



## **INTERNATIONAL RECTIFIER CORPORATION**

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### **WARP Speed™ IGBTs - Fast Enough To Replace Power MOSFETs in Switching Power Supplies at over 100 kHz**

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#### **Introduction:**

IGBTs have long held the promise of being able to more cost-effectively replace power MOSFETs in moderate-voltage range (i.e., 400-600 V) applications. However, they have thusfar not been able to deliver on that promise, due primarily to two reasons: 1) IGBTs were not quite fast enough to cover many of the applications; and 2) despite the indications that IGBTs *ought* to cost less by design, they simply were not yet cost effective, especially compared to the rapidly falling prices of power MOSFETs in the last couple of years.

International Rectifier's latest development in IGBTs addresses both these issues. They have switching characteristics that are very close to those of power MOSFETs, without sacrificing the inherently superior conduction characteristics of IGBTs. Thus, the WARP Speed™ IGBTs can offer a smaller die area for the same output power. The smaller die area results in lower gate charge and lower cost in many off-line power conversion applications for 400-600V devices switching at up to 150 kHz.

#### **Replacing MOSFETs with IGBTs**

Due to the higher usable current density of IGBTs, an IGBT with a die two sizes smaller can usually handle two to three times more current than a typical MOSFET it replaces (e.g., even in the past the IRFP450 could generally be replaced by IRG4PC30U below 50 kHz). The IGBT's die size is typically about 40% that of the MOSFET required to handle the same output power, so the cost is usually lower as well. Now, with the advent of higher-frequency WARP Speed IGBTs, the same can apply at frequencies up to 150 kHz.

The gate drive requirement for IGBTs is similar to that for MOSFETs, and may even be simpler due to smaller die size and input capacitance. For existing designs, adjusting the value of the gate resistor has little effect on the switching-loss behavior.

Following example illustrates WARP Speed™ IGBTs performance in a Power Factor Correction circuitry when favorably compared with its two die size larger cousin - Power HEXFETs :

**Test Conditions :**

|                              |                                              |
|------------------------------|----------------------------------------------|
| Converter Topology           | : Dual Forward converter                     |
| Output Power Rating          | : 250 Watts max.                             |
| PFC Topology                 | : Boost converter with single-switch         |
| Power MOSFET Used            | : 500V, 0.4 ohm Rds(on), 14A, TO-247 package |
| WARP Speed™ IGBT Substituted | : IRG4BC30W, TO-220 package                  |
| Operating Frequency          | : 100KHz                                     |
| Bus voltage                  | : 384V                                       |

| Power MOSFET                             | IGBT - IRG4BC30W |
|------------------------------------------|------------------|
| (All measured values in actual circuits) |                  |

**Conduction Loss :**

$$P_{cond} = I_{D(rms)}^2 * R_{ds(on)_{Hot}} * D = 4.54W$$

$$P_{cond} = V_{ce(on)} * I_c * D = 4.66W$$

**Switching Loss :**

$$P_{sw} = I_d * V_{ds} * t_{sw} * f_{sw} = 10.9W$$

$$P_{sw} = E_{ts(Hot)} * f_{sw} = 11.2W$$

**Total Loss Pd :**

$$P_d = P_{cond} + P_{sw} = 15.44W$$

$$P_d = P_{cond} + P_{sw} = 15.86W$$

$$\text{Case temperature } T_c = 56^\circ C$$

$$\text{Case temperature } T_c = 66^\circ C$$

$$\text{Junction temperature } T_j = P_d * R_{th-jc} + T_c = 74^\circ C$$

$$T_j = P_d * R_{th-jc} + T_c = 93^\circ C$$

The case study above shows that an IGBT can be used to generate same amount of output power as a much larger Power MOSFET does in a hard-switching application. The circuit designer will appreciate the component cost saving and board space saving as a result of this direct replacement. One should notice that IGBT has a slightly higher junction temperature than its two die size larger Power MOSFET because of the higher junction-to-case thermal resistance. In this case,  $T_j$  for WARP Speed™ IRG4BC30W is running with full load at  $93^\circ C$ , still a  $57^\circ C$  temperature safe margin from its maximum limitation -  $150^\circ C$ .

Figure 1 below shows typical waveforms of Gate-Vgs, Current-Ic and Voltage-Vce for WARP Speed™ IGBT (IRG4BC30W) running at 100KHz in a 250 Watt Power Factor Correction boost converter.

