High-Speed TRENCHSTOP 5 IGBT

IGBTs are historically known for having long tail currents with focus on drive applications and anything switching up to 30 kHz was known as “High Speed”, where conduction losses were penalized to get switching losses down. In 2008, Infineon launched a ground breaking technology called the HighSpeed3, which is the highest efficiency IGBT capable of switching up to 100 kHz with a MOSFET-like turn-off switching behavior. Now Infineon’s TRENCHSTOP™ 5 technology is capable of switching well beyond 100 kHz. **Mark Thomas, Discrete IGBT Product Marketing, Infineon Technologies AG, Villach, Austria**

The TRENCHSTOP™5 technology is an optimization of the TRENCHSTOP™ concept combining Trench gate and Field Stop structures. In order to minimize total power losses, the chip thickness is reduced to 50 µm and an optimization of the carrier profile has been carried out to provide a reduction of charge carriers within the drift zone that have to be removed during the turn-off phase. These two measures allow for a significant reduction in conduction losses ($V_{CE(sat)}$) and turn-off switching losses (E_{off}). Despite the chip thickness reduction, a 650 V blocking capability is achieved, 50 V higher than the previous generation. Additionally, thanks to a new transistor stripe cell structure the gate charge (Q_g) is reduced and current density is increased.

The combination of all the above mentioned innovations result in an IGBT with the lowest combination of conduction losses ($V_{CE(sat)}$) and total switching losses (E_{ts}), thus producing the highest efficiency IGBT.

TRENCHSTOP 5 is the name for the base technology and from this two device families are being initially released to address different application requirements and fulfill designers’ needs. The designer has the opportunity to select between the HighSpeed5 (H5) and HighSpeed5 Fast (F5) versions. The H5 family is characterized by an optimized field-stop design and is aimed to complement the HighSpeed3 IGBT family; it allows for the “plug-and-play” replacement of IGBTs without any special effort in adjusting the board design. It provides soft voltage rise during hard commutation at turn-off even with low gate resistor (Rg) values and very high di/dt.

The F5 meanwhile, is the extended performance solution. It provides higher efficiency, but more design effort is required to harvest the benefits. The driver stage should be equipped with split turn-on ($R_{g,on}$)/ turn-off ($R_{g,off}$) gate resistors to maximize efficiency and control voltage overshoot during turn-off. It is the best fit for optimized PCB design with low stray inductance both in the commutation loop and packages and used in combination with Silicon Carbide diodes (SiC)

Comparison with Infineon’s HighSpeed3 Technology

Compared to the HighSpeed3 (HS3) family, the TRENCHSTOP 5 shows a significant improvement in all static and dynamic parameters. It provides

* 50 V higher blocking voltage to allow for bus voltage increases without compromising reliability. Also for solar applications, cosmic radiation robustness in increased,
- 250 mV lower conduction losses (Vce(sat)) and a factor of 2 lower turn-on/-off switching losses (Eon and Eoff), resulting in the highest efficiency high speed IGBT ever released,
- drastic reduction of Coss, Cres ensures benchmark light load efficiency,
- 50% reduction in gate charge (Qg) allows for lower power driver ICs to be used without sacrificing performance and enables a system cost reduction.

Mild positive temperature coefficient of the conduction and switching losses mean efficiency is not sacrificed when devices are driven with higher junction temperatures and thermal run away during paralleling is not a problem.

The TRENCHSTOP 5 uses the new Rapid Silicon diode as the free-wheeling diode (FWD), which offers 50 ns reverse recovery time (t_{rr}) and temperature stable forward voltage (V_F). This ensures turn-on losses are minimized and overall efficiency is optimized.

