Discrete 600V GenX3 XPT IGBTs

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1. Introduction

Engineers who design power conversion systems with discrete IGBTs usually select devices on the basis of performance and cost. Their emphasis is often on voltage ratings, packages, thermal performance data (TJM, RthJC and ZthJC), the device's parameters (VCE (sat), Eon, Eoff) associated with power loss, and sometimes the SCSOA rating (usually for motor drive circuits). However, other factors such as cooling, reliable performance in the field, the total cost of the designing the board and the driving and protection of devices within applications, are frequently overlooked in the initial selection process.

During the last 3-4 years (this publication having been written in November 2011), several manufacturers of power semiconductors introduced extremely efficient "Trench Field Stop" IGBTs. These IGBTs allow significant improvements in efficiency, because conduction and switching losses are greatly reduced in comparison to the industry offerings of a few years ago. Unfortunately, these improvements came with increased gate charge, reduced peak gate voltage, a reduced SCSOA rating, and more. Application scopes are limited for these new devices when considering the costs of protecting IGBTs, driving them with high gate currents, applying meticulous attention to eliminating parasitic inductance in real-life circuits, and adding snubber circuits.

Experienced engineers know that very serious material losses can occur if IGBTs are not rugged enough or not properly protected from overstress. Extended overtemperature and electrical overstress protection should be factored into the total cost of power conversion systems that will require many years of reliable operation.

To address the market demand for robust, high-efficiency, easy-to-drive discrete IGBTs, IXYS Corporation developed a family of planar 600V X-XPT (eXtremely rugged eXtremely light Punch Through) IGBTs which we refer to as *GenX3 IGBTs*. The design of our GenX3 IGBTs comes from an understanding of the mechanisms of various stresses that cause early device failures. These 600V IGBTs are intended for applications requiring both high efficiency and ruggedness.

2. Ruggedness, Reliability and Peace of Mind

As they relate to ruggedness and ease of use, the common features of the 600V GenX3 IGBTs are:

- Maximum junction temperature T_{JM}=175 °C, low R_{thJC} and high P_C rating.
- Square (600V at 150 °C) Reverse Bias Safe Operating Area (RBSOA), self clamping capability – devices are rated and 100% tested for significant avalanche energy in Unclamped Inductive Switching (UIS).
- 10 µs Short Circuit Safe Operating Area (SCSOA) at 150 °C and 360V and wide Forward Bias Safe Operating Area (FBSOA).
- Positive $dV_{CE(sat)}/dT$ and tight distribution of parameters ($V_{GE(th)}$, $V_{CE(sat)}$)
- Low gate charge and low input capacitance in Off and On states.
- Low ratio of C_{res}/C_{ies}, relatively high gate on voltage even at high temperatures and low intrinsic gate resistance.

To offer perspective on a group by group basis, let us highlight how these features boost power conversion circuit efficiency, affect the reduction of total cost, and increase the reliability of the solution when using very robust IXYS GenX3 XPT IGBTs.

- IXYS recommends designers using these IGBTs at below 175°C, which is the maximum temperature rating of the chip. If the junction temperature (T_J) increases and sustains at the maximum temperature over a long time, the designer can expect irreversible changes in the encapsulating epoxy of the discrete packages. The significance of this 175°C temperature rating is the ability for the chip to survive short bursts of power which bring T_J close to its maximum 175°C value. This high temperature, together with the low thermal resistance ratings obtained as a result of thin chip technology, allow the chips to dissipate excessive heat into the base of the power package.

- The wide RBSOA and the self-clamping ability of these IGBTs add a high level of endurance against collector-emitter (C-E) voltage spikes that exceed the BV_{CES} rating. This RBSOA and self-clamping ruggedness is related to the *turn-off* of the high collector current with the inductive load (i.e., the stray inductance between collector and voltage clamp) and the forward recovery of freewheeling diodes in H-bridge circuits. Viewed practically, this ruggedness allows these IGBTs to be used at higher rail voltage at a higher dI_C/dt. This ruggedness translates, then, into the ability of these devices to operate at higher switching frequencies, higher collector current and higher overvoltage stress, and eliminates the need for snubber circuits to protect IGBTs from overvoltage.

