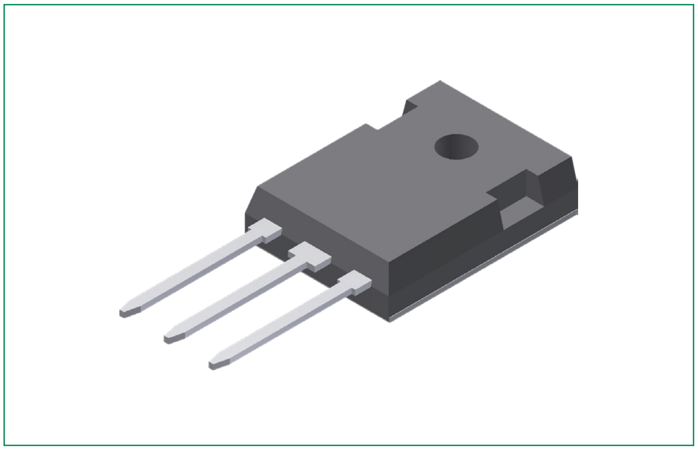
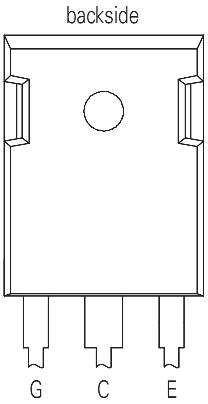
IXYH40N120B4H1

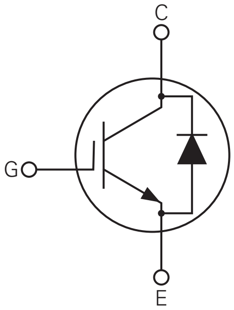
1200 V, 40 A XPT™ Gen4 IGBT with Sonic Diode

Extreme Light Punch Through IGBT for 5–30 kHz Switching



Pinout Diagram (TO-247-3L)





G: Gate; **C:** Collector; **E:** Emitter; **backside:** Collector

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 5–30 kHz Switching
- Positive Thermal Coefficient of $V_{CE(sat)}$
- International Standard Package
- High Current Handling Capability
- High Power Density
- Low Gate Drive Requirement
- Anti-Parallel Sonic Diode

Applications:

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

Product Summary

Characteristic	Value	Unit
V_{CES}	1200	V
I_{C110}	40	A
$V_{CE(sat)}$	2.10	V
$t_{fi(typ)}$	110	ns

Revised: XZ 04/19/2023

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	112	A
I_{C110}	Continuous Collector Current	T_C = 110°C	40	A
I_{F110}	Diode Forward Current	T_C = 110°C	32	A
I_{CM}	Pulsed Collector Current	T_C = 25°C, 1 ms	240	A
SSOA (RBSOA)	Switching Safe Operating Area (Reverse Biased Safe Operating Area)	V_{GE} = 15 V, T_{VJ} = 150°C, R_G = 5 Ω, Clamped Inductive Load, $I_{CM} = V_{CE} \leq 0.8 \times V_{CES}$	80	A
P_C	Collector Power Dissipation	T_C = 25°C	600	W
T_J	Junction Temperature	–	-55 to 175	°C
T_{JM}	Maximum Junction Temperature	–	175	°C
T_{stg}	Storage Temperature	–	-55 to 175	°C
T_L	Lead Temperature for Soldering	1.6 mm (0.062 in.) from Case for 10 s	300	°C
M_d	Mounting Torque	–	1.13 / 10	Nm/lb.in
W	Weight	–	6	g

Thermal Characteristics

Symbol	Characteristic	Value			Unit
		Min.	Typ.	Max.	
$R_{th,\ JC}$	Thermal Resistance, junction-to-case	–	–	0.25	°C/W
$R_{th,\ CS}$	Thermal Resistance, case-to-heat sink	–	0.21	–	°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 = 250 µA, $V_{CE} = V_{GE}$	4.0	–	6.5	V
I_{GES}	Gate-Emitter Leakage Current	V_{CE} = 0 V, V_{GE} = ±20 V	–	–	±100	nA
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	–	–	5	mA
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage[1]	I_C = 32 A, V_{GE} = 15 V	–	1.8	2.1	V
		I_C = 32 A, V_{GE} = 15 V, T_J = 150°C	–	2.1	–	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 = 32 A, V_{CE} = 10 V		12	22	–	S
C_{ies}	Input Capacitance	V_{GE} = 0 V, V_{CE} = 25 V, f = 1 MHz		–	1670	–	pF
C_{oes}	Output Capacitance			–	165	–	
C_{res}	Reverse Transfer Capacitance			–	60	–	
$Q_{g(on)}$	Total Gate Charge	V_{GE} = 15 V, V_{CE} = 0.5 x $V_{CES,}$ I_C = 32 A		–	94	–	nC
Q_{ge}	Gate-Emitter Charge			–	15	–	
Q_{gc}	Gate-Collector Charge			–	40	–	
$t_{d(on)}$	Turn-on Delay Time[2]	Inductive Load, V_{GE} = 15 V, V_{CE} = 0.8 x V_{CES}, I_C = 32 A, $R_{G(ext)}$ = 5 Ω	T_J = 25°C	–	19	–	ns
			T_J = 150°C	–	16	–	
t_{ri}	Turn-on Rise Time[2]		T_J = 25°C	–	53	–	ns
			T_J = 150°C	–	47	–	
E_{on}	Turn-on Energy[2]		T_J = 25°C	–	5.9	–	mJ
			T_J = 150°C	–	8.9	–	
$t_{d(off)}$	Turn-off Delay Time[2]		T_J = 25°C	–	220	–	ns
			T_J = 150°C	–	300	–	
t_{fi}	Turn-off Fall Time[2]		T_J = 25°C	–	110	–	ns
			T_J = 150°C	–	190	–	
E_{off}	Turn-off Energy[2]		T_J = 25°C	–	2.9	–	mJ
			T_J = 150°C	–	4.4	–	

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 = 32 A, V_{GE} = 0 V	–	2.2	2.8	V
		I_F = 32 A, V_{GE} = 0 V, T_J = 125°C	–	2.7	–	
I_{RM}	Reverse Recovery Current	I_F = 32 A, V_{GE} = 0 V, T_J = 125°C -di_F/dt= 400 A/μs, V_R = 600 V	–	23	–	A
t_{rr}	Reverse Recovery Time		–	430	–	ns
$R_{th, JC}$	Thermal Resistance, junction-to-case	–	–	–	0.35	°C/W

