature

see chapter 2.6; analogous to Figure 2.23b

Forward output characteristic $I_C = f(V_{CE})$

Figure 2.16 shows the output characteristics for T_j = 25°C and 125°C (typical values) with parameter V_{GE}, also see chapters 1.2.2.2 and 2.6.



a) b)

Figure 2.16 Typical IGBT output characteristic $I_C = f(V_{CE})$ with paramter V_{GE}
a) T_j = 25°C b) T_j = 125°C

Transfer characteristic $I_C = f(V_{GE})$

The transfer characteristic (Figure 2.17) describes the behaviour of the IGBT within the active area at V_{CE} = 20 V and t_p = 80 µs (linear operation). The collector current is coupled with the gate-emitter voltage via transfer transconductance: $I_C = g_{fs} * (V_{GE}-V_{GE(th)})$.

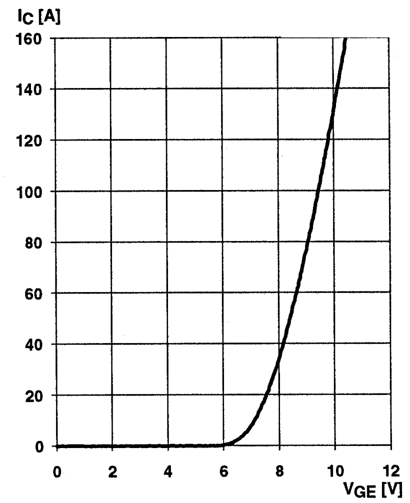


Figure 2.17 Typical transfer characteristic $I_C = f(V_{GE})$

Gate charge characteristic

see chapter 1.2.3

Internal capacitances versus collector-emitter voltage

see chapter 1.2.3

Switching times versus collector current

Figure 2.18 shows typical dependencies of switching times $t_{d(on)}$ (turn-on delay time), t_r (rise time), $t_{d(off)}$ (turn-off delay time) and t_f (fall time) on the collector current I_C during hard switching of inductive loads.

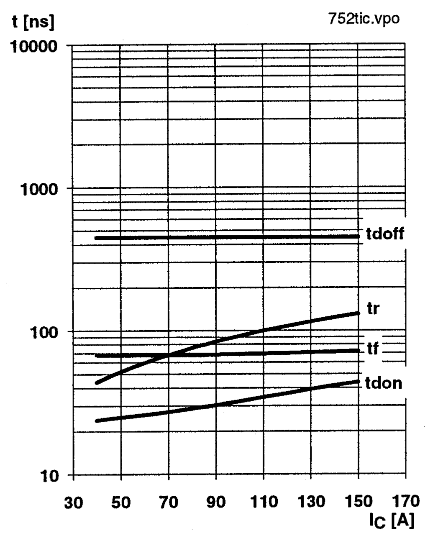


Figure 2.18 Typical dependency of switching times on collector current (inductive load)

The slightly overproportional increase of t_r verifies that di_C/dt does not increase to the same extent as I_C when the collector current rises.

Switching times versus gate resistor

see chapter 3.5.2

CAL diode forward characteristic

see chapter 1.3.1.1

Diode turn-off energy dissipation

Figure 2.19 demonstrates the dependency of the diode turn-off energy E_{offD} on the diode current I_F conducted before turn-off, and on the turn-on speed of the IGBT determined by gate resistance R_G, during current commutation between free-wheeling diode and IGBT (hard switching).

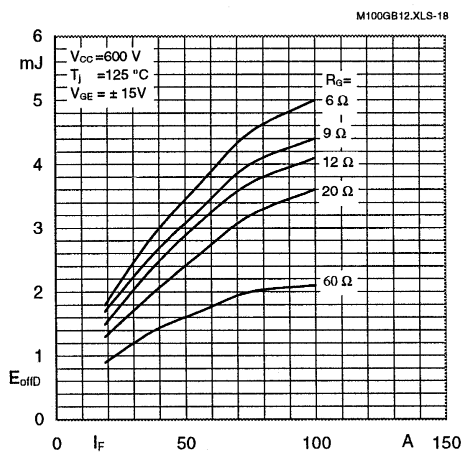


Figure 2.19 Diode turn-off energy dissipation E_{offD} versus collector current I_C and gate resistance R_G

As expected, the diode turn-off losses increase with the forward current as well as with the rate of rise of commutation current due to a simultaneous rise of storage charge and reverse current amplitude (see chapter 1.3.1.3).

Transient thermal impedances of IGBT and free-wheeling diode

see chapter 3.2.2.3

Free-wheeling diode reverse recovery current as function of forward on-state current

Figure 2.20 shows typical values of the peak reverse recovery current I_{RRM} versus forward current I_F and di/dt determined by the gate resistance $R_G = R_{Gon}$.

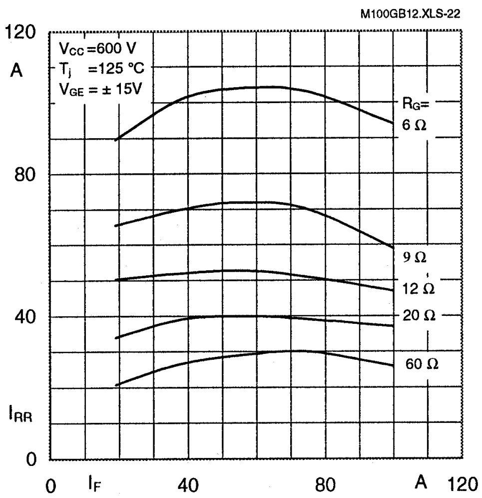


Figure 2.20 Typical peak reverse recovery current I_{RRM} of free-wheeling diode versus I_F and R_G

As expected, the peak reverse recovery current is higher, the faster the IGBT is switched on (low R_{Gon}).
At first, the reverse recovery current will increase together with rising forward current. If high collector currents are applied, the share of charge carriers in the CAL-diode drift area, which already re-combine during commutation, will increase with the duration of commutation; therefore, I_{RRM} will again drop in the high current range.

Free-wheeling diode reverse recovery current as function of di_F/dt

Figure 2.21 depicts the typical dependency of the free-wheeling diode reverse recovery current I_{RRM} on di/dt, determined by control of the given gate resistances $R_G = R_{Gon}$ of the IGBT on the measuring conditions indicated.

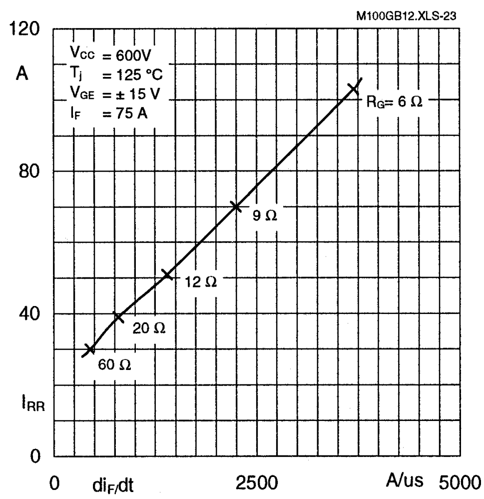


Figure 2.21 Typical free-wheeling diode reverse recovery current I_{RRM} versus di/dt and R_G

The reverse recovery current increases almost linearly to di/dt.