600V Trench IGBTs Reduce Power Loss in DC/AC Inverter Applications

Selecting the best IGBT for an application can be confusing and time consuming, so is it worth the time? In this article, we will attempt to simplify the selection process by providing an explanation for the trade-offs to be considered. To illustrate the benefits, we will describe the performance improvement possible with a new generation of 600V IGBTs targeted for DC/AC inverter applications. By using optimised trench IGBTs, we can improve efficiency or reduce system heatsink size or increase current density out of the same board assembly. **Wibawa Chou, Application Engineer, International Rectifier, USA**

The new devices use field stop trench technology to reduce both conduction and switching losses in high frequency switching applications, such as UPS and solar inverters enabling higher efficiency power conversion, and have been optimised for switching at 20kHz with low short circuit requirements (Figure 1). In order to verify this claim, we have built a 500W DC/AC inverter using similar sized IGBTs and analysed differences in performance.

Figure 1: New 600V trench IGBTs optimised for 20kHz switching applications

Basic trench IGBT

Recent advancements in IGBT technology have enabled the latest generation of 600V trench IGBTs targeted for 20kHz operation. Figure 2 shows cross-sections of planar and trench IGBTs, respectively. In a planar IGBT, the polysilicon gate is 'planar' or horizontal with respect to the p^+ body region. In a trench IGBT, the polysilicon gate is 'trenched down' into the p^+ body region as shown in Figure 2. This has the benefit of reducing channel resistance to electron flow and eliminating current crowding, since now electrons flow vertically in the channel. In a planar IGBT, electrons enter the channel at an angle creating current crowding which increases resistance for electron flow. Enhancing electron flow in a trench IGBT results in a large reduction of $V_{ce(on)}$.

In addition to reducing $V_{ce(on)}$, switching energy is also reduced by changing the construction of the IGBT to a thinner structure. Thinner structure allows for faster hole/electron recombination which translates into reducing IGBT tail current at turn off. In order to maintain the same breakdown voltage capability, an n-field stop layer is created to stop the electric

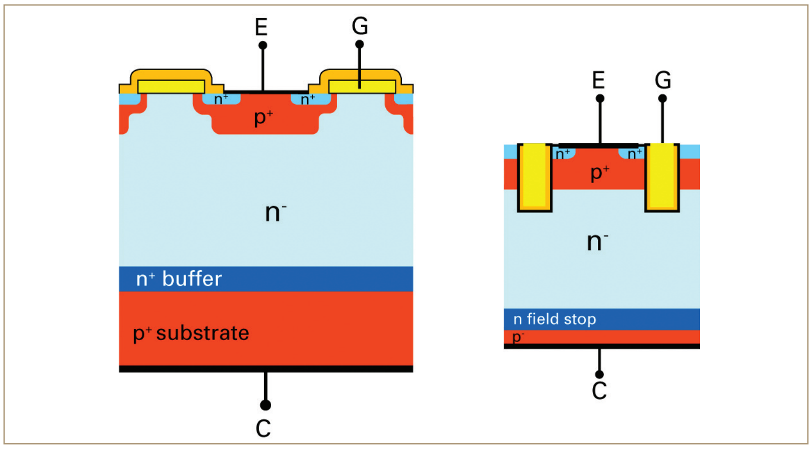

Figure 2: Planar IGBT and trench IGBT construction

field from reaching into the collector region as voltage across the IGBT increases. The combinations of lower conduction and switching energy allows for a smaller inverter size or increase power density out of the same inverter assembly. Table 1 shows parameter comparisons of similar sized planar and trench IGBTs.

