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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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.

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).

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:

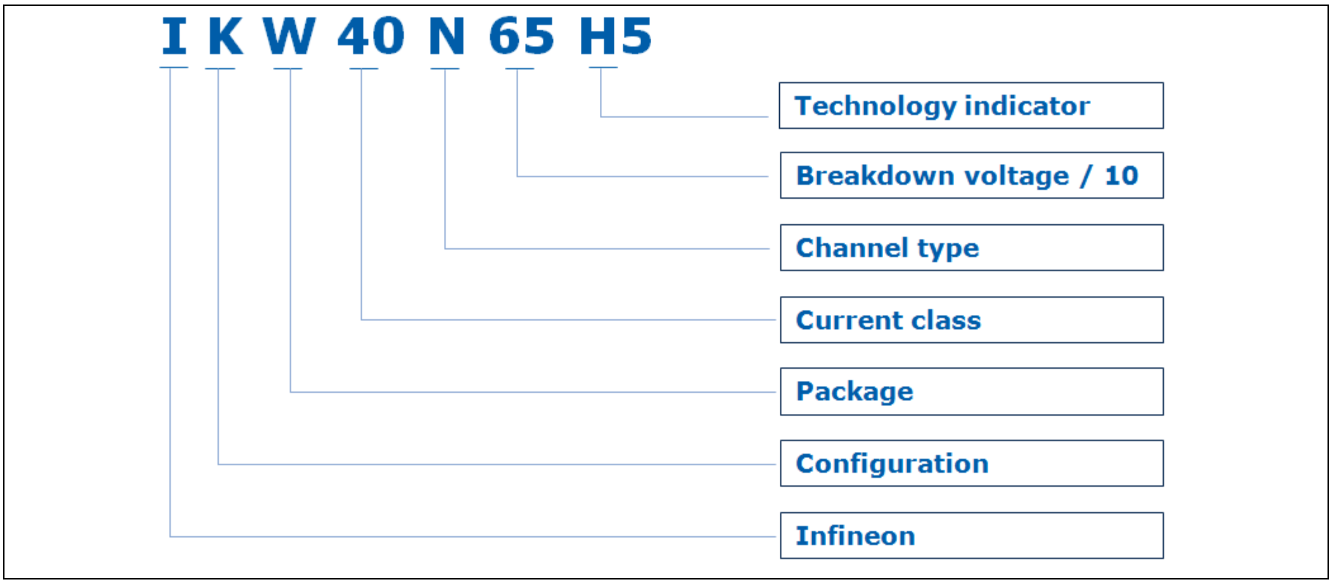

Figure 1 Designation of IGBT part number

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.

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 D²PAK
		D						TO-252 DPAK
		H						TO-220 real-2-pin
		I						TO-262 I²PAK
		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 5th Gen diode
						S		SiC 5th 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 $V_{CE(sat)}$ 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

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} T_C = 25°C T_C = 100°C	I_C	 74.0 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:

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

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

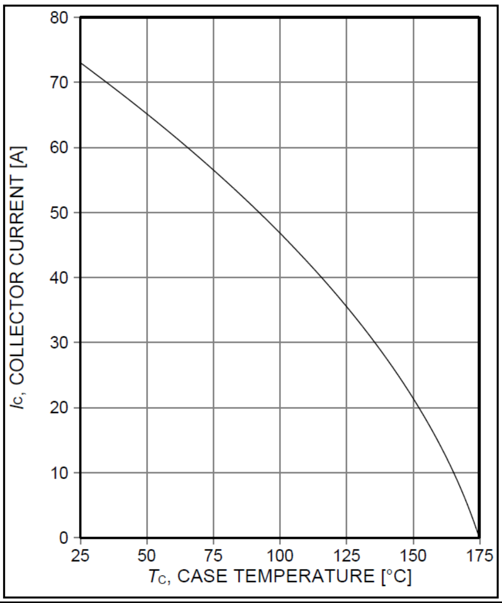

Figure 2 Collector current as function of the case temperature

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 $T_{jmax} \leq 175°C$. 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 $V_{CE} \leq 650V$, $T_{vj} \leq 175°C$	-	120.0	A

Current rating of DuoPack diode I_F and I_{Fpuls}

Diode forward current, limited by T_{vjmax} $T_C = 25°C$ $T_C = 100°C$	I_F	36.0 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 Transient Gate-emitter voltage (t_p = 10µs, D < 0.010)	V_{GE}	±20 ±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°C Power dissipation T_C = 100°C	P_{tot}	255.0 120.0	W

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

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

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.

