

# TRENCHSTOP™ 1200 V IGBT7 Application Note

## About this document

### Scope and purpose

For IGBT modules, variable speed drives is the most important application. One major topic in drive applications is the limitation of switching speed due to the inherent limitation of the motor insulation system. Therefore, switching slopes ( $dv/dt$ ) are restricted to the range of 2 to 10  $kV/\mu s$  with a typical target of 5  $kV/\mu s$ . Moreover, a motor overload is typically only required for a short time, e.g. to provide initial breakaway torque at start-up. These requirements are addressed by Infineon's new 1200 V TRENCHSTOP™ IGBT7 and emitter-controlled diode EC7 technology. The IGBT7 is based on the latest micro-pattern trench technology, and offers a significantly reduced on-state loss compared to IGBT4. A high level of controllability is provided as well as operation at 175°C under short-term overload conditions. This application note introduces the 1200 V TRENCHSTOP™ IGBT7 and emitter-controlled diode EC7, describing the chips and their characteristics. It also gives some application examples to support engineers in applying these new devices.

### Intended audience

This application note is intended for people who would like an introduction to TRENCHSTOP™ IGBT7 1200 V.

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Introduction

# 1 Introduction

## 1.1 Instructions

The following information is provided only as a reference for the implementation of the device and is not to be regarded as a description or warranty of a certain functionality, condition or quality of the device. This application note is intended to provide an explanation of the parameters and diagrams given in the datasheet of TRENCHSTOP™ IGBT7 modules. It provides background information for designers of power electronic systems and provides detailed clarification of the information in the datasheet.

## 1.2 IGBT7 overview

Infineon's 1200 V TRENCHSTOP™ IGBT7 is based on the latest micro-pattern trench technology, which provides greatly reduced losses and a high level of controllability. The chip is specifically optimized for industrial drives applications, in other words for lower static losses, higher power density and softer switching [1]. Additionally, by raising the allowed maximum chip operation temperature up to 175 °C, a significant increase of power density can be obtained. The key benefits highlighted in Figure 1 include:

- Lower on-state voltage  $V_{CE(sat)}$  and  $V_f$
- $T_{vj,op}=175^{\circ}C$  during overload
- Enhanced controllability of  $dv/dt$
- Optimized switching losses for  $dv/dt = 5kV/\mu s$
- 8  $\mu s$  short-circuit robustness
- Improved FWD (free-wheeling diode) softness

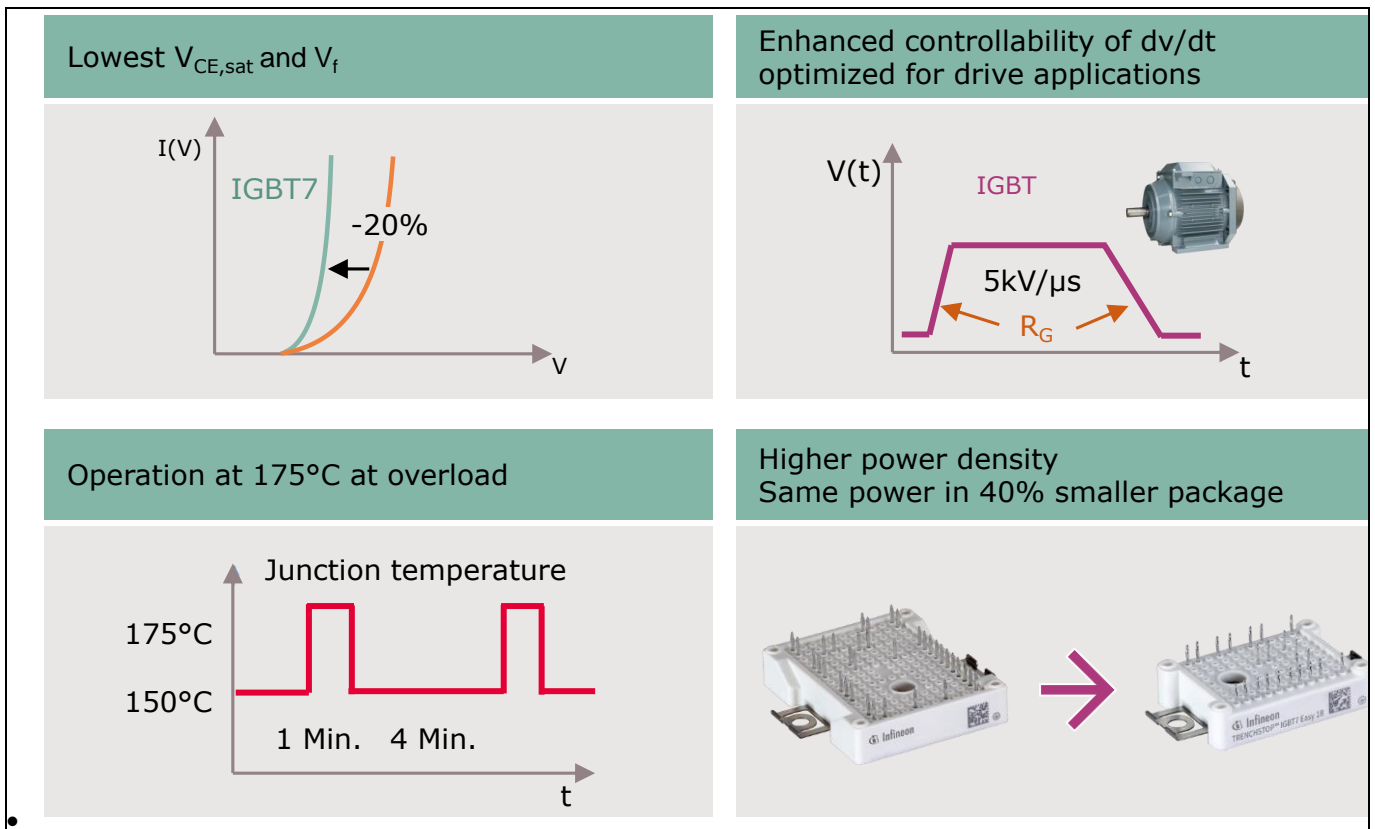


Figure 1 Key technical benefits of TRENCHSTOP™ IGBT7

Introduction

1.3 Chip technology

For this IGBT generation (IGBT7), an IGBT structure based on micro-pattern trenches (MPT) is used. This cell concept is characterized by implementing parallel trench cells separated by sub-micron mesas [2] in contrast to the formerly used square trench cells. Figure 2 shows a schematic drawing of an MPT structure with possible trench designs. For trench cells with smaller cell pitches and narrow mesas between gate areas, the carrier storage close to the emitter electrode increases considerably. Therefore there is a significant increase in electrical conductivity in the drift zone, which leads to a significant reduction in forward voltage.

Figure 3 shows the final trade-off point for 1200V IGBT7 and previous generations of Infineon IGBT chips. Compared to the last IGBT4 generation, the IGBT7 shows almost the same turn-off losses while making a big step in the reduction of static losses. Its on-state voltage is reduced by around 20% compared to the IGBT4 T4 chip. This brings significant loss reduction in the final application, especially for industrial drives applications which usually operate with moderate switching frequency.

Not only the IGBT itself, but also the FWD for the IGBT7, the emitter-controlled diode EC7, is tailored to drive applications. Compared to the previous emitter-controlled diode EC4, it has a 100 mV lower forward voltage drop, and also an improvement in reverse-recovery softness [1].

