

# Discrete IGBT

## Explanation of discrete IGBTs' datasheets

Application Note

### About this document

#### Scope and purpose

This application note is intended to provide an explanation of the parameters and diagrams given in the datasheet of Infineon discrete IGBTs. The designer of power electronic systems requiring an IGBT will be provided with background information to be able to use the datasheet in the proper way.

The following information is given as a hint for the utilization of the IGBT device and shall not be regarded as a description or warranty of a certain functionality, condition or quality of the device.

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## Introduction

# 1 Introduction

Datasheets provide information about products and their parameters, which characterize the products. With this information designers could compare devices from different suppliers. Furthermore, the information indicates the device's limits.

Datasheet values describe the device's behavior at different junction temperatures and testing conditions. The dynamic characterization tests, from which the switching losses are extracted, are related to a specific test setup with its individual characteristics. Therefore, these values can deviate from a final user application and between datasheets of older and newer products.

The attached diagrams, tables and explanations refer to the IKW40N65H5 rev. 2.1 datasheet published in 2015-05-06 as an example. Table 3 and Table 4 only, refer respectively to IHW20N120R5 rev. 2.1 and IHW15N120E1 rev. 2.1. For the latest version of datasheets please refer to Infineon's website [www.infineon.com](http://www.infineon.com).

Infineon's IGBT datasheets are normally arranged to contain:

- A cover page with a short description of part number, IGBT technology and diode in case of DuoPack
- Summarized features, key parameters, applications as well as basic package information
- Maximum rated electrical values and IGBT thermal resistance as well as diodes in case of DuoPack
- Electrical characteristics at room temperature, both static and dynamic parameters
- Switching characteristics at 25°C and 150 or 175°C
- Electrical characteristics diagrams
- Package drawings
- Figures of definition for key parameters
- Revision history

## 1.1 Status of datasheets

There are three different document types available. They correlate to the status of the product development. The datasheet types used are:

Target datasheet, a document that contains values that are expected to be achieved. Values from these datasheets are commonly used for initial calculations and approximations. Nevertheless those information and values cannot be guaranteed for the final product; thus the design of a power system should only rely on values from the final datasheet.

Preliminary datasheet differentiating from a final datasheet in a way that certain data values are still missing, for example the maximum values. These missing values in the preliminary data sheet are marked *to be defined* (t.b.d). The preliminary datasheet is based on engineering samples, which are very close to final products.

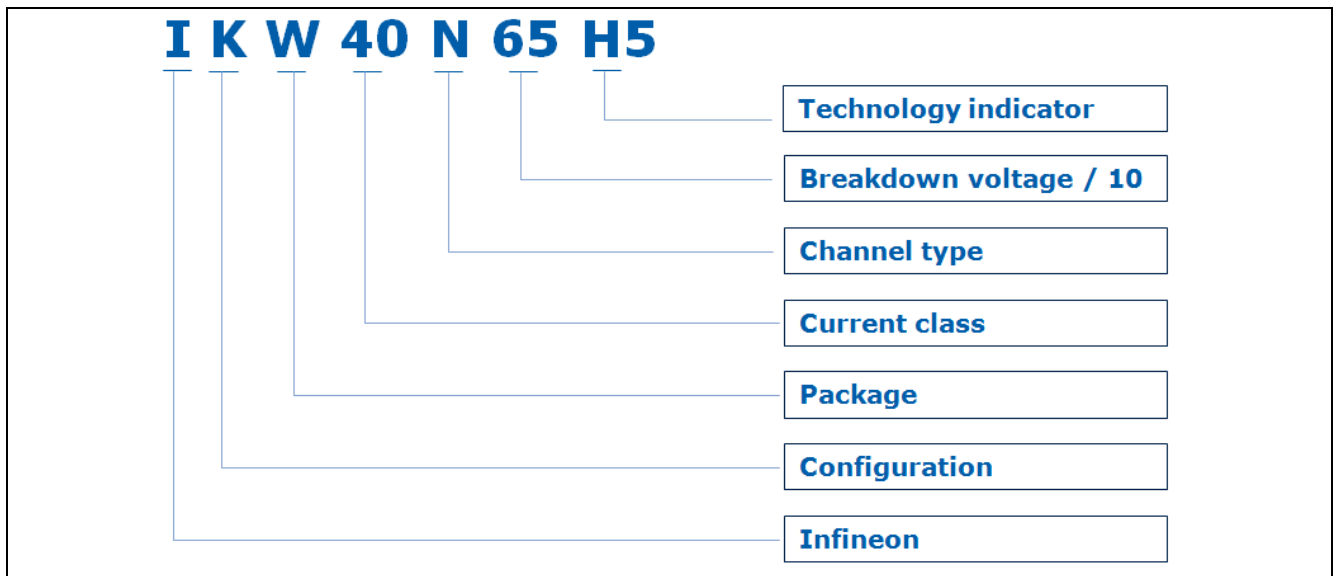
Normally the watermark of 'Draft' exists on preliminary datasheets.

Final datasheet including all the values, which are missing in the preliminary datasheet. Major changes of IGBT and diode characteristics or changes in datasheet values after the release of the final datasheet are accompanied by a Product Change Note (PCN).

## Introduction

### 1.2 Type designation

IGBTs are marked with a part number. This label contains main information related to the part, please refer to Figure 1 for product families launched before December 2014 Figure 7:



**Figure 1 Designation of IGBT part number**

Thus, the part number indicates the manufacturer to be Infineon Technologies, the device configuration single IGBT or DuoPack, the package type, the current class, the channel type, the break down voltage and finally the product generation related to the technology.

Table 1 summarizes a detailed description of possible labels for the different products including discrete IGBTs and diodes. It provides a useful tool to interpret each product part number. Group 7 is applicable for products launched after December 2014. It contains the diode's information for DuoPack devices.

## Introduction

**Table 1 Infineon discrete IGBTs and diodes detailed nomenclature rules.**

| I | K | W | 75 | N | 65  | E | S5  | Explanation   |
|---|---|---|----|---|-----|---|-----|---|
| 1 | 2 | 3 | 4  | 5 | 6   | 7 | 8   | Group   |
| I |   |   |    |   |     |   |     | Infineon  |
| S |   |   |    |   |     |   |     | Formerly Siemens  |
|   | D |   |    |   |     |   |     | Single diode  |
|   | G |   |    |   |     |   |     | Single IGBT   |
|   | H |   |    |   |     |   |     | Reverse conducting IGBT for soft switching applications               |
|   | K |   |    |   |     |   |     | IGBT + anti-parallel diode  |
|   |   | A |    |   |     |   |     | TO-220 FullPAK  |
|   |   | B |    |   |     |   |     | TO-263 D <sup>2</sup> PAK   |
|   |   | D |    |   |     |   |     | TO-252 DPAK   |
|   |   | H |    |   |     |   |     | TO-220 real-2-pin   |
|   |   | I |    |   |     |   |     | TO-262 I <sup>2</sup> PAK   |
|   |   | P |    |   |     |   |     | TO-220  |
|   |   | Q |    |   |     |   |     | TO-247 PLUS   |
|   |   | U |    |   |     |   |     | TO-251 IPAK   |
|   |   | V |    |   |     |   |     | TO-220 real-2-pin FullPAK   |
|   |   | W |    |   |     |   |     | TO-247  |
|   |   |   | 75 |   |     |   |     | Current in A at 100°C case temperature                                |
|   |   |   |    | E |     |   |     | EmCon diode   |
|   |   |   |    | N |     |   |     | N-channel   |
|   |   |   |    | T |     |   |     | Trenchstop (1200V only)   |
|   |   |   |    |   | 60  |   |     | 600V  |
|   |   |   |    |   | 65  |   |     | 650V  |
|   |   |   |    |   | 90  |   |     | 900V  |
|   |   |   |    |   | 100 |   |     | 1000V   |
|   |   |   |    |   | 110 |   |     | 1100V   |
|   |   |   |    |   | 120 |   |     | 1200V   |
|   |   |   |    |   | 135 |   |     | 1350V   |
|   |   |   |    |   | 160 |   |     | 1600V   |
|   |   |   |    |   |     | B |     | Emitter Controlled diode  |
|   |   |   |    |   |     | C |     | Emitter Controlled full rated diode                                   |
|   |   |   |    |   |     | D |     | Rapid1 diode  |
|   |   |   |    |   |     | E |     | Rapid1 full rated diode   |
|   |   |   |    |   |     | M |     | Rapid2 diode  |
|   |   |   |    |   |     | N |     | Rapid2 full rated diode   |
|   |   |   |    |   |     | R |     | SiC 5 <sup>th</sup> Gen diode   |
|   |   |   |    |   |     | S |     | SiC 5 <sup>th</sup> Gen full rated diode                              |
|   |   |   |    |   |     |   | -   | Trenchstop™ (1200V)   |
|   |   |   |    |   |     |   | F5  | Fastest IGBT based on Trenchstop™ 5 technology                        |
|   |   |   |    |   |     |   | H3  | High speed 3 based on Trenchstop™ technology                          |
|   |   |   |    |   |     |   | H5  | High speed IGBT based on Trenchstop™ 5 technology                     |
|   |   |   |    |   |     |   | HS  | High speed (600V)   |
|   |   |   |    |   |     |   | L5  | Low V <sub>CE(sat)</sub> technology based on Trenchstop™ 5 technology |
|   |   |   |    |   |     |   | R   | Reverse conducting IGBT   |
|   |   |   |    |   |     |   | R2  | Reverse conducting IGBT Gen2  |
|   |   |   |    |   |     |   | R3  | Reverse conducting IGBT Gen3  |
|   |   |   |    |   |     |   | R5  | RC next generation  |
|   |   |   |    |   |     |   | S5  | Soft switching technology based on Trenchstop™ 5 technology           |
|   |   |   |    |   |     |   | T   | Trenchstop™ (600V)  |
|   |   |   |    |   |     |   | T2  | Trenchstop™ Gen2 (IGBT4), 1200V only                                  |
|   |   |   |    |   |     |   | WR5 | RC next generation optimized for welding applications                 |

## IGBT datasheet parameters

## 2 IGBT datasheet parameters

This section is dedicated to the IGBTs' electrical features. For a better understanding it is helpful to read this part along with a datasheet.

### 2.1 Maximum ratings

In this paragraph, the maximum ratings parameters for the IGBT are listed.

Exceeding one of the device's maximum ratings may lead to a device fail, even if simultaneously other parameters do not exceed the limits.

#### Collector-emitter voltage $V_{CE}$

|                           |          |     |   |
|---------------------------|----------|-----|---|
| Collector-emitter voltage | $V_{CE}$ | 650 | V |
|---------------------------|----------|-----|---|

The value defines the lowest breakdown voltage limit based on statistical distribution out of IGBT mass production. Furthermore, it defines the maximum permissible voltage between collector and emitter at a junction temperature of 25°C. Exceeding this limit leads to a reduction of the device's lifetime or to the device failure.

This value is validated by the parameter  $V_{(BR)CES}$  specified in the static characteristics section of the datasheet. Please refer to paragraph 2.2.

#### DC collector current $I_C$

|   |       |              |   |
|---|-------|--------------|---|
| DC collector current, limited by $T_{vjmax}$<br>$T_C = 25^\circ\text{C}$<br>$T_C = 100^\circ\text{C}$ | $I_C$ | 74.0<br>46.0 | A |
|---|-------|--------------|---|

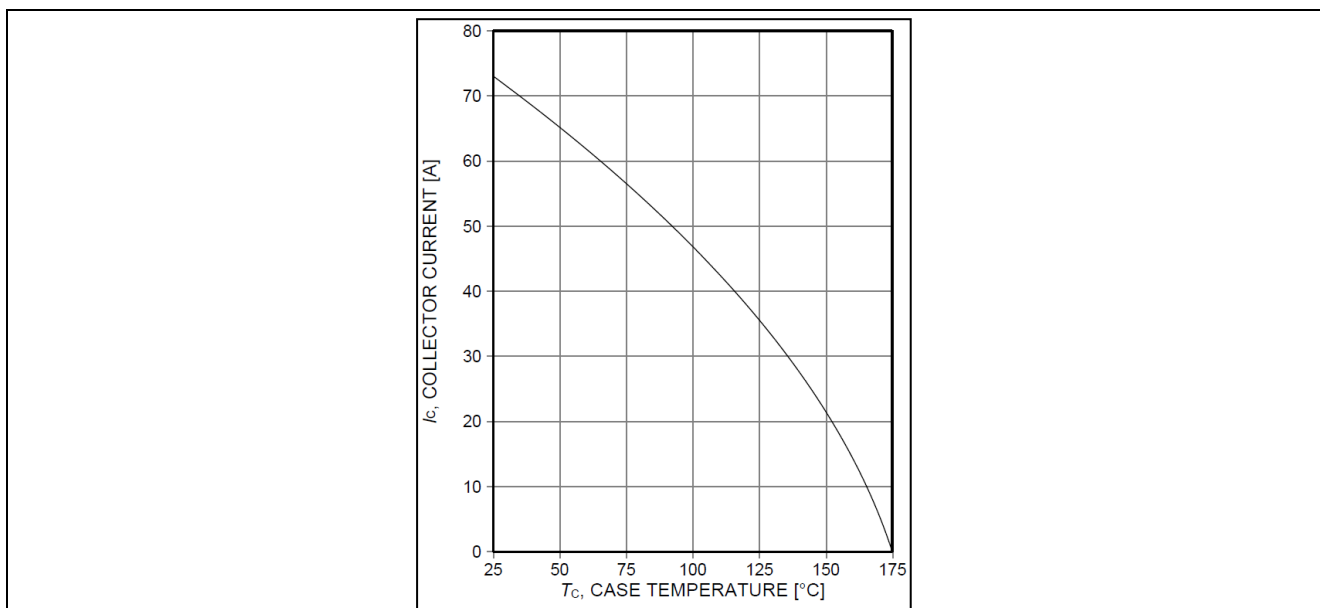
$I_C$  is defined as the DC collector-emitter current value, which leads to an IGBT junction temperature  $T_{vjmax}$  with a starting temperature of  $T_C$  (usually 25°C or 100°C).