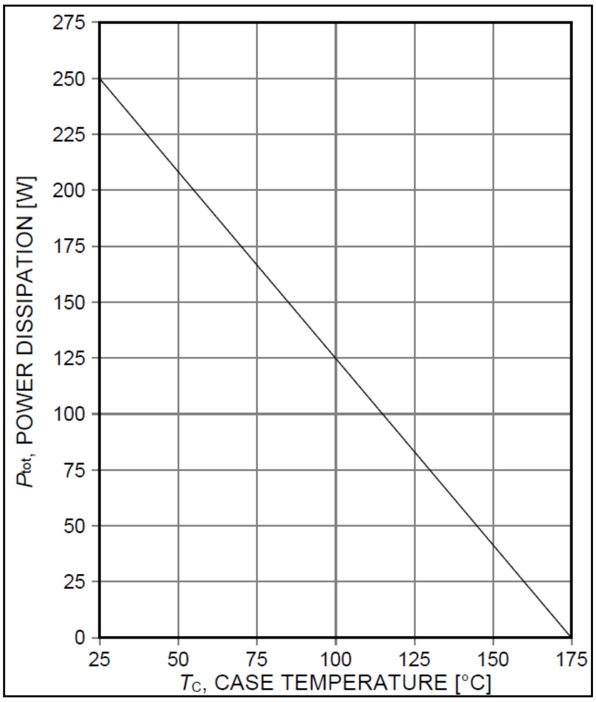

Figure 3 Total power dissipation as a function of the case temperature

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°C with the first generation of Trenchstop™ technology. It is indeed 25°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 $R_{th(j-a)}$.

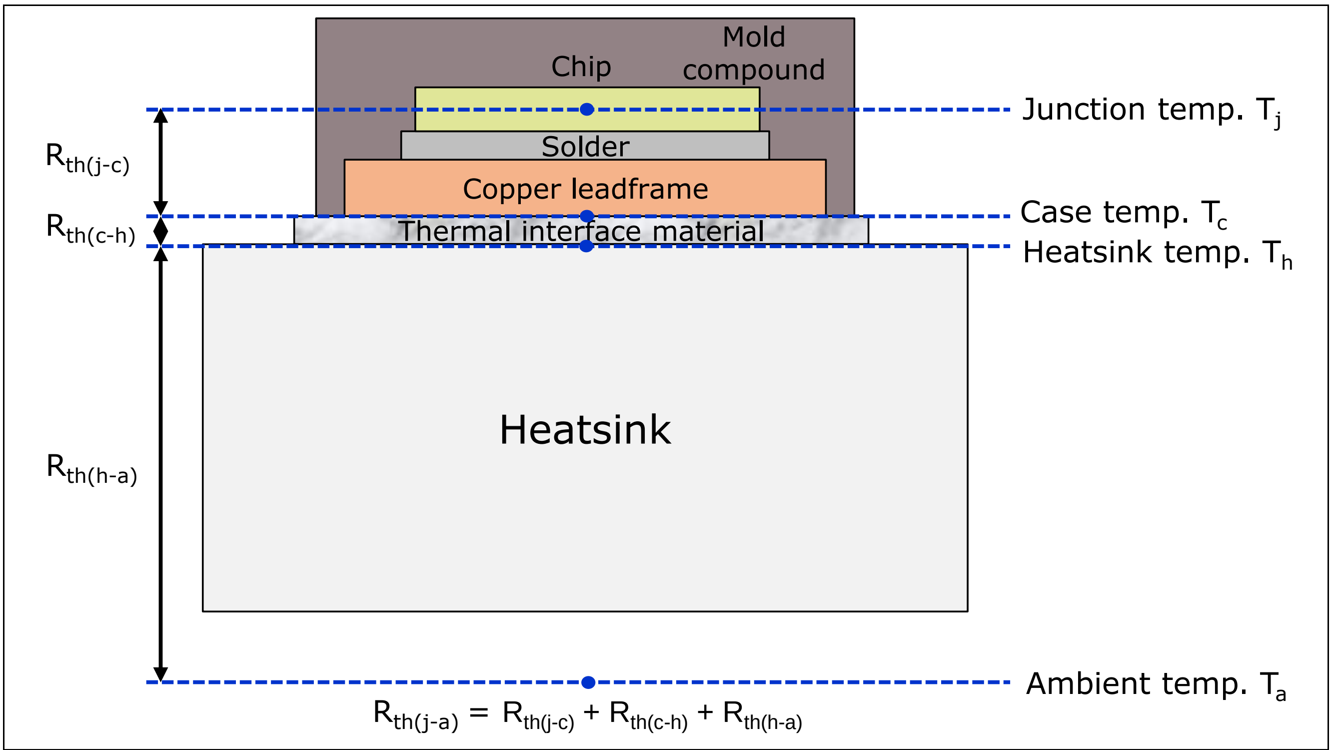

Figure 4 Thermal resistance chain of IGBT in application

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 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.