- An extended SCSOA gives designers additional freedom of selection and timing of the overcurrent protection circuit due to potential short circuit events that can occur in the case of stalled motor drive rotors and/or other power converter circuits. The example circuit is shown in Figure 1 shows a load placed between the IGBT collector and the DC voltage (V_{CS}) source. When this load is shorted, V_{CE} is connected to the IGBT collector, causing the collector current to rapidly rise.

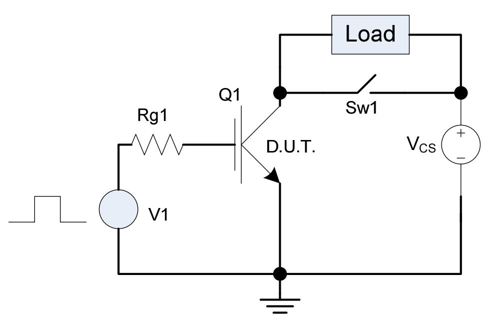

Figure 1. Short-Circuit IGBT Operation

As time passes, the temperature of the device will rise due to power loss. It is therefore desirable for the IGBT to withstand high current flows under this condition while also supporting high collector voltage. The key to survivability for the IGBT in this case is to hold this high current under short-circuit conditions for a period of time that is sufficiently long to allow the control circuit to detect a fault and turn the device off. A 10 µs rating for SCSOA at 600V for GenX3 IGBTs is very conservative, because most modern overcurrent protection solutions that detect SC events turn off the IGBT within 5 µs. As a result, this 10 µs rating can allow for the use of less advanced solutions, and therefore offer extra peace of mind. The actual capability of these IGBTs exceeds 20 µs, which explains why IXYS decided not to define a limit on the number of short circuit events that may occur over the lifetime of the IGBTs. The short-circuit current of our GenX3 IGBTs is much lower than that of *Trench Field Stop* IGBTs, and we do not expect damage to our IGBTs even after many tens of thousands of events. The extended FBSOA capability of these IGBTs can be a critical survival factor in the case of external events that can cause reduction of the gate drive voltage supply during system start-up or due to failures of other circuit components.

- A positive $dV_{CE(sat)}/dT$ and a tight distribution of parameters allow for easy paralleling of these GenX3 IGBTs. However, please note that the paralleling of IGBTs co-packed with Fast Recovery Diodes requires special consideration, even the matching of diodes in some cases. GenX3 IGBTs co-packed with Sonic diodes (which display an H1 suffix in their part numbers) can be paralleled with minimal effort due to the fact that the Sonic diodes' dV_F/dT becomes positive at relatively low diode current.

- GenX3 IGBTs exhibit a smaller gate charge Q_G and input capacitance C_{ies} compared to Trench Field Stop IGBTs (see Table 2 for a comparison of these two devices). The smaller values of these parameters reduce switching delay times; as a result, gate drive circuit requirements make the prevention of *shoot through* in high-frequency bridge circuits easier and less expensive, plus decrease the adverse effects of parasitic gate loop inductance.

- The low ratio of Miller (G-C) capacitance to Gate-Emitter capacitance, in combination with relatively high V_{GEth} and low intrinsic gate resistance, provides these devices with excellent immunity against external $dV_{ce}/_{dt}$, and allow IGBT operation in noisy circuits without requiring extreme attention to the protection of the IGBT from parasitic *turn-on*.

IXYS' GenX3 IGBTs are manufactured in our world-class semiconductor factories using proprietary IXYS design processes and manufacturing techniques. Our family of GenX3 IGBT devices is expected to expand in the near future.

3. 600V GenX3 Product Family

GenX3 IGBTs are currently offered in several power ratings and in two speed grades (B- and C-).They are assembled in standard industry packages, in proprietary packages as single IGBTs, and in co-packs with Fast Recovery Diodes. Each grade is balanced for the individual requirements of your application as it relates to dynamic losses, static losses, switching speed, and soft recovery time.

GenX3 IGBTs can be identified in the IXYS catalog by the prefix *IXX* and the suffix *3*. XPT discrete IGBTs are optimized for hard switching applications at 5-30 kHz (B- grade) and 30-60 kHz (C- grade).