Dynamic behavior

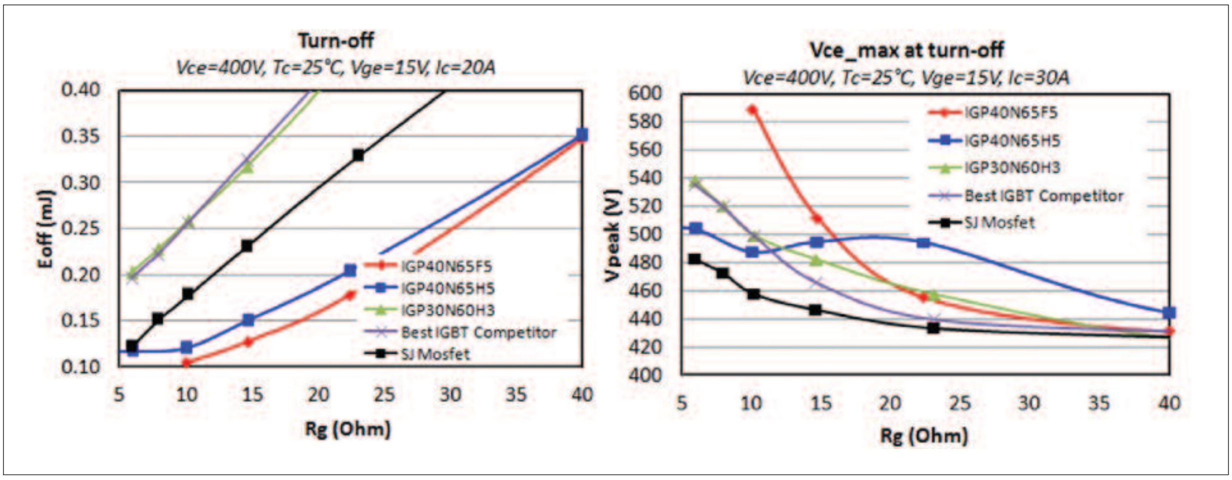
In order to highlight a new technology it is important to explain the gate resistor controllability of the switching behavior. On the left hand side of Figure 1, the turn-off controllability as function of Rg during a standard double pulse test circuit is highlighted, with stray inductance of 45 nH in the commutation loop. The E_{off} curve of both H5 and F5 are drastically lower compared to traditional fast IGBTs, and in the same range of Superjunction MOSFETs at low R_g of 5 Ω.

The right hand plot of Figure 1 shows the collector-emitter voltage at turn-off as function of Rg. The plot helps to underline the difference between H5 and F5, thus the need for the two families. The H5 shows a smooth switching behavior, with voltage overshoot of the same order as the HighSpeed 3. The F5 meanwhile, is characterized by higher voltage overshoot at turn-off, but exhibits higher efficiency. The typical waveforms are also shown in Figure 2, where the F5 shows much faster current drop during turn off, translating unavoidably in higher voltage overshoot (L*di/dt).

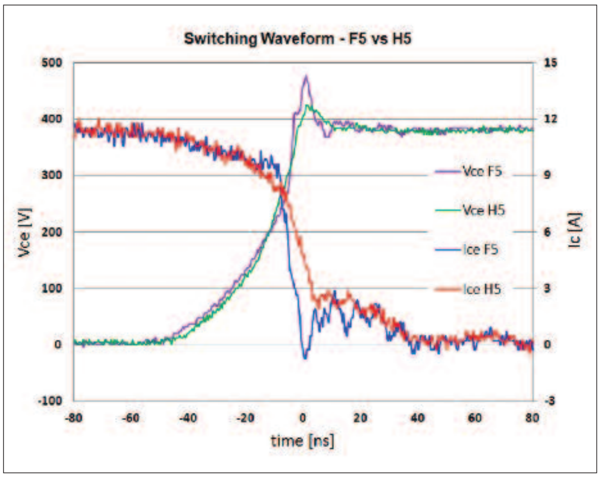
Figure 3 shows the relationship between the turn-on losses (E_{on}) and turn-on gate resistor value ($R_{g,on}$) for both F5 and H5. From Figure 3 it can be seen that the TRENCHSTOP 5 shows very similar behavior to a superjunction MOSFET of equivalent rating, and significantly lower losses compared to previous IGBTs. It can also be concluded that the turn-on behavior of the F5 and H5 is controllable via the turn-on gate resistor ($R_{g,on}$) over a wide range.

