**Diodes for IGCT- and GTO Applications**

**Application Note**

# Applying Fast Recovery Diodes


ABB

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## Application Note

**Thomas Setz**

**ABB Switzerland Ltd**

**Semiconductors**

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# 1 Introduction

ABB Switzerland Ltd, Semiconductors (ABB) has a long history of producing high power fast recovery diodes for applications such as Voltage Source Converters (VSC), Current Source Converters (CSC) and DC choppers. The diodes are typically used in combination with IGCTs and GTOs as freewheeling diodes, snubber diodes and clamp diodes.
When designing with fast recovery diodes, there are certain issues to be considered, the most important of these are addressed in this application note.

# 2 Fast Recovery Diode product range from ABB

## 2.1 GTO Diodes

### 2.1.1 GTO Freewheeling Diodes

This type of diode is mainly designed for use in anti-parallel to a GTO. A GTO needs a snubber that limits dv/dt and di/dt. These diodes are therefore designed to work under conditions with a turn-off di/dt of some hundred amps per microsecond in combination with a dv/dt in a range of some hundred volts per microsecond. Additional important attributes are high cosmic radiation withstand ratings when blocking and low electrical losses in on-state and during switching.
The ABB Switzerland Ltd, Semiconductors GTO freewheeling diode product range is presented in Table 1.

| **Part number** | $V_{RRM}$ | $V_{DC}$ | $I_{F(AV)M}$ | $I_{FSM}$ | | $V_{(T0)}$ | $r_F$ | $I_{RM}$ | $Q_{rr}$ | $T_{VJM}$ | $R_{th(j-c)}$ | $R_{th(c-h)}$ | $F_m$ | Housing "Type" Ø x h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_c$ = 85°C | 1 ms $T_{VJM}$ | 10 ms $T_{VJM}$ | $T_{VJM}$ | | di/dt=300 A/us | | | | | | |
| | V | V | A | kA | kA | V | mΩ | A | µC | °C | K/kW | K/kW | kN | [mm] |
| **5SDF 05D2505** | 2500 | 1500 | 420 | 27 | 8.5 | 1.7 | 0.62 | 470 | 840 | 125 | 40 | 8 | 11 | "D" 60 x 26 |
| **5SDF 11F2501** | 2500 | 1500 | 950 | 65 | 21 | 1.2 | 0.38 | 550 | 1200 | 125 | 20 | 5 | 22 | "F" 75 x 26 |
| **5SDF 07F4501** | 4500 | 2800 | 650 | 44 | 16 | 1.4 | 1.00 | 600 | 1900 | 125 | 20 | 5 | 22 | "F" 75 x 26 |
| **5SDF 13H4501** | 4500 | 2800 | 1200 | 60 | 25 | 1.3 | 0.48 | 800 | 3000 | 125 | 12 | 3 | 40 | "H" 95 x 26 |
| **5SDF 10H6004** | 6000 | 3800 | 1100 | 44 | 18 | 1.5 | 0.60 | 1000 | 6000 | 125 | 12 | 3 | 40 | "H" 95 x 26 |

Table 1: GTO freewheeling diode product range

### 2.1.2 Snubber Diodes

Snubber diodes are optimized for the use in GTO snubber circuits. These diodes are designed for switching with high di/dt against high dv/dt. Electrical losses and cosmic radiation withstand rating are not as important as with freewheeling diodes.
The ABB Switzerland Ltd, Semiconductors snubber diode product range is presented in Table 2.

| **Part number** | $V_{RRM}$ | $V_{DC}$ | $I_{F(AV)M}$ | $I_{FSM}$ | | $V_{(T0)}$ | $r_F$ | $I_{RM}$ | $Q_{rr}$ | $T_{VJM}$ | $R_{th(j-c)}$ | $R_{th(c-h)}$ | $F_m$ | Housing "Type" Ø x h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_c$ = 85°C | 1 ms $T_{VJM}$ | 10 ms $T_{VJM}$ | $T_{VJM}$ | | di/dt=100 A/us | | | | | | |
| | V | V | A | kA | kA | V | mΩ | A | µC | °C | K/kW | K/kW | kN | [mm] |
| **5SDF 05D2501** | 2500 | 1100 | 490 | 27 | 8.5 | 1.4 | 0.5 | 250 | 900 | 125 | 40 | 8 | 11 | "D" 60 x 26 |
| **5SDF 03D4501** | 4500 | 2400 | 320 | 12 | 5.0 | 2.0 | 1.5 | 200 | 1000 | 125 | 40 | 8 | 11 | "D" 60 x 26 |
| **5SDF 07H4501** | 4500 | 2400 | 900 | 40 | 16.0 | 1.8 | 0.9 | 260 | 1700 | 125 | 12 | 3 | 40 | "H" 95 x 26 |
| **5SDF 02D6002** | 6000 | 3000 | 250 | 11.4 | 3.6 | 2.5 | 2.5 | 260 | 2000 | 125 | 40 | 8 | 11 | "D" 60 x 26 |

Table 2: GTO snubber diode product range

## 2.2 IGCT Diodes

The design of IGCT diodes is optimized for switching against highest dv/dt. This is typically the case in applications with IGCTs where the semiconductors don't have any dv/dt snubber but rather a so called clamp circuit. The clamp circuit (Fig. 13) limits the commutation voltage but doesn't limit the dv/dt of IGCTs and diodes during turn-off. To handle the speed of the switching, an inductive snubber is used to reduce di/dt.
The ABB Switzerland Ltd, Semiconductors IGCT diode product range is presented in Table 3.

| **Part number** | $V_{RRM}$ | $V_{DC}$ | $I_{F(AV)M}$ | $I_{FSM}$ | | $V_{(T0)}$ | $r_F$ | $I_{RM}$ | di/dt max. | $T_{VJM}$ | $R_{th(j-c)}$ | $R_{th(c-h)}$ | $F_m$ | Housing "Type" Ø x h |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $T_c$ = 70°C | 1 ms $T_{VJM}$ | 10 ms $T_{VJM}$ | $T_{VJM}$ | | | | | | | | |
| | V | V | A | kA | kA | V | MΩ | A | A/us | °C | K/kW | K/kW | kN | [mm] |
| **5SDF 03D4502** | 4500 | 2800 | 275 | 10 | 5 | 2.15 | 2.80 | 355 | 300 | 115 | 40 | 8 | 16 | "D" 60 x 26 |
| **5SDF 05F4502** | 4500 | 2800 | 435 | 32 | 16 | 2.42 | 2.10 | 610 | 430 | 115 | 17 | 5 | 20 | "F" 75 x 26 |
| **5SDF 10H4502** | 4500 | 2800 | 810 | 40 | 24 | 2.42 | 1.10 | 1150 | 650 | 115 | 12 | 3 | 44 | "H" 95 x 26 |
| **5SDF 10H4503** | 4500 | 2800 | 1100 | 47 | 20 | 1.75 | 0.88 | 1520 | 600 | 125 | 12 | 3 | 40 | "H" 95 x 26 |
| **5SDF 10H4520** | 4500 | 2800 | 1440 | 56 | 25 | 1.75 | 0.88 | 1600 | 600 | 140 | 10 | 3 | 40 | "H" 95 x 26 |
| **5SDF 16L4503** | 4500 | 2800 | 1650 | 47 | 26 | 1.90 | 0.79 | 1200 | 600 | 125 | 6.5 | 3 | 40 | "L" 120 x 26 |
| **5SDF 02D6004** | 5500 | 3300 | 175 | 8 | 3 | 3.35 | 7.20 | 300 | 220 | 115 | 40 | 8 | 16 | "D" 60 x 26 |
| **5SDF 04F6004** | 5500 | 3300 | 380 | 22 | 10 | 2.70 | 2.80 | 600 | 340 | 115 | 22 | 5 | 20 | "F" 75 x 26 |
| **5SDF 08H6005** | 5500 | 3300 | 585 | 40 | 18 | 4.50 | 1.30 | 900 | 440 | 115 | 12 | 3 | 44 | "H" 95 x 26 |

Table 3: IGCT diode product range

# 3 Data sheet users guide

Section 3.1 is a detailed guide to the proper understanding of an IGCT-Diode data sheet. Parameters and ratings are defined while following the sequence in which parameters appear in the data sheet. For explanation purposes, data and diagrams associated with the IGCT diode 5SDF 10H4503 have been used. However, this guide is applicable to all IGCT diodes. For actual data of 5SDF 10H4503 please refer to the Datasheet in the ABB internet website.
Data sheets of GTO freewheeling diodes and snubber diodes are similarly specified and are therefore to read similarly.