From Table 1, the lower $V_{ce(on)}$ and lower switching energy loss of the newest optimised trench IGBT clearly predicts a more efficient inverter design. Comparing the products step by step illustrates the benefits of selecting the optimised part for the design. Comparing column two to four shows the advantage of lower $V_{ce(on)}$ when short circuit rating is not required, both devices are the same generation. Comparing column two to three shows the large improvement achieved when NPT devices were used to achieve improved short circuit rated products. Now comparing column 4 to 5 illustrates how the new optimised parts have improved both $V_{ce(on)}$ and switching losses E_{ts} with lower thermal impedance and lower gate charge. To achieve all these improvements a trade-off was required. The short circuit withstand time was eliminated, consistent with the requirements of the targeted application.

Part Number	IRG4BC20KDPBF	IRG15B60KDPBF	IRG4BC20UDPBF	IRGB4056DPBF
Technology	Planar Gate Punch Through	Planar Gate Non Punch Through	Planar Gate Punch Through	Trench Gate Field Stop
BV_{ces}	600V	600V	600V	600V
$V_{ce(on)}$, I_c=12A, 150°C	3.6V	2.50V	2.30V	1.90V
E_{ts}, I_c=12A, 150°C	1400µJ	580µJ	980µJ	510µJ
Q_g	34nC	36nC	27nC	25nC
R_{th}	2.1°C/W	1.4°C/W	2.1°C/W	1.07°C/W
T_{sc} at 125°C	10µs	10µs	2µs	3µs

Table 1: Planar and trench IGBTs parameter comparisons

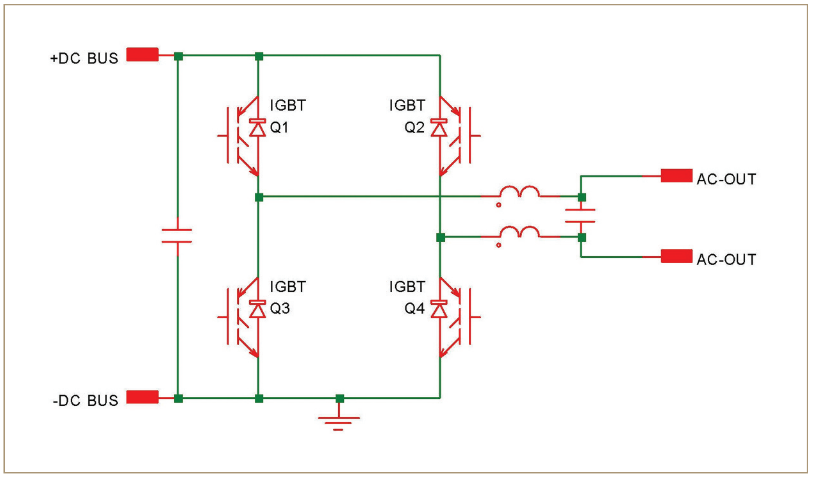

Figure 3: Implementation of a full bridge DC/AC inverter

DC/AC inverter implementation

The DC/AC inverter system discussed here is specific to only a system that requires true sine wave output at 50 or 60Hz. Square wave or quasi sine wave inverters will not be discussed here, as implementations of such inverters usually do not require the power devices to operate at 20kHz switching frequency.

Applications that require true sine wave output can typically be found in uninterruptible power supplies (UPS), solar inverters or frequency converters, just to name a few applications. A typical implementation utilises a full bridge inverter shown in Figure 3. The DC bus voltage can be derived from a bank of batteries in the case of a UPS, a solar panel in the case of a solar inverter, or rectified AC mains in the case of a frequency converter. The output of the inverter is a true sine wave voltage after the LC filter of Figure 3. In this topology, two of the IGBTs (Q1 and Q2) are considered high side devices whose gate voltages are driven 15V above the DC bus voltage. An easy way to achieve this is with a high voltage gate drive IC with bootstrap power supply. A driver IC can typically drive a pair of complementary high and low side IGBTs. Therefore, only two such driver ICs are required to implement a full bridge inverter. The input signals to the driver ICs can come from a microcontroller or can be implemented using analog circuitry.