$I_C$  is obtained by the equation:

$$\Delta T = T_{vjmax} - T_C = R_{th(j-c)} \cdot I_C \cdot V_{CEsat@T_{vjmax}} \quad [1]$$

Furthermore, the figure section in the datasheets depicts  $I_C$  as a function of the case temperature  $T_C$  as given in Figure 2.

## IGBT datasheet parameters



**Figure 2 Collector current as function of the case temperature**

The value at 100°C is typically used as current rating of the device and the device's name. Please note that based on this formula, an IGBT with low  $V_{CEsat}$  results in higher current rating for the same chip size compared to a fast IGBT, which has normally a higher  $V_{CEsat}$ . However, since the IGBT is used as a switch, not only conduction losses but also switching losses contribute to the total power losses.

To determine, whether or not the product fulfills the application's requirements, calculations and verifications are mandatory to be performed. They are based on design parameters like topology, switching frequency, voltage, temperature, cooling capabilities, external  $R_G$  and others.

### Pulse collector current $I_{Cpuls}$

|  |             |       |   |
|--|-------------|-------|---|
| Pulsed collector current, $t_p$ limited by $T_{vjmax}$ | $I_{Cpuls}$ | 120.0 | A |
|--|-------------|-------|---|

$I_{Cpulse}$  is defined as the maximum transient current at both turn-on and turn-off. In theory it is limited by the power dissipation within a specific period of time, which allows the device to be operated within the maximum junction temperature limit of  $T_{jmax} \leq 175^\circ\text{C}$ . However, there are some other limitations, for instance bonding wire configuration, reliability consideration as well as a margin to avoid IGBT latching. With state-of-the-art IGBTs it is usually rated at 3~4 times nominal current to keep a high level of reliability as well as life time.

Moreover, this value also defines the current limitation given in the SOA.

|  |   |       |   |
|--|---|-------|---|
| Turn off safe operating area $V_{CE} \leq 650\text{V}$ , $T_{vj} \leq 175^\circ\text{C}$ | - | 120.0 | A |
|--|---|-------|---|

### Current rating of DuoPack diode $I_F$ and $I_{Fpuls}$

|  |             |              |   |
|--|-------------|--------------|---|
| Diode forward current, limited by $T_{vjmax}$<br>$T_C = 25^\circ\text{C}$<br>$T_C = 100^\circ\text{C}$ | $I_F$       | 36.0<br>21.0 | A |
| Diode pulsed current, $t_p$ limited by $T_{vjmax}$   | $I_{Fpuls}$ | 120.0        | A |

The same definition as used for the pulse collector current  $I_{Cpuls}$  is used to define the diode forward continuous current  $I_F$  and the diode pulse current  $I_{puls}$  in case of DuoPack device.

## IGBT datasheet parameters

### Gate-emitter voltage $V_{GE}$

|  |          |                      |   |
|--|----------|----------------------|---|
| Gate-emitter voltage<br>Transient Gate-emitter voltage ( $t_p = 10\mu s$ , $D < 0.010$ ) | $V_{GE}$ | $\pm 20$<br>$\pm 30$ | V |
|--|----------|----------------------|---|

This parameter specifies the maximum gate voltage. Therefore, it defines a gate driver or gate clamp limitation. Two conditions can be specified. The first one labeled as *static* and corresponds to the gate voltage maximum values in case of continuous operation without damaging the device itself. The second one is labeled *transient* and corresponds to the maximum values during transient operation. In this case, it defines the maximum transient voltage, which could be applied to the gate without causing damages or degradations. If the voltage stress on the gate is accidentally higher than specified, an immediate failure may occur or it might cause an oxide degradation, which could lead to a later failure.

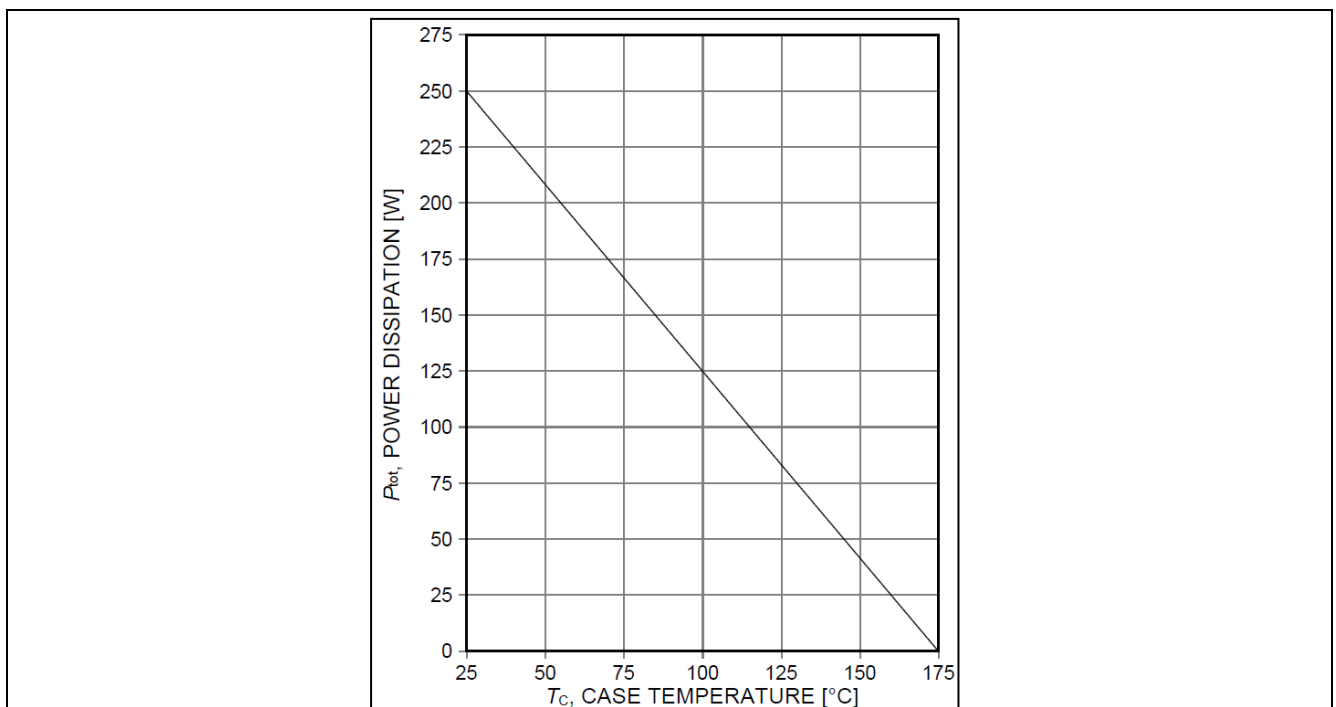
### Power dissipation $P_{tot}$

|   |           |                |   |
|---|-----------|----------------|---|
| Power dissipation $T_C = 25^\circ C$<br>Power dissipation $T_C = 100^\circ C$ | $P_{tot}$ | 255.0<br>120.0 | W |
|---|-----------|----------------|---|

$P_{tot}$  describes the maximum power dissipation allowed, correlated to the IGBT's junction to case thermal resistance. It can be calculated as

$$P_{tot} = \frac{\Delta T}{R_{th(j-c)}} \quad [2]$$

In the datasheet's figure section, the total power dissipation is given as a function of the case temperature as it can be seen in Figure 3.



**Figure 3 Total power dissipation as a function of the case temperature**

## IGBT datasheet parameters

### Operating junction temperature $T_{vj}$

|                                |          |            |    |
|--------------------------------|----------|------------|----|
| Operating junction temperature | $T_{vj}$ | -40...+175 | °C |
|--------------------------------|----------|------------|----|

This parameter is extremely important for the design. Although the device will not fail immediately once the limit is exceeded, the maximum junction temperature should never exceed its maximum rating. This will lead to device degradation and reduced lifetime.

Infineon Technologies IGBTs achieved  $T_{jmax} = 175^{\circ}\text{C}$  with the first generation of Trenchstop™ technology. It is indeed  $25^{\circ}\text{C}$  higher than conventional ones like PT- and NPT-technologies. In an application with a given thermal setup, a device with higher specified maximum junction temperatures could achieve longer life times in comparison to conventional IGBTs with lower specified temperature rating. In other words, customers are able to drive higher current out of the same power system, corresponding to higher power density.

### Thermal resistance $R_{th(j-c)}$

|   |               |      |     |
|---|---------------|------|-----|
| IGBT thermal resistance, junction - case  | $R_{th(j-c)}$ | 0.60 | K/W |
| Diode thermal resistance, junction - case | $R_{th(j-c)}$ | 1.80 | K/W |

The thermal resistance characterizes the thermal behavior of power semiconductors at steady state. Correspondingly, the thermal impedance  $Z_{th(j-c)}$  describes the device's thermal behavior during transient pulses.

The IGBT/diode case should be considered as the leadframe of device. In case of a FullPAK, the central pin should be considered as the case.

The maximum value stated in the datasheet takes the tolerance during mass production into consideration. It is the value to be used for the product design-in.

The thermal resistance junction to case  $R_{th(j-c)}$  is a key parameter to determine the thermal behavior of semiconductor devices. However in any design, it is not enough to compare this value directly from one product to another. In the thermal dissipation path of a power system, as illustrated in Figure 4, the thermal resistance junction to ambient  $R_{th(j-a)}$  plays the most important role, as it dictates the thermal limits in operating conditions. It consists of a resistance case to ambient  $R_{th(c-h)} + R_{th(h-a)}$  and the resistance from junction to case  $R_{th(j-c)}$ . In most cases, the  $R_{th}$  of the thermal interface material, isolation - if applicable - and heatsink is dominating the  $R_{th(j-a)}$ . For the IKW40N65H5, the  $R_{th(j-c)max}$  is 0.6 K/W. The thermal resistance value of typical thermal interface material (TIM) and isolation like isolation foil could be as low as 1 K/W and the thermal resistance heatsink to ambient could range anywhere from 1 K/W with forced ventilation to tens of K/W without ventilation. Therefore, the  $R_{th(j-c)}$  impact is only in the order of some single digit percent to some tens of percent compared to the total  $R_{th(j-a)}$ .



