Free-wheeling diode recovered charge as function of di_F/dt

Figure 2.22 shows the typical dependency of the free-wheeling diode recovered charge Q_{rr} on di/dt for different collector currents I_C. In addition, the gate resistances $R_G = R_{Gon}$ have been entered which determine the given di/dt on the measuring conditions indicated.

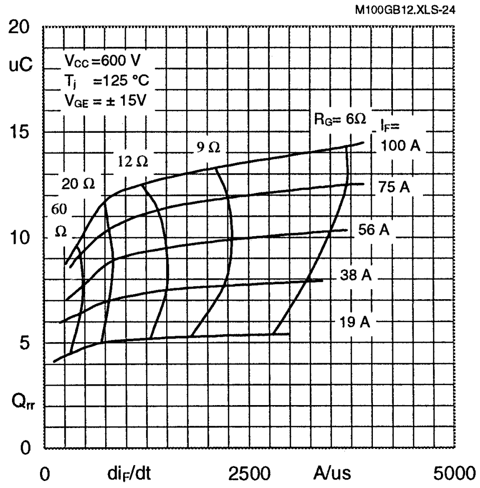


Figure 2.22 Typical free-wheeling diode recovered charge versus di/dt, R_G and I_C

Just like the reverse recovery current, the free-wheeling diode recovered charge will rise together with the collector current and di/dt. The rate of rise will be more distinct for high collector currents than for the low current range.

Rated collector current at short circuit as a function of gate-emitter voltage and temperature

see chapter 3.6.2

2.4 Special parameters for MiniSKiiPs

Apart from IGBTs and diodes for inverters and brake choppers diodes (or thyristors) for input rectifiers are also integrated in the MiniSKiiP.
Supplementary to forward and blocking characteristics (maximum ratings, characteristics), the follwing parameters are specified for MiniSKiiPs:

Rectifier diode surge forward current I_{FSM}

Peak value of a sinusoidal wave 50 Hz, which the diode is able to withstand without being damaged in the case of breakdown, if this does not occur too often.

Rectifier diode peak load integral $\int i^2dt$

Reference parameter for the selection of fuses to be calculated as follows:
$\int i^2dt = I_{FSM}^2 * T/4 = 5*10\text{-}3s * I_{FSM}^2$ (@ f = 50 Hz)

Resistance/ temperature coefficient of the temperature sensor

Features of current sensors

2.5 Special parameters for SKiiPPACKs

SKiiPPACK datasheets have to include for example:
- static/dynamic maximum ratings and characteristics of IGBT and free-wheeling diode chips;
- thermal characteristics (including heatsink);
- indications on isolation voltage of module and of all potential separations;
- indications on threshold values of protective function;
- input level, output performance and delay times of the driver and
- indications on features related to mechanical stress and climate conditions.

Therefore, SKiiPPACK datasheets are much more complex, although, on the other hand, all indications concerning the dependency of parameters on different driver conditions may be ignored.

2.6 Temperature dependency of static and dynamic characteristics of power modules

Almost all electrical characteristics of IGBTs, power MOSFETs and free-wheeling diodes are more or less dependent on the chip temperature.
The following table reflects the characteristic tendencies of the most important component parameters at rising temperature (<: rises; <<: rises steeply; >: falls; -: no notable temperature dependency).
The special features marked with * are only valid for PT-IGBTs.
For dimensioning in practice, the parameters marked with **!**, which will be detailed later on, are of main importance due to their distinct dependency on the temperature. For the temperature dependency of the parameters of free-wheeling diodes please refer to the explanations under chapter 1.3.

Parameter	**MOSFET**	**IGBT**	**Free-wheeling diode**
Avalanche breakdown voltage	<	<	<
Blocking current, blocking power dissipation	<	<	<
Turn-on resistance/forward on-state voltage, forward power dissipation	<<!	<(>*)!	>
Turn-on time/energy dissipation during turn-on	<	<	-
Turn-off time/energy dissipation during turn-off	<	<(<<*)!	<<
Threshold voltage	>	>	>
Forward transconductance	>	>	-