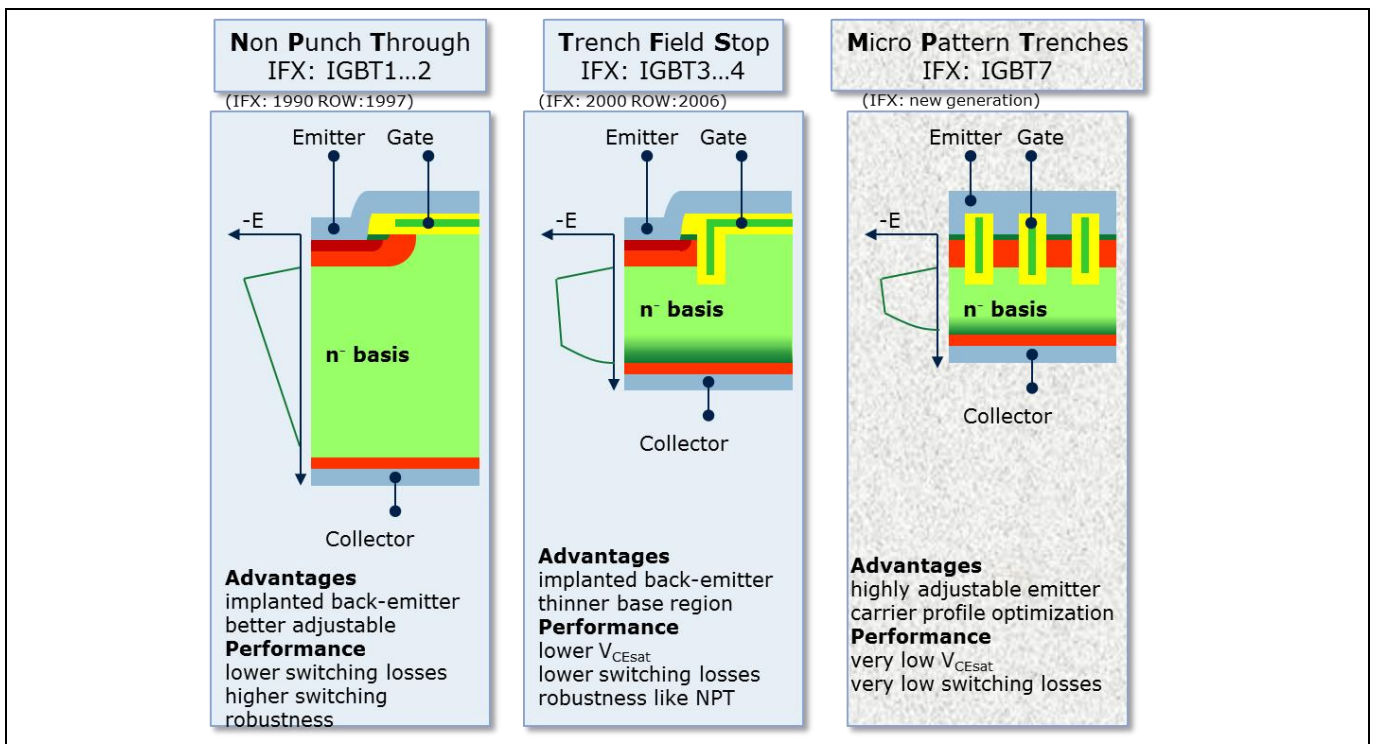


Figure 2 Chip technology overview

Introduction

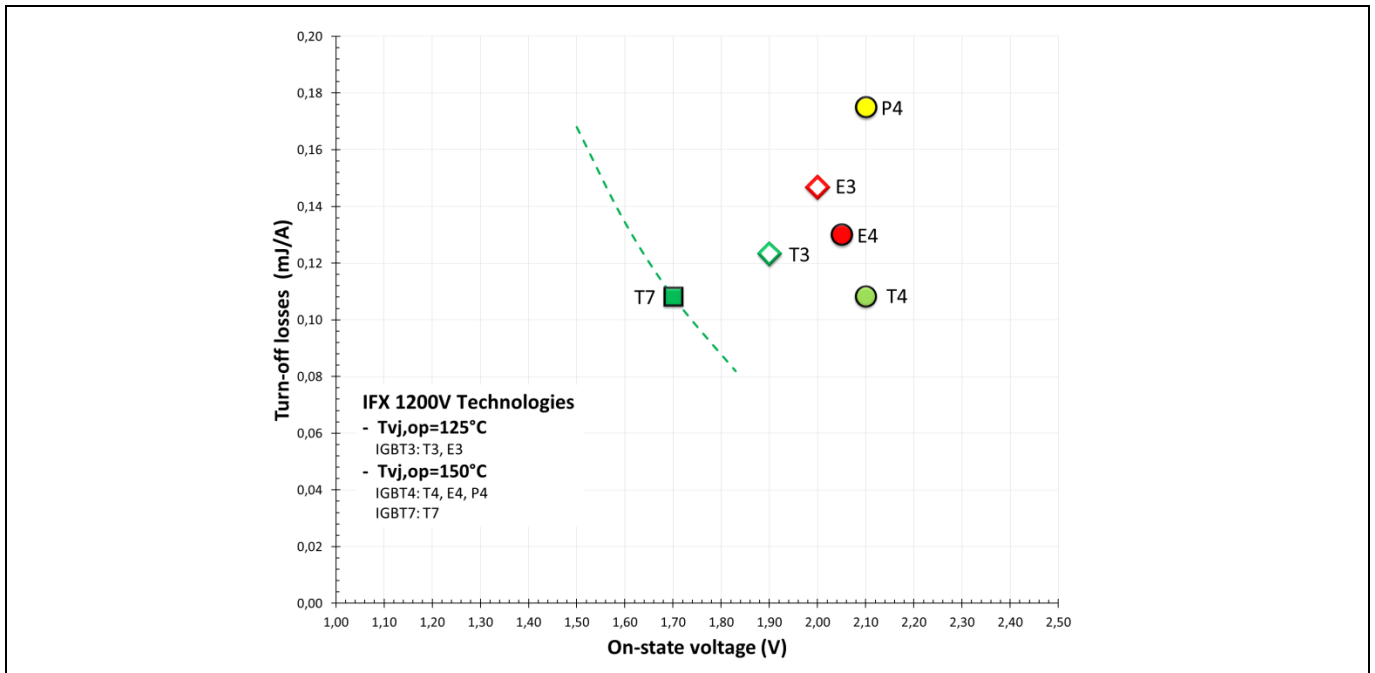


Figure 3 Trade-off diagram Infineon IGBT generations for industrial drives

### 1.4 Module technology

The TRENCHSTOP™ IGBT7 1200 V has already been introduced in the well-established Easy packages and will soon be introduced in the Econo package. A line-up of the first products to use this new IGBT technology can be seen in Figure 4. A 25 A PIM module is now available in the Easy1B package, and a 50 A PIM module is available in the Easy2B package. For the six-pack modules, power density has also been considerably increased.

