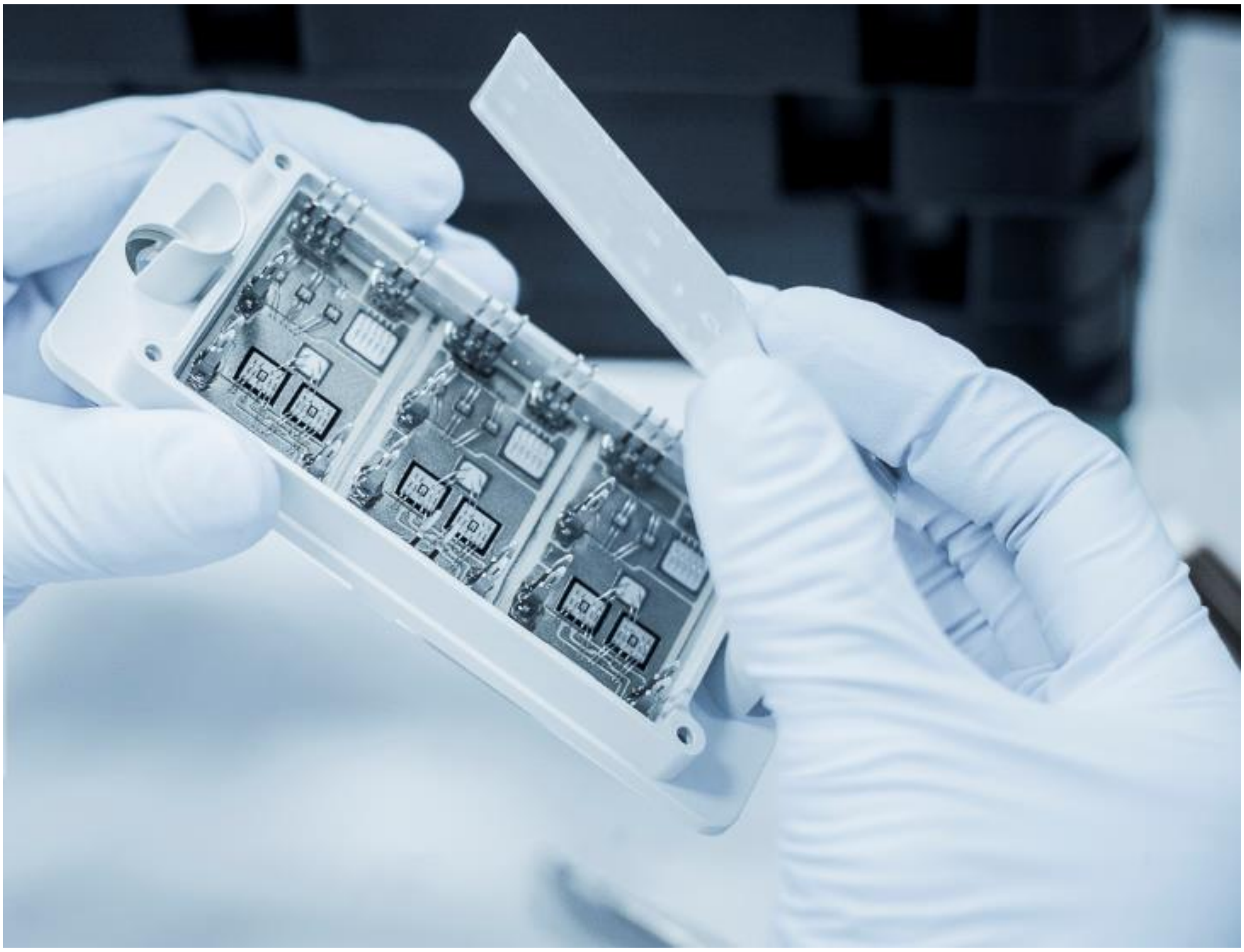
Power module datasheet explanation

Explanation and measurement of datasheet values



Date	Revision Level	Description	Page Number(s)
7/28/2020	1	Initial release	118

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1 Abstract

Designers of power electronic applications such as frequency inverters are guided by documents like datasheets or handling instructions that show the electrical boundaries of the devices or give hints and recommendations for mechanical and thermal dimensioning.

This document explains conditions and data sources used in Vincotech's datasheets, application sheets and handling instructions and gives also hints for the design.

2 Introduction and general overview of the datasheet

The content of the datasheet is in the following order:

- Main page (features, 3D picture, simple schematic, etc.)
- Max ratings
- Characteristic values
- Characteristics (graphs)
- Switching definitions
- Module section (ordering code, outline, detailed schematic, ID table, packaging)
- Document section (handling, UL information, modifications, disclaimer)

2.1 Header and Footer

Vincotech

10-0B066PA010SB-M993F09
datasheet

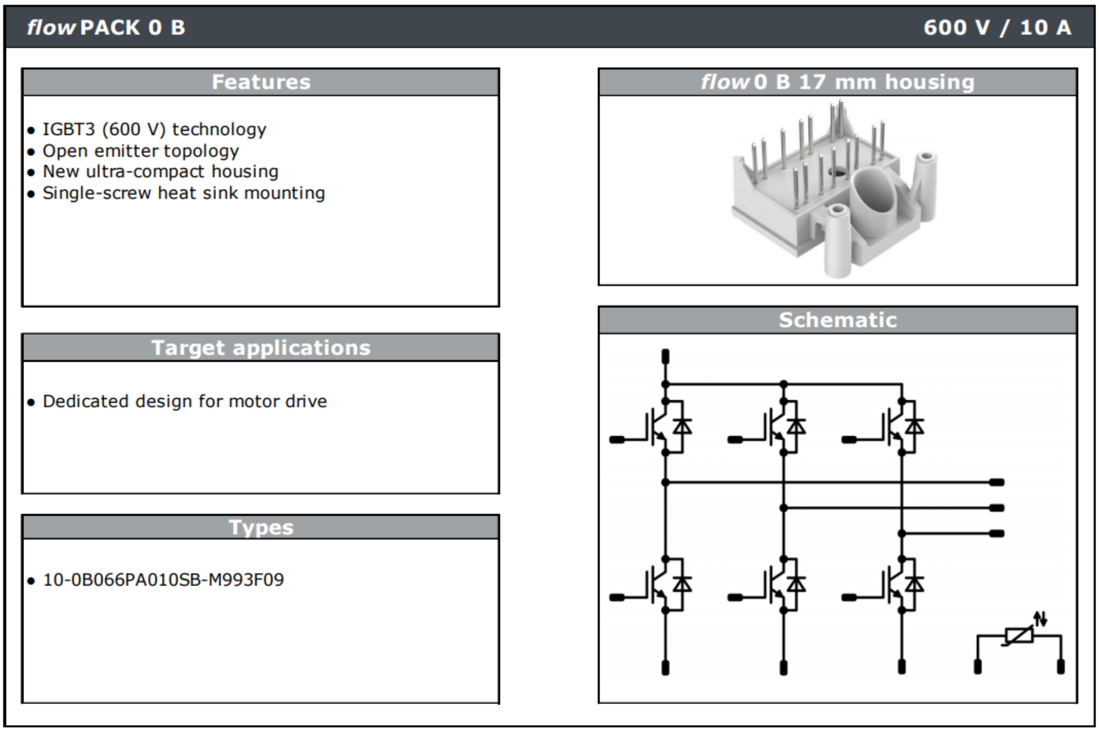
The header contains Vincotech’s logo. On the right, the module name is shown above the text “datasheet”.

Copyright Vincotech | 1 | 23 Jun. 2017 / Revision 3

In the footer, information on page number, revision and copyright holder can be found. The revision is always an integer number. The date is written in the following format: DD MM YYYY

2.2 Main page

The main page has a border with the product line and nominal values of the module is defined by the main components or system voltage marked in the header.



Vincotech

2.2.1 Features and target applications

The “Features” text box shows the key features of the technology, topology and the housing. The “Target applications” text lists target applications for which dedicated products can be found.

2.2.2 Housing

The header contains the Vincotech’s housing construction with its heights. The main page right upper corner section represents the 3D picture of a housing.

2.2.3 Schematic

It represents the topology of a module without functions.

2.2.4 Types

The name of the product(s).

2.3 Max. ratings

The maximum ratings have a common structure for each component, including a common header.

Maximum Ratings

T_j = 25 °C, unless otherwise specified

Parameter	Symbol	Condition	Value	Unit

2.4 Module properties

Module properties are placed in the maximum ratings section which contains the thermal properties and isolation properties.

Module Properties

Thermal Properties				
Storage temperature	T_{stg}		-40...+125	°C
Operation temperature under switching condition	T_{jop}		-40...(T_{jmax} - 25)	°C
Isolation Properties				
Isolation voltage	V_{isol}	DC Test Voltage* t_p = 2 s	6000	V
		AC Voltage t_p = 1 min	2500	V
Creepage distance			min. 12,7	mm
Clearance			9,08	mm
Comparative Tracking Index	CTI		≥ 600	

*100 % tested in production

2.5 Characteristic values

The characteristic values have a common structure for each component, including a common header.

Characteristic Values

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	

Each component can have static, dynamic and thermal values.

2.6 Characteristics (Graphs)

The figures have sequential numbering in the header, restarting from 1 for each components. Figures also have a short explanation and a function form of the plotted characteristics.

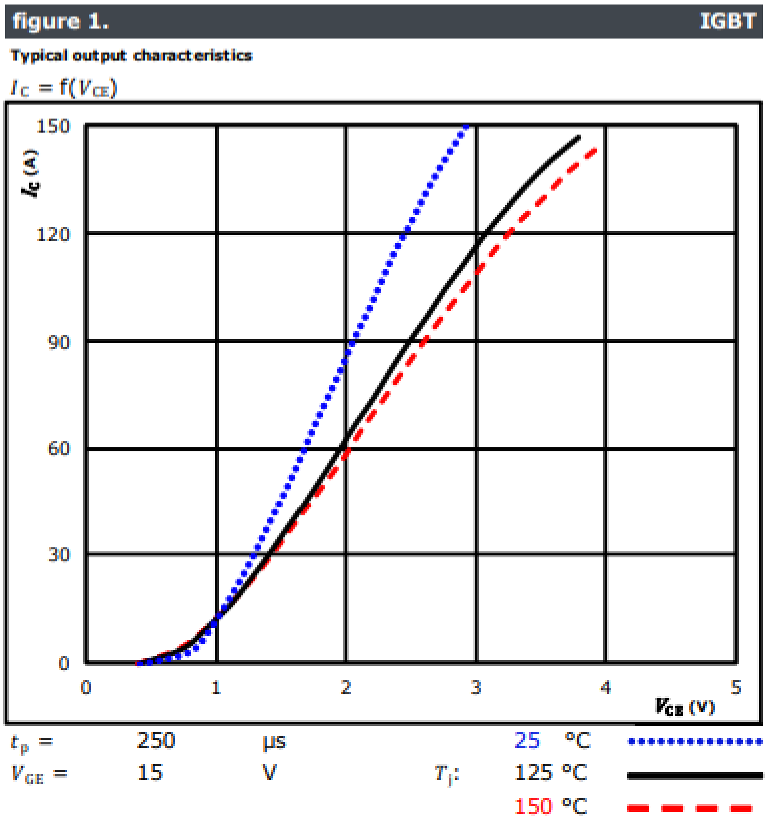


Figure 1: Typical output characteristics

Each figure has its own characteristics with given conditions. Conditions can be found below the plot or as an additional information inside the plot area or on the curve itself. All axis have labels describing the plotted attribute.

2.7 Switching definitions

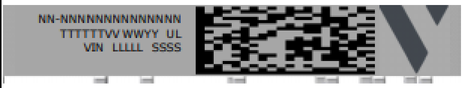
The "switching definitions" section describes the measurement evaluation methods for the direct and derived parameters. All figures are generic figures for each switch type (IGBT, MOSFET). They explain Vincotech´s switching evaluation method which is not in all cases aligned with IEC standard recommendations.

2.8 Module section

The purpose of this section is to show the general properties of the module. These parts provide an overview of the electrical and mechanical features of the product.

2.8.1 Ordering code and marking

This section describes the variants of the power module (eg. TIM, Lids). Marking of the power module is illustrated with an example picture of the module´s side.

Ordering Code & Marking							
Version			Ordering Code				
without thermal paste 12 mm housing with Press-fit pins			10-EY126PA050M7-L196F78T				
with thermal paste 12 mm housing with Press-fit pins			10-EY126PA050M7-L196F78T-/3/				
without thermal paste 12 mm housing with solder pins			10-E2126PA050M7-L196F78Z				
with thermal paste 12 mm housing with solder pins			10-E2126PA050M7-L196F78Z-/3/				
	Text	Name		Date code	UL & VIN	Lot	Serial
		NN-NNNNNNNNNNNNNN-TTTTTTVV		WWYY	UL VIN	LLLLL	SSSS
	Datamatrix	Type&Ver	Lot number	Serial	Date code		
		TTTTTTTVV	LLLLL	SSSS	WWYY		

All available option codes, which belongs to the mechanical construction and the Thermal Interface Material (TIM) are listed in this section.

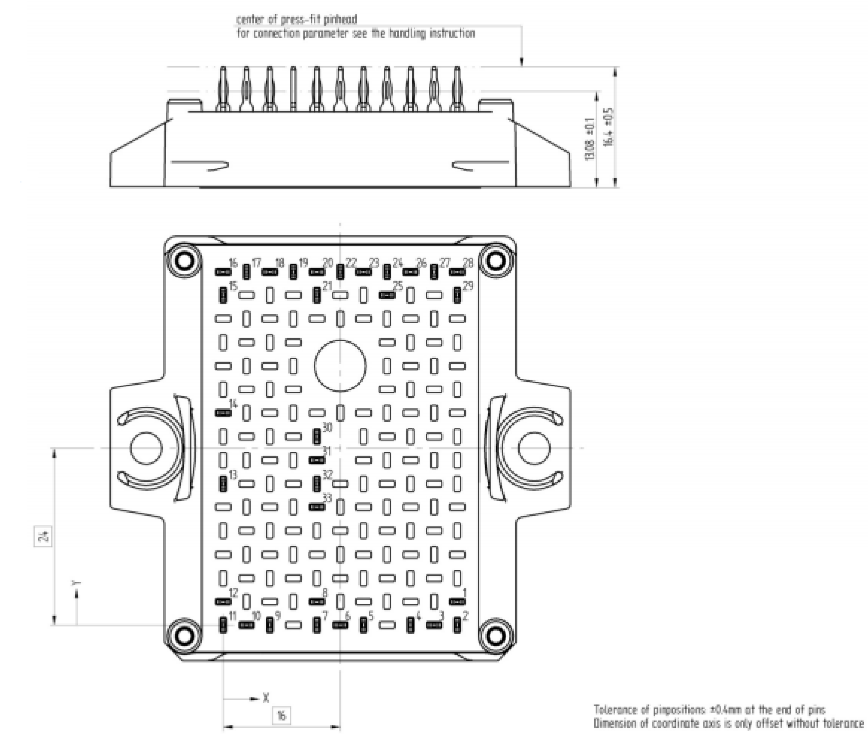
2.8.2 Outline

The mechanical drawing, the pin functions and its coordinates are described within this section. More details on the housing dimension and a 3D model file can be found on Vincotech´s webpage.

Outline

Pin table

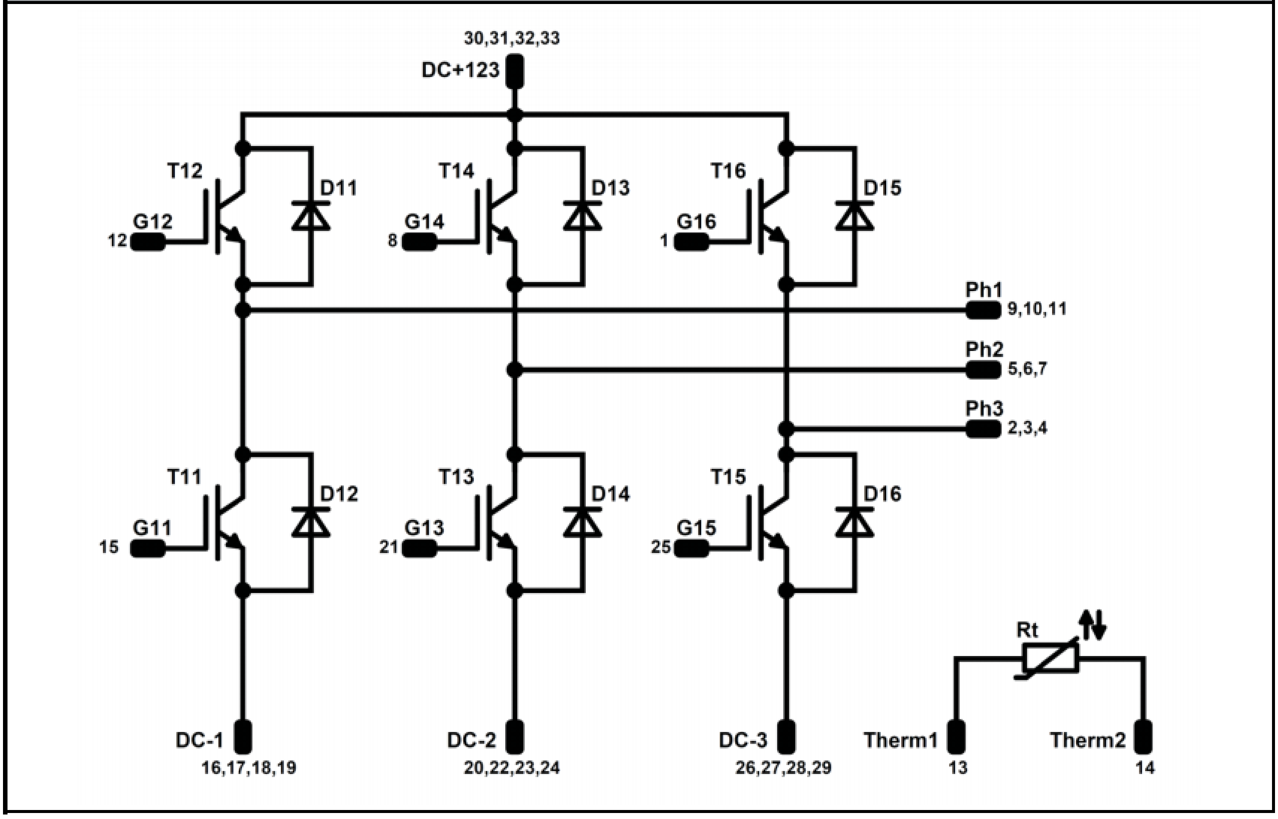
Pin	X	Y	Function
1	32	3,2	G16
2	32	0	Ph3
3	28,8	0	Ph3
4	25,6	0	Ph3
5	19,2	0	Ph2
6	16	0	Ph2
7	12,8	0	Ph2
8	12,8	3,2	G14
9	6,4	0	Ph1
10	3,2	0	Ph1
11	0	0	Ph1
12	0	3,2	G12
13	0	19,2	Therm1
14	0	28,8	Therm2
15	0	44,8	G11
16	0	48	DC-1
17	3,2	48	DC-1
18	6,4	48	DC-1
19	9,6	48	DC-1
20	12,8	48	DC-2
21	12,8	44,8	G13
22	16	48	DC-2
23	19,2	48	DC-2
24	22,4	48	DC-2
25	22,4	44,8	G15
26	25,6	48	DC-3
27	28,8	48	DC-3
28	32	48	DC-3
29	32	44,8	DC-3
30	12,8	25,6	DC+
31	12,8	22,4	DC+
32	12,8	19,2	DC+
33	12,8	16	DC+



2.8.3 Detailed schematic

The product-specific schematic includes the component designators, pin names and numbers.

Pinout



2.8.4 ID table

To be able to link component functions with physical components, an explaining table is required.

Identification					
ID	**Component**	**Voltage**	**Current**	**Function**	**Comment**
T11, T12, T13, T14, T15, T16	IGBT	1200 V	50 A	Inverter Switch	
D11, D12, D13, D14, D15, D16	FWD	1200 V	50 A	Inverter Diode	
Rt	NTC			Thermistor	

In this table the component´s nominal values which are stated in the supplier’s datasheet can be found.

The product´s packaging is important from a logistic point of view. The packaging quantity and sample or standard order definitions can be found in this section.

Packaging instruction				
Standard packaging quantity (SPQ) 100	>SPQ	Standard	<SPQ	Sample

2.9 Document section

Additional document-related information is located at the last page of the datasheet.

Handling instruction
Handling instructions for *flow* E2 packages see vincotech.com website.

Package data
Package data for *flow* E2 packages see vincotech.com website.

UL recognition and file number
This device is certified according to UL 1557 standard, UL file number E192116. For more information see vincotech.com website.

This refers to links to supplementary documents like handling instructions, housing dimensions and UL file. This section is always part of the datasheet.

For modification tracking a single row table is used.

Document No.:	Date:	Modification:	Pages
10-Ex126PA050M7-L196F78x-D3-14	20 Dec. 2018	Corrected Cr&Cl values Short circuit ratings	2 1, 6

The modification date is identical to the date found in the footer. Modification and pages describe the changes made since the last full revision. The page which contains changes are listed here.

The disclaimer is located at the end of the document.

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As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, or (c) whose failure to perform when properly used in accordance with instructions for use provided in labelling can be reasonably expected to result in significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

3 Datasheet parameters IGBT

3.1 Maximum values IGBT

The maximum values describe the electrical limits of the component which must not be exceeded.

3.1.1 Collector-emitter voltage - V_{CES}

The collector-emitter voltage is the maximum rated voltage between collector and emitter terminals of an IGBT when the gate is shortened with the emitter. Usually this value is measured at a junction temperature of 25 °C which is specified in the supplier’s datasheet.

Datasheet example:

Collector-emitter voltage	V_{CES}		1200	V

Data source:
Supplier datasheet

Conditions:

- T_j = 25 °C
- V_{GE} = 0 V short circuit

3.1.2 Collector current - I_C

The value of the forward current through an IGBT I_C is the maximum allowed DC current through the main terminals in forward direction during continuous operation. No additional losses are allowed in the chip or other thermally-coupled devices.
The maximum achievable forward current of an IGBT is limited by the gate voltage.

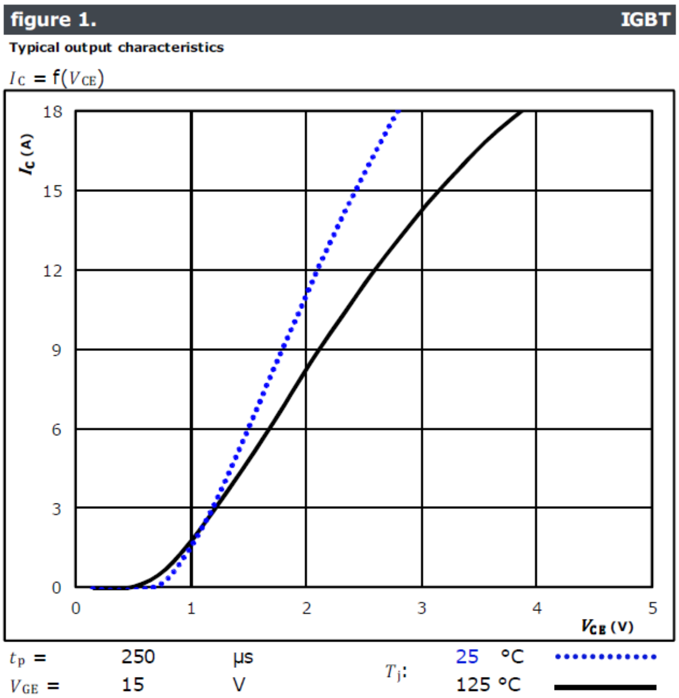


Figure 2: Collector current as a function of collector-emitter voltage

The current stated in the datasheet is calculated using the equation shown below. I_C is referred to the heatsink temperature. The heatsink temperature T_s is given to 80 °C.

$$I_C = \frac{T_{jmax} - T_s}{V_{CEsat} \cdot R_{th(j-s)}}$$

The values to determine the collector current are usually given at the maximum allowed junction temperature and a fixed case or heatsink temperature.
Very often the DC collector current is also known as the nominal chip current rating. I_C calculation is made on typical V_{GE} voltage.

Datasheet example:

Collector current	I_C	$T_j = T_{jmax}$ $T_s = 80$ °C	8	A

The condition is given with a heatsink temperature of 80 °C; and maximum junction temperature.

Data source:
Calculated value based on the static measurement, the chip maximum junction temperature and measured $R_{th(j-s)}$ value.

Conditions:

- $T_j = T_{jmax}$
- $T_s = 80$ °C
- V_{GE} = apply the recommended operating gate emitter voltage based on supplier datasheet, typically 15 V

3.1.3 Repetitive peak collector current - I_{CRM}

The nominal current rating can be exceeded for a short time. This current is defined as repetitive peak collector current. These ratings indicate how much pulsed current the device can handle which is significantly higher than the rated continuous current. This current rating is defined by the chip supplier. It doesn't take into consideration the bond wire and thermal limitation of the module construction.

Datasheet example:

Repetitive peak collector current	I_{CRM}	t_p limited by T_{jmax}	18	A

Data source:
Supplier datasheet

Conditions:

- Repetition rate and duty cycle must be set to the range where T_j is less or equal to T_{jmax}.

3.1.4 Total power dissipation - P_{tot}

The total power dissipation is the power that a device can dissipate without exceeding the maximum allowed junction temperature. The case temperature or the heatsink temperature is also given for this condition.

The total power dissipation is always a calculated value. The total power dissipation is calculated at maximum ΔT, where $\Delta T = T_{jmax} - T_{s}$. This is reached at maximum junction temperature.

The power dissipation capability of one device is a function of thermal construction and thermal gradient ΔT.

Datasheet example:

Total power dissipation	P_{tot}	$T_j = T_{jmax}$	T_s = 80 °C	96	W

Data source:
Vincotech gives the total power dissipation capability as a calculated value based on the following formula:

$$P_{tot} = \frac{\Delta T}{R_{th(j-s)}}$$

Within the formula above the following variables are used:
ΔT –difference between the maximum junction temperature of semiconductor according to supplier datasheet and the heatsink temperature [K];
$R_{th(j-s)}$ – thermal resistance, junction to heatsink $\left[\frac{K}{W}\right]$; according to Vincotech thermal measurement.

Conditions:

- $T_j = T_{jmax}$
- T_s = 80 °C

3.1.5 Gate-emitter voltage - V_{GES}

The V_{GES} gives the maximum G-E voltage which must not be exceeded under any condition. Exceeding this limit may cause life time degradation or oxide breakdown and dielectric rupture. This range with reasonable guard band is 100 % tested by the supplier. The leakage current corresponding to V_{GES} is specified within the characteristics values.

Datasheet example:

Gate-emitter voltage	V_{GES}		±20	V

Data source:
Supplier datasheet

Conditions:

- T_j= 25 °C
- V_{CE} = 0 V short circuit

3.1.6 Short circuit ratings - t_{psc}

If a short circuit event occurs, the collector current rapidly rises so that the IGBT limits the current amplitude to a safe level for a period of time. This period of time allows the user (control circuitry) to turn off the device without damage. The number of short circuit events may be limited to a maximum number for the whole lifetime of the device, and the minimum time between two short circuit events as well. The short circuit withstand capability depends on chip technology. Not all the chip technologies used by Vincotech are short circuit rated.

