CHOOSING BETWEEN MULTIPLE DISCRETES AND HIGH CURRENT MODULES

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Introduction

Many circuits using HEXFETs or IGBTs operate at current in the range of tens to hundreds of amps. IR's packages that cover this range are shown in Figure. 1.

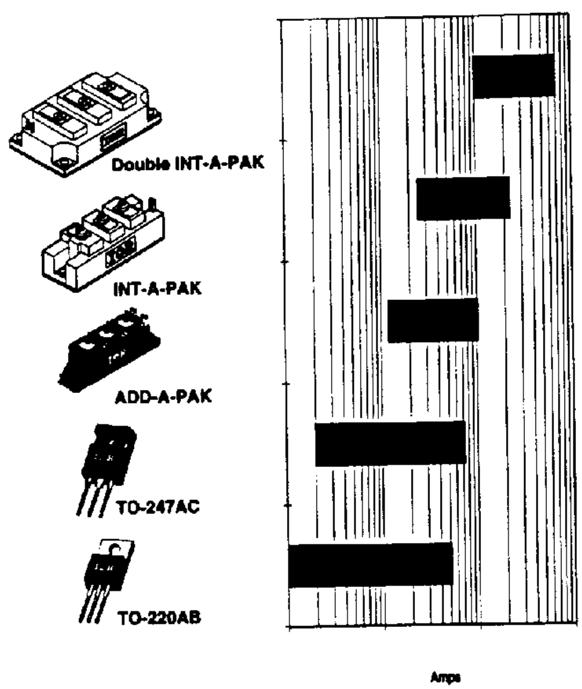

Figure 1. Current Ratings of Discrete TO-220AB, TO-247AC, and High Current Module Packages

The discrete TO-220 and TO-247 packages contain a single MOSFET, a single IGBT, or an IGBT with antiparallel HEXFRED fast recovery diode (Co-Pack). The TO-247 has a rated maximum current of 70A; full-load continuous operating design current of this package is typically in the range of 10 to 20A. Both the TO-220 and TO-247 discrete packages are manufactured in volume and offer low cost-per-ampere.

The isolated high current modules generally contain half-bridge, "chopper," or single switch configurations. Current ratings range from 25A, for a 1200V half-bridge Int-a-pak, to 600A, for a single-switch 600V Double Int-a-pak.

Attractive features of high current modules are that they are electrically isolated, easy to mount to heatsinks, and easy to interconnect with other modules to form the overall circuit. They also avoid the need for paralleling for currents up to several hundred amperes. Cost-per-ampere of high current modules is higher than for discretes, in terms of the basic semiconductor *component* cost — though not necessarily in terms of final *system* cost.

Figure 1 shows a range of overlap of current ratings covered by both discretes and high current modules. Within this range, the discrete often will offer the most cost-effective system design because of its lower cost-per-ampere.

TO-220 and TO-247 Co-Packs add to the attraction of the discrete packages for inverter circuits because they reduce the required number of components by 50%, compared to using discrete IGBTs with separate diodes.

The range of overlap where discretes can offer an alternative to high current modules can be extended by using multiple discretes in parallel.

Multiple discretes offer the potential for system cost savings versus high current modules because of the lower cost per ampere of the semiconductor *components*. Whether overall cost savings will be achieved will depend upon the design requirements for the specific application, and how these requirements will affect the total *system* cost.

This Design Tip presents a brief discussion and general guidelines that will assist the user in choosing between multiple discretes or high current modules for specific design situations.

Considerations for paralleling discretes are discussed sufficiently for a general qualitative understanding of the issues. The reader should refer to other, more specific, IR application literature for greater detail on paralleling.

Cost of Module as Function of Its Rated Current

As shown in Figure 1, a given module package covers a range of current ratings. A given module package, at its highest rating, contains the largest area of silicon die that it can accommodate; it is said to be "fully loaded." The same module with lower current ratings contains less than the full complement of silicon, and is "partially loaded."