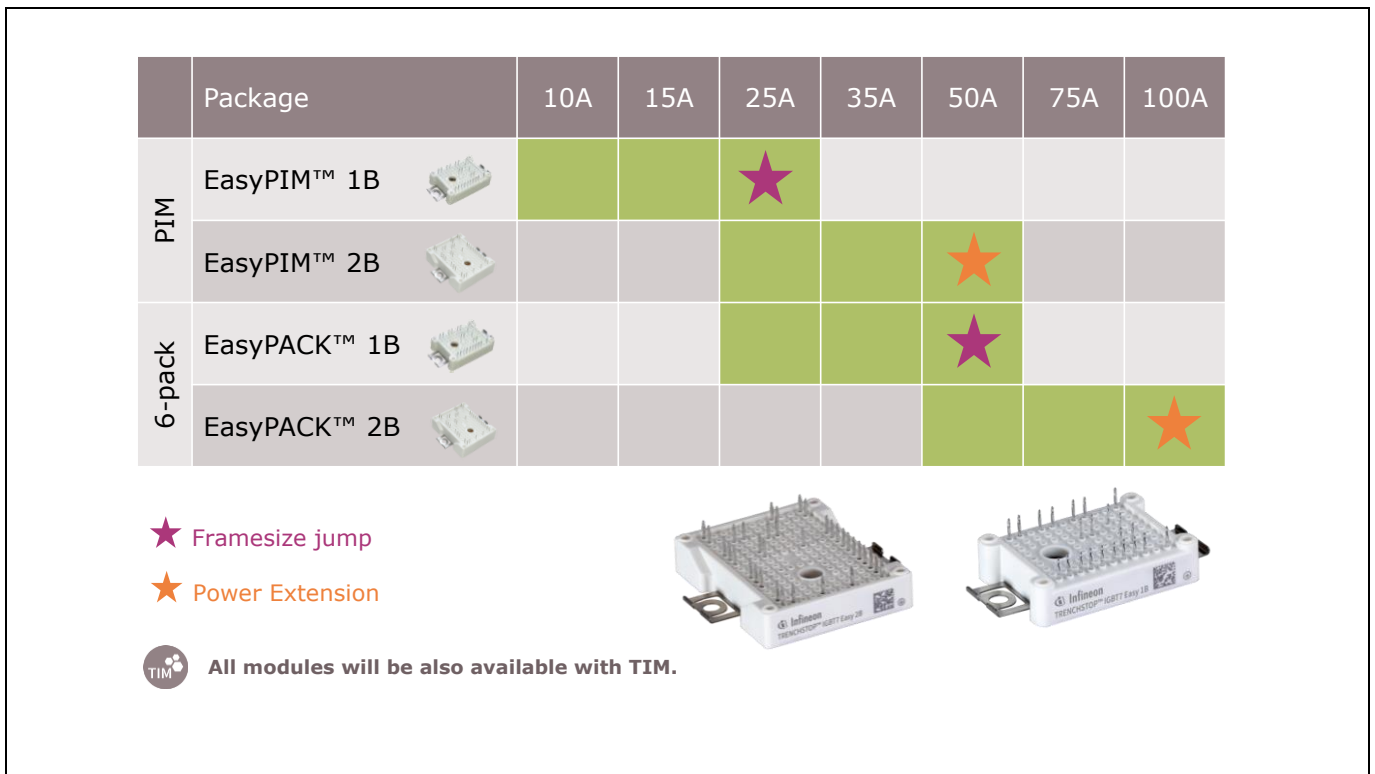


Figure 4 Portfolio of TRENCHSTOP™ IGBT7 for Easy package

## Application of TRENCHSTOP™ IGBT7

## 2 Application of TRENCHSTOP™ IGBT7

This section describes the main aspects for the design-in of IGBT7 power modules, and the main technical differences as compared to IGBT4. These include:

- Optimized switching dv/dt rates
- Higher maximum operation junction temperature up to 175°C
- Short-circuit capability tailored to drive applications

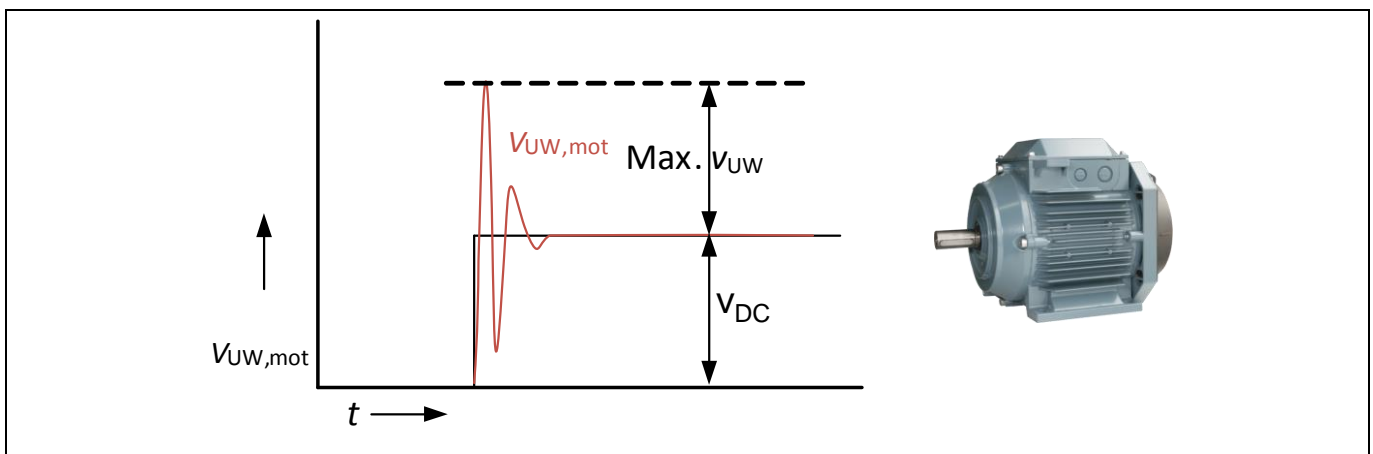
A general guidance to the application of Infineon industrial power modules and their datasheet descriptions can be found in [3] and [4].

### 2.1 Switching speed dv/dt optimization

#### 2.1.1 Motor-insulation stress

Motors supplied with typical pulsed width modulated (PWM) voltage signals from inverters will experience higher electrical stress in their insulation systems. There is also the possibility that damage will be caused to the bearings due to the generation of parasitic current flowing from the rotor to motor frame. These effects are due to the pulse rise time of the semiconductor switching events ( $t_r$ ) which results in a dv/dt of PWM pulses. The use of long motor cables leads to even higher peak voltages at the motor terminals. The so-called “critical cable length”  $l_{\text{cable,crit}}$  describes the cable length between inverter and motor where the motor terminal voltage reaches twice the inverter output voltage. Assuming a propagation speed of traveling waves in a cable of  $150 \text{ m} / \mu\text{s}$ , and a pulse rise time  $t_r$  of  $0.1 \mu\text{s}$ , the critical cable length will be [5]:  $l_{\text{cable,crit}} = 0.1 \mu\text{s} \cdot 0.5 \cdot 150 \text{ m} / \mu\text{s} = 7.5 \text{ m}$ .

The resulting voltage spikes and rise times can lead to arcing and eventually to coil-insulation failure. Therefore, motor manufacturers typically recommend not exceeding a dv/dt limit at the inverter terminals of approximately **5 kV/ $\mu\text{s}$**  under worst-case conditions for 400 V motors [6].