Datasheet example:

Short circuit ratings	t_{SC}	V_{GE} = 15 V V_{cc} = 800 V T_j = 150 °C	10	µs

Data source:
Supplier datasheet

Conditions:

- Gate-Emitter voltage during short circuit: V_{GE}
- DC link voltage: V_{CC}
- Junction temperature at the beginning of short circuit: T_j

3.1.6.1 Short circuit duration as a function of V_{GE}

Short circuit withstand time given within the max section is specified for a certain V_{GE} voltage. The typical value for IGBT is +15 V. If a short circuit occurs, the IGBT desaturates and limits the current to the short circuit current level. The IGBT transfer characteristic imposes the short circuit current level. Higher V_{GE}, leads to higher short circuit current. The energy during a short circuit event needs to be dissipated by the IGBT chip. This is because the time is so short that no thermal spreading nor thermal conduction to the DCB and heatsink takes place. So it is obvious that if the short circuit current level increases, the short circuit withstand time must be decreased accordingly. There will be a linear dependency of the short circuit withstand time by V_{GE}.

Datasheet example:

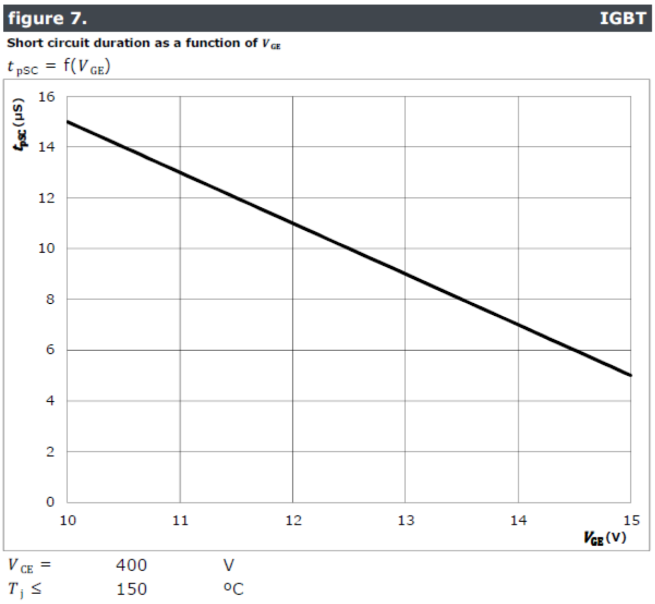


Figure 3: Short circuit duration as a function of V_{GE}

Data source:
Supplier datasheet

Conditions:
- DC link voltage: V_{CC}
- Junction temperature at the beginning of short circuit: T_j

3.1.6.2 Short circuit collector current as a function of V_{GE}

Due to the high-gain characteristic of IGBTs, the collector current will rise to an undetermined value limited by its transconductance, higher V_{GE} will lead to higher short circuit currents. When a short circuit is detected, the IGBT must be switched off within the short circuit withstand time. The dependency of short circuit current as a function of V_{GE} is shown in the graph below.

Datasheet example:

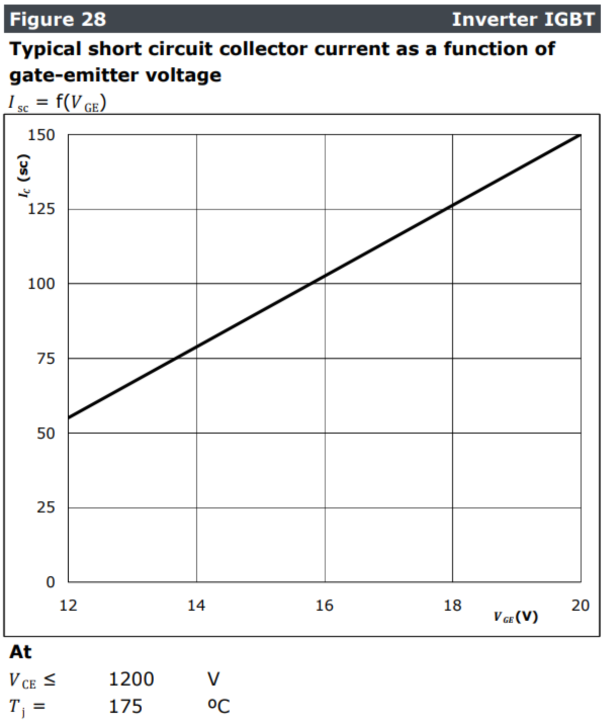


Figure 4: Short circuit current as a function of V_{GE}

Data source:
Supplier datasheet

Conditions:
- DC link voltage: V_{CE}
- Junction temperature at the beginning of short circuit: T_j

3.1.7 Maximum junction temperature - T_{jmax}

The maximum junction temperature T_{jmax} is the temperature of the junction of a device that can be tolerated without damage in non-switching condition. The maximum operation temperature T_{jop} is usually 25 K lower than the maximum junction temperature.

Datasheet example:

Maximum junction temperature	T_{jmax}		175	°C

Data source:
Supplier datasheet

Conditions:
No condition

3.2 Characteristic values IGBT

This chapter describes the characteristic values, which are the main representative parameters, of the component.

3.2.1 Gate-Emitter threshold voltage - $V_{GE(th)}$

The gate-emitter threshold voltage is the voltage at which the collector current begins to flow. All IGBTs show variations in $V_{GE(th)}$ between devices which is normal. Therefore, a range of $V_{GE(th)}$ is specified, with the minimum and maximum representing the edges of the $V_{GE(th)}$ distribution. Those are usually given at a junction temperature of 25 °C. The threshold voltage has a negative temperature coefficient, meaning that when the device heats up, the IGBT will turn on at a lower gate-emitter voltage. This temperature coefficient is typically around −8 mV/K, the same as for a power MOSFET.

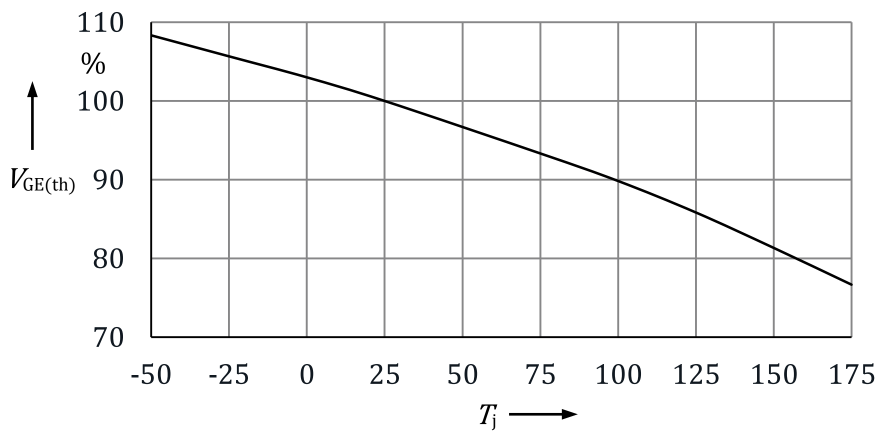


Figure 5: Threshold voltage as a function of junction temperature

Test conditions are the collector current, gate-emitter voltage which equals the collector-emitter voltage and junction temperature. These are also given in the datasheet.

Datasheet example:

Gate-emitter threshold voltage	$V_{GE(th)}$	$V_{GE} = V_{CE}$			0,00018	25	5	5,8	6,5	V

Data source:
Supplier datasheet

Conditions:

- Specified value in the supplier datasheet or: $V_{CE} = V_{GE}$
- Specified value in the supplier datasheet: I_C

3.2.2 Typical transfer characteristics

The typical transfer characteristics show the collector current as a function of gate-emitter voltage at two or three different temperatures. One value is typically given at a low temperature (25 °C) and another at high temperature (125 °C or 150 °C or both). This depends on the chip's maximum junction temperature. In case of IGBTs the typical transfer characteristic is always given on nominal collector current. During the measurement the Collector-Emitter voltage V_{CE} kept on 10 V.

Datasheet example:

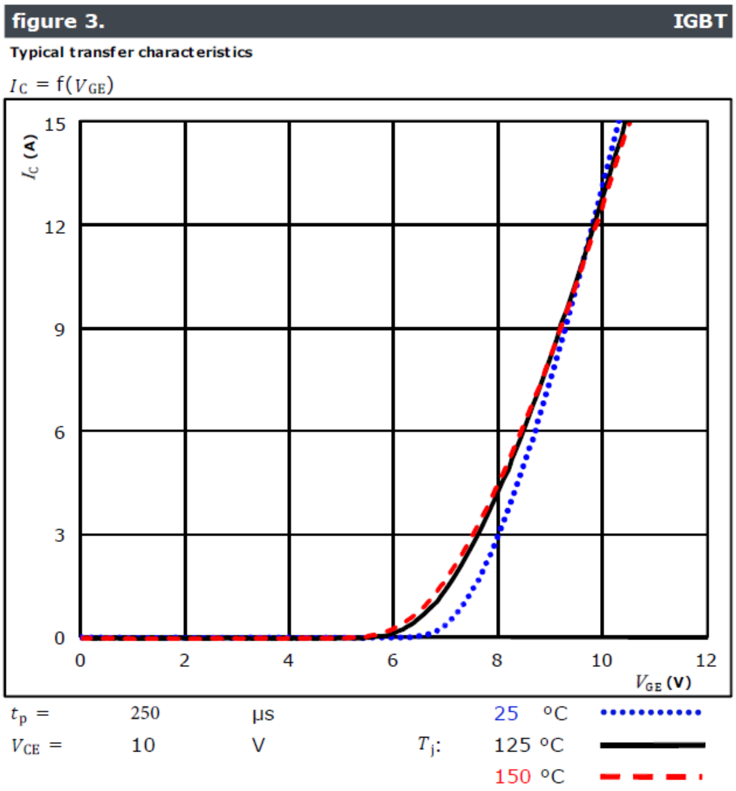


Figure 6: Typical transfer characteristics

Data source:
The typical transfer characteristics are measured by curve tracer equipment by Vincotech.

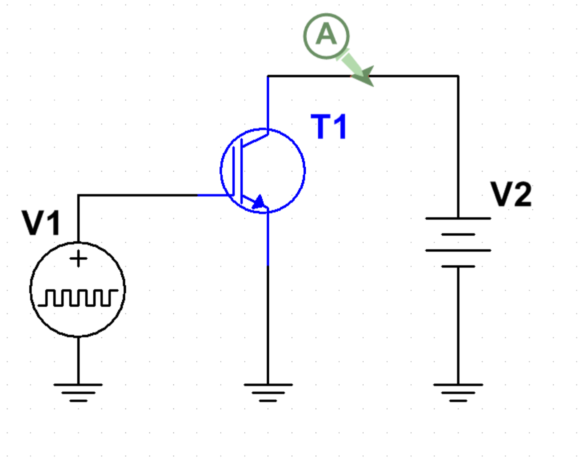


Figure 7: The arrangement of the measurement

Conditions:

- V_{CE} = 10 V
- t_p = 250 µs (pulse width of collector-emitter voltage)
- T_j = 25 °C, 125 °C or/and 150 °C

3.2.3 Collector-Emitter saturation voltage - V_{CEsat}

The collector-emitter saturation voltage is the voltage drop through the IGBT when a current flows in forward direction with specified conditions. The voltage drop is a function of current. A higher current will lead to a higher forward voltage.

The forward voltage is also a function of temperature. Most devices show positive temperature coefficients above a certain current level that make it easy to parallel semiconductors. Older technologies have negative temperature coefficients that make paralleling more complex.

The forward voltage of an IGBT is also a function of the gate-emitter voltage. A gate-emitter voltage higher than the recommended value will result in a lower voltage drop.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	
Collector-emitter saturation voltage	V_{CEsat}		15		25	25 125 150	1,58	1,82 2,11 2,18	2,07	V

Data source:
In case of maximum and minimum collector-emitter saturation voltage the data source is the supplier datasheet.

The typical collector-emitter saturation voltage is determined by the output characteristic measurement on the IGBT nominal current and 15 V gate-emitter voltage.

The collector-emitter saturation voltage is given at low temperature (25 °C) and at high temperature (125 °C or 150 °C or both). It depends on the chip’s maximum junction temperature.

Conditions:

- I_C = IGBT nominal collector current
- V_{GE} = 15 V
- T_j = 25 °C, 125 °C or/and 150 °C

3.2.4 Typical output characteristics

Every final datasheet contains two graphs to represent the output characteristics. On Figure 8 the left side figure shows the collector-emitter saturation voltage as a function of collector current on two or three different temperatures. One value is typically given at a low temperature (25 °C) and another at high temperature (125 °C or 150 °C or both). The output characteristic measured until 3 times of nominal current.

On Figure 8 the right side figure shows the collector-emitter saturation voltage as a function of collector current and different gate-emitter voltages at T_{jmax} – 25 K. In case of IGBTs the gate-emitter voltage is always given from 7 V to 17 V with 1 V steps.

Datasheet example:

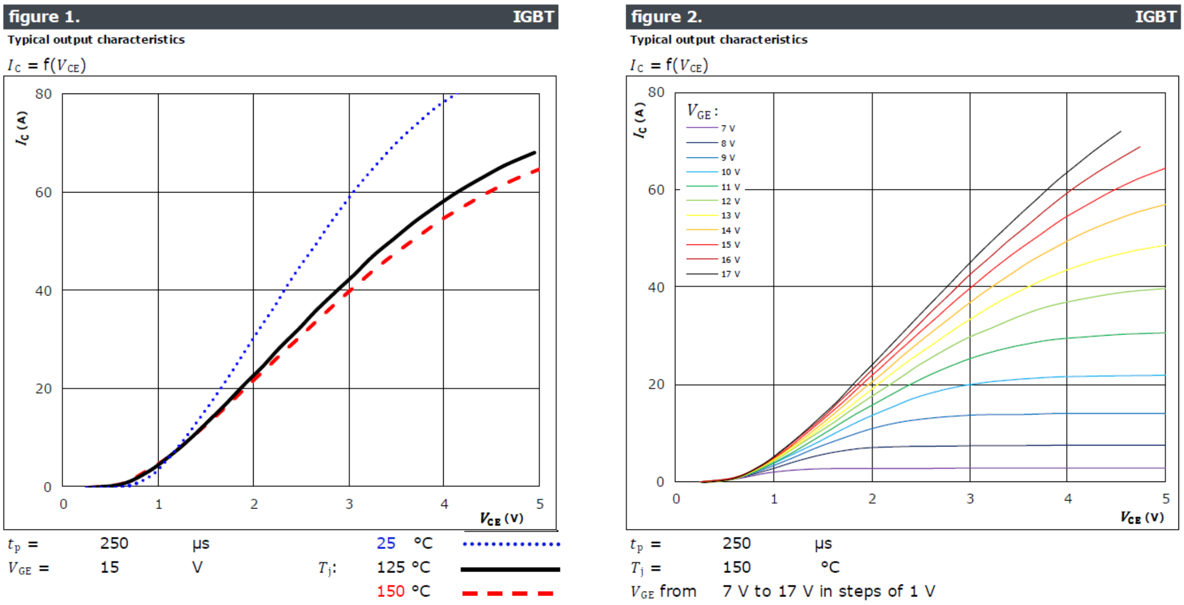


Figure 8: Datasheet example for typical output characteristics

Data source:
The typical output characteristics are measured by curve tracer equipment by Vincotech characterization lab.
The given forward voltage in the module datasheet is always measured on module pins. If a sense pin is available, then this pin is used for sensing. Alternatively a separate pin with the same potential, which is not loaded by current, is used for sensing.

The arrangement of the measurement:

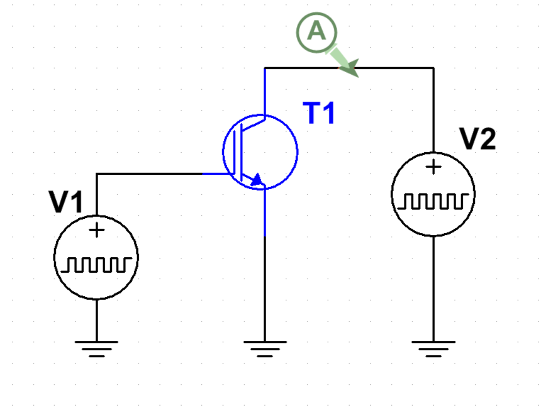


Figure 9: The arrangement of the measurement

Conditions of Figure 8 left side:

- V_{GE} = 15 V
- T_j = 25 °C, 125 °C or/and 150 °C
- t_p = 250 µs (pulse width of collector-emitter voltage)

Conditions of Figure 8 right side:

- V_{GE} = 7 V – 17 V in step of 1 V
- T_j = 125 °C or 150 °C
- t_p = 250 µs (pulse width of collector-emitter voltage)

3.2.5 Collector cut-off current – I_{CES}

The collector (-emitter) cut-off current I_{CES} is the current that flows through the device when the gate emitter terminals are shorted and a voltage equal to the rated blocking voltage is applied across the collector and emitter terminals. It is also called leakage current. The cut-off current increases with increasing junction temperature.

Datasheet example:

Collector-emitter cut-off current	I_{CES}		0	600		25			0,04	µA

Data source:
Supplier datasheet

Conditions:

- T_j = 25 °C
- V_{GE} = 0 V short circuit
- V_{CE} = V_{CES}

3.2.6 Gate-emitter leakage current - I_{GES}

The leakage current I_{GES} is the current that flows into the device's gate when collector and emitter terminals are shorted and a voltage equal to the maximum rated gate-emitter voltage is applied across these terminals. The leakage current increases with increasing junction temperature.

Datasheet example:

Gate-emitter leakage current	I_{GES}		20	0		25			300	nA

The condition is given with a junction temperature of 25 °C; sometimes also with higher-temperatures.

Data source:
Supplier datasheet

Conditions:

- Specified at the recommended gate-emitter voltage (V_{GE}) with collector-emitter shorted (V_{CE} = 0) and T_j = 25 °C.

3.2.7 Internal gate resistance - r_g

Depending on the chip technology, the switch (IGBT or MOSFET) may have an internal gate resistance.
The value of the internal gate resistor is an important parameter for gate current peak value scaling at the gate driver design.

Datasheet example:

Internal gate resistance	r_g							2		Ω

Data source:
Supplier datasheet

Conditions:
No condition

3.2.8 Parasitic capacitances

IGBTs have a parasitic capacitance between each of its three terminals. Figure: 11 shows input capacitance C_{ies}, output capacitance C_{oss} and the reverse transfer capacitance C_{res}.

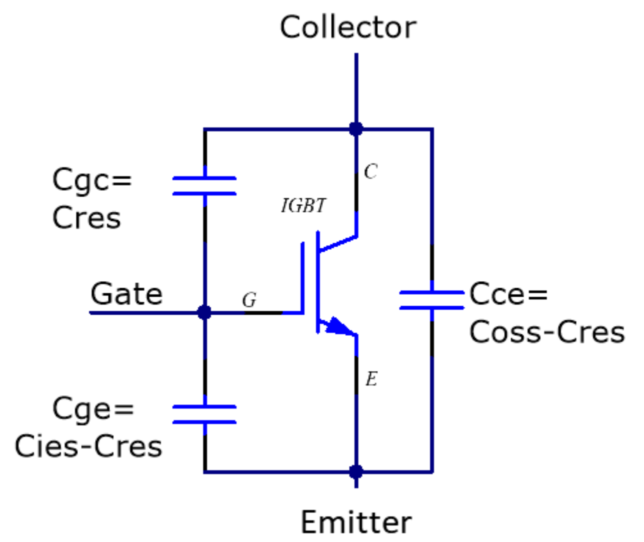


Figure 10: IGBT parasitic capacitance

The parasitic capacitances decrease over a range of increasing collector-to-emitter voltage, especially the output and reverse transfer capacitances. This variation is linked to the gate charge data.

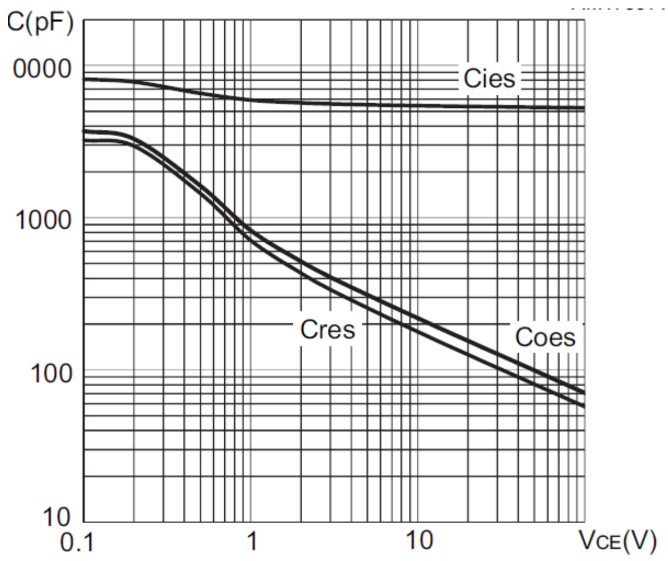


Figure 11: IGBT parasitic capacitances as a function of V_{CE}

3.2.8.1 Input capacitance - C_{ies}

$\boldsymbol{C_{ies} = C_{GE} + C_{GC}}$

The input capacitances C_{ies} is the parasitic capacitance of the IGBT which will determine the gate drive requirements under switching condition. As the parasitic capacitances´ values strongly depend on the operation point of the IGBT these values should not be used to simulate oscillation or EMI behavior.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V]	V_{CE} [V]	I_C [A]	T_j [°C]	Min	Typ	Max	
Input capacitance	C_{ies}	f = 1 Mhz	0	25		25		4810		pF
Output capacitance	C_{oes}							184		
Reverse transfer capacitance	C_{res}							79		

Data source:

Supplier datasheet

Conditions:

Typical values:

- V_{CE} = 25 V
- f = 1 MHz
- V_{GE} = 0 V

3.2.8.2 Output capacitance - C_{oes}

The output capacitance C_{oes} is located between the collector and emitter with the gate shorted to the emitter for AC currents. Hence, C_{oes} is the sum of the paralleled capacitances C_{CE} and C_{GC}. It is one of three key parameters of the dynamic behavior of an IGBT.

$$C_{oes} = C_{CE} + C_{GC}$$

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V]	V_{CE} [V]	I_C [A]	T_j [°C]	Min	Typ	Max	
Input capacitance	C_{ies}	f = 1 Mhz	0	25		25		4810		pF
Output capacitance	C_{oes}							184		
Reverse transfer capacitance	C_{res}							79		

Data source:
Supplier datasheet

Conditions:

Typical values:

- V_{CE} = 25 V
- f = 1 MHz
- V_{GE} = 0 V

3.2.8.3 Reverse transfer capacitance - C_{res}

The reverse transfer capacitance, often referred to as the Miller capacitance, is one of the major parameters affecting voltage rise and fall times during switching. The reverse transfer capacitance is equal to the gate-to-collector capacitance.

$$C_{res} = C_{GC}$$

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V]	V_{CE} [V]	I_C [A]	T_j [°C]	Min	Typ	Max	
Input capacitance	C_{ies}	f = 1 Mhz	0	25		25		4810		pF
Output capacitance	C_{oes}							184		
Reverse transfer capacitance	C_{res}							79		

Data source:
Supplier datasheet

Conditions:

Typical values:

- V_{CE} = 25 V
- f = 1 MHz
- V_{GE} = 0 V

3.2.9 Gate charge - Q_G

The gate charge is the required charge to raise the gate-emitter voltage from a specified low level to a specified higher level. This is often given within the condition of gate-emitter voltage of −15 V to +15 V or from 0 V to +15 V.

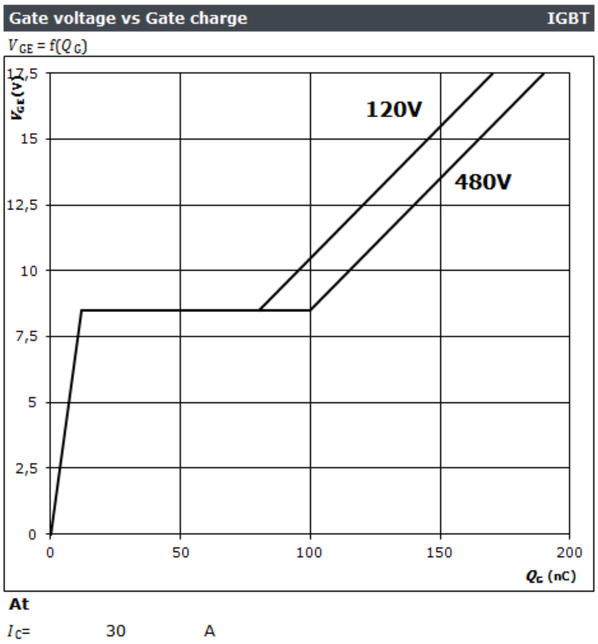


Figure 12: Gate charge curve

The specified conditions are the junction temperature, the applied voltage to the device and the collector current. The applied voltage is typically at 80 % and 20 % of device voltage rating.

Datasheet example:

Gate charge	Q_g		15	480	30	25		167		nC

Data source:
Supplier datasheet

Conditions:

Typical values:

- V_{GE} = 15 V
- V_{CE} = 20 and 80 % of the V_{CES}
- $I_C = I_{Cnom}$
- T_j = 25 °C

3.2.10 Thermal resistance - R_{th}

Thermal resistance is the resistance between two different parts. Usually, the first part is the junction of a semiconductor. The second part can be the heatsink, the case or the ambient. It is measured in K/W. To calculate the thermal resistance, losses are applied to the device and the difference between the temperatures of the two parts is monitored.

The thermal resistance characterizes the thermal behavior of power semiconductors at steady state. R_{th} describes the ability of a given material to resist a heat flow. If more components are paralleled, then these are considered as one single component and the R_{th} is measured accordingly.
By definition the R_{th} is:

$$R_{\mathrm{th(j\text{-}s)}} = \frac{\Delta T}{P} = \frac{T_{\mathrm{j}} - T_{s}}{P} = \left[\frac{K}{W}\right]$$

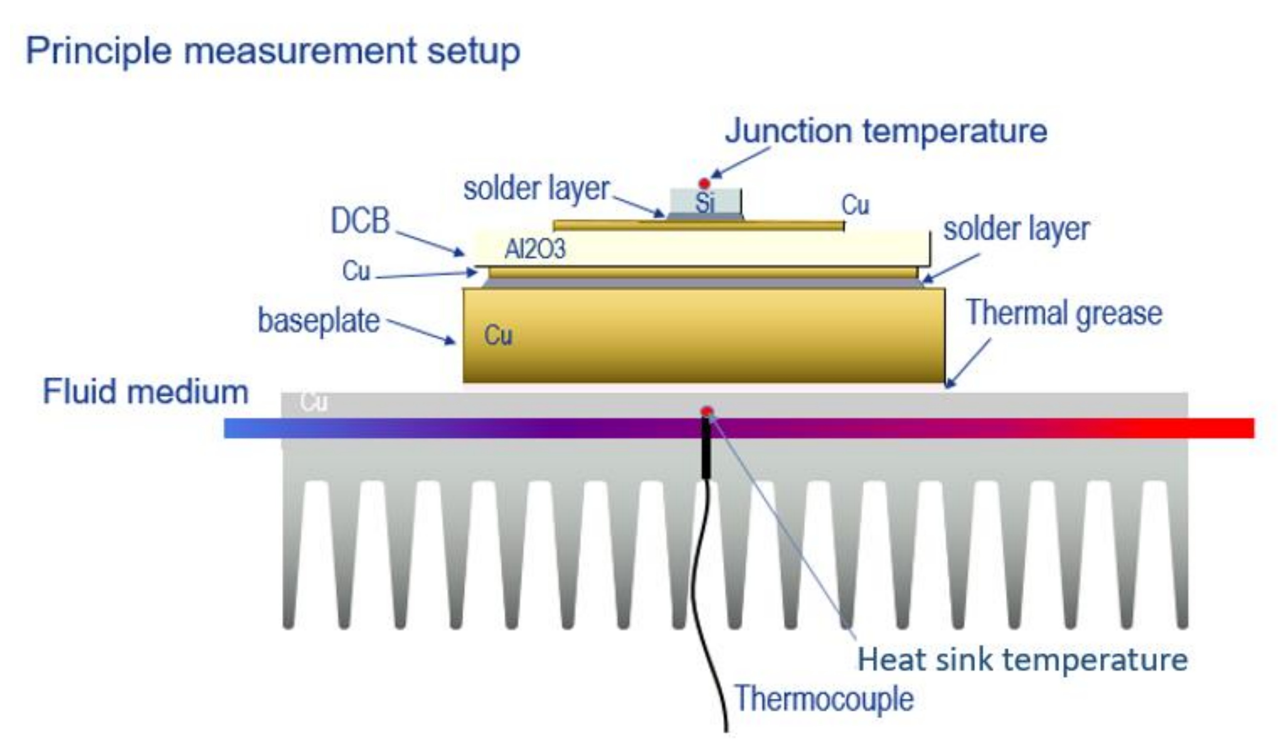


Figure 13: Measurement setup

The most challenging in R_{th} measurement is the chip temperature measurement. There are different ways to measure the temperature of IGBT using infrared cameras or thermocouples at chip surfaces or using temperature dependence of semiconductor properties like the forward voltage drop.
This forward voltage drop dependency by junction temperature is called T-V curve or $V_{f} = f(T_{j})$.