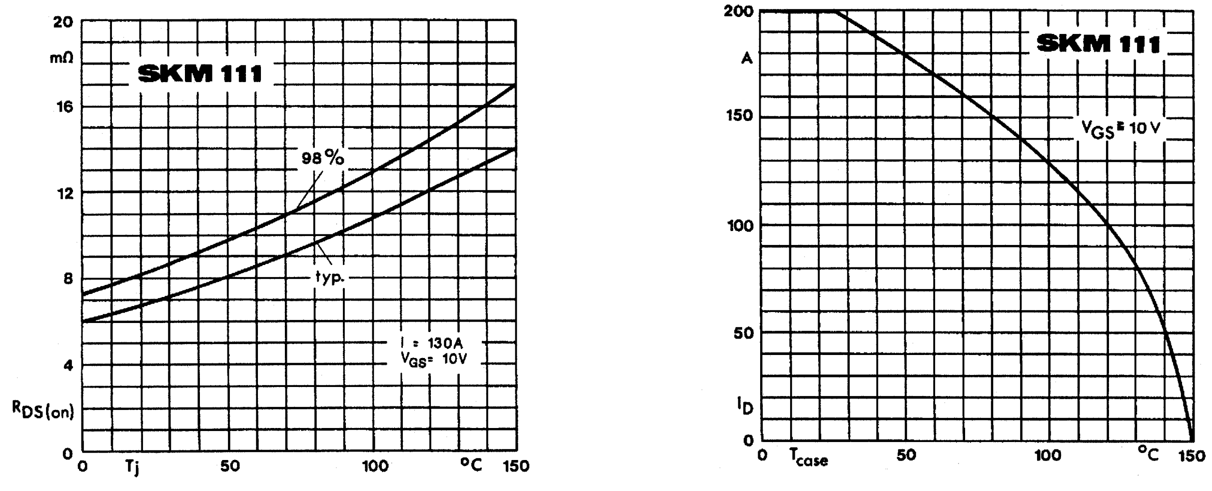
For the interpretation of the parameters indicated in the datasheets it should be taken into consideration that many ratings for power MOSFETs and IGBTs are related to a case temperature of 25°C and have still to be converted to the maximum operating temperature by means of other indicated parameters.
This goes mainly for the maximum permissible drain or collector current I_D, I_{DM}, I_C, I_{CM} and the maximum power dissipation P_{tot} or P_D, respectively, which have to be reduced to ratings under realistic operating conditions as described in chapter 3.1.2.
The required current reduction is determined by the forward and blocking power dissipations which are also temperature-dependent, as well as by the switching losses.

The fact that *blocking current and blocking power dissipation* will increase by factor 3...6 between 25°C and 125°C is of only minor importance for dimensioning, because the blocking power dissipation contributes to only a small share of total power dissipation.

In contrast to this, the forward on-state temperature dependency is of major importance, which, therefore, shall be examined separately for the single components:

Power MOSFET

Figure 2.23 shows the increasing on-resistance $R_{DS(on)}$ of a power MOSFET and the resulting over-proportional derating of the continuos drain current I_D at higher temperatures with an example.



a)

b)

Figure 2.23 Forward on-state behaviour of a 100 V power MOSFET versus temperature
a) On-resistance $R_{DS(on)}$ b) Continuous drain current I_D derating

$R_{DS(on)}$ is doubled within the operating temperature range of 25...150°C; at T_{case} = 80°C only 75 % of the maximum drain current I_D can be utilized even under static conditions.
On the other hand, the positive temperature coefficient of the forward on-state voltage offers advantages such as simplified paralleling ability and high resistivity during hard switching.

IGBT

The various concepts of IGBTs (PT/NPT, see chapter 1.2.1) also differ in their thermal behaviour.
This is explained in Figure 2.24 with the basic characteristic of the collector-emitter saturation voltage V_{CEsat} over the collector current I_C at a chip temperature of 25°C and 125°C.