What can be concluded from Figures 3, 4 and 5 is as follows:

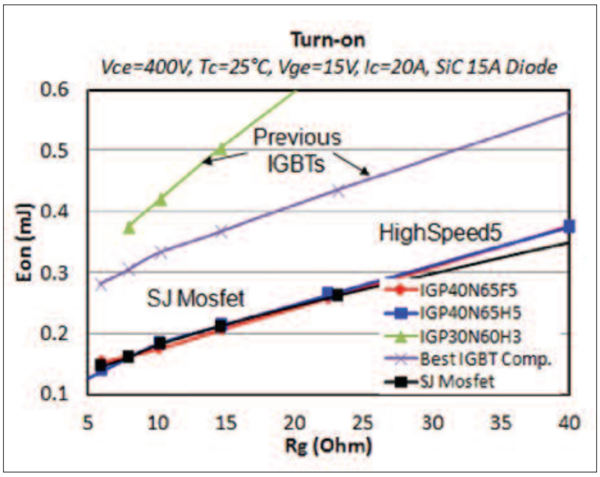
- Two families are required to provide



ABOVE Figure 1: Turn-off dependence of gate resistor: turn-off Energy (left) and voltage overshoot (right)



RIGHT Figure 2: Typical turn-off waveform H5 vs F5



LEFT Figure 3: Effect of $R_{g,on}$ on turn-on energy

designers with either an IGBT that is easy to handle and thus can be easily implemented (H5) or an IGBT that is snappy, needs care during implementation to reduce commutation loop inductance, but offers extended higher efficiency (F5).

- Turn-off controllability of the voltage overshoot and the switching losses is possible.
- Turn-on controllability is possible and turn-on switching losses are on par with superjunction MOSFETs.
- Ultimately there is a trade-off between switching losses and voltage overshoot. F5 needs to be driven with higher ohmic gate resistors compared to the H5, to limit the voltage overshoot.
- F5 has the highest efficiency due to the higher di/dt and is recommended for low inductance commutation loops and in combination with Silicon Carbide (SiC) diodes.
- H5 can be driven with gate resistors down to 5 Ω due to the softer turn-off behavior compared to F5.

Application measurements

For this industrial application measurement example, the H5 has been analyzed compared to the HighSpeed3 equivalent products.

Due to the dramatic improvement in efficiency seen by the H5 in the application test, designers have to make one of two fundamental decisions:

1. Do I maintain the traditional switching frequency of 20 kHz seen in state-of-the-art photovoltaic inverters to get the highest efficiency out of the TRENCHSTOP™ 5? or
2. Do I drive the switching frequency higher, keeping the same level of efficiency seen with the HighSpeed3 or the same case temperatures, but concentrate on system costs by reducing the size of the passive components?

To provide information to help answer questions 1 and 2 a very simple test condition of a 20 A square wave with 50 % duty cycle and maximum junction temperature 100°C was used. This was defined to show the power loss improvement the H5 offers compared to Infineon's HighSpeed 3 in terms of switching frequency. The results of this simple test where the curves of total power loss per IGBT vs. switching frequency are shown in Figure 4.

Relating to question 1, at 20 kHz switching frequency, the total power loss per IGBT dropped from 32.80 W, when the HighSpeed3 was used, to 25.04 W, when the H5 was implemented. What the results show is that just by implementing the new H5 (with no changes to driver circuit or board layout), power losses were reduced by more than 23 %. Furthermore, when the IKW40N65H5, which has the Rapid Silicon diode as the free-wheeling diode, was replaced with the IGW40N65H5 in combination with Infineon's 2nd generation Silicon Carbide (SiC) diode, provided a further 11 % power loss reduction.

Just by implementing the H5, immediate IGBT loss reduction was

Figure 4: **P_{tot} vs switching frequency**

observed, resulting in higher efficiency. Concentrating on systems offering higher efficiency allows designers to differentiate their designs and add extra value, which in turn can be sold at higher market prices.

Relating to question 2 and the affects of switching frequency versus power losses are now considered.

Let's first consider maintaining the same level of switching losses as the HighSpeed3 when the H5 is used. Under the simple test condition described above and again as shown in figure 4, switching frequency could be increased by more than 42%, to 35 kHz, when the HighSpeed3 was replaced by the H5. The switching frequency could be extended a further 28%, to 48 kHz, when the H5 was used in combination with a SiC diode.