Collector-emitter saturation voltage V_{CEsat}

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

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.

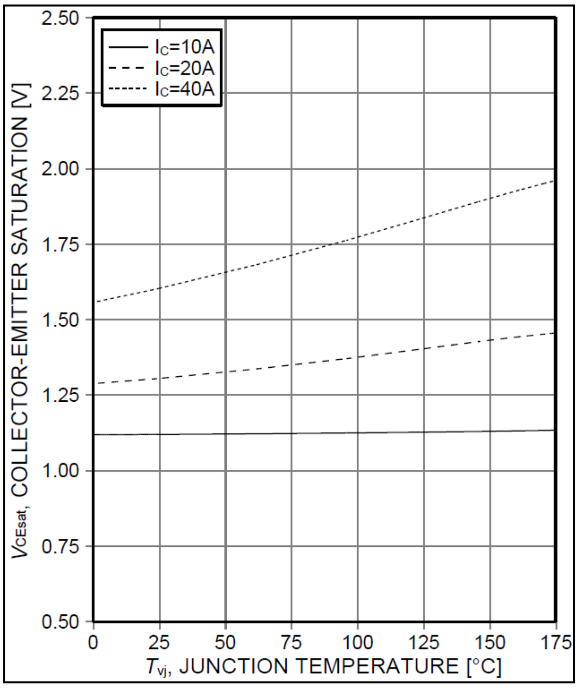

Figure 5 **V_{CEsat} as a function of the junction temperature**

Diode forward voltage V_F

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

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.

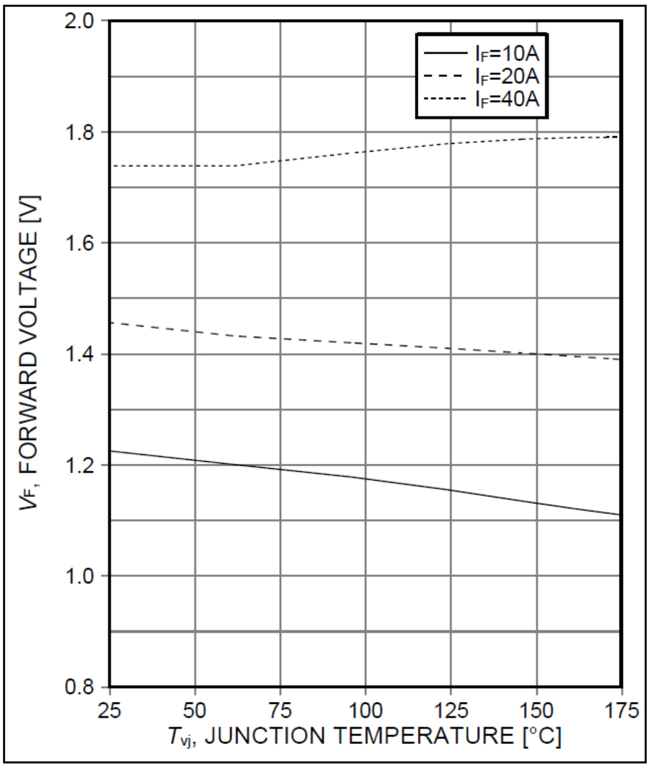

Figure 6 Diode forward voltage as a function of the junction temperature

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

Gate-emitter threshold voltage	$V_{GE(th)}$	I_C = 0.40mA, 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.

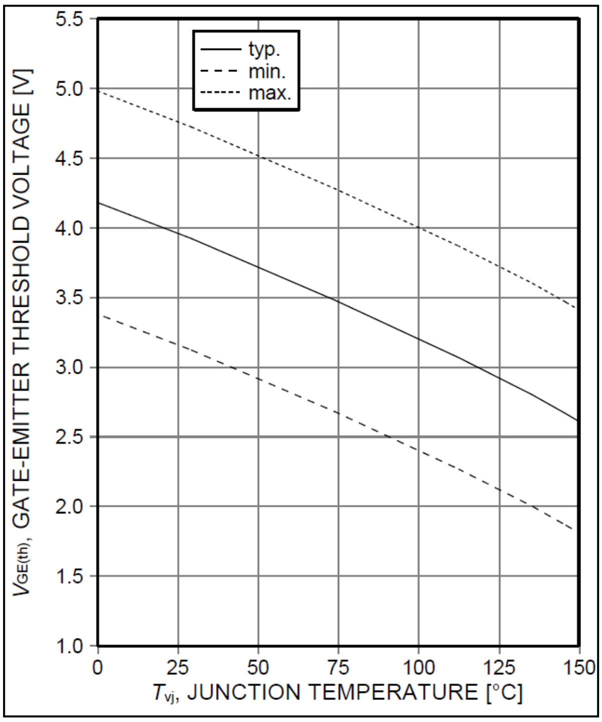

Figure 7 Gate –emitter threshold voltage as a function of the junction temperature