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

Characteristic Curves

Fig. 1. Output Characteristics @ T_J = 25°C

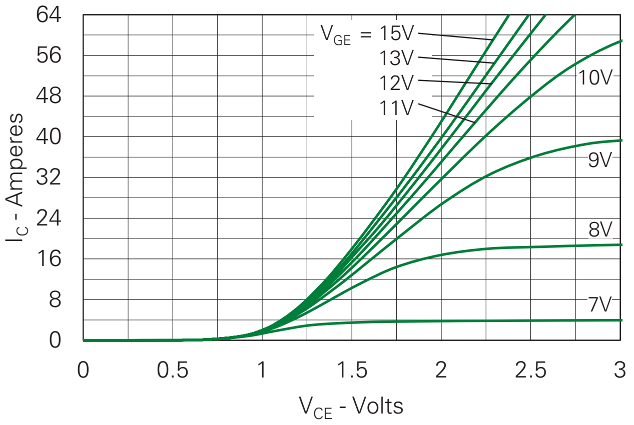


Fig. 2. Extended Output Characteristics @ T_J = 25°C

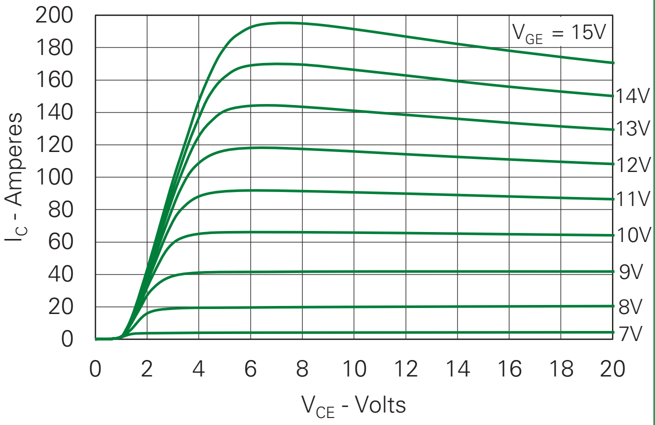


Fig. 3. Output Characteristics @ T_J = 150°C

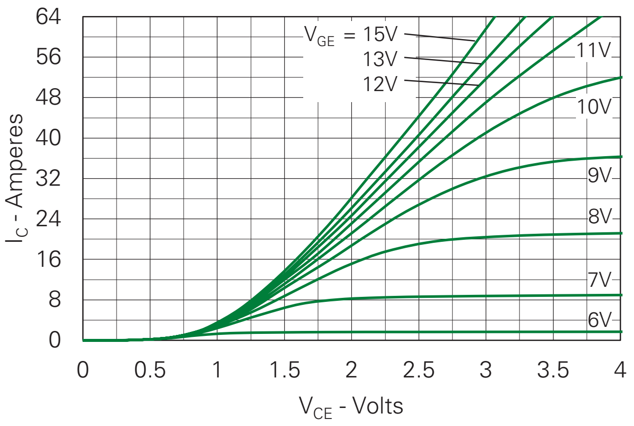


Fig. 4. Dependence of $V_{CE(sat)}$ on Junction Temperature

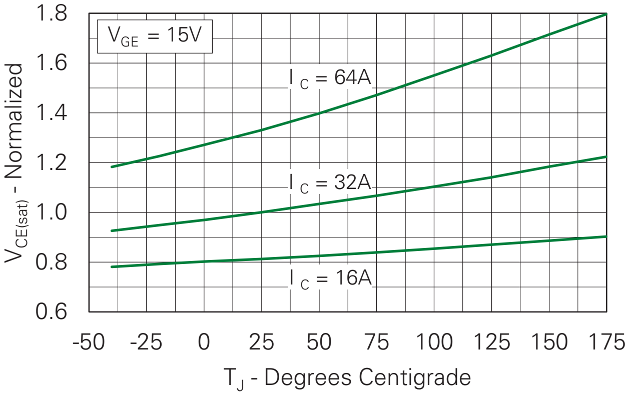


Fig. 5. Collector-to-Emitter Voltage vs. Gate-to-Emitter Voltage

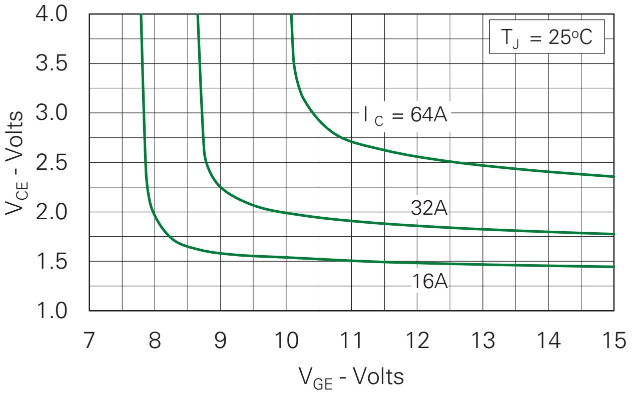
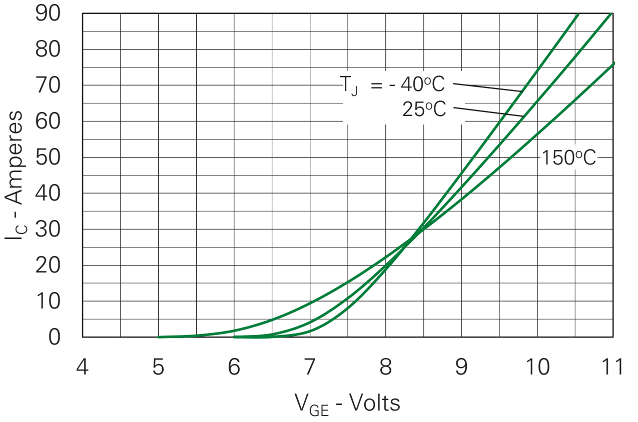
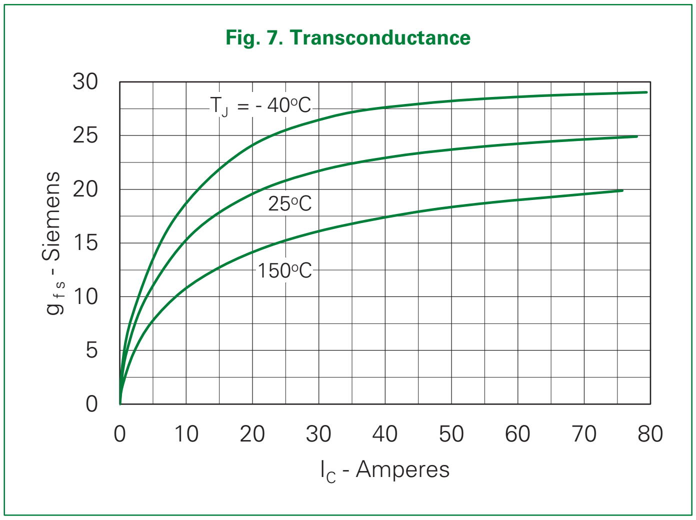
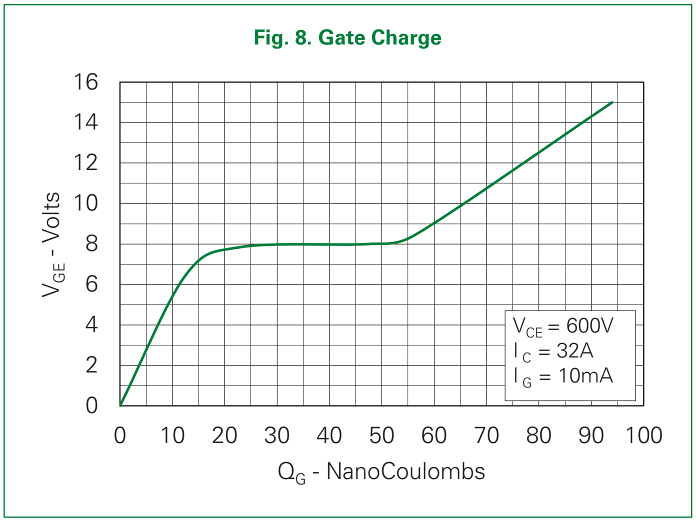
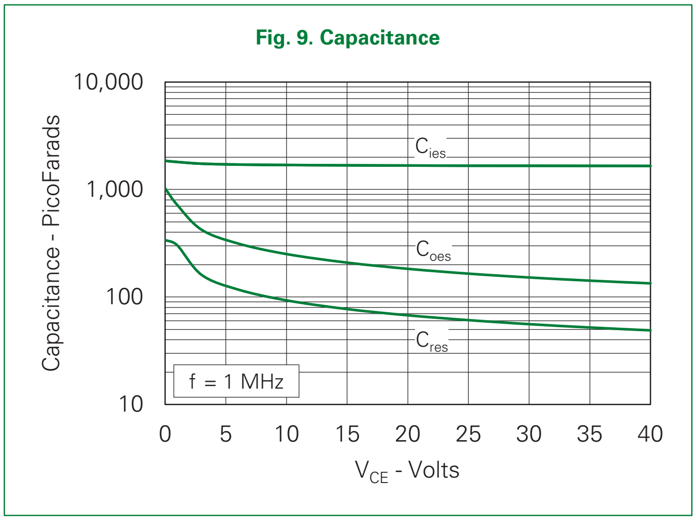