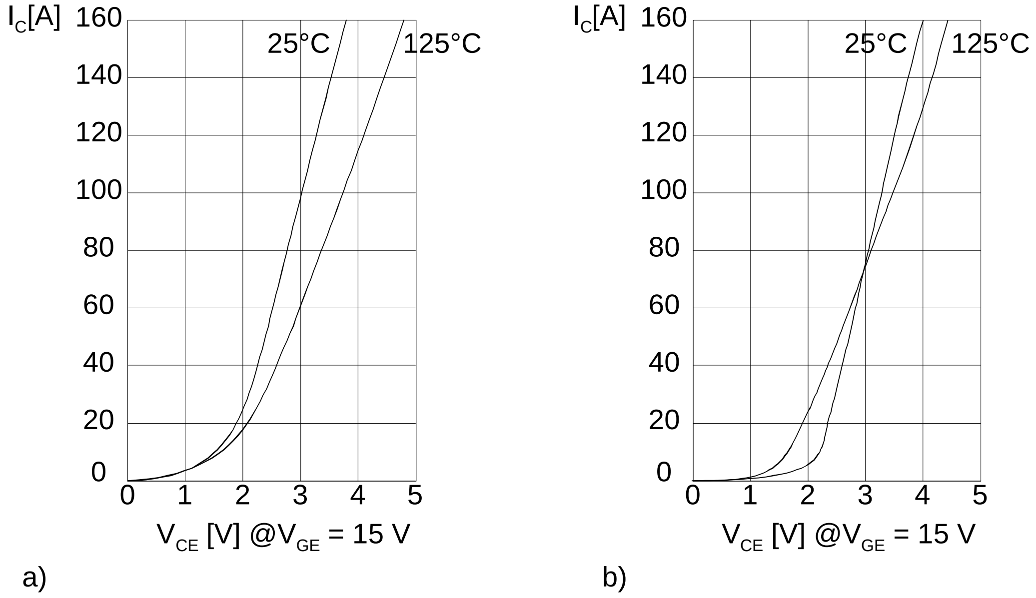


Figure 2.24 Forward characteristics of IGBTs
a) SEMITRANS NPT-IGBT 100A@25°C b) PT-IGBT 100A@25°C

The temperature coefficient of the forward on-state voltage V_{CEsat} of the NPT-IGBT is positive for the whole current (approx. 8 mV/K at I_C@25°C). The temperature coeffcient of V_{CEsat} of the PT-IGBT, however, is negative for the actually utilized forward current range and rises to zero only when rated current has been approximated.
The resulting consequences for NPT-IGBTs compared to PT-IGBTs are higher forward power dissipation on the one hand, and a better current symmetry on the other hand (homogeneous temperature spreading/ ruggedness, unselected paralleling ability).

The I_C-derating characteristic versus temperature analogous to Figure 2.22b is included in the IGBT-datasheets as well.

As already mentioned, MOSFET and IGBT *switching times and switching losses* will also increase when the temperature rises.
However, since dimensioning for “hot“ chips has to be done in practice anyway, most ratings included in the current datasheets are taken at 125°C .

In this respect, another difference between NPT- and PT-IGBTs should be referred to (Figure 2.25, see chapters 1.2.1 and 1.2.3)

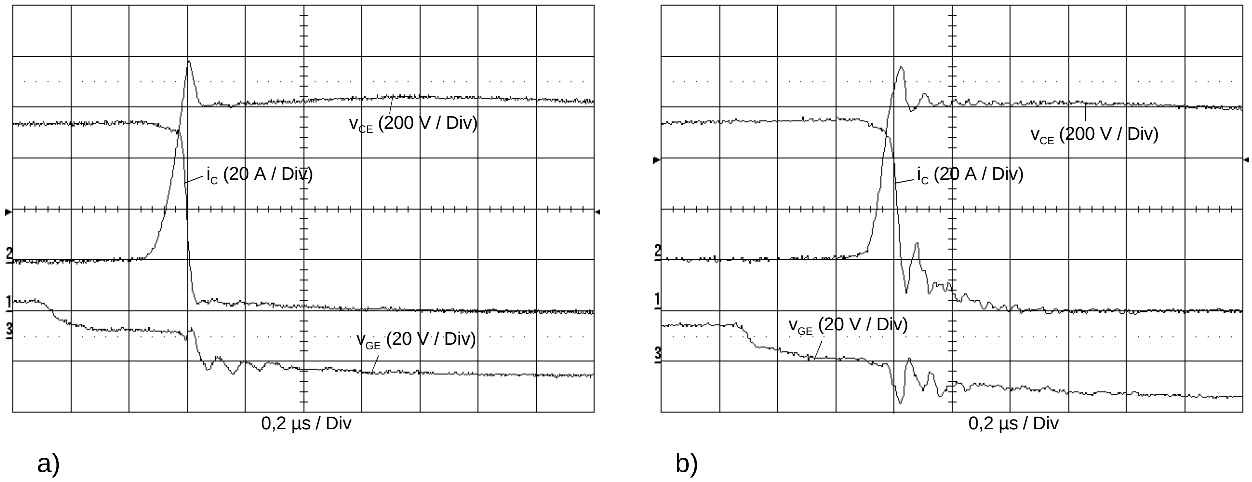


Figure 2.25 Turn-off behaviour of IGBTs
a) SEMITRANS NPT-IGBT b) PT-IGBT

The tail current I_t generated during turn-off will increase together with the temperature. Whereas the tail current of an NPT-IGBT will have risen by almost 100 % at 125°C compared to 25°C (Figure 2.25a), the tail current of PT-IGBT (Figure 2.25b) will be almost tripled within this temperature range. This results in clearly reduced switching losses of NPT-IGBTs at high temperatures compared to PT-types.