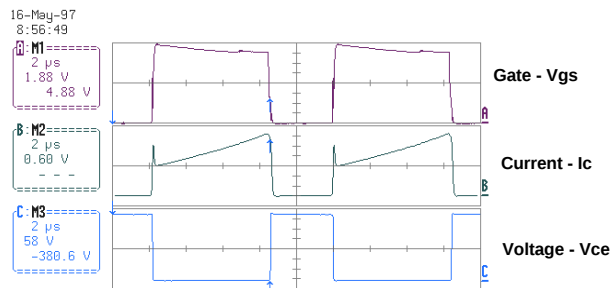
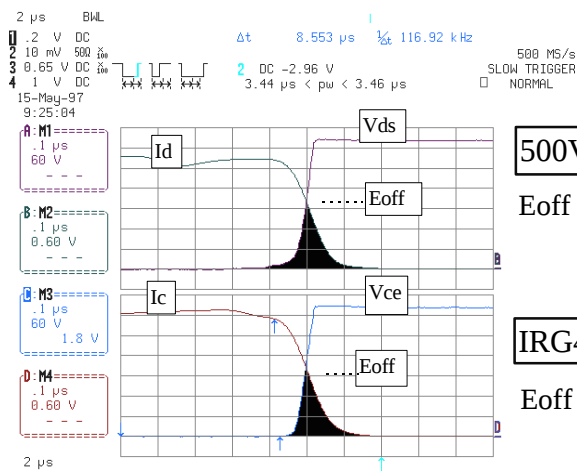


Figure 1. WARP Speed™ IGBT  
Switching Waveforms in a PFC Boost



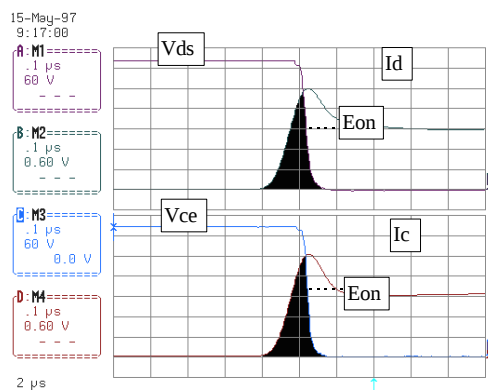
500V Power MOSFET

Eoff = 47.5uJ

IRG4BC30W

Eoff = 53.5uJ

Figure 2. Turn-off Switching Loss (Eoff)  
Comparison Between Power MOSFETs and  
IGBTs



500V Power MOSFET

Eon = 61.4uJ

IRG4BC30W

Eon = 58.4uJ

Figure 3. Turn-on Switching Loss (Eon)  
Comparison Between Power MOSFETs and  
IGBTs

Figure 2 and Figure 3 above provides further evidence to WARP Speed™ IGBTs during both turn-on and turn-off switching performances when compared to two size larger Power MOSFETs. An Eoff of 12% higher WARP Speed IGBTs is being offsets by an Eon of 5% lower.

And finally, because the package style and pinouts of IGBTs and MOSFETs are similar, no fundamental mechanical or layout changes are required.

### Speed Limit of IGBTs:

The maximum switching frequency for IGBTs is limited mainly by the total switching energy loss,  $E_{ts}$ . In the past, IGBT manufacturers have attempted to develop new technologies which could offer lower  $E_{ts}$  for higher operating frequency and higher switching efficiency design.

In single- and dual-transistor topologies in power conversion (i.e., non- motor control) applications such as SMPS, PFC and welding, there is usually a triangular or trapezoidal current waveform and therefore a higher current being conducted through the device at turn-off. This is why IGBTs have had difficulty in the past competing with power MOSFETs: due to the minority-carrier recombination “current tail”, the non-ideal turn-off characteristic of IGBTs is precisely where the greatest current levels are, and this is where most of the losses usually occur. In a typical 80 to 100 kHz power supply application, one might expect to find that for a MOSFET about 75% of the losses would be conduction losses due to the device’s  $R_{ds(on)}$  -- whereas for an IGBT in the same application, about 70% of the losses would be due to switching losses, primarily in turn-off. Thus, improvements in the turn-off characteristics of IGBTs would be of greatest leverage in reducing overall losses.