## IGBT datasheet parameters

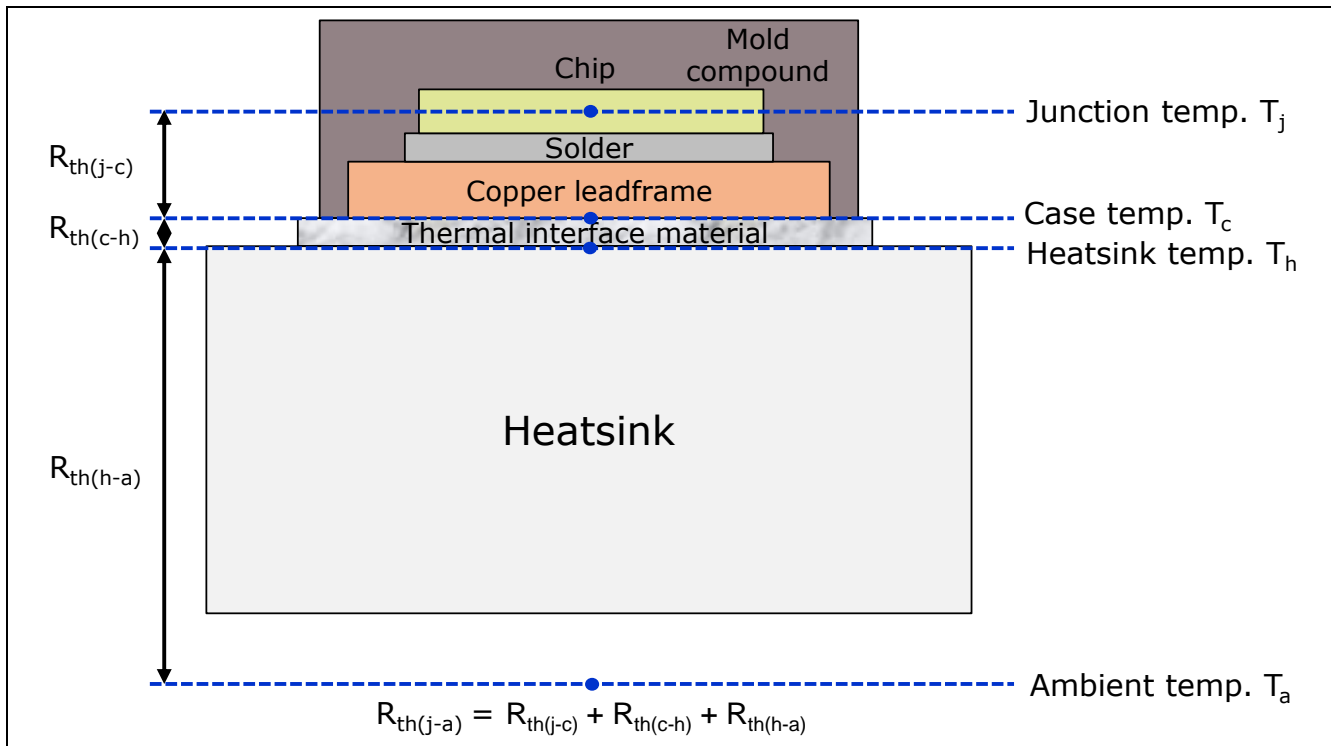


Figure 4 Thermal resistance chain of IGBT in application

## 2.2 Static characteristics

### Collector-emitter breakdown voltage $V_{(BR)CES}$

|                                     |               |                             |     |   |   |   |
|-------------------------------------|---------------|-----------------------------|-----|---|---|---|
| Collector-emitter breakdown voltage | $V_{(BR)CES}$ | $V_{GE} = 0V, I_C = 0.20mA$ | 650 | - | - | V |
|-------------------------------------|---------------|-----------------------------|-----|---|---|---|

This parameter specifies the minimum breakdown voltage at a specific leakage current. The current is for this example  $I_c = 0.2 \text{ mA}$ , which corresponds to different chip sizes as well as different IGBT technologies. The collector-emitter breakdown voltage varies with junction temperature. Usually it has a positive temperature coefficient for most Infineon IGBT products.

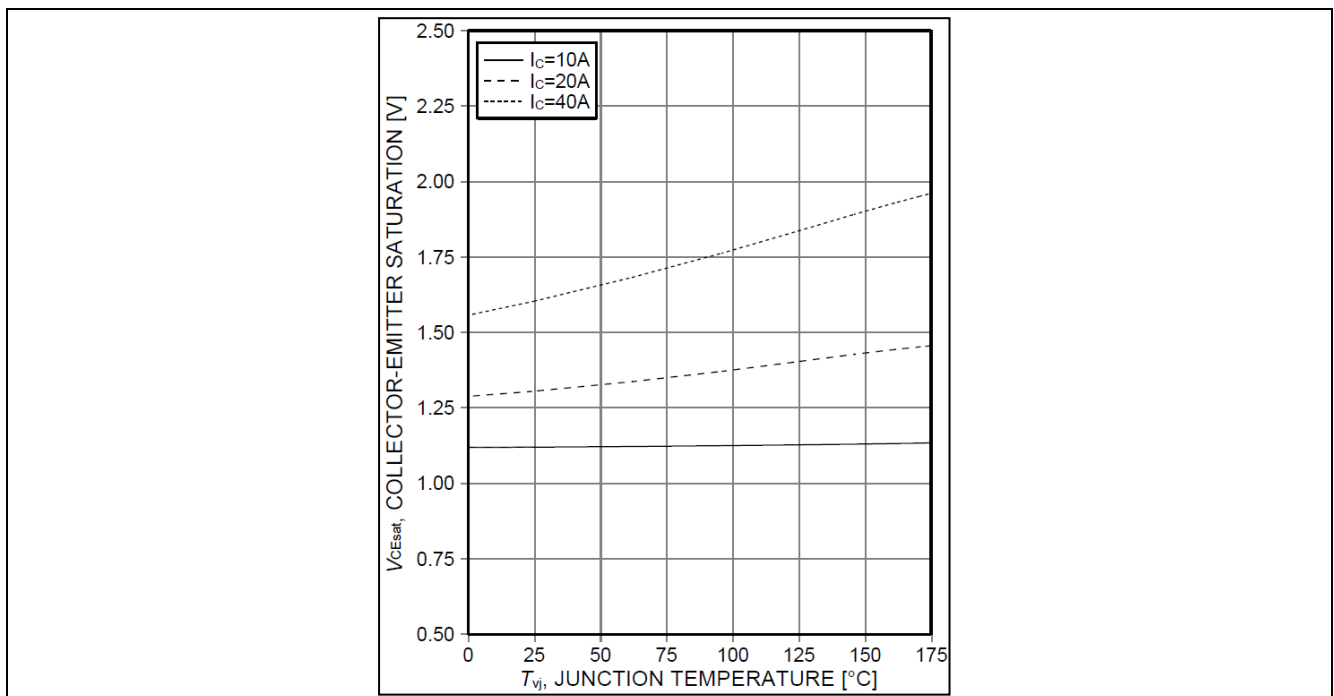
## IGBT datasheet parameters

### Collector-emitter saturation voltage $V_{CEsat}$

|                                      |             |                               |   |      |      |   |
|--------------------------------------|-------------|-------------------------------|---|------|------|---|
| Collector-emitter saturation voltage | $V_{CEsat}$ | $V_{GE} = 15.0V, I_C = 40.0A$ |   |      |      |   |
|                                      |             | $T_{vj} = 25^{\circ}C$        | - | 1.65 | 2.10 | V |
|                                      |             | $T_{vj} = 125^{\circ}C$       | - | 1.85 | -    |   |
|                                      |             | $T_{vj} = 175^{\circ}C$       | - | 1.95 | -    |   |

$V_{CEsat}$  represents the voltage drop between collector and emitter, when the nominal current is flowing through the IGBT. It is specified typically at a gate voltage of 15 V and at several junction temperatures.

In the datasheet's figure chapter, the chart of typical  $V_{CEsat}$  values as a function of the junction temperature is given, represented in Figure 5. With the latest Trenchstop™ 5 technology, a 40 A IGBT shows positive temperature coefficient starting from 10 A. Such characteristics facilitate paralleling of IGBT for high power applications, because the current is shared among the devices automatically. IGBT devices of traditional PT technologies show a negative temperature coefficient even at nominal currents. This results in high reliability risks in parallel operation. Therefore, it limits the maximum power capability.



**Figure 5**  $V_{CEsat}$  as a function of the junction temperature

IGBT datasheet parameters

Diode forward voltage  $V_F$

|                       |       |                            |   |      |      |   |
|-----------------------|-------|----------------------------|---|------|------|---|
| Diode forward voltage | $V_F$ | $V_{GE} = 0V, I_F = 20.0A$ |   |      |      |   |
|                       |       | $T_{vj} = 25^{\circ}C$     | - | 1.45 | 1.80 | V |
|                       |       | $T_{vj} = 125^{\circ}C$    | - | 1.40 | -    |   |
|                       |       | $T_{vj} = 175^{\circ}C$    | - | 1.40 | -    |   |

The diode forward voltage ( $V_F$ ) refers to the voltage across the diode during conduction mode. In the datasheet’s figure chapter, the typical  $V_F$  values as function of temperature are given as shown in Figure 6. Note that it is usually characterized by a slightly negative temperature coefficient at nominal diode current.

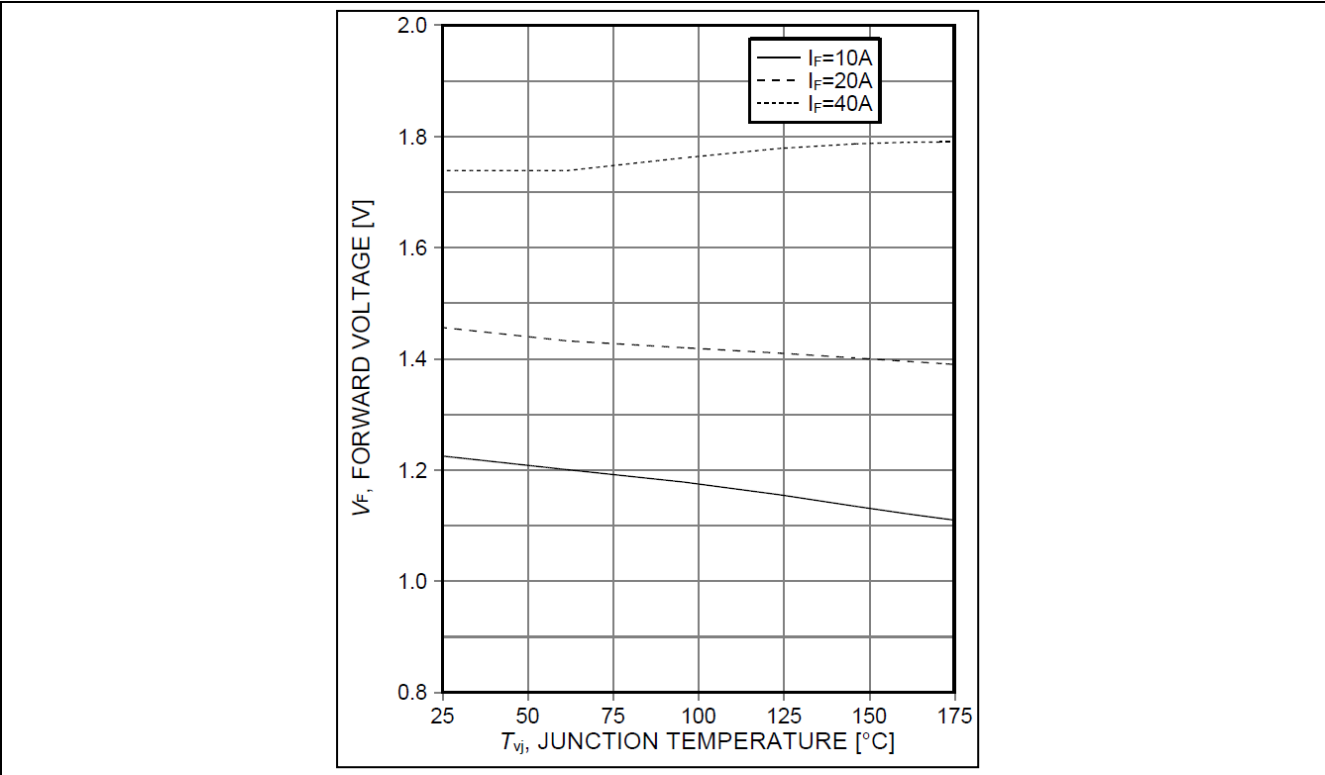


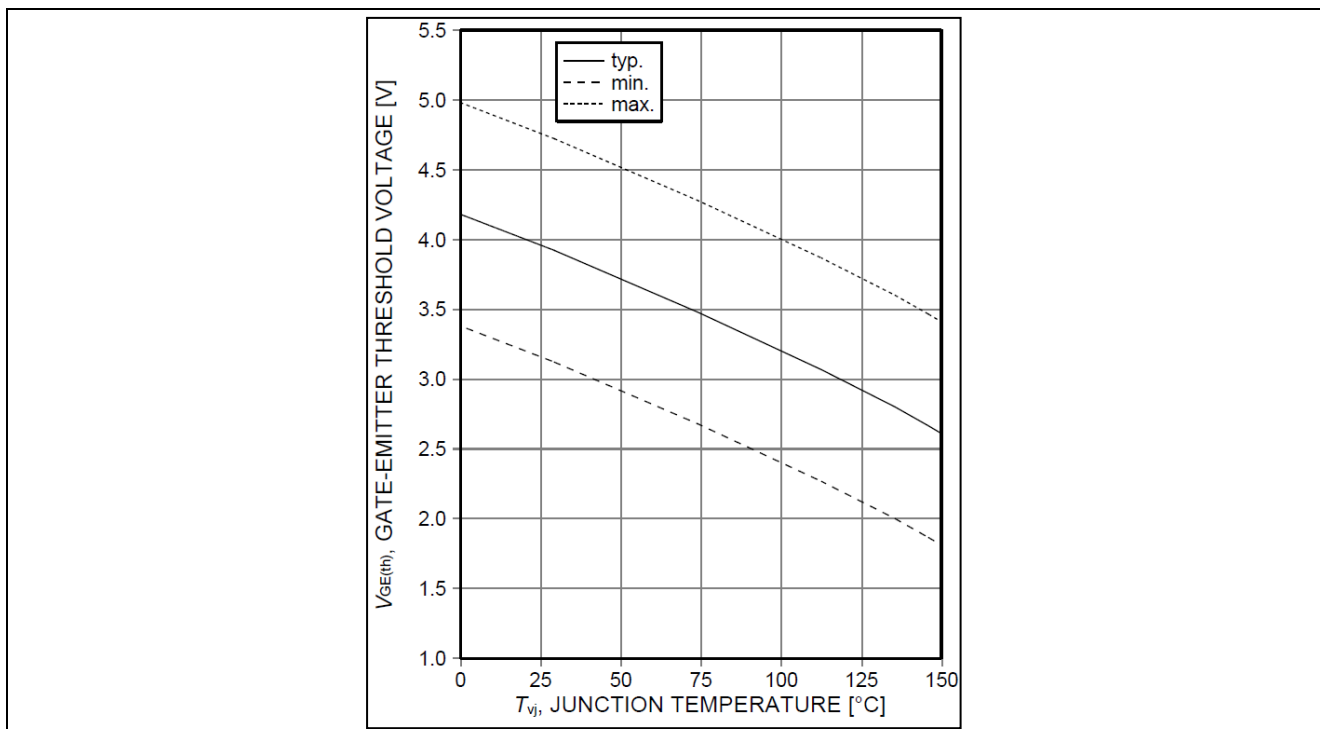
Figure 6 Diode forward voltage as a function of the junction temperature

