Application Note

Handling and Mounting Littelfuse miniBLOC - SOT227B

Objectives

This application note discusses mounting and handling for Littelfuse power semiconductors in SOT227B package, the miniBLOC, as depicted in Figure 1. Information is provided focusing on special precautions to be considered during mounting.

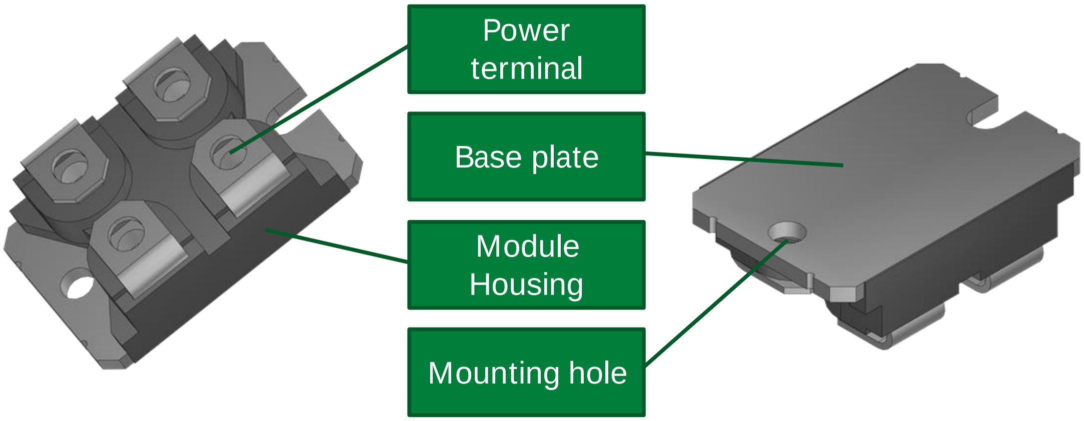

Figure 1: Littelfuse miniBLOC, in SOT227B

Applications

- Industrial motor drives
- PV inverters
- UPS systems
- DC-DC converters
- Commercial vehicles

Target Audience

This document is intended for potential adopters of power semiconductors who want to determine the appropriate mounting and cooling solution to ensure proper package mounting and thermal performance.

Contact Information

For more information on the topic of mounting this kind of device, contact the Littelfuse Power Semiconductor team of product and applications experts:

- PowerSemiSupport@Littelfuse.com

Rev 22.08a

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1. Introduction

The miniBLOC is the intermediate link between discrete power devices like the TO-263 and power semiconductor modules like Littelfuse Y-series. Though it features a DCB-substrate to carry the dies, the molded housing structure characterizes it to be a discrete component rather than a power module. The internal DCB substrate inherently offers electrical insulation, allowing for mounting of several miniBLOCs to the same heat sink without additional means of isolation. The base plate in turn acts as large-area interface between the semiconductor and a heat sink.

The package provides features beneficial for power electronic applications. These include:

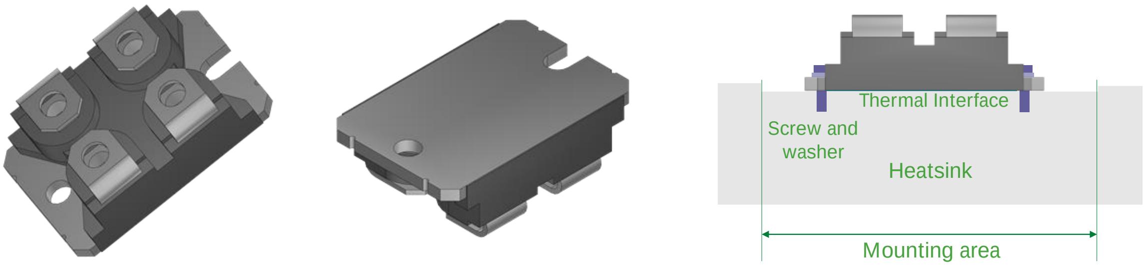
- High electric insulation strength
- High thermal performance
- Current ratings to support applications up to hundreds of kilowatts
- Internal construction is designed to reduce stray inductance and parasitic capacitances, leading to improved EMI-performance

With the four terminals, the miniBLOC is available in a variety of technologies including IGBT, thyristor , Si- and SiC- diode and MOSFET in voltage classes from 40 to 2500 V and current ratings up to 600A.

There are a few miniBLOCs, such as the DSEC 240-04A and the DSEC 240-06A, that feature a non-isolated construction and an electrically active base plate. These are diode devices, designed for special purposes. Despite the slightly different internal construction, the recommendations made in this application note are valid for these types as well.

2. Recommended Heat Sink Assembly

Semiconductor power devices are designed to be mounted onto a heat sink, most often using screws. A layer of Thermal Interface Material (TIM) is needed to ensure a high thermal conductivity from the dice to the heatsink. After the application of thermal interface material is completed, the component can be mounted to a heatsink by mounting screws. An example of a SOT227B assembly is sketched in Figure 2.



(a) Power device, top-view (b) Power device, bottom-view (c) Mounted to the Heat Sink

Figure 2. Mounting the miniBLOC to a Heat Sink

2.1. Heat Sink Preparation

When the package is mounted, the base plate becomes the crucial surface for thermal management. A heatsink needs to be mounted for heat dissipation, as depicted in Figure 2. There are dedicated mounting holes in the package; the proper set of dimensions for the drill-hole-pattern is given in the correlating datasheet.

To ensure a low value of thermal resistance, the contact surface of the heat sink must be flat, even, and clean. For the mounting area, the surface quality must achieve or exceed the values given in Figure 3.

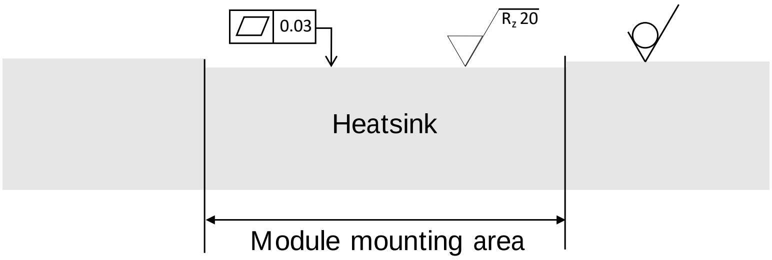


Figure 3. **Heat Sink's Surface Requirements to Mount** Power Modules

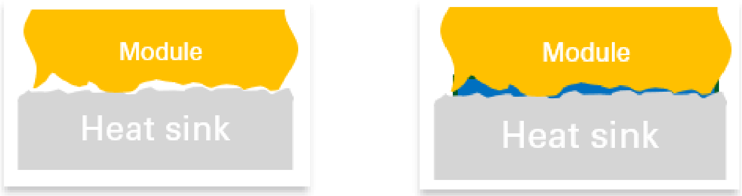
Prior to mounting, cleaning all surfaces with a suitable cleaning agent is advised.

2.2. Use of Thermal Interface Materials

The use of Thermal Interface Materials (TIM) is mandatory to achieve a suitable contact between the device's base and the heat sink surface. It reduces the thermal resistance case-to-heatsink, R_{thch}. Thermal interface materials are available as thermal pad and thermal grease or compound. Unlike the discrete packages where the copper cooling pad is usually electrically active, packages with solid metal base plates internally feature a DCB structure which uses a layer of ceramic as electrical isolation. With up to 4500 V isolation voltage, the packages provide the option to use electrically non-isolated thermal interface materials. It is not recommended to use an interface material with isolation such as silicone-pads sometimes used for discrete packaged devices. These materials inherently exhibit a higher thermal resistance compared to thermal greases or conductive thermal pads.

The thermal interface materials should be applied evenly to the device base plate or the heat sink surface. Ideally, screen printing is used to achieve accurate and reproduceable results. A screen thickness of 100µm with a fill-factor of 70-80% and a regular pattern of honeycomb-shaped openings has proven to be a reasonable approach.

As no electrical isolation is required from the TIM layer, it is recommended to have a very thin layer of TIM so that the material just fills the gaps and voids between the device's copper pad and the heatsink, as seen in Figure 4.



(a) Without TIM, air gaps remain

(b) With TIM, the gaps are filled, contact area increases, and thermal resistance is reduced

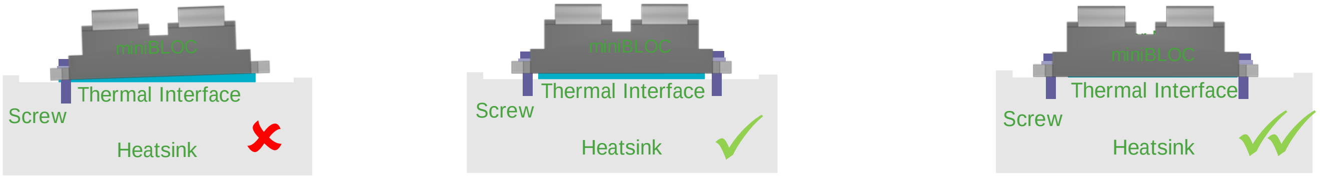
Figure 4. Improving Thermal Transfer by using Thermal Interface Material (TIM)

If a solid thermal pad is considered, softer materials with high thermal conductivity are preferred to better fill the gaps. The thermal pad should be as thin as possible to provide the lowest thermal resistance. The mounting mechanism using screws provides proper pressure on the thermal interface material to ensure a low value of thermal resistance. A procedure to create a proper stencil and set up a basic stencil-printing equipment is described in detail in the application note *Basics of Stencil Generation to Apply Thermal Grease to Power Semiconductors*, which can be downloaded from the Littelfuse website.