**Figure 5** Example of a voltage waveform at the motor terminals

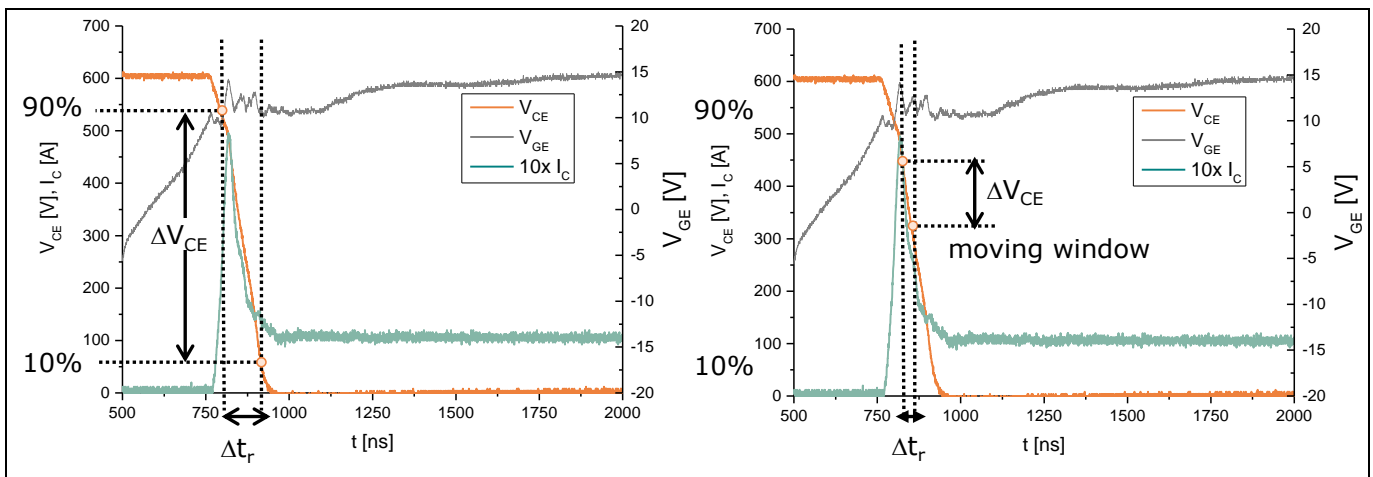
#### 2.1.2 Definition of $dv_{\text{CE}}/dt$

For trench IGBTs, the switching speed dv/dt rises during turn-on with decreasing load current and junction temperature. When setting the value of the gate resistor, a common way to adjust the switching speed is to consider a turn-on event is at 10% of the nominal module current  $I_{\text{Cnom}}$ , at a junction temperature of 25°C, and at a nominal bus voltage [7]. The switching speed during turn-off rises with increasing load current, and therefore the value of the turn-off gate resistor can be set at 100% of the nominal current.

## Application of TRENCHSTOP™ IGBT7

The switching speed of the IGBTs is defined as  $dv/dt = \Delta V_{CE} / \Delta t_r$ . The voltage and time difference can be determined in two different ways. The most common way is to use static 90% and 10% values of the DC-link voltage as shown in Figure 6a. An alternative way is to define a 20% moving window, and determine the maximum gradient as indicated in Figure 6b. This definition has been termed as  $dv/dt_{max}$  and can be considered as a worst-case condition dimensioning. This definition is also helpful as far as EMI is concerned.

Please note the shape of the curve also depends on the stray inductance of the gate driver, the value of the gate resistor and the value of the parasitic capacitance in the test setup.



**Figure 6** Example of turn-on switching curves for a)  $dv/dt_{10-90}$  definition b)  $dv/dt_{max}$  definition for FS100R12W2T7 at 10%  $I_{Cnom}$ ,  $T_{vj} = 25^\circ\text{C}$

### 2.1.3 Controllability of $dv/dt$

When designing an industrial drive, it is important to adjust the voltage slope  $dv/dt$  according to the motor insulation requirements (Chapter 2.1.1) or to meet EMI limitation. For this purpose, the TRENCHSTOP™ IGBT7 offers a high level of controllability. The controllability corresponds to the device's ability to vary the  $dv/dt$  by adjustment of the value of the gate resistor ( $R_G$ ). This, in turn, will affect the total switching losses ( $E_{tot}$ ) [1].

As an example, Figure 7 depicts the  $dv/dt$  of the IGBT as a function of gate resistance  $R_G$  for the module FS100R12W2T7. At nominal  $R_G$  of  $1.8\ \Omega$ , the turn-off  $dv/dt_{10-90}$  is already below  $5\ \text{kV}/\mu\text{s}$ , and turn-on  $dv/dt_{10-90}$  is very close to this limit. With increasing  $R_G$ , both turn-on and turn-off  $dv/dt$  decreases. Especially turn-on  $dv/dt$  decreases dramatically with  $R_{gon}$  in the range of  $2\ \text{kV}/\mu\text{s}$  to  $8\ \text{kV}/\mu\text{s}$ . This means with a slightly bigger  $R_G$  than nominal  $R_G$  in the datasheet, the  $dv/dt$  below  $5\ \text{kV}/\mu\text{s}$  can be achieved.

## Application of TRENCHSTOP™ IGBT7

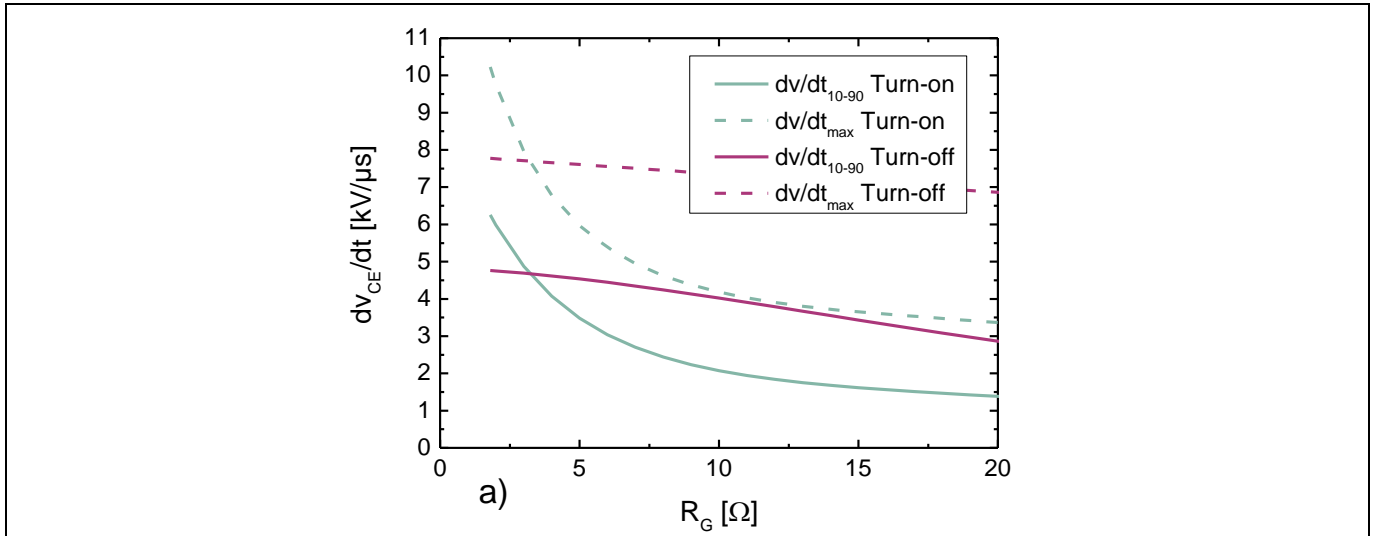


Figure 7 IGBT dv/dt versus gate resistance  $R_G$  for FS100R12W2T7

### 2.1.4 How to choose $R_G$ with optimized dv/dt

Only the 10-90% defined dv/dt ( $dv/dt_{10-90}$ ) values are indicated in the TRENCHSTOP™ IGBT7 datasheets. The 10-90% defined  $dv/dt_{10-90}$  is required to be within a certain limitation for motor lifetime. The datasheet dv/dt diagrams present both turn-on dv/dt and turn-off dv/dt as a function of the gate resistance  $R_G$ . The turn-on dv/dt curve is specified at 10% nominal current and room temperature, the turn-off curve at nominal current and room temperature. It should be noted that the dv/dt level, especially the turn-on dv/dt, are not absolute, but are also dependent on the final test setup. Therefore it provides only an indication, and needs to be verified in the final application.