Figure 2 illustrates that a fully loaded 200A, 600V Int-a-pak half-bridge has the same silicon die area as eight TO-247 Co-Packs. A partially loaded 50A, 600V Int-a-pak half-bridge, by contrast, contains the equivalent silicon of just two TO-247 packages.

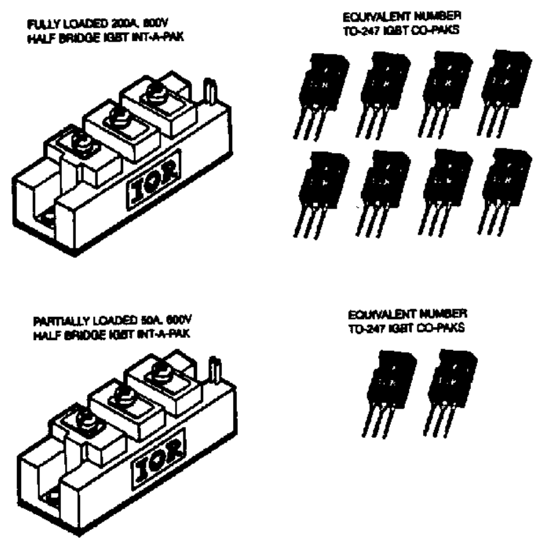

Figure 2. Equivalence Between IGBT INT-A-Paks of Different Current Ratings and TO-247 IGBT Co-Packs

Since module package cost is essentially fixed, independent of how much silicon goes inside it, a fully loaded module will inevitably have lower cost-per-amp than a partially loaded one.

Cost of Module versus Discretes

The simple construction of the discrete package, coupled to its high manufacturing volumes, ensures that the discrete's cost-per-ampere will always be less than that of a high current module. Cost-per-ampere of a fully loaded module may be 150% or more of the cost of the equivalent number of discrete *components*.

Against the *component* cost advantage of the discrete, the user must weigh additional assembly costs, derating needed for paralleling, and technical practicality of using multiple discretes. These factors depend upon the specific design requirements.

Electrical Connections

A basic difference between the discrete and the high current module is the method of making electrical connections to the package.

A discrete TO-220 or TO-247 is designed for soldering to a Printed Circuit Board (PCB). The maximum continuous operating current that can be handled by a PCB is typically less than 100A. This tends to set a natural limit on the number of discretes that can conveniently be connected in parallel.

High current modules, by contrast, have screw terminals; they are designed primarily for cable-lug or busbar connections, as illustrated in Figure 3(a). The high current module can also be connected directly via through-holes to a PCB, as illustrated in Figure 3(b). This type of connection is best suited to operating currents below 100A.

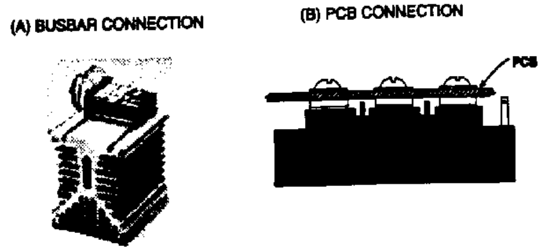

Figure 3. Methods of Making Connection to INT-A-Pak Module

Equalizing Junction Temperatures of Multiple Discretes

Paralleling of multiple discretes requires that power losses and — more importantly — junction temperatures of each device should be equalized as much as possible.

Some unbalance of losses is inevitable, because of differences in electrical characteristics between different devices. The variation of characteristics between individual devices will require a certain amount of current derating, typically around 20%. Even with this derating, good thermal coupling is necessary to force individual junction temperatures to "equalize."

The need for tight thermal coupling between the junctions of individual discretes weighs against an electrical isolation barrier, such as a "Silpad," being placed directly at the cooling surface of a TO-220 or TO-247. This places a thermal barrier between individual discretes and tends to decouple individual junction temperatures. For this reason, electrically isolated "Fullpak" TO-220 and TO-247 packages are not ideal for paralleling.