2.3. Detailed Mounting Procedure

Mounting the module by screws inherently achieves mounting forces in a range of kilonewton. Though the base plate is highly resistant to pressure, the internal DCB-structure is very sensitive towards bending. Therefore, careful handling and step-by-step tightening of the screws is mandatory to achieve the desired pressure distribution and prevent bending the internal DCB.
Besides the mounting forces, an even distribution of thermal interface material is important. Uneven distribution, particularly with higher amount of material in the center of the module, may also lead to high local forces that could damage the DCB inside the power module.
Using solid sheets as thermal interface material is not a recommended solution as these typically remain too thick and limit the module's thermal performance. Additionally, they may lead to further issues during mounting.

Figure 5(a) illustrates that the module lifts on one side in case the first screw is bolted down too much and Figure 5(b) and Figure 5(c) show a two-step sequence to prevent this from happening.



(a) To be prevented: Bolting down one side may tilt the module which leads to bending

(b) Recommended: Loosely bolt down all screws to the point **where the screw's head touches the washer**

(c) In a further step, tighten the screws to their final torque using a precise torque wrench

Figure 5: Bolting down the screw – Incorrect and Correct Method

The tightening procedure is summarized in Table 1.

Table 1: Mounting Sequence to mount SOT227B

Package Type	Screw Diameter	Step 1	Step 2	Step 3	Step 4
SOT227B	4 mm	Bolt down both screws, so that the screws' heads get the washers to contact the base pate	Apply 0.5 Nm to both screws	Wait for the assembly to settle. Settling time depends on the TIM in use and varies from 5-10 minutes	Apply no more than 1.5 Nm to both screws

In case imperial screws are preferred for mounting, a screw 8-36 is the closest replacement for M4. The mounting torque needs to be limited to not exceed 11.5 lb-in

3. Further Mechanical Aspects

Besides the data and procedures to mount power electronic components, influences that arise from mechanical parts and physics need detailed attention. Some details that appear to be of minor impact can lead to unexpected effects with highly detrimental consequences.

3.1. Metric Thread, Imperial Thread, Self-tapping Screws

The recommended material for mounting the module to the heat sink is a metric screw with spring-washer and captivated washer as described by ISO 10644. Zinc- or nickel-plated steel screws with a property class 6.8 or higher, as depicted in Figure 6, are recommended.

Figure 6: Phillips-style Screws and Captivated Washers acc. to ISO 10644

Using screws with imperial scale is an option too. However, due to the different diameters and thread's pitch, the ratio between turning angle, torque, and resulting mounting forces also changes. Purely translating newton meter (Nm) into pound inches (lb-in) might result in misleading values. Individual verification of the result is advised to verify proper pressure and pressure distribution is achieved.

In case self-tapping screws like those described in DIN7504-K and ISO15480 are preferred, dedicated tests are needed to correlate torque, turning angle, and mounting force. As the torque mainly depends on the drill-hole's diameter and the heat sink material, no general recommendation can be made. Using washers and spring-washers in combination with self-tapping screws is advised.

3.2. Mounting the Electronics and DC-link Components

Power modules are robust regarding pressure applied, but highly sensitive towards pulling forces. Pulling forces can be a consequence of dynamic influences like shock and vibration but as well result from the combination of materials used in the construction and their tolerances.
A mechanical assembly must ensure that the resulting forces to the terminals remain directed as pictured in Figure 7.

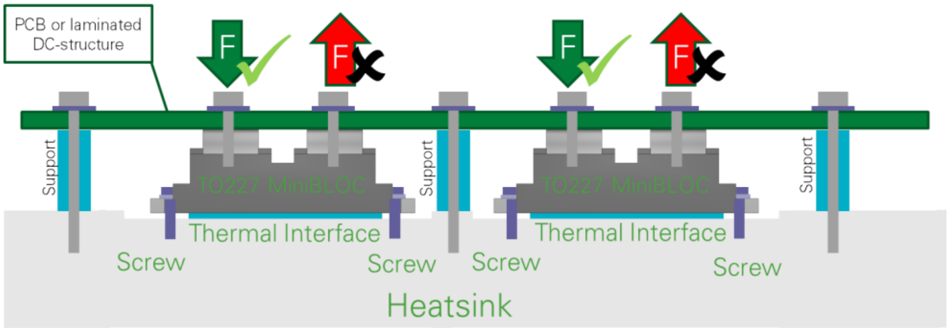


Figure 7: Module assembly with Power-Terminals attached

A total force of up to 100N applying pressure to the module is tolerable while no pulling force may remain after mounting is complete. To achieve this, properly dimensioned supports must be installed. These prevent static forces as well as dynamic events from reaching the terminals. Including all tolerances, the supports' length needs to remain below the height of the module in use.
Larger components like DC-link capacitors, output terminals, or heavy current sensors require additional support. In case of vibration, undampened oscillating masses may inject destructive forces into the power component.

To mount the DC-link-structure to the modules, either as PCB or laminated copper plates, 4 suitable screws are delivered with each miniBLOC, a tube with 10 devices contains 40 screws. In case a different type of screw is desired, the screws mandatorily need to comply with the information given in the data sheet. The maximum length of the screws depends on the thickness of the structure mounted on top of the modules. Caution is advised as too long screws can damage the housing, enter electrically sensitive areas, and cause severe damage.

As the nuts embedded in the modules feature metric threads, the use of screws according to imperial scale is not an option for mounting the power terminals. The nuts are held in place by the housing. Applying too high torque can lead to damage of the housing and in turn to loss of function.

The terminal screws can support a maximum torque of 1.1 Nm or 9 lb-in. Especially in combination with oils used to prevent corrosion, the friction during mounting can change massively, leading to a distortion in the ratio of torque and turning angle. The same applies when using adhesive-based thread lockers.

When handling sub-assemblies, supporting the whole setup to move it is recommended. Using the bus bar or the PCB as a handle includes a high risk of applying pulling forces and therefore needs to be prevented.

If a module is being replaced, ensure there is no contamination in the threaded hole; for example, thermal paste that has been solvent washed into the threads, as this may limit the screws' engagement resulting in false fastener tension and module clamping force.
In situations where blind holes are not required for maintaining corrosion or pressure sealing performance, threaded through holes can be used as these can be brushed, washed clean, and inspected easily.

3.3. Insulation Management

Two major parameters require to be considered when PCB-layouts and DC-link-components are designed:

- Clearance – the shortest possible distance between two points, and
- Creepage distance – the shortest path from one point to another point along an uninterrupted line on solid material

Particularly when using laminated bus bar structures, isolating the layers from each other remains an important task.

In high-voltage environments, arcing between different voltage levels must be prevented. Arcing takes place over air-gaps – clearance distances – so the voltage level expected in the final system defines the distance between pads and traces as well as between active areas and heat sinks or other grounded parts. Even if the clearance between two points is chosen to be high enough, the insulation strength can be reduced by conductive particles over a longer period. This depends on the degree of pollution, which relates to the ambient conditions the device is used in.

IEC60664-1 gives an insight about the relevant conditions that need to be considered to determine the creepage and clearance distances in a targeted design.

4. Conclusion

Littelfuse miniBLOC devices with their base plate and molded housing structure are mechanically robust components. Still, care needs to be taken to not bend the module during the mounting process and a mechanical arrangement must be designed to prevent pulling forces at the terminals. Applying thermal interface material by a well-controlled screen-printing process further helps to reduce unwanted mechanical stress to the device.

If these aspects are considered, mounting the devices can successfully be done by implementing established procedures and processes.

Revision History

Version	Date	Changes
22.08a	August 2022	Initial version created for release

For additional information please visit www.Littelfuse.com/powersemi

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IXYN110N120B4H1

1200 V, 110 A XPT™ Gen4 IGBT with Sonic Diode

Extreme Light Punch Through IGBT for 5 – 30 kHz Switching

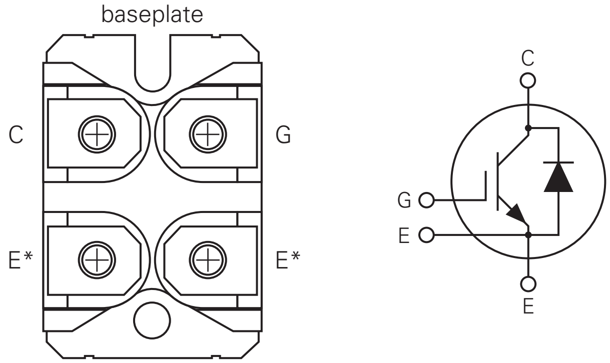
Description:

Developed using our proprietary XPT™ thin-wafer technology and state-of-the-art Trench IGBT process, these devices feature reduced thermal resistance, low energy losses, fast switching, low tail current, and high current densities.