Leakage currents I_{CES} and I_{GES}

Zero gate voltage collector current	I_{CES}	V_{CE} = 650V, V_{GE} = 0V T_{vj} = 25°C T_{vj} = 175°C	- -	- -	40.0 4000.0	µA
Gate-emitter leakage current	I_{GES}	V_{CE} = 0V, V_{GE} = 20V	-	-	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°C is not relevant in typical applications, because the device's junction temperature cannot reach 175°C in off-state. Therefore, datasheets of new products do not include the maximum value at T_{vj} = 175°C anymore. A typical value is specified instead.

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 instrumements to describe the controllability of the IGBT, they should not be understood as operating conditions.

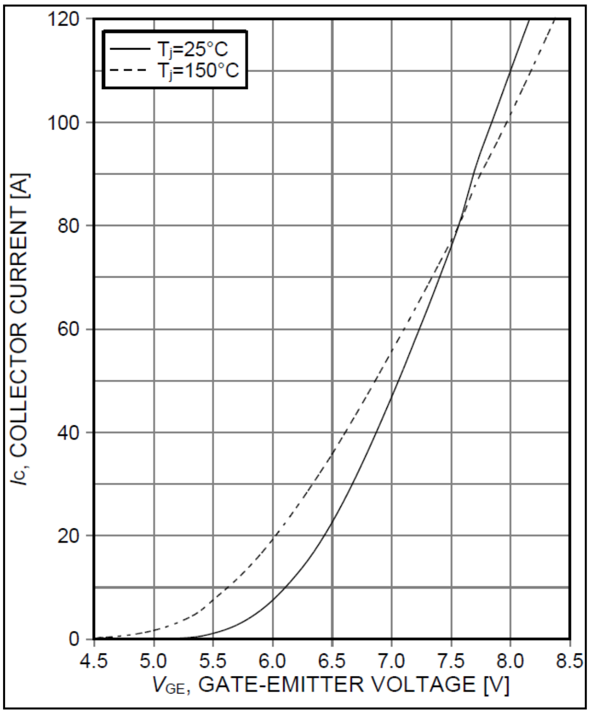

Figure 8 Typical transfer characteristic

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.

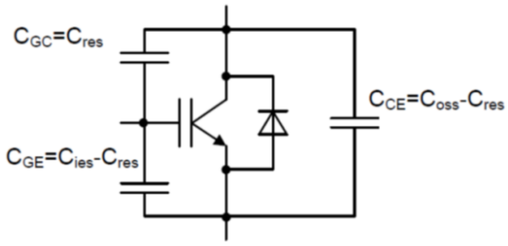

Figure 9 IGBT simplified equivalent circuit

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.

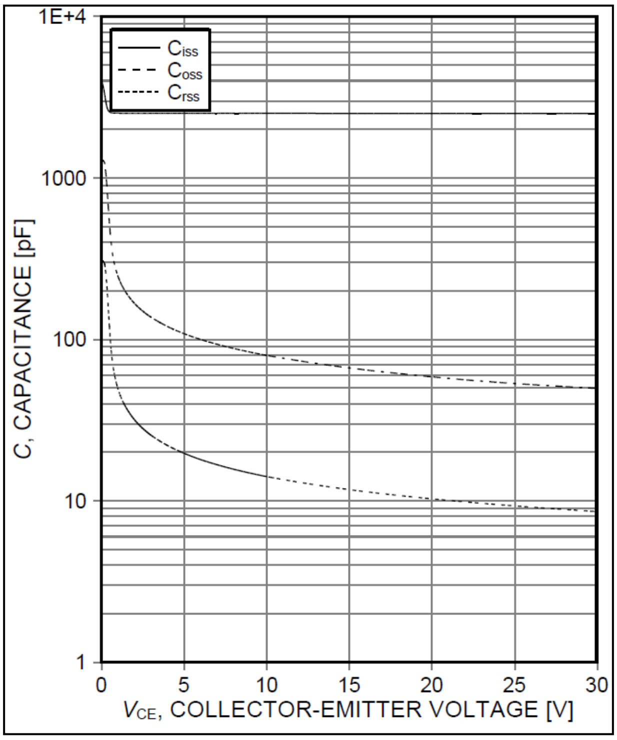

Figure 10 Typical capacitance values as function of collector-emitter voltage

Gate charge Q_G

Gate charge	Q_G	V_{CC} = 520V, I_C = 40.0A, 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:

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

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.