Parallel discretes should be mounted on a common heatsink. If electrical isolation is required, the discretes can be mounted on a common heatspreader to thermally couple the junctions. The heatspreader also serves the purpose of a mechanical carrier for the discretes during assembly. The isolation barrier is placed between the busbar and the main heatsink structure, as illustrated in Figure 4.

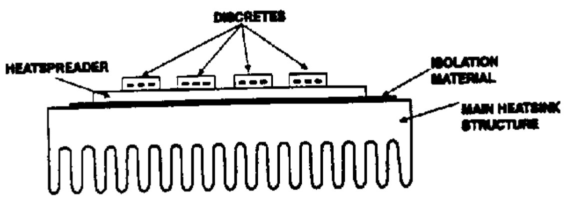

Figure 4. Use of Heatspreader to Provide Thermal Coupling Between Discretes

Unbalance due to Circuit Layout

External circuit unbalance due to non-symmetrical layout can cause significant differences in losses between parallel discretes. The most serious effects of non-symmetrical layout will be current unbalance during switching intervals and unbalanced switching losses. The most sensitive stray circuit elements to be balanced are the individual common emitter inductances. This is illustrated in Figure 5.

If switching losses are relatively small in relation to the conduction losses, a certain amount of circuit-induced unbalance of switching losses can be tolerated, and symmetrical layout will not be super-critical. This will depend on the design requirements of the application.

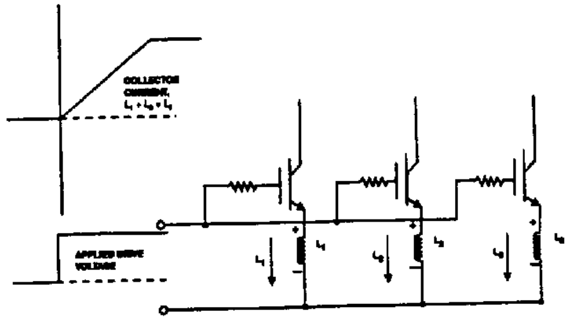

Figure 5. Common emitter circuit inductances L1, L2, L3 develop Ldi/dt voltages during switching, modifying the gate-emitter voltage applied to the IGBTs. Unbalanced inductances cause unbalanced drive voltages and unbalanced currents.

Switching losses will be low where switching frequency and/or switching voltage is relatively low. The simple in-line arrangement of discretes, shown in Figure 6(a), though not electrically symmetrical, can be satisfactory in these circumstances.

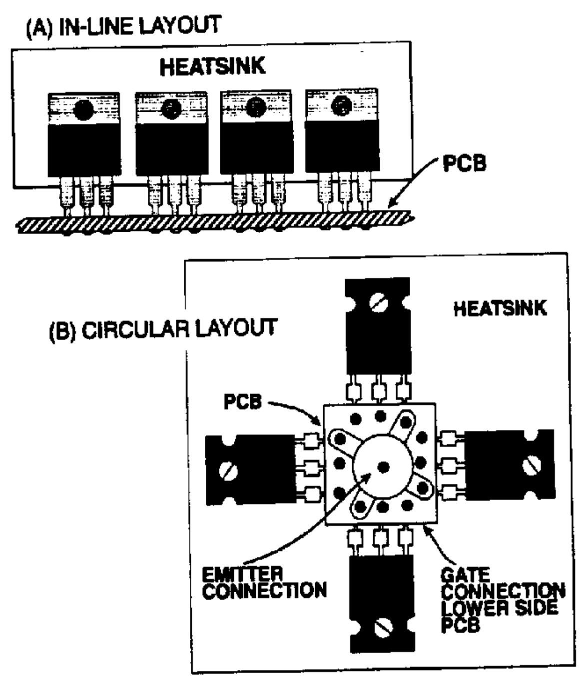

Figure 6. Different Layouts of Discretes

Where switching losses are significant, careful attention to layout is important. The symmetrical layout illustrated in Figure 6(b) is ideal, in terms of balancing individual common emitter inductances and equalizing switching losses.