Features & Benefits:

- Optimized for 5–30kHz Switching
- miniBLOC, with Aluminium Nitride Isolation
- 2500V~ Isolation Voltage
- High Current Handling Capability
- Positive Thermal Coefficient of $V_{CE(sat)}$
- High Power Density
- Low Gate Drive Requirement
- International Standard Package
- Anti-Parallel Sonic Diode

Pinout Diagram (SOT-227B)



G: Gate; **C:** Collector; **E:** Emitter; **baseplate:** Isolated
*Either emitter terminal can be used as Main or Kelvin Emitter

Applications:

- Power Inverters
- UPS
- Motor Drives
- SMPS
- PFC Circuits
- Battery Chargers
- Welding Machines

Product Summary

Characteristic	Value	Unit
V_{CES}	1200	V
I_{C110}	110	A
$V_{CE(sat)}$	2.10	V
$t_{fi(typ)}$	130	ns

Maximum Ratings

Symbol	Characteristic	Conditions	Value	Unit
V_{CES}	Collector-Emitter Voltage	T_J = 25°C to 175°C	1200	V
V_{GES}	Gate-Emitter Voltage	Continuous	±20	V
V_{GEM}	Transient Gate-Emitter Voltage	Transient	±30	V
I_{C25}	Continuous Collector Current	T_C = 25°C	218	A
I_{LRMS}	Terminal Current Limit	–	200	A
I_{C110}	Continuous Collector Current	T_C = 110°C	110	A
I_{F110}	Diode Forward Current	T_C = 110°C	74	A
I_{CM}	Pulsed Collector Current	T_C = 25°C, 1 ms	820	A
SSOA (RBSOA)	Switching Safe Operating Area (Reverse Biased Safe Operating Area)	V_{GE} = 15 V, T_{VJ} = 150°C, R_G = 2 Ω, I_{CM} = 0.8 x V_{CES}	220	A
P_C	Collector Power Dissipation	T_C = 25°C	830	W
T_J	Junction Temperature	–	-55 to 175	°C
T_{JM}	Maximum Junction Temperature	–	175	°C
T_{stg}	Storage Temperature	–	-55 to 175	°C
V_{ISOL}	Isolation Voltage	50/60 Hz, I_{ISOL} ≤ 1 mA, t = 1 min	2500	V~
		50/60 Hz, I_{ISOL} ≤ 1 mA, t = 1 s	3000	
M_d	Mounting Torque	–	1.5 / 13	Nm/lb.in
	Terminal Connection Torque	–	1.3 / 11.5	
W	Weight	–	30	g

Thermal Characteristics

Symbol	Characteristic	Value			Unit
		Min.	Typ.	Max.	
$R_{th,\ JC}$	Thermal Resistance, junction-to-case	–	–	0.18	°C/W
$R_{th,\ CS}$	Thermal Resistance, case-to-heat sink	–	0.05	–	°C/W

Electrical Characteristics – Static (T_J = 25°C unless otherwise specified)

Symbol	Characteristic	Conditions	Value			Unit
			Min.	Typ.	Max.	
BV_{CES}	Collector-Emitter Breakdown Voltage	I_C = 250 µA, V_{GE} = 0 V	1200	–	–	V
$V_{GE(th)}$	Gate-Emitter Threshold Voltage	I_C = 3 mA, V_{CE} = V_{GE}	4.5	–	6.5	V
I_{CES}	Zero Gate Voltage Collector Current	V_{CE} = V_{CES}, V_{GE} = 0 V	–	–	50	µA
		V_{CE} = V_{CES}, V_{GE} = 0 V, T_J = 125°C	–	–	7	mA
I_{GES}	Gate-Emitter Leakage Current	V_{CE} = 0 V, V_{GE} = ±20 V	–	–	±100	nA
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage[1]	I_C = I_{C110}, V_{GE} = 15 V	–	1.66	2.10	V
		I_C = I_{C110}, V_{GE} = 15 V, T_J = 150°C	–	1.95	–	V

Note 1: Pulse test, t ≤ 300 µs, duty cycle, d ≤ 2%

Electrical Characteristics – Dynamic (T_J = 25°C unless otherwise specified)

Symbol	Characteristic	Conditions		Value			Unit
				Min.	Typ.	Max.	
g_{fs}	Transconductance[1]	I_C = 55 A, V_{CE} = 10 V		40	68	–	S
C_{ies}	Input Capacitance	V_{CE} = 25 V, V_{GE} = 0 V, f = 1MHz		–	5460	–	pF
C_{oes}	Output Capacitance			–	480	–	
C_{res}	Reverse Transfer Capacitance			–	220	–	
$Q_{g(on)}$	Total Gate Charge	I_C = I_{C110}, V_{GE} = 15 V, V_{CE} = 0.5 x V_{CES}		–	340	–	nC
Q_{ge}	Gate-Emitter Charge			–	52	–	
Q_{gc}	Gate-Collector Charge			–	144	–	
$t_{d(on)}$	Turn-on Delay Time[2]	Inductive Load, V_{GE} = 15 V, V_{CE} = 0.5 x V_{CES}, I_C = 50 A, $R_{G(ext)}$ = 2 Ω	T_J = 25°C	–	45	–	ns
			T_J = 150°C	–	34	–	
t_{ri}	Turn-on Rise Time[2]		T_J = 25°C	–	50	–	ns
			T_J = 150°C	–	38	–	
E_{on}	Turn-on Energy[2]		T_J = 25°C	–	3.60	–	mJ
			T_J = 150°C	–	4.95	–	
$t_{d(off)}$	Turn-off Delay Time[2]		T_J = 25°C	–	390	–	ns
			T_J = 150°C	–	440	–	
t_{fi}	Turn-off Fall Time[2]		T_J = 25°C	–	130	–	ns
			T_J = 150°C	–	210	–	
E_{off}	Turn-off Energy[2]		T_J = 25°C	–	3.85	–	mJ
			T_J = 150°C	–	6.45	–	

Note 1: Pulse test, t ≤ 300 μs, duty cycle, d ≤ 2%
Note 2: Switching times and energy losses may increase for higher $V_{CE(clamp)}$, T_J, or R_G.

Reverse Sonic Diode (FRD) (T_J = 25°C unless otherwise specified)

Symbol	Characteristic	Conditions	Value			Unit
			Min.	Typ.	Max.	
V_F	Diode Forward Voltage[1]	I_F = 100 A, V_{GE} = 0 V	–	2.20	2.70	V
		I_F = 100 A, V_{GE} = 0 V, T_J = 150°C	–	2.15	–	
I_{RM}	Reverse Recovery Current	I_F = 50 A, V_{GE} = 0 V, T_J = 150°C $-di_F/dt$= 750 A/μs, V_R = 600 V	–	43	–	A
t_{rr}	Reverse Recovery Time		–	270	–	ns
$R_{th, JC}$	Thermal Resistance, junction-to-case	–	–	–	0.41	°C/W