Based on targeted dv/dt, the corresponding  $R_G$  can be read out from the datasheet diagram. Always higher  $R_G$  can get lower dv/dt. Turn-on losses  $E_{on}$  increase considerably regarding turn-on gate resistor  $R_{gon}$ . Considering lower power losses, it is always preferable to choose lower  $R_{gon}$ . With the IGBT7, strong controllability of turn-on dv/dt, small  $R_{gon}$  can be used to achieve low turn-on losses, and at the same time, keep turn-on dv/dt within specifications. The turn-off gate resistor  $R_{goff}$  only has a small effect on the turn-off losses  $E_{off}$ . Larger  $R_{goff}$  can be used to get low dv/dt with an insignificant switching loss increase.

### 2.1.5 Influence of an additional gate capacitor

The IGBT gate-emitter capacitor ( $C_{GE}$ ) and gate-collector capacitor ( $C_{GC}$ ) are optimized to let the IGBT7 have the full control of dv/dt, and to have an optimized switching waveform. Also the  $C_{GE}$  is designed to be large enough to avoid parasitic turn-on effects. This negates the need for additional gate capacitors. However parasitic effects when using zero voltage for turn-off still should be checked. The worst case for parasitic turn-on happens at lowest  $R_{gon}$  and highest  $R_{goff}$ . Additional gate capacitors can increase the risk of gate oscillations and will increase the gate driver supply requirements.

### 2.1.6 Higher gate charge

To achieve good controllability of dv/dt and avoid parasitic turn on, IGBT7 shows higher gate charge ( $Q_G$ ) than the previous generation IGBT4. Driving power should be checked to make sure the power supply and the driving circuit has enough power rating. The required driving power ( $P_{Gdr}$ ) can be calculated by the following equation. The  $Q_G$  to be used in the equation should be chosen according to the applied driver output voltage.[4]

$$P_{Gdr} = Q_G \times (V_{GE(on)} - V_{GE(off)}) \times f_{sw}$$

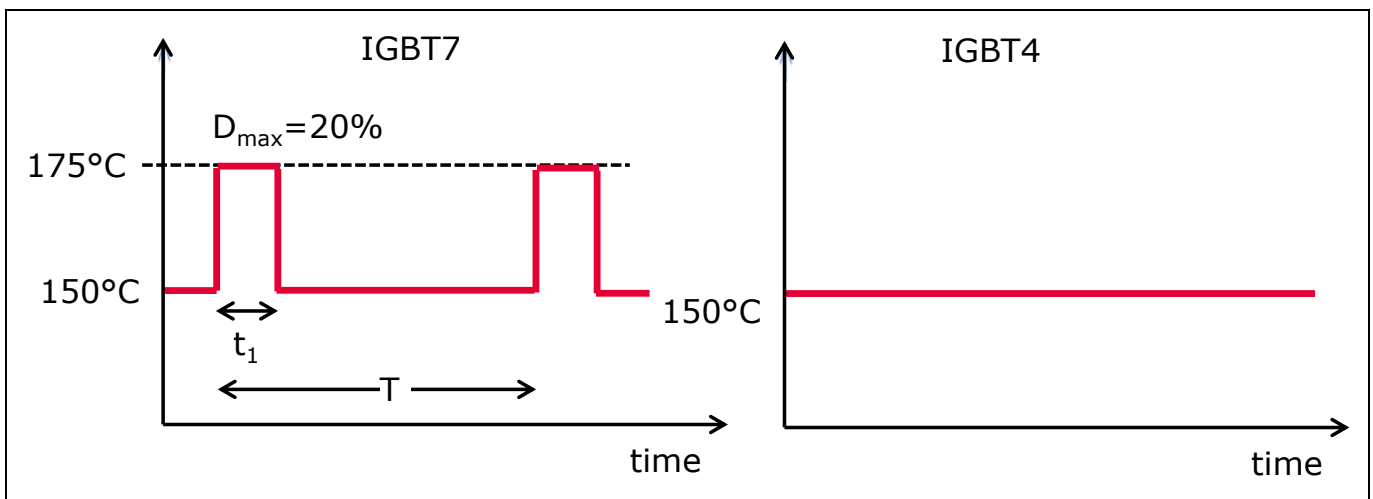


## 2.2 Maximum junction temperature up to 175°C

### 2.2.1 Definition of 175°C operation junction temperature

The TRENCHSTOP™ IGBT7 allows operation at a temperature of  $T_{vjop}=175^{\circ}\text{C}$  under overload conditions [8]. This matches the typical requirement in the drives application where high current and thus temperature are only required short term.

Figure 8 shows the definition of the allowed operation junction temperature under switching conditions for IGBT7. For normal operation, the maximum junction temperature is  $150^{\circ}\text{C}$ . During overload conditions, a maximum junction temperature above  $T_{vjop}=150^{\circ}\text{C}$  and up to  $T_{vjop}=175^{\circ}\text{C}$  is allowed for a maximum duration of  $t_1=60$  seconds. The overload duration where the  $T_{vjop}$  is above  $150^{\circ}\text{C}$  must be within 20% of the load cycle time (T), e.g.  $t_1=60\text{s}$  every  $T=300\text{s}$ . Using this increased junction temperature capability, compared to a maximum  $T_{vjop}=150^{\circ}\text{C}$ , can enable higher power density, but also can result in higher heatsink temperatures.



**Figure 8** Maximum operation junction temperature definition for IGBT7 and IGBT4

The maximum temperature definition shown in Figure 8 should be considered as the maximum  $T_{vjop}$  limitation including the temperature ripple due to the fundamental output frequency. Figure 9 provides two examples of junction temperature profiles. In Figure 9a, the temperature of  $150^{\circ}\text{C}$  exceeds the maximum curve of the junction temperature for  $t_1=50\text{s}$ . It is below  $150^{\circ}\text{C}$  for the rest of the  $T=300\text{s}$  cycle. Therefore, the duty cycle is 16.7%. This condition would be allowed from a maximum operating junction temperature point of view. Another example is shown in Figure 9b. In this case the temperature of  $150^{\circ}\text{C}$  exceeds the maximum curve of the junction temperature for the whole period of the load profile. Therefore, this operation would not be allowed.