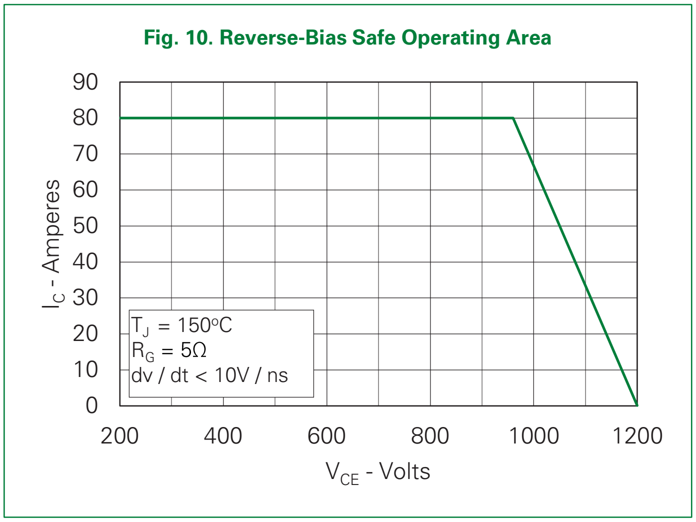
Fig. 6. Input Admittance

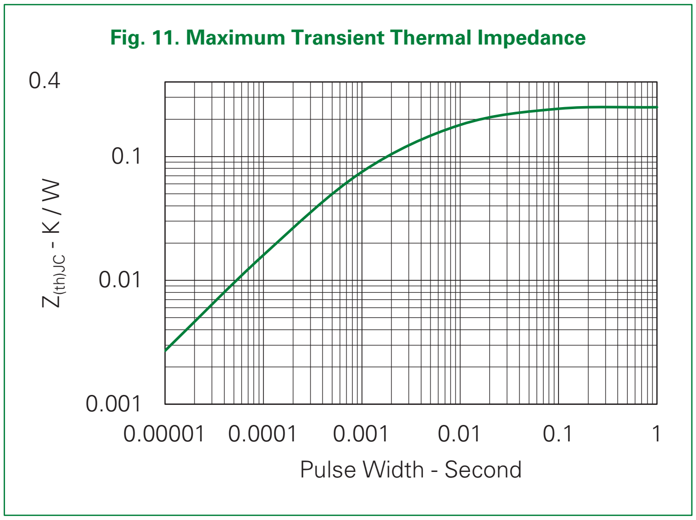


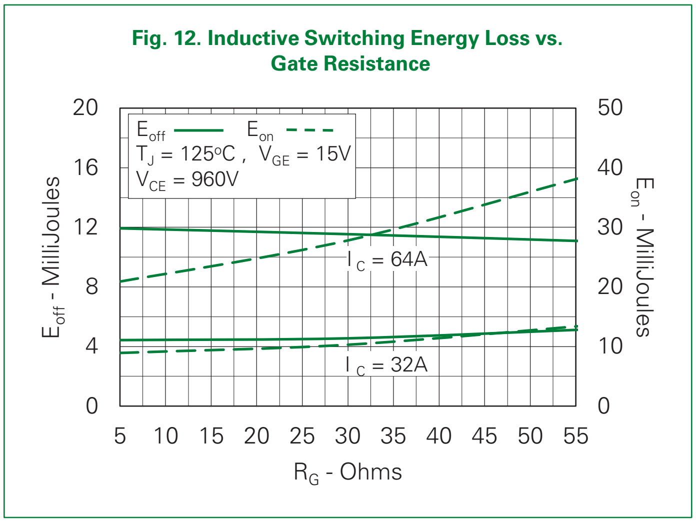












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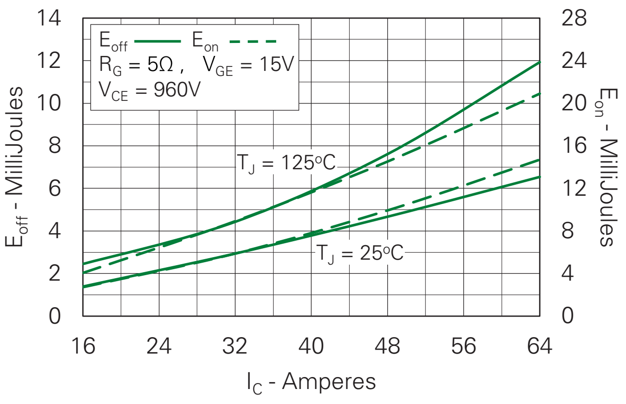