This is, in fact, what IR has done with its WARP Speed™ IGBTs. We have lowered  $E_{off}$  losses to about half of the value of our already industry-leading UltraFast U-Series. This roughly 50% improvement virtually doubles the frequency range of IGBTs without significant impact on power losses.

### WARP Speed IGBT Specifications:

It is clear that IR offers the lowest  $E_{ts}$  (total switching loss) in the marketplace today. As such, we can look at Figure 4 results and form comparisons for analysis.

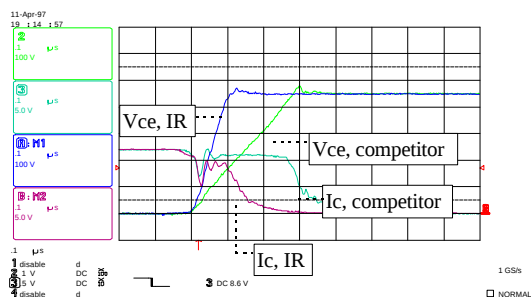


Figure 4. IR vs. nearest competitor IGBT in  $E_{off}$  Performance

When compared to IR’s latest-generation U-series devices, the major changes in the specs of the WARP Speed™ IGBTs are in the  $V_{ce(on)}$  and switching energies (all other changes were second

order). You can see from the Table 1 below that the  $V_{ce(on)}$  has increased from a typical value of 1.7V for U's to 2.1V for the new W-type devices, an increase of roughly 24%. However, the increased on-state losses are more than compensated for by improvements in switching:  $E_{ts}$  decreased by about 40% from typical values of 1360uJ down to 800uJ, and the all-important  $E_{off}$  has decreased by 50% (from about 1100 uJ to about 550 uJ for a typical 40A-rated device). This tradeoff would be of great advantage in applications where the  $E_{off}$  had a greater impact on overall losses than  $V_{ce(on)}$  -- i.e., typical power supply applications.

Table 1.  $V_{ce(on)}$ ,  $E_{ts}$  and  $E_{off}$  comparison between U-type and W-type IGBTs

|              | U-type IGBT | W-type IGBT | Difference in % |
|--------------|-------------|-------------|-----------------|
| $V_{ce(on)}$ | 1.7 V       | 2.1 V       | +24%            |
| $E_{ts}$     | 1360 uJ     | 800 uJ      | -40%            |
| $E_{off}$    | 1100 uJ     | 550 uJ      | -50%            |

### How can we tell if it's better?

Is it "better"? Increasingly, "better" means "it does the job that I need it to do." So, we can compare an IGBT to a competitive IGBT, or to a MOSFET, and see which is better -- or, we can see which one gets the job done for the lowest cost. When one compares the costs of the WARP Speed versus alternatives below 150 kHz, the WARP Speed<sup>TM</sup> generally comes out the lowest. Cost-reduction was the objective of the design of the WARP Speed<sup>TM</sup> project at IR, and this was achieved.

Still, an achievement such as this raises the ever-ongoing issue of specifications and "specsmanship". In essence, we have lowered costs by making an application-specific device. It has a HIGHER on-state voltage, and therefore it will have a lower DC current rating -- which, of course, is what the manufacturer puts at the top of the data sheet and which is also what 90% of designers look at when they are choosing which IGBT to use. This would lead the designer to choose a less-qualified IGBT for the application, or to continue to use a MOSFET and not choose an IGBT at all. The most useful information to look at is what this device will do while *switching, in the conditions of the application*, and at such conditions for power supplies, the new WARP Speed<sup>TM</sup> IGBTs from International Rectifier probably offer the best option to the designer for reducing his or her costs.

It remains for both manufacturer and designer to push for specifications that reflect the conditions of the applications, so that meaningful comparisons between devices can be made and so that everyone benefits from the development of better and better application-specific components. In the meantime, if you cannot get sufficient information from each manufacturer, then you'll simply need to try the devices out to verify the claims they make.

**Product Family Notes:**

The first 5 device types in the WARP Speed™ of IGBTs from International Rectifier are rated from 5A to 50A, in the industry-standard TO-220 and TO-247 packages, and are to be offered beginning this month. Other current ratings and packages will follow throughout the remainder of 1997. The IRG4PC30W (which typically replaces the industry-standard IRFP450) costs “significantly less than \$1.25” in volume.