Application of TRENCHSTOP™ IGBT7

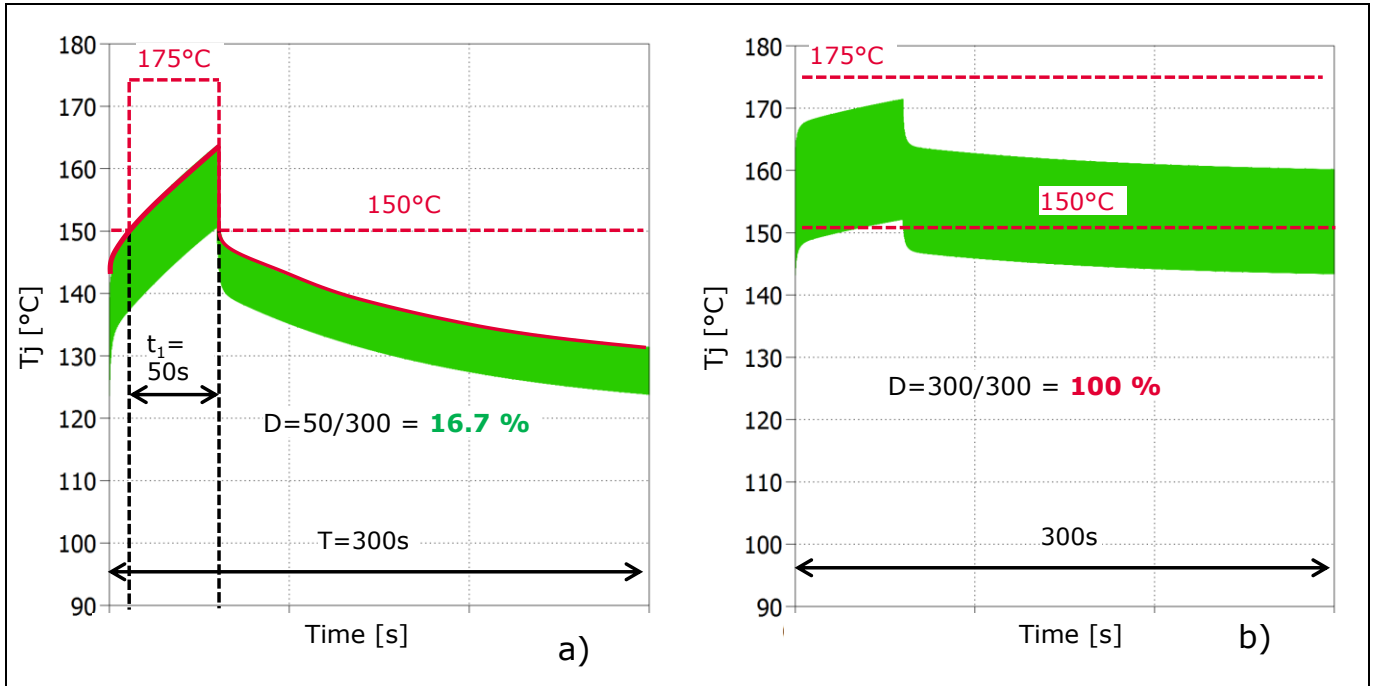


Figure 9 Examples illustrating when the 175°C junction temperature operation is a) allowed and b) not allowed

## 2.2.2 System-temperature limitation for even higher IGBT operation temperature

The TRENCHSTOP™ IGBT7 allows a 25°C higher operation junction temperature than the IGBT4. With this feature, the system using IGBT7 has even higher power density and component temperatures, e.g. PCB, heatsink and module frame. Several restrictions should be considered as described below.

### 2.2.2.1 Frame-temperature limitation

The RTI (relative temperature index) value is specified in the datasheet. The value is the characteristic parameter related to thermal degradation of the plastic material. During the operation, the module-frame temperature should not exceed this value. Otherwise, the UL standard ratings will be violated.

### 2.2.2.2 PCB-temperature limitation

With the increased junction temperature, the power density of the system can be higher. This means that the current that goes through each pin can increase, as the pinout for IGBT7 and IGBT4 PIM modules are the same. With this increase in current, the PCB temperature rise should be carefully considered. The maximum allowed PCB temperature depends on the PCB material itself. Thicker copper layers, wider tracks, increased number of layers, and system cooling can help to reduce PCB temperature.

### 2.2.2.3 Heatsink-temperature limitation

The heatsink temperature should not exceed the allowed operation temperature of the thermal interface material. If the module is pre-applied with Infineon’s thermal interface material TIM [10], the value is 150°C.

## Application of TRENCHSTOP™ IGBT7

## 2.3 Short-circuit protection

Short-circuit withstand time  $t_{sc}$  for IGBT7 is defined to be  $t_{sc}=8\ \mu\text{s}$  at a temperature of  $T_{vjop}=150^\circ\text{C}$ . With this slight short-circuit withstand-time reduction from the  $10\ \mu\text{s}$  of IGBT4, the IGBT7 performance has been further improved enabling the system to show lower power losses and better thermal behavior.

### 2.3.1 Short-circuit protection definition

Short-circuit withstand time  $t_{sc}$  that is specified in the datasheet is based on the IGBT arm shoot-through mode as shown in Figure 10a. The short-circuit loop impedance is so low that the short-circuit current reaches its saturation level immediately. The short-circuit withstand time is counted from 10% of the short-circuit current at the rising edge, to 10% of the short-circuit current at the falling edge. More details are given in [4].

For a motor phase-to-phase short circuit, which typically has higher short-circuit impedance, the short-circuit current rises slowly due to this impedance. IGBT will first go into saturation mode, only when the short-circuit current has reached its saturation level, the IGBT goes into desaturation, and the  $V_{CE}$  voltage rises up to the DC link voltage. In such a short-circuit mode, short-circuit time is counted from the  $V_{CE}$  desaturation rising edge at 20% of the DC link voltage to 10% of the short-circuit current falling edge. At the start of the short-circuit event, until the IGBT goes into hard desaturation, the  $V_{CE}$  voltage is lower, so the losses in the chip are not as high as during the phase when the IGBT sees a higher  $V_{CE}$  voltage. So this initial period is not included in the short-circuit time.