Note 1: Pulse test, t ≤ 300 μs, duty cycle, d ≤ 2%

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Characteristic Curves

Fig. 1. Output Characteristics @ T_J = 25ºC

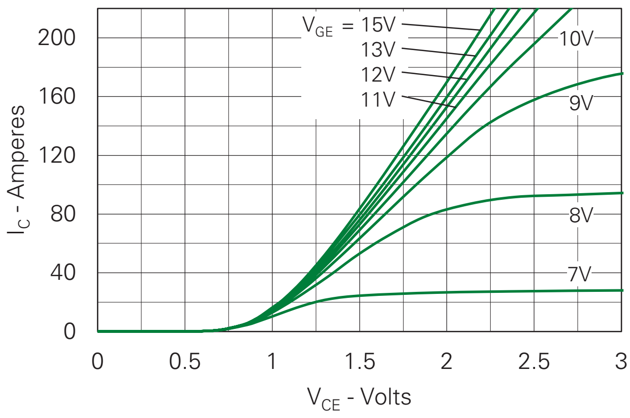


Fig. 2. Extended Output Characteristics @ T_J = 25ºC

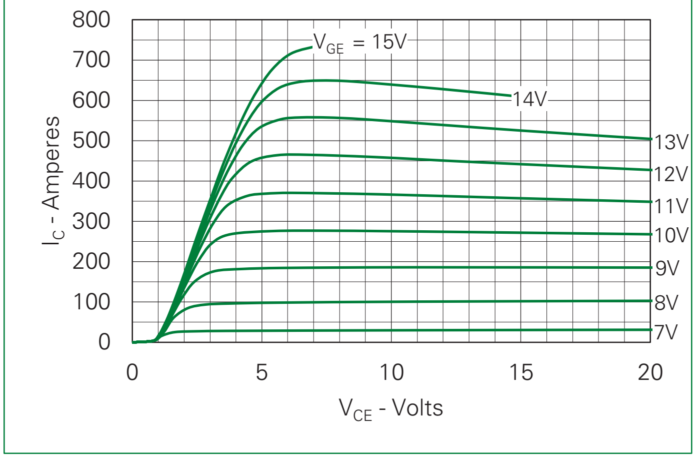


Fig. 3. Output Characteristics @ T_J = 150ºC

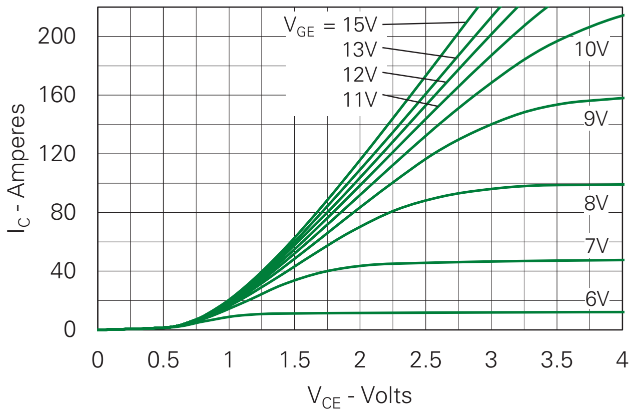


Fig. 4. Dependence of $V_{CE(sat)}$ on Junction Temperature

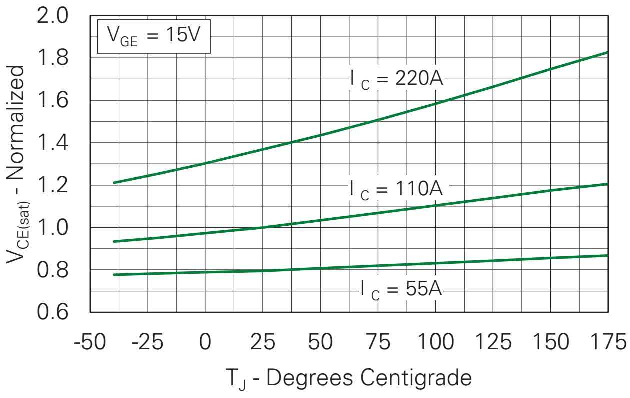


Fig. 5. Collector-to-Emitter Voltage vs. Gate-to-Emitter Voltage

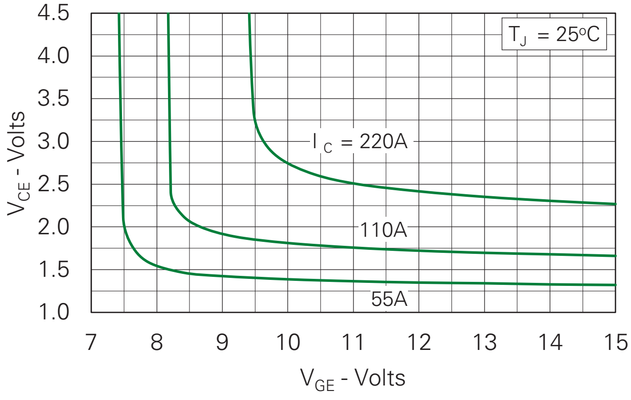
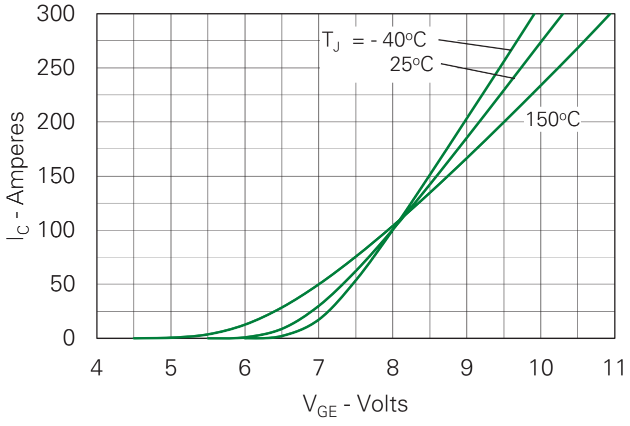


Fig. 6. Input Admittance



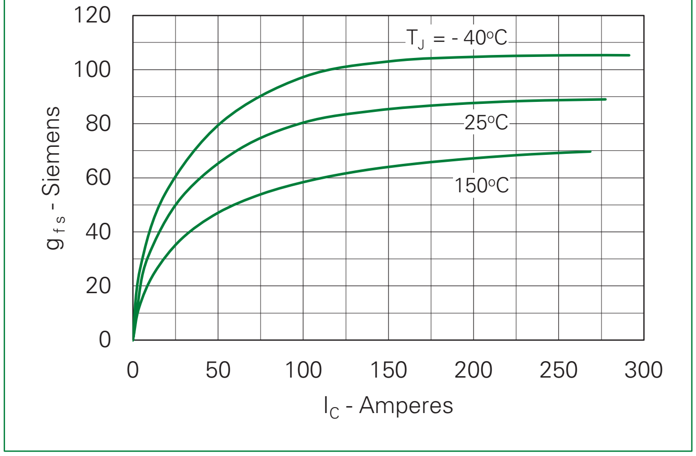


Fig. 7. Transconductance
120
100
80
60
40
20
0
0
50
100
150
200
250
300
g_{fs} - Siemens
I_C - Amperes
T_J = - 40ºC
25ºC
150ºC

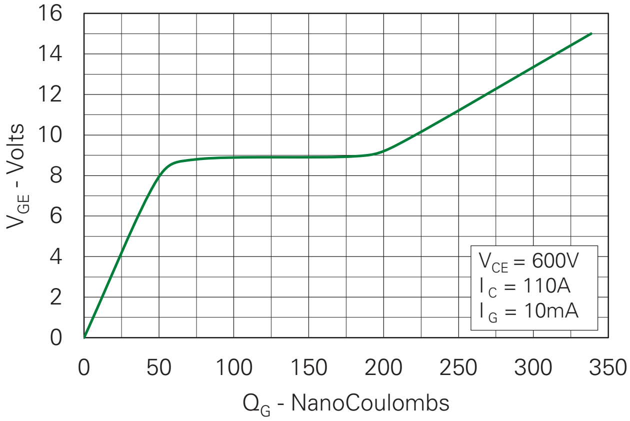


Fig. 8. Gate Charge
16
14
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
V_{GE} - Volts
Q_G - NanoCoulombs
V_{CE} = 600V
I_C = 110A
I_G = 10mA

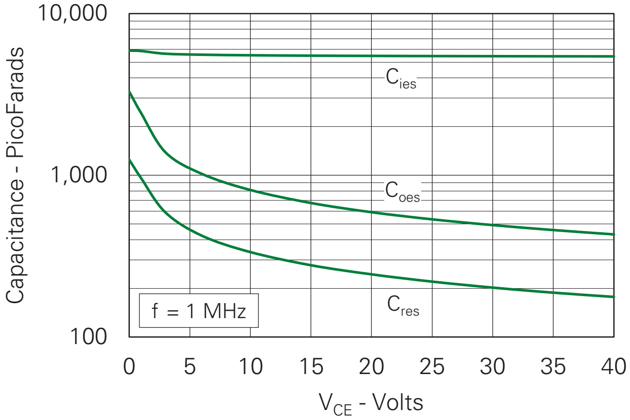


Fig. 9. Capacitance
10,000
1,000
100
0
5
10
15
20
25
30
35
40
Capacitance - PicoFarads
V_{CE} - Volts
C_{ies}
C_{oes}
C_{res}
f = 1 MHz

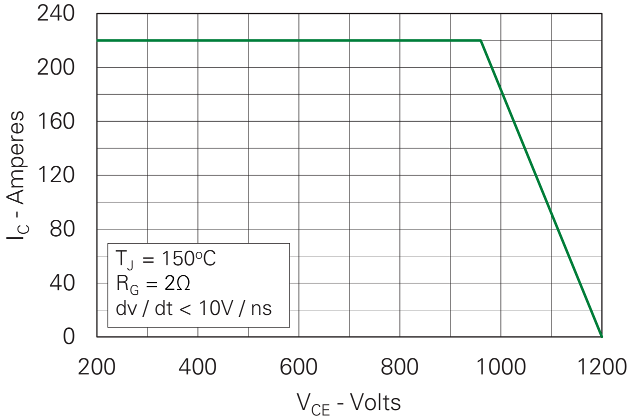


Fig. 10. Reverse-Bias Safe Operating Area
240
200
160
120
80
40
0
200
400
600
800
1000
1200
I_C - Amperes
V_{CE} - Volts
T_J = 150ºC
R_G = 2Ω
dv / dt < 10V / ns

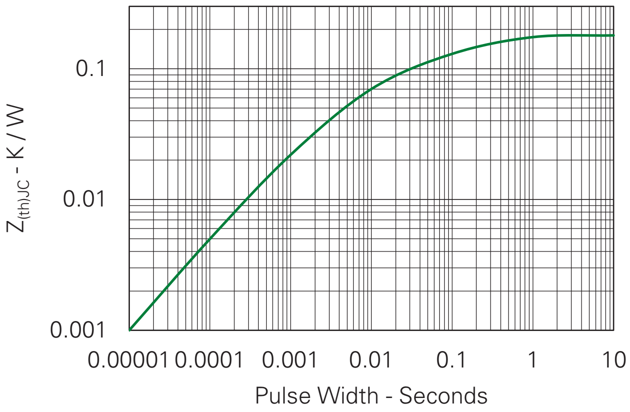


Fig. 11. Maximum Transient Thermal Impedance
0.1
0.01
0.001
0.00001
0.0001
0.001
0.01
0.1
1
10
$Z_{(th)JC}$ - K / W
Pulse Width - Seconds

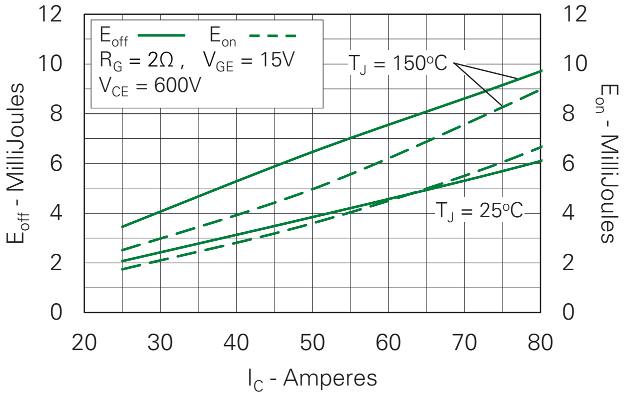


Fig. 12. Inductive Switching Energy Loss vs. Collector Current
12
10
8
6
4
2
0
20
30
40
50
60
70
80
E_{off} - MilliJoules
E_{on} - MilliJoules
I_C - Amperes
E_{off}
E_{on}
R_G = 2Ω , V_{GE} = 15V
V_{CE} = 600V
T_J = 150ºC
T_J = 25ºC