R_{th} measurement steps using the T-V dependency

- The first step is to heat the module passively while forcing a constant low current (approx. 10mA/cm^2) through the semiconductor for temperature dependency measurement of V_{CE}. On this current level the self-heating of the chip can be neglected. The measured module is heated up and then cooled down with constant temperature change rate (max 1 °C/min) in a specified temperature range (usually 30 °C to 50 °C).
- Applying current to heat the module actively
- Determine the actual junction temperature by measuring the voltage drop with a current
- Calculate R_{th}

$$R_{\text{th(j-s)}} = \frac{\Delta T}{P} = \frac{T_{\text{j}} - T_{\text{s}}}{V_{\text{CE}} \cdot I_{\text{C}}}$$

T_s, V_{CE}, I_C-direct measured with 4 wire measurement method
T_j determined in the first three steps
Detailed information will follow in this chapter.

Factors that can influence the R_{th} value

Type of the cooling concept:
The thermal construction will determine the lateral spreading of the heat. Thermal resistance is a function of the thermal conductivity of the heatsink. Each layer in the direction of temperature drop influences the thermal spreading of the next layer. When a highly conductive material such as copper is used for the heatsink base, the thermal spreading inside the module will be less compared to the use of the same heatsink made of aluminum.

Thermal conductivity of the heatsink:
The R_{th} value strongly depends by the thermal conductivity of the heatsink used in measurement setup. A measurement made with a good thermal conductivity heatsink will result a worse R_{th} than a measurement made with a worse thermal conductivity heatsink.

$R_{th(j\text{-}s)}$ natural ≤ $R_{th(j\text{-}s)}$ forced ≤ $R_{th(j\text{-}s)}$ water
$R_{th(j\text{-}s)}$ Al ≤ $R_{th(j\text{-}s)}$ Cu

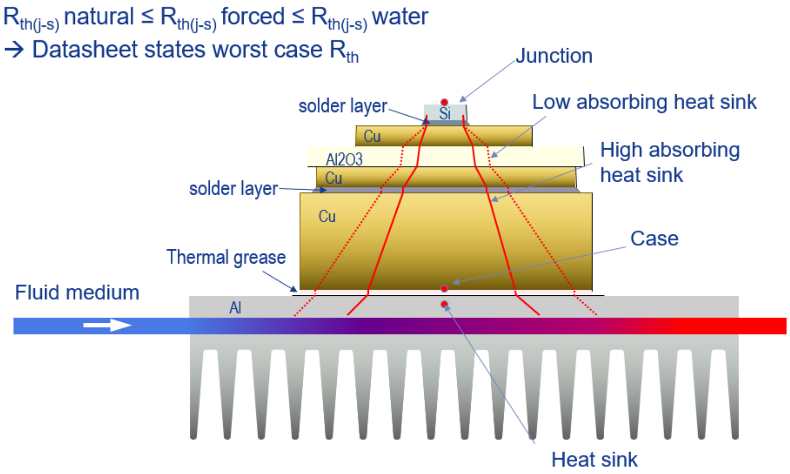


Figure 14: Thermal spreading as a function of cooling concept

Type and thickness of the thermal grease:
The type and thickness of the applied thermal internface material (TIM) influences the R_{th}. TIM must be specified in the datasheet as measurement condition, TIM thickness must be specified within the handling instructions.

Thermal couple position-sensing point of the reference temperature:

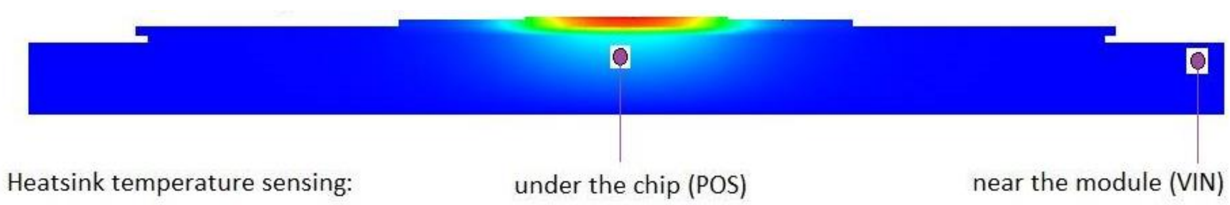


Figure 15: Heatsink temperature measurement

The temperature sensing point can be near the module or below the chip.

$T_{s(POS)} > T_{s(VIN)} \rightarrow R_{th(POS)} < R_{th(VIN)}$

Power–sense connection for dissipated power loss calculation:
By using the Kelvin sense connection the dissipated power on stray resistances of the module will not be assigned to the device under test.

$$R_{th4WIRE} = \frac{\Delta T}{P_{DUT}} \geq R_{th2WIRE} = \frac{\Delta T}{P_{DUT} + P_{stray}}$$

If the 4-wire connection is not possible by module construction, for a precise R_{th} measurement special samples should be used with additional sense pins.

Temperature dependency (TD)

The aim is to define the temperature dependency of the dies. The measured module is mounted on a heatsink and is passively heated up and then cooled down with a constant temperature change rate (max. 1 K/min) in a specified temperature range (usually 30 °C to 50 °C). The V_{CE}/V_{DS} voltage is measured periodically during the heating and cooling phase. This V_{CE}/V_{DS} voltage is produced by a constant measurement current which "loads" the chip. The measurement current has to be set according to the size of the chip (approx. 10 mA/cm²).

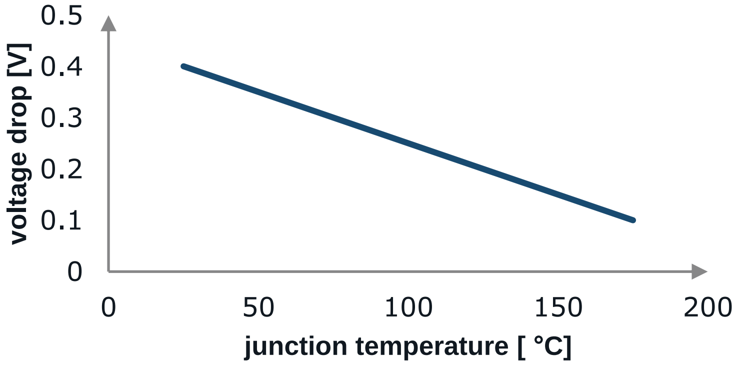


Figure 16: Temperature dependency

Determine the cooling curve (CC)

The chip temperature is increased by applying a pre-defined load current which raises the junction temperature significantly. The applied heating power is registered for P calculation as: V_{CE}, I_C. The load current is switched off and after the transient effect (some 100µs) the measurement current is turned on. This measurement current is the same as in the previous step. The V_{CE}/V_{DS} voltage is measured and recorded. The chip temperature can be calculated from the measured voltage value.

Determine the actual junction temperature

The actual junction temperature can be easily determined by the registered T-V (forward voltage dependency by temperature) curve and the measured V_{CE}/V_{DS} voltage.

Calculate R_{th}

Using the well-known formula

$$R_{\mathrm{th(j-s)}} = \frac{\Delta T}{P} = \frac{T_{\mathrm{j}} - T_{\mathrm{s}}}{V_{\mathrm{CE}} \cdot I_{\mathrm{C}}}$$

3.2.10.1 Thermal resistance junction to sink - $R_{th(j-s)}$

Datasheet example:

Thermal

Thermal resistance junction to sink	$R_{th(j-s)}$	λ_{paste} = 3,4 W/mK (PSX)						1,41		K/W

Data source:
The R_{th} value is a function of chip size, chip thickness and thermal construction. If all these parameters are the same the same R_{th} value will be assigned and measured for these components just once.

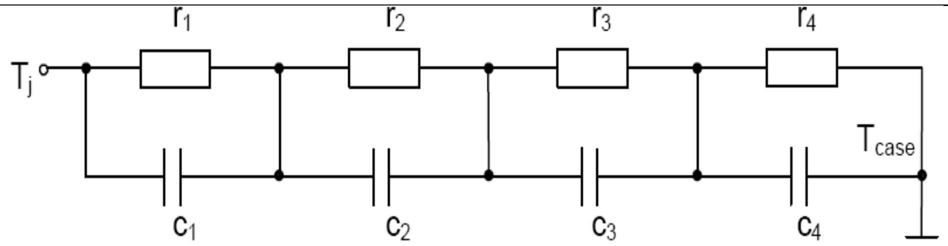
Conditions:
- Thermal conductivity of the thermal interface material, and its thickness
- Thermal cross coupling is not considered
- The result is in K/W unit

3.2.10.2 Transient thermal impedance as a function of pulse width

The Foster thermal model is used for the transient thermal impedance specification. The transient thermal impedance formulas don´t represent physical layers, they are the result of curve fitting of the cooling curve.

$$Z_{th} = \sum_{i=1}^{n} R_i (1 - e^{-\frac{t}{\tau_i}})$$

$$\tau_i = R_i C_i$$



$$T_j(t) = P(t) * Z_{thjc}(t) + T_{case} = P(t) * \sum_{i=1}^{n} R_i (1 - e^{-\frac{t}{\tau_i}}) + T_{case}$$

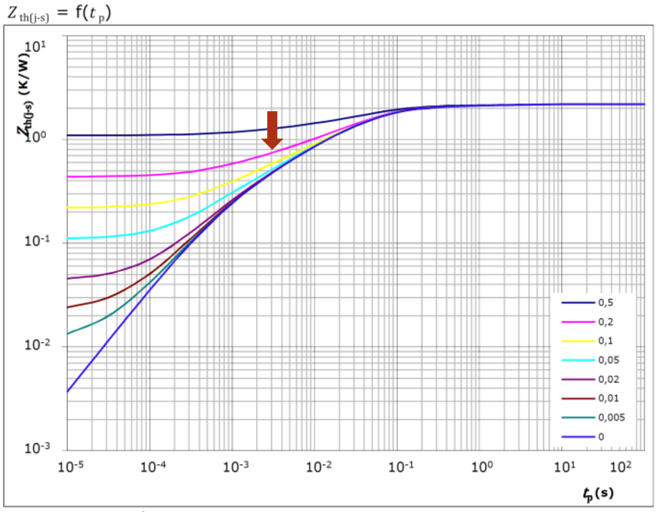
Figure 17: Foster thermal model

Datasheet example:

figure 2. **FWD**

Transient thermal impedance as a function of pulse width

$Z_{th(j-s)} = f(t_p)$



$D = t_p / T$

$R_{th(j-s)} =$ 2,19 K/W

FWD thermal model values

R (K/W)	τ (s)
6,49E-02	4,22E+00
1,67E-01	4,66E-01
9,76E-01	5,57E-02
5,62E-01	1,45E-02
3,00E-01	2,81E-03
1,17E-01	5,62E-04

Figure 18: Transient thermal impedance curves

Example how to use this characteristic to determine the Z_{th}:

X-axis pulse width, assuming a value of: 3 ms
Parameter – duty cycle, assuming a value of: 0.2
From these parameters the pulse frequency is calculated.
For a pulse with frequency of 66.6 Hz and a duty cycle of 0.2 from transient thermal impedance characteristics the Z_{th} value turns out to be equal to 0.75 K/W (red arrow).

Data source:

Vincotech´s laboratory measurement. A detailed description of the test setup can be found at the IGBT section. Diodes with the same mechanical properties (chip size, material and thickness) will be assigned with the same R_{th} value.

Conditions:

- Thermal conductivity of the thermal interface material and its thickness
- Thermal cross coupling is not considered

3.2.11 Safe operating area (SOA)

Two different kinds of safe operating areas can be defined:

- Forward bias SOA (FBSOA)
- Reverse bias SOA (RBSOA)

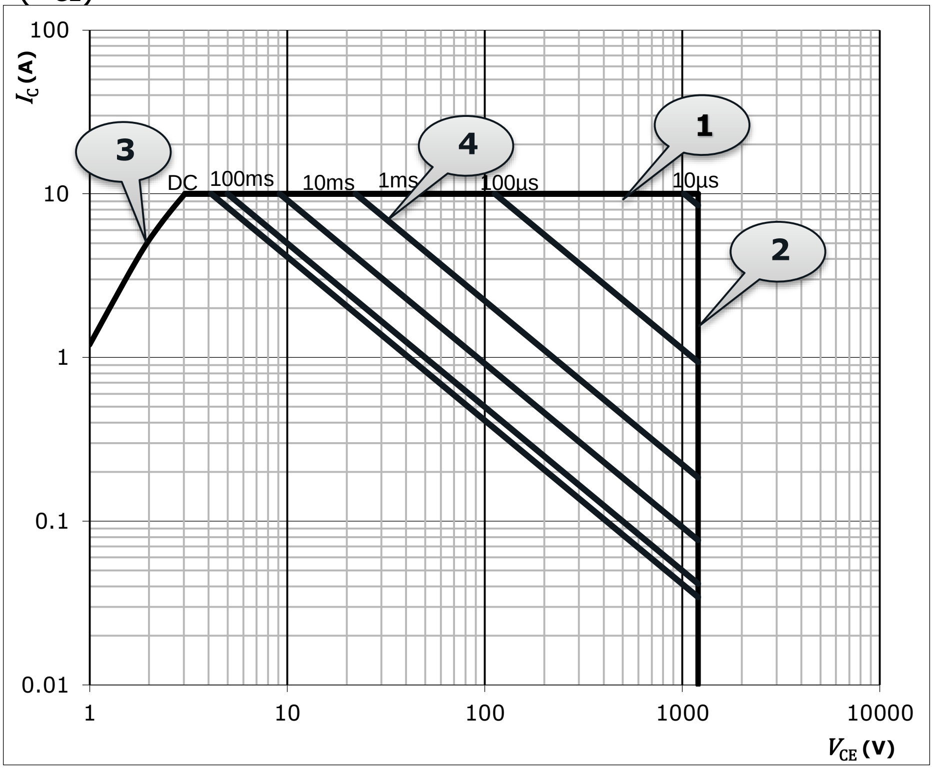
The forward bias safe operating area (FBSOA) defines the range of voltage, current and power values where the IGBT operation is safe. The IGBT's SOA must not be exceeded during turn-on and turn-off.

Datasheet example:

Figure 5. **IGBT**

Safe Operating Area

I_C = f(V_{CE})



D = single pulse
T_s = 80 °C
V_{GE} = ±15 V
T_j = T_{jmax}

Figure 19: Example for safe operating area

FBSOA limitations:

1. Area limited by the maximum rating pulse collector-current $I_{C(peak)}$ typical value: 3x I_{Cnom}
2. Area limited by maximum rating collector-emitter voltage V_{CES}
3. Area limited by forward characteristic
4. Area limited by collector-dissipation region

The dissipation region limitation calculation:

$$P(t_p) = \frac{\Delta T}{Z(t_p)}$$

where:
$Z(t_p)$ is the thermal impedance valid for single pulse with duration t_p
$P(t_p)$ is the maximum power dissipation for single pulse t_p

Data source:
Supplier datasheet, Vincotech´s laboratory measurement of Z_{th}

Conditions:
- Single pulse switching
- Heatsink temperature 80 °C
- Junction temperature less than T_{jmax}
- Gate voltage between $V_{GE\ on}$ and $V_{GE\ off}$ voltage

The reverse bias safe operating area (RBSOA) is defined more detailed on page 51 in the 3.3.7 Reverse bias safe operating area (RBSOA) chapter.

3.3 Switching characteristics

The switching characterization equipment is designed for switching characterization of switches and diodes in three typical configurations: booster, half bridge and three-level inverter.
Both switches, low side and high side switches, can be measured in HB configuration. When an MNPC topology is measured, e.g., 1200 V switches and 600 V diodes are paired to be characterized and vice versa. The gate driver is programmable through an isolated optical interface.

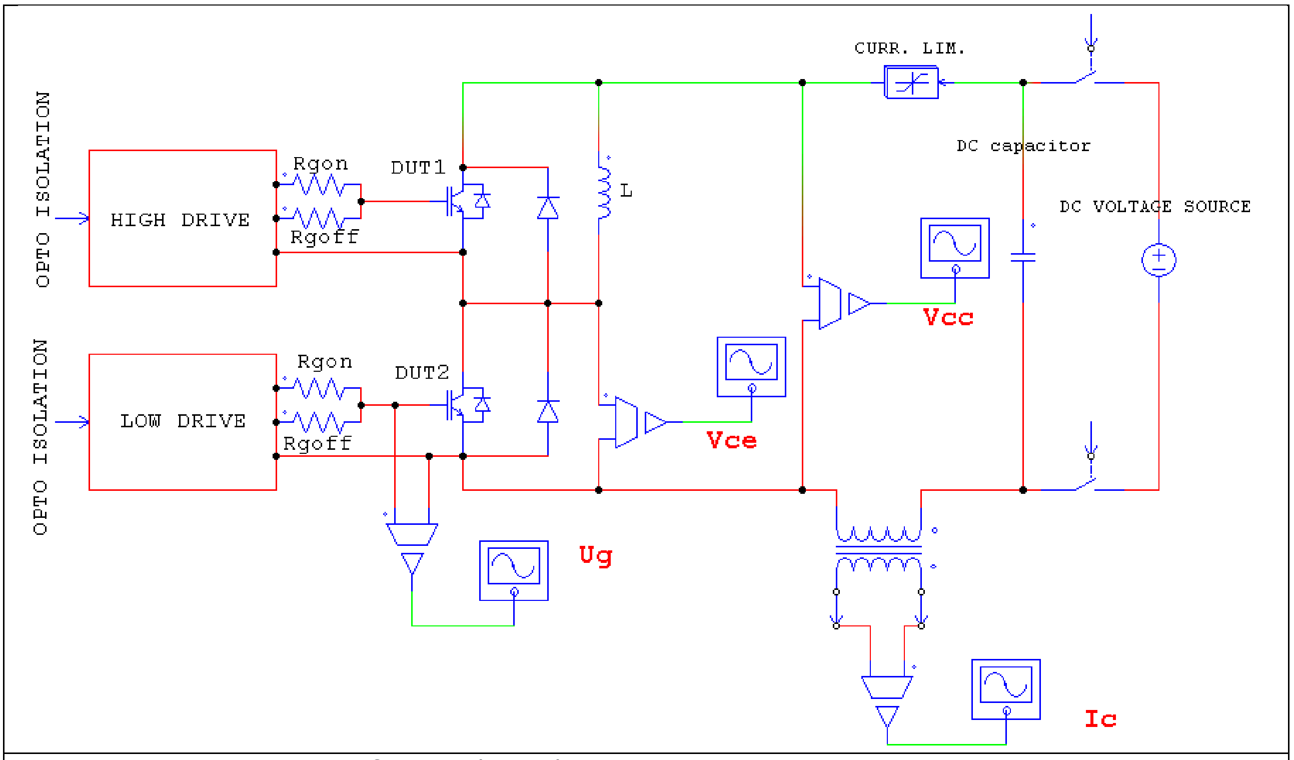


Figure 20: Test circuit setup for a HB low side measurement

Conditions:
Conditions can be varying based on chip technology, module topology and application.

Typical values:

- T_j = 25 °C, 125 °C, 150 °C (usually highest temperature is 25 K below T_{jmax})
- R_{gon}, R_{goff} range: 0.5 - 128 Ω in power of two
- V_{gon} = 15 V
- V_{goff} = 0 V/-15 V based on module topology
- I_C series: 20 % I_{Cnom}; 60 % I_{Cnom}; 100 % I_{Cnom}; 140 % I_{Cnom}; 180 % I_{Cnom}
- V_{cc} voltage: usually 50% of the breakdown voltage based on chip technology and topology

3.3.1 Turn-on delay time - t_{don} (IEC 60747-9)

The turn-on delay time is measured between the rising slope of the voltage at the input terminals and the rising slope of the current through the device.
Each measuring point is at 10 % of the nominal value as can be seen in the next figure.

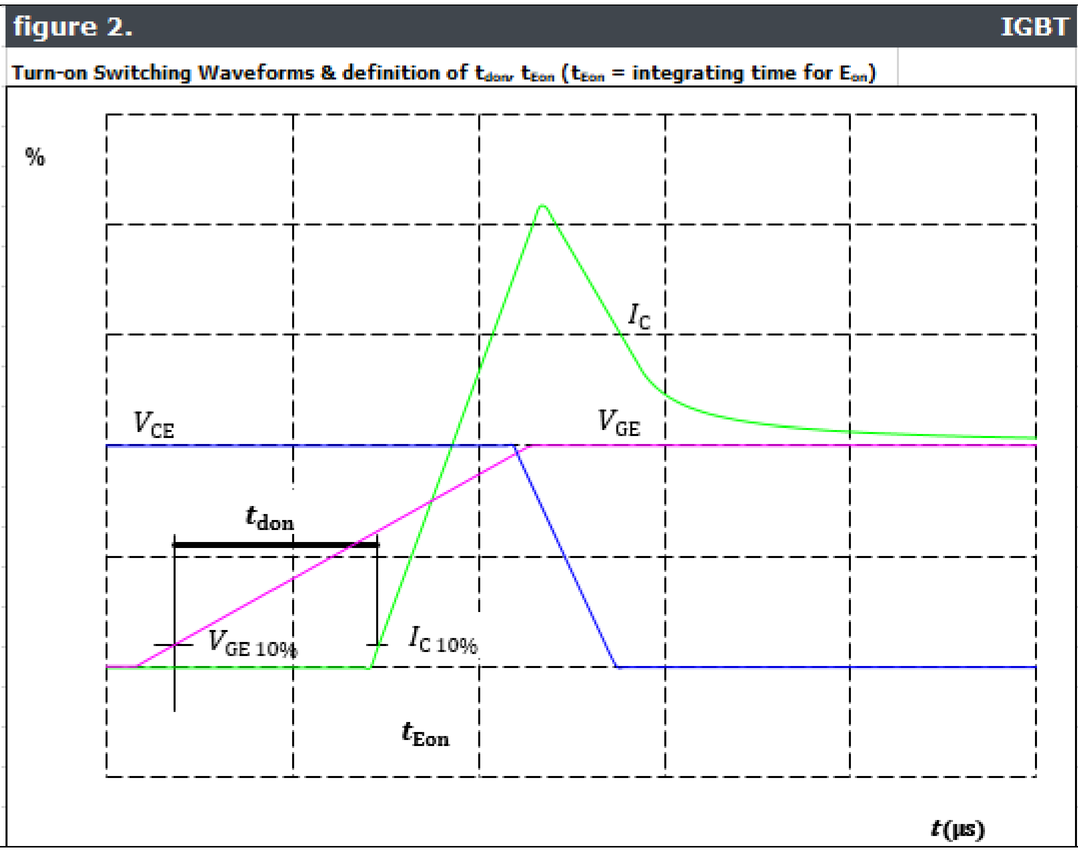


Figure 21: Turn-on delay time definition

The value of the inductive load, the gate-emitter voltage as well as the resistance in the gate-emitter circuit, the collector-emitter voltage after turn-on and the collector current before turn-on are given as conditions.

Data source:
Dynamic measurement for the given transistor-diode commutation pair in the same layout.

Conditions:
Defined as in the switching characteristic main chapter.

3.3.2 Rise time - t_r (IEC 60747-9)

Rise time is the time which the collector current takes to increase from 10 % to 90 % of its final steady state value. The current overshoot (diode recovery effect) is not considered to be 100 % value.

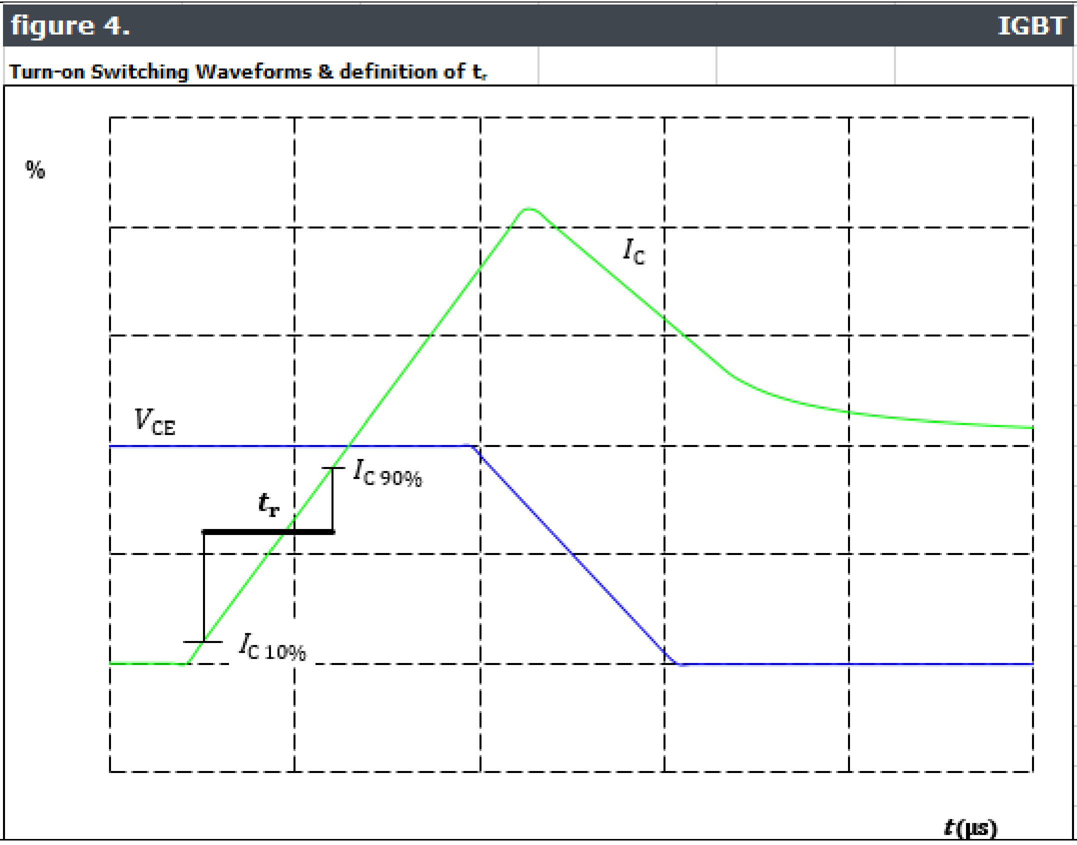


Figure 22: Rise time definition

The value of the inductive load, gate-emitter voltage as well as the resistance in the gate-emitter circuit, the collector-emitter voltage after turn-on and the collector current before turn-on are given as conditions.

Data source:
Dynamic measurement for the given transistor-diode commutation pair in the same layout.

Conditions:
Defined as in the switching characteristic main chapter.

3.3.3 Turn-off delay time - t_{doff}

Turn-off delay time is measured between the falling slope of the voltage at the input terminals and the rising slope of the voltage being blocked by the device. Each measuring point is at 90 % of the nominal value.