## 3.1 IGCT-Diode data sheet

| | | | |
|---|---|---|---|
| $V_{RRM}$ | = | 4500 | V |
| $I_{F(AV)M}$ | = | 1100 | A |
| $I_{FSM}$ | = | $20\times10^3$ | A |
| $V_{(T0)}$ | = | 1.75 | V |
| $r_T$ | = | 0.88 | mW |
| $V_{DClink}$ | = | 2800 | V |

**Fast Recovery Diode**

**5SDF 10H4503**

Doc. No. 5SYA1163-01 Oct. 06

- **Patented free-floating technology**
- **Industry standard housing**
- **Cosmic radiation withstand rating**
- **Low on-state and switching losses**
- **Optimized for snubberless operation**

The key features give the basic voltage and current ratings of the diode. These ratings are repeated later in the data sheet where the conditions at which the value is valid are shown. Each of them is explained at the appropriate place in this section. The parameter values are followed by a short description of the main features of the diode.

## Blocking

***Maximum rated values*** [1)]

| Parameter | Symbol | Conditions | Value | Unit |
|---|---|---|---|---|
| Repetitive peak reverse voltage | $V_{RRM}$ | f = 50 Hz, $t_p$ = 10ms, $T_{vj}$ = 125°C | 4500 | V |
| Permanent DC voltage for 100 FIT failure rate | $V_{DC\text{-}link}$ | Ambient cosmic radiation at sea level in open air. (100% Duty) | 2800 | V |
| Permanent DC voltage for 100 FIT failure rate | $V_{DC\text{-}link}$ | Ambient cosmic radiation at sea level in open air. (5% Duty) | 3200 | V |

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Repetitive peak reverse current | $I_{RRM}$ | $V_R = V_{RRM}$, $T_{vj}$ = 125°C | | | 50 | mA |

**$V_{RRM}$:** Maximum voltage that the device can block repetitively. Above this level the device may be damaged or become destroyed. This parameter is measured with 10 ms half-sine pulses with a repetition frequency of 50 Hz. The limit for maximum single-pulse voltage (**$V_{RSM}$**) is normally not stated in the ABB datasheets since it is equal to $V_{RRM}$.

**$V_{DC\text{-}link}$:** These numbers define the maximum DC-link voltage of a voltage source inverter or a chopper application to achieve maximum 100 FIT (Failure in Time, 1 FIT corresponds to 1 failure in $10^9$ component hours) under the defined conditions. For more details please read the ABB application note 5SYA2061 “Cosmic ray on FRD”. Switching against higher voltage than the maximum stated $V_{DC\text{-}link}$ is not recommended since it can lead to abrupt cut-off of the reverse recovery current of the diode, so called snap-off.

**$I_{RRM}$:** The maximum leakage current at the given conditions.

## Mechanical data

***Maximum rated values*** [1)]

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Mounting force | $F_m$ | | 36 | 40 | 46 | kN |
| Acceleration | a | Device unclamped | | | 50 | $m/s^2$ |
| Acceleration | a | Device clamped | | | 200 | $m/s^2$ |

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Weight | m | | | | 0.83 | kg |
| Housing thickness | H | | 26.0 | | 26.4 | mm |
| Surface creepage distance | $D_S$ | | 33 | | | mm |
| Air strike distance | $D_a$ | | 20 | | | mm |

Note 1 Maximum rated values indicate limits beyond which damage to the device may occur

**$F_m$**: The mounting force is the recommended force to be applied for optimal device performance. Too low a mounting force will increase the thermal impedance thus leading to higher junction temperature excursions resulting in a lower operating lifetime for the diode. Too high a clamping force may crack the wafer during load cycling. It is important to apply a homogeneous force over the whole contact area. Otherwise, electrical and reliability performance are reduced. For details please consult the ABB application note 5SYA2036 “Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors”.

**a:** Maximum permissible acceleration in any direction at the given conditions. The value for a clamped device is only valid within the given mounting force limits.

**m:** Weight of the device.

**H:** Height of the device when clamped at the given force.

**$D_s$:** The surface creepage distance is the shortest path along the housing between anode and cathode.

**$D_a$:** The air strike distance is defined as the shortest direct path between anode and cathode.

## On-state

***Maximum rated values*** [1)]

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Max. average on-state current | $I_{F(AV)M}$ | Half sine wave, $T_C$ = 70 °C | | | 1100 | A |
| Max. RMS on-state current | $I_{F(RMS)}$ | | | | 1740 | A |
| Max. peak non-repetitive surge current | $I_{FSM}$ | $t_p$ = 10 ms, $T_{vj}$ = 125°C, $V_R$ = 0 V | | | $20×10^3$ | A |
| Limiting load integral | $I^2t$ | | | | $2×10^6$ | $A^2s$ |
| Max. peak non-repetitive surge current | $I_{FSM}$ | $t_p$ = 30 ms, $T_{vj}$ = 125°C, $V_R$ = 0 V | | | $12×10^3$ | A |
| Limiting load integral | $I^2t$ | | | | $2.16×10^6$ | $A^2s$ |

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| On-state voltage | $V_F$ | $I_F$ = 2500 A, $T_{vj}$ = 125°C | | 3.1 | 3.8 | V |
| Threshold voltage | $V_{(T0)}$ | $T_{vj}$ = 125°C<br>$I_F$ = 500...2500 A | | | 1.75 | V |
| Slope resistance | $r_T$ | | | | 0.88 | mΩ |

**$I_{F(AV)M}$** and **$I_{F(RMS)}$:** are the maximum allowable average and RMS device currents defined for 180 ° sine wave pulses of 50% duty cycle at the specified case temperature. The definitions are arbitrary but standard thus allowing device comparisons.

$I_{FSM}$ **and** $I^2t$**:** The maximum peak forward surge current and the integral of the square of the current over one period are defined for 10 ms and 30 ms wide, half sine-wave current pulses without reapplied voltage. Above these values, the device may fail (short-circuit). These parameters are required for protection co-ordination. For currents that clearly differ from half sine wave shape the above stated numbers and the curves in Fig. 4 and Fig. 5 are not applicable. For evaluation of such cases please contact ABB's Application Support. Additional information is provided in section 4.3.3.

$V_F$**:** The forward voltage drop of the diode at the given conditions.

The threshold voltage $V_{(T0)}$ and the slope resistance $r_T$ allow a linear representation of the diode forward voltage drop and are used for simple calculations of conduction losses in the current range stated under "conditions".

## Turn-on

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Peak forward recovery voltage | $V_{FRM}$ | $dI_F/dt$ = 600 A/µs, $T_{vj}$ = 125°C | | | 80 | V |
| | | $dI_F/dt$ = 3000 A/µs, $T_{vj}$ = 125°C | | | 250 | V |

$V_{FRM}$**:** The dynamic peak forward voltage drop of the diode during turn-on. $V_{FRM}$ and $dI_F/dt$ are defined in Fig 12. A more detailed description is written in section 4.3.1.

## Turn-off

***Maximum rated values*** [1)]

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Max. decay rate of on-state current | $di/dt_{crit}$ | $I_F$ = 4000 A, $V_{DC-Link}$ = 2800 V<br>$-dI_F/dt$ = 600 A/µs, $L_{CL}$ = 300 nH<br>$C_{CL}$ = 10 µF, $R_{CL}$ = 0.65 Ω,<br>$T_{vj}$ = 125°C, $D_{CL}$ = 5SDF 10H4503 | | | 600 | A/µs |

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Reverse recovery current | $I_{RM}$ | $I_F$ = 3300 A, $V_{DC-Link}$ = 2800 V<br>$-dI_F/dt$ = 600 A/µs, $L_{CL}$ = 300 nH<br>$C_{CL}$ = 10 µF, $R_{CL}$ = 0.65 Ω,<br>$T_{vj}$ = 125°C, $D_{CL}$ = 5SDF 10H4503 | | | 1520 | A |
| Reverse recovery charge | $Q_{rr}$ | | | | 5250 | µC |
| Turn-off energy | $E_{rr}$ | | | | 9.5 | J |

$di/dt_{crit}$**:** Maximum turn-off di/dt that the device can handle at the stated conditions. Above this level the device may be destroyed. Especially higher values in $L_{CL}$ or $V_{DC-Link}$ drastically reduce turn-off capability.