Table 1 offers a list of 600V GenX3 IGBTs with I_{C25} current rated at ~ 60A, 100A, 120A, 150A, 160A, 170A, 190A,210A, 340A and 380A. Table 1 also includes the values of $V_{CE(sat)}$, Q_G, t_{fi}, E_{off} and g_{fs}. These devices are available as both single-pack or co-pack with Sonic diodes in standard discrete packages (TO-247, TO-264); they can also be packaged for customer-specific (SMPD) designs. Because of the super-fast recovery characteristics of the Sonic fast recovery diodes (FREDs), the combination of XPT and Sonic diodes yields a new generation of powerful and competitive devices that provide excellent fast switching characteristics.

The IXXH50N60C3D1 is an example of a co-packed IGBT containing a 600V XPT and a Sonic diode integrated in a TO-247 package.

Table 1: Listed GenX3 IGBTs

GenX3 IGBT XPT Part Number	Voltage/ Current @ 25°C	$V_{CE(sat)}$ (V) max	t_{fi} (ns)	E_{off} (mJ)	Q_G (nC)	g_{fs} (typ) (S)	Package Type
IXXH30N60C3D1	600V/60A	2.2V @ I_C =24A	32	0.45	37	14	Co-pack, TO- 247
IXXH30N60B3D1	600V/60A	1.85V @ I_C =24A	125	0.80	39	14	Co-pack, TO- 247
IXXH30N60B3	600V/60A	1.85V @ I_C =24A	125	0.80	39	14	Single, TO- 247
IXXH50N60C3	600V/100A	2.3V @ I_C =36A	42	0.33	64	18	Single, TO-247
IXXH50N60C3D1	600V/100A	2.3V @ I_C =36A	42	0.33	64	18	Co-pack, TO-247
IXXH50N60B3	600V/120A	1.8V @ I_C =36A	135	0.74	70	19	Single, TO-247
IXXH50N60B3D1	600V/120A	1.8V @ I_C =36A	135	0.74	70	19	Co-pack, TO-247
IXXH75N60B3	600V/160A	1.85V @ I_C =60A	125	2.1	107	32	Single, TO- 247
IXXH75N60B3D1	600V/160A	1.85V @ I_C =60A	125	2.1	107	32	Co-pack, TO- 247
IXXH75N60C3	600V/150A	2.20V @ I_C =60A	75	1.40	107	33	Single, TO- 247
IXXH75N60C3D1	600V/150A	2.20V @ I_C =60A	75	1.40	107	33	Co-pack, TO- 247
IXXK100N60C3H1	600V/170A	2.2V @ I_C =70A	75	0.95	150	40	Co-pack, TO-264
IXXX100N60C3H1	600V/170A	2.2V @ I_C =70A	75	0.95	150	40	Co-pack, PLUS 247
IXXH100N60C3	600V/190A	2.2V @ I_C =70A	75	0.95	150	40	Single, TO-247
IXXK100N60B3H1	600V/190A	1.8V @ I_C =70A	150	2.0	143	40	Co-pack, TO-264
IXXH100N60B3	600V/210A	1.8V @ I_C =70A	150	2.0	143	40	Single, TO-247
IXXK200N60B3	600V/380A	1.7V @ I_C =100A	110	2.90	315	45	Single, TO- 264
IXXX200N60B3	600V/380A	1.7V @ I_C =100A	110	2.90	315	45	Single, PLUS247
IXXK200N60C3	600V/340A	2.1V @ I_C =100A	80	1.70	315	35	Single, TO- 264
IXXX200N60C3	600V/340A	2.1V @ I_C =100A	80	1.70	315	35	Single, PLUS247
MMIX1X100N60B3H1	600V/100A	1.80V @ I_C =70A	150	2.80	143	22	SMPD

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4. Comparison to *Trench Field Stop* IGBTs

Table 2 shows a datasheet comparison of IXYS part number IXXH50N60C3D1 to Infineon's TrenchStop IGBT (IKW50N60H3).

Table 2: Comparison of IXXH50N60C3D1 with Infineon IKW50N60H3:

IGBT Part Number	Ratings Volt/Amp at 25C	$V_{CE(sat)}$ Volt	Q_G (nC)	t_{sc} SCSOA (µS)	C_{ies} nC	Ratio of Cgc/Cge	E_{AS} (mJ)
IXXH50N60C3D1 Co-pack (TO-247)	600V/100A	2.3V	64	10	2324	42/2278 = 0.0184	200
IKW50N60H3 Co-pack (TO-247)	600V/100A	2.3V	315	5	2960	96/2864 = 0.0335	--

This table lists voltage and current ratings data for the device, namely $V_{CE(sat)}$, gate charge (Q_G), SCSOA and input capacitance (C_{ies}). Across multiple die sizes, it is evident that these XPT IGBTs are very comparable with the existing Infineon part. For example, the IXXH50N60C3 part shows much lower gate charge – which translates to lower switching losses. High switching speed is determined by the time required to establish voltage changes across input capacitance, in which $C_{ies} = C_{GE}+C_{GC}$. The lower the input capacitance of the device (C_{ies}), the higher the switching speed, due to the decrease in time that it takes to change the voltage. Clearly, the XPT has shown significant performance enhancement in its switching characteristics.