## IGBT datasheet parameters

### Gate-emitter threshold voltage $V_{GE(th)}$

|                                |              |   |     |     |     |   |
|--------------------------------|--------------|---|-----|-----|-----|---|
| Gate-emitter threshold voltage | $V_{GE(th)}$ | $I_C = 0.40\text{mA}$ , $V_{CE} = V_{GE}$ | 3.2 | 4.0 | 4.8 | V |
|--------------------------------|--------------|---|-----|-----|-----|---|

This parameter represents the gate voltage, which initiates a current flow from collector to emitter. Figure 7 depicts the detailed temperature behavior of the gate threshold voltage.



**Figure 7 Gate-emitter threshold voltage as a function of the junction temperature**

### Leakage currents $I_{CES}$ and $I_{GES}$

|                                     |           |  |   |   |                |               |
|-------------------------------------|-----------|--|---|---|----------------|---------------|
| Zero gate voltage collector current | $I_{CES}$ | $V_{CE} = 650\text{V}$ , $V_{GE} = 0\text{V}$<br>$T_{vj} = 25^\circ\text{C}$<br>$T_{vj} = 175^\circ\text{C}$ | - | - | 40.0<br>4000.0 | $\mu\text{A}$ |
| Gate-emitter leakage current        | $I_{GES}$ | $V_{CE} = 0\text{V}$ , $V_{GE} = 20\text{V}$   | - | - | 100            | nA            |

These parameters indicate the upper limit of leakage current between collector and emitter ( $I_{CES}$ ) or gate and emitter ( $I_{GES}$ ). They are normally determined by the technology as well as the manufacturing and process tolerances. Note that  $I_{CES}$  correlates to the breakdown voltage. When the device is in off-mode with voltage applied between collector and emitter,  $I_{CES}$  flows in the IGBT and it introduces some quiescent losses. In order to reduce the impact of these losses,  $I_{CES}$  has to be kept as low as possible during the development phase. A low leakage value would contribute to higher quality and reliability of the final product as well.

The leakage current specification at  $T_{vj} = 175^\circ\text{C}$  is not relevant in typical applications, because the device's junction temperature cannot reach  $175^\circ\text{C}$  in off-state. Therefore, datasheets of new products do not include the maximum value at  $T_{vj} = 175^\circ\text{C}$  anymore. A typical value is specified instead.

## IGBT datasheet parameters

### Transconductance $g_{fs}$

|                  |          |                             |   |      |   |   |
|------------------|----------|-----------------------------|---|------|---|---|
| Transconductance | $g_{fs}$ | $V_{CE} = 20V, I_C = 40.0A$ | - | 50.0 | - | S |
|------------------|----------|-----------------------------|---|------|---|---|

The transconductance  $g_{fs}$  stands for the current flow variation according to a gate voltage change. As presented in Figure 8, the curve's slope at every single point is exactly the transconductance value for a specific collector current, gate voltage and temperature condition.

Figure 8 also indicates the gate voltage threshold dependency of the temperature.  $V_{GE(th)}$  is the voltage to be applied to the gate to activate a current flow in the IGBT. It is lower at higher temperatures, approximately 4.5 V at 150°C and 5.4 V at 25°C, that means a negative temperature coefficient of  $V_{GE(th)}$ . This should be carefully considered in parallel operations.

The transconductance  $g_{fs}$  and Figure 8 are instruments to describe the controllability of the IGBT, they should not be understood as operating conditions.

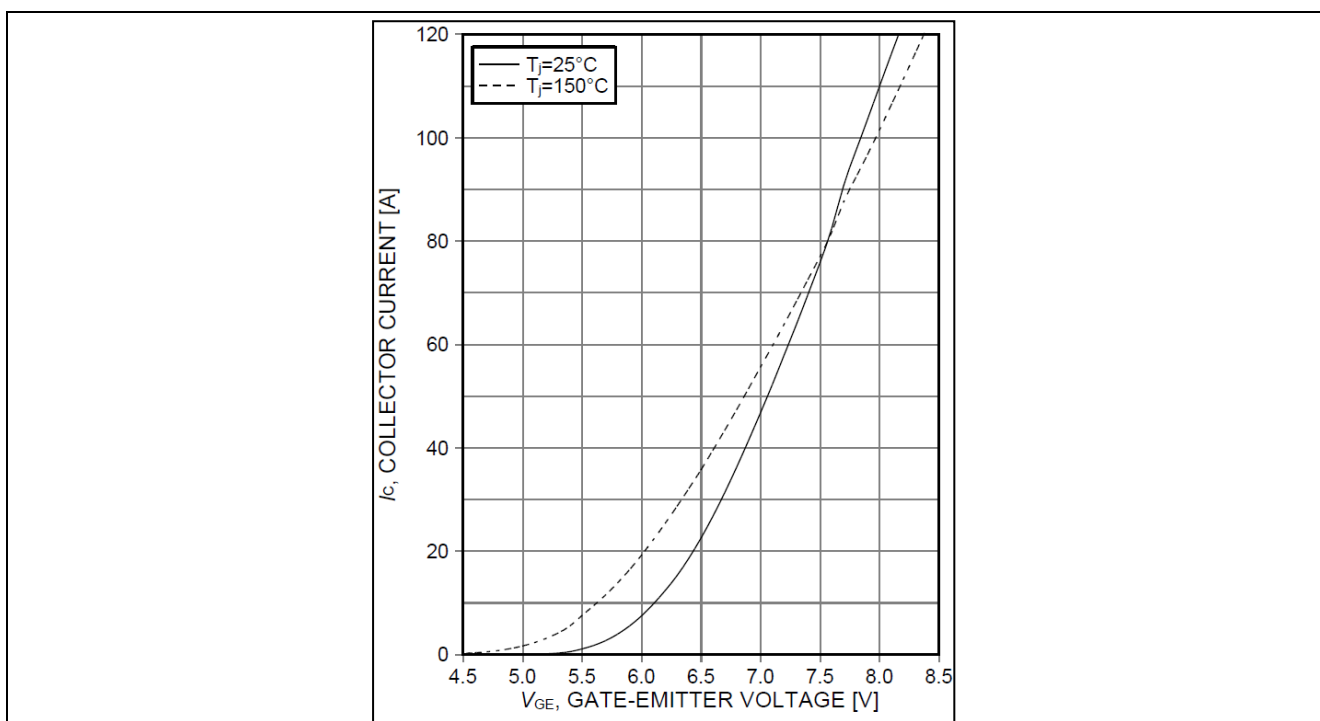


Figure 8 Typical transfer characteristic

## 2.3 Dynamic characteristics

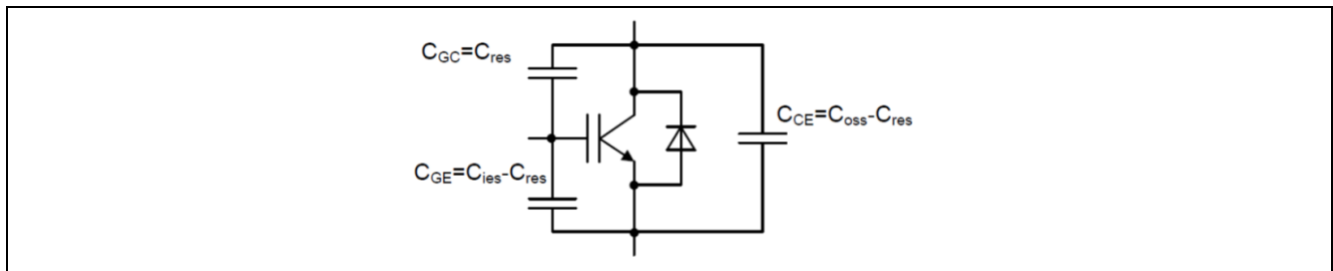
The dynamic characteristics refer to the device parameters, which are related to gate driving as well as switching characteristics.

### Input, output and reverse transfer capacitance $C_{ies}$ , $C_{oes}$ and $C_{res}$

|                              |           |                                       |   |      |   |    |
|------------------------------|-----------|---------------------------------------|---|------|---|----|
| Input capacitance            | $C_{ies}$ | $V_{CE} = 25V, V_{GE} = 0V, f = 1MHz$ | - | 2500 | - | pF |
| Output capacitance           | $C_{oes}$ |                                       | - | 50   | - |    |
| Reverse transfer capacitance | $C_{res}$ |                                       | - | 9    | - |    |

Figure 9 shows an equivalent circuit diagram for the IGBT and provides an electrical visualization of above mentioned parameters.

## IGBT datasheet parameters



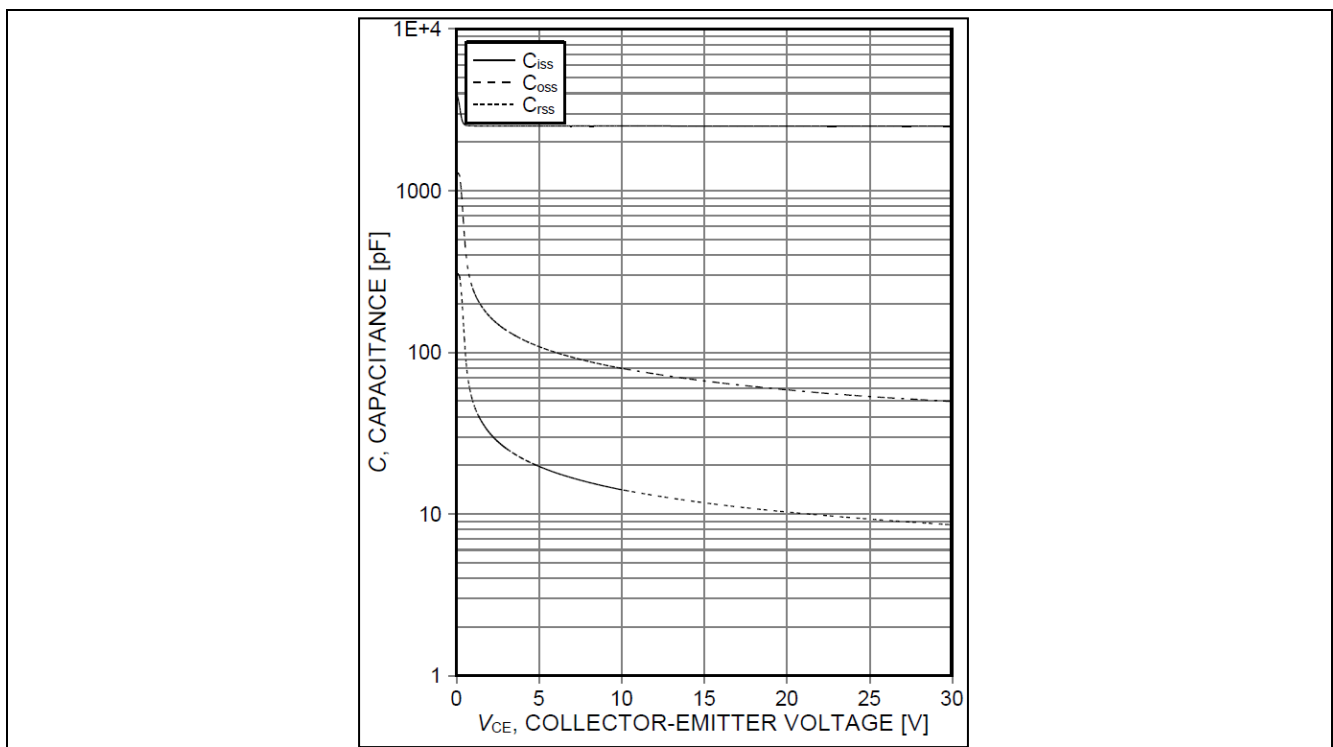
**Figure 9 IGBT simplified equivalent circuit**

The input capacitance  $C_{ies}$ , given by the sum of  $C_{res}$  and  $C_{GE}$ , is a key parameter to design the driver stage. It has to be charged and discharged within every switching cycle. Therefore, it defines the gate charge losses. On the other hand  $C_{GE}$  reduced the risks of parasitic turn-on due to the current through the capacitor  $C_{res}$  during switching events in half bridge configurations.