$I_{RM}$**:** Maximum reverse recovery current at the stated conditions. Dependencies of di/dt and forward current $I_F$ are shown in Fig. 9.

$Q_{rr}$**:** Maximum reverse recovery charge at the stated conditions. Dependencies of di/dt and forward current $I_F$ are shown in Fig. 8.

$E_{rr}$**:** Maximum turn-off energy at the stated conditions. The $E_{rr}$ value is highly depending on the on-state voltage of the individual diode. This should be considered when doing loss simulations. Since $V_F$ typically shows a scatter in the range of some 100 mV we recommend doing diode total-loss calculations at application conditions with the extreme combinations $E_{rr-1}$_@ $V_{F-max}$ and $E_{rr-2}$_@ $V_{F-min}$. This corresponds to either a diode with high on-state or a diode with low on-state. Please see Fig 10. In this particular case we recommend to simulate diode losses with a device

A) VF = 2.6V @ IF = 3300A -> $E_{rr-2}$ = 9.5 Ws @ the stated conditions
B) VF = 4.25V @ IF = 3300A -> $E_{rr-1}$ = 6.0 Ws @ the stated conditions

To adapt the datasheet conditions to the application conditions, di/dt and IFM can be linear interpolated between the curves in Fig 6 and Fig 7. Small differences in the range of 15% in $V_{DC-link}$ can be linear extrapolated. For loss calculations with parameters that greatly differ from the stated datasheet conditions please contact ABB's Application Support.

# Thermal

***Maximum rated values*** *[Note 1]*

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Operating junction temperature range | $T_{vj}$ | | 0 | | 125 | °C |
| Storage temperature range | $T_{stg}$ | | -40 | | 125 | °C |

***Characteristic values***

| Parameter | Symbol | Conditions | min | typ | max | Unit |
|---|---|---|---|---|---|---|
| Thermal resistance junction to case | $R_{th(j-c)}$ | Double-side cooled $F_m$ = 36...46 kN | | | 12 | K/kW |
| | $R_{th(j-c)A}$ | Anode-side cooled $F_m$ = 36...46 kN | | | 24 | K/kW |
| | $R_{th(j-c)C}$ | Cathode-side cooled $F_m$ = 36...46 kN | | | 24 | K/kW |
| Thermal resistance case to heatsink | $R_{th(c-h)}$ | Double-side cooled $F_m$ = 36...46 kN | | | 3 | K/kW |
| | $R_{th(c-h)}$ | Single-side cooled $F_m$ = 36...46 kN | | | 6 | K/kW |

**Analytical function for transient thermal impedance:**

$$Z_{th(j-c)}(t) = \sum_{i=1}^{n} R_{th\,i}\left(1 - e^{-t/\tau_i}\right)$$

| i | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $R_{th\,i}$(K/kW) | 7.705 | 2.748 | 1.009 | 0.539 |
| $\tau_i$(s) | 0.5244 | 0.0633 | 0.0065 | 0.0015 |

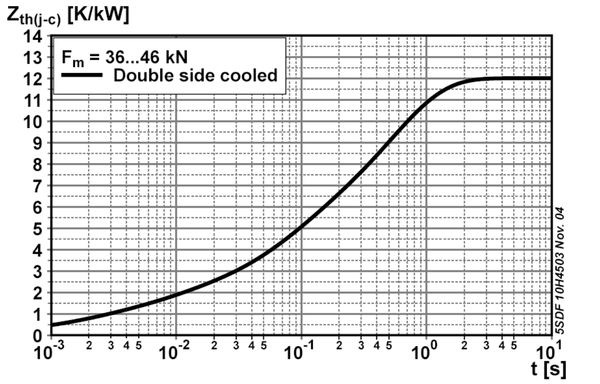



Fig. 1 Transient thermal impedance junction-to-case

**$T_{vj}$**: The operating junction temperature range gives the limits within which the silicon of the diode should be used. If the limits are exceeded, the ratings for the device are no longer valid and there is a risk of catastrophic failure.

**$T_{stg}$:** The temperature interval within which the diode must be stored to ensure that it will be operational at a later use. **$T_{stg-min}$** and **$T_{stg-max}$** are the extreme temperatures and are not recommended for long time storage. For long time storage please refer to Specification 5SZK 9104 "Specification of environmental class for pressure contact Diodes, PCTs and GTOs – STORAGE"

The thermal resistance junction to case**, $R_{th(j-c)}$**, and the thermal resistance case to heat sink, **$R_{th(c-h)}$**, are measures of how well the power losses can be transferred to the cooling system. The values are given both for double-sided cooling, where the device is clamped between two heat sinks, and single-sided cooling, where the device is clamped to only one heat sink. The values are valid for a homogeneously applied clamping force over the whole contact area of the diode. The temperature rise of the "virtual junction" (the silicon wafer inside the diode) in relation to the heat sink is calculated using Equation 1. $R_{th(j-c)}$ and $R_{th(c-h)}$ should be as low as possible since the temperature of the silicon determines the current capability of the diode. Furthermore the temperature excursion of the silicon wafer determines the load-cycling capability and thus the life expectancy of the diode.

$$\Delta T_{JH} = P_{loss} * \left(R_{th(j-c)} + R_{th(c-h)}\right) \quad [K] \qquad E^{qn}\ 1$$

where $\Delta T_{JH}$ is the temperature difference between the silicon wafer and the heat sink.

The transient thermal impedance emulates the rise of junction temperature versus time when a constant power is dissipated in the junction. This function can either be specified as a curve or as an analytic function with the superposition of four exponential terms. The analytic expression is particularly useful for computer calculations.

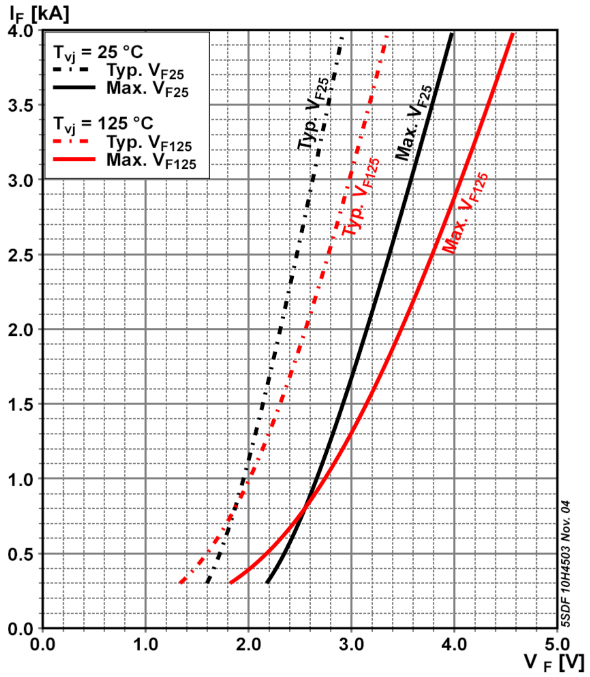
**Max. on-state characteristic model:**

$$V_{F25} = A_{Tvj} + B_{Tvj} \cdot I_F + C_{Tvj} \cdot \ln(I_F + 1) + D_{Tvj} \cdot \sqrt{I_F}$$

Valid for $I_F$ = 300 – 30000 A

| $A_{25}$ | $B_{25}$ | $C_{25}$ | $D_{25}$ |
|---|---|---|---|
| $-79.52\times10^{-6}$ | $83.80\times10^{-6}$ | $99.41\times10^{-3}$ | $1.09\times10^{-3}$ |

The model gives a mathematical expression for the maximum on-state voltage at Tvj = 25 °C for the given current interval which is much greater than the interval given for the simple linear model given by $V_{(T0)}$ and $r_T$.




On-state voltage drop of the diode as a function of the on-state current at the given temperatures for normal operation current levels.