Using this topology, it is possible to reduce the power dissipation by up to 30%, simply by changing the power devices Q1 to Q4 from an older short

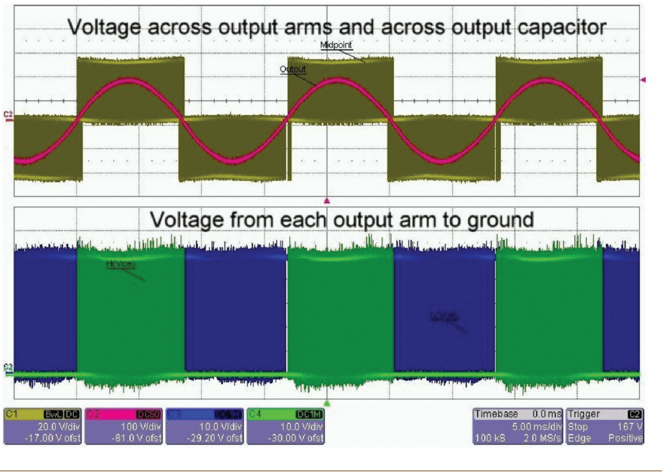

Figure 4: Typical voltage waveforms across the inverter arms and output capacitor

circuit rated planar IGBT to the newer optimised trench IGBTs. The switching frequency of this inverter is selected at 20kHz to prevent the output inductor L1 from generating audible noise. In this topology, Q1 is sine pulse width modulated at 20kHz, while Q4 is kept on during the positive 50 or 60Hz half cycle. Q2 and Q3 are kept off during this positive half cyle. During the negative 50 or 60Hz half cycle, Q2 is sine pulse width modulated at 20kHz while Q3 is kept on. Q1 and Q4 are turned off during this negative half cycle.

The resulting output waveforms are presented in Figure 4 which shows the voltage across the output arms of the full bridge inverter prior to the LC filter. The voltage waveform shows both the 20kHz switching of the IGBTs, as well as the 60Hz commutation. It can be seen that since the power devices operate at both 20kHz and 60Hz, lower conduction and switching losses of trench IGBTs are beneficial in reducing overall power dissipation of the inverter.

Figure 4 also shows the output voltage across the output capacitor after the 20kHz switching artifacts have been removed by the LC filter. The output is a true sine wave voltage. In order to meet total harmonic distortion (THD) requirement of the application, one usually adjusts the value of the output inductor and capacitors appropriately.