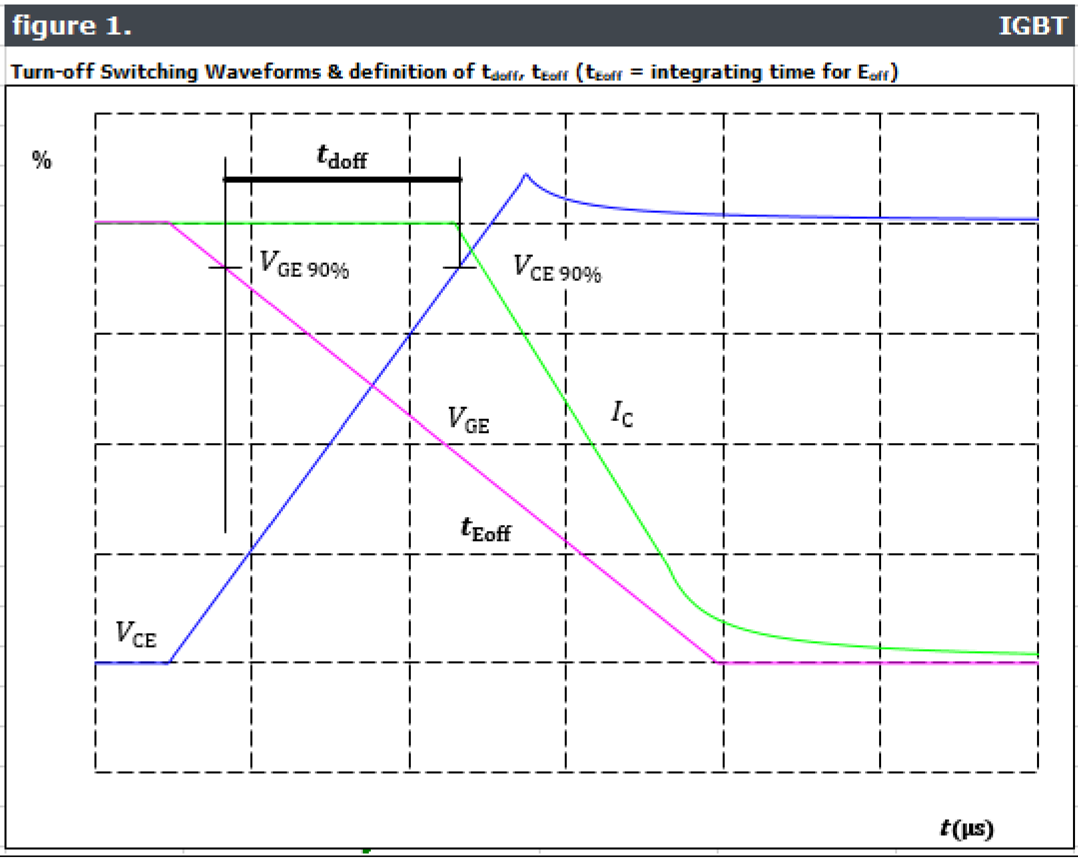


Figure 23: Turn-off delay time definition

The value of the inductive load, gate-emitter voltage as well as the resistance in the gate-emitter circuit, the collector-emitter voltage after turn-off and the collector current before turn-off are given as conditions.
This measurement method is not the same like in the IEC 60747-9 but gives a very similar result.

Data source:
Dynamic measurement for the given transistor-diode commutation pair in the same layout.

Conditions:
Defined as in the switching characteristic main chapter.

3.3.4 Fall time - t_f

Fall time is the time which the collector current takes to decrease from 90 % to 10 % of its initial value. In order to neglect IGBT tail current the fall time is measured on a fitted line to $I_{c40\%}$ and $I_{c60\%}$. The IEC 60747-9 standard does not specify how to handle the tail current. Therefore this method and the values are not compatible. The standard specifies t_f between 90 % and 10 % of the nominal value of the falling collector current.

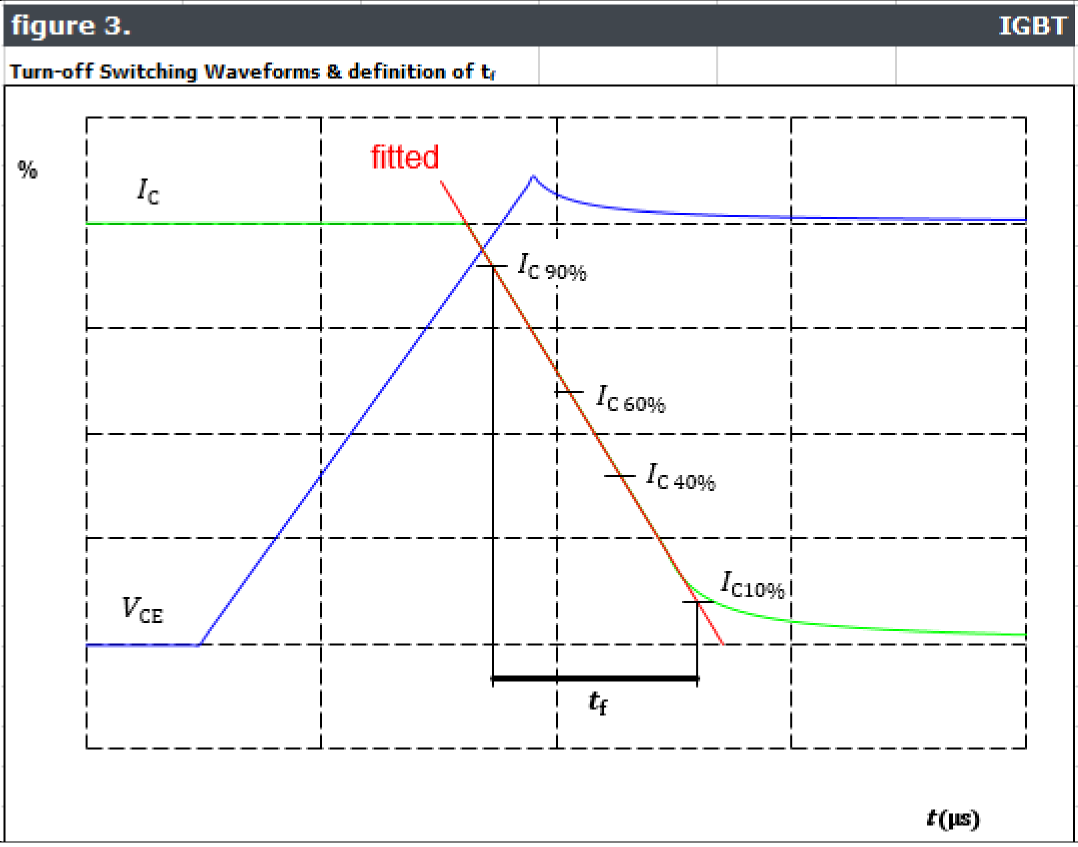


Figure 24: Fall time definition

The value of the inductive load, gate-emitter voltage as well as the resistance in the gate-emitter circuit, the collector-emitter voltage after turn-off and the collector current before turn-off are given as conditions.

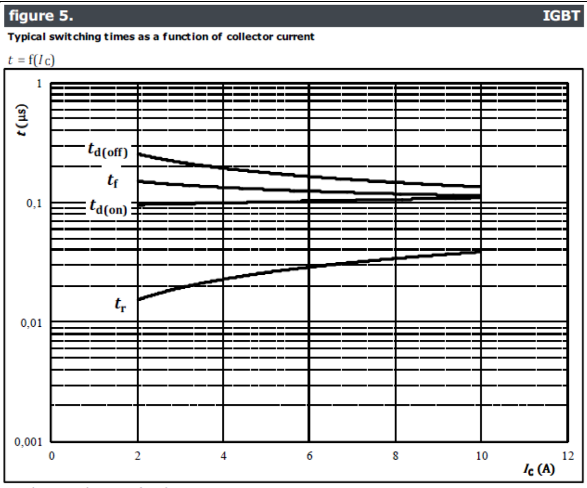
Data source:
Dynamic measurement for the given transistor-diode commutation pair in the same layout

Conditions:
Defined as in the switching characteristic main chapter.

Datasheet example:

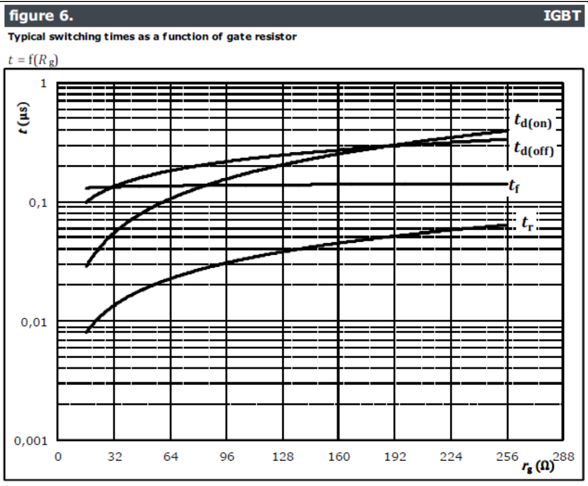
All four previously defined time-related values are provided in a table showing also the values for selected R_g and I_C values for all measured temperatures. The selected R_g and I_C are usually the middle values of the swept parameters. The typical switching time graphs as a function of R_g and I_C are given at high junction temperature typically at T_{jmax} – 25 K.

Turn-on delay time	$t_{d(on)}$	R_{goff} = 64 Ω R_{gon} = 64 Ω	±15	300	6	25 150		105 102		ns
Rise time	t_r					25 150		22 28		
Turn-off delay time	$t_{d(off)}$					25 150		142 164		
Fall time	t_f					25 150		103 132		



With an inductive load at

T_j =	150	°C
V_{CE} =	300	V
V_{GE} =	±15	V
R_{gon} =	64	Ω
R_{goff} =	64	Ω



With an inductive load at

T_j =	150	°C
V_{CE} =	300	V
V_{GE} =	±15	V
I_C =	6	A

Figure 25: Datasheet example of switching times

3.3.5 Turn-on energy - E_{on} (per pulse)

The turn-on energy is the dissipated energy of the IGBT during the off-on transition. By definition, this energy is the integral of the power loss over the switching period.

$$E_{on} = \int_{t_2}^{t_1} V_{CE} * I_C * dt$$

Data source:
Double pulse test. The turn-on energy is measured at the second IGBT turn-on. First the IGBT is turned on as long as the linearly increasing current trough inductive load reaches the desired I_C value. When the desired I_C is reached, the IGBT is turned off, and the inductive current commutates to the freewheeling diode. The current during the freewheeling time is considered as constant. At the second turn-on of the IGBT the current is commutated from FWD to IGBT. During OFF-ON transition of the IGBT the V_{GE}, V_{CE} and I_C are recorded and the integral is calculated with t_{Eon}.

Integration limits definition: t_{Eon}

- Integration start time at: 10 % V_{GE}
- Integration stop time at: 3 % V_{CE}

Vincotech´s limits slightly differ from IEC 60747-9 integration limits.

- IEC 60747-9 integration limits: Integration start time at: 10 % V_{GE}
- Integration stop time at: 2 % V_{CE}

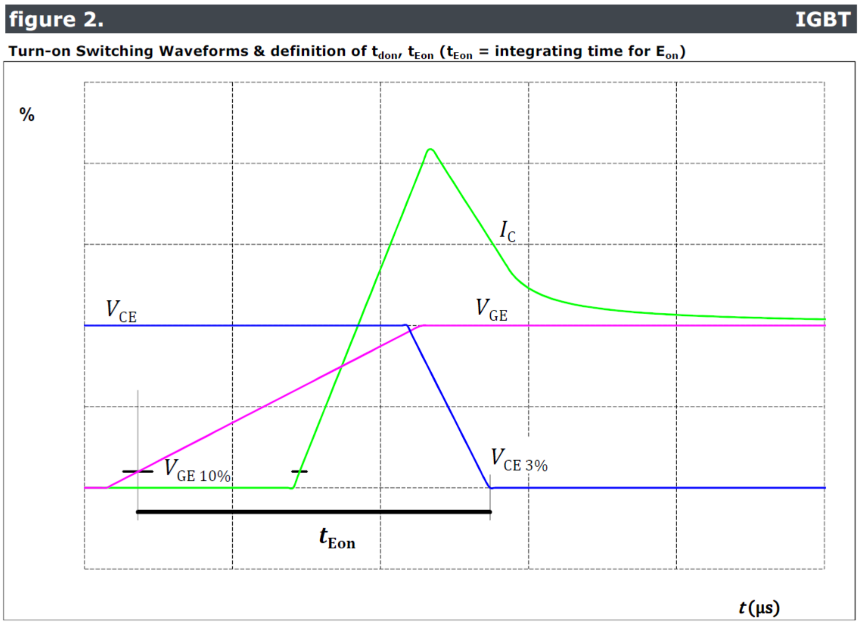


Figure 26: Integration time definition for E_{on}

Conditions:
Defined as in the switching characteristic main chapter.

3.3.6 Turn-off energy - E_{off} (per pulse)

The turn-off energy is the dissipated energy of the IGBT during the on-off transition. By definition this energy is the integral of the power loss over the switching period.

$$E_{off} = \int_{t_2}^{t_1} V_{CE} * I_C * dt$$

Data source:
Double pulse test. The IGBT is turned on as long as the linearly increasing current trough inductive load reaches the desired I_C level. When the desired I_C is reached the IGBT is turned off. During ON-OFF transition of the IGBT the V_{GE}, V_{CE}, I_C is recorded and the integral is calculated with t_{Eoff}.

Integration limits definition: t_{Eoff}

- Integration start time at: 90 % V_{GE}
- Integration stop time at: 1 % I_C

Vincotech´s limits slightly differ from IEC 60747-9 integration limits.

- IEC 60747-9 integration limits: Integration start time at: 90 % V_{GE}
- Integration stop time at: 2 % I_C

figure 1. **IGBT**

Turn-off Switching Waveforms & definition of t_{doff}, t_{Eoff} (t_{Eoff} = integrating time for E_{off})

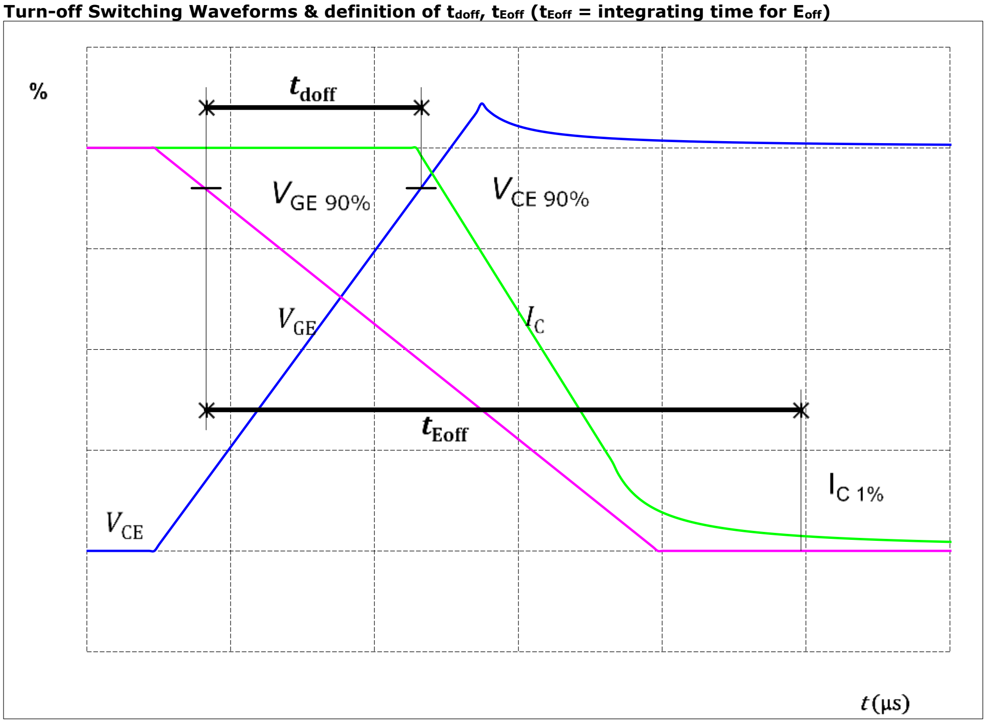


Figure 27: Integration time definition for E_{off}

Datasheet example:
The switching energies are typically given at nominal IGBT current or the middle value of the I_C measurement current series and the middle value of the measurement R_G series, at room temperature 25 °C and high temperature 125 °C and/or 150 °C (usually highest temperature is 25 K below T_{jmax}).

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	
Turn-on energy (per pulse)	E_{on}	Q_{rFWD} = 11,6 µC	±15	600	100	25		3,26		mWs
		Q_{rFWD} = 17,3 µC				125		4,87		
		Q_{rFWD} = 19,2 µC				150		5,37		
Turn-off energy (per pulse)	E_{off}					25		6,61		
						125		8,77		
						150		9,49		

Vincotech measures the switching parameters at five different current levels and five different R_{gon}/R_{goff}. In order to provide a complete overview of the parts´ switching behavior, several charts are plotted in the switching characteristics section of the datasheet.

- Typical switching energy losses as a function of collector current
- Typical switching energy losses as a function of gate resistor

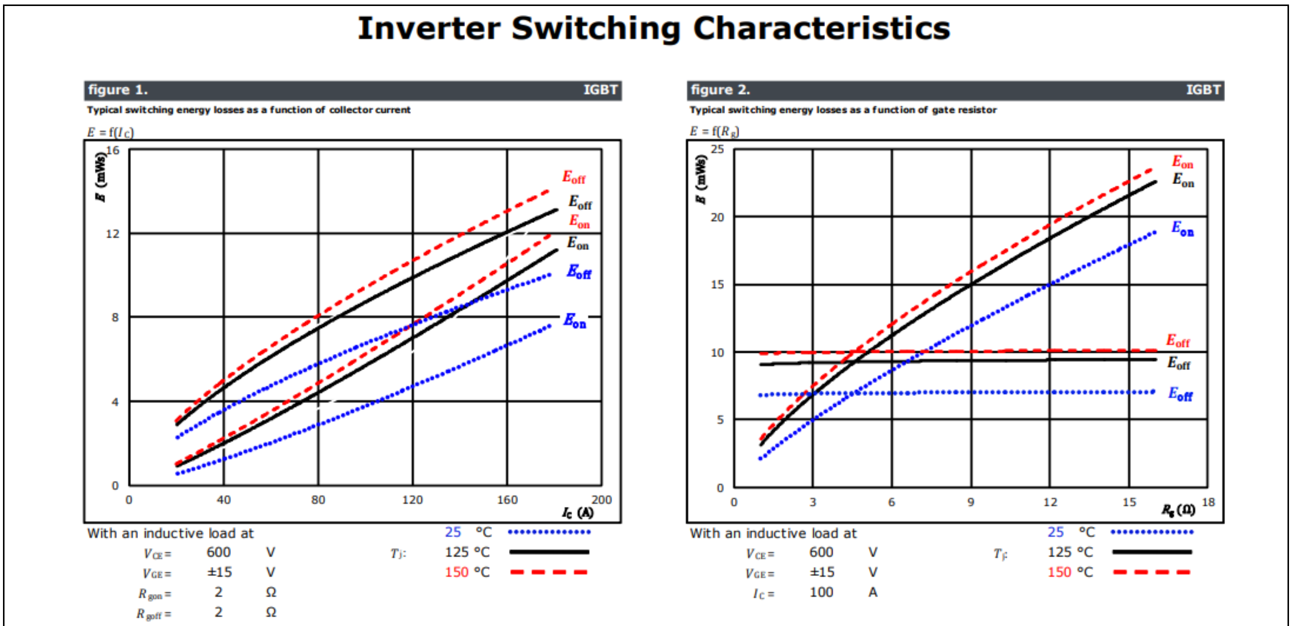


Figure 28: Energies as a function of I_C and R_g

Conditions:
Defined as in the switching characteristic main chapter.

3.3.7 Reverse bias safe operating area (RBSOA)

The RBSOA is important during the turn-off transient. The reverse biased safe operating area curve gives the maximum current and voltage which the device can handle simultaneously during turn-off. Usually, the current that can be turned off is limited to twice the nominal current of the IGBT.

The device will not breakdown if operated within the limits of this curve. The maximum current is a function of the peak voltage appearing between the collector and emitter during turn-off. The peak value of V_{CE} is the sum of the DC link voltage and the product of $L_P \frac{di}{dt}$ where L_P is the stray inductance of the power module. The conditions of this diagram are the junction temperature, the stray inductance, the gate resistor and the gate voltage.

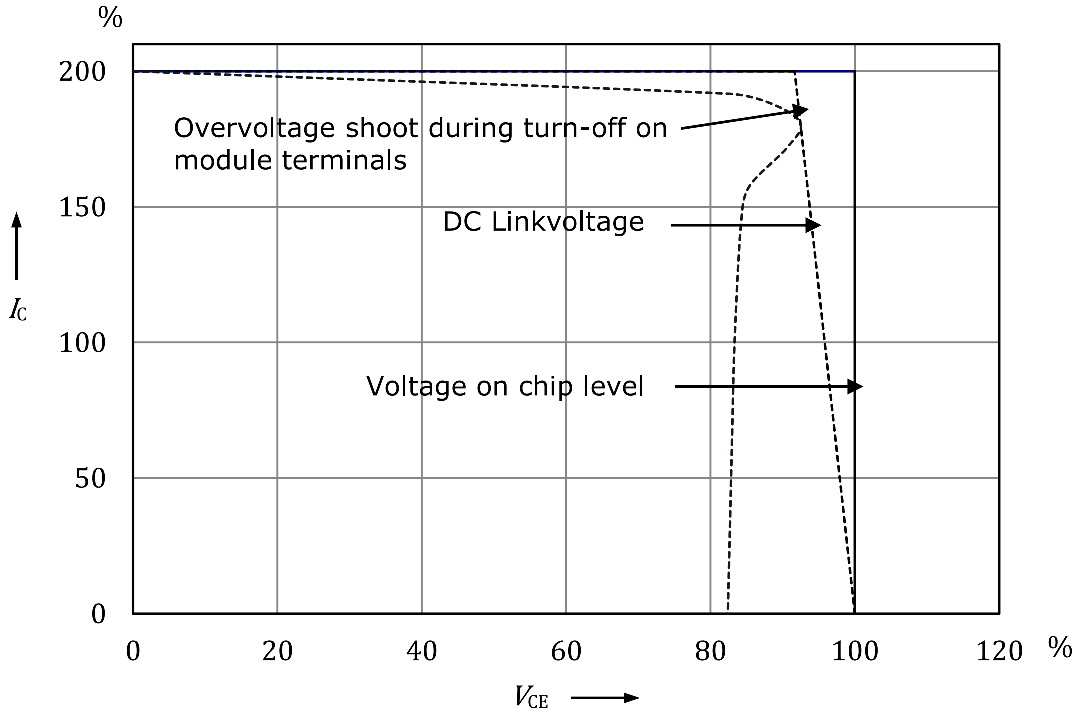


Figure 29: RBSOA diagram of an IGBT

Usually, two lines are provided in the RBSOA diagram. The continuous line gives the values of the current and voltage that the chip itself can handle. Due to the fact that these values cannot be measured, the dashed line illustrates the voltage at the terminals of the module. These are always lower values than at the chip level because of the voltage drop through the bond wires and the internal stray inductance of the module. Normally, the allowed voltage overshoot on the module terminals during turn-off is not shown in the RBSOA diagram but it is used here for a better illustration.

The conditions are the stray inductance, junction temperature, a single pulse or testing frequency, the gate-emitter voltage and the gate resistor as well as the value of the resistor between gate and emitter if any resistor is used.

Data source:
Module stray inductance determined during turn-off switching measurement. Maximum operation voltage derated with the voltage overshoot generated by the internal stray inductance.

$$I_{\mathrm{CMAX}} = 2 \cdot I_{\mathrm{Cnom}}$$

In case of paralleled chips I_{Cnom} is multiplied by the paralleled chip number.

Datasheet example:

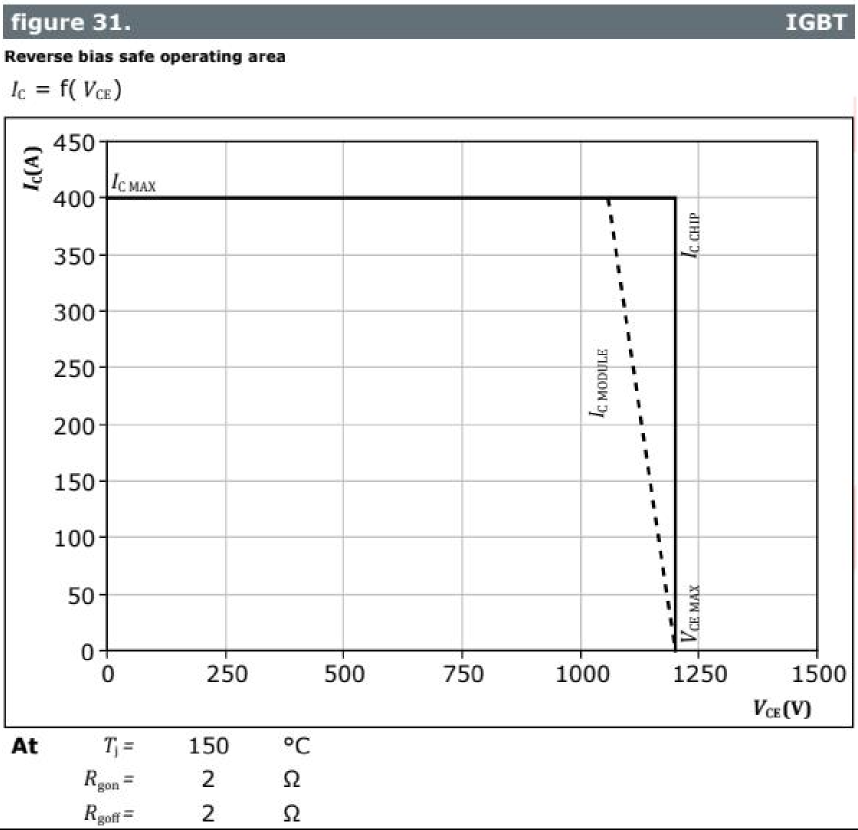


Figure 30: RBSOA diagram of an IGBT

Conditions:
The highest temperature measurement is used at the selected R_g and I_C values.

4 Datasheet parameters diode

4.1 Maximum values

4.1.1 Peak repetitive reverse voltage - V_{RRM}

The repetitive peak reverse voltage is the voltage that a diode can withstand repetitively during blocking without damage. Usually, this value is measured at a junction temperature of 25 °C.

Datasheet example:

Peak repetitive reverse voltage	V_{RRM}		1200	V

Data source:
Supplier datasheet. In parallel devices the value is the same. In series devices the values can be added.

Conditions:

- T_j = 25 °C

4.1.2 Continuous (direct) forward current - I_F

The value of the forward current through a diode I_F is the maximum allowed DC current through the main terminals in forward direction in continuous operation. No additional losses are allowed in the chip or other thermally coupled devices.

The current given in the datasheet is calculated using the following equation. I_F can be referred to the case temperature or to the heatsink temperature (only heatsink reference is used).

$$I_F = \frac{T_{j\,max} - T_s}{V_F \cdot R_{th(j-s)}}$$

The values to determine the continuous forward current are usually given at the maximum allowed junction temperature and a fixed case or heatsink temperature.

Datasheet example:

Continuous (direct) forward current	I_F	$T_j = T_{jmax}$	T_s = 80 °C	40	A

Data source:
For the calculation static measurement, chip maximum junction temperature, and the measured R_{th} value is used.

Conditions:

- $T_j = T_{jmax}$
- T_s = 80 °C

4.1.3 Repetitive peak forward current - I_{FRM}

The diode forward nominal current can be exceeded for a short time. This forward current is defined as repetitive peak collector current I_{FRM} for a specified repetitive pulse duration. This repetitive pulse duration is not specified in Vincotech´s datasheets. It depends on the thermal impedance Z_{th} and the maximum junction temperature T_j. The pulse duration and its repetition rate must be set in order not to exceed the maximum junction temperature T_j of the chip at a given thermal construction.