Having the opportunity to increase the frequency, whilst maintaining the same thermal performance, brings about a cost and reliability benefit. This can be realized by using smaller and lighter magnetic components, and reducing or even eliminating the use of electrolytic capacitors. Although increasing the switching frequency increases the design complexity, clear benefits can be achieved for applications like solar and UPS, where the costs of the passive components dominate the bill of material.

When reverting to the examination of junction temperature versus switching frequency, the assumption is made that the junction temperature of all the power devices fulfill the derating requirement e.g. 80 % of the maximum junction temperature (T_{jmax}), which then allows for the maximum allowable power loss per device to be defined. Taking a practical example to demonstrate the performance of the H5, assume the specification of the maximum junction temperature is 100°C.

Taking the same test condition mentioned above (20 A square wave, 50 % duty cycle) for a 40 A device, the maximum power loss for a standard TO-247 package would be 40 W. At 40 W, the maximum operating frequency of HighSpeed 3, with respect to maximum junction temperature of 100°C, is around 28 kHz. The new H5 could however be driven up to 50 kHz, which represents nearly a 50 % increase in switching frequency, whilst maintaining the same junction temperature. This result highlights, for the same level of junction temperature (bearing in mind junction temperature is proportional to lifetime reliability) switching frequency can be dramatically increased. Of course, as in life, there are trade-offs and going beyond 33 kHz (according to this simple calculation) efficiency would be lower than when the HighSpeed3 is implemented at 20 kHz. The great thing about the TRENCHSTOP 5 is the designer really has a number of options to optimize his design to reach their design specifications.

Figure 5 shows an example of a HERIC topology which was measured at Fraunhofer Institute ISE. The H5 allows for the switching frequency to be tripled from 16 to 48 kHz compared to corresponding HighSpeed3 device by keeping the same efficiency over the entire load range.

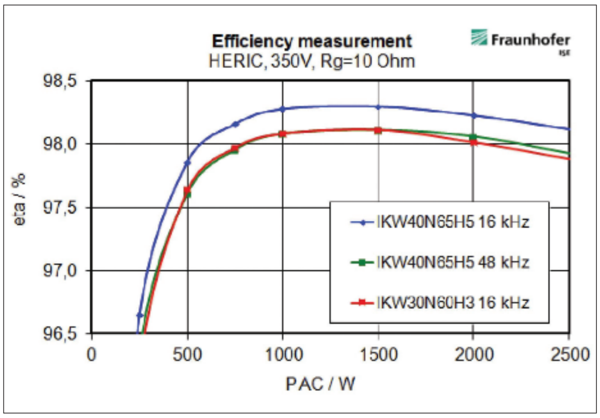


Figure 5: **HERIC efficiency at different switching frequencies**

Conversely, by maintaining the switching frequency at 16 kHz, overall system efficiency has been increased. A clear design strategy is necessary to get the best out of the new TRENCHSTOP 5 IGBTs. Further improvements in efficiency can be attained when a Silicon Carbide diode is used as the free-wheeling diode or the F5 IGBT is used. It will be those designers and companies who are able to successfully manage design strategies to be able offer differentiated systems to their end customers and increase their own market share.

Conclusion

Through application measurements it has been proven that the TRENCHTOP 5 sets a new benchmark for IGBTs switching greater than 16 kHz. As a result of the best optimization of carrier profile in combination with Infineon's further advancement of thin wafer technology, a drastic reduction in both turn-off and turn-on losses in hard switching applications, along with a low $V_{ce(sat)}$ value provide an IGBT that can achieve more than 98 % system efficiency in a photovoltaic inverter. Furthermore, the overshoot and EMI behavior is well controlled and is on the same level as the well-known HighSpeed 3 series. The H5 with the Rapid diode as the free-wheeling diode offers an ease-of-use solution for high performance industrial applications like photovoltaic inverters, UPS and welding. The H5 in combination with SiC further increases this efficiency range, while further optimisation is available when using the F5 version. The TRENCHSTOP 5 offers designers many advancements in IGBT performance. It is now up to designers to harness the full capability.

Literature

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