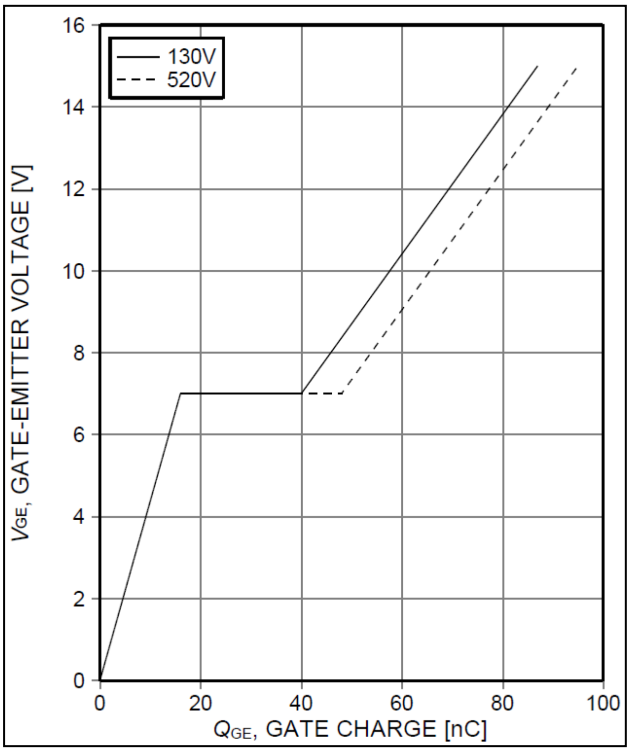

Figure 11 Typical gate charge as function of gate-emitter voltage

Internal emitter inductance L_E

Internal emitter inductance measured 5mm (0.197 in.) from case	L_E	PG-TO220-3 PG-TO247-3	-	7.0 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.

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°C						
Turn-on delay time	$t_{d(on)}$	T_{vj} = 25°C, V_{CC} = 400V, I_C = 20.0A, V_{GE} = 0.0/15.0V, $R_{G(on)}$ = 15.0Ω, $R_{G(off)}$ = 15.0Ω, $L\sigma$ = 30nH, $C\sigma$ = 30pF $L\sigma$, $C\sigma$ from Fig. E Energy losses include "tail" and diode reverse recovery.	-	22	-	ns
Rise time	t_r		-	12	-	ns
Turn-off delay time	$t_{d(off)}$		-	165	-	ns
Fall time	t_f		-	13	-	ns
Turn-on energy	E_{on}		-	0.39	-	mJ
Turn-off energy	E_{off}		-	0.12	-	mJ
Total switching energy	E_{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°C and high temperature 150°C or 175°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.

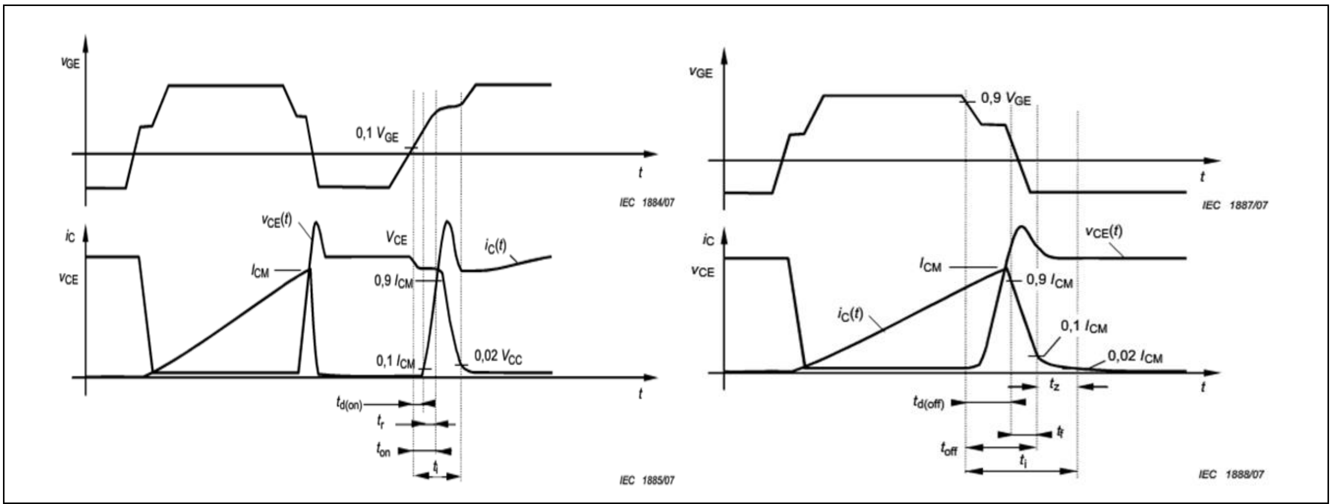

Figure 12 Definition of switching time according to IEC60747-9 (2007) standard Left: turn-on; right: turn-off

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.