Fig. 13. Inductive Switching Energy Loss vs. Collector-Emitter Voltage

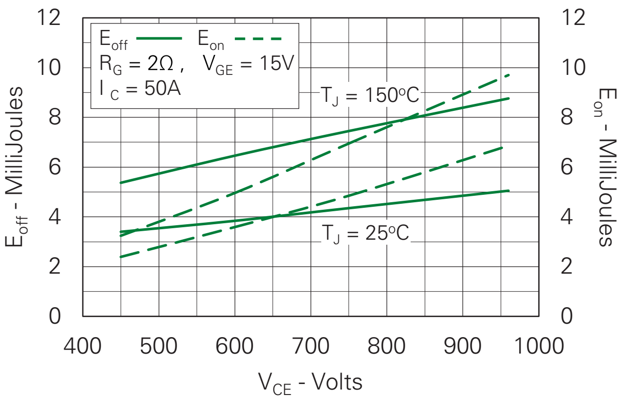


Fig. 14. Inductive Switching Energy Loss vs. Gate Resistance

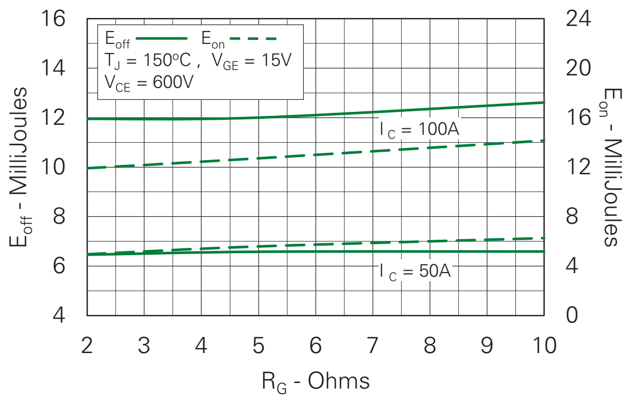


Fig. 15. Inductive Switching Energy Loss vs. Junction Temperature

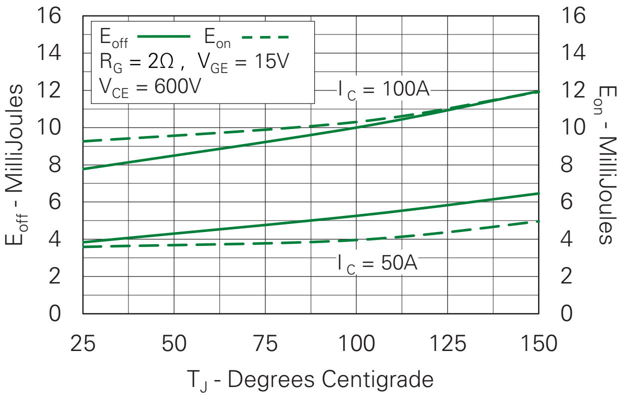


Fig. 16. Inductive Turn-off Switching Times vs. Gate Resistance

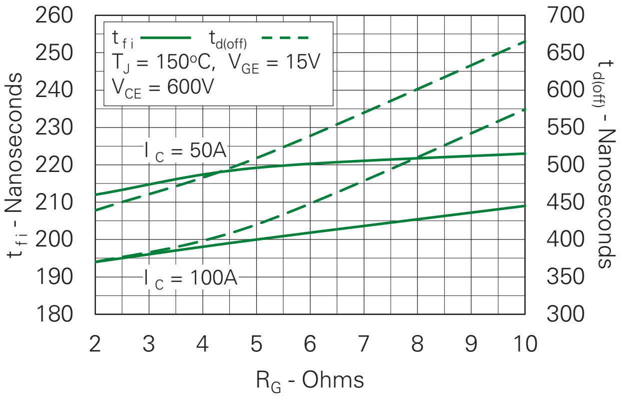


Fig. 17. Inductive Turn-off Switching Times vs. Collector Current

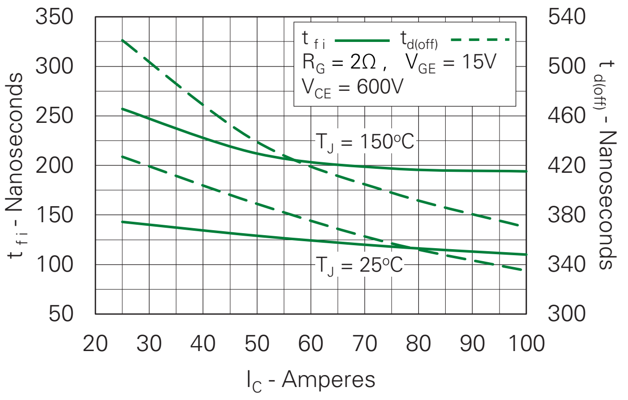


Fig. 18. Inductive Turn-off Switching Times vs. Junction Temperature

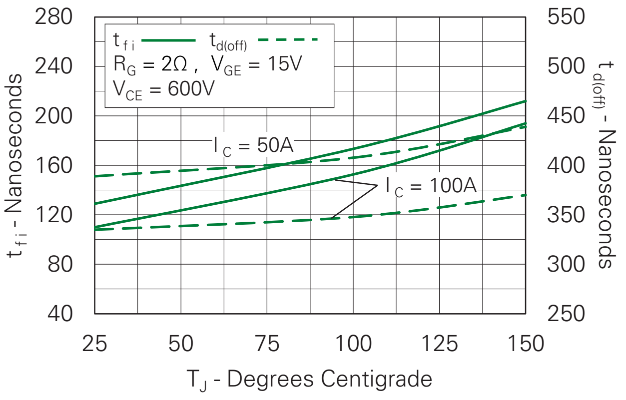


Fig. 19. Inductive Turn-on Switching Times vs. Gate Resistance

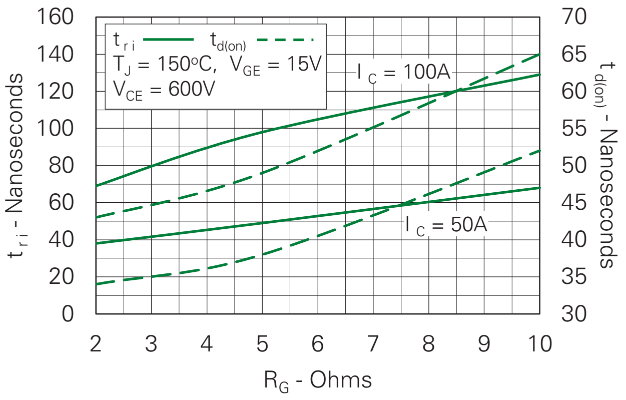


Fig. 20. Inductive Turn-on Switching Times vs. Collector Current

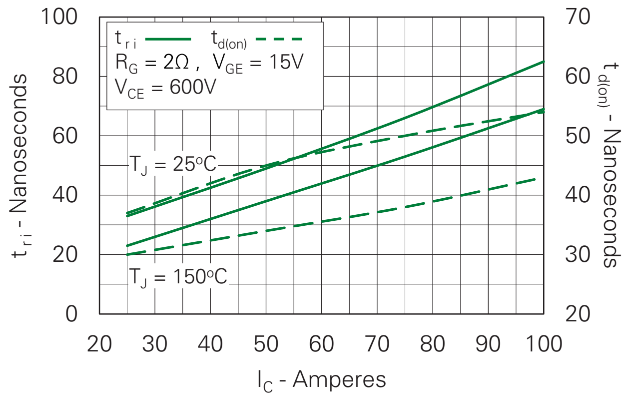


Fig. 21. Inductive Turn-on Switching Times vs. Junction Temperature

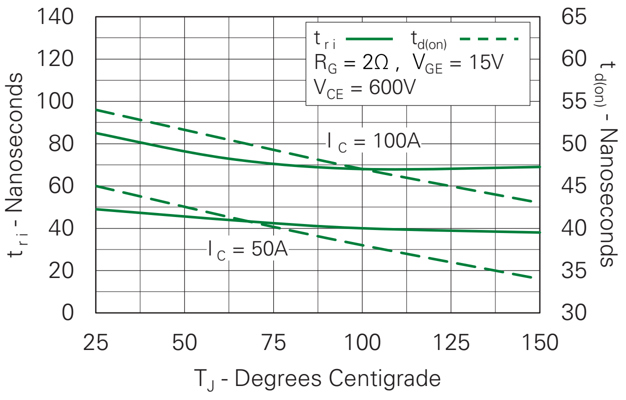


Fig. 22. Maximum Peak Load Current vs. Frequency

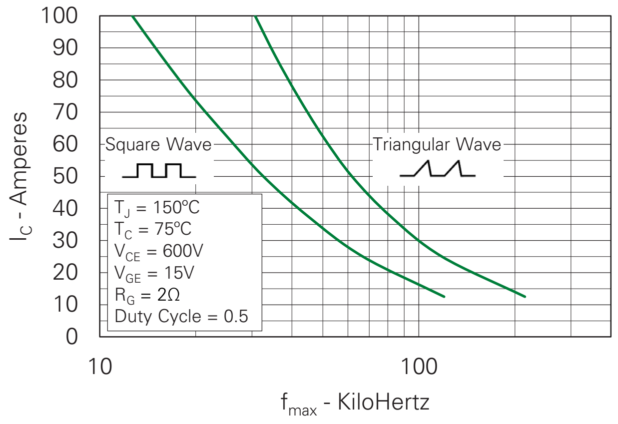


Fig. 23. Diode Forward Characteristics

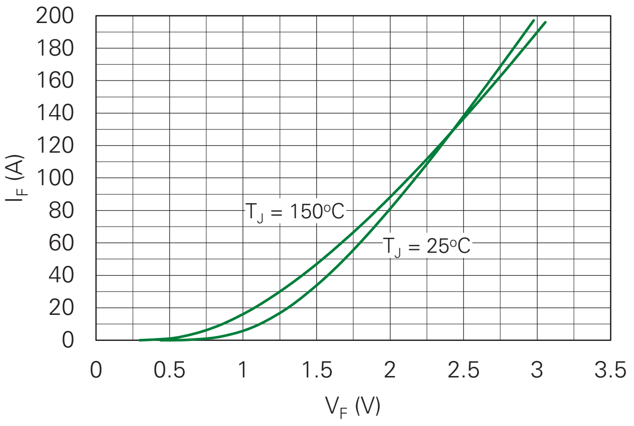


Fig. 24. Reverse Recovery Charge vs. -di$_F$/dt

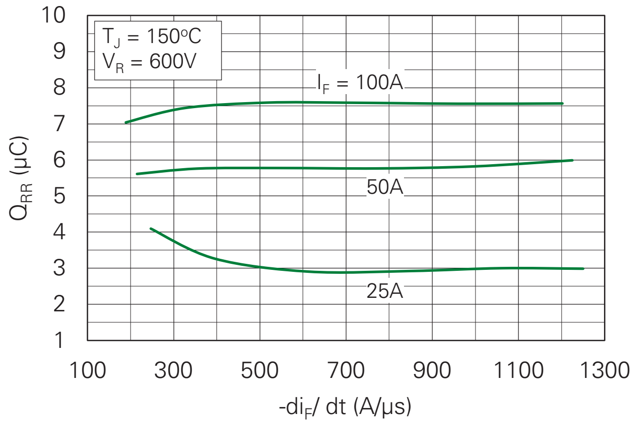


Fig. 25 Reverse Recovery Current vs. -di_F/dt

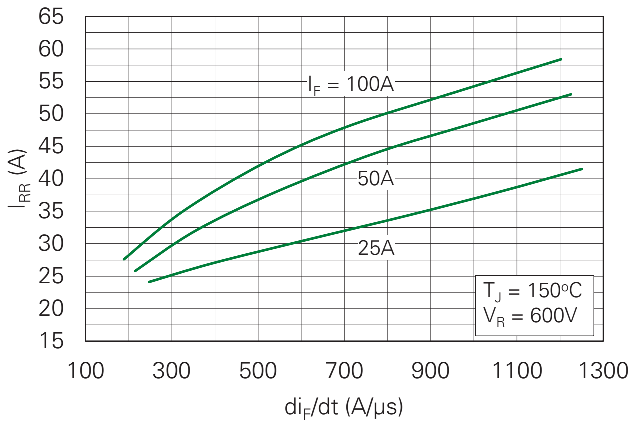


Fig. 26. Reverse Recovery Time vs. -di_F/dt

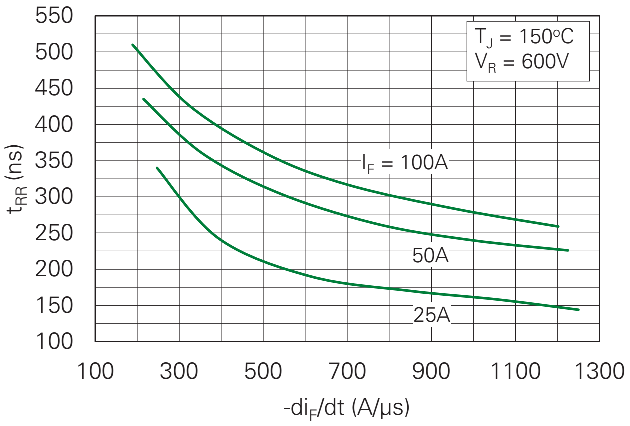