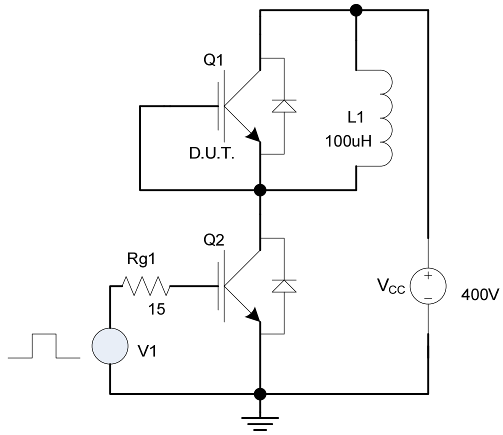
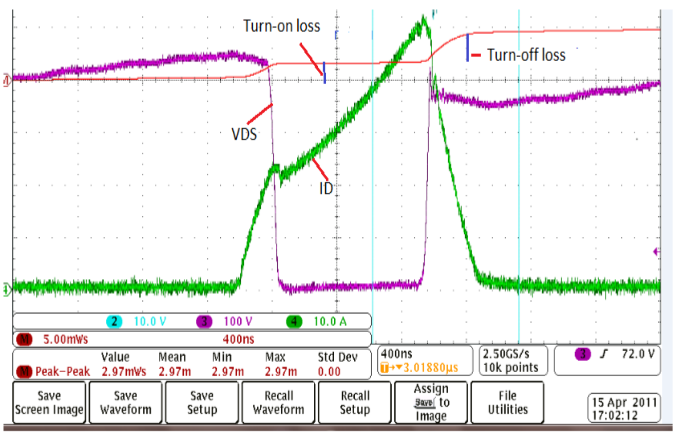


Figure 2A. Inductive Switching Test Circuit



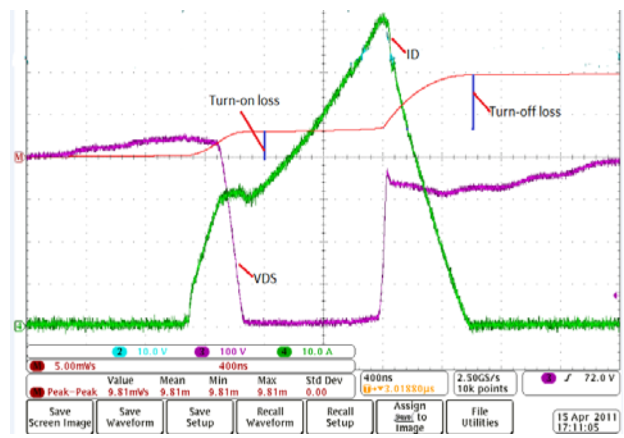


Figure 2B. IXXH50N60C3 Switching Waveforms

Figure 2C. Infineon's IKW50N60H3 Waveforms

Figure 2A shows the simplified inductive load test circuit used for this experiment. Figure 2B and 2C show the corresponding switching waveforms. All tests are operated under the same operating conditions, in which V_{CC}= 400V, I_D = 50A, V_{GS}= 15V and L1= 100μH.

Table 3 shows both the turn-on and turn-off switching parameters for both IGBTs, tested at 25°C and 125°C. At 25°C, the total energy loss for IXXH50N60C3D1 is 1.340 mJ, whereas IKW50N60H3 tests at 1.415mJ. Similarly, at 125 °C, the total energy loss for IXXH50N60C3D1 is 1.915mJ, whereas IKW50N60H3 is 2.270mJ. Under hard inductive switching, these turn-on losses are larger than the turn-off losses, even without considering the significant diode turn-off losses that occur during the IGBT turn on. The turn-on is a major current phenomenon determined by the MOSFET block of the IGBT. For this reason, a fast gate drive can significantly reduce loss. Conversely, the IGBT turn-off characteristics are determined by the stored charge in the drift region of the device; these are estimated by the dV/dt and dI/dt at turn-off and the subsequent current tail that are determined by the rate of charge extraction. The result shows that IXXH50N60C3D1 has better switching performance in comparison with IKW50N60H3.

