# 500V IGBTS REPLACE MOSFETS AT LOWER COST

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## Introduction:

International Rectifier's 500V IGBTs have switching characteristics that are very close to those of power MOSFETs, without sacrificing the superior conduction characteristics of IGBTs. They offer advantages over MOSFETs in high-voltage, hard-switching applications. These advantages include lower conduction losses and smaller die area for the same output power. The smaller die area results in lower input capacitance and cost.

## Replacing MOSFETs with IGBTs:

Because the package style and pinouts of MOSFETs and IGBTs are identical, no mechanical or layout changes are required.

The gate drive requirement for IGBTs is similar to MOSFETs. A gate voltage between 12V and 15V is sufficient for turn-on, and no negative voltage is required at turn-off. The value of the series gate resistor may have to be increased to avoid ringing at the gate of the IGBT due to smaller die size.

## 1. Power Dissipation:

In high-voltage MOSFETs, power dissipation is mostly due to conduction losses; switching losses are negligible up to 50kHz. On the other hand, conduction losses in the IGBT are less than in the MOSFET, but switching losses become significant above 10kHz.

## Design Example:

| | |
|---|---|
| Switched DC Current | = 7.5A |
| Duty cycle | = 0.5 |
| Bus voltage | = 310V |
| Junction temperature | = 125°C |
| MOSFET used | = IRFP450 |
| $R_{DS(on)}$ (25°C) | = 0.4Ω |
| Operating frequency | = 50kHz |
| Current waveform | = square wave |

On-resistance of the IRFP450 MOSFET at 125°C is (from the data sheet):

$$R_{DS(on)}(125°C) = 0.816\Omega.$$

Conduction loss in the MOSFET at 125°C:

$$P_D = R_{DS(on)(125°C)} * I^2 * D = 23W$$

Assuming 75ns switching times and 50kHz switching frequency, switching losses in the MOSFET at 7.5A are approximately:

$$P_{sw} = 6.5 \text{ W}$$

Total power loss in the MOSFET is:

$$P_{tot} = 29.5W$$

Replacing the MOSFET with an IRGP430U IGBT, conduction loss in the IGBT is:

$$P_C = V_{CE(125°C)} * I_c * D$$

On-state collector-emitter voltage at 125°C and 7.5 A is from Figure 5 on the data sheet:

$$V_{CE@125°C} = 2.03V.$$

Conduction loss in the IGBT is:

$$P_c = 2.03V * 7.5A * 0.5 = 7.62W$$

Due to the IGBT's higher usable current density, the same power dissipation in the IGBT and MOSFET results in higher junction temperature for the IGBT because of higher junction-to-case thermal resistance.

To maintain junction temperature parity, the power dissipation in the IGBT needs to be reduced to:

$$P_{DIGBT} = P_D*(R_{\theta SA} + R_{\theta CSM} + R_{\theta JCM}) / (R_{\theta SA} + R_{\theta CSI} + R_{\theta JCI})$$

Where:

| | |
|---|---|
| $R_{\theta SA}$ | Heatsink-to-ambient thermal resistance. |
| $R_{\theta CSM}$ | MOSFET case-to-sink thermal resistance |
| $R_{\theta JCM}$ | MOSFET junction-to-case thermal resistance. |
| $R_{\theta CSI}$ | IGBT case-to-sink thermal resistance. |
| $R_{\theta JCI}$ | IGBT junction-to-case thermal resistance. |

Total power dissipation is composed of both conduction and switching losses. Conduction losses were calculated above. Applying the formula above results in $P_{DIGBT}$=23.2W.

Maximum allowable power loss due to switching losses:

$$P_{SW} = P_{TOT} - P_{COND}$$
$$P_{SW} = 23.2W - 7.6W = 15.6W$$

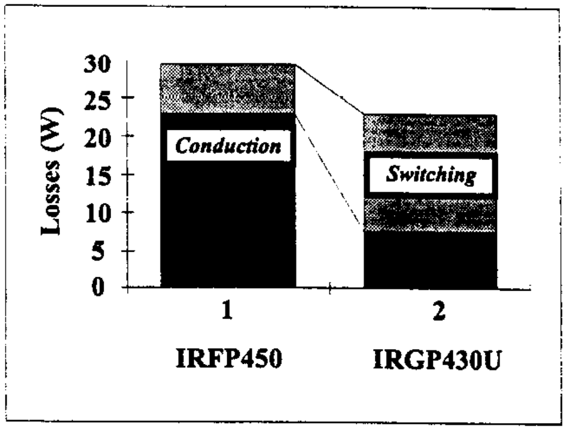



***Figure 1 - Power losses in an IRGPC450 MOSFET and a IRGP430U IGBT at 7.5A current both switching at 50kHz.***

Maximum switching frequency for same junction temperature in same thermal environment:

$$f_{max} = 10.3W/0.226mJ = 56.4kHz$$

The switching energy number comes from data sheet information. It will be appreciated that, being operated with lower losses, the IGBT design is more efficient.

The sources of power dissipation in the IRFP450 MOSFET and IRGP430U IGBT are shown in Figure 1.

## Selecting IGBT:

Figure 2 provides an easy method to select an IGBT which can replace IRFP460, IFRP450 or IRFP440 MOSFET in hard-switching applications. The first step is to find the proper curve in the chart, based on the MOSFET's part number. The part number of the recommended replacement IGBT is shown next to the curve. In general, a given MOSFET can be replaced with a two die size smaller 500V IGBT (e.g. IRFP450→IRGP430U). The IGBT's die size is typically about 40% of the MOSFET's die size.