The minor temperature dependency of *threshold voltage and forward transconductance* has practically no importance for switching operation. But it is a basic restriction to linear operation of power modules.

2.7 Reliability

Reliability, i.e. maintaining the promised characteristics over a defined period of time, is one of the most important quality features of power modules.
On the one hand, power modules are outstanding for their high electrical and thermal efficiency; on the other hand, premature failure may cause danger, direct and consequent damage and, last but not least, high costs.
Reliability is very difficult to express due to comparably small lots, often extreme long life requirements (10...30 a) and complex test specifications, but may be defined by

- exact control of all influences on production processes (built-in reliability),
- reliability testing under conditions very close to the application in order to discover typical failure mechanisms,
- testing of the components within the system and control of the most important parameters. [231]

Some selected tests for power modules are shown in the following without going into details of the extensive EN ISO 9001 quality assurance system, based on which SEMIKRON is able to grant a 2 year TQM warranty on all its power semiconductors.

The following standard tests are being carried out for release and re-qualification of MOSFET and IGBT modules still to become finalised by further, individual product-specific reliablity testing:

Test	Standards	Test conditions
High temperature blocking voltage (HTRB)	DIN 41749, IEC 147-4	1.000h, V_{DSmax}, V_{CEmax}, T_{jmax}
Hot gate stress	DIN 45930, CECC 50000-4, 5.2	1.000h, V_{GSmax}, V_{GEmax}, T_{jmax}
High temperature storage	DIN 45930, CECC 50000-4, 4.3	1.000h, T_{stgmax}
Low temperature storage		1.000h, T_{stgmin}
Humidity temperature blocking	DIN 45930, CECC 50000-4, 4.3	1.000h, 85°C, 85 % relative humidity. V_{CE}, V_{DS} = 0.8 V_{CEmax}, V_{DSmax} ; ≤ 80 V
Temperature cycling	DIN IEC 68-2-14-test Na	100 temperature cycles T_{stgmax}/T_{stgmin}
Power cycling	DIN 41794, IEC 147-4	20.000 cycles, ΔT_j=100 K
Solder temperature	DIN IEC 68-2-20, test Tb	260±5°C, 10±1 s
Solderability	DIN IEC 68-2-20, test Ta	235±5°C, aging 3
Vibration/ acceleration	acc.to DIN IEC 68-2-6,test F_c	5 g

The following failure criteria according to standard MIL-STD-19500 are valid:

Gate-drain-/gate-emitter leakage current I_{GSS}, I_{GES}: > ± 20 nA or >100 % of initial rating

Zero gate voltage drain current or
collector-emitter cut-off current I_{DSS}, I_{CES}: > ± 100 µA or >100 % of initial rating
(max. 2x of specified max. rating)

On-resistance/forward voltage $R_{DS(on)}$, V_{CEsat}: > 120 % of initial rating

max. change of threshold voltage $V_{GS(th)}$, $V_{GE(th)}$: >± 20 % of initial rating

Thermal resistance junction to case R_{thjc}: > 120 % of initial rating

Isolation test voltage V_{isol}: < specified maximum rating

Figure 2.26 and Figure 2.27 show examples for test procedures depicting measuring circuits and procedures for temperature cycling and power cycling.