Fig. 27. Dynamic Parameters Q_{RR}, I_{RR} vs. Junction Temperature

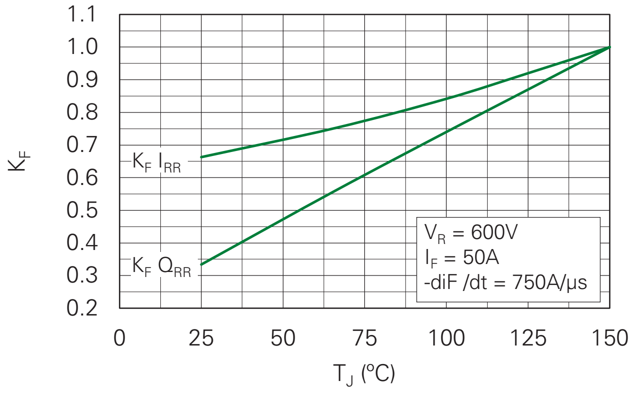
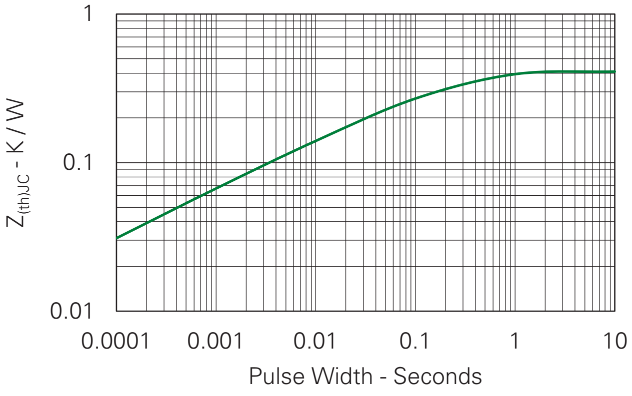
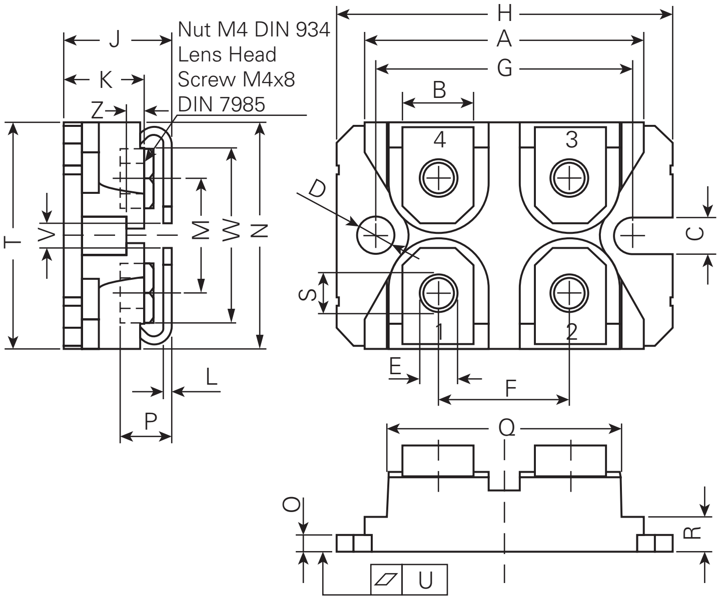


Fig. 28. Maximum Transient Thermal Impedance (Diode)



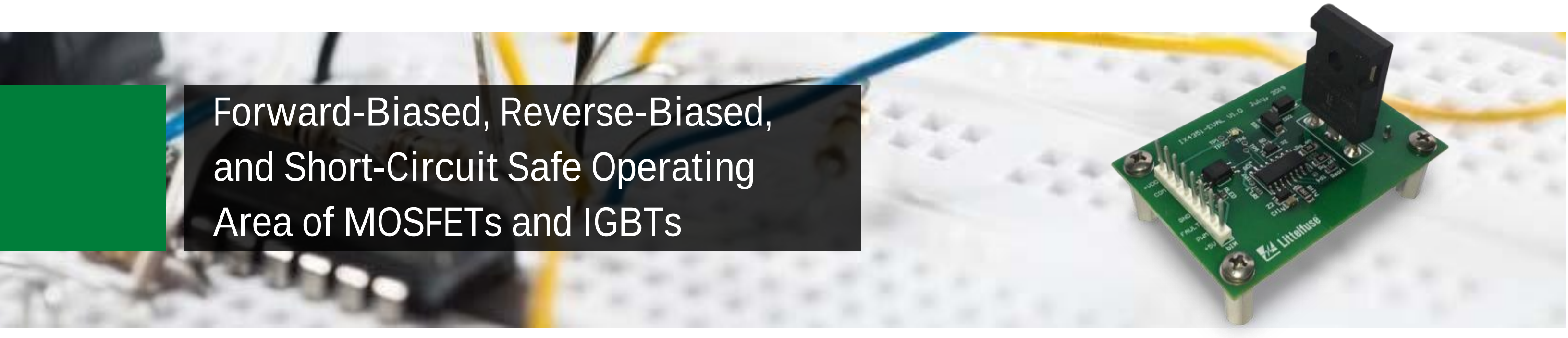
Revised: XZ 04/19/2023

Part Outline Drawing (SOT-227B)



Symbol	Inches			Millimeters		
	Min.	Typical	Max.	Min.	Typical	Max
A	1.240	–	1.255	31.50	–	31.88
B	0.307	–	0.323	7.80	–	8.20
C	0.161	–	0.169	4.09	–	4.29
D	0.161	–	0.169	4.09	–	4.29
E	0.161	–	0.169	4.09	–	4.29
F	0.587	–	0.595	14.91	–	15.11
G	1.186	–	1.193	30.12	–	30.30
H	1.488	–	1.505	37.80	–	38.23
J	0.460	–	0.481	11.68	–	12.22
K	0.351	–	0.378	8.92	–	9.60
L	0.029	–	0.033	0.74	–	0.84
M	0.492	–	0.516	12.50	–	13.10
N	0.990	–	1.001	25.15	–	25.42
O	0.077	–	0.084	1.95	–	2.13
P	0.195	–	0.244	4.95	–	6.20
Q	1.045	–	1.059	26.54	–	26.90
R	0.155	–	0.174	3.94	–	4.42
S	0.179	–	0.191	4.55	–	4.85
T	0.968	–	0.994	24.59	–	25.25
U	-0.002	–	0.004	-0.05	–	0.10
V	0.126	–	0.217	3.20	–	5.50
W	0.780	–	0.830	19.81	–	21.08
Z	0.098	–	0.106	2.50	–	2.70

Forward-Biased, Reverse-Biased, and Short-Circuit Safe Operating Area of MOSFETs and IGBTs



Objectives

This document explains the operating conditions that a power semiconductor is supposed to work in without being damaged. Focus is set on the *Forward-Biased Safe Operating Area* (FBSOA), the *Reverse Biased, Safe Operating Area* (RBSOA) and the *Short-Circuit Safe Operating Area* (SCSOA).