Fig. 13. Inductive Switching Energy Loss vs. Collector Current

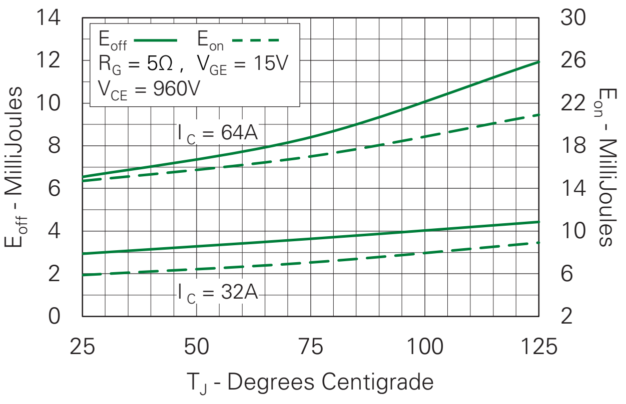


Fig. 14. Inductive Switching Energy Loss vs. Junction Temperature

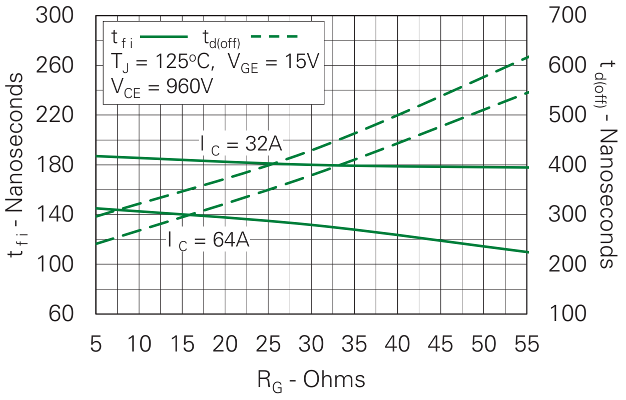


Fig. 15. Inductive Turn-off Switching Times vs. Gate Resistance

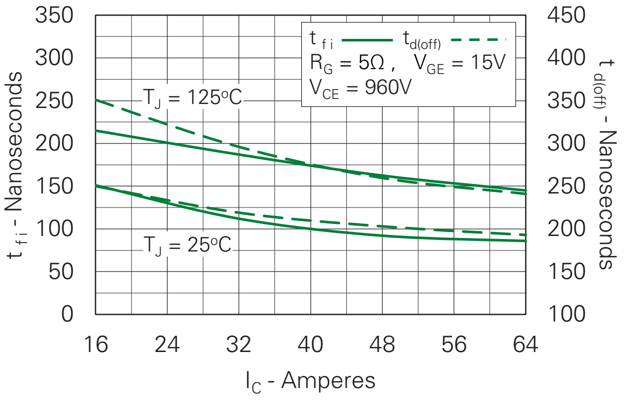


Fig. 16. Inductive Turn-off Switching Times vs. Collector Current

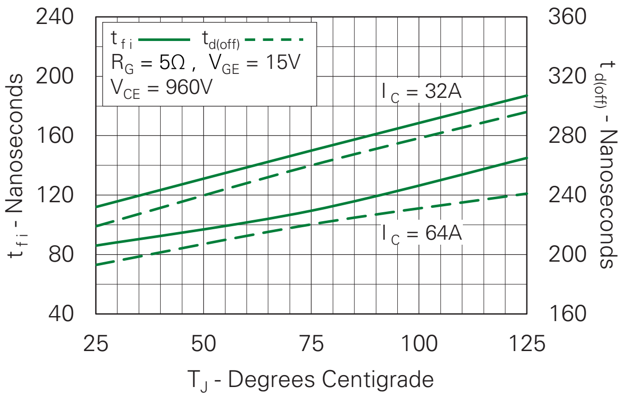


Fig. 17. Inductive Turn-off Switching Times vs. Junction Temperature

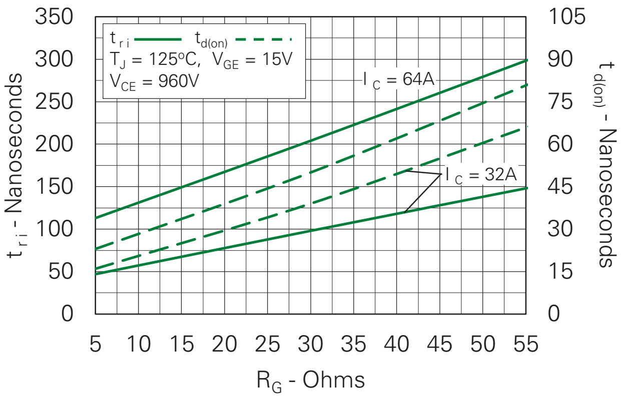


Fig. 18. Inductive Turn-on Switching Times vs. Gate Resistance

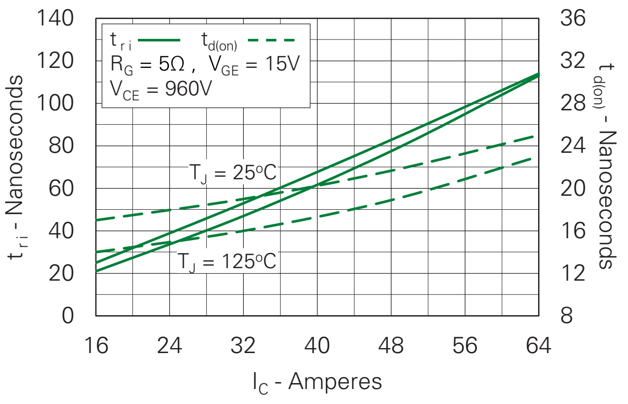


Fig. 19. Inductive Turn-on Switching Times vs. Collector Current

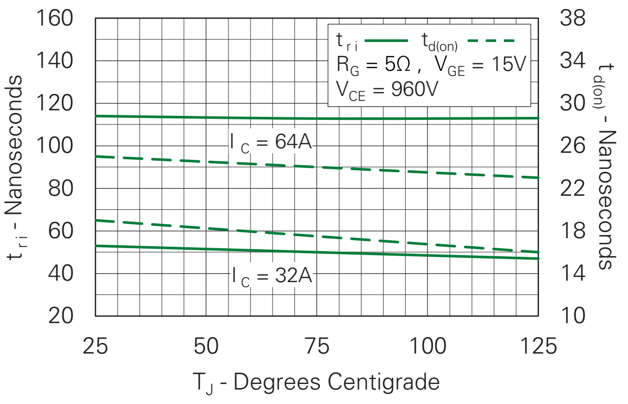