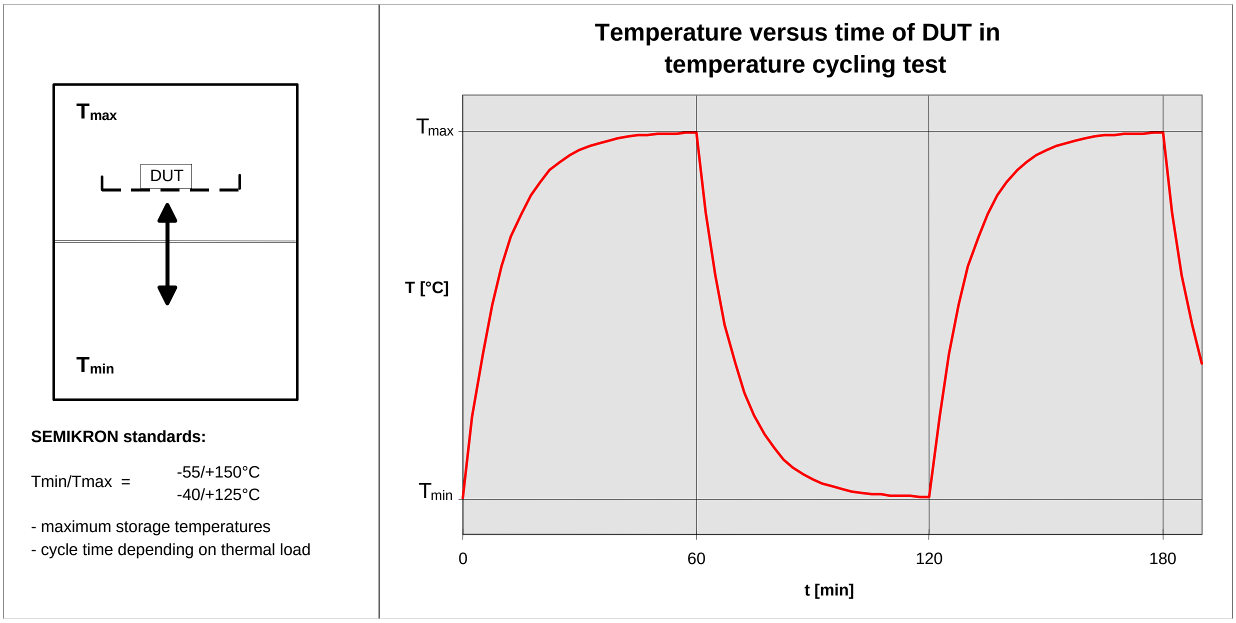
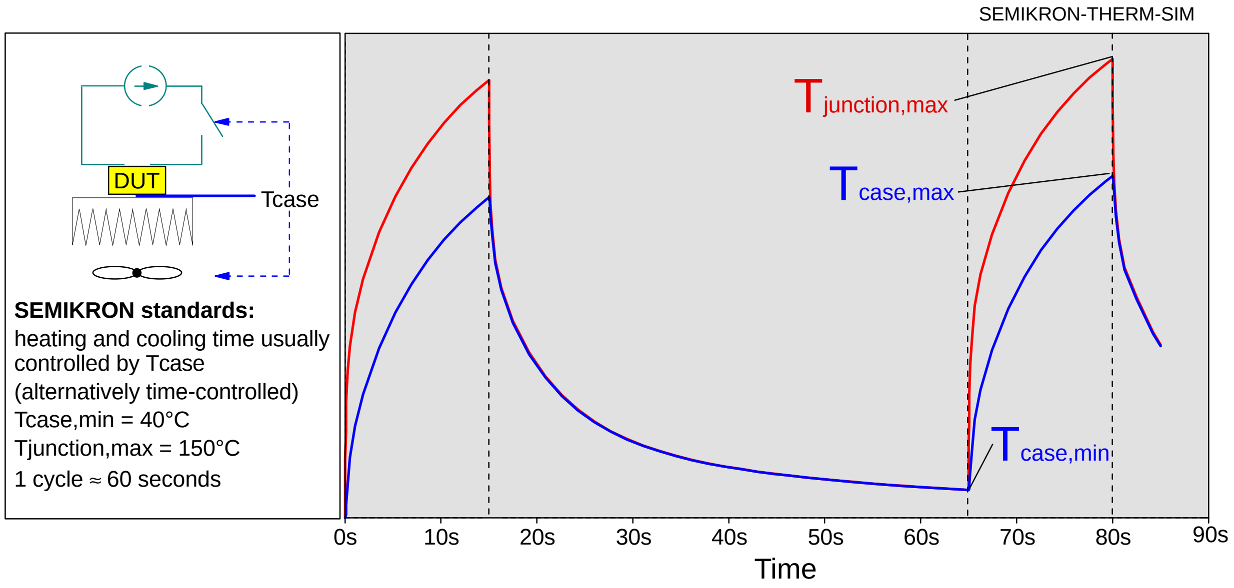


Figure 2.26 Temperature cycling: measuring circuit and measuring procedure



SEMIKRON standards:
heating and cooling time usually controlled by Tcase
(alternatively time-controlled)
Tcase,min = 40°C
Tjunction,max = 150°C
1 cycle ≈ 60 seconds

Figure 2.27 Power cycling: measuring circuit and measuring procedure

Principal characteristics of power modules related to reliability may be checked by means of temperature and power cycling testing, see also chapter 1.4.2.4. Therefore, these tests are of decisive importance for the qualification of modules.