The reverse transfer capacitance  $C_{res}$ , also known as miller capacitance, determines the time constant, which dictates the crossing time between current and voltage during switching. As a result, it is influencing the switching losses. The factor  $C_{res}/C_{GE}$  has a high influence on the coupling effect between collector-emitter's  $dV/dt$  and  $V_{GE}$ . Reducing the ratio enables fast switching capability as well as avoiding unwanted parasitic turn-on of the device.

$C_{oss}$  is the output capacitance. It is the sum of  $C_{CE}$  and  $C_{res}$ . It has a high influence on the EMI behavior, because it impacts the collector-emitter  $dV/dt$ .

As given in Figure 10, all these capacitances have a non-linear behavior as a function of the collector-emitter voltage.



**Figure 10 Typical capacitance values as function of collector-emitter voltage**

## IGBT datasheet parameters

### Gate charge $Q_G$

|             |       |   |   |      |   |    |
|-------------|-------|---|---|------|---|----|
| Gate charge | $Q_G$ | $V_{CC} = 520V, I_C = 40.0A,$<br>$V_{GE} = 15V$ | - | 95.0 | - | nC |
|-------------|-------|---|---|------|---|----|

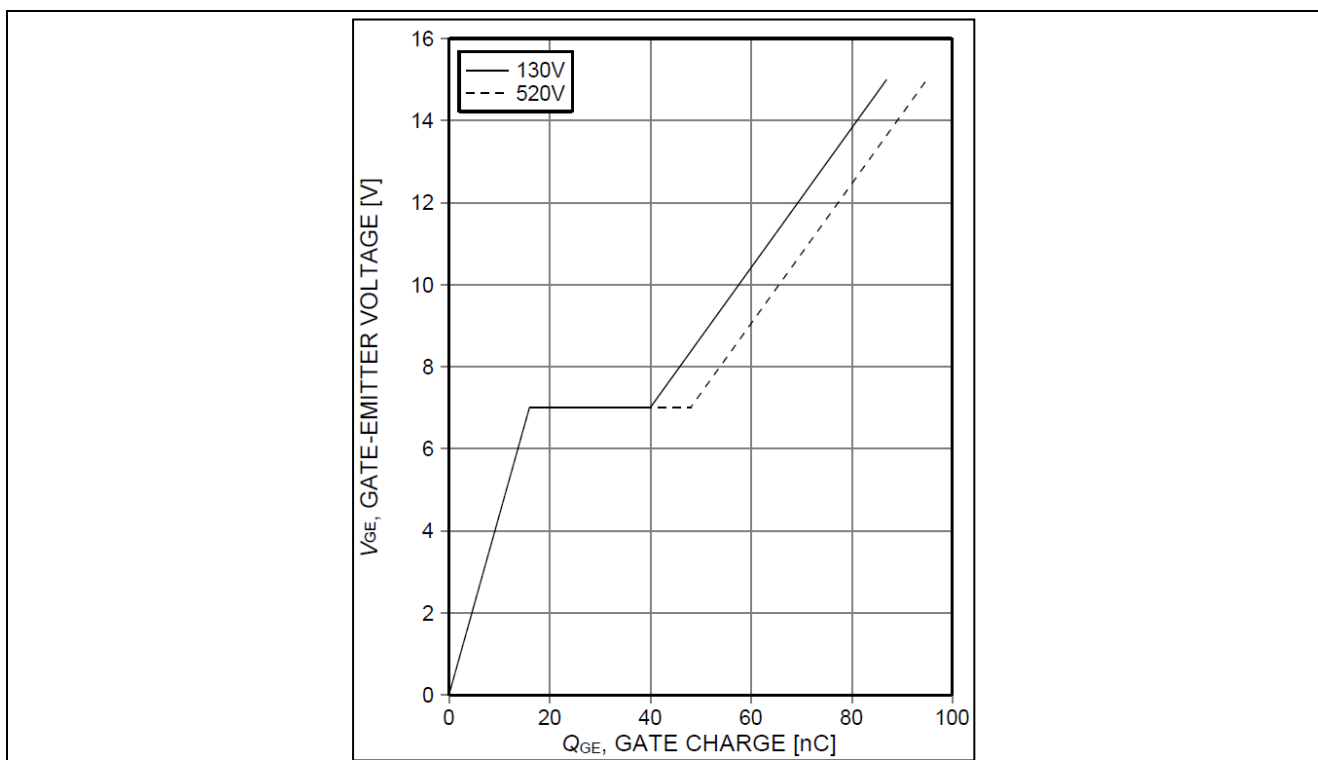
This parameter describes the charge required to drive the gate voltage  $V_{GE}$  to a certain value, which is typically 15 V. It constitutes a main factor for the driving losses. Consequently, it affects the whole drive circuit design and dimensioning. The driving losses can be derived by the equation:

$$P_{Gdr} = Q_G \cdot (V_{GE(on)} - V_{GE(off)}) \cdot f_{sw} \quad [3]$$

Figure 11 shows the typical gate charge diagram, where it is possible to read the  $Q_G$  values needed to drive  $V_{GE}$  to a certain value.

$Q_G$  is a function of the load current and the collector-emitter voltage. Usually it is plotted for the nominal value of  $I_C$  and for different  $V_{CE}$  values, like 130 V and 520 V in Figure 11.

Notice that  $V_{CE}$  has not a significant impact on this parameter.



**Figure 11 Typical gate charge as function of gate-emitter voltage**

### Internal emitter inductance $L_E$

|  |       |                          |   |             |   |    |
|--|-------|--------------------------|---|-------------|---|----|
| Internal emitter inductance<br>measured 5mm (0.197 in.) from<br>case | $L_E$ | PG-TO220-3<br>PG-TO247-3 | - | 7.0<br>13.0 | - | nH |
|--|-------|--------------------------|---|-------------|---|----|

$L_E$  contributes to the total commutation loop inductance value, which normally defines both the voltage overshoot as well as parts of the switching losses. Therefore, the value needs to be minimized especially for IGBTs operated at high switching frequencies.

*Note: The voltage drop across the internal emitter inductance cannot be measured externally, but needs to be considered for the maximum  $V_{CE}$ -voltage during switching off.*

## IGBT datasheet parameters

### 2.4 Switching characteristics

The switching characteristics indicate the basic switching performance of the device. The switching characteristics are normally specified at several conditions.

It should be considered that switching performances are highly dependent on several factors, for instance: collector current, collector-emitter-voltage, temperature, external gate resistance as well as board design and parasitic parameters especially inductances and capacitances. Therefore, a direct comparison between parts from different manufactures based on datasheet values might not be a fair comparison. Thus, it is highly recommended to evaluate the devices by means of application tests and proper characterization.

**Table 2 Switching characteristics of the IGBT**

| Parameter   | Symbol              | Conditions  | Value |      |      | Unit |
|---|---------------------|---|-------|------|------|------|
|   |                     |   | min.  | typ. | max. |      |
| IGBT Characteristic, at $T_{vj} = 25^{\circ}\text{C}$ |                     |   |       |      |      |      |
| Turn-on delay time                                    | $t_{d(\text{on})}$  | $T_{vj} = 25^{\circ}\text{C}$ ,<br>$V_{CC} = 400\text{V}$ , $I_C = 20.0\text{A}$ ,<br>$V_{GE} = 0.0/15.0\text{V}$ ,<br>$R_{G(\text{on})} = 15.0\Omega$ , $R_{G(\text{off})} = 15.0\Omega$ ,<br>$L_{\sigma} = 30\text{nH}$ , $C_{\sigma} = 30\text{pF}$<br>$L_{\sigma}$ , $C_{\sigma}$ from Fig. E<br>Energy losses include “tail” and diode reverse recovery. | -     | 22   | -    | ns   |
| Rise time   | $t_r$               |   | -     | 12   | -    | ns   |
| Turn-off delay time                                   | $t_{d(\text{off})}$ |   | -     | 165  | -    | ns   |
| Fall time   | $t_f$               |   | -     | 13   | -    | ns   |
| Turn-on energy  | $E_{\text{on}}$     |   | -     | 0.39 | -    | mJ   |
| Turn-off energy                                       | $E_{\text{off}}$    |   | -     | 0.12 | -    | mJ   |
| Total switching energy                                | $E_{\text{ts}}$     |   | -     | 0.51 | -    | mJ   |

As given in Table 2, this section provides switching times as well as switching losses for a certain measurement setup in well-defined and specified conditions. Usually, the switching characteristics are specified at one or two collector current values, at room temperature  $25^{\circ}\text{C}$  and high temperature  $150^{\circ}\text{C}$  or  $175^{\circ}\text{C}$ .

Those entities are usually measured and evaluated according to the definitions of international standards, like JEDEC or IEC60747-9 (2007) as depicted in Figure 12.

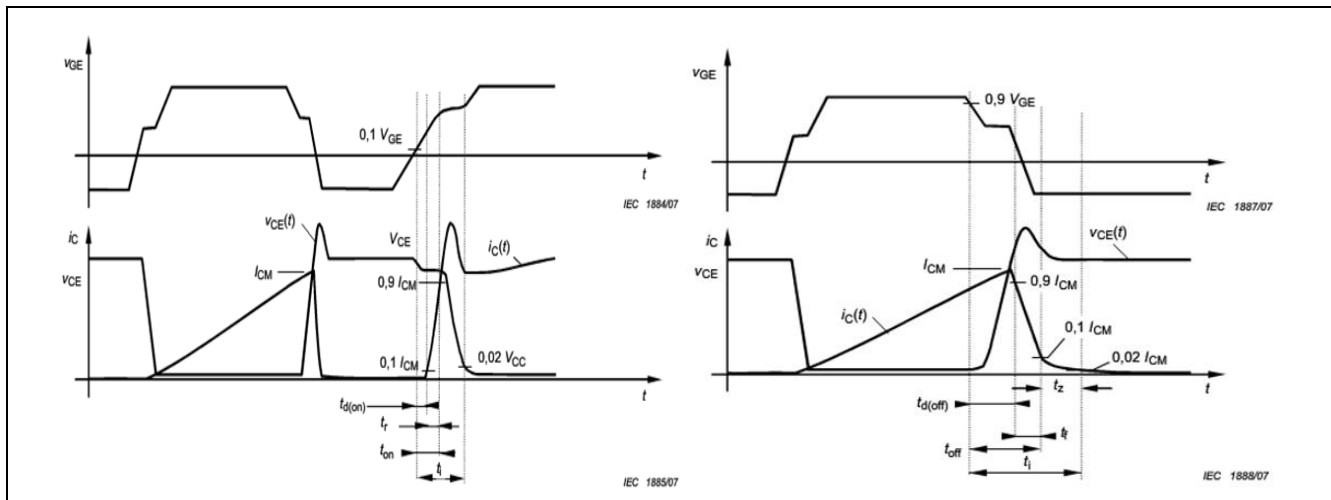
Referring to Figure 12 switching timings are:

- $t_{d(on)}$  : time interval from 10% of  $V_{GE}$  to 10% of  $I_{CM}$  (left side)
- $t_r$  : time interval from 10% of  $I_{CM}$  to 90% of  $I_{CM}$  (left side)
- $t_{d(off)}$  : time interval from 90% of  $V_{GE}$  to 90% of  $I_{CM}$  (right side)
- $t_f$  : time interval from 90% of  $I_{CM}$  to 10% of  $I_{CM}$  (right side)

Where  $V_{GE}$  is the gate voltage and  $I_{CM}$  is the collector current.



## IGBT datasheet parameters



**Figure 12 Definition of switching time according to IEC60747-9 (2007) standard**

**Left: turn-on; right: turn-off**

The switching losses  $E_{on}$  and  $E_{off}$  are calculated as the integral of the power loss over the switching period. The power loss is the product of  $V_{CE}$  and  $I_C$ . In this case, the timing definition takes the IGBT tail current effect into account.