Fig. 2 Max. on-state voltage characteristics

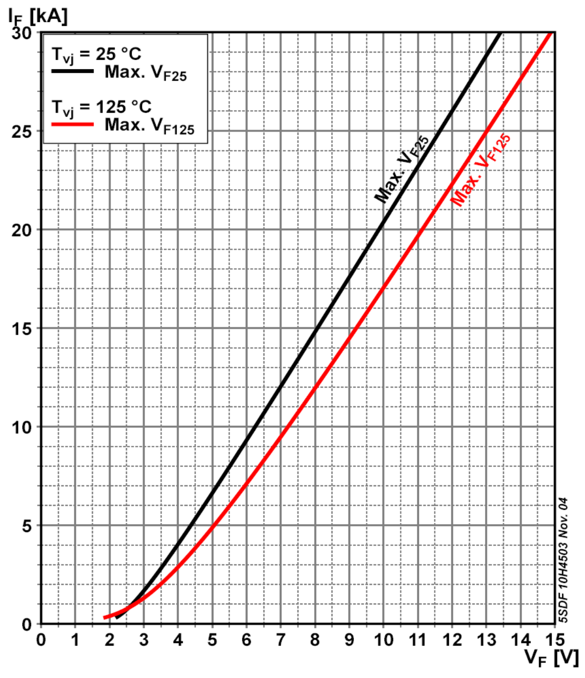
**Max. on-state characteristic model:**

$$V_{F125} = A_{Tvj} + B_{Tvj} \cdot I_F + C_{Tvj} \cdot \ln(I_F + 1) + D_{Tvj} \cdot \sqrt{I_F}$$

Valid for $I_F$ = 300 – 30000 A

| $A_{125}$ | $B_{125}$ | $C_{125}$ | $D_{125}$ |
|---|---|---|---|
| $-79.52\times10^{-6}$ | $83.80\times10^{-6}$ | $99.41\times10^{-3}$ | $1.09\times10^{-3}$ |

The model gives a mathematical expression for the maximum on-state voltage at $T_{vj}$ = 125 °C for the given current interval which is much greater than the interval given for the simple linear model given by $V_{(T0)}$ and $r_T$.




On-state voltage drop of the diode as a function of the on-state current at the given temperatures for the extended current levels up to the magnitude of $I_{FSM}$. The curves are calculated with above mathematical expressions.

Fig. 3 Max. on-state voltage characteristics

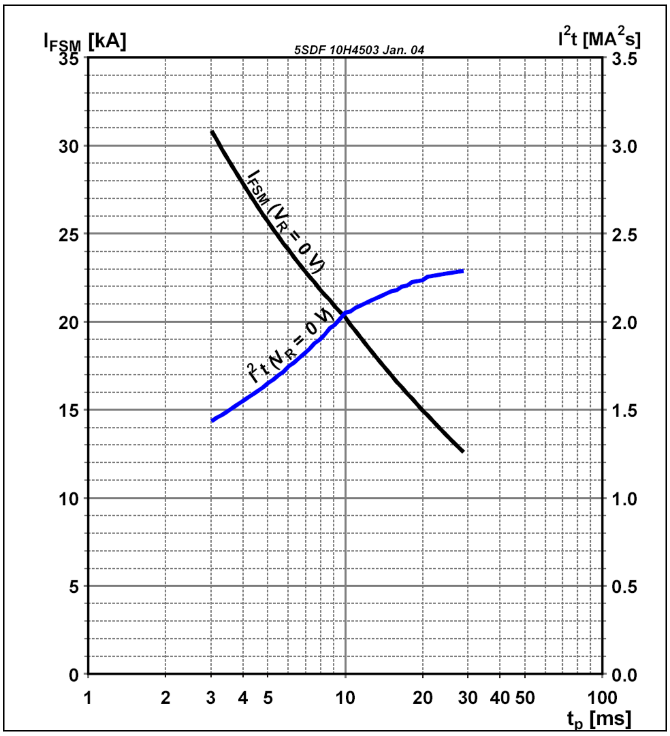



Fig. 4 Surge on-state current vs. pulse length. Half-sine wave

Surge current limit and surge current integral for half-sine pulses of different pulse widths with no reapplied voltage. The curves are given for a starting temperature of $T_{vj\text{-}max}$.

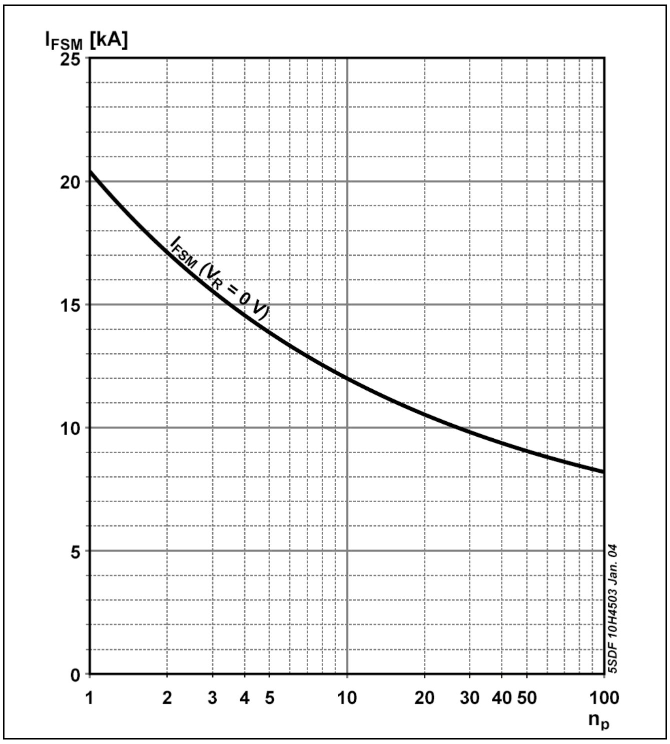



Fig. 5 Surge on-state current vs. number of pulses, half-sine wave, 10 ms, 50Hz

Surge current limit with no reapplied voltage as a function of the number of applied 10 ms half-sine pulses with a repetition rate of 50 Hz for a starting temperature of $T_{vj\text{-}max}$.

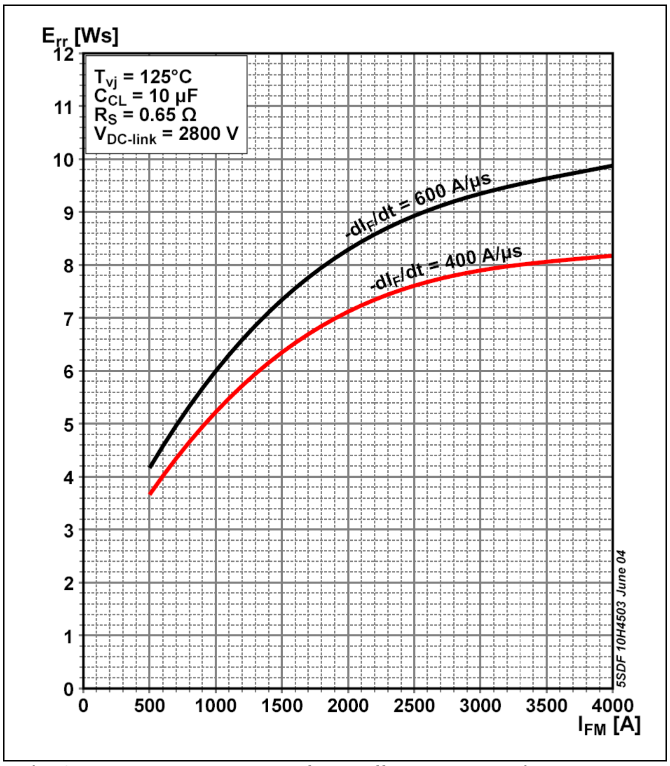



Fig. 6 Upper scatter range of turn-off energy per pulse vs. turn-off current

Maximum turn-off energy at the given conditions as a function of the on-state current $I_F$ before the commutation. See figure 12 for definitions.

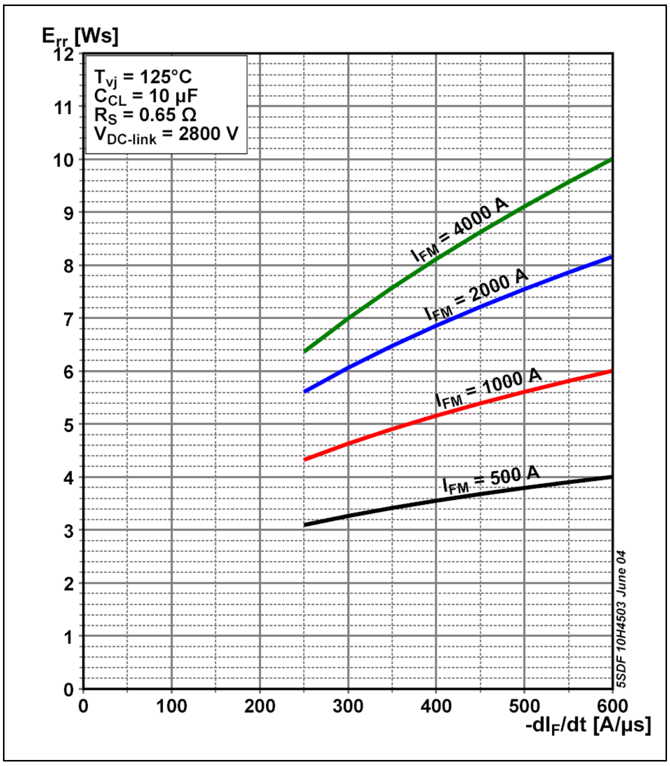



Fig. 7 Upper scatter range of turn-off energy per pulse vs. reverse current rise rate

Maximum turn-off energy at the given conditions as a function of the rate of decline of current before the commutation. See figure 12 for definitions.