Datasheet example:

Repetitive peak forward current	I_{FRM}		12	A

Data source:
Supplier datasheet

Conditions:
- Junction temperature ≤ T_{jmax}

4.1.4 Surge (non-repetitive) forward current - I_{FSM}

I_{FSM} is the peak value of the forward current through a diode including all non-repetitive transient currents. The nominal current rating of a diode can be exceeded in an application under some conditions. In case of pre-charging the capacitors of a frequency inverter especially a high current can flow through the diode. This capability is defined as the surge peak forward current. Usually this is given in the datasheet for a half sine wave of 10 ms.

Datasheet example:

Surge (non-repetitive) forward current	I_{FSM}	50 Hz Single Half Sine Wave		270	A
Surge current capability	I^2t	t_p = 10 ms 50 Hz sine	$T_j = 150\,°C$	370	A^2s

Data source:
Supplier datasheet

Conditions:
- Junction temperature T_j
- t_P duration – specified as 10 ms for 50 Hz or 8.3 ms for 60 Hz half sine wave

4.1.5 Surge current capability - I^2t

The I^2t value specifies the surge current capability of the diode for non-switching applications. Characterizes the device power dissipation capability within half-sine wave. The surge forward current and surge current capability are in strong relation, the formula between these two values for a 50 Hz sine wave current is:

$$I^2t = \int_0^{10mS} I^2(t) * t * dt = \frac{1}{2} * I^2{}_{FSM} * 10mS$$

$$I_{FSM} = \sqrt{\frac{2 * I^2t}{10mS}}$$

Datasheet example:

Surge (non-repetitive) forward current	I_{FSM}	50 Hz Single Half Sine Wave	270	A
Surge current capability	I^2t	t_p = 10 ms 50 Hz sine $T_j = 150\,°C$	370	A^2s

Data source:
Supplier datasheet

Conditions:

- Junction temperature T_j
- t_P duration – specified as 10 ms for 50 Hz or 8.3 ms for 60 Hz half sine wave

4.1.6 Total power dissipation - P_{tot}

The total power dissipation is the power that a device can dissipate without exceeding the maximum allowed junction temperature. The case temperature or the heatsink temperature is also given for this condition.

The total power dissipation is a calculated value in every case. The total power dissipation is calculated at maximum ΔT which is reached at maximum junction temperature. Please note that this maximum power dissipation is a theoretical value which can be dissipated by the diode without exceeding the maximum junction temperature in this given thermal construction. The power dissipation capability of one device is a function of thermal construction and thermal gradient ΔT.

Datasheet example:

Total power dissipation	P_{tot}	$T_j = T_{jmax}$	T_s = 80 °C	52	W

Data source:
Vincotech gives the total power dissipation capability as a calculated value based on the following formula:

$$P_{\text{tot}} = \frac{\Delta T}{R_{\text{th(j-s)}}}$$

where:
ΔT – temperature difference between the junction of semiconductor and the heatsink $[K]$; according to supplier datasheet
$R_{th(j\text{-}s)}$ – thermal resistance, junction to heatsink $\left[\frac{K}{W}\right]$; according to Vincotech thermal measurement

Conditions:

- $T_j = T_{jmax}$
- T_s = 80 °C

4.1.7 Maximum junction temperature - T_{jmax}

The maximum junction temperature T_{jmax} is the temperature of the junction of a device that can be tolerated without damage. The maximum operation temperature T_{jop} is usually 25 K lower than the maximum junction temperature.

Datasheet example:

Maximum junction temperature	T_{jmax}		175	°C

Data source:
Supplier datasheet

Conditions:
No condition

4.2 Characteristic values

4.2.1 Forward voltage - V_F

The forward voltage V_F is the voltage drop through a diode when a current flows in the forward direction. The voltage drop is a function of current. A higher current will lead to a higher forward voltage.

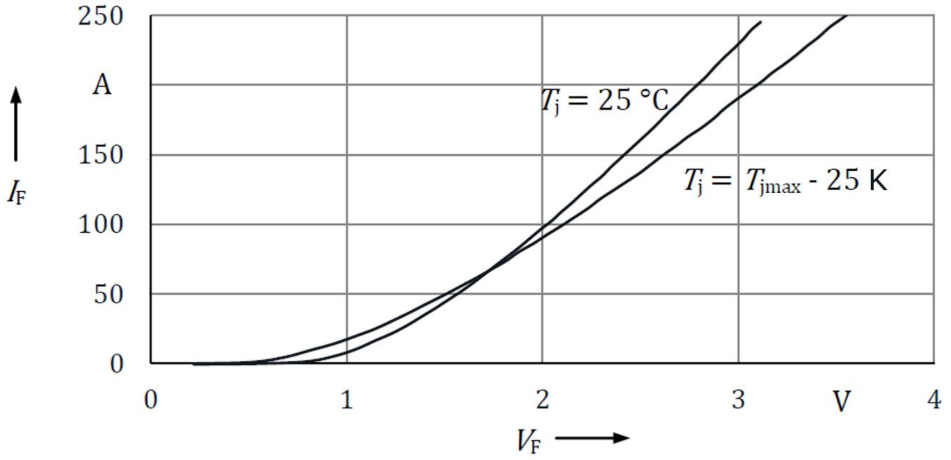


Figure 31: Forward voltage as a function of forward current

As it can be seen in the diagram, the forward voltage is also a function of temperature. Most devices show positive temperature coefficients above a certain current which make it easy to parallel the semiconductors.

Usually V_F is given with the conditions of the nominal chip current at two or three different junction temperatures. If the T_{jmax} is 150 °C two values are given if 175 °C three values.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	
Forward voltage	V_F				25	25 125 150		1,90 1,90 1,88	2,05	V

Data source:
The max. and min. values come from the supplier datasheet.
The typical forward voltage is determined by the typical forward characteristic measurement on the nominal forward current.

The forward voltage is given at a lower temperature (25 °C) and a higher temperature (125 °C or 150 °C or both). It depends on the chip's maximum junction temperature.

Conditions:

- I_F = diode nominal forward current
- T_j = 25 °C, 125 °C or/and 150 °C

4.2.2 Typical forward characteristics

The typical forward characteristic shows the forward current as a function of the forward voltage at two or three different temperatures. Typically, the forward characteristic is given at a low temperature (25 °C) and a high temperature (125 °C or 150 °C or both). It depends on the chip's maximum junction temperature. In case of diodes, the typical forward characteristic is always given up to three times of the nominal forward current.

Datasheet example:

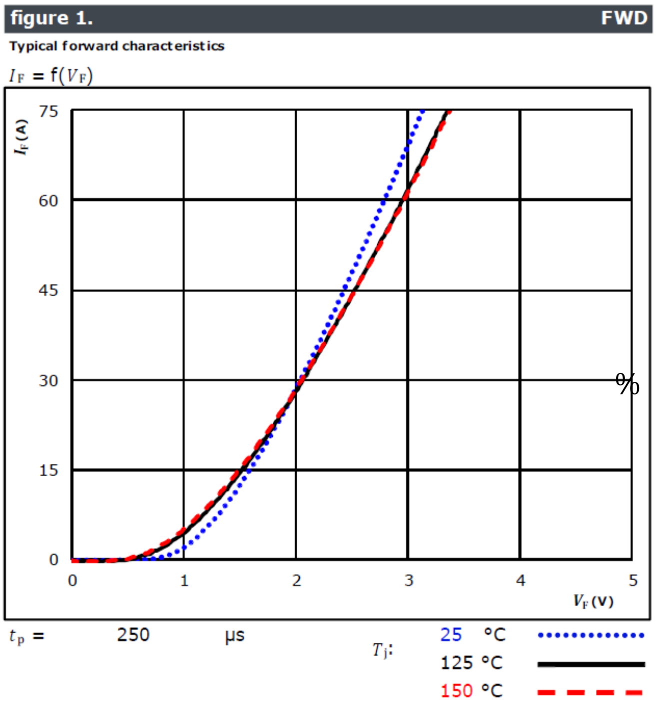


Figure 32: Typical forward characteristic

Data source:

The typical forward characteristics are measured by curve tracer equipment. The bond wire effect, i.e. the voltage drop on bond wires, is minimized by four wire measurement. The forward voltage is always measured on module pins. If a Kelvin sense pin is available then this pin is used for sensing.

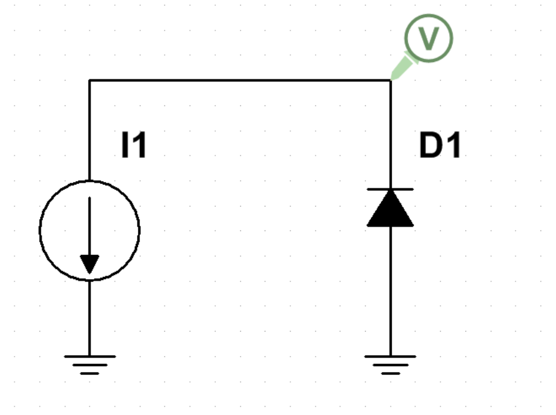


Figure 33: The arrangement of the measurement

Conditions:

- t_p = 250 µs (pulse width of forward current)
- T_j = 25 °C, 125 °C or/and 150 °C

4.2.3 Reverse leakage current - I_R

Reverse leakage current I_R is the current flowing when V_{RRM} is applied in reverse direction to the diode.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
				V_r [V]	I_F [A]	T_j [°C]	Min	Typ	Max	
Static										
Reverse leakage current	I_R			1200		25 150			240 28000	µA

Data source:
Supplier datasheet.
In parallel connection of IGBT with FWD, values are specified for each component, although this value cannot be verified by production test.

Conditions:

- T_j = 25 °C, 125 °C or/and 150 °C
- Repetitive peak reverse voltage: V_{RRM}

4.2.4 Thermal resistance - R_{th}

A detailed general description of the R_{th} measurement can be found at the IGBT section. In case of diode the laboratory measurement of R_{th} is the same.

4.3 Switching characteristics

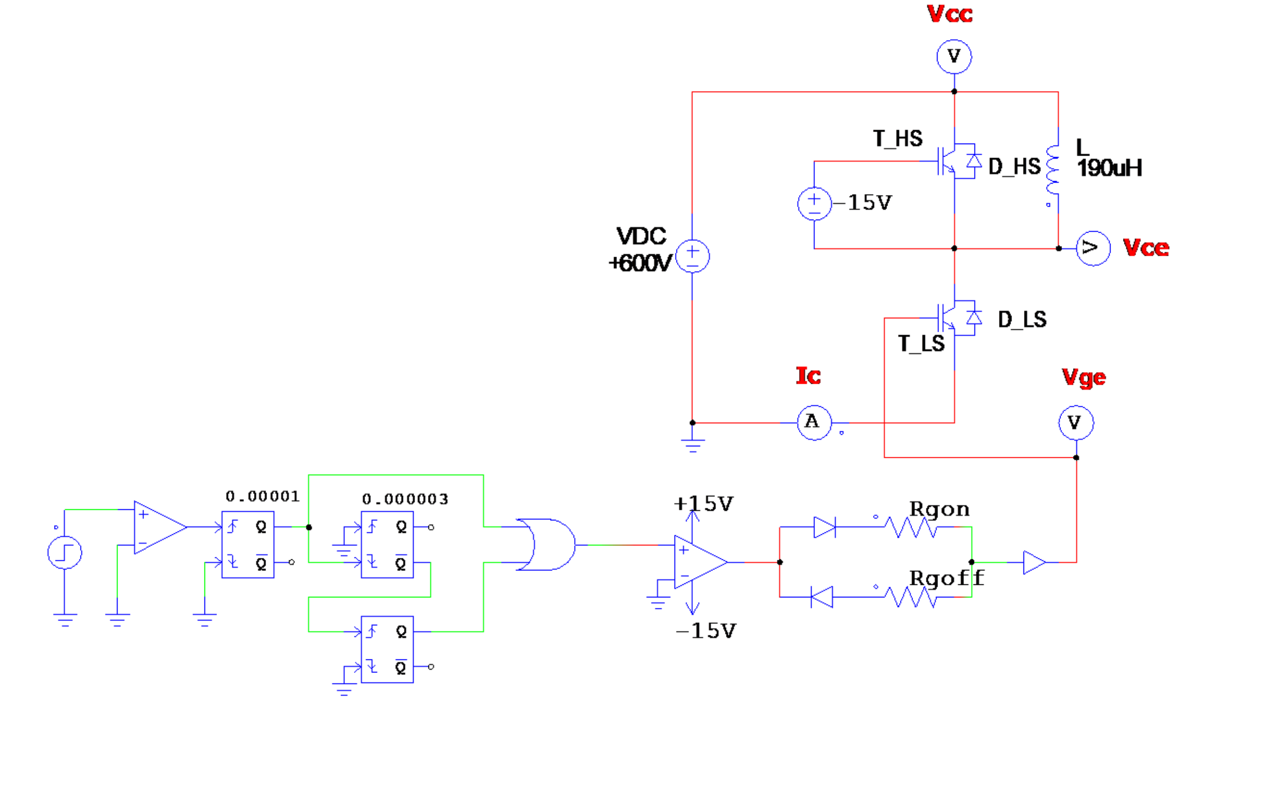


Figure 34: HB switching measurement setup

A detailed description of the dynamic measurement setup can be found at the IGBT section.

4.3.1 Peak recovery current - I_{RRM}

The peak of the recovery current I_{RRM} is the maximum of the diode recovery current which is derived from the IGBT turn-on current waveform.

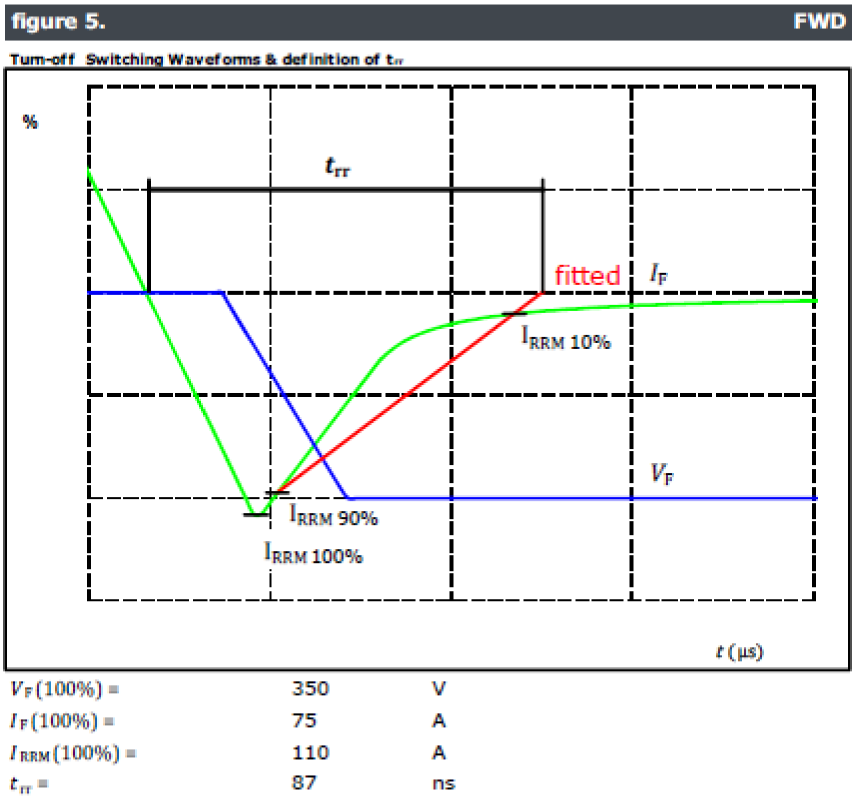


Figure 35: Reverse recovery of the diode

Datasheet example:

Dynamic

Peak recovery current	I_{RRM}					25 125 150		191 216 226		A
Reverse recovery time	t_{rr}					25 125 150		47 128 138		ns
Recovered charge	Q_r	di/dt = 8514 A/µs di/dt = 7480 A/µs di/dt = 7164 A/µs	±15	350	150	25 125 150		8,090 13,155 12,787		µC
Reverse recovered energy	E_{rec}					25 125 150		2,837 4,160 3,926		mWs
Peak rate of fall of recovery current	$(di_{rf}/dt)_{max}$					25 125 150		12381 9491 8721		A/µs

As the switching behavior of the diode strongly depends on IGBT turn-on speed, all these parameters have only a meaning at a certain di_F/dt, which is the typical fall rate of forward current imposed by IGBT. The fall rate of forward current is measured between -5 % … +5 % of reverse recovery current. That's why always di_F/dt must be specified as parameters.

In the switching section these values can be found in a graphical form, represented as a function of collector current and as a function of IGBT turn-on gate resistance.

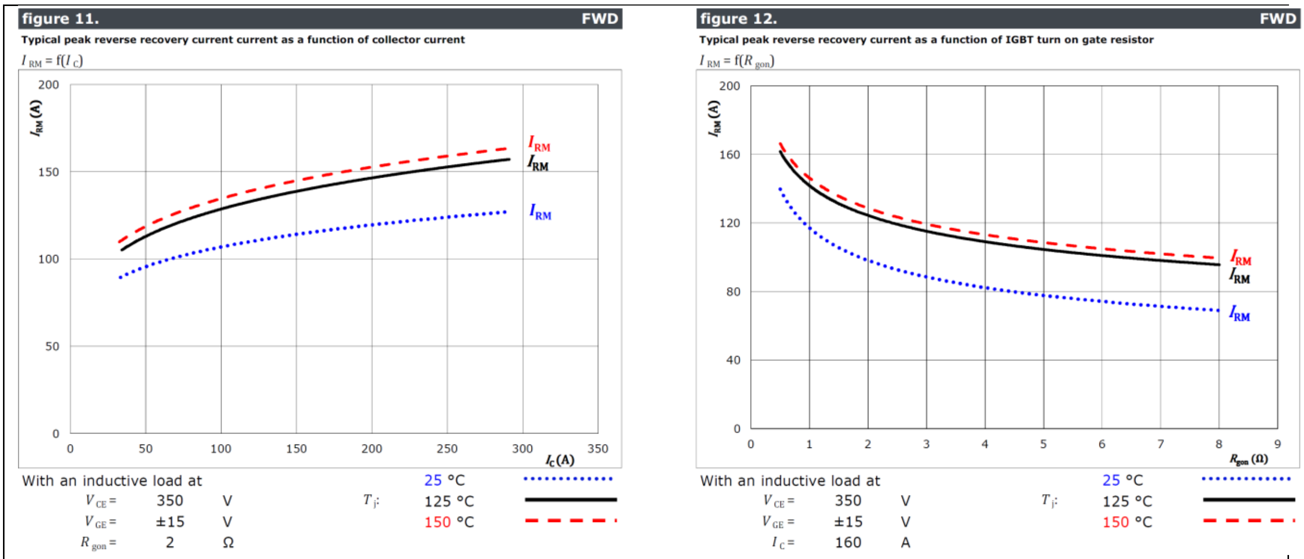


Figure 36: Peak recovery current as a function of collector current and IGBT turn-on gate resistance.

Data source:
Vincotech´s laboratory double pulse characterization measurement. A detailed description of the test setup can be found at the IGBT section.

Conditions:
Conditions are the same as defined in the IGBT section.

4.3.2 Reverse recovery time - t_{rr}

The reverse recovery time is the interval between the first zero-crossing of the decaying diode current and the second zero-crossing determined by the tangent fitted on the diode current at 90 % and 10 % of the peak reverse recovery current.

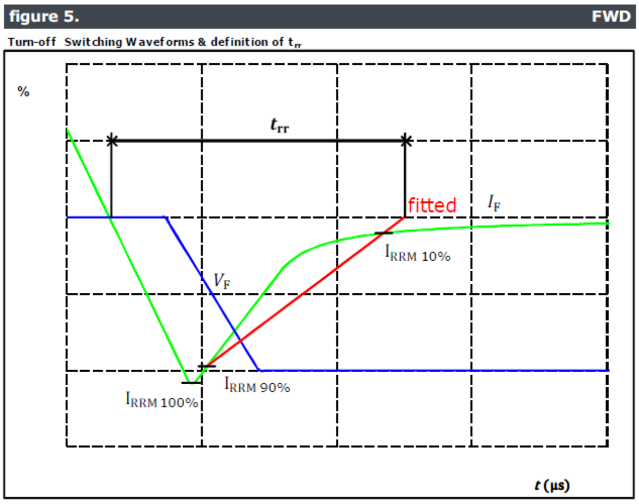


Figure 37: Definition of reverse recovery time

Data source:

Vincotech´s laboratory double pulse characterization measurement. A detailed description of the test setup can be found at the IGBT section.

Conditions:

Conditions are the same as defined in the IGBT section.

Datasheet example:

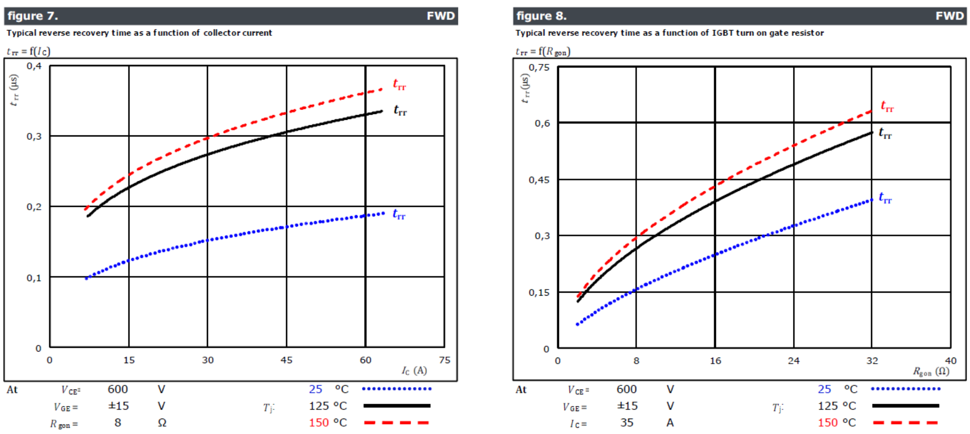


Figure 38: Datasheet examples

4.3.3 Recovered charge - Q_r

The recovered charge is the amount of charge which is recovered during the turn-off event of the diode.

$$Q_r = \int_{t0}^{t1} i_R \mathrm{d}t$$

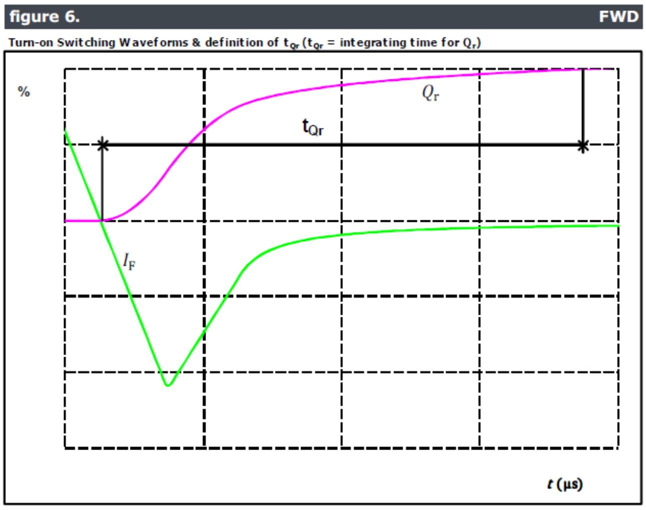


Figure 39: Definition of recovered charge

Integration limits definition: t_{Qr}

Integration start time at: zero crossing of I_F

Integration stop time at: zero crossing time of $I_F + 2*t_{rr}$

Conditions:

Defined above in the IGBT switching characteristic section

Datasheet example:

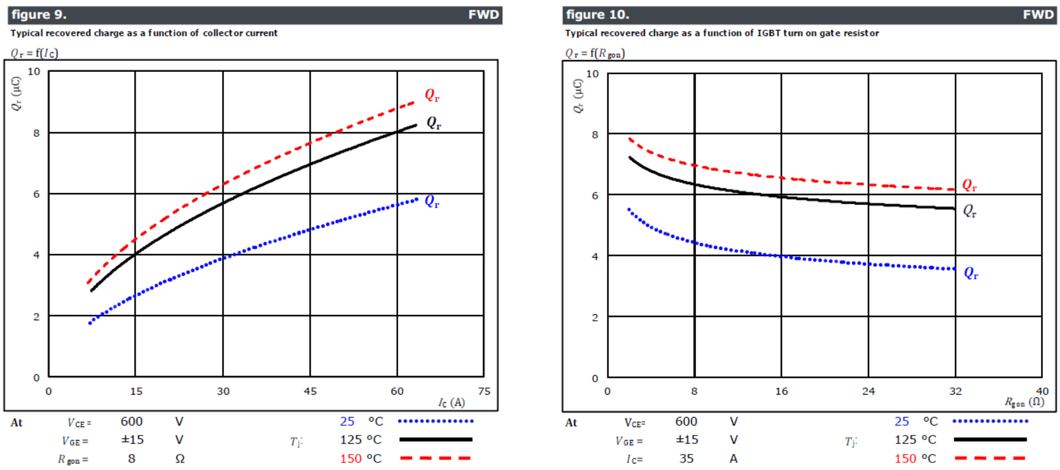


Figure 40: Datasheet examples

4.3.4 Reverse recovery energy - E_{rec}

The reverse recovered energy is the power dissipation of the diode during its turn-off event.

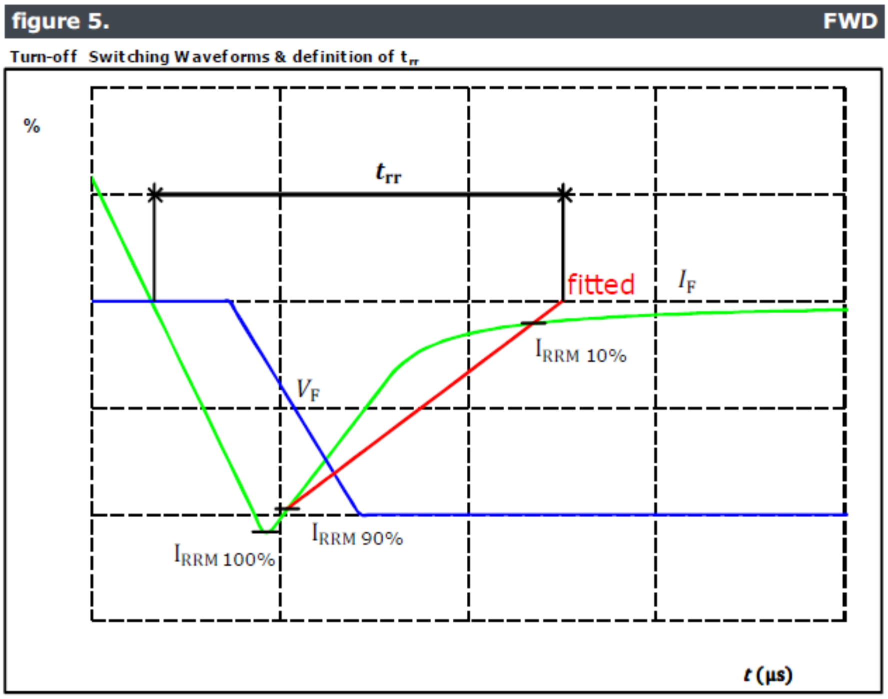


Figure 41: Diode recovery waveform

E_{rec} is calculated with the following formula:

$$E_{rec} = \int_{t0}^{t1} i_R \cdot v_R \cdot dt$$

t_0 = zero crossing time of I_F
$t_1 = t_0 + 2 * t_{rr}$

The specified conditions are the forward current, the rate of the falling current decay ($-di_F/dt$), the reverse voltage and the junction temperature.