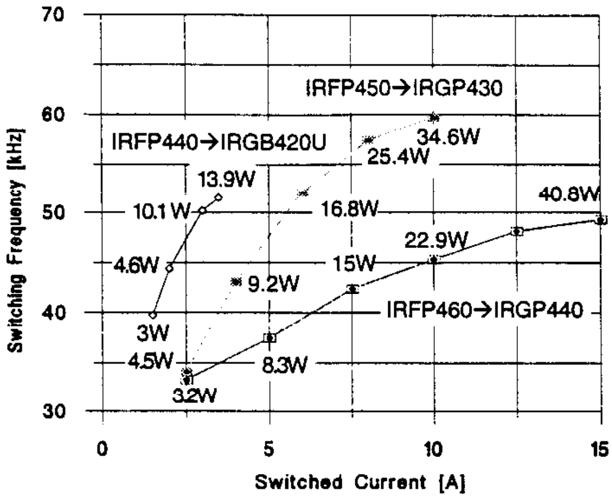



*Figure 2 - Maximum operating frequency of IGBT vs. switched current. IGBT replaces 2-size larger MOSFET in hard-switching application. Operating IGBT at frequency indicated, junction temperature of IGBT equals junction temperature of MOSFET it replaces.*
*($T_{ambient}$ = 65°C, $T_j$ = 125°C, Duty cycle = 0.5)*

The next step is to find the maximum operating frequency for the IGBT. By definition, at the maximum operating frequency the IGBT operates at the same junction temperature as the replaced MOSFET. To find the maximum operating frequency, select the operating current on the horizontal axis and read the maximum operating frequency on the vertical axis.

Using the power dissipation values for the IGBT in Figure 2, the heatsink can be sized for a given ambient temperature.

## 2. Gate Resistor and Snubber:

The smaller die size and input capacitance of the IGBT may result in faster switching speed than the MOSFET replaced. A larger-value gate resistor slows down turn-on speed, but has little effect on turn-off. Unlike the MOSFET, the turn-off speed of the IGBT cannot be controlled with a series gate resistor.

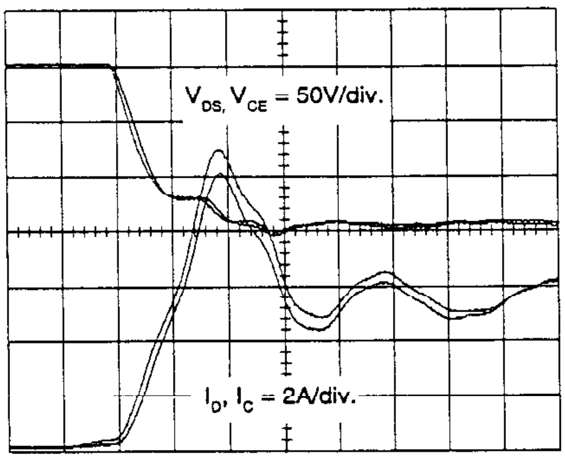
High turn-off speed can generate excessive ringing and voltage spikes in the circuit. If a snubber is used, resizing the components helps reduce noise. Minimizing stray inductances in the wiring and transformer is the most effective way of reducing noise in new designs.

## 3. Emitter-Collector Diode:

In applications where the body diode of the MOSFET is used, IGBT-HEXFRED® diode Co-Paks improve performance and efficiency while reducing current spikes, due to better diode performance.

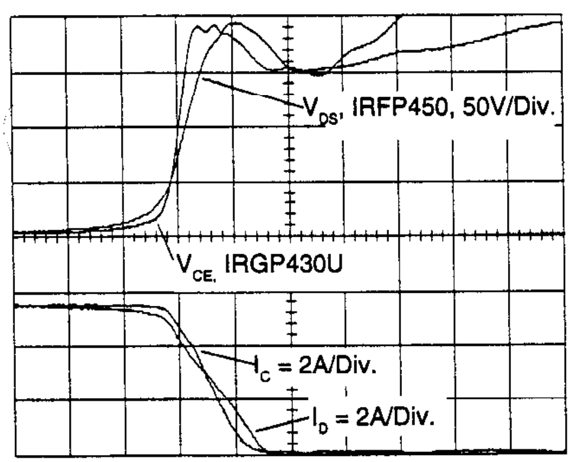
## 4. Test Results:

Figures 3 and 4 show the turn-on and turn-off waveforms for an IRFP450 MOSFET and an IRGP430U IGBT, both switching 5.5A at 160V. The switching waveforms were taken in a 400W, single-ended forward converter. Because of different die sizes, a 10 Ohm gate resistor was used for the MOSFET and 33 Ohm for the IGBT. The waveforms show same turn-on speed and faster turn-off for the IGBT.




Horiz.: 50ns/div.

***Figure 3 - Turn-on waveforms. The IRFP450 and IRGP430 are switching 5.5A at 160V***




Horiz.: 100ns/div

***Figure 4 - Turn-Off Waveforms, 5.5A at 160V***

## 5. Additional Information:

Application Note AN-990, *Application Characteristics of IGBTs*, provides details on how to calculate IGBT losses.

Application Note AN-983A, *IGBT Characteristics*, describes the fundamentals of IGBT operation.