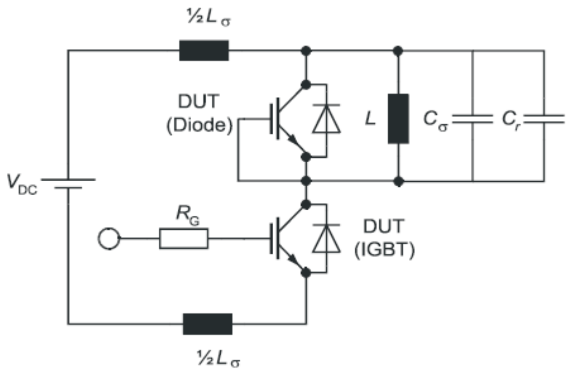

Figure 13 Setup to conductc the IGBT's dynamic characterization

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 paramenters are the same as has been explained previously.

Table 3 Switching characteristics of the IGBTs for resonant applications

IGBT Characteristic, at T_{vj} = 25°C

Turn-off delay time	$t_{d(off)}$	T_{vj} = 25°C, V_{CC} = 600V, I_C = 20.0A, V_{GE} = 0.0/15.0V, $R_{G(on)}$ = 10.0Ω, $R_{G(off)}$ = 10.0Ω, $L\sigma$ = 175nH, $C\sigma$ = 40pF $L\sigma$, $C\sigma$ from Fig. E 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°C

Turn-off delay time	$t_{d(off)}$	T_{vj} = 25°C, V_{CC} = 65V, I_C = 15.0A, V_{GE} = 0.0/18.0V, $R_{G(off)}$ = 10.2Ω Energy losses include "tail" according Figure B. (Test circuit Figure E, C_r = 300nF).	-	130	-	ns
Fall time	t_f		-	1000	-	ns
Turn-off energy, soft switching	E_{off}	dv/dt = 50.0V/µs	-	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.

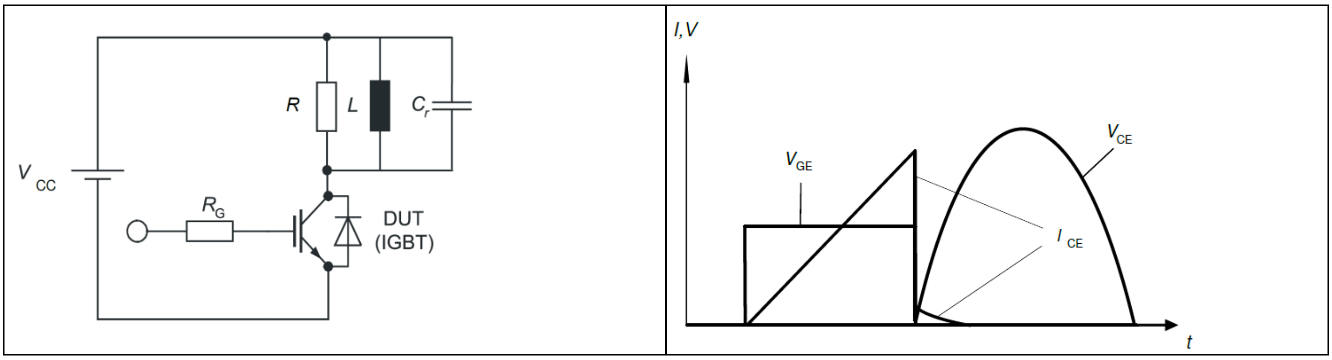

Figure 14 Setup and typical waveforms for soft turn-off parameters definition

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°C, V_R = 400V, I_F = 20.0A, di_F/dt = 1000A/µs	-	62	-	ns
Diode reverse recovery charge	Q_{rr}		-	0.45	-	µC
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/µs

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 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 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.