Data source:
Double pulse test. The switch in the commutation loop is turned on taking over the output current of the power module. V_F and I_F are monitored simultaneously. In case of differential probe measurement the diode voltage is measured directly. In case of single ended probe measurement the diode's voltage is calculated from the DC link voltage and the switched node's potential difference. The diode current is calculated from the measured switch current and calculated output current. During the ON-OFF transition of the diode the product of measured current and voltage is calculated.

Integration limits definition: t_{Erec}

- Integration start time at: zero crossing of I_F
- Integration stop time: zero crossing time + 2* t_{rr}

Conditions:

Defined above in the IGBT switching characteristic section

The switching energy is specified at diode's nominal current or the middle value of the measurement current series and the middle value of the measurement R_g series, at room temperature 25 °C and high temperature 125 °C and/or 150 °C.If the T_{jmax} is 150 °C two values are given if 175 °C three values.

Dynamic

Peak recovery current	I_{RRM}					25 125 150		77 76 77		A
Reverse recovery time	t_{rr}					25 125 150		157 284 311		ns
Recovered charge	Q_r	di/dt = 2681 A/μs di/dt = 2670 A/μs di/dt = 2690 A/μs	±15	600	35	25 125 150		4,34 6,18 6,90		μC
Reverse recovered energy	E_{rec}					25 125 150		1,96 2,82 3,13		mWs
Peak rate of fall of recovery current	$(di_{rr}/dt)_{max}$					25 125 150		2734 2205 2101		A/μs

Vincotech measures the switching parameters at five different current levels and five different R_{gon}/R_{goff} values. In order to provide a complete overview of the part's switching behavior several charts are plotted in the switching characteristics section of the datasheet.

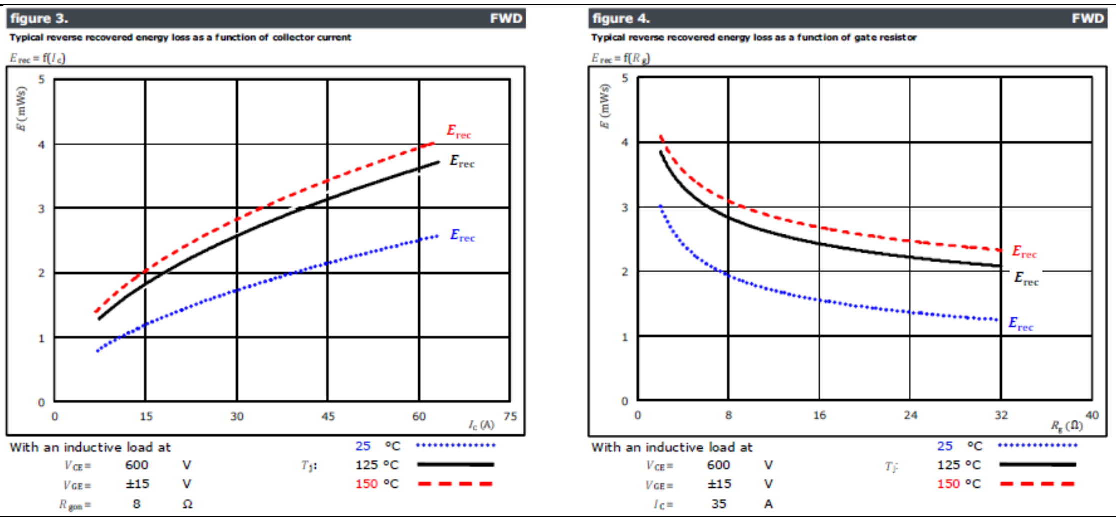


Figure 42: Energies as a function of I_F and R_g
Typical switching energy losses as a function of forward current
Typical switching energy losses as a function of gate resistor

4.3.5 Peak rate of fall of recovery current - dI_r

The peak rate of fall of recovery current is considered to be between 75 % I_{RRM} and 50 % I_{RRM} and is calculated with the following formula:

$$dI_R/dt = \frac{75\% \cdot I_{RRM} - 50\% \cdot I_{RRM}}{t_{75\%} - t_{50\%}}$$

These limits may be changed during the evaluation if the max. value of the fall of reverse recovery current is not within the 75 % to 50 % interval of I_{RRM}.

Datasheet example:

Dynamic

Peak recovery current	I_{RRM}	di/dt = 8514 A/µs di/dt = 7480 A/µs di/dt = 7164 A/µs	±15	350	150	25 125 150		191 216 226		A
Reverse recovery time	t_{rr}					25 125 150		47 128 138		ns
Recovered charge	Q_r					25 125 150		8,090 13,155 12,787		µC
Reverse recovered energy	E_{rec}					25 125 150		2,837 4,160 3,926		mWs
Peak rate of fall of recovery current	$(di_{rf}/dt)_{max}$					25 125 150		12381 9491 8721		A/µs

The rate of fall of forward current is imposed by the IGBT. Meanwhile the rate of fall of recovery current is imposed by FWD. These values can be found in the switching section in a graphical form, represented as a function of collector current and as a function of IGBT turn on gate resistance.

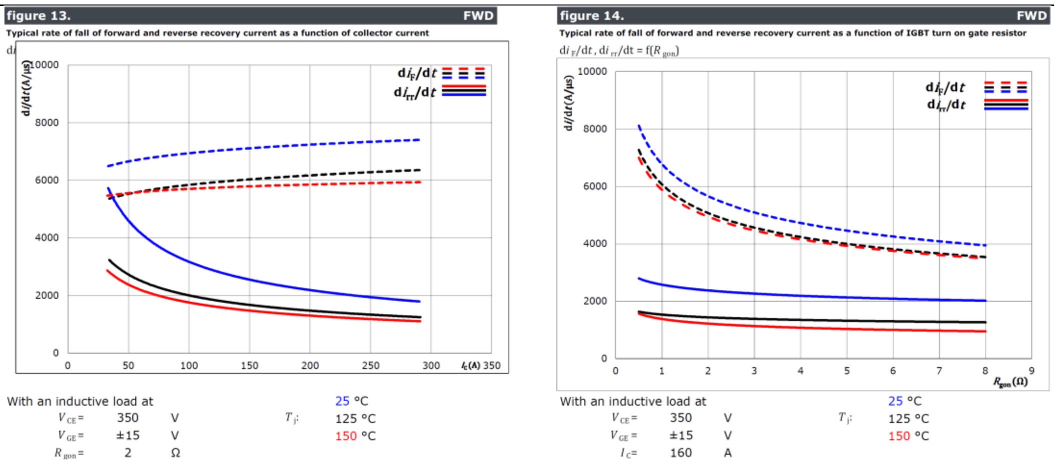


Figure 43: Typical rate of fall of forward and reverse recovery current as a function of collector current and as a function of IGBT turn-on gate resistor

Data source:

Vincotech´s laboratory double pulse measurement. A detailed description of the test setup can be found in IGBT section.

Conditions:

Defined above in the IGBT switching characteristic section.

5 Datasheet parameters MOSFET

5.1 Maximum values of MOSFET

5.1.1 Drain-source voltage - V_{DSS}

The drain-source voltage is the maximum rated voltage between drain and source terminals of a MOSFET when the gate is shorted with the source. Usually, this value is measured at a junction temperature of 25 °C which is specified in the supplier datasheet.

Datasheet example:

Drain-source voltage	V_{DSS}		650	V

Data source:
Supplier datasheet

Conditions:
- T_j = 25 °C
- V_{GE} = 0 V short circuit

5.1.2 Drain current - I_D

The value of the forward current I_D through a MOSFET is the maximum allowed DC current through the main terminals in forward direction in continuous operation. No additional losses are allowed, otherwise the device may be destroyed. The maximum achievable forward current of a MOSFET is limited by the gate voltage and the maximum junction temperature. The current stated in the datasheet is calculated using the following equation. I_D is referred to the maximum allowed junction temperature and 80°C heatsink temperature.

$$I_D = \sqrt{\frac{T_{j\,max} - T_s}{r_{DS(on)} \cdot R_{th(j-s)}}}$$

Calculation method and datasheet representation is the same as IGBT. In case of silicon MOSFET 10 V gate voltage is selected, in case of SiC MOSFET the manufacturer's recommended voltage is being used.

Data source:
Calculated value based on the static measurement, the chip maximum junction temperature and measured $R_{th(j-s)}$ value.

Conditions:
- T_j = T_{jmax}
- T_s = 80 °C
- V_{GS} = apply the recommended operating gate source voltage based on supplier datasheet

5.1.3 Peak drain current - I_{DM}

I_{DM} represents the maximum limit of current in MOSFET SOA (safe operating area).

The maximum current values in the forward direction are limited by the power loss caused by drain-source on-state resistance. Since current ratings are affected by heat dissipation conditions, the maximum allowable current values are specified so that the channel temperature will not exceed the $T_{j(max)}$ value. On the other hand, the drain current I_{DM} that a MOSFET can carry is restricted not only by power loss but also by the current-carrying capability of a package, the maximum channel temperature, the safe operating area and other factors.

Datasheet example:

Parameter	Symbol	Condition	Value	Unit
Peak drain current	I_{DM}	t_p limited by T_{jmax}	510	A

Data source:
Supplier datasheet

Conditions:
- t_p limited by T_{jmax}

5.1.4 Avalanche energy, single pulse - E_{AS}

This is the maximum energy that can be dissipated by the device during a single pulse avalanche operation. Typically, the avalanche rating on the data sheet is the value of the energy that increases the junction temperature from 25 °C to T_{jmax}, assuming a constant case temperature of 25 °C and assuming a specified value of I_D. From the repetitive avalanche current I_{AR} and starting junction temperature of 25 °C, the junction temperature is brought up to the maximum that is stated in the absolute maximum ratings.

Datasheet example:

Avalanche energy, single pulse	E_{AS}	I_D = 13,4 A V_{DD} = 50 V	1954	mJ

Data source:
Supplier datasheet

Conditions:
- I_D – drain current
- V_{DD} – DC-link voltage

5.1.5 Avalanche energy, repetitive - E_{AR}

This value is defined as the energy at I_{AR} during repetitive operation, and the value is usually calculated with a 10 kHz power pulse train with a 50 % duty cycle and the nominal power rating of the device.

Datasheet example:

Avalanche energy, repetitive	E_{AR}	I_D = 13,4 A V_{DD} = 50 V	2,96	mJ

Data source:
Supplier datasheet

Conditions:

- I_D – drain current
- V_{DD} – DC-link voltage

5.1.6 Avalanche current, repetitive - I_{AR}

This is the maximum repetitive current that can be dissipated by the device during avalanche operation at the same circuit conditions described in testing avalanche ruggedness. From starting junction temperature of 25 °C, the junction temperature is brought up to the maximum allowed junction temperature.

Datasheet example:

Avalanche current, repetitive	I_{AR}	t_p limited by T_{jmax} $P_{AV} = E_{AR}$*f	13,4	A

Data source:
Supplier datasheet

Conditions:

- P_{AV} – Avalanche power
- E_{AR} – Avalanche energy

5.1.7 MOSFET d*v*/d*t* ruggedness

When the reverse current of the body diode of a power MOSFET is commutated, it enters the reverse recovery state. After zero-crossing the reverse current of the body diode the voltage is changing (d*v*/d*t*) and a displacement current, $I = C \cdot (\mathrm{d}v/\mathrm{d}t)$ start to flow to the capacitance *C* of the PN junction between drain and gate, thereby causing a voltage drop by the current and resistance. This voltage drop, in turn, causes the parasitic NPN transistor to turn on. At this time, if the drain-source voltage V_{DS} is high the parasitic NPN transistor might enter secondary breakdown. As is the case the MOSFET d*v*/d*t* is very high, the diode might suffer a catastrophic failure, although the failure modes are different.

Datasheet example:

MOSFET dv/dt ruggedness	dv/dt	V_{DS} = 0...480 V	50	V/ns

Data source:
Supplier datasheet

Conditions:
The switched voltage is specified.

5.1.8 Total power dissipation

The total power dissipation is the power that a device can dissipate without exceeding the maximum allowed junction temperature. The case temperature or the heatsink temperature is also given for this condition.

The total power dissipation is a calculated value in every case. The total power dissipation is calculated at maximum ΔT which is reached at maximum junction temperature. Please note that this maximum power dissipation is a theoretical value which can be dissipated by the diode without exceeding the maximum junction temperature in this given thermal construction. The power dissipation capability of one device is a function of thermal construction and thermal gradient ΔT.

Datasheet example:

Total power dissipation	P_{tot}	$T_j = T_{jmax}$	T_s = 80 °C	52	W

Data source:

Vincotech gives the total power dissipation capability as a calculated value based on the following formula:

$$P_{\mathrm{tot}} = \frac{\Delta T}{R_{\mathrm{th(j-s)}}}$$

where:

ΔT – temperature difference between the junction of semiconductor and the heatsink $[K]$; according to supplier datasheet

$R_{th(j\text{-}s)}$ – thermal resistance, junction to heatsink $\left[\frac{K}{W}\right]$; according to Vincotech thermal measurement

Conditions:

- $T_j = T_{jmax}$
- T_s = 80 °C

5.1.9 Gate-Source voltage - V_{GSS}

V_{GSS} is the maximum allowable gate-to-source voltage with drain and source shorted. This rating depends on the di-electric strength of the gate oxide. This value could be specified differently for static and dynamic operation. For Si-based devices static V_{GSS} value is +/-20 V and dynamic value is +/-30 V. In case of SiC devices different limitations may apply.

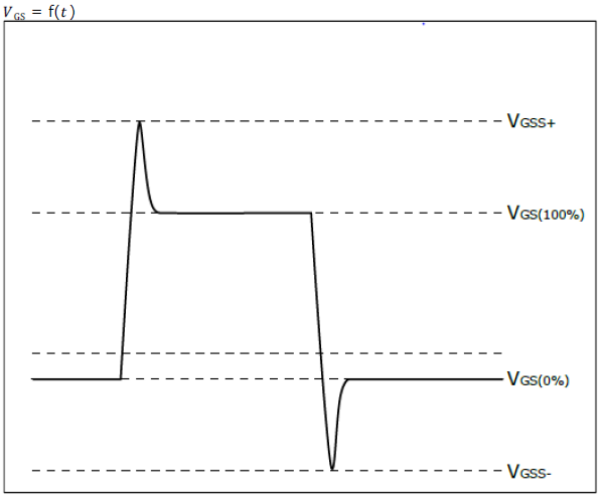
Datasheet example:

Parameter	Symbol	Condition	Value	Unit
Gate-source voltage	V_{GSS}		±20	V

figure 6. MOSFET

Gate maximum operating boundaries

$V_{GS} = f(t)$



At

V_{GSS+} = 25 V

$V_{GS}(100\%)$ = 20 V

$V_{GS}(0\%)$ = -5 V

V_{GSS-} = -10 V

Figure 44: Gate maximum operating boundaries

Data source:
Supplier datasheet

Conditions:
- V_{DS} = 0 V short circuit
- Dynamic – AC (f > 1 Hz)

5.1.10 Reverse diode dv/dt

During commutation the reverse diode of the MOSFET shorts the voltage across its terminals until the I_{RM} is reached. From this point the diode will block the voltage. The slope of the voltage rise is specified by this value.

Datasheet example:

Reverse diode dv/dt	dv/dt	V_{DS} = 0...400 V	15	V/ns

Data source:
Supplier datasheet

Conditions:
The switched voltage is specified.

5.1.11 Maximum junction temperature - T_{jmax}

The maximum junction temperature T_{jmax} is the temperature of the junction of a device that can be tolerated without damage in non-switching condition. The maximum operation temperature T_{jop} is usually 25 K lower than the maximum junction temperature.

Datasheet example:

Maximum junction temperature	T_{jmax}		175	°C

Data source:
Supplier datasheet

Conditions:
No condition

5.2 Characteristic values MOSFET

5.2.1 Drain-source on-state resistance - $r_{DS(on)}$

This parameter states the resistance between drain and source during on-state at a specified drain current. This value is temperature dependent.

The resistance increases with increasing temperature and decreases with rising V_{GS}. Therefore, the MOSFET should be driven with a gate voltage much higher than $V_{GS(th)}$.

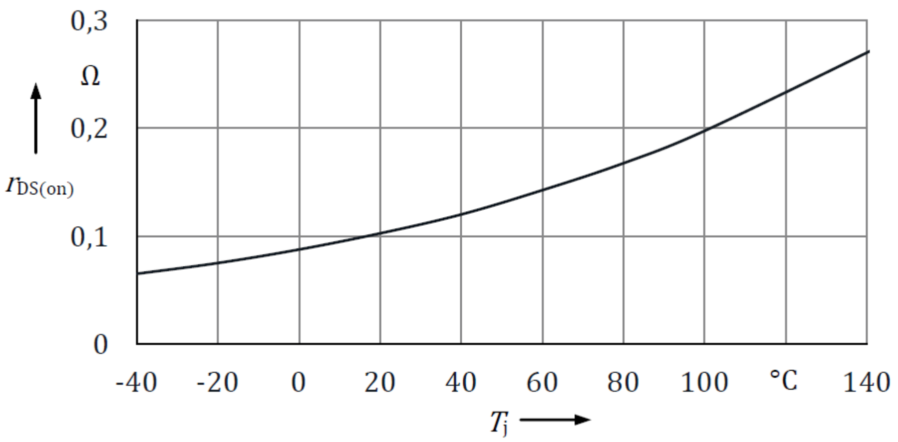


Figure 45: Typical temperature dependency of $r_{DS(on)}$

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	
Static										
Drain-source on-state resistance	$r_{DS(on)}$		10		44,4	25 125		41 84	51,8	mΩ

Data source:

In case of maximum and minimum drain-source on-state resistance the data source is the supplier datasheet.

The typical drain-source on-state resistance is determined by the output characteristic measurement at the same drain current at which the supplier defines the typical or/and maximum value. During the output characteristics measurement the voltage drop is measured. It is always measured on module pins.

If a sense pin is available, then this pin is used for sensing. Alternatively a separate pin with the same potential, which is not loaded by current, is used for sensing.
The drain-source on-state resistance is calculated from the voltage drop with the following formula:

$$r_{\mathrm{DS(on)}} = \frac{V_{\mathrm{DS(sat)}}}{I_{\mathrm{D}}}$$

$V_{\mathrm{DS(sat)}}$ – drain-source saturation voltage
I_{D} – drain current

The drain-source on-state resistance is given at a lower temperature (25°C) and at a higher temperature (125 °C or 150 °C or both). It depends on the chip's maximum junction temperature. If T_{jmax} is 150 °C two values are given if 175 °C three values.

Conditions:

- I_{D} = drain current
- V_{GS} = 15 V or 18 V (most typically gate-source voltages)
- T_{j} = 25 °C, 125 °C or/and 150 °C

5.2.2 Typical output characteristics

In each case the final datasheet contains two types of output characteristics.

Figure 1 shows the drain-source saturation voltage as a function of drain current at two or three different temperatures. Typically, it is given at a lower temperature (25 °C) and a higher temperature (125 °C or 150 °C or both). It depends on the chip's maximum junction temperature. In case of MOSFETs figure 1 is always given on three times of nominal drain current and typically 15 V or 18 V gate-source voltage. It depends on the chip technology.

Figure 2 shows the drain-source saturation voltage as a function of drain current and different gate-source voltages on high temperature. The temperature condition is usually 125 °C or 150 °C. It depends on the chip's maximum junction temperature. In case if MOSFETs the gate-source voltage is always given from 0 V to 20 V with 2 V steps.

The current level of Figure 1 and Figure 2 is given on three times of nominal drain current.

Datasheet Example:

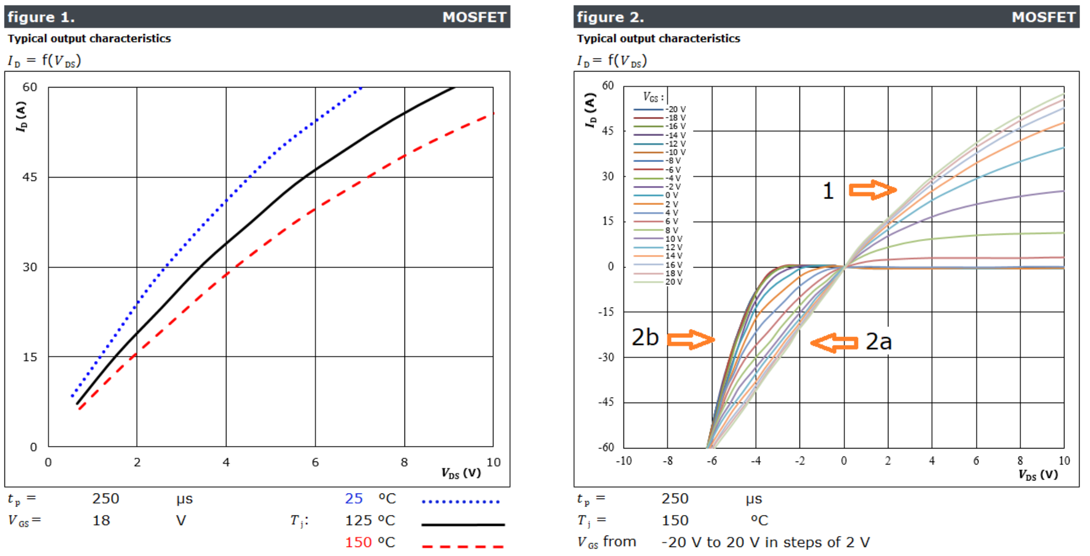


Figure 46: Datasheet example

1 – On-region characteristics
2a – third-quadrant operation, reverse current direction, positive gate-source voltage (open channel)
2b – third quadrant operation, reverse current direction, negative gate-source voltage (body diode)

Data source:
The typical output characteristics are measured by curve tracer equipment.

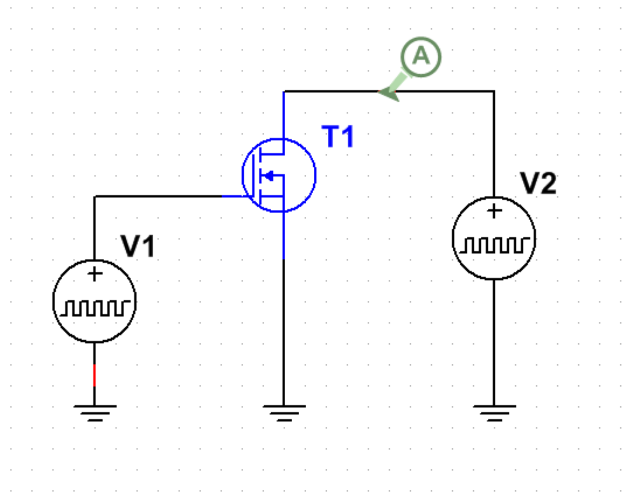


Figure 47: The arrangement of the measurement

Conditions of Figure 46 left side:

- V_{GS} = 15 V or 18 V (most typically gate-source voltages)
- T_j = 25 °C, 125 °C or/and 150 °C
- t_p = 250 µs (pulse width of drain-source voltage)

Conditions of Figure 46 right side:

- V_{GS} = 0 V – 20 V in step of 2 V
- T_j = 125 °C or 150 °C
- t_p = 250 µs (pulse width of drain-source voltage)

5.2.3 Gate-source threshold voltage - $V_{GS(th)}$

The gate-source threshold voltage is the voltage at which the drain current begins to flow. All MOSFETs show variations in $V_{GS(th)}$ between devices which is normal. Therefore, a range of $V_{GS(th)}$ is specified, with the minimum and maximum representing the edges of the $V_{GS(th)}$ distribution. Those are usually given at a junction temperature of 25 °C. The threshold voltage has a negative temperature coefficient, meaning that when the device heats up, the MOSFET will turn on at a lower gate-source voltage. This temperature coefficient is typically around −8 mV/K, the same as for an IGBT.

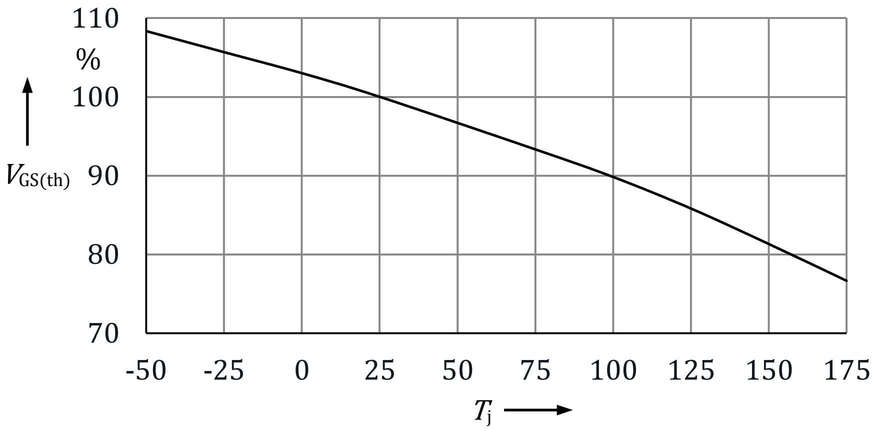


Figure 48: Threshold voltage as a function of junction temperature

Test conditions are the drain current, gate-source voltage which equals the drain-source voltage and junction temperature. These are also given in the datasheet.

Datasheet example:

Gate-source threshold voltage	$V_{GS(th)}$	$V_{GS} = V_{DS}$			0,00296	25	2,4	3	3,6	V

Data source:
Supplier datasheet

Conditions:
- Specified value in the supplier datasheet or: $V_{DS} = V_{GS}$
- Specified value in the supplier datasheet: I_D

.

5.2.4 Typical transfer characteristics

The typical transfer characteristics show the collector current as a function of gate-source voltage at two or three different temperatures. One value is typically given at a low temperature (25 °C) and another at high temperature (125 °C or 150 °C or both). This depends on the chip's maximum junction temperature. In case of MOSFETs the typical transfer characteristic is always given on nominal drain current. During the measurement the Drain-Source voltage V_{DS} kept on 10 V.

Datasheet example:

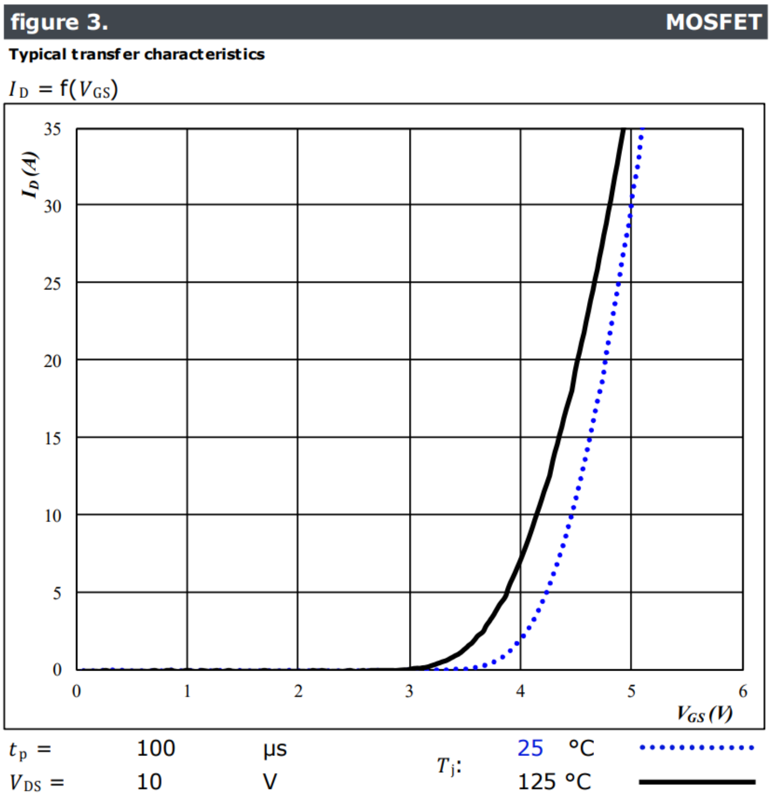


Figure 49: Typical transfer characteristics

Data source:

The typical transfer characteristics are measured by curve tracer equipment by Vincotech.