Table 3: Inductive Load Switching Data for IXXH50N60C3D1 and IKW50N60C3

Test Conditions: Rg = 5 Ohm, V_{CC} = 400V, I_c = 50A, L1~100µH							
Temp: 25°C	**Turn-Off Delay Time**	**Fall Time**	**Turn-On Delay Time**	**Rise Time**	**Turn-Off Energy Loss**	**Turn-On Energy Loss**	**Total Energy Loss**
Part Number	$T_{d(off)}$ (ns)	T_f (ns)	$T_{d(on)}$ (ns)	T_r (ns)	E_{off} (mJ)	E_{on} (mJ)	$E_{o)}+E_{off}$ (mJ)
IXXH50N60C3D1	68	34	28	53	0.43	0.91	1.340
IKW50N60H3	225	30	32	50	0.485	0.93	1.415
Temp: 125°C							
IXXH50N60C3D1	76	30	27	51	0.515	1.4	1.915
IKW50N60H3	242	27	30	41	0.5	1.77	2.270

5. Possible Applications

Selecting the best IGBT for an application can be time-consuming. In a power-switching application, an IGBT that receives high electrical and thermal stress will either short-circuit or experience turn-off switching of its clamped inductive load. The short-circuit performance (SCSOA) determines forward-biased SOA (FBSOA) capability, while turn-off at clamped inductive load determines reverse-biased SOA (RBSOA) capability. The ability to endure these stresses is one of the important requirements in the IGBT application.

GenX3 IGBTs are optimized to reduce power losses, improve efficiency, reduce system heat sink size and increase the current density in a board assembly. They are targeted for UPS, motor controls, DC-to-AC inverters, welding, renewable energy (solar inverters, wind power systems), smart grid and industrial power management circuits such as medical power systems, DC-to-DC converters, PFC circuits, and lighting power systems.

GenX3 IGBTs are offered in two speed grades (B- and C-) and optimized for hard switching applications at 5-30 kHz (for B- grade) and 30-60 kHz (for C- grade). These new devices can be identified in the IXYS catalog by the prefix *IXX* (see Table 1 for a list of part numbers). You can also search the IXYS website (www.ixys.com); simply enter *IXX* in the **Part Number** text field and click **Go** to display a list of GenX3 XPT part numbers).

6. Recommended Reading

Techniques used in DMOS IGBT construction are described in the following documentation.

- *Method of Making a Stable High Voltage Semiconductor Device*
  US Patent # 5904544, Date of Patent: May 08, 1999
  Inventors: Dr. Nathan Zommer
  IXYS Corporation, Santa Clara, CA
- Patent on Rugged IGBT Structure: *Rugged and Fast Power MOSFET and IGBT*
  US Patent # 20030067034
  Inventors: Dr. Vladimir Tsukanov and Dr. Nathan Zommer
  IXYS Corporation
- *The Optimal IGBT for Motor Drive Applications- Drive With XPT IGBTs*, an IXYS Application Note on XPT IGBTs (this title appeared on Bodo's Power, Europe)
  Application Note # IXAN0070 (visit www.ixys.com and navigate to **IXYS Division** → **IXYS Power** → **Application Notes** by Topics in the Technical Resources section)

- IXYS Technical Paper on XPT IGBTs: *650V XPT IGBTs in an SMPD Package*
  I. Imrie, E. Wysotzki, O. Zschieschang, A. Lashek-Enders
  Bodo's Power, April 20-23, 2011
- TrenchStop-IGBT -Next Generation IGBT for Motor Drive Application
  A TrenchStop-IGBT App Note by Infineon, V1.0, October 2004

A definition of terms related to IGBTs and IGBT test methods can be found here:

- *Insulated Gate Bipolar Transistor (IGBT) Basics*
  IXYS IGBT Basic Application Note # IXAN0063 (visit www.ixys.com and navigate to **IXYS Division** → **IXYS Power** → **Application Notes** by Topics in the Technical Resources section)