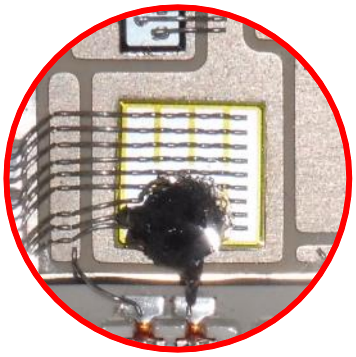


Figure 1. To be prevented – an IGBT destroyed by RBSOA-exceedance

Applications

The information compiled in this document is relevant for the power semiconductor itself and thus for all its applications.

Target Audience

This document is intended for all developers, design- and test-engineers involved in building power semiconductor applications.

Contact Information

For more information on the topic of safely operating power devices, contact the Littelfuse Power Semiconductor team of product and applications experts:

- PowerSemiSupport@Littelfuse.com

Rev 24.02a

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List of Figures

Introduction

Power semiconductors like IGBTs, GTOs, thyristors, diodes, or bipolar junction transistors (BJT) have been developed into robust and reliable devices which can by now handle power levels into the MW-range and even beyond.

Despite these developments, they all have physical limitations which need to be known and respected to prevent damage to these components and the system they are mounted in. Depending on the instantaneous mode of operation, different conditions are described by a varying set of parameters, often referred to as operating area.

1. Safe Operating Area (SOA), also called Forward-Bias Safe Operating Area (FBSOA)

When a power semiconductor like an IGBT is used to conduct current in the predestined direction, the physical limits of the device to be considered include:

- the maximum collector current I_C,
- the saturation voltage V_{CEsat} across the device,
- the power generated by the product $I_C \cdot V_{CEsat}$, and
- the maximum junction temperature T_{VJ} allowed.

In cases where the power semiconductor is a MOSFET, dedicated to be operated in linear mode, the current can be influenced by tuning the gate-source-voltage accordingly. As a consequence, the drain-source-voltage V_{DS} of the devices changes which in turn impacts the losses. The device must dissipate these losses and the thermal impedance of the device poses the limits here.

For these operating conditions, the FBSOA-diagram features the forward voltage, the current and limits imposed by thermal development. Looking at Figure 2, it becomes obvious that growing losses can only be tolerated for shorter periods of time.

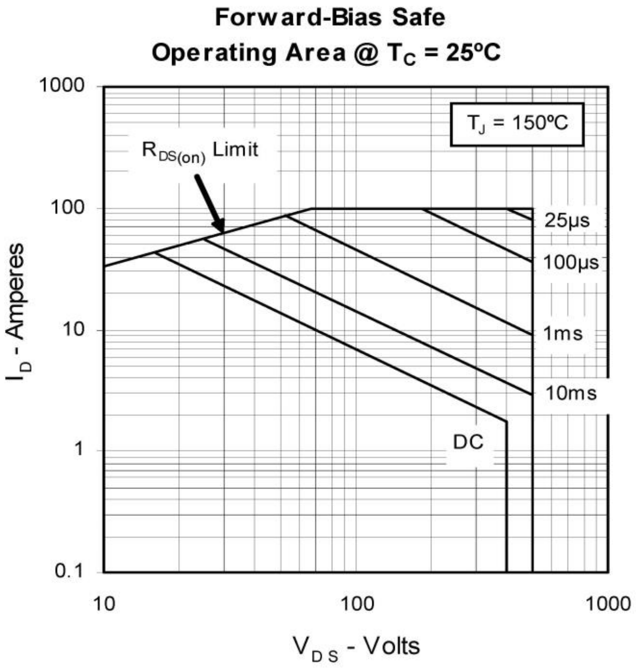


Figure 2. SOA Diagram for the IXTX46N50L

Any combination of forward voltage and current that is found below the correlating lines within the diagram is a legal point of operation as long as the junction temperature remains below the maximum limit and the duration of the loading is properly chosen. De-rating must be considered if the case temperature is different from the 25°C the diagram in Figure 2 refers to.

2. Reverse Biased Safe Operating Area (RBSOA)

Power semiconductors like IGBTs or MOSFETs can turn off a current rather quickly but not at infinite speed. As the switching procedure does take some time, transient phenomena happen that need to be considered.

During this short period, when the device turns from conducting into blocking mode, the Reverse Biased Safe Operating Area needs to be respected at any time.

The limits are given by the current which is turned off and the voltage that appears across the device. The plot in Figure 3 schematically displays a turn-off event in detail.

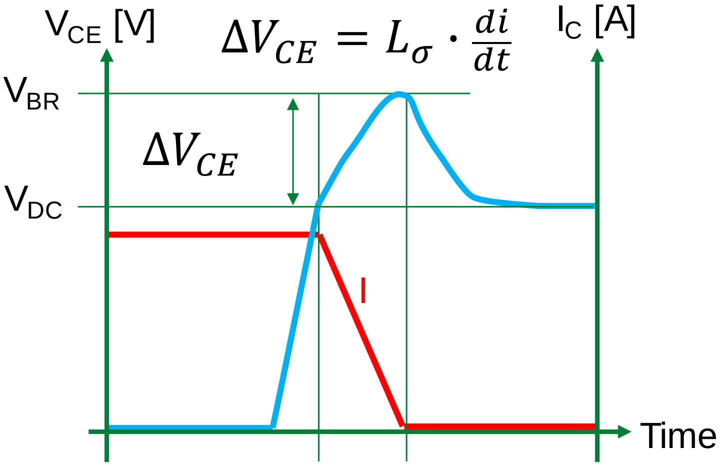


Figure 3. Voltage and current waveforms during a turn-off event

In the graph, it can clearly be seen that the voltage across the device first reaches the DC-link's voltage level before the current starts declining. Because of the current change rate di/dt and the inherently contained stray inductances L_σ, the voltage spike ΔV_{CE} is added on top of the DC-link voltage. If this spike exceeds the device's breakdown voltage V_{BR} – even for a very short period of time – the device will be destroyed.

The square-shaped Reverse Biased Safe Operating Area therefore is given by maximum current $I_{C,max}$ and the breakdown voltage V_{BR}, as depicted in Figure 4. Here too, the junction temperature poses a further limit.

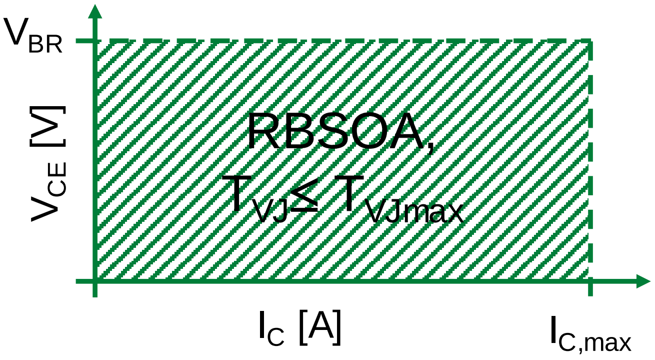
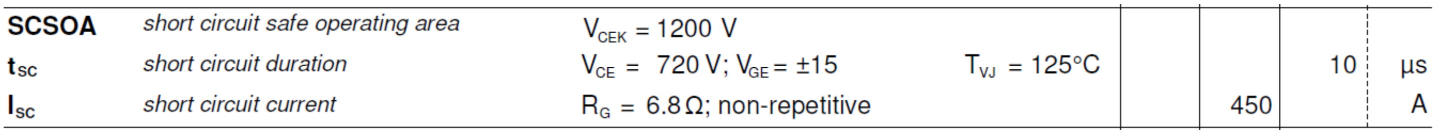


Figure 4. RBSOA-shape, limited by maximum current and breakdown voltage

3. Short-Circuit Safe Operating Area (SCSOA)

Devices that feature desaturation, like most IGBTs, can withstand short-circuit events for a distinct duration. Corresponding datasheets highlight this information as Short Circuit Safe Operating Area or SCSOA. Such a datasheet's excerpt is given in Figure 5.



SCSOA	*short circuit safe operating area*	V_{CEK} = 1200 V					
t_{SC}	*short circuit duration*	V_{CE} = 720 V; V_{GE} = ±15	T_{VJ} = 125°C			10	µs
I_{SC}	*short circuit current*	R_G = 6.8 Ω; non-repetitive			450		A

Figure 5. SCSOA information taken from the MDMA280UB1600PTED datasheet

The short circuit condition demands that the IGBT goes into desaturation. In this mode, no further charge carriers remain available which also limits the current. Typically, IGBTs limit the short-circuit current to about three to four times their rated current. In the example in Figure 5, the 160 A-device is expected to limit the short circuit current to 450 A. This situation is tolerable for 10 µs only and limited by thermal development.

4. Resulting challenges for the designer

Combining the two areas for Reverse Biased Safe Operation and Short Circuit Safe Operation into a single diagram reveals a gap between them, as pictured in Figure 6.