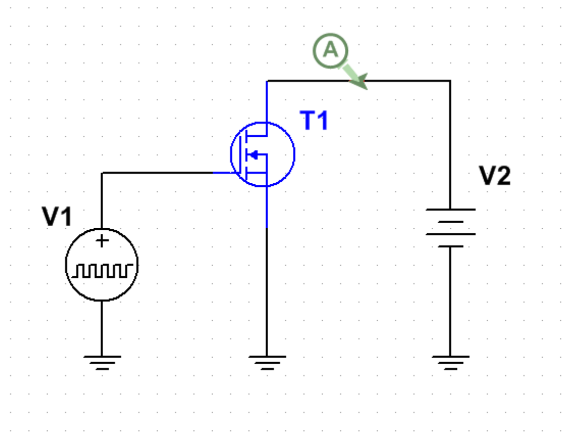


Figure 50: The arrangement of the measurement

Conditions:

- V_{DS} = 10 V
- t_p = 250 µs (pulse width of drain-source voltage)
- T_j = 25 °C, 125 °C or/and 150 °C

5.2.5 Drain current at zero gate voltage - I_{DSS}

The drain leakage current I_{DSS} flows through the device when the gate source terminals are shorted and a voltage of the rated blocking voltage capability is applied across the drain-source terminals. The leakage current increases with increasing junction temperature.
The condition is given with a case temperature of 25 °C; sometimes also with a second higher specified temperature.

Datasheet example:

Zero Gate Voltage Drain Current	I_{DSS}		0	600		25			5	µA

The condition is given with a junction temperature of 25 °C; sometimes also with higher-temperatures.

Data source:
Supplier datasheet

Conditions:

- Specified at the recommended gate-source voltage (V_{GS}) with drain-source shorted (V_{DS} = 0) and T_j = 25 °C.

5.2.6 Drain current at zero gate voltage - I_{DSS}

The drain leakage current I_{DSS} flows through the device when the gate source terminals are shorted and a voltage of the rated blocking voltage capability is applied across the drain-source terminals. The leakage current increases with increasing junction temperature.

Datasheet example:

Zero Gate Voltage Drain Current	I_{DSS}		0	600		25			5	µA

Data source:
Supplier datasheet

Conditions:
- T_j = 25 °C
- V_{GS} = 0 V short circuit
- V_{DS} = V_{DSS}

5.2.7 Internal gate resistance - r_g

Depending on the chip technology, the MOSFET may have an internal gate resistance. The equivalent gate resistance for paralleled chips is given as:

$$r_{gs} = \frac{r_g}{n}$$

where:
r_g is the internal gate resistance in one chip
n –number of paralleled chips.

The equivalent gate resistance in Vincotech’s datasheets is always given as the resultant of the paralleled chips. Paralleled components with the same function in a circuitry are considered to be one component, even if the paralleled chips can be accessed with separate gate pins. In some cases, for a good dynamic current sharing for each individual MOSFET additional gate or source resistor may be assembled in the power module.

These additional balancing resistors are included in the total gate resistor calculation. The value of the internal gate resistor is an important parameter for the gate current peak value scaling at gate driver design.

Datasheet example:

Internal gate resistance	r_g	f = 1MHz	0	100		25		0,7		Ω

Data source:
Supplier datasheet, plus calculation based on the number of paralleled chips and additional gate summarization resistance.

Conditions:

Supplier condition:

- Example 1: f = 1 MHz, open drain
- Example 2: V_{GS} = 0 V, f = 1 MHz, V_{AC} = 25 mV

5.2.8 Gate charge - Q_G

The gate charge is the charge required to raise the gate-source voltage from a specified low level to a specified higher level.

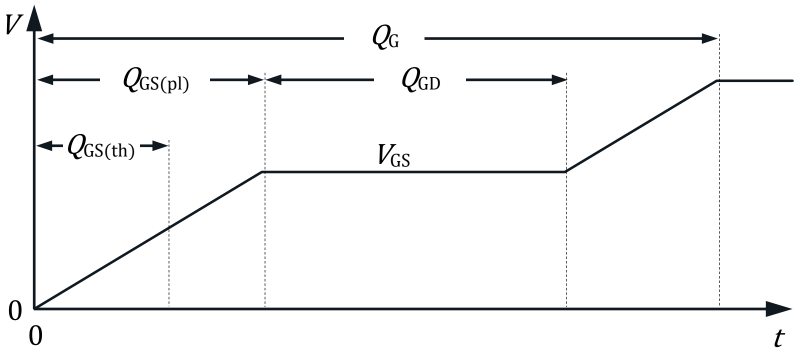


Figure 51: Gate charge curve

The time it takes to charge the gate of a MOSFET can be divided into four sections. In the first step, the charge $Q_{GS(th)}$ is needed to load the gate until the threshold level $V_{GS(th)}$ is reached. This time interval is part of the plateau gate charge $Q_{GS(pl)}$ which raises the level to the load of the Miller plateau. When this level is reached, the gate voltage stays at this level for a certain time because the current loads the Miller capacitance (Q_{GD}). When the Miller capacitance is fully loaded, the gate charge raises the gate potential to its final value.

The calculation method and the data source is the same as for IGBT. In case of MOSFET, the value of gate-to-source and gate-to-drain charge is also given with the same method.

Datasheet example:

Gate charge	Q_g							290		
Gate to source charge	Q_{GS}		0/10	480	44,4	25		36		nC
Gate to drain charge	Q_{GD}							150		

Data source:

Supplier datasheet

Conditions:

- In the characteristic values section, the gate charge is given with V_{GS}, V_{DD} and T_j are specified. In case of unipolar control (0 V to 10 V) only the final gate voltage is shown.

5.2.9 Input capacitance - C_{iss}

In a power MOSFET, the gate is insulated by a thin silicon oxide. Therefore, a power MOSFET has capacitances between the gate-drain, gate-source and drain-source terminals. The gate-drain capacitance C_{gd} and the gate-source capacitance C_{gs} are mainly determined by the structure of the gate electrode, while the drain-source capacitance C_{ds} is determined by the capacitance of the vertical p-n junction.

$$C_{iss} = C_{gs} + C_{gd}$$

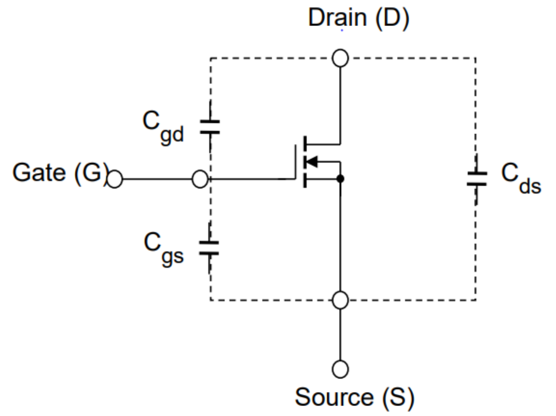


Figure 52: Power MOSFET capacitances

Datasheet example:

MOSFET Characteristic Values

Parameter	Symbol	Conditions					Value			Unit
			V_{GS} [V]	V_{DS} [V]	I_D [A]	T_j[°C]	Min	Typ	Max	
Static										
Short-circuit input capacitance	C_{iss}	f = 1MHz	0	1000		25		2850		pF
Short-circuit output capacitance	C_{oss}							240		
Reverse transfer capacitance	C_{rss}							22,8		

Data source:
Supplier datasheet

Conditions:

- Drain-Source short
- T_j = 25°C
- V_{DS}-specified
- f = 1 MHz
- V_{GS} – measurement voltage specified

5.2.10 Output capacitance - C_{oss}

The output capacitance is the sum of the drain-source capacitance and the gate-drain capacitance:

$$C_{oss} = C_{ds} + C_{gd}$$

Datasheet example:

MOSFET Characteristic Values

Parameter	Symbol	Conditions					Value			Unit
			V_{GS} [V]	V_{DS} [V]	I_D [A]	T_j[°C]	Min	Typ	Max	
Static										
Short-circuit input capacitance	C_{iss}	f = 1MHz	0	1000		25		2850		pF
Short-circuit output capacitance	C_{oss}							240		
Reverse transfer capacitance	C_{rss}							22,8		

Data source:
Supplier datasheet

Conditions:

- T_j = 25 °C
- V_{DS} - specified
- V_{GS} - specified
- f = 1 MHz

5.2.11 Reverse transfer capacitance - C_{rss}

Reverse transfer capacitance:

$$C_{rss} = C_{gd}$$

Datasheet example:

MOSFET Characteristic Values

Parameter	Symbol	Conditions					Value			Unit
			V_{GS} [V]	V_{DS} [V]	I_D [A]	T_j[°C]	Min	Typ	Max	
Static										
Short-circuit input capacitance	C_{iss}	f = 1MHz	0	1000		25		2850		pF
Short-circuit output capacitance	C_{oss}							240		
Reverse transfer capacitance	C_{rss}							22,8		

Data source:
Supplier datasheet

Conditions:

- T_j = 25 °C
- V_{DS} - specified
- V_{GS} - specified
- f = 1 MHz

5.2.12 Reverse diode forward voltage - V_{SD}

The diode forward voltage, V_{SD}, is the specified maximum forward drop of the body-drain diode at a specified value of source current.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
			V_{GE} [V] V_{GS} [V]	V_{CE} [V] V_{DS} [V] V_F [V]	I_C [A] I_D [A] I_F [A]	T_j [°C]	Min	Typ	Max	
Reverse Diode Static										
Diode forward voltage	V_{SD}		0		44,4	25		0,9		V

Data source:
Supplier datasheet

Conditions:

- V_{GS} = 0 V – gate-source voltage
- I_D – drain current, also given at same current that $r_{DS(on)}$
- T_j – junction temperature, also given at 25 °C

5.2.13 Thermal resistance junction to sink - $R_{th(j-s)}$

A detailed description of the R_{th} measurement can be found at the IGBT section.

The only difference between the IGBT R_{th} and MOSFET R_{th} measurement is the temperature-forward voltage dependency curve measurement (V-T curve).
In case of IGBT, the low value measurement current is flowing through the IGBT meanwhile its forward voltage is recorded. In case of MOSFET, its intrinsic body diode forward voltage is recorded under the passive heating interval.

5.3 Switching characteristics

The IEC 60747 standard specifies a different measurements for MOSFETs with resistive load to characterize its switching behavior. Vincotech measures all parameters with inductive load. The switching measurement of MOSFET is done in the same way as for the IGBT. The definition of the measured parameters and the datasheet representation is also the same.

6 Datasheet parameters thyristor

6.1 Maximum values thyristor

6.1.1 Repetitive peak reverse voltage - V_{RRM}

The repetitive peak reverse voltage is the voltage that a thyristor can withstand repetitively during blocking without damage. Usually, this value is measured at a junction temperature of 25 °C.

Datasheet example:

Repetitive peak reverse voltage	V_{RRM}		1600	V

Data source:
Supplier datasheet. In parallel devices the value is the same. In series devices the values can be added.

Conditions:

- T_j = 25 °C

6.1.2 Mean on-state current – $I_{T(AV)}$

The value of the mean on-state current through a thyristor $I_{T(AV)}$ is the maximum allowed DC current through the main terminals in forward direction in continuous operation. No additional losses are allowed in the chip or other thermally coupled devices. The current given in the datasheet is calculated using the following equation. $I_{T(AV)}$ can be referred to the case temperature or to the heatsink temperature (only heatsink reference is used).

$$I_{\mathrm{T(AV)}} = \frac{T_{\mathrm{j\,max}} - T_{\mathrm{s}}}{V_{\mathrm{T}} \cdot R_{\mathrm{th(j-s)}}}$$

The values to determine the continuous forward current are usually given at the maximum allowed junction temperature and a fixed case or heatsink temperature.

Datasheet example:

Mean on-state current	$I_{T(AV)}$	$T_j = T_{jmax}$	T_s = 80 °C	151	A

Data source:
For the calculation static measurement, chip maximum junction temperature, and the measured R_{th} value is used.
Conditions:

- T_j = T_{jmax}
- T_s = 80 °C

6.1.3 Surge on-state current – I_{TSM}

I_{TSM} is the peak value of the forward current through a thyristor including all non-repetitive transient currents. The nominal current rating of a thyristor can be exceeded in an application under some conditions. In case of pre-charging the capacitors of a frequency inverter especially a high current can flow through the thyristor. This capability is defined as the surge peak forward current. Usually this is given in the datasheet for a half sine wave of 10 ms.

Datasheet example:

Surge on-state current	I_{TSM}	t_p = 10 ms	T_j = 130 °C	1250	A
I^2t value	I^2t			7810	A^2s

Data source:
Supplier datasheet

Conditions:
- Junction temperature T_j
- t_P duration – specified as 10 ms for 50 Hz or 8.3 ms for 60 Hz half sine wave

6.1.4 I^2t value

The I^2t value specifies the surge current capability of the thyristor for non-switching applications. Characterizes the device power dissipation capability within half-sine wave. The surge forward current and surge current capability are in strong relation, the formula between these two values for a 50 Hz sine wave current is:

$$I^2t = \int_0^{10mS} I^2(t) * t * dt = \frac{1}{2} * I^2{}_{TSM} * 10mS$$

$$I_{TSM} = \sqrt{\frac{2 * I^2 t}{10mS}}$$

Datasheet example:

Surge on-state current	I_{TSM}	t_p = 10 ms	T_j = 130 °C	1250	A
I^2t value	I^2t			7810	A^2s

Data source:
Supplier datasheet

Conditions:
- Junction temperature T_j
- t_P duration – specified as 10 ms for 50 Hz or 8.3 ms for 60 Hz half sine wave

6.1.5 Mean total power loss - $P_{\text{tot(AV)}}$

The mean total power losses are given during a full cycle. These are the usual power losses generated by the on-state, gate and some additional losses.

$$P_{tot(AV)} = P_{\text{TAV}} + P_{\text{GAV}} + P_{add(AV)}$$

The major losses are caused by the on-state and gate losses:

P_{TAV} – on-state losses caused by the on-state voltage and the current through the device

P_{GAV} – gate losses caused by an applied voltage and the current flowing into the gate

Additional losses $P_{\text{add(AV)}}$ are generated in off-state

$$P_{add(AV)} = P_{TT(AV)} + P_{RQ(AV)} + P_{D(AV)} + P_{R(AV)}$$

$P_{\text{TT(AV)}}$ – losses caused during turn-on switching
$P_{\text{RQ(AV)}}$ – losses caused during turn-off switching due to reverse recovery
$P_{\text{D(AV)}}$ – losses during turn-off state
$P_{\text{R(AV)}}$ – losses resulting from reverse power

Datasheet example:

Mean total power loss	$P_{\text{tot(AV)}}$	$T_j = T_{\text{jmax}}$	T_s = 80 °C	168	W

Data source:

Vincotech gives the total power dissipation capability as a calculated value based on the following formula:

$$P_{\text{tot(AV)}} = \frac{\Delta T}{R_{\text{th(j − s)}}}$$

Within the formula above the following variables are used:

ΔT –difference between the maximum junction temperature of semiconductor according to supplier datasheet and the heatsink temperature [K];

$R_{\text{th(j-s)}}$ – thermal resistance, junction to heatsink $\left[\frac{K}{W}\right]$; according to Vincotech thermal measurement.

Conditions:

- $T_{\text{j}} = T_{\text{jmax}}$
- T_{s} = 80 °C

6.1.6 Maximum junction temperature - T_{jmax}

The maximum junction temperature T_{jmax} is the temperature of the junction of a device that can be tolerated without damage in non-switching condition. The maximum operation temperature T_{jop} is usually 25 K lower than the maximum junction temperature.

Datasheet example:

Maximum junction temperature	T_{jmax}		175	°C

Data source:
Supplier datasheet

Conditions:
No condition

6.2 Characteristic values thyristor

6.2.1 On-state voltage – V_T

The on-state voltage V_T is the voltage drop through a thyristor when a current flows in the forward direction. The voltage drop is a function of current. A higher current will lead to a higher forward voltage.

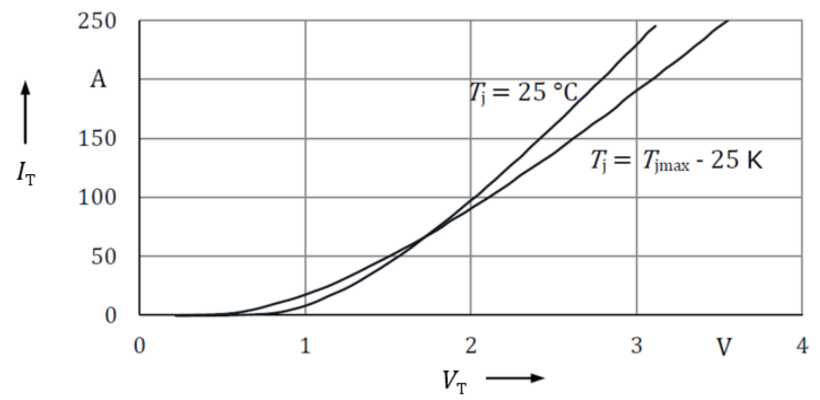


Figure 53: On-state voltage as a function of on-state current

As it can be seen in the diagram, the on-state voltage is also a function of temperature. Most devices show positive temperature coefficients above a certain current which make it easy to parallel the semiconductors.

Usually V_T is given with the conditions of the nominal chip current at two or three different junction temperatures. If the T_{jmax} is 150 °C two values are given if 175 °C three values.

Datasheet example:

On-state voltage	V_T				125	25 125		1,11 1,06	1,2	V

Data source:
The max. and min. values come from the supplier datasheet.
The typical forward voltage is determined by the typical forward characteristic measurement on the nominal forward current. The typical forward characteristics are measured by curve tracer equipment. The bond wire effect, i.e. the voltage drop on bond wires, is minimized by four wire measurement. The forward voltage is always measured on module pins. If a Kelvin sense pin is available then this pin is used for sensing.

The forward voltage is given at a lower temperature (25 °C) and a higher temperature (125 °C or 150 °C or both). It depends on the chip's maximum junction temperature.

Conditions:

- $I_{F(AV)}$ = thyristor nominal forward current
- T_j = 25 °C, 125 °C or/and 150 °C

6.2.2 On-state threshold voltage – $V_{T(TO)}$

The threshold voltage is determined by the intersection point of the straight line and the voltage curve. It is used to calculate power losses in the forward direction of diodes and thyristors.

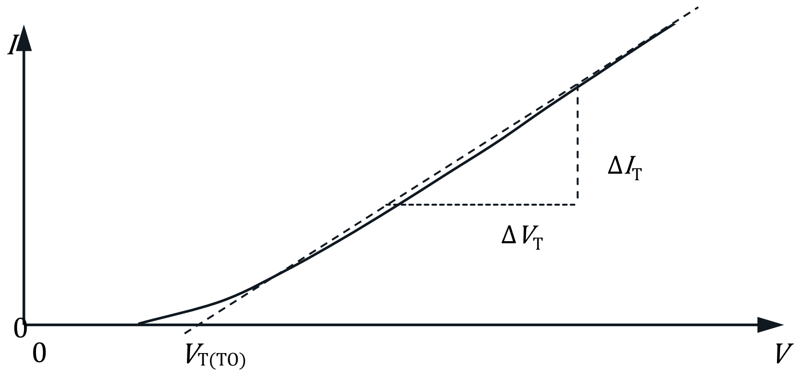


Figure 54: On-state threshold voltage

In datasheets, it is specified in relation to the junction temperature of the semiconductor. Additionally, the on-state slope resistance r_T is needed to calculate the power losses.

Datasheet example:

On-state threshold voltage	$V_{T(TO)}$				45	130			0,85	V

Data source:
Supplier datasheet

Conditions:

- $I_{T(AV)}$: Usually nominal value
- T_j: Usually operating temperature

6.2.3 On-state slope resistance – r_T

Resistance is represented by a straight line as an approximation to the forward characteristics of a semiconductor. This is used to calculate power losses in the conducting direction of diodes and thyristors.

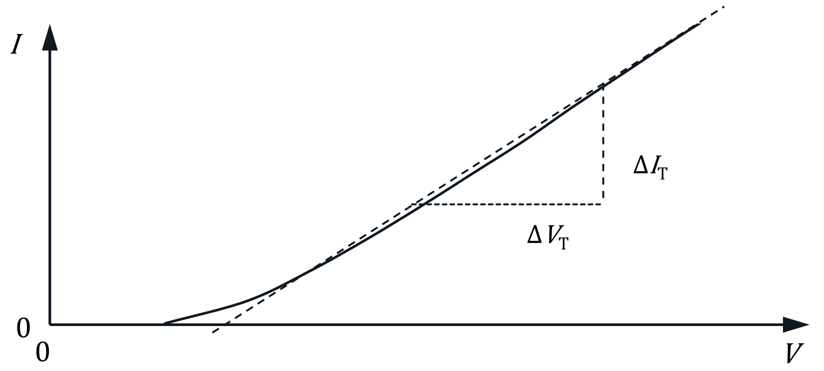


Figure 55: Slope resistance

The straight line of r_T is the quotient of ΔI_T and ΔV_T. In datasheets, it is specified in relation to the junction temperature of the semiconductor. To calculate power losses additionally, the threshold voltage $V_{T(TO)}$ is required.

Datasheet example:

On-state slope resistance	r_T				45	130			7,9	mΩ

Data source:
Supplier datasheet

Conditions:
- $I_{T(AV)}$: Usually nominal value
- T_j: Usually operating temperature

6.2.4 Critical rate of rise of off-state voltage - $(\mathrm{d}v_D/\mathrm{d}t)_{cr}$

This is the maximum value for the rate of rise of a voltage applied to the thyristor in forward direction at which it will not switch from the off-state to the on-state. The thyristor can break through and self-trigger if this value is exceeded.
The conditions are given to be the maximum junction temperature, off-state voltage which is preferably half or two thirds of the repetitive peak off-state voltage V_{DRM}, a linear or exponential rise of the off-state voltage and the triggering condition.

Datasheet example:

Critical rate of rise of off-state voltage	$(\mathrm{d}v/\mathrm{d}t)_{cr}$					130			50	V/µs

Data source:
Supplier datasheet

Conditions:

- T_j – Typical value is T_{jmax}

6.2.5 Critical rate of rise of on-state current - $(\mathrm{d}i_T/\mathrm{d}t)_{cr}$

This value is the maximum allowed rate that the thyristor can withstand without damage. Only a part of the thyristor conducts the main current right after triggering. This is because the conduction begins in the die area right next to the gate and then quickly spreads to cover the whole area. The current carrying capability is therefore limited in the very beginning.
The conditions are given to be the maximum junction temperature, off-state voltage which is preferably half or two thirds of the repetitive peak off-state voltage V_{DRM}, peak value of the on-state current pulse, repetition frequency, pulse width, the triggering conditions and the snubber network, if present.

Datasheet example:

Critical rate of rise of on-state current	$(\mathrm{d}i_T/\mathrm{d}t)_{cr}$					130			1000	A/µs

Data source:
Supplier datasheet

Conditions:

- T_j – Typical value is T_{jmax}

6.2.6 Circuit commutated turn-off time – t_q

The thyristor needs some time after it is switched off by an external circuit before a forward voltage can be applied again. This time is defined as the circuit commutated turn-off time. It is the time interval between the decreasing current and the rising voltage crosses zero. The thyristor will switch on again when the time is below this value.

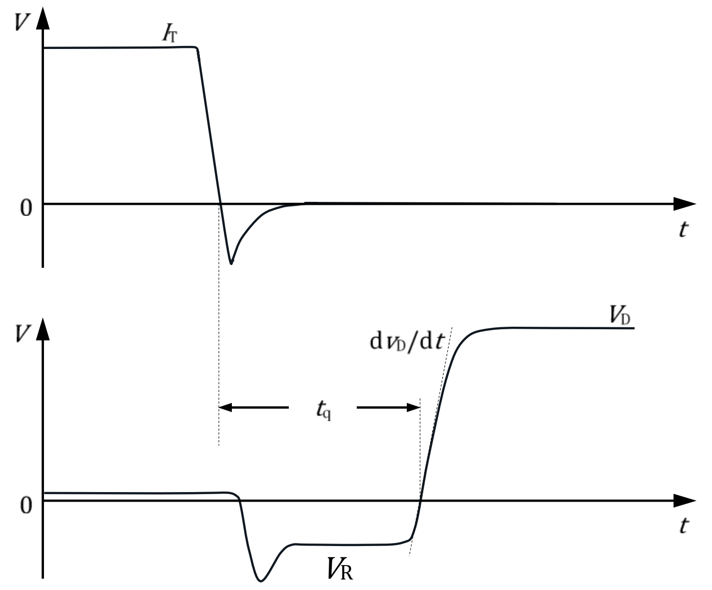


Figure 56: Definition of the circuit commutated turn-off time

The maximum junction temperature, the off-state voltage which is preferably two thirds of the repetitive peak off-state voltage V_{DRM}, the rate of fall of on-state current ($-di/dt$), the on-state current I_T, the continuous (direct) reverse voltage V_R are given as conditions.

Datasheet example:

Circuit commutated turn-off time	t_q					130		150		µs

Data source:
Supplier datasheet

Conditions:

- T_j – Typical value is T_{jmax}

6.2.7 Holding current – I_H

The holding current of a thyristor is the minimum current required through the device to keep it in on-state. The thyristor will switch to off-state when this value is below the holding current, e.g. close to zero crossing.

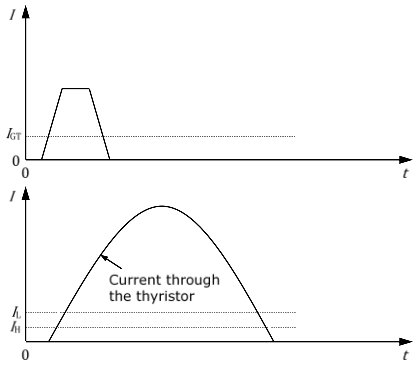


Figure 57: Holding current of a thyristor

The holding current is always below the latching current. The holding current will increase at lower temperatures, so the drive circuit must provide enough current to ensure proper operation at the expected temperature.

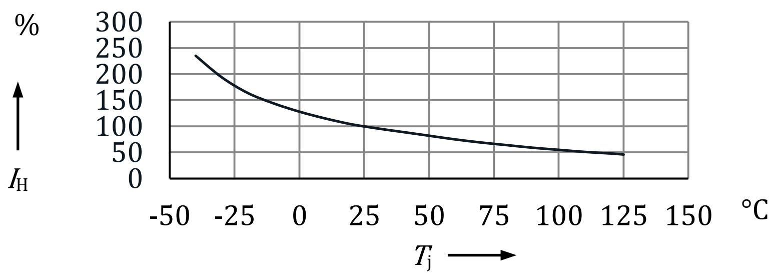


Figure 58: Holding current of a thyristor vs. temperature

A continuous off-state voltage V_D (usually 6 V or 12 V) is another condition in addition to the junction temperature.

Datasheet example:

Holding current	I_H					25			165	mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.8 Latching current - I_L

The latching current of a thyristor is the minimum current required through the device to keep it in on-state after the trigger pulse has been removed and when the thyristor was previously in off-state. The thyristor does not switch to on-state if e.g. the trigger pulse is too short to reach the latching current.

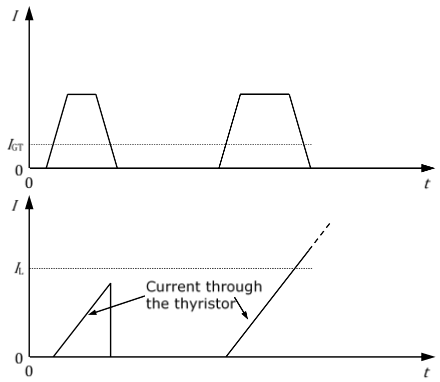


Figure 59: Latching current of a thyristor

The latching current will increase at lower temperatures, so the drive circuit must provide enough current to ensure proper operation at the expected temperature.