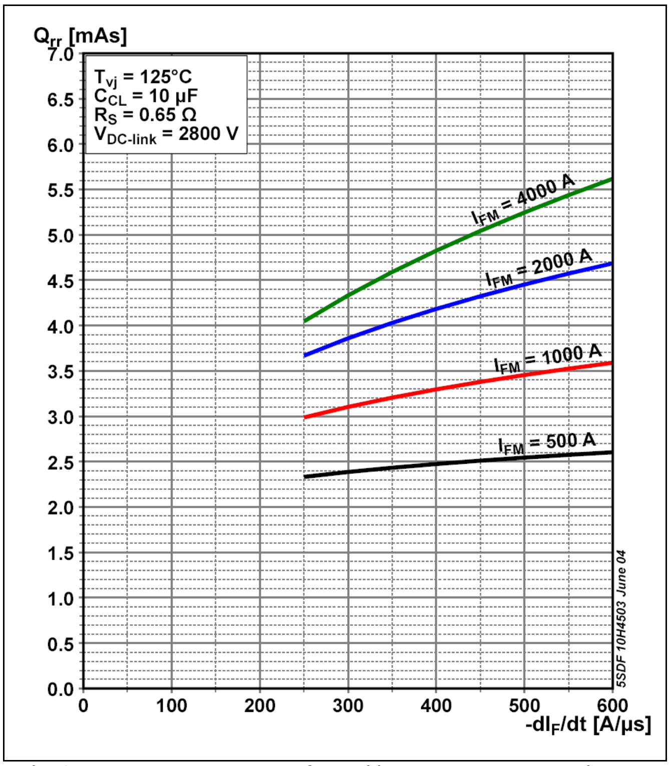



Fig. 8 Upper scatter range of repetitive reverse recovery charge vs. reverse current rise rate.

Maximum reverse recovery charge at the given conditions as a function of the rate of decline of current before the commutation. See figure 12 for definitions.

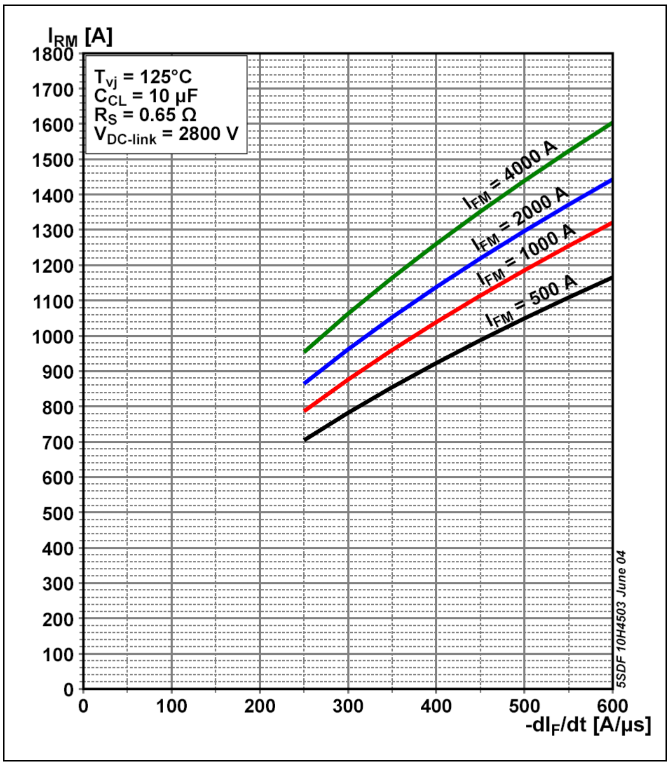



Fig. 9 Upper scatter range of reverse recovery current vs. reverse current rise rate

Maximum reverse recovery current at the given conditions as a function of the rate of decline of current before the commutation. See figure 12 for definitions.

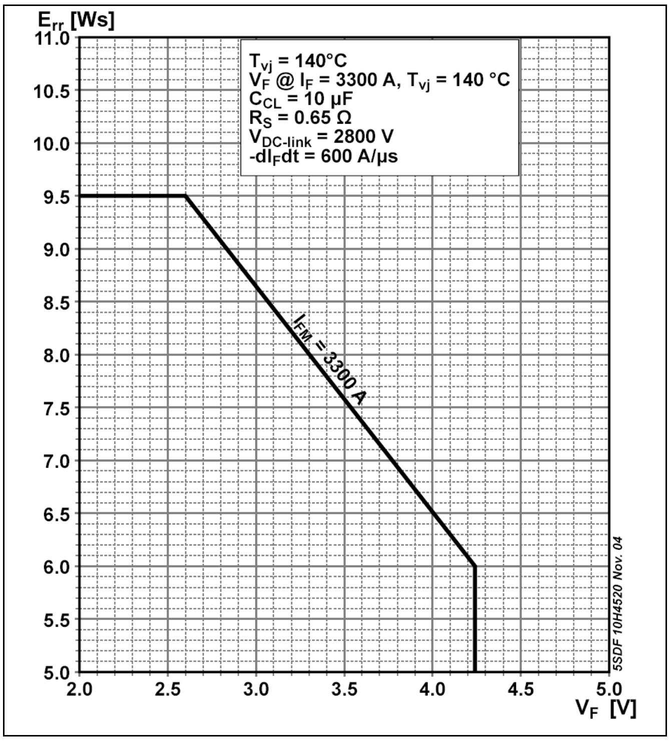



Fig. 10 Max. turn-off energy per pulse vs. on-state voltage.

Maximum turn-off switching energy depending on the on-state of the diode at the given conditions. The curve represents the upper scatter range of $E_{rr}$ of the production distribution.

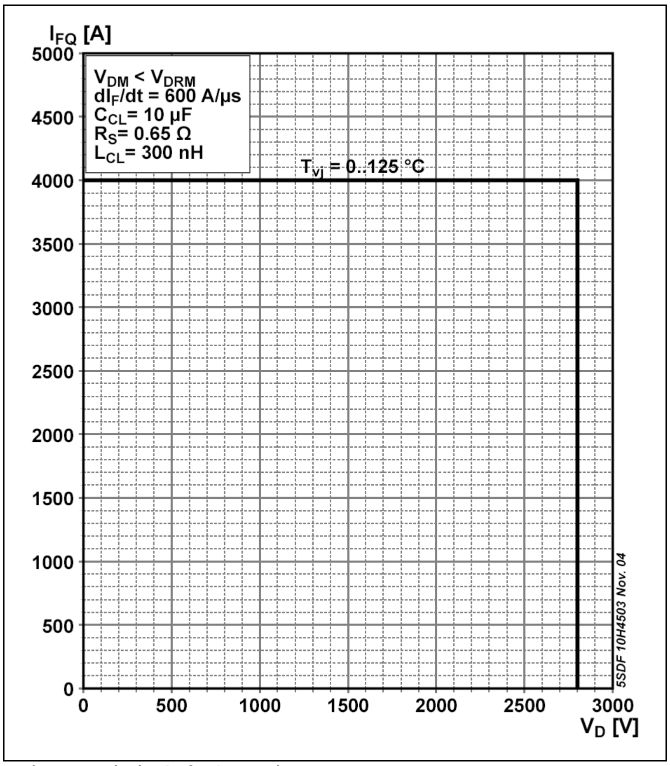



Fig. 11 Diode Safe Operating Area

Safe operating area at the given conditions. See figure 12 for definitions. Use of the diode outside these operation conditions could lead to catastrophic failures and should therefore be avoided.