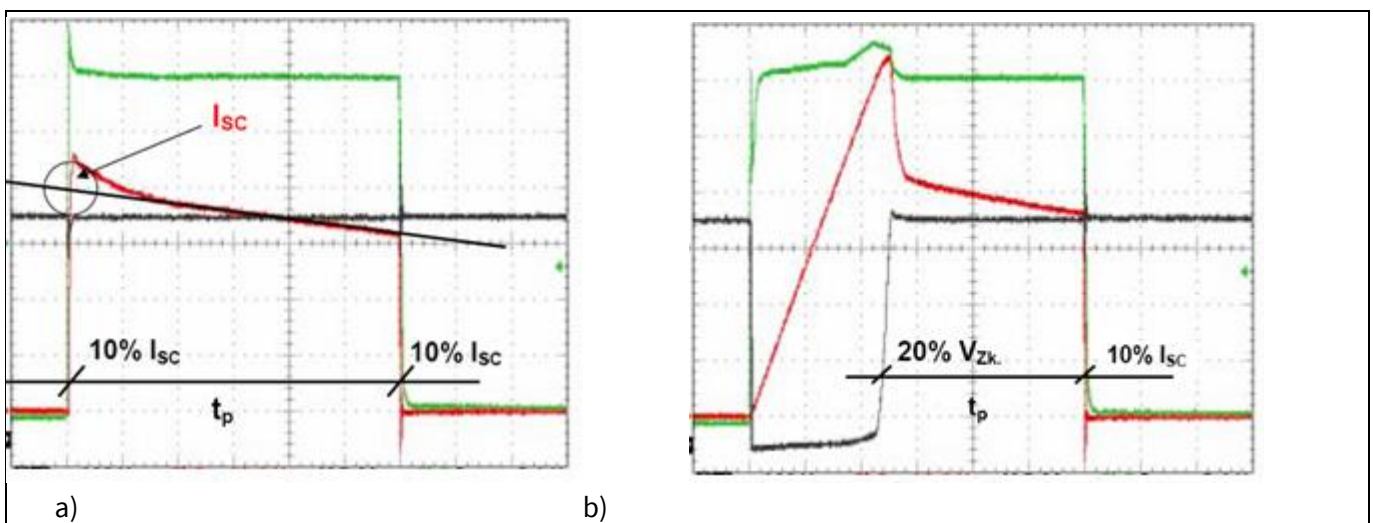


Figure 10 a) Short-circuit definition A b) Short-circuit definition B

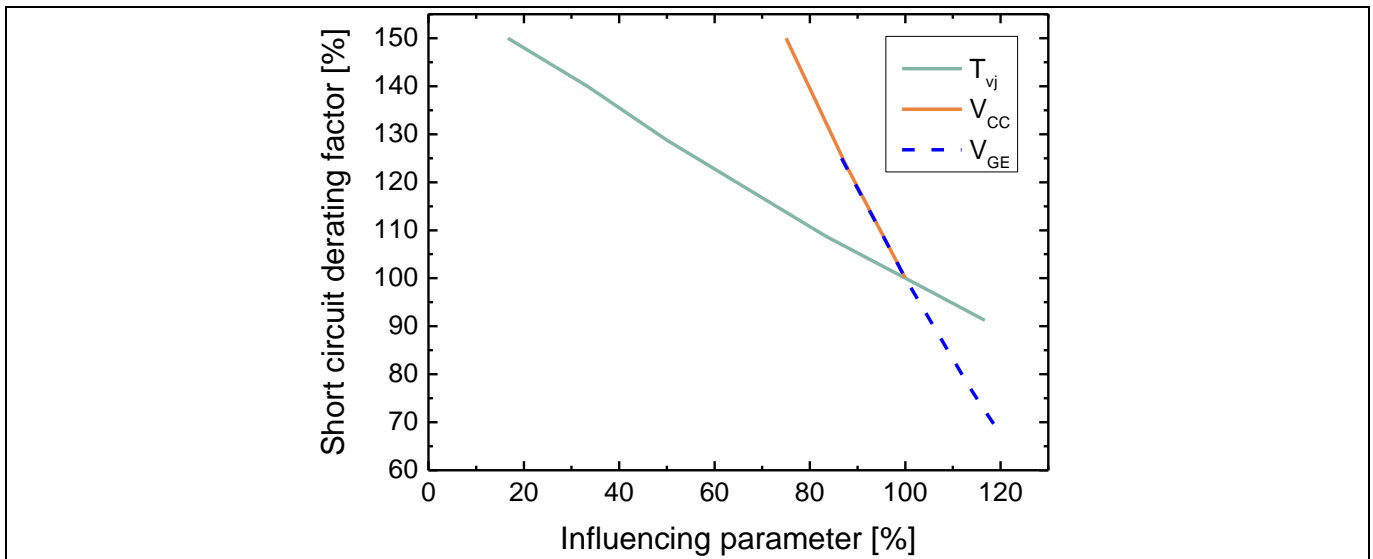
### 2.3.2 Short-circuit time derating curve

The short-circuit withstand time strongly depends on application conditions such as gate voltage, junction temperature at the time of the short circuit, and the DC link voltage. The higher the gate voltage, the higher the IGBT short-circuit current level, which will lead to a reduced short-circuit withstand time. Higher short-circuit starting temperature and higher DC link voltage can also lead to a reduced short-circuit withstand time.

For 1200 V IGBT7 datasheets, short-circuit withstand time is always specified at  $V_{CC}=800\ \text{V}$  DC link voltage,  $V_{GE}=15\ \text{V}$  gate voltage, and a starting junction temperature of  $T_{vj}=150^\circ\text{C}$  at the time of the short circuit. These values are considered as 100%. When the application condition is different from the specified datasheet

## Application of TRENCHSTOP™ IGBT7

conditions, the allowed short-circuit time may also change. Figure 11 provides the short-circuit withstand time regarding DC link voltage, maximum junction temperature and gate voltage.



**Figure 11 Short-circuit rating factors as a function of temperature, DC link and gate voltage**

For example, in a real application, the operating conditions are assumed to be as follows:

- The starting junction temperature is 140°C
- DC link voltage is 600V
- The gate voltage is 14V

From the graphs in Figure 11, the following rating factors can be derived:

$A_1$  (derating factor for  $T_{vj}$ ) = 1.05,

$A_2$  (derating factor for  $V_{CC}$ ) = 1.5,

$A_3$  (derating factor for  $V_{GE}$ ) = 1.1.

The final short-circuit withstand time for the application conditions is then calculated by multiplying the datasheet value  $t_{p\_DS}$  by the derating factors:

$$t_{p1} = t_{p\_DS} \times A_1 \times A_2 \times A_3 = 8 \mu s \times 1.05 \times 1.5 \times 1.1 = 13.86 \mu s$$

## Advantages of TRENCHSTOP™ IGBT7

### 3 Advantages of TRENCHSTOP™ IGBT7

#### 3.1 Application example

In this section, an application example for General Purpose Drives (GPD) is provided comparing modules built with IGBT4 and IGBT7 technologies. The focus is on the increase of power density resulting in a reduction of system cost. This can be achieved by using a 40% smaller power module, the Easy1B instead of the Easy2B.

Simulations of losses and junction temperatures were run under overload conditions assuming the industry's normal-duty (ND) and heavy-duty (HD) operating conditions according to the values in Table 1 below.

**Table 1 Application parameters**

Parameter	Symbol	Value
DC link voltage	$U_{DC}$	540 V
Motor power (400V <sub>ac</sub> )	$P_N$	ND: 7.5 kW HD: 5.5 kW
Rated motor current for continuous operation (100%)	$I_N$	ND: 17.8 A HD: 13 A
Power factor	$\cos(\varphi)$	0,85
Modulation index	$m_i$	1
Output frequency	$f_{out}$	50 Hz
Switching frequency	$f_{sw}$	4000 Hz
Maximum switching slope	$dv_{CE,on10-90}/dt$	5 kV/ $\mu$ s
Thermal resistance heatsink to ambient (per switch)	$R_{thHA}$	1.5 K/W (Easy2B IGBT4) 3.2 K/W (Easy1B IGBT7)
Heatsink thermal time constant	$T_H$	60 s
Ambient temperature	$T_A$	40°C (ND), 50°C (HD)
Load profile		ND: 3s 150%• $I_N$ ; 60s 110%• $I_N$ HD: 3s 200%• $I_N$ ; 60s 150%• $I_N$

Please note that all values provided here are only guidance. The nominal motor current  $I_N$  is not a fixed value, but depends on the manufacturer, the power factor and the number of poles of the motors. Induction motors inherently offer a pullout torque that is typically twice the nominal torque [9]. Hence, a maximum overload current of 200% was chosen.

The module parameters can be seen in Table 2. Focussing on application requirements, the gate resistance has been selected so that a  $dv/dt$  of 5 kV/ $\mu$ s is not exceeded, as described in 2.1.3. The switching losses were measured with the standard double-pulse test.

Advantages of TRENCHSTOP™ IGBT7

Table 2 Module parameters

Parameter	IGBT4	TRENCHSTOP™ IGBT7
Power module	FP25R12W2T4 (EasyPIM™ 2B)	FP25R12W1T7 (EasyPIM™ 1B)
$V_{CE,0}$ @ $I_{nom}$ , 125°C	2.15 V	1.65 V
$E_{on} + E_{off} + E_{rec})/I_{Cnom}$ 600V, 125°C @5kV/μs	0.29 mJ/A	0.31 mJ/A
$T_{vjop,max}$	150°C	175°C

Figure 12 shows the simulated junction temperature as a function of the thermal resistance of the heatsink  $R_{thHA}$  for the different load profiles. The parameter  $R_{thHA}$  indicates the cooling performance of the system. It is defined here as a value per single switch (IGBT+FWD) [11].

As illustrated, a temperature of 150°C is the limit for IGBT4. According to Figure 12  $R_{thHA} = 1.72$  K/W for the normal-duty profile must be chosen. A much higher value of  $R_{thHA} = 3.25$  K/W can be selected for the IGBT7 because the maximum junction temperature can go up to 175°C. A lower performance heatsink can be used due to the increase in maximum junction temperature.