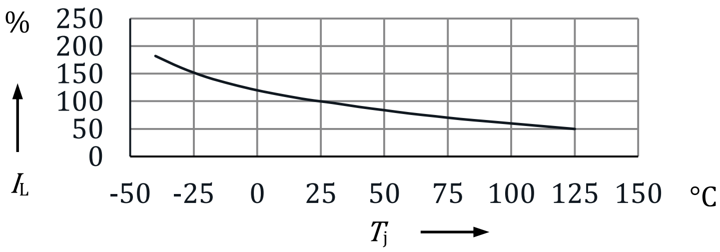


Figure 60: Latching current of a thyristor vs. temperature

The continuous off-state voltage and the values as well as the shape of the gate trigger pulse are further conditions in addition to the junction temperature. To make it simpler, the pulse length t_p, the applied gate current I_G and the di/dt of the gate current are given instead of all parameters of the gate trigger pulse. Often neither the gate current nor di/dt are given because today's gate drive circuits are fast enough so that a square gate pulse is assumed.

Datasheet example:

Latching current	I_L					25			330	mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.9 Direct reverse current – I_{RD}

The direct reverse current I_{RD} is the current flowing when V_{RRM} is applied in reverse direction to the thyristor.

Datasheet example:

Direct reverse current	I_{RD}			1600		25			0,2	mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C
- Repetitive peak reverse voltage: V_{RRM}

6.2.10 Gate trigger voltage – V_{GT}

The gate trigger voltage is the voltage required to produce the gate trigger current.

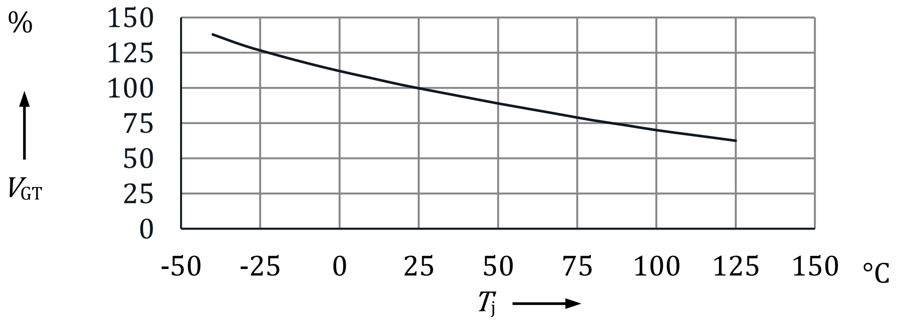


Figure 61: Gate trigger voltage of a thyristor vs. temperature

The necessary gate trigger voltage will increase at lower temperatures. The junction temperature is given as a condition in the datasheet.
A continuous off-state voltage V_D (usually 6 V or 12 V) is an additional condition besides the junction temperature.

Datasheet example:

Gate trigger voltage	V_{GT}					25			1,98	V

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.11 Gate trigger current - I_{GT}

The gate trigger current of a thyristor is the minimum current applied to switch the device from off-state to on-state. Usually, the gate trigger current should be at least 50 % higher than the maximum rated gate trigger current. The thyristor does not switch to on-state if the trigger pulse is too short to reach the latching current, for example.

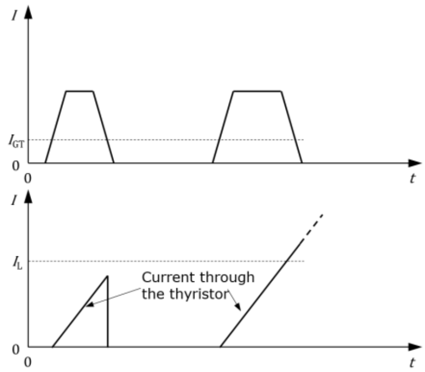


Figure 62: Gate trigger current of a thyristor

The gate trigger current will increase at lower temperatures, so the drive circuit must provide enough current to ensure proper operation at the expected temperature.

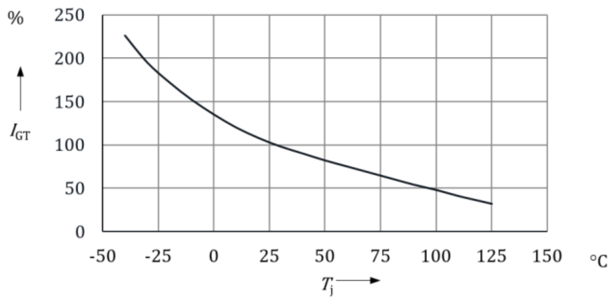


Figure 63: Gate trigger current of a thyristor vs. temperature

A continuous off-state voltage V_T (usually 6 V or 12 V) is another condition in addition to the junction temperature.

Datasheet example:

Gate trigger current	I_{GT}					25			100	mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.12 Gate non-trigger voltage – V_{GD}

At the maximum rated operation temperature, and at a specified main terminal off−state voltage applied, this parameter specifies the maximum DC voltage that can be applied to the gate and still not switch the device from off−state to on−state. The rating is defined at quasi worst-case conditions. The non-trigger voltage is of particular importance in a noisy environment where electromagnetic interference can lead to spurious thyristor triggering. Inductive or capacitive interference in the triggering circuits must be kept below this value. The junction temperature, preferably two thirds of the repetitive peak off-state voltage V_{DRM} and the gate drive parameters are the specified conditions.

Datasheet example:

Latching current	I_L					25			330	mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.13 Gate non-trigger current - I_{GD}

The maximum value of gate current required to switch the device from the off−state to the on−state under specified conditions. The designer should consider the maximum gate trigger current as the minimum trigger current value that must be applied to the device in order to assure its proper triggering. This is a maximum value and therefore defined at quasi worst-case condition. The non-trigger current is of particular importance in a noisy environment where electromagnetic interference can lead to spurious thyristor triggering. Inductive or capacitive interference in the triggering circuits must be kept below this value.The junction temperature, preferably two thirds of the repetitive peak off-state voltage V_{DRM}, and the gate drive parameters are the specified conditions.

Datasheet example:

Gate non-trigger current	I_{GD}					115	6			mA

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

6.2.14 Gate trigger characteristics

The above mentioned parameters shown in one single figure. Gate current and gate voltage at which none of the thyristors of a specified type are triggered.

Datasheet example:

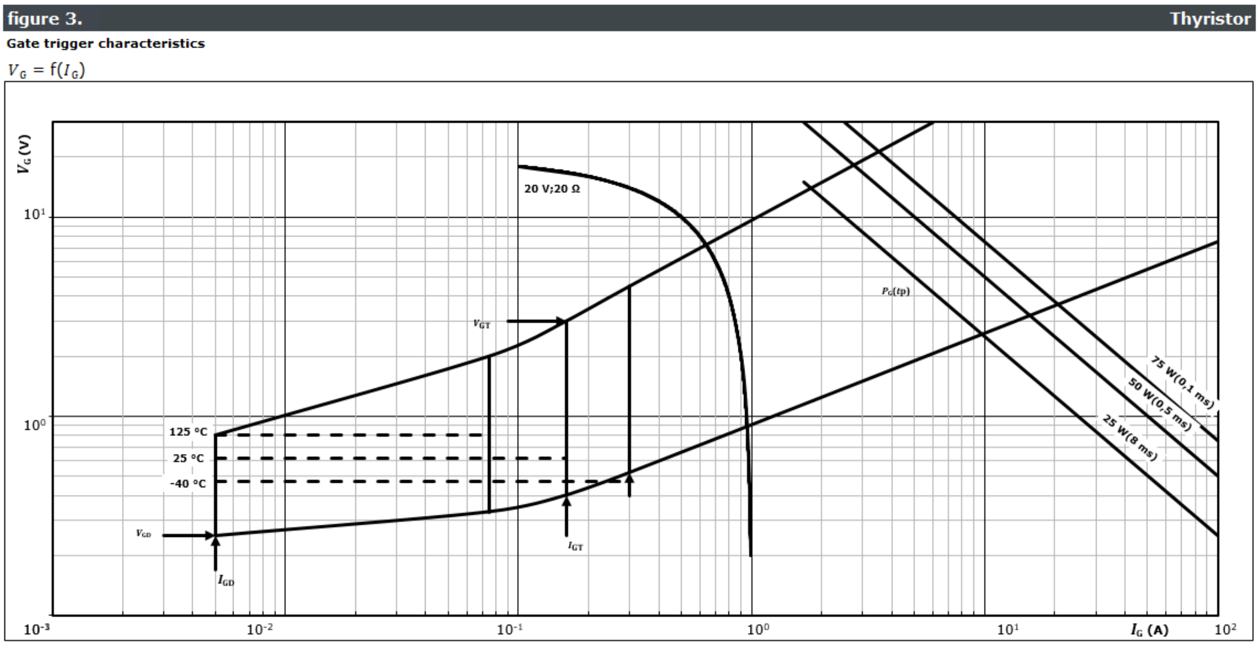


Figure 64: Datasheet example

Data Source:
Supplier datasheet
Power limitation curves imposed by Z_{th}

Conditions:
- ≤ 6V driving voltage in the main circuit
- Rectangular gate current pulse of at least 100 us
- T_j=T_{jmax}

7 Datasheet parameters for passive components

7.1 Thermistor

Most power modules include temperature sensor in order to monitor the power module temperature in application. Usually it is a Negative Temperature Coefficient (NTC) thermistor with resistance that decreases while temperature increases. Since the case to heatsink thermal resistance of a power module is in general a very small the measured temperature is assume to be close to the heatsink temperature.

Several parameters are needed to describe the electrical behavior of a thermistor. The parameters commonly used in Vincotech datasheets are explained here.

7.1.1 Rated resistance – R_{25}, R_{100}

The thermistor's rated resistance R_{25} specifies the nominal resistance value at a defined temperature of 25 °C under zero power conditions. Sometimes, a second value measured at a higher temperature, e.g. 100 °C, is given. In this case, R_{25} specifies the nominal resistance while R_{100} represents the resistance value at the nominal tolerance.

Datasheet example:

Rated resistance	R					25		22		kΩ

Data source:
Supplier datasheet

Conditions:

- T_j – Typical value is 25°C

7.1.2 Deviation of R_{100}

The denoted tolerance of a thermistor is only valid at a defined temperature. This tolerance will increase regardless of the direction of temperature change, as the following table illustrates. Therefore, the tolerance at this special point has to be stated separately.

T/°C	R_{nom}/Ω	R_{min}/Ω	R_{max}/Ω	$\Delta_{R/R}$/±%
−55	2089434.5	1506495.4	2672373.6	27.9
0	71804.2	59724.4	83884	16.8
10	43780.4	37094.4	50466.5	15.3
20	27484.6	23684.6	31284.7	13.8
25	22000	19109.3	24890.7	13.1
30	17723.3	15512.2	19934.4	12.5
60	5467.9	4980.6	5955.1	8.9
70	3848.6	3546	4151.1	7.9
80	2757.7	2568.2	2947.1	6.9
90	2008.9	1889.7	2128.2	5.9
100	**1486.1**	**1411.8**	**1560.4**	**5**
150	400.2	364.8	435.7	8.8

Table 3: Example of NTC resistance and tolerance values

Datasheet example:

Deviation of R_{100}	$\Delta_{R/R}$	R_{100} = 1484 Ω				100	-5		5	%

Data source:
Supplier datasheet

Conditions:

- T_j = 100 °C

7.1.3 Power dissipation - *P*

This value shows the maximum allowed power that can be dissipated by the thermistor.

Datasheet Example:

Power dissipation	*P*					25		5		mW

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

7.1.4 Power dissipation constant

The power dissipation constant of a thermistor represents the power required to raise a thermistor's body temperature by 1 K. This constant will change for different ambient temperatures.

$$\delta = \frac{\Delta P}{\Delta T} = \frac{\mathrm{W}}{\mathrm{K}}$$

Datasheet example:

Power dissipation constant						25		1,5		mW/K

Data source:
Supplier datasheet

Conditions:
- T_j – Typical value is 25°C

7.1.5 A-value, B-value (PTC)

In case of PTC the resistance as a function of temperature can be calculated with the following equation:

$$\mathrm{R}(T) = 1000\,\Omega * [1 + A * (T - 25\ ^{\circ}C) + B * (T - 25\ ^{\circ}C)^2]$$

The thermistor’s A- and B-value is provided in the datasheet to calculate the resistance-temperature relationship.

Datasheet example:

A-value	$A_{(25/50)}$					25		$7{,}635*10^{-3}$		1/K
B-value	$B_{(25/100)}$					25		$1{,}731*10^{-5}$		1/K²

Data source:
Supplier datasheet

Conditions:
- T_{j} – Typical value is 25°C

7.1.6 B-value (NTC)

The curve fit constant B is specified through resistance measurements at 25 °C and 100 °C. The unit of B is Kelvin. The usual value is between 2000 K and 6000 K. Sometimes B is given with different temperature values such as $B_{(25/80)}$ or $B_{(25/50)}$.
It is necessary to describe the R/T curve progression of the NTC thermistor with the following equation:

$$R(T) = R_{25} \cdot e^{\left(B_{25/100} \cdot \left(\frac{1}{T} - \frac{1}{T_{25}}\right)\right)}$$

The B-value is determined by the ceramic material and can be calculated through this expression:

$$B = \frac{\ln(R_{25}) - \ln(R_{100})}{\frac{1}{T_{25}} - \frac{1}{T_{100}}}$$

$R(T)$ – resistance at any temperature
R_{25} – rated resistance at 25 °C (datasheet value)
R_{100} – resistance at 100 °C
$B_{25/100}$ – curve fit constant, also sensitivity index (datasheet value)
T_{25} – 25 °C in Kelvin (298.15 K)
T_{100} – 100 °C in Kelvin (373.15 K)
T – NTC temperature in Kelvin

Datasheet example:

B-value	$B_{(25/50)}$	Tol. ±1 %				25		3962		K
B-value	$B_{(25/100)}$	Tol. ±1 %				25		4000		K

Data source:
Supplier datasheet

Conditions:

- T_j – Typical value is 25°C

7.1.7 Vincotech thermistor reference

All thermistors have a unique identifier, for Vincotech internal identification purposes.

Datasheet example:

Vincotech thermistor reference									I	

Data source:
Supplier datasheet

Conditions:

- No condition

7.2 Capacitor

The purpose of the integrated DC link capacitors in power modules is to moderate the voltage overshoot caused by the internal module stray inductance. The parameters for the integrated capacitors commonly used in Vincotech datasheets are explained here.

7.2.1 Maximum DC voltage - V_{MAX}

The maximum voltage that can be applied to the capacitor without damage to its dielectric material.

Datasheet example:

Maximum DC voltage	V_{MAX}		500	V

Data source:
Supplier datasheet

Conditions:

- T_j = 25 °C

7.2.2 Operation temperature - T_{op}

The operation temperature is a temperature range the capacitor can withstand without damage.

Datasheet example:

Operation Temperature	T_{op}		-55...+125	°C

Data source:
Supplier datasheet

Conditions:
No conditions

7.2.3 Capacitance - *C*

The nominal capacitance value of a device.

Datasheet example:

Capacitance	*C*						270		nF

Data source:
Supplier datasheet

Conditions:
- T_j = 25 °C
- DC bias voltage = 0 V

7.2.4 Tolerance

The minimum and maximum capacitance tolerance in percent.

Datasheet example:

Tolerance						-20		20	%

Data source:
Supplier datasheet

Conditions:
No conditions

7.2.5 Dissipation factor

The dissipation factor is the ratio of the ESR (equivalent series resistance) and the capacitive reactance X_C (series capacitance) or the active power and the reactive power at a sinusoidal voltage at a given frequency.

Dissipation factor can be used to calculate the ESR value of the capacitor and limit the allowed RMS current on the capacitor.

Datasheet example:

Dissipation factor		f = 1 kHz				25			2,5	%

Data source:
Supplier datasheet

Conditions:
- f = 1 kHz
- T_j = 25 °C

7.2.6 Climatic category

The climatic category indicates the climatic conditions at which the capacitor may be operated.

Datasheet example:

Climatic category							55/125/56	

Data source:
Supplier datasheet

Conditions:
No conditions

7.3 Resistor / Shunt

The currently used shunt resistors are low resistive precision resistors. They can be used to measure AC or DC currents by the voltage drop those currents create across the resistor. The principal of measurement is the Ohm's law:

$$V = I \times R$$

7.3.1 Max DC current - I_{MAX}

Maximum current rating or maximum DC current capability of the shunt is defined by the formula:

$$P = I^2 \times R$$

Datasheet example:

Parameter	Symbol	Conditions	Value	Unit
Max DC current	I_{MAX}	$T_c = 25$ °C	15	A
Power dissipation	P_{tot}	$T_c = 25$ °C	5	W

Data source:
Calculation from the power rating specified by supplier and nominal resistance value.

Conditions:
- T_c =25 °C

7.3.2 Power dissipation - P_{tot}

The resistor manufacturer has determined the maximum power in still air and/or with a specified heatsink that will limit the resistor´s internal hot spot temperature to a safe level. This is the rated power and must not be exceeded. In power module applications, the maximum power capability is used as reference, considering that the heat conduction performances of the power module is much higher.

Datasheet example:

Parameter	Symbol	Conditions	Value	Unit
Max DC current	I_{MAX}	$T_c = 25$ °C	15	A
Power dissipation	P_{tot}	$T_c = 25$ °C	5	W

Data source:
Supplier datasheet

Conditions:
- T_c =25 °C

7.3.3 Resistance - *R*

The most important parameter of the shunt resistor is its nominal resistance. This allows to calculate the voltage drop across its terminals when a given current passes over the shunt. A Kelvin connection to a four-terminal resistor is essential for precise current sensing. This four-terminal measurement is used in Vincotech´s IPM modules, or the shunt is connected in a four-terminal mode to additional module pins where the customer has direct access to the shunt.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
						T_j[°C]	Min	Typ	Max	
Static										
Resistance	R							22		mΩ
Tolerance							-1		+1	%
Temperature coefficient	t_c					20 - 60			30	ppm/K
Internal heat resistance	R_{thi}								10	K/W
Inductance	L								3	nH

Data source:
Supplier datasheet

Conditions:
- T_c = 25 °C

7.3.4 Tolerance

The shunt resistor tolerance will determine the current measurement accuracy. This tolerance doesn’t consider other factors like thermocouple effect, temperature coefficient of resistance. This tolerance is just the manufacturing tolerance of the device.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
						T_j[°C]	Min	Typ	Max	
Static										
Resistance	R							22		mΩ
Tolerance							-1		+1	%
Temperature coefficient	t_c					20 - 60			30	ppm/K
Internal heat resistance	R_{thi}								10	K/W
Inductance	L								3	nH

Data source:
Supplier datasheet

Conditions:

- T_c = 25 °C

7.3.5 Temperature coefficient - t_c

The shunt´s temperature coefficient expresses its resistance drift over the specified temperature range. The resistance change over the specified temperature range is considered linear.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
						T_j[°C]	Min	Typ	Max	
Static										
Resistance	R							22		mΩ
Tolerance							-1		+1	%
Temperature coefficient	t_c					20 - 60			30	ppm/K
Internal heat resistance	R_{thi}								10	K/W
Inductance	L								3	nH

Data source:
Supplier datasheet

Conditions:

- Temperature range specified by supplier, for example: 20 – 60 °C

7.3.6 Internal heat resistance - R_{thi}

Internal heat resistance is the thermal internal resistance of the component. This is usually determined between the contact or soldering points and the hot spot (center of the resistor material).

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
						T_j[°C]	Min	Typ	Max	
Static										
Resistance	R							22		mΩ
Tolerance							-1		+1	%
Temperature coefficient	t_c					20 - 60			30	ppm/K
Internal heat resistance	R_{thi}								10	K/W
Inductance	L								3	nH

Data source:
Supplier datasheet

Conditions:
- T_c = 25 °C

7.3.7 Inductance - L

This is the internal parasitic stray inductance of the resistor / shunt component.

Datasheet example:

Parameter	Symbol	Conditions					Value			Unit
						T_j[°C]	Min	Typ	Max	
Static										
Resistance	R							22		mΩ
Tolerance							-1		+1	%
Temperature coefficient	t_c					20 - 60			30	ppm/K
Internal heat resistance	R_{thi}								10	K/W
Inductance	L								3	nH

Data source:
Supplier datasheet

Conditions:
- T_c = 25 °C

8 General properties

This section covers general properties of the power module which are not related to specific power module components.

8.1 Storage temperature - T_{stg}

The storage temperature is the ambient temperature range within the module can be stored without mechanical or electrical load so that permanent variations in its metrological properties do not occur. The storage temperature is typically between −40 °C and +125 °C. Limits are given through the module's materials. This is linked neither to the maximum junction temperature T_{jmax} nor to the operation junction temperature T_{jop} of the semiconductors used in the module.

Datasheet example:

Storage temperature	T_{stg}		-40...+125	°C

Data source:
This is a static value in the datasheet. This temperature range applies to all products.

Conditions:
No conditions

8.2 Operation junction temperature under switching condition - T_{jop}

The operation junction temperature T_{jop} is the temperature range of the junction of a semiconductor that can be tolerate without damage. This condition is usually given for operation with conduction losses and switching losses. The operation junction temperature (under switching conditions) is 25 K lower as the maximum junction temperature of the semiconductors.

Datasheet example:

Operation temperature under switching condition	T_{jop}		-40...(T_{jmax} - 25)	°C

Data source:
This is a static value in the datasheet. This temperature range applies to all products.

Conditions:
No condition

8.3 Isolation voltage - V_{isol}

The isolation voltage is the minimum voltage a device has to withstand between the electrical connections and the base. This is also known as a high potential test. All main pins or main terminals as well as the control pins or control terminals are connected during this test. The applied impulse voltage is a function of the working voltage and the overvoltage category.

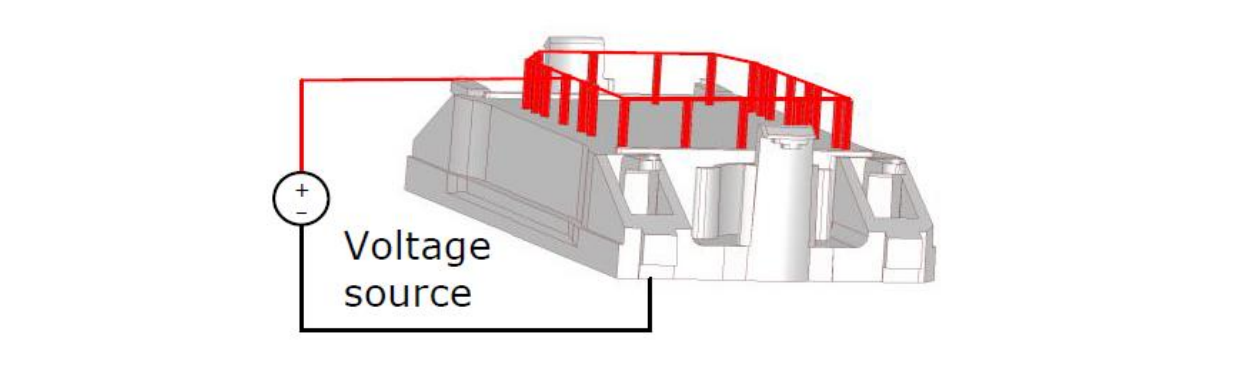


Figure 74: Isolation test of a ceramic

The device passed the test if the leakage current measured with an ampere meter or a current probe is below the specified value. An AC voltage or an equivalent DC voltage can be used. The voltage source is applied for at least one minute for a type test or 1.2 times the voltage for one second for a 100 % production test. The conditions are given as the ambient or case temperature, the isolation voltage, the limit of the isolation current specified in the test specification and the test time if less than 60 seconds.

Datasheet example:

Isolation voltage	V_{isol}	DC Test Voltage*	t_p = 2 s	6000	V
		AC Voltage	t_p = 1 min	2500	V

Data source:

The UL1557 standard requires the minimum test voltages, but Vincotech is testing a higher voltage than the criterion. The test voltage depends on the mechanical construction.

In general the test voltages are as following:

Modules without baseplate – 6000 V DC

Modules with baseplate – 4000 V DC

MiniSKiiP® modules – 5500 V DC

Conditions:

DC Voltage:

- t_p = 2 s (test voltage pulse width)

AC Voltage:

- t_p = 1 min (test voltage pulse width)

8.4 Clearance and creepage distances

Clearance is the shortest distance between two conductive parts, or between a conductive part and the surface of the equipment, measured through air. Components that are mounted on the printed circuit board must also be considered in the evaluation of clearance.

Electrical and environmental factors affect the minimum expected clearance distance. Factors are the pollution degree in the environment that the equipment will be installed in, the overvoltage category of the equipment, the working voltage, the comparative tracking index of the housing material and the specified maximum installation altitude. Creepage distance is the shortest path between two conductive parts, or between a conductive part and the surface of the equipment, measured along the surface of the insulation. All conductive parts are considered when evaluating creepage distance, including the pads around soldered connections.

Electrical and environmental factors affect the minimum expected creepage distance. Factors are the pollution degree in the environment that the equipment will be installed in, the overvoltage category of the equipment, the working voltage, the comparative tracking index of the housing material and the specified maximum installation altitude.

Datasheet example:

Creepage distance			min. 12,7	mm
Clearance			11,17	mm

Data source:
The clearance and creepage distances are measured by mechanical CAD software.

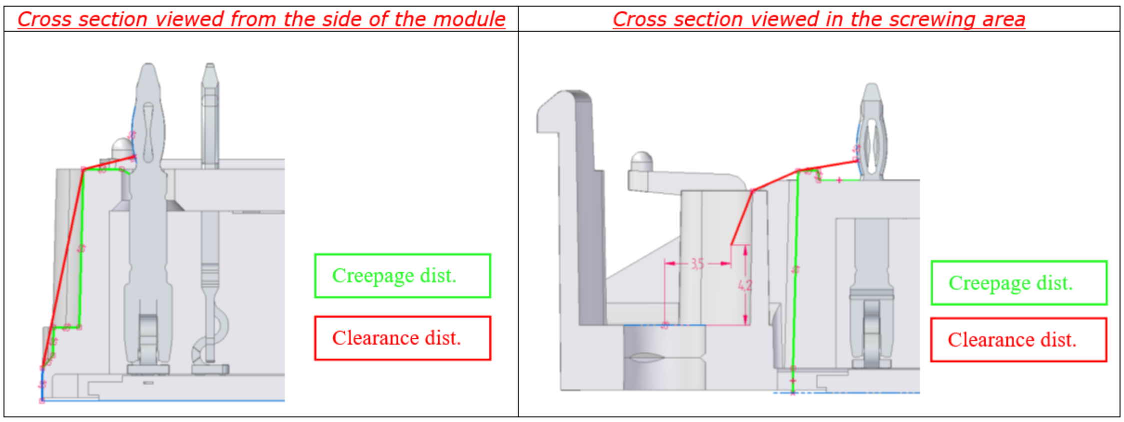


Figure 76: Clearance and creepage

The products are designed according to UL840. This standard requires the minimum clearance and creepage distances. If the value is larger than 12.7 mm the exact value is not given, because in that case the deformation tests may be omitted.

Conditions:
No conditions.

8.5 Comparative tracking index - CTI

Tracking is an electrical breakdown on the surface of an insulating material. A large voltage difference gradually creates a conductive leakage path across the surface of the material by forming a carbonized track.

For power modules, CTI values are categorized in different material groups.

Material group	I	II	IIIa	IIIb
CTI value	600 ≤ CTI	400 ≤ CTI < 600	175 ≤ CTI < 400	100 ≤ CTI < 175

Table 4: CTI values by categories

High-value materials are often used in applications where high voltage is applied or where a high degree of pollution has to be considered.

Datasheet example:

Comparative Tracking Index	CTI		≥ 600	

Data source:
Supplier datasheet

Conditions:
No conditions