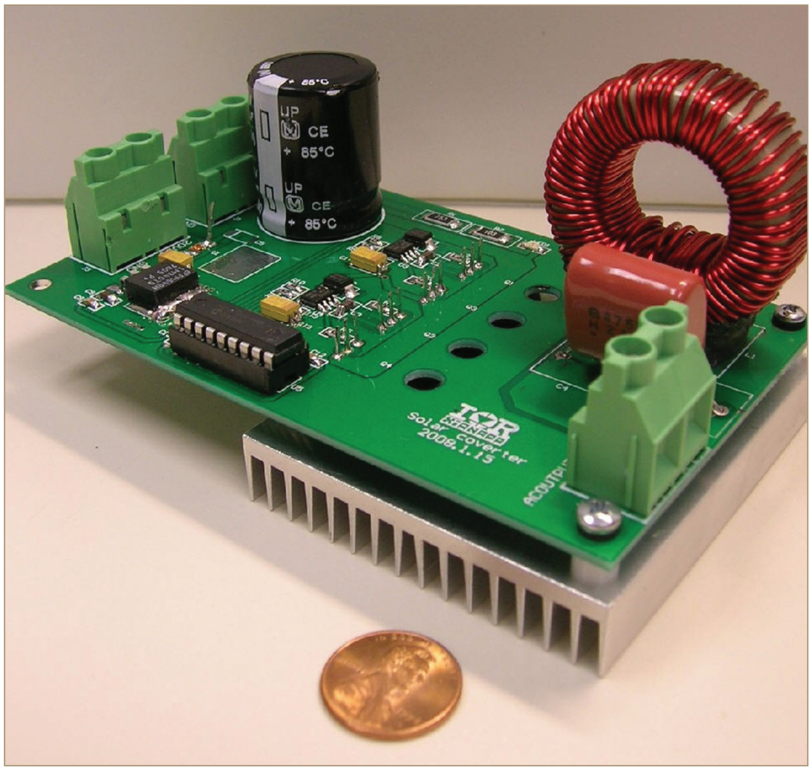

Figure 5: DC/AC inverter demo board

DC/AC inverter demo board

Figure 5 shows the demo board that IR built to compare the performance of best planar and trench IGBTs using the scheme discussed previously. This demo board is capable of delivering 500W of output power without requiring forced air cooling. It measures 3in x 5in and is based on the schematic shown in Figure 3. A microcontroller is used to generate appropriate signals for the high voltage gate driver ICs that drive the IGBTs. The IGBTs are soldered on the bottom of the board and are mounted to a 3in x 2.5in x 0.5in heatsink.

The 500W target for this demo board is ideal for a distributed power solar inverter application where the power electronics are integrated with the solar panel. Figure 6 shows the heatsink temperature difference between the best planar IGBT and the optimised trench IGBT at 500W output power. The heatsink temperature of the demo board with planar IGBT and the one with trench IGBT are 101 and 85°C, respectively. Replacing the power devices with trench IGBTs showed a 16% reduction in heatsink temperature. This gives the design engineer an opportunity to increase power density out of the same circuit board assembly simply by swapping out the power devices or reducing the size of the power electronic assembly by reducing the size of the heatsink if the same temperature is to be maintained.

Conclusion

The new optimised family of 600V trench IGBTs have been designed to reduce conduction and switching losses at 20kHz compared to older IGBTs. The target application for these IGBTs is DC/AC inverters typically found in UPS, solar inverter and frequency converter applications where true sine wave output voltage is required. International Rectifier built a 500W DC-AC inverter demo board using a full bridge topology to verify the power loss reduction by measuring heatsink temperature differences. In this experiment, it was shown that replacing the power devices with new optimised trench IGBT devices delivered a 16% reduction in heatsink temperature. The reduced losses provided an efficiency improvement of approximately 30% from previous generation IGBT devices.

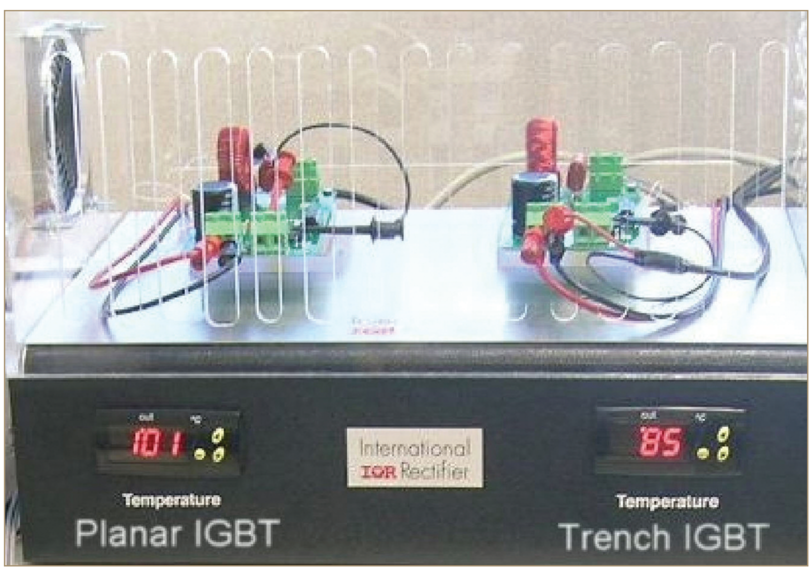

Figure 6: Heatsink temperature differences between trench and planar IGBTs at 500W inverter output power