Following the IEC standard:

- For  $E_{on}$ :  $t_{sw}$  starts at 10% of  $V_{GE}$  and lasts until 2% of  $V_{CE}$
- For  $E_{off}$ :  $t_{sw}$  starts at 90% of  $V_{GE}$  and lasts until 2% of  $I_{CM}$ .
- $E_{ts}$ , total switching losses, is the sum of  $E_{on}$  and  $E_{off}$ .

The test setup used for deriving the switching characteristics is shown in Figure 13.

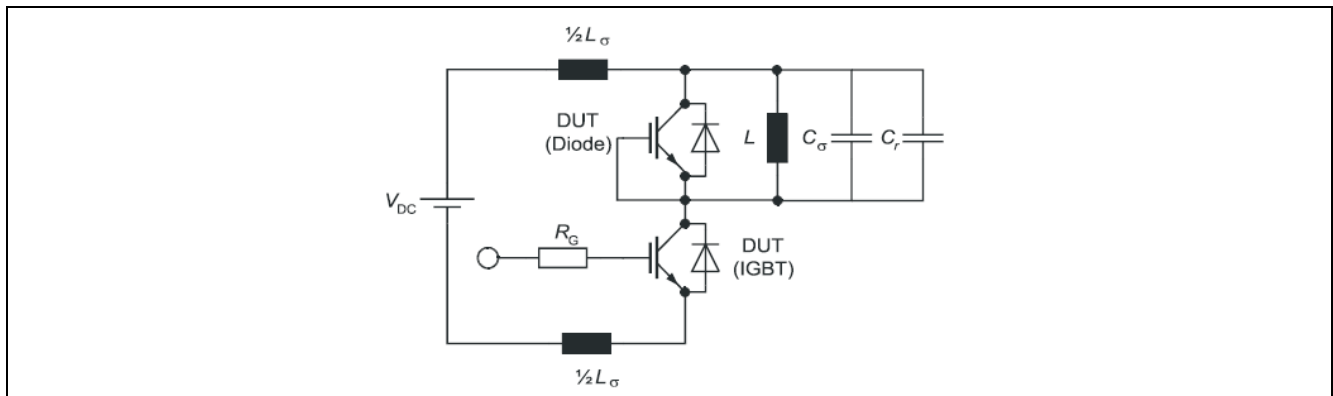
Usually the IGBTs used as high side switch and low side switch are identical. The low side IGBT is the device under test, called DUT IGBT. The gate of the high side IGBT is directly connected to or even negatively biased against the emitter to allow conducting of the anti-parallel diode only. The high side anti-parallel diode is called DUT diode.

The load current could be easily adjusted by controlling the conduction time of the low side IGBT but it is also defined by the DC-link voltage and the loop inductance. When the current reaches the desired value, the low side IGBT would be switched off. Based on waveforms during this process, the switching time as well as energy at turn-off could be easily obtained.

After the IGBT is fully turned off, the whole current freewheels through the high side diode. Since the value of the load inductance  $L$  is relatively high, the load current does not decay during the short freewheeling phase.

Then the IGBT is switched on again to measure the switching time and energy during turn-on. However, due to recovery characteristics of the diode, the IGBT's  $E_{on}$  also includes the recovery energy from the high side diode. Therefore, the anti-parallel diode has to be selected carefully to achieve the best match with the IGBT technology.

## IGBT datasheet parameters



**Figure 13 Setup to conduct the IGBT's dynamic characterization**

Due to accuracy limitations of the equipment as well as existence of parasitic capacitance, which might cause oscillations on the tail current, it is difficult to determine the time, at which  $I_{CM}$  is exactly 2%.

This implies that there might be some discrepancies concerning the switching time definitions used by different manufacturers and the ones provided by standards.

Based on previous considerations, Infineon Technologies typically calculates  $E_{on}$  in the interval between 10% of  $V_{GE}$  until 3% of  $V_{CE}$ , and  $E_{off}$  in the interval from 90% of  $V_{GE}$  to 1% of  $I_{CM}$ . The slightly lower turn-on time is compensated by the higher turn-off time. In any case the adapted definition should be published in official documents like datasheets and application notes.

Moreover, in order to provide a complete overview of the part's switching behavior, several charts are plotted in the datasheet. Those are:

1. Switching time  $t_{sw}$  as a function of the collector current  $I_C$ .
2. Switching time  $t_{sw}$  as a function of the external gate resistor  $R_G$ .
3. Switching time  $t_{sw}$  as a function of the junction temperature  $T_j$ .
4. Switching energies  $E_{on}$ ,  $E_{off}$  and  $E_{ts}$  as a function of the collector current  $I_C$ .
5. Switching energies  $E_{on}$ ,  $E_{off}$  and  $E_{ts}$  as a function of the gate resistor  $R_G$ .
6. Switching energies  $E_{on}$ ,  $E_{off}$  and  $E_{ts}$  as a function of the junction temperature  $T_j$ .
7. Switching energies  $E_{on}$ ,  $E_{off}$  and  $E_{ts}$  as a function of the collector-emitter voltage  $V_{CE}$ .

For IGBTs that are intended for resonant application (induction cooking, inverterized microwave ovens, industrial welding, battery charging), only the indications of turn-off parameters are included in the datasheet. This modification is made because these devices operate generally in soft switching commutations at turn-on and therefore the indications of turn-on parameters are of no use.

0 is taken from the datasheet of IHW20N120R5 and contains the same information about the turn-off characteristics that has been already presented before. Additionally, the testing conditions are also indicated. The test circuit and the procedure to measure these parameters are the same as has been explained previously.

**Table 3 Switching characteristics of the IGBTs for resonant applications**

## IGBT datasheet parameters

### IGBT Characteristic, at $T_{vj} = 25^{\circ}\text{C}$

|                     |              |  |   |      |   |    |
|---------------------|--------------|--|---|------|---|----|
| Turn-off delay time | $t_{d(off)}$ | $T_{vj} = 25^{\circ}\text{C}$ ,<br>$V_{CC} = 600\text{V}$ , $I_C = 20.0\text{A}$ ,<br>$V_{GE} = 0.0/15.0\text{V}$ ,<br>$R_{G(on)} = 10.0\Omega$ , $R_{G(off)} = 10.0\Omega$ ,<br>$L\sigma = 175\text{nH}$ , $C\sigma = 40\text{pF}$<br>$L\sigma$ , $C\sigma$ from Fig. E<br>Energy losses include "tail" and diode reverse recovery. | - | 260  | - | ns |
| Fall time           | $t_f$        |  | - | 50   | - | ns |
| Turn-off energy     | $E_{off}$    |  | - | 0.75 | - | mJ |

**Table 4 Soft switching characteristics of the IGBTs for resonant application**

### IGBT Characteristic, at $T_{vj} = 25^{\circ}\text{C}$

|                                 |              |   |   |      |   |    |
|---------------------------------|--------------|---|---|------|---|----|
| Turn-off delay time             | $t_{d(off)}$ | $T_{vj} = 25^{\circ}\text{C}$ ,<br>$V_{CC} = 65\text{V}$ , $I_C = 15.0\text{A}$ ,<br>$V_{GE} = 0.0/18.0\text{V}$ ,<br>$R_{G(off)} = 10.2\Omega$<br><br>Energy losses include "tail" according Figure B. (Test circuit Figure E, $C_r = 300\text{nF}$ ). | - | 130  | - | ns |
| Fall time                       | $t_f$        |   | - | 1000 | - | ns |
| Turn-off energy, soft switching | $E_{off}$    | $dv/dt = 50.0\text{V}/\mu\text{s}$  | - | 0.03 | - | mJ |

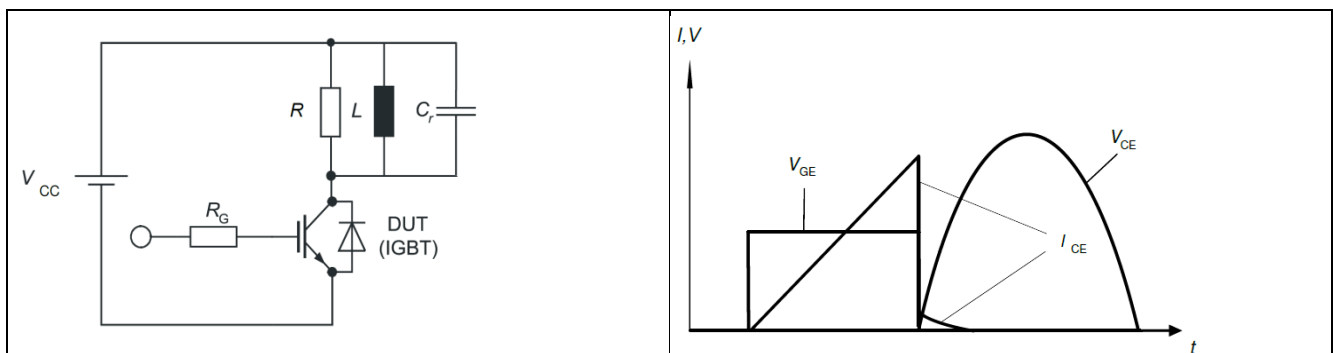
Sometimes, as shown in Table 4, soft turn-off energy is indicated instead of the common turn-off energy. This value corresponds to the turn-off energy of the IGBT when a snubber capacitance is included for limiting the  $dV_{CE}/dt$ . The rate of rise of the  $V_{CE}$  is indicated in the testing condition, whilst the other electrical parameters are assumed to be the same as indicated in timings section. Table 4 is taken from the datasheet of IHW15N120E1.

The soft  $E_{off}$  calculation is slightly different from the hard turn-off case. In particular:

- $E_{off}$  is measured as the integral of the power losses (product of  $V_{CE}$  and  $I_C$ ) between  $t_1$  and  $t_2$ , where  $t_1$  is the time at 90% of  $V_{GE}$  and  $t_2$  is the time at 1% of  $I_C$ .

The test setup used for deriving the switching characteristics is shown in Figure 14 together with the typical waveforms of the circuit. The DUT IGBT is operating as low side switch and the high side load consists of a parallel RLC network. The load current could be adjusted by controlling the conduction time of the IGBT but it is also defined by the DC-link voltage and the loop inductance. When the current reaches the desired value, the low side IGBT would be switched off. Based on waveforms measured during this process, the switching time as well as energy at turn-off could be easily obtained.

When the IGBT is turned-off the inductor current recirculates into the paralleled capacitor. The rate of rise of the  $V_{CE}$  at the desired load current can be tuned by choosing a proper value of the capacitance  $C_r$ .



**Figure 14 Setup and typical waveforms for soft turn-off parameters definition**

## IGBT datasheet parameters

For IGBTs for resonant applications, the following charts are plotted in the datasheet, either for hard switching or soft switching:

1. Turn-off switching time  $t_{sw}$  as a function of the collector current  $I_C$ .
2. Turn-off switching time  $t_{sw}$  as a function of the external gate resistor  $R_G$ .
3. Turn-off switching time  $t_{sw}$  as a function of the junction temperature  $T_j$ .
4. Turn-off switching energy  $E_{off}$  as a function of the collector current  $I_C$ .
5. Turn-off switching energy  $E_{off}$  as a function of the gate resistor  $R_G$ .
6. Turn-off switching energy  $E_{off}$  as a function of the junction temperature  $T_j$ .
7. Turn-off switching energy  $E_{off}$  as a function of the collector-emitter voltage  $V_{CE}$ .

For DuoPack and Reverse-Conducting IGBTs (IKx and IHx), also the electrical features for the anti-parallel diode are specified in the datasheet.

The main parameters that define the diode's switching behavior can be listed as:

- Reverse recovery time and charge
- Peak reverse recovery current
- Peak rate of fall of reverse recovery current during a defined pulse length.

These values are usually provided at one or two diode forward current values as well as at room temperature 25°C and high temperature, like 150°C or 175°C.

**Table 5 Switching characteristics of the anti-parallel diode**

|  |              |   |   |      |   |                  |
|--|--------------|---|---|------|---|------------------|
| Diode reverse recovery time                                      | $t_{rr}$     | $T_{vj} = 25^\circ\text{C},$<br>$V_R = 400\text{V},$<br>$I_F = 20.0\text{A},$<br>$di_F/dt = 1000\text{A}/\mu\text{s}$ | - | 62   | - | ns               |
| Diode reverse recovery charge                                    | $Q_{rr}$     |   | - | 0.45 | - | $\mu\text{C}$    |
| Diode peak reverse recovery current                              | $I_{rrm}$    |   | - | 12.5 | - | A                |
| Diode peak rate of fall of reverse recovery current during $t_b$ | $di_{rr}/dt$ |   | - | -290 | - | A/ $\mu\text{s}$ |

Since the anti-parallel diode often acts as freewheeling diode in applications, its recovery behavior is very important, especially at high switching frequency operation. Its performance is strongly influenced by the diode forward current  $I_F$ , by forward current change rate  $di_F/dt$  as well as the operating temperature.