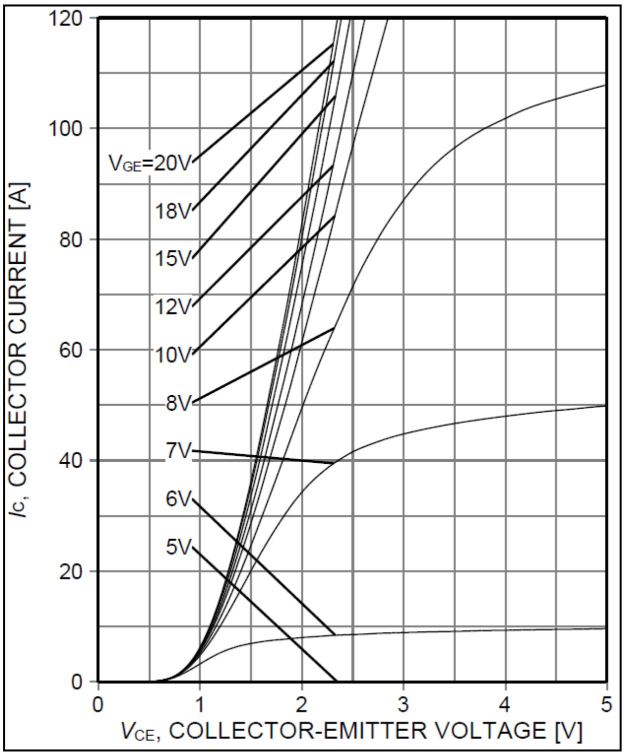

Figure 15 Output characteristics

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

Short circuit withstand time V_{GE} = 15.0V, V_{CC} ≤ 400V Allowed number of short circuits < 1000 Time between short circuits: ≥ 1.0s T_{vj} = 150°C	t_{SC}	5	µs

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 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.

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.

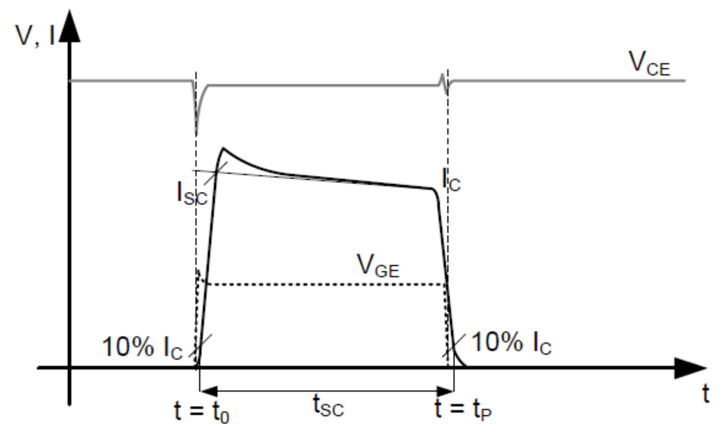

Figure 16 Typical waveform of IGBT short circuit

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 Max. 1000 short circuits Time between short circuits: ≥ 1.0s	$I_{C(SC)}$	V_{GE} = 15.0V, V_{CC} ≤ 400V, t_{SC} ≤ 5µs T_{vj} = 150°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.