Figures 7 and 8, for HEXFETs and IGBTs respectively, show typical boundaries of switching voltage and average device switching frequency that correspond to switching losses of 15% and 30% of the total device losses in hard switching applications[1]. Layout will generally not be super-critical where switching losses are less than 15%; it becomes increasingly more so as switching losses increase above this level.

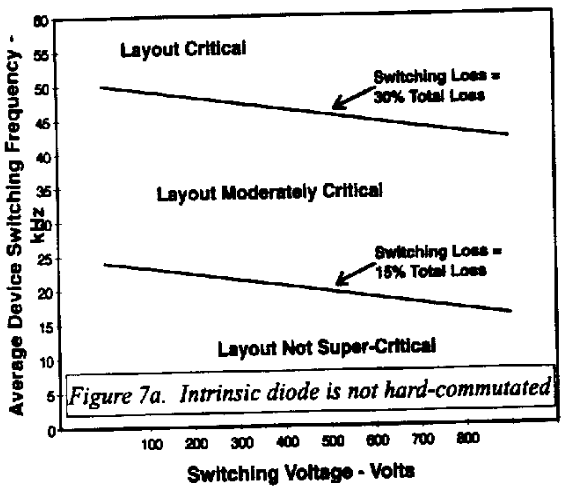

Figure 7a. Intrinsic diode is not hard-commutated

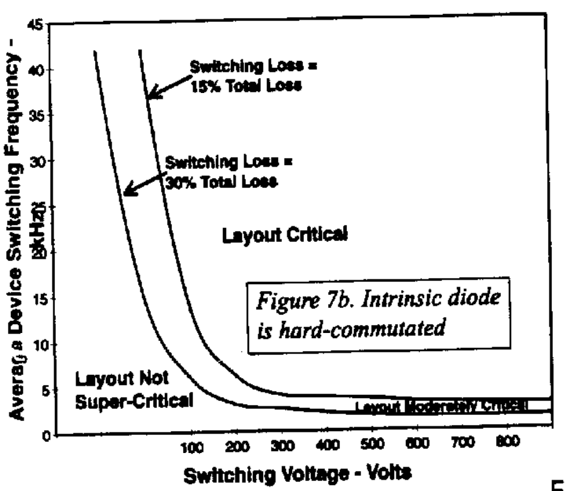

Figure 7b. Intrinsic diode is hard-commutated

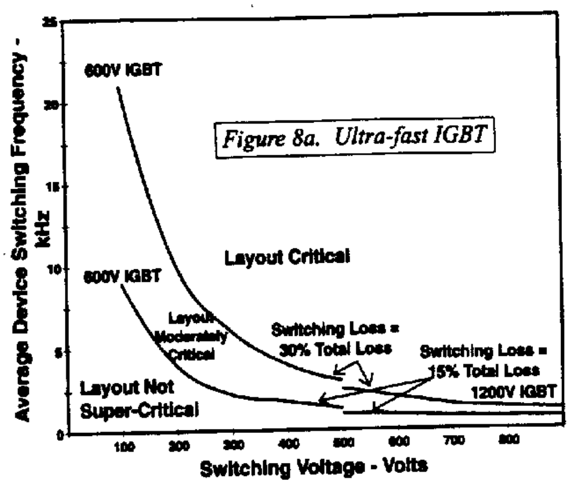

Figure 8a. Ultra-fast IGBT

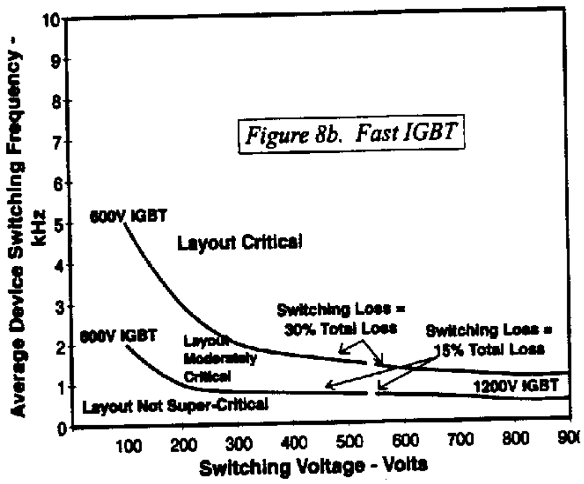

Figure 8b. Fast IGBT

Figure 7(b) shows that if the HEXFET's internal diode is hard commutated — as is the case in sinusoidal PWM inverters — the area of operation for non-critical layout is generally restricted to low voltage operation because the switching losses caused by recovery of the HEXFET's intrinsic diode increase significantly as voltage increases.

[1] Note that the average device switching frequency in a sinusoidally modulated PWM inverter is *half* the output PWM frequency. Thus for this type of circuit, average device switching frequency should be multiplied by 2 to obtain the output PWM frequency.

Figures 7 and 8 are intended only as a general indication of the operating areas that are "easy" or "less easy" for parallel discretes, based on layout considerations.

Tables 1 and 2 relate this basic information to typical circuits.

Table 1 ***Design Situations for Multiple Discretes For Which Layout is not Super-critical***	
Design Conditions	***Typical Circuits***
Operating frequency of HEXFET or IGBT is low	Line frequency inverter Line frequency ACswitch
Operating voltage of HEXFET or IGBT at switching instant is low	Inverters operating from battery voltage below 100 V Zero-voltage-switching resonant inverters
Operating current of HEXFET or IGBT at switching instant is low	Zero-current-switching resonant inverters
HEXFET internal diode is not hard-communtated	Forward, flyback, bridge inverters