Fig. 20. Inductive Turn-on Switching Times vs. Junction Temperature

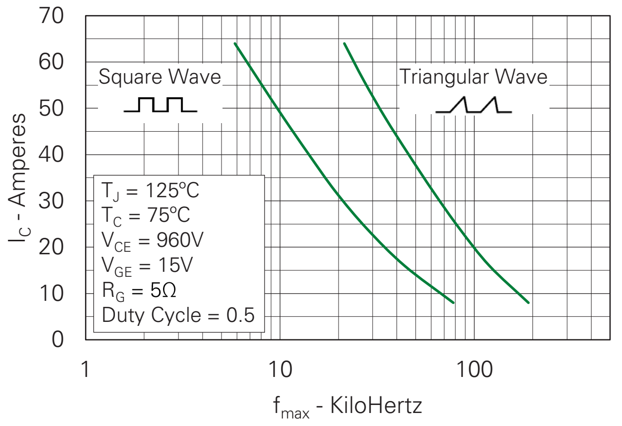


Fig. 21. Maximum Peak Load Current vs. Frequency

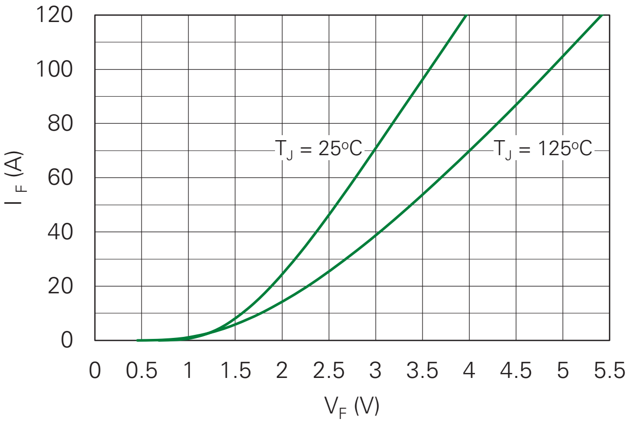


Fig. 22. Diode Forward Characteristics

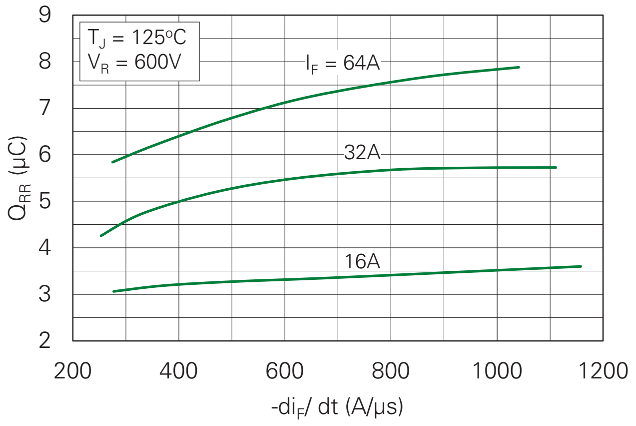


Fig. 23. Reverse Recovery Charge vs. $-di_F/dt$

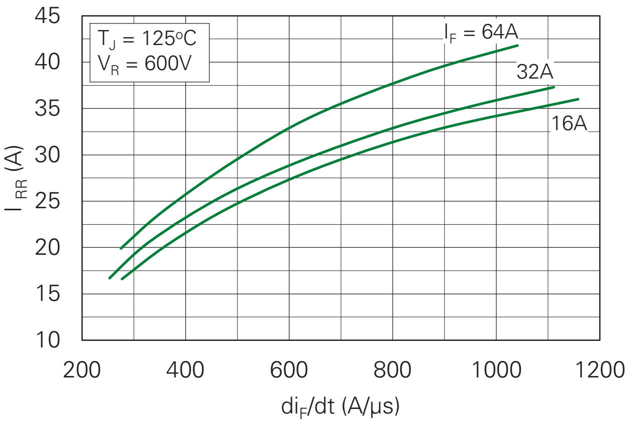


Fig. 24 Reverse Recovery Current vs. $-di_F/dt$

Fig. 25. Reverse Recovery Time vs. -di$_F$/dt

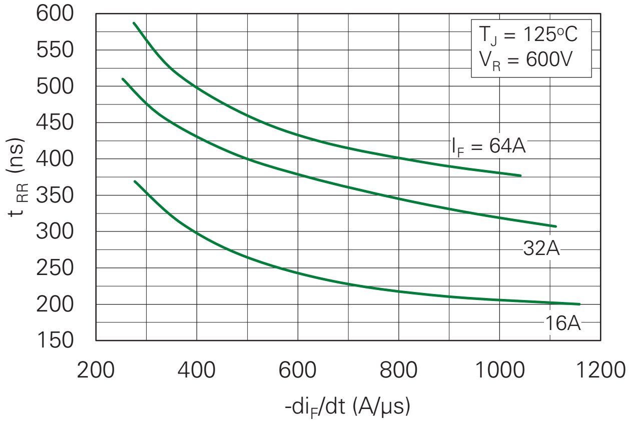


Fig. 26. Dynamic Parameters Q_{RR}, I_{RR} vs. Junction Temperature

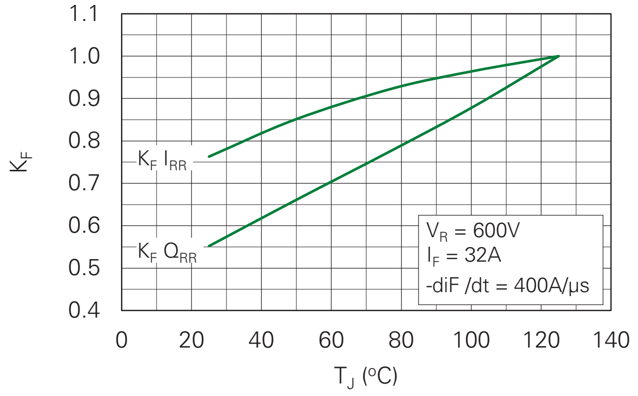
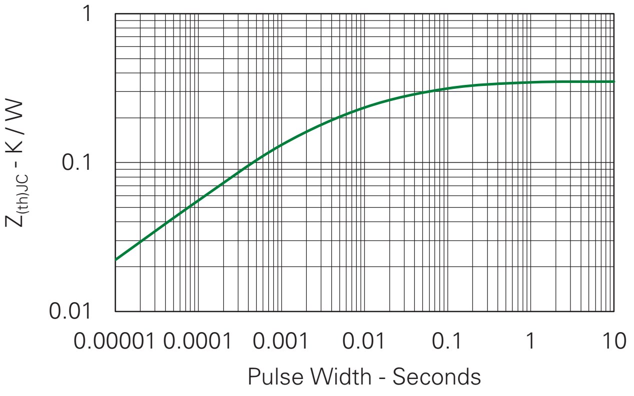
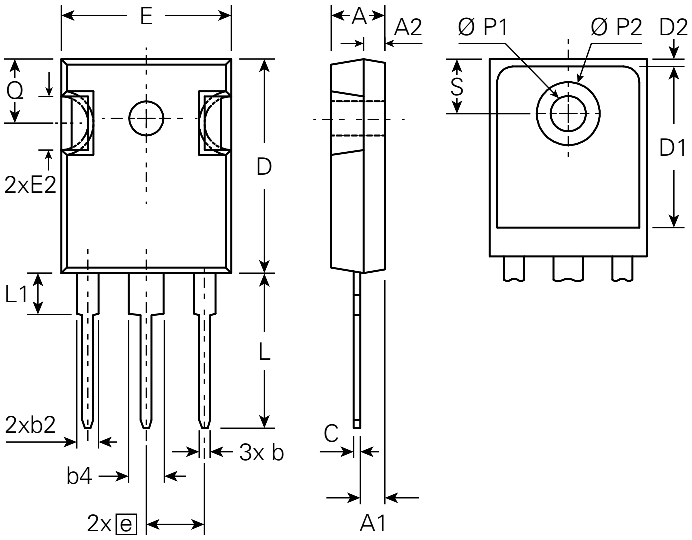


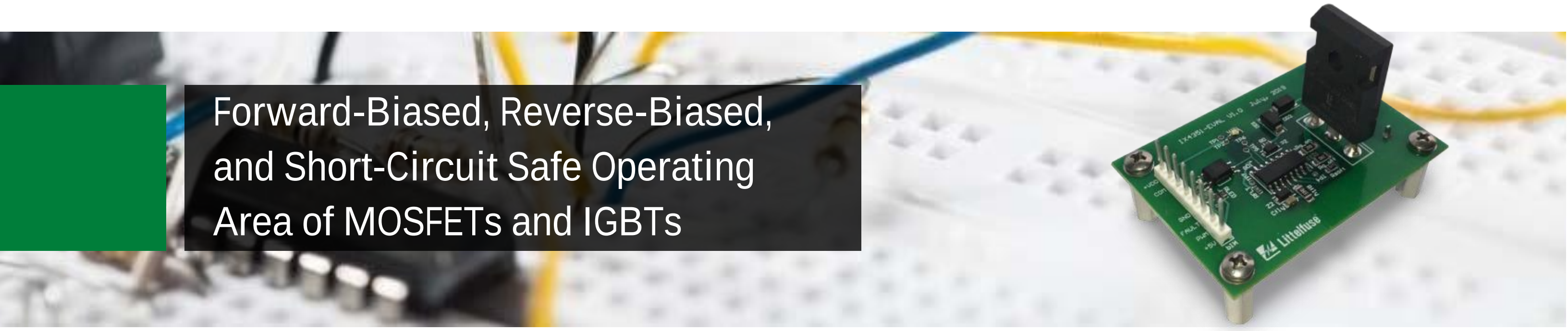