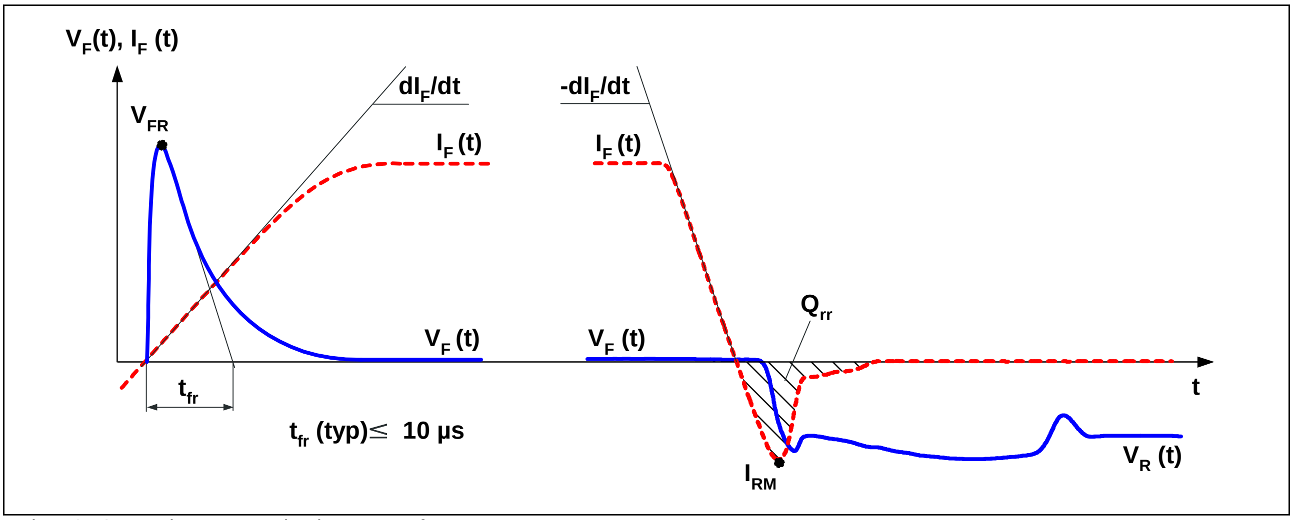


Fig. 12 General current and voltage waveforms

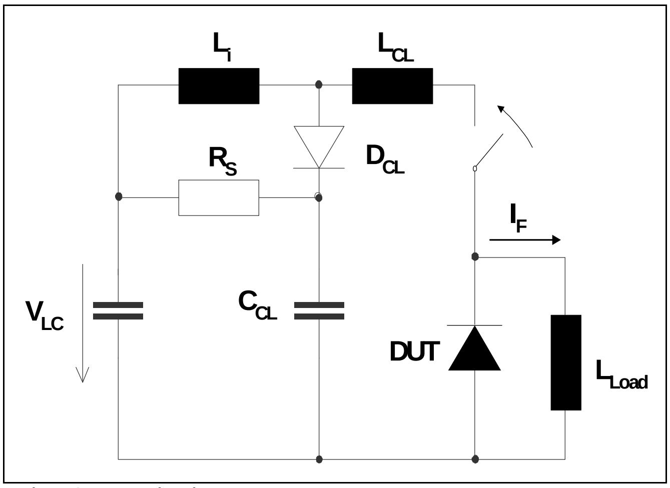


Fig. 13 Test circuit.

Electrical circuit used when determining the turn-on and turn-off data sheet ratings. $C_{CL}$, $D_{CL}$, $R_S$ and $L_{CL}$ represent the clamp circuit to limit switching over-voltages. $L_{CL}$ is a stray inductance and restricts the switching capability of the circuit. It should be designed as small as possible in an application.

The turn-off parameters Err and Qrr are only specified on the DUT position as a freewheeling diode. The reason is that on clamp position ($D_{CL}$) turn-off losses are typically not the limiting criteria.

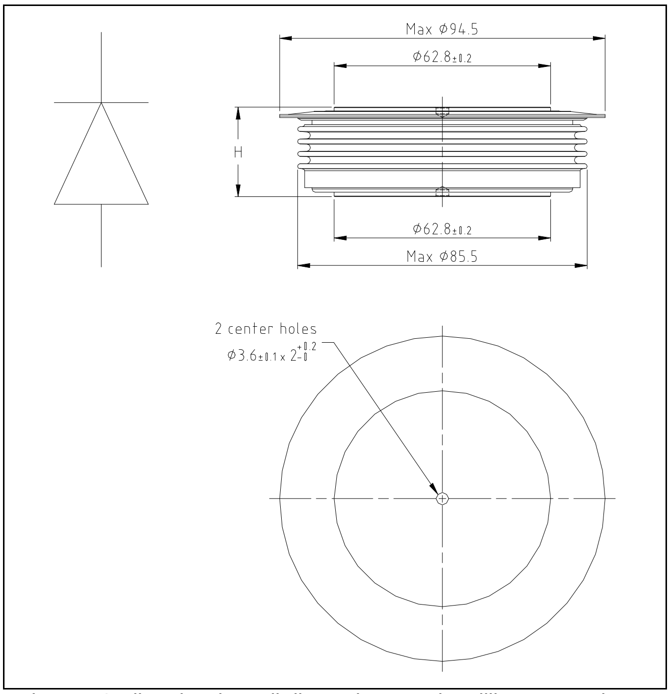


Fig. 14 Outline drawing, all dimensions are in millimeters and represent nominal values unless stated otherwise

## Related documents:

| Doc. Nr. | Titel |
|---|---|
| 5SYA 2036 | Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors |
| 5SYA 2061 | Failure rates of fast recovery diodes due to cosmic rays |
| 5SZK 9104 | Specification of environmental class for pressure contact diodes, PCTs and GTO, STORAGE. Available on request, please contact ABB's Application Support. |
| 5SZK 9105 | Specification of environmental class for pressure contact diodes, PCTs and GTO, TRANSPORTATION. Available on request, please contact ABB's Application Support. |

Please refer to http://www.abb.com/semiconductors for current versions.

A list of applicable documents is included at the end of the data sheet.

# 4 Design recommendations

## 4.1 Determine the right diode for standard application conditions

If the application conditions are close to the specified conditions in the datasheets of the used GTO or IGCT ABB recommends the use of the following diodes. If several diodes are recommended by ABB, the decision should be made according to the needs of the application:

- High expected losses in the diode -> use the larger diode
- GTO/GCT and diodes in one combined mechanical clamp system -> use the diode with adequate mounting force
- Application conditions very close to the GTO/IGCT SOA limits -> use the larger diode

GTO applications:

| GTO Type | Recommended freewheeling diodes | Recommended snubber diodes |
|---|---|---|
| 5SGA 15F2502 | 5SDF 05D2505<br>5SDF 11F2501 | 5SDF 05D2501 |
| 5SGA 20H2501 | 5SDF 05D2505<br>5SDF 11F2501 | 5SDF 05D2501 |
| 5SGA 25H2501 | 5SDF 05D2505<br>5SDF 11F2501 | 5SDF 05D2501 |
| 5SGA 30J2501 | 5SDF 11F2501 | 5SDF 05D2501 |
| 5SGA 06D4502 | 5SDF 03D4501 | 5SDF 03D4501 |
| 5SGA 20H4502 | 5SDF 03D4501<br>5SDF 07F4501 | 5SDF 03D4501 |
| 5SGA 30J4502 | 5SDF 07F4501<br>5SDF 13H4501 | 5SDF 03D4501 |
| 5SGA 40L4501 | 5SDF 13H4501 | 5SDF 03D4501<br>5SDF 07H4501 |
| 5SGF 30J4502 | 5SDF 07F4501<br>5SDF 13H4501 | 5SDF 03D4501<br>5SDF 07H4501 |
| 5SGF 40L4502 | 5SDF 13H4501 | 5SDF 03D4501<br>5SDF 07H4501 |

Table 4: Recommended diodes for GTO applications

| **IGCT Type** | **Recommended freewheeling diodes** | **Recommended clamp diodes** | **Recommended NPC diodes**** |
|---|---|---|---|
| 5SHX 08F4510 | Integrated | 5SDF 03D4502 | 5SDF 03D4502 |
| 5SHX 14H4510 | Integrated | 5SDF 03D4502<br>5SDF 05F4502 | 5SDF 03D4502<br>5SDF 05F4502<br>5SDF 10H4503 |
| 5SHX 26L4510 | Integrated | 5SDF 03D4502<br>5SDF 05F4502 | 5SDF 05F4502<br>5SDF 10H4503<br>5SDF 10H4520 |
| 5SHX 06F6010 | Integrated | 5SDF 02D6004 | 5SDF 02D6004<br>5SDF 04F6004 |
| 5SHX 10H6010 | Integrated | 5SDF 02D6004<br>5SDF 04F6004 | 5SDF 04F6004<br>5SDF 08H6005 |
| 5SHX 19L6010 | Integrated | 5SDF 02D6004<br>5SDF 08H6005 | 5SDF 04F6004<br>5SDF 08H6005 |
| 5SHY 35L4510<br>5SHY 35L4511<br>5SHY 35L4512<br>5SHY 55L4500 | 5SDF 10H4503<br>5SDF 10H4520<br>5SDF 16L4503 | 5SDF 05F4502<br>5SDF 10H4503<br>5SDF 10H4520 | 5SDF 10H4503<br>5SDF 10H4520<br>5SDF 16L4503 |

Table 5: Recommended diodes for IGCT applications

** Note: NPC diodes stand for **N**eutral **P**oint **C**lamp diodes. These diodes are typically used in 3-level inverters. The conditions to which these diodes are subjected are typically similar to the conditions of a freewheeling diode used in an IGCT inverter.