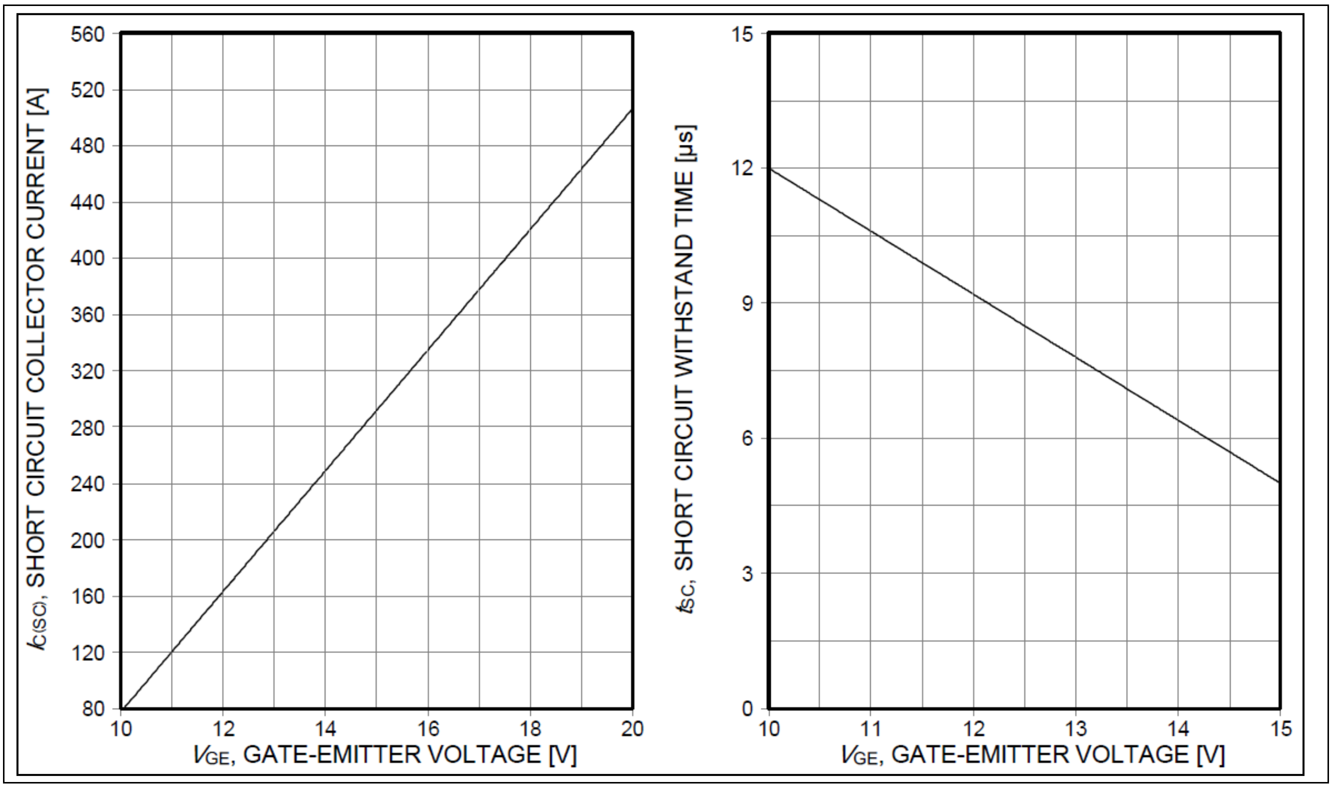

Figure 17 Typical short circuit collector current (left) and withstand time (right) as a function of the gate voltage

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.

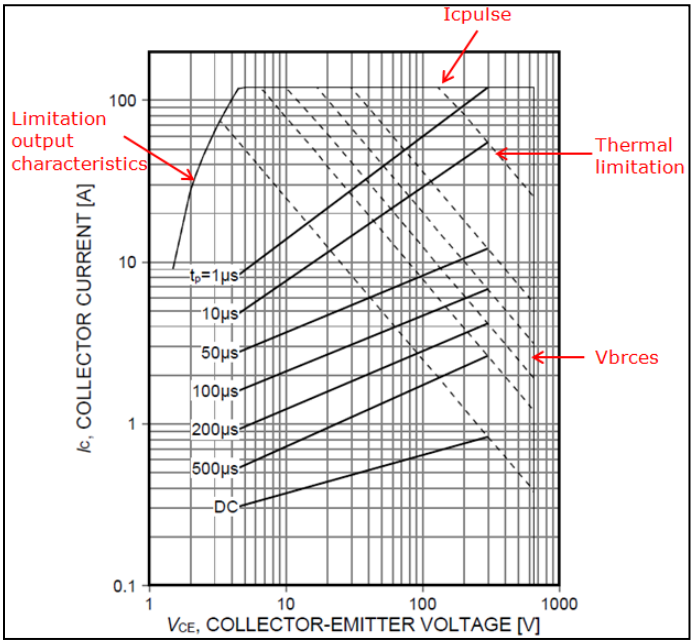

Figure 18 Forward bias SOA

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:

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

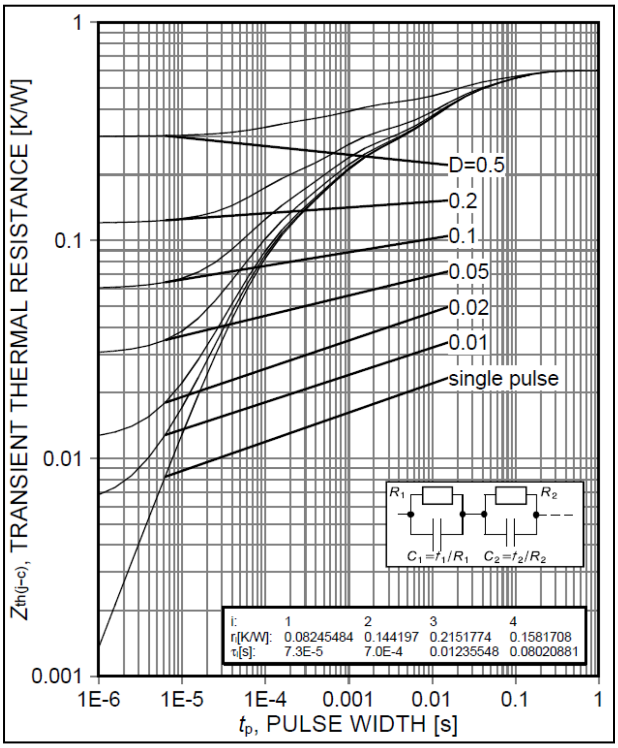

Figure 19 IGBT transient thermal resistance as a function of pulse length

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

Turn off safe operating area $V_{CE} \leq 650V$, $T_{vj} \leq 175°C$	-	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}.

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_{σ}	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_{σ}	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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