Fig. 27. Maximum Transient Thermal Impedance (Diode)



Part Outline Drawing (TO-247-3L)



Symbol	Inches			Millimeters		
	Min.	**Typical**	**Max.**	**Min.**	**Typical**	**Max**
A	0.185	–	0.209	4.70	–	5.30
A1	0.087	–	0.102	2.21	–	2.59
A2	0.059	–	0.098	1.50	–	2.49
b	0.039	–	0.055	0.99	–	1.40
b2	0.065	–	0.094	1.65	–	2.39
b4	0.102	–	0.135	2.59	–	3.43
c	0.015	–	0.035	0.38	–	0.89
D	0.819	–	0.844	20.79	–	21.45
D1	0.515	–	–	13.07	–	–
D2	0.020	–	0.053	0.51	–	1.35
E	0.609	–	0.639	15.48	–	16.24
E1	0.530	–	–	13.45	–	–
E2	0.170	–	0.216	4.31	–	5.48
e	0.215 BSC			5.45 BSC		
L	0.780	–	0.799	19.80	–	20.30
L1	–	–	0.177	–	–	4.49
Ø P1	0.140	–	0.144	3.55	–	3.65
Ø P2	–	–	0.291	-	–	7.39
Q	0.212	–	0.244	5.38	–	6.19
S	0.242 BSC			6.14 BSC		



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).