## 4.2 Determine the right diode for customized application conditions

If the application conditions differ from the specified conditions in the datasheet, the following parameters must be defined:

a) **Diode type?**

| | |
|---|---|
| Freewheeling diode, dv/dt at turn-off < 700V/µs | GTO freewheeling diode |
| Freewheeling diode, dv/dt at turn-off > 700V/µs | IGCT diode |
| Snubber diode in a GTO-application, no dc-blocking operation | GTO snubber diode |
| Clamp diode in an IGCT-application | IGCT diode |

b) **Voltage class?**

Diodes with higher blocking voltage typically show

- Higher forward recovery during turn-on
- Increased ruggedness and softness while turning off
- Higher on-state and switching losses
- Much lower cosmic radiation FIT rate at compared voltage. Please consider application notes 5SYA2051 “Voltage ratings of high power semiconductors” and 5SYA2061 “Cosmic ray on FRD”

c) **Diode-diameter?**

Diodes with larger diameter show

- Lower forward recovery during turn-on
- Increased ruggedness
- Lower on-state losses
- Proportional to the silicon area higher cosmic radiation FIT rate at compared voltage
- Lower thermal impedance
- The need for higher clamping force. From a mechanical point of view it is often preferable to clamp IGCT (GTO) und its related diodes in one single clamp system. If devices in one mechanical clamp have unequal pole-piece diameter, force spreaders have to be used. Please consider application note 5SYA2036 “Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors”

## 4.3 Diode switching and important parameters to consider

### 4.3.1 Diode turn-on

During turn-on of a diode the two parameters turn-on energy ($E_{on}$) and peak forward recovery voltage ($V_{FRM}$) are important to review regarding the specific needs of the application.

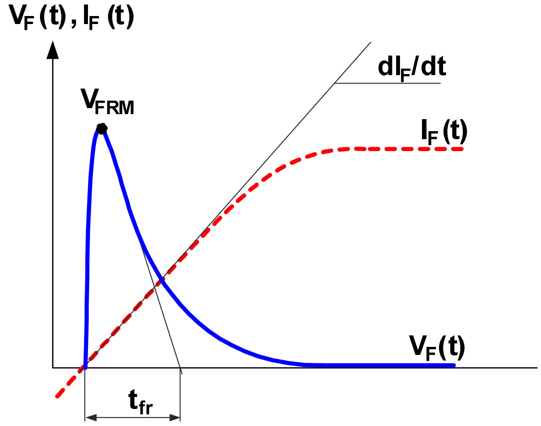



Fig. 15 shows the initial forward voltage overshoot $V_{FRM}$, when a diode turns on with a high di/dt. $V_{FRM}$ is the peak voltage, and $t_{fr}$ characterizes the decay of the overshoot. The voltage overshoot originates from the fact that conductivity of the diode is initially reduced, because the number of free charge carriers available is much lower than in the steady-state. The device needs time to build up the required electron and hole concentration, within the bulk of the silicon.

Measurements have shown that the $V_{FRM}$ vs. di/dt characteristic is slightly digressive. $V_{FRM}$ values at 125 °C are about double those at 25 °C. This behavior can be explained by reduced charge carrier mobility at elevated temperatures.

Fig. 15 Peak forward recovery voltage as a function of time

Comparing $V_{FRM}$ values between diodes of different thickness, it is obvious that dynamic forward voltage increases exponentially with device thickness. This is explicable by the difficulty in achieving steady-state carrier concentration in a thick device within a few µs. Fig. 16 shows typical $V_{FRM}$ values relating to the active wafer area of ABB diodes. The red and orange curves belong to 6kV IGCT diodes and 5.5kV IGCT diodes at $T_{vj}$ = 125°C, 80°C and 25°C while the blue colored curve is applicable for 4.5kV diodes at $T_{vj}$ = 125°C. To estimate typical $V_{FRM}$ values of ABB diodes at a specific $di_F/dt$ the "di/dt per wafer area" of Fig. 16 has to be multiplied by the active wafer area of the diode. The active area of the different diodes correspond to the housing type which is listed in tables 1-3 where

D - housing corresponds to an active area of 24.3 $cm^2$
F - housing corresponds to an active area of 33.8 $cm^2$
H - housing corresponds to an active area of 46.3 $cm^2$
L - housing corresponds to an active area of 65.2 $cm^2$

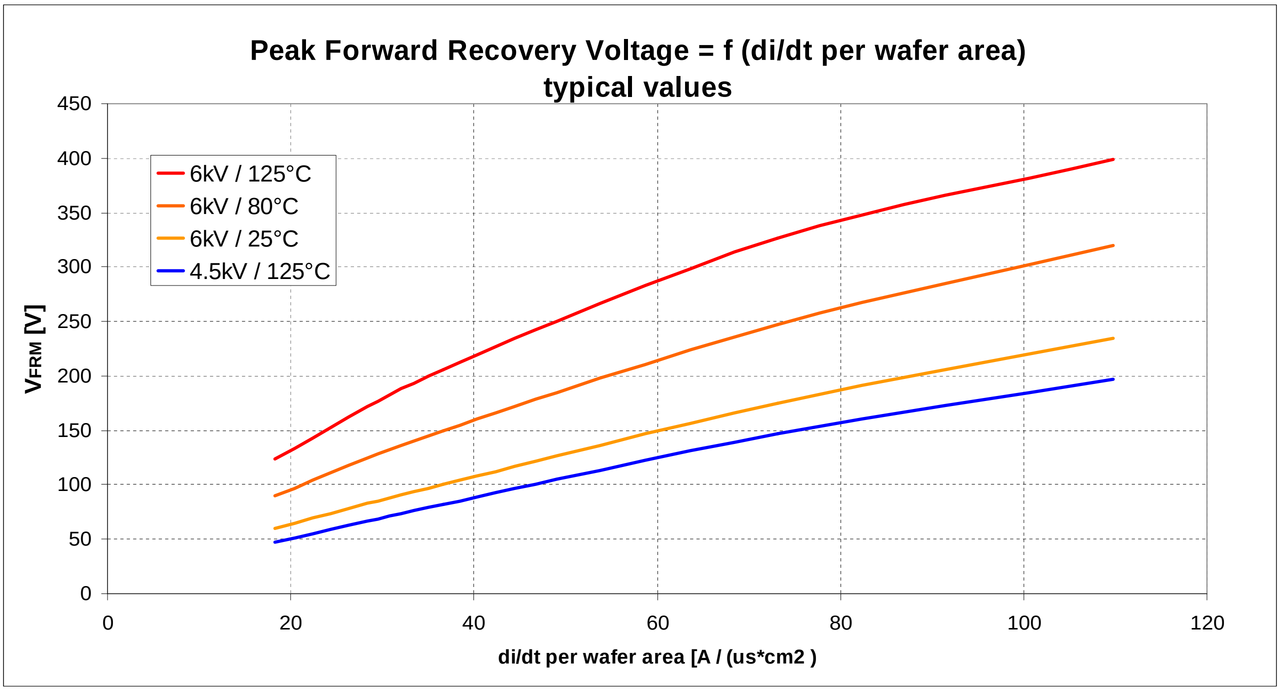



Fig. 16 Peak forward recovery voltage as a function of di/dt per wafer area

To estimate turn-on losses of a diode equation 2 can be taken to calculate the order of magnitude of $E_{on}$.

$$E_{on\_typ} \approx 1/6 * V_{FRM} * di_F/dt * t_{fr}^2 \quad [Ws] \qquad E^{qn}\ 2$$

Where $E_{on\_typ}$ are the estimated typical turn-on losses, $di_F/dt$ is the applied turn-on di/dt, $V_{FRM}$ is the peak forward recovery voltage at $di_F/dt$ and $t_{fr}$ is the time constant of $V_{FRM}$. $T_{fr}$ depends on different parameter but can be chosen as 5µs for this raw calculation.