Furthermore the anti-parallel diode influences the overall performance of the IGBT, especially the turn-on.

To provide a complete overview of the anti-parallel diode's characteristics, several diagrams concerning the switching performance are provided in the datasheet. Those are:

1. Reverse recovery time  $t_{rr}$  as a function of the diode's current slope  $di_F/dt$ .
2. Reverse recovery charge  $Q_{rr}$  as a function of the diode's current slope  $di_F/dt$ .
3. Reverse recovery peak current  $I_{rr}$  as a function of the diode's current slope  $di_F/dt$ .
4. Peak rate of fall of recovery current  $di_{rr}/dt$  as a function of the diode's current slope  $di_F/dt$ .

## 2.5 Other parameters and figures

This section is dedicated to the description of additional parameters and figures, which are usually present in IGBT datasheets.

### Output characteristics

The output characteristics represent the voltage  $V_{CE}$  as a function of the current  $I_C$  conducted. To provide a complete overview it is normally given at several gate voltages  $V_{GE}$ . Those curves depend on the junction

IGBT datasheet parameters

temperature. Therefore two dedicated diagrams are provided in the datasheet, one at room temperature 25°C like Figure 15 and one at high temperature 150°C or 175°C.

Referring to Figure 15 it is possible to see, how the load current tends to saturate at a certain value, if the gate voltage  $V_{GE}$  is set below 10 V.

To avoid IGBT's saturation also called linear mode of operation, it is recommended to drive it with at least  $V_{GE} = 15\text{ V}$ .

Fast switching devices usually have higher transconductance values. As a result, lower driving voltage like +12 V could also be considered mainly to achieve benefits like:

- 1. Increasing the short circuit withstand time for higher reliability
- 2. Reducing the voltage overshoot during switch off
- 3. Reducing the driving losses for gate drivers operated at high frequency

The drawbacks of lower gate voltages should be considered too; higher conduction loss as well as higher switching losses.

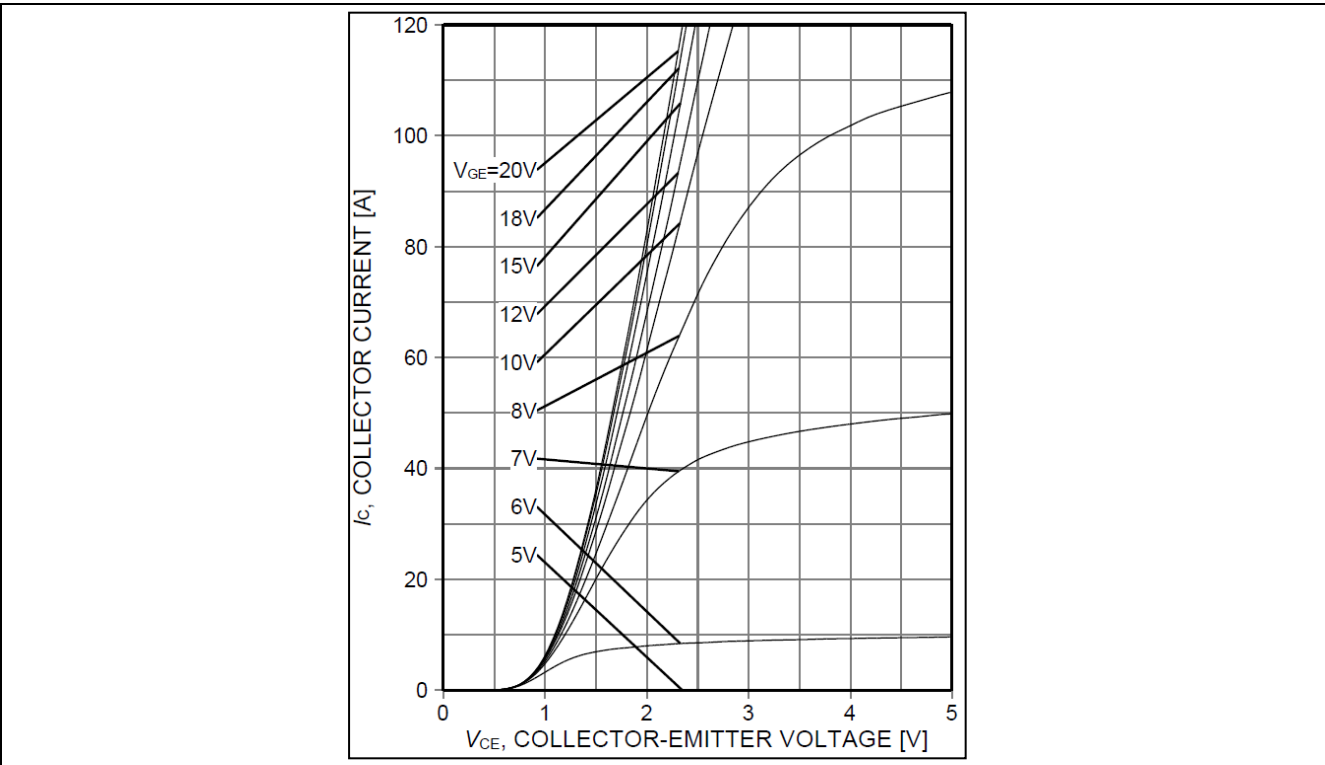


Figure 15 Output characteristics

Short circuit withstand time  $t_{sc}$  (example of IKW40N60H3)

Short circuit withstand time  
 $V_{GE} = 15.0\text{V}$ ,  $V_{CC} \leq 400\text{V}$   
Allowed number of short circuits < 1000  
Time between short circuits:  $\geq 1.0\text{s}$   
 $T_{vj} = 150^\circ\text{C}$

$t_{sc}$

5

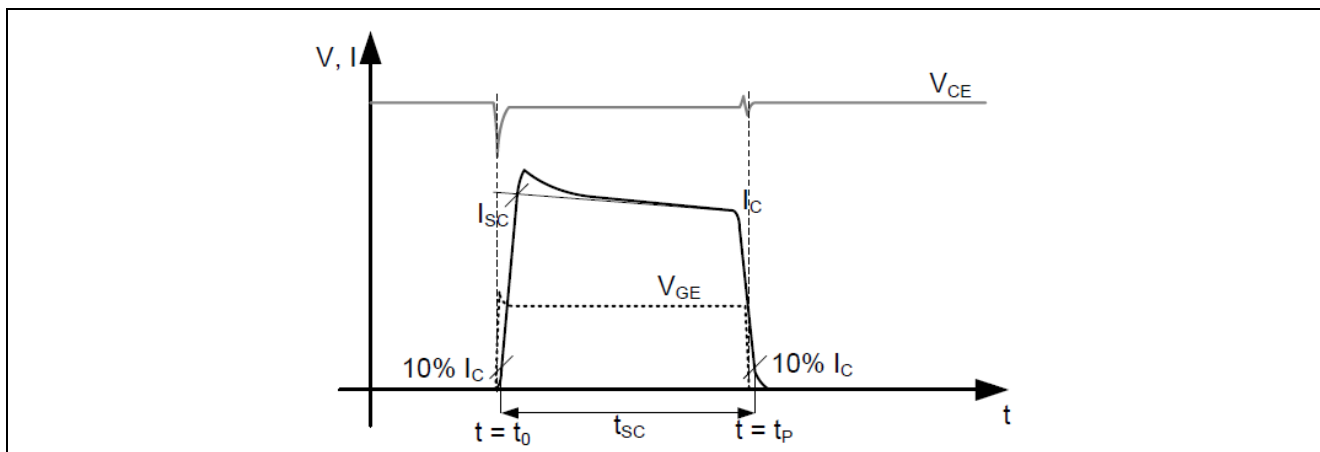
$\mu\text{s}$

$t_{sc}$  defines the time interval, which the device can withstand in short circuit condition without failing. It is defined at high junction temperatures 150°C or 175°C, at a gate voltage of  $V_{GE} = +15\text{ V}$  and a certain bus voltage  $V_{CC}$ . The bus voltage for this parameter is typically below the device breakdown 400 V for 600 V voltage class device.

The typical waveform during short circuit type I is depicted in Figure 16.

## IGBT datasheet parameters

During a short circuit event, the collector current raises rapidly according to the DC-link's voltage and loop inductance. Afterwards it stays at a high value corresponding to the saturation current at the specific gate voltage. However, the voltage drop across the IGBT is more or less the same as the DC-link voltage. Therefore, a huge power loss is generated in the chip, leading to a fast increase of the junction temperature. In spite of the fact that the current slightly decreases due to the higher junction temperature, the power losses are extremely high and will destroy the IGBT after a certain period of time. To avoid IGBT destruction in short circuit operation, it is necessary to protect the IGBT accordingly.



**Figure 16 Typical waveform of IGBT short circuit**

In general, the short circuit withstand time varies from technology to technology and it indicates the level of the IGBT robustness. Note that it is often the outcome from the technology trade-off optimization. Higher short circuit withstand time is obtained by limiting the carrier density as well as the IGBT transconductance. This reduces switching and conduction performances.

### Short circuit collector current $I_{C(SC)}$ (example of IKW40N60H3)

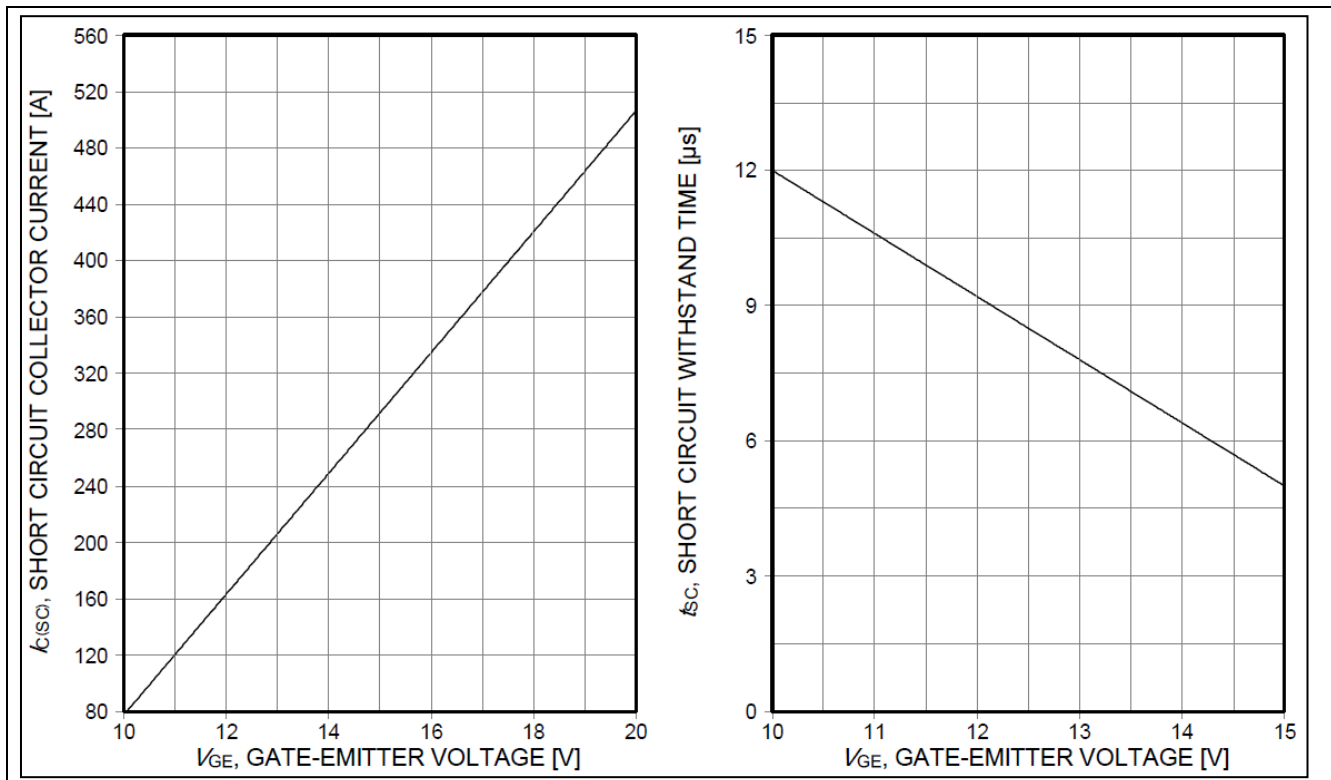
|   |             |  |   |     |   |   |
|---|-------------|--|---|-----|---|---|
| Short circuit collector current<br>Max. 1000 short circuits<br>Time between short circuits: $\geq 1.0s$ | $I_{C(SC)}$ | $V_{GE} = 15.0V, V_{CC} \leq 400V,$<br>$t_{SC} \leq 5\mu s$<br>$T_{vj} = 150^{\circ}C$ | - | 235 | - | A |
|---|-------------|--|---|-----|---|---|

The typical value of short circuit current is specified for short circuit rated IGBTs.