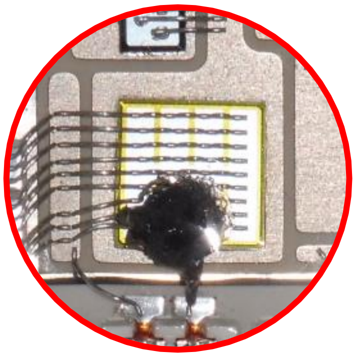


Figure 1. To be prevented – an IGBT destroyed by RBSOA-exceedance

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

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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.

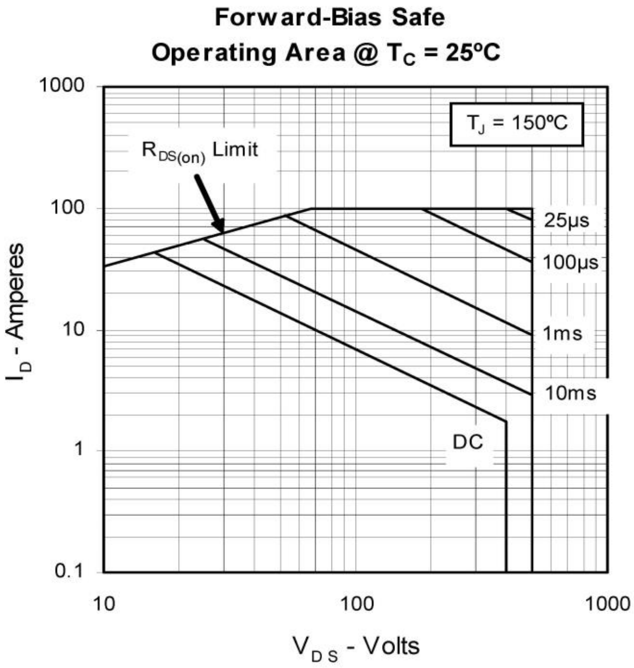


Figure 2. SOA Diagram for the IXTX46N50L

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.

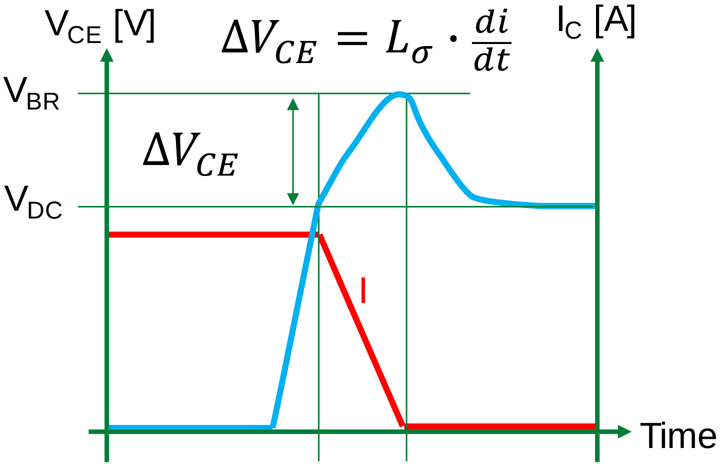


Figure 3. Voltage and current waveforms during a turn-off event

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.

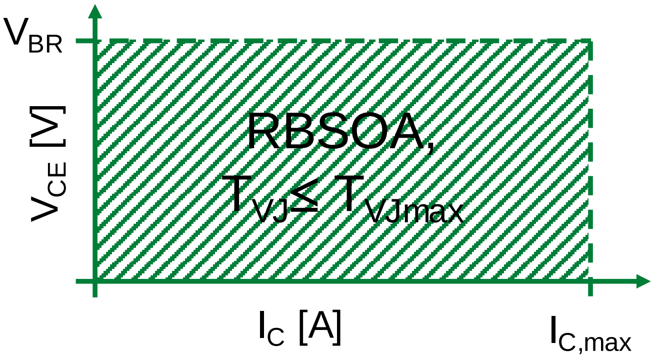
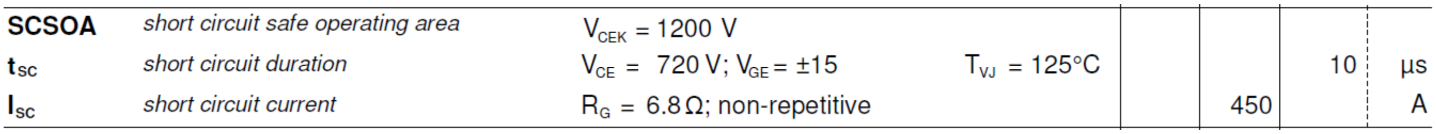


Figure 4. RBSOA-shape, limited by maximum current and breakdown voltage

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.

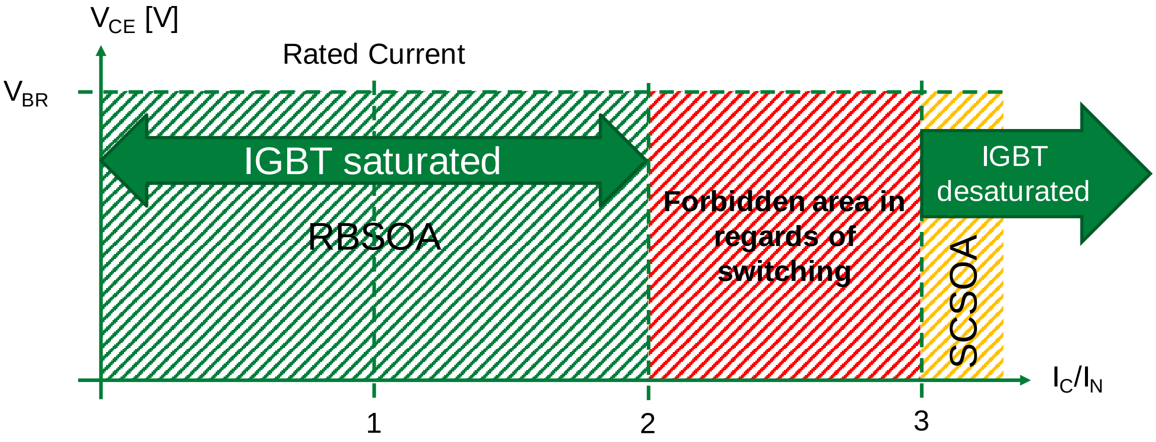


Figure 6. RBSOA, SCSOA, and the undefined region in between

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:

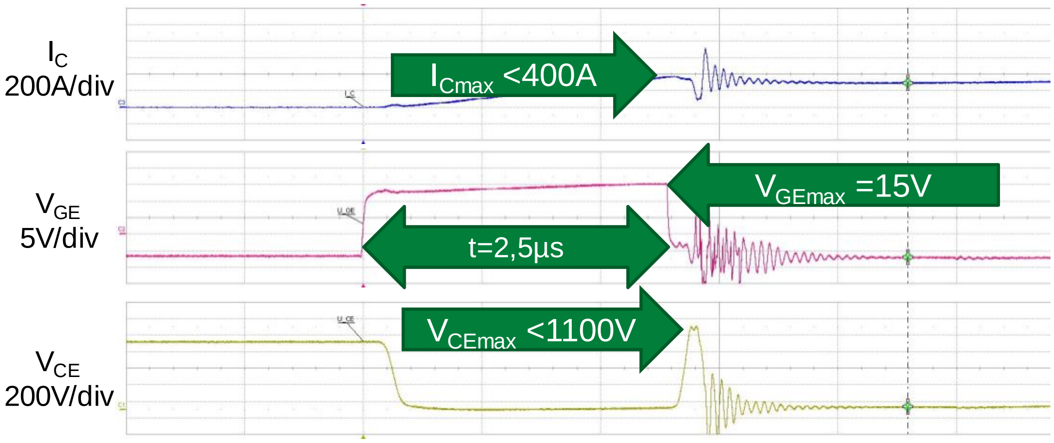


Figure 7. Measurement results from a destructive turn-off event

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:

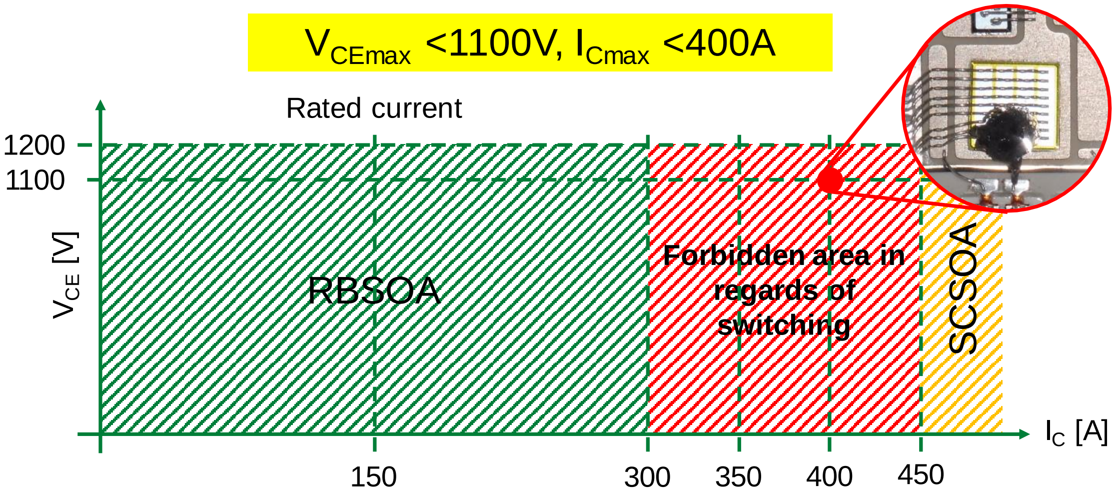


Figure 8. Locating the point of turn-off

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.

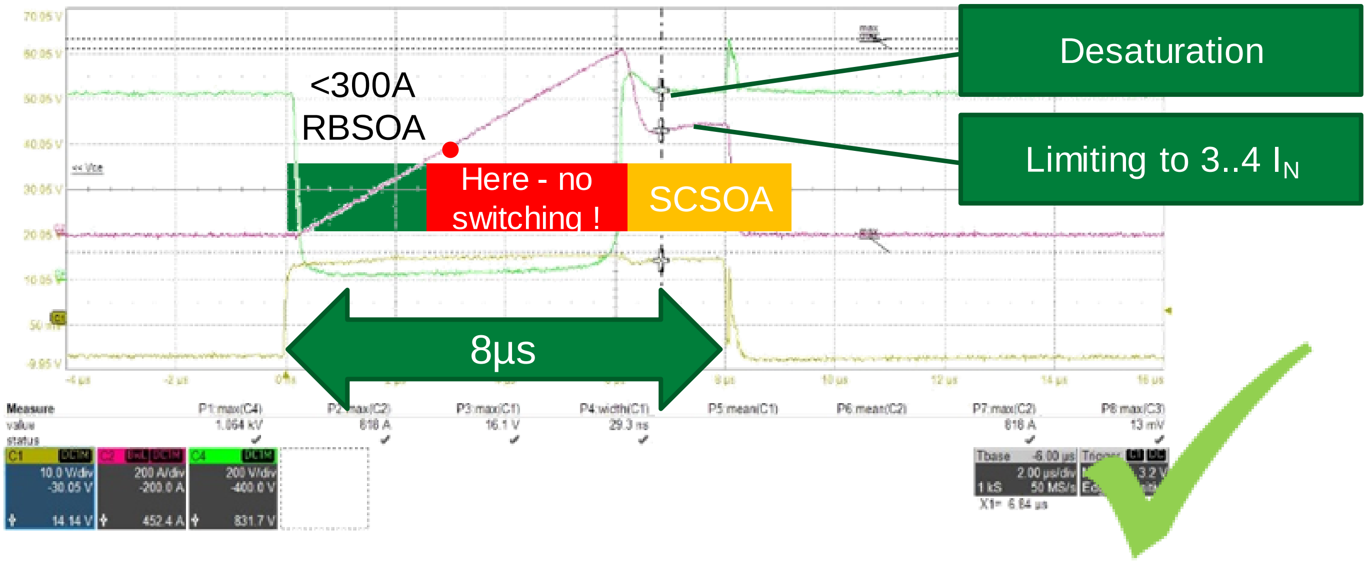


Figure 9. Properly turned off overcurrent or short-circuit event

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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