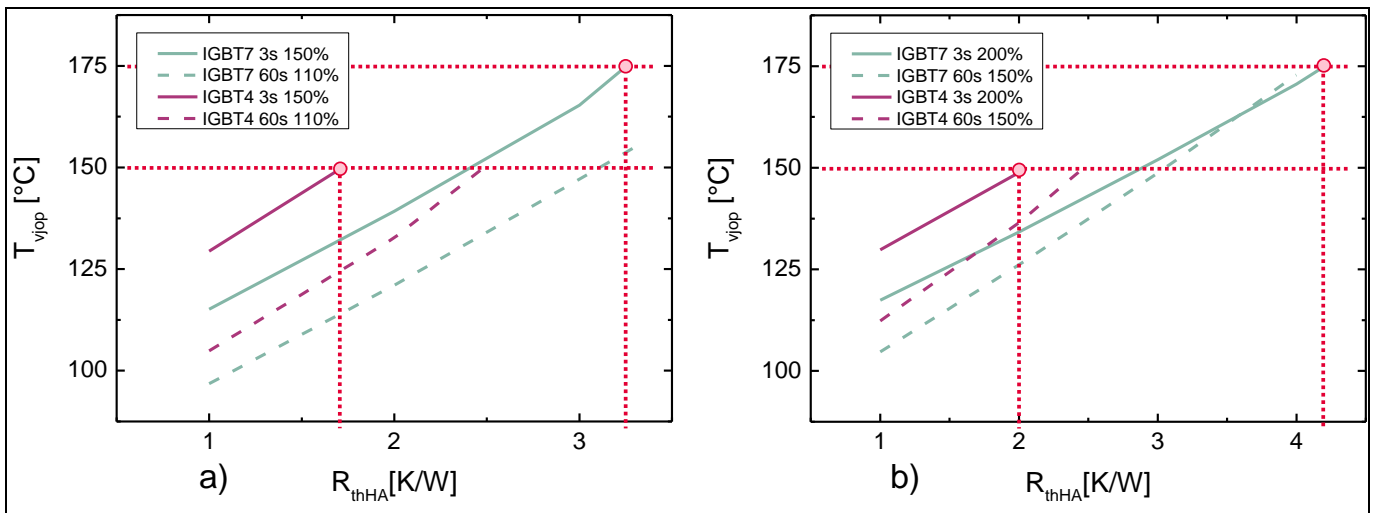


Figure 12 Junction temperature as a function of  $R_{thHA}$  for a) normal duty (ND) b) heavy duty (HD)

### 3.2 Selection of power modules for General Purpose Drives

Industrial motor power classes are standardized according to the IEC. Table 3 provides guidance in selecting EasyPIM™ power modules for a certain power class. Typically, General Purpose Drives feature a dual power rating, i.e. a frequency converter can serve both standard load profiles. Heavy duty is normally rated one power class below normal duty. Of course, the final design of the power modules depends on many parameters such as cooling conditions, and must be confirmed by the user. Infineon’s IPOSIM tool supports the user in selecting the right power modules at the required operating conditions [11].

Advantages of TRENCHSTOP™ IGBT7

Table 3 Motor power classes (400 V) and typical EasyPIM™ power modules

Motor power ND [kW]	Motor power HD [kW]	Power module
0.55	0.37	FP10R12W1T7
0.75	0.55	FP10R12W1T7
1.1	0.75	FP10R12W1T7
1.5	1.1	FP10R12W1T7
2.2	1.5	FP10R12W1T7
3.0	2.2	FP10R12W1T7
4.0	3.0	FP15R12W1T7
5.5	4.0	FP15R12W1T7
7.5	5.5	FP25R12W1T7
11	7.5	FP35R12W2T7
15	11	FP50R12W2T7

### 3.3 Inverter test

In order to verify the higher efficiency of the TRENCHSTOP™ IGBT7 devices, a laboratory test inverter was set up and tested. For this test, IGBT4 and IGBT7 power modules were used with approximately the same chip area and heatsink. The gate resistance was selected in order to limit dv/dt to 5 kV/μs under worst-case conditions. Figure 13 shows the junction temperatures for the IGBT4 module and the new TRENCHSTOP™ IGBT7 module at the same output current and operating conditions. The maximum temperature of 150°C was reached with IGBT4, while the junction temperature of IGBT7 was only at about 120°C. This confirms the significantly reduced power loss using IGBT7.

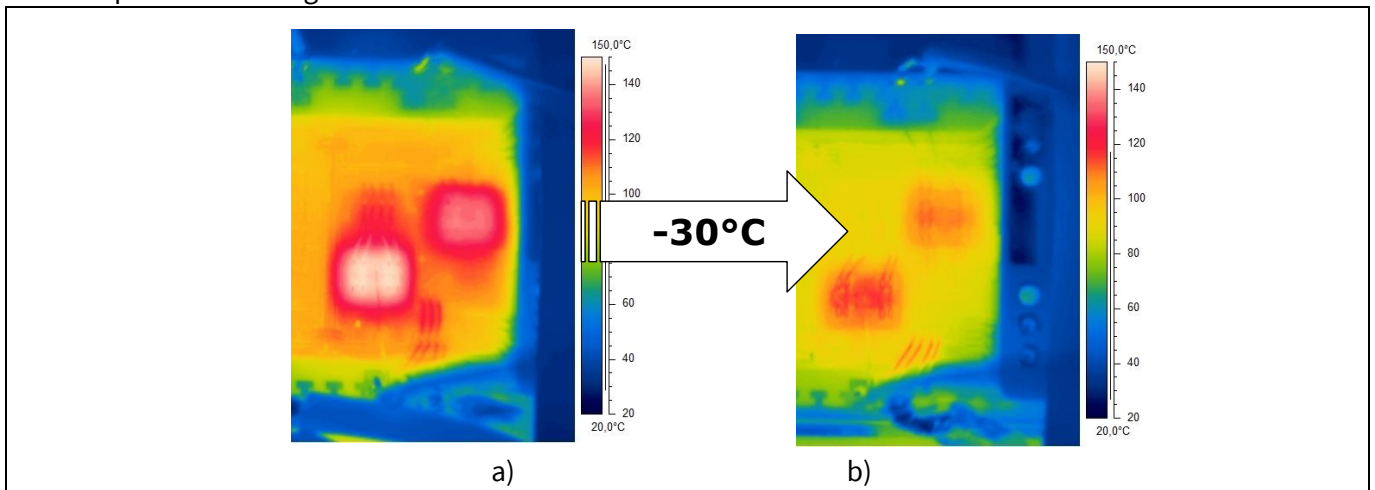


Figure 13 H-bridge inverter test and comparison of junction temperatures for a) IGBT4 and b) IGBT7 at the same output current

### 3.4 Conclusion

The investigations comparing IGBT4 and IGBT7 have shown the significant benefits of IGBT7 especially for variable-speed drive applications. The simulation results of IGBT7 in the Easy 1B & Easy 2B package show the potential of significantly higher power density than with IGBT4. This is because IGBT7 can offer the same current rating but in a smaller package. In addition, IGBT7 has been optimized for operation at a dv/dt level of 5

**Advantages of TRENCHSTOP™ IGBT7**

kV/ $\mu$ s to meet the requirements of motor-insulation systems. The improved diode softness shown in [1] will potentially offer benefits for system motor drive EMI performance. Finally, experimental tests under the same conditions in the lab show that IGBT 7 has lower power losses than IGBT4.

In conclusion IGBT7 is an attractive solution for variable speed drives requiring high efficiency and power density.



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**Title**

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**Revision History**

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## Revision History

### Major changes since the last revision

<b>Document version</b>	<b>Date of release</b>	<b>Description of changes</b>
1.0	18.06.2018	First version

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**Edition <yyyy-mm-dd>**

**Published by**

**Infineon Technologies AG**

**81726 Munich, Germany**

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**AppNote Number 201814**

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