Table 2 ***Design Situations for Multiple Discretes For Which Layout is Critical***	
Design Conditions	***Typical Circuits***
Operating frequency and voltage of HEXFET are high, internal diode is hard-commutated	PWM inverter
Operating frequency and voltage of IGBT are high	PWM Inverter Buck Converter Boost Converter

Heatsink Mounting Area

The symmetrical layout of discretes shown in Figure 6(b), (two similar sections for a half-bridge) with the same silicon area as a fully loaded Int-a-pak, would require three to four times more heatsink mounting area.

The simpler, non-symmetrical, in-line arrangement of TO-247 Co-paks shown in Figure 6(a), on the other hand, with the same silicon area as a fully loaded Int-a-pak, would require slightly less heatsink area. The savings in heatsink area become more significant when in-line Co-Packs are compared against a partially loaded Int-a-pak.

Summary

Table 3 shows a summary of the factors that will influence the choice between multiple discretes and high current modules, and typical applications that are potentially suited to each design approach.

Table 3 ***Summary***	
Factors that favor multiple discretes	***Factors that favor high current module***
A few discretes in parallel are needed	Beyond the capability of a few discretes in parallel
Current is below rating of fully loaded module	Fully loaded module is needed
High volume manufacturing geared to handling discretes	Low-to-medium volume manufacturing
Design time not critical	Important to minimize design time
Electrical isolation not required	Electrical isolation is required
Design will use printed circuit board	High-current cable-lug or busbar connections needed
HEXFET internal diode is not hard-communtated	Forward, flyback, bridge inverters
Typical Applications	
Line frequency inverters Low-voltage PWM inverters for UPS Line-frequency AC switches/breakers Electric vehicle controllers Resonant power supplies Resonant HF welders HEXFET switching power supplies	PWM AC motor drives Line voltage PWM inverters for UPS High current power factor correction