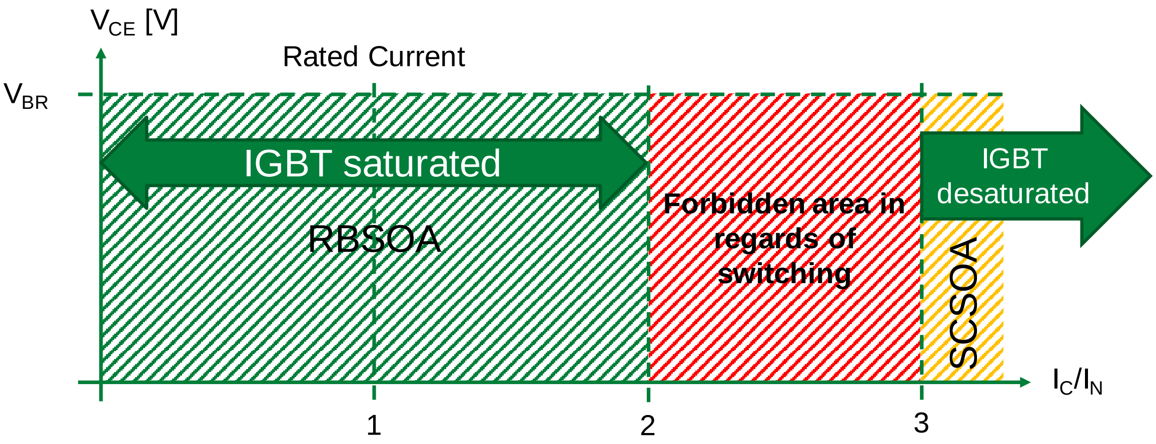


Figure 6. RBSOA, SCSOA, and the undefined region in between

Within the gap marked as forbidden area, located between twice and three times rated current, turning off the device is not allowed as it may lead to its destruction. The root cause of the destruction is found in very high local current densities, transiently forming during switching. The thermal limits in that case are reached already and additional burden due to switching losses leads to exceeding the limits. In turn, single cells on the chip fail and create a connection between collector and emitter. The current can no longer be turned off and the damage grows.

To overcome this situation, techniques to ensure that the IGBT reaches desaturation mode and enters the SCSOA can be used. The simplest way is to wait, instead of reacting on an overcurrent too quickly. Implementing a certain dead-time and fully exploit the 10 µs that the IGBT can withstand the conditions is a valid approach.

Further methods include the so-called 2-Level turn-off. The device is not turned off by immediately cancelling or even reversing the gate-emitter voltage. Instead, the gate-emitter voltage is first reduced to minimize the number of charge carriers available for current transport. This speeds up reaching the desaturation stage. A few microseconds later, when desaturation is reached, the gate-emitter voltage is set to zero or reversed. The device is then safely turned off within the SCSOA-specification.

This fact becomes particularly important when handling overcurrent situations.

From a given setup, measurements from a destructive turn-off event seen in Figure 7 were analyzed:

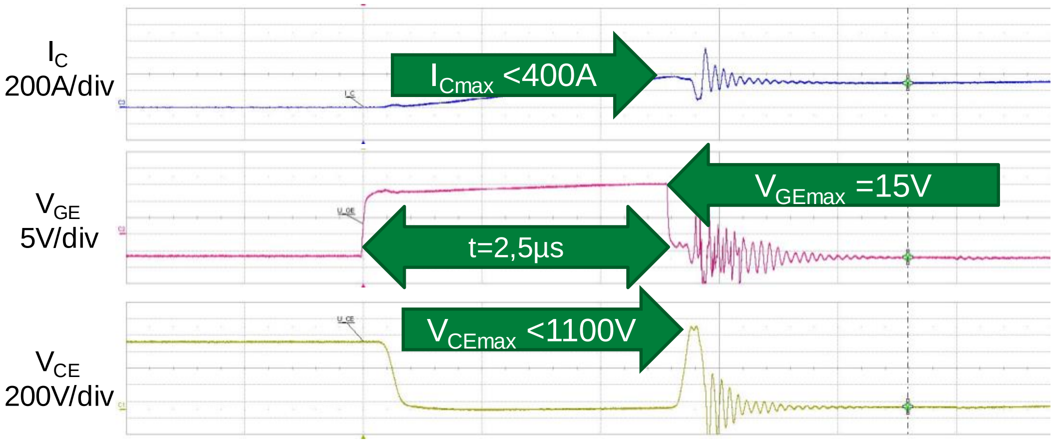


Figure 7. Measurement results from a destructive turn-off event

As the measurement reveals, the current turned off was well below the 450 A short-circuit limit. The gate-emitter-voltage was well-controlled, the time it took to turn off was below the 10 µs-limit and the overvoltage spike did not exceed the 1200 V the device is rated for. Still, the IGBT was destroyed, and the question raised, why so?

Entering the point of the turn-off into the diagram in Figure 6, the violation that happens becomes obvious in Figure 8:

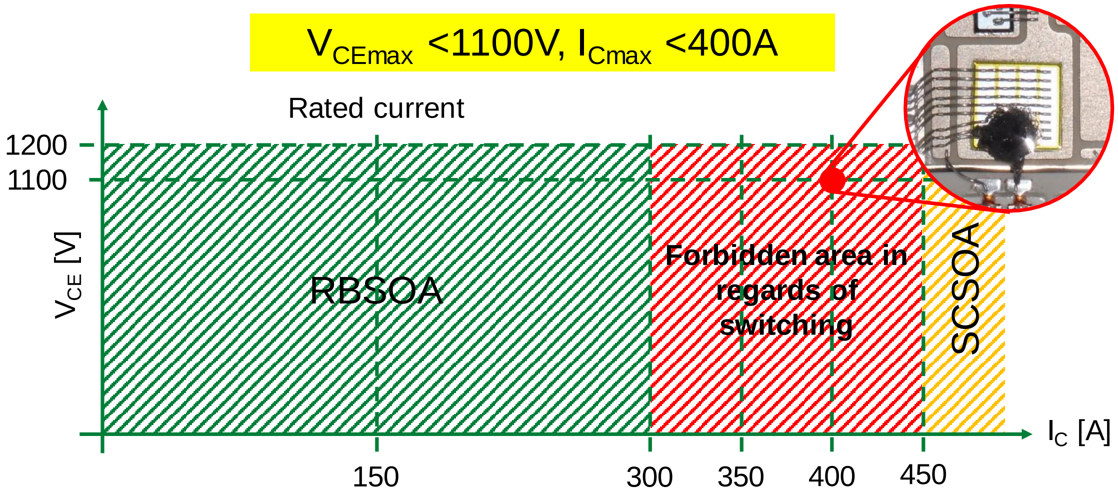


Figure 8. Locating the point of turn-off

Clearly, the switching event was done within the no-go-area with the destructive effect previously predicted.

To clear the situation, the control strategy for short circuit was changed. Instead of reacting on the overcurrent signal instantly and turn off after just 2.5 µs, a blanking time of about 6 µs was added.

Figure 9 represents the measurement done in the same setup.

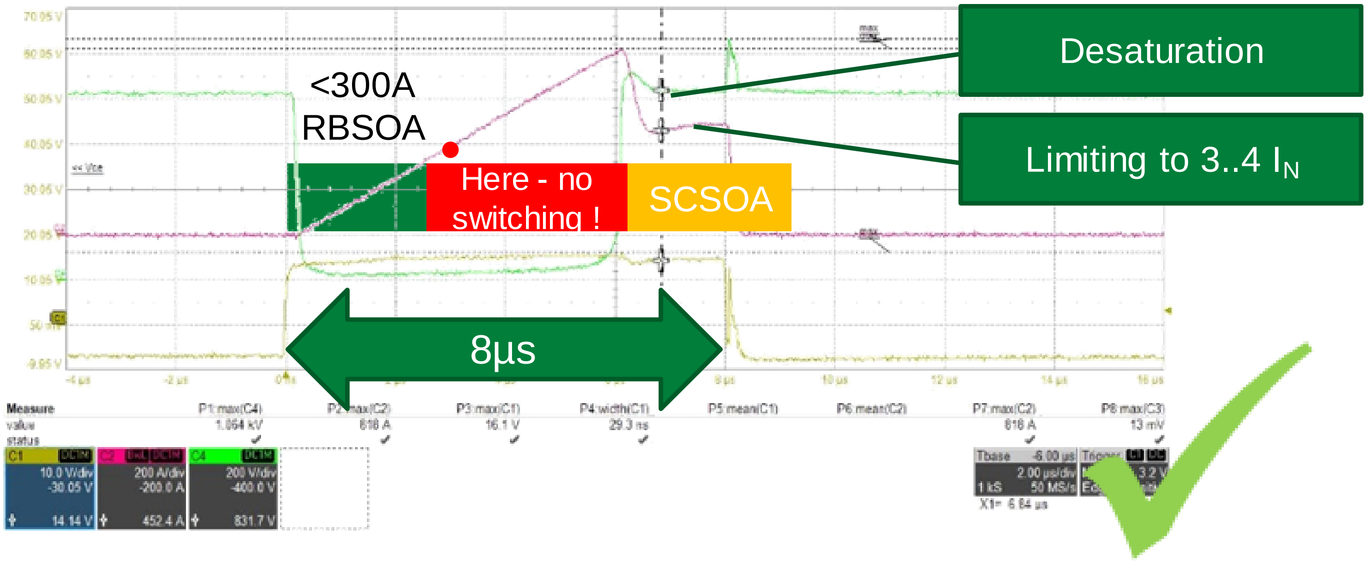


Figure 9. Properly turned off overcurrent or short-circuit event

While the red dot marks the former turn-off point, the current is now allowed to grow further. At first sight, this seems to worsen the situation as the losses and, as such, the chip temperature grows. However, after about 6 µs the IGBT reaches desaturation, enters the SCSOA and the turn-off after 8 µs is safely done without damaging the component.

MOSFETs, other than IGBTs, don’t feature a dedicated SCSOA. At high currents, the MOSFET goes into linear operation as depicted in the FBSOA-diagram, so short-circuit and overcurrent events are covered by diagrams as given in Figure 2.

5. Conclusion

Handling overcurrent events, especially short circuit events, is challenging but manageable. Doing so while remaining within the given specifications can successfully be achieved.

Simply turning off a detected overcurrent as fast as possible may not be the best strategy as it may lead to damage caused by so-called RBSOA-exceedance. Ensuring that the IGBT reaches desaturation is a key factor in handling short circuit events with this technology.

For additional information please visit www.Littelfuse.com/powersemi

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