In the datasheet, two charts are available as presented in Figure 17. It shows the  $t_{SC}$  and  $I_{C(SC)}$  behavior as a function of the gate voltage  $V_{GE}$ .

Note that  $t_{SC}$  decreases and  $I_{C(SC)}$  instead increases for higher  $V_{GE}$  values, which is correlated to the output characteristics.

## IGBT datasheet parameters



**Figure 17 Typical short circuit collector current (left) and withstand time (right) as a function of the gate voltage**

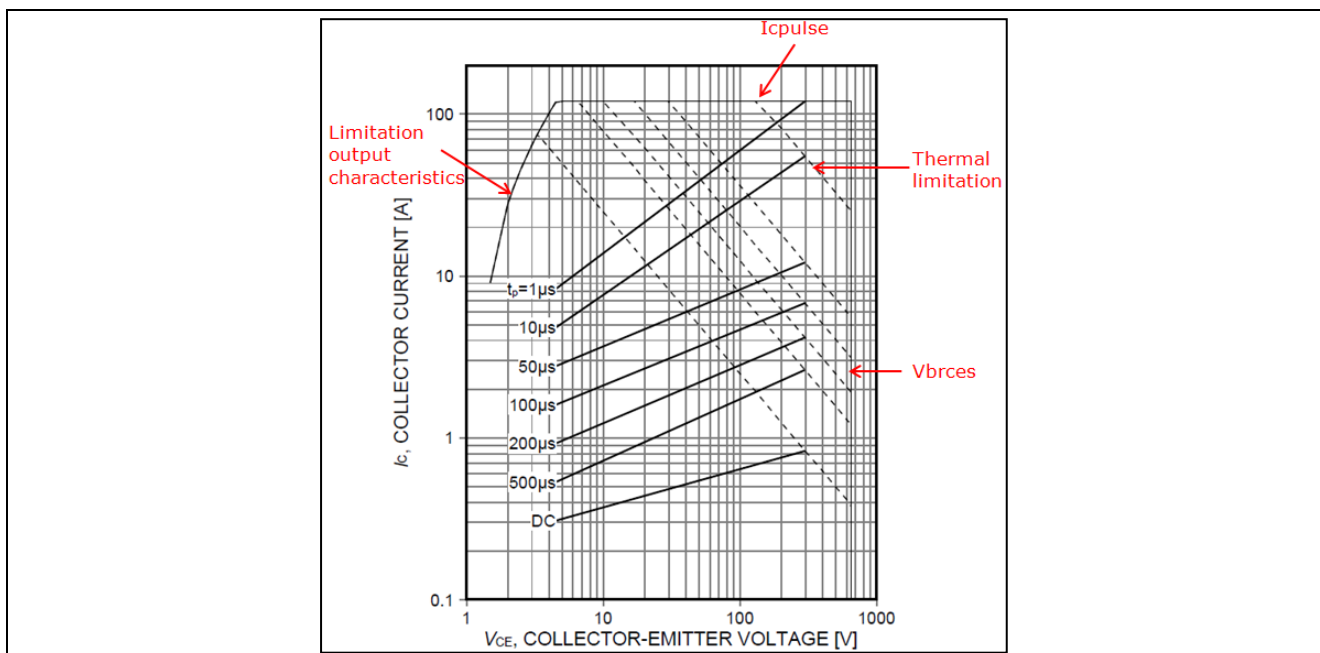
### Safe operating area (SOA)

Two different kinds of safe operating areas can be defined:

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

The forward bias SOA (FBSOA) defines the IGBT's safe operating conditions during forward biasing operation. It is represented in the Cartesian space  $V_{CE}$  vs.  $I_C$  with an area limited by four parameters. The upper current limit is defined by the device pulse current capability  $I_{Cpulse}$ , the maximum voltage limitation is defined by the device breakdown voltage  $V_{(BR)CES}$ , and the minimum one by the output characteristics in linear mode. At last, the device safe operation area is limited by thermals, represented with dashed lines in the charts, corresponding to the device's transient power dissipation capability.

## IGBT datasheet parameters

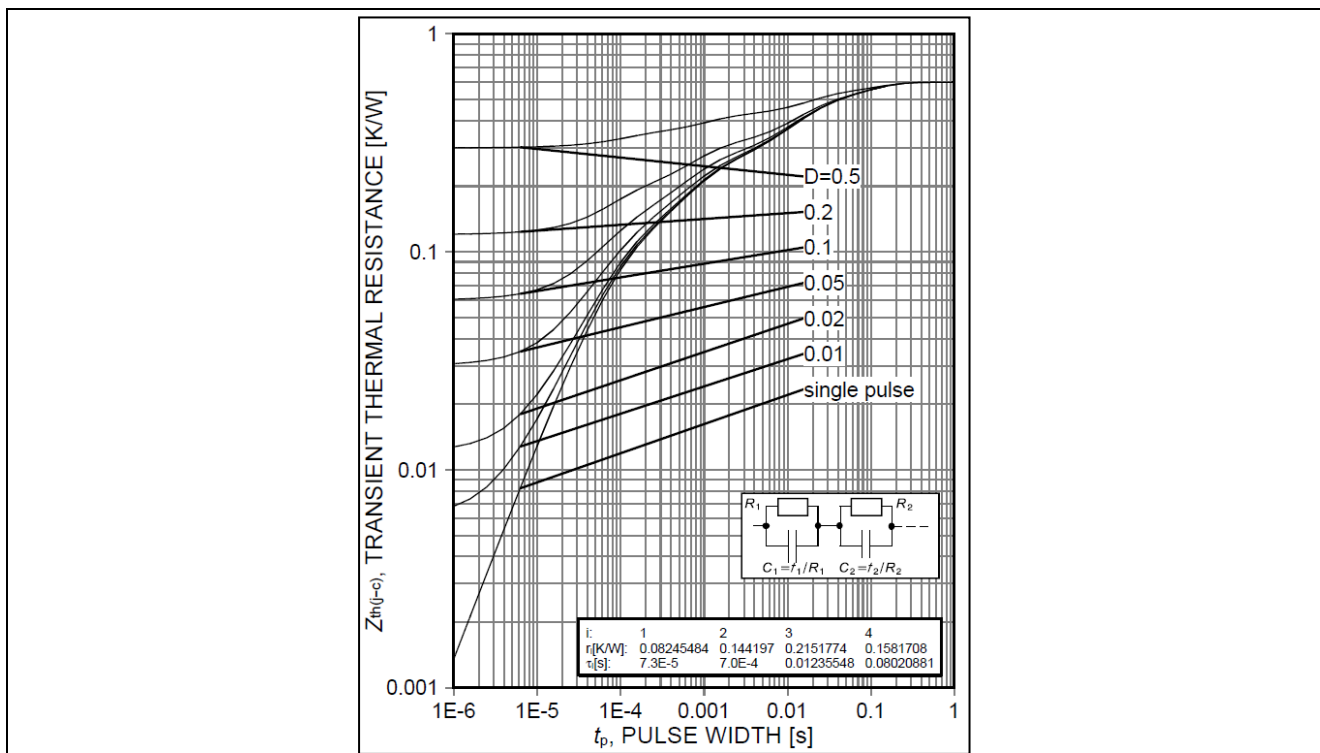


**Figure 18 Forward bias SOA**

It is possible to derive values for the thermal limitation in the SOA curve based on the IGBT transient thermal impedance given in Figure 19 and equation [4]:

equation:

$$P_{transient} = \frac{T_{jmax} - T_c}{Z_{th(j-c)}} = V_{CE} \cdot I_C \quad [4]$$



**Figure 19 IGBT transient thermal resistance as a function of pulse length**



### IGBT datasheet parameters

The second safe operating area is the Reverse Bias SOA or RBSOA, which is defined by:

|  |   |       |   |
|--|---|-------|---|
| Turn off safe operating area $V_{CE} \leq 650V$ , $T_{vj} \leq 175^{\circ}C$ | - | 120.0 | A |
|--|---|-------|---|

The parameter provides the safe operating conditions for IGBTs during turn-off and it usually refers to an inductive load. With state-of-the-art IGBT technologies the RBSOA is a square shaped area defined by the device breakdown voltage  $V_{(BR)CES}$  and the maximum pulse current  $I_{Cpulse}$ .

## Symbols and terms

### 3 Symbols and terms

|                    |   |
|--------------------|---|
| A                  | Anode   |
| C                  | Collector, capacitance                                    |
| $C_{ies}, C_{iss}$ | Input capacitance   |
| $C_{oes}, C_{oss}$ | Output capacitance  |
| $C_{res}, C_{rss}$ | Reverse transfer capacitance                              |
| $C_{CE}$           | Collector-Emitter capacitance                             |
| $C_{GC}$           | Gate-Collector capacitance                                |
| $C_{GE}$           | Gate-Emitter capacitance                                  |
| $C_{\sigma}$       | Stray capacitance   |
| D                  | Duty cycle  |
| $di_F/dt$          | Rate of diode current raise                               |
| $di_{rr}/dt$       | Peak rate of diode current fall during recovery process   |
| $dv/dt$            | Rate of voltage rise                                      |
| E                  | Emitter, energy   |
| $E_{off}$          | Turn-off loss energy                                      |
| $E_{on}$           | Turn-on loss energy                                       |
| f                  | Frequency   |
| G                  | Gate  |
| $g_{fs}$           | Transconductance  |
| I                  | Current   |
| $I_C$              | Collector current   |
| $I_{CES}$          | Leakage current collector-emitter                         |
| $I_{Cpuls}$        | Pulsed collector current                                  |
| $I_F$              | Diode forward current                                     |
| $I_{FSM}$          | Maximum non-repetitive half-sine wave surge current 50 Hz |
| $I_{GES}$          | Leakage current gate-emitter                              |
| $I_{rrm}$          | Diode peak recovery current                               |
| K                  | Cathode   |
| $L_{\sigma}$       | Parasitic inductance                                      |
| $L_E$              | Internal emitter inductance                               |
| $P_{sw}$           | Switching power loss                                      |
| $P_{tot}$          | Total power dissipation                                   |
| $Q_G, Q_{Gate}$    | Gate charge   |

## Symbols and terms

|                         |  |
|-------------------------|--|
| $Q_{rr}$                | Reverse recovery charge                          |
| $R_G$                   | Gate resistance                                  |
| $R_{th(j-a)}, R_{thja}$ | Thermal resistance junction to ambient           |
| $R_{th(j-c)}, R_{thjc}$ | Thermal resistance junction to case              |
| $T_a$                   | Ambient temperature                              |
| $T_c$                   | Case temperature                                 |
| $t$                     | Time   |
| $t_{d(off)}$            | Turn-off delay time                              |
| $t_{d(on)}$             | Turn-on delay time                               |
| $t_f$                   | Fall time  |
| $T_j$                   | Junction temperature                             |
| $t_p$                   | Pulse duration time                              |
| $t_{off}$               | Turn-off time                                    |
| $t_{on}$                | Turn-on time                                     |
| $t_r$                   | Rise time  |
| $t_{rr}$                | Reverse recovery time                            |
| $T_{stg}$               | Storage temperature                              |
| $T_{vj}$                | Operation junction temperature                   |
| $V$                     | Voltage  |
| $V_{bus}$               | Bus voltage                                      |
| $V_{(br)ces}$           | Breakdown voltage                                |
| $V_{cc}$                | Supply voltage                                   |
| $V_{CEsat}$             | Collector-emitter saturation voltage             |
| $V_F$                   | Diode forward voltage                            |
| $V_{GE}$                | Gate-Emitter voltage                             |
| $V_{GE(th)}$            | Gate-Emitter threshold voltage                   |
| $V_{SD}$                | Inverse diode forward voltage                    |
| $V_{plateau}$           | Gate plateau voltage                             |
| $Z_{th(j-a)}, Z_{thja}$ | Transient thermal resistance junction to ambient |
| $Z_{th(j-c)}, Z_{thjc}$ | Transient thermal resistance junction to case    |

## 4 References

- [1] Infineon Application note AN2011-05 V1.1 'Industrial IGBT Modules – Explanation of Technical Information', May 2013, Warstein, Germany

## Revision history

### Major changes since the last revision

| Page or reference | Description of change   |
|-------------------|---|
| Page 2            | Added indication of reference devices for dynamic characteristics of IGBT used in soft switching applications |
| Page 18-19        | Added explanation of soft-switching dynamic characteristics   |
|                   |   |
|                   |   |

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**Email: [erratum@infineon.com](mailto:erratum@infineon.com)**

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