Example 1: 5SDF 10H4503, 4.5 kV IGCT diode in L-housing on freewheeling position, $di_F/dt$ = 600 A/µs, $T_{vj}$ = 125°C

- è di/dt per wafer area = 600 A/µs / 46.3 $cm^2$ = 13 A/(µs*$cm^2$)
- è $V_{FRM} \approx$ 40 V
- è $E_{on\_typ} \approx$ 1/6 * 40 V * 600 A/µs * 5$µs^2$ = 0.1 Ws

Example 2: 5SDF 02D6004, 6 kV IGCT diode in D-housing on clamp position, $di_F/dt$ = 2500 A/µs, $T_{vj}$ = 125°C

- è di/dt per wafer area = 2000 A/µs / 24.3 $cm^2$ = 82 A/µs*$cm^2$
- è $V_{FRM} \approx$ 350 V
- è $E_{on\_typ} \approx$ 1/6 * 350 V * 2000 A/µs * 5$µs^2$ = 2.9 Ws

It is obvious that turn-on losses of a diode on a freewheeling position are in most cases negligible since the diode typically has a large diameter and the $di_F/dt$ is in the range below 1000 A/µs.
On a clamp position or on a snubber position the turn-on losses can become relevant. $di_F/dt$ is equal to the turn-off di/dt of the Switch (GTO or IGCT) and can be much higher than on a freewheeling position. Typical $di_F/dt$ that can be expected are in the range of the turn-off current of the switch per 1µs. E.g. turn-off of 3000A leads to a $di_F/dt$ in the range of 3000 A/µs.

As a further effect $V_{FRM}$ of diodes on a GTO-snubber position or on an IGCT freewheeling- or clamp-position increases the dynamic commutation voltage of the Switch (GTO, IGCT with its freewheeling diode). This so called spike voltage $V_{DSP}$ is specified in the GTO and IGCT datasheets under "general current and voltage waveforms". High values of this spike voltage reduce the switching capability of the switch. Because of this a larger snubber diode or IGCT diode increases the turn-off capability of the switch and vice versa. In terms of turn-off capability of the switch it is also recommended not to use too high voltage diodes. Typically snubber, clamp and freewheeling diodes are of the same voltage class as the related GTO or IGCT. It only makes sense to choose diodes of a higher voltage class if ruggedness in terms of turn-off switching of the diode itself is critical.

### 4.3.2 Diode turn-off

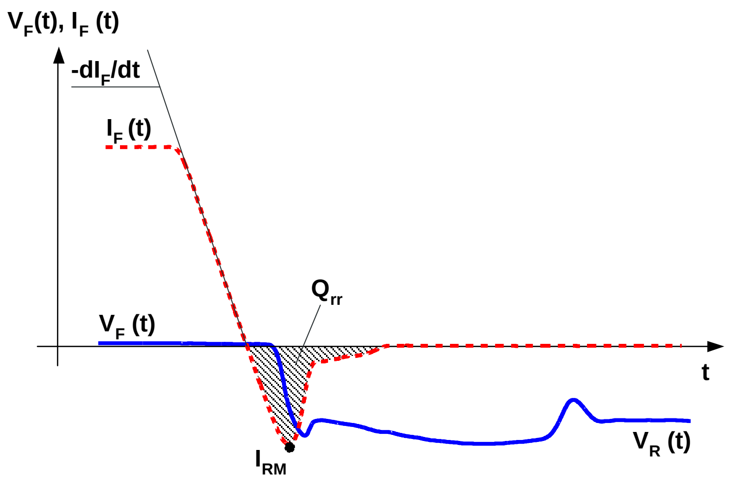



Fig 17 shows the turn off of an IGCT diode on a freewheeling position. The forward current, $I_F$, is switched off with a certain $di_F/dt$ (determined by the driving voltage and the di/dt limiting inductance), and continues to flow in the reverse direction until the pn junction is able to block reverse voltage. At this time, the reverse recovery current has reached its peak value $I_{RM}$. The subsequent decay of the current and rise in reverse voltage are mainly determined by the diode itself and the applied voltage as a function of time. The applied voltage shape depends on the circuit of the application

Fig. 17 Turn-off of an IGCT freewheeling diode

It is the goal of the diode design engineer to ensure that the tail current decays in a “soft” manner, meaning without ringing or overshoot provoking “snap”, and that tail current and tail time are so small as to not contribute much to turn-off losses, despite reverse voltage being already high at this time. The application specific $V_R(t)$ is one of the main reasons that different diode designs are recommended for application conditions such as GTO-snubber diode, GTO-freewheeling diode or IGCT freewheeling- NPC- and clamp-diode. It is not recommended to use diodes above the maximum values specified in the data sheets. Especially the use of diodes in IGCT applications without dv/dt limitation is very sensitive regarding $V_{DC\text{-}Link}$ and $L_{CL}$.

### 4.3.3 Surge current rating

$I_{FSM}$ is the maximum allowed, non-repetitive and pulse-width dependent peak value of a half-sinusoidal surge current, applied at an instant when the diode is operating at its maximum junction temperature $T_{vjm}$. Although, in practice, the case temperature prior to a surge is always below $T_{vjm}$, both the junction and the housing are heated to $T_{vjm}$ when the surge current limit is established. This worst-case test condition provides an additional margin to the real stress in an application.
During a surge, the junction heats up to a temperature well above its rated maximum value. Therefore, the diode is no longer able to block rated voltage, so the $I_{FSM}$ values are valid only for $V_R$ = 0 V after the surge, i.e. without reapplied voltage. Although a single surge does not cause any irreversible damage to the silicon wafer, it should not be allowed to occur too frequently.

$I^2t$ is an abbreviation and stands for $\int I_F^2\,dt$. This value is derived from the $I_{FSM}$ value discussed above, according to equation 3:

$$I^2t = \int_0^{t_p} I_F{}^2(t)dt = \frac{I_{FSM}{}^2 \cdot t_p}{2}$$ (for half-sinusoidal waveforms) [$A^2s$] Eqn 3

To protect the diode, the $I^2t$ of a semiconductor fuse must be lower than the maximum $I^2t$ of the diode. The caveat for IFSM applies similarly to $I^2t$.

The shape of $I_{FSM}$ of applications depends on the protection concept and the electrical circuit and is therefore individual. The sinusoidal waveforms described in the datasheets typically don’t appear in applications with fast switching diodes. $I_{FSM}$ is a standardised value that enables comparison of datasheets of different devices and even of different manufacturers. When $I_{FSM}$ is expected to be close to the diode capability, ABB is able to simulate the stress that occurs under application conditions. As input data for the simulation i(t), starting values of $T_{case}$ and $T_{junction}$ and the mounting force $F_m$ are needed. I(t) should be available in a numerical form such as ASCII or Excel.

# 5 Additional notes

## 5.1 References


1) IEC 60747 “Semiconductor Devices”
2) 5SYA2036 “Recommendations regarding mechanical clamping of Press Pack High Power Semiconductors”
3) 5SYA2051 “Voltage ratings of high power semiconductors”
4) 5SYA2061 “Failure rates of fast recovery diodes due to cosmic rays”
5) 5SZK9104 “Specification of environmental class for pressure contact diodes, PCTs and GTO, STORAGE”
6) 5SZK9105 “Specification of environmental class for pressure contact diodes, PCTs and GTO, TRANSPORTATION”


The application notes, Reference 2 - 4, are available at www.abb.com/semiconductors

The environmental specifications 5 – 6 are available on request; please contact ABB’s Application Support

## 5.2 Application support

For further information please contact:


Customer support:
Raffael Schnell
Phone +41 58 5861 366, fax +41 58 5861 306
e-mail raffael.schnell@ch.abb.com

Address:
**ABB Switzerland Ltd**
**Semiconductors**
Fabrikstrasse 3
CH-5600 Lenzburg
Switzerland
E-Mail abbsem@ch.abb.com
Internet www.abb.com/semiconductors


Data sheets for the devices and your nearest sales office can be found on the ABB Switzerland Ltd, Semiconductors internet web site:
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