Replacing MOSFETs with IGBTs

New SMPS IGBTs have a cost/performance advantage over MOSFETs in certain applications. High voltage MOSFETs still shine at relatively low current and high frequency (150kHz and higher). IGBTs dominate at higher current and frequencies generally below 200kHz unless soft switched. Paying attention to key differences when replacing MOSFETs with lower cost IGBTs will help ensure success. **Jonathan Dodge, Advanced Power Technology, Bend, USA**

FRANCAIS

Les nouveaux transistors de puissance à porte isolée SMPS sont, pour certaines applications, plus efficaces et économiques que les transistors MOS à effet de champ. Les Transistors MOS à effet de champ à haute puissance restent performants avec des tensions relativement faibles et des fréquences élevées (à partir de 150 kHz). Les transistors de puissance à porte isolée sont plus appropriés pour des tensions plus élevées et des fréquences en règle générale inférieures à 200 kHz, sauf avec un commutateur logiciel. Lorsque des transistors MOS à effet de champ sont remplacé par des transistors de puissance à porte isolée à plus faible coût, il est important de faire attention aux spécificités propres à chaque type de transistor pour garantir le succès d'un tel programme. **Jonathan Dodge, Advanced Power Technology, Bend, Oregon, États-Unis**

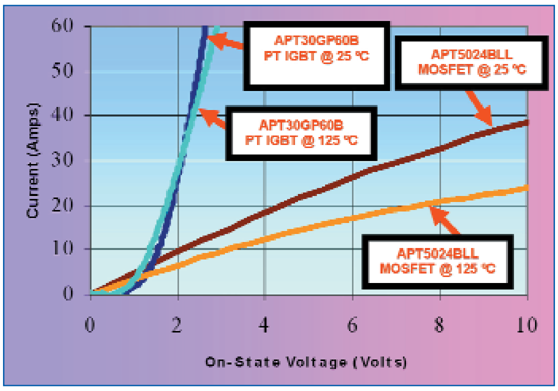
DEUTSCH

Neue IGBTs für Schaltnetzteile weisen einen Kosten/Leistungsvorteil gegenüber MOSFETs in gewissen Applikationen auf. Hochvolt-MOSFETs sind weiterhin bei relativ geringen Strömen und hohen Schaltfreqenzen (150 kHz und höher) im Vorteil. IGBTs dominieren bei höheren Strömen und generell bei Schaltfrequenzen unterhalb 200 kHz, sofern nicht weich geschaltet. Bei Berücksichtigung der wesentlichen Unterschiede wird der Ersatz von MOSFETs durch kostengünstigere IGBTs ein Erfolg. Jonathan Dodge, Advanced Power Technology, Bend, USA

Two major drawbacks of high voltage MOSFETs (BV_{DSS} of 200V or higher) have been solved by Power MOS7 IGBTs from Advanced Power Technology: on-resistance and strong temperature dependence of on-resistance.

Figure 1 shows the dramatic improvement in on resistance and its temperature coefficient compared with a MOSFET of the same size. At 30A, the IGBT in Figure 1 has an effective on-resistance of 90mΩ worst case, compared to the 240mΩ of the same size MOSFET, a factor of 2.7 improvement at room temperature. At 125°C, the IGBT has 5.6 times lower on resistance than the MOSFET. This is the second strong point of the IGBT; on-state voltage changes very little with temperature.

Figure 1 (right). Current versus on-state voltage for same size Power MOS7 MOSFET and IGBT, 15V Gate bias



TRADE-OFFS FOR LOW CONDUCTION LOSS

Trapped minority carriers at turn-off cause a tail current in the IGBT. This tail current is the main drawback of IGBTs because it increases the turn-off switching time and loss compared to a MOSFET. Punch-through IGBTs like the Power MOS7 series utilise active minority carrier lifetime control which quickly recombines minority carriers in the IGBT and dramatically shortens the tail current.

There is a trade-off between the amount of lifetime control and the on-state voltage. Faster turn-off results in lower turn-off energy loss, called E_{off}, and higher on-state voltage, hence higher conduction loss. Figure 2 shows the normalised E_{off} versus $V_{CE(on)}$ relationship for a typical manufacturing range of $V_{CE(on)}$ in 600V Power MOS7 IGBTs. The balance of this E_{off} versus $V_{CE(on)}$ trade-off and general advances in IGBT technology are what allow Power MOS7 IGBTs to displace MOSFETs in a larger number of applications. This trend of IGBTs displacing high voltage MOSFETs will continue because there is much more room left for improvement in IGBT performance than in high voltage MOSFET performance. MOSFETs with voltage ratings below 500V will be surpassed by the cost/performance advantage of IGBTs, probably down to 200V ratings.

The part-to-part variation in $V_{CE(on)}$ strongly affects current sharing when paralleling. MOSFETs have some part-to-part variation in $R_{DS(on)}$, but the magnitude of variation is relatively small. Sorting based on $V_{CE(on)}$ is recommended when paralleling PT IGBTs, whereas sorting of MOSFETs is generally not necessary. The $V_{CE(on)}$ temperature coefficient of PT IGBTs is actually a secondary issue when paralleling; the variation in $V_{CE(on)}$ is the main issue.

WHEN TO USE AN IGBT

An IGBT can be a good choice in applications with a bus voltage of 200V and higher. In general, 600 and 900V Power MOS7 IGBTs can be used in hard switched applications at or below about 200kHz, and the 1200V IGBTs can be used at or below about 50kHz hard switched.

The turn-on speed of these IGBTs is practically identical to that of a MOSFET, making them well suited for soft turn-on applications like a phase shift bridge. Just as with MOSFETs, soft turn-on can significantly extend the usable frequency range of IGBTs. An advantage of these IGBTs is that they do not conduct current from emitter to collector.

Applications such as a phase shift bridge that requires emitter to collector current flow can use an IGBT and an anti-parallel diode in the same package. The performance of the diode in these 'Combi' devices is far superior to the body diode of a MOSFET.

Soft turn-off can work well with PT IGBTs due to active lifetime control, but turn-off time will be longer than for a MOSFET because of the time required to recombine trapped minority carriers. MOSFETs perform the best at very high frequency soft switched applications because of shorter turn-off delay and current fall times.

In general, MOSFETs beat IGBTs at very high frequency or very high efficiency at relatively low current. They do so by utilising much more silicon area per application than IGBTs and therefore at significantly higher cost. An analogy would be to compare the cost/performance of a sports car with an economy car. The main advantage of IGBTs over MOSFETs is lower cost. Depending on operating conditions, higher efficiency and power density are also advantages.

APPLICATION EXAMPLE

Hard-switched applications like a PFC boost converter with a 400V bus are definitely candidates for IGBTs. Simulations based on inductive switching tests compare the performance of two paralleled APT5024BLL 500V, 22A Power MOS7 MOSFETs, a single APT5014B2LL 500V, 35A Power MOS7 MOSFET, and a single APT30GP60B 600V, 49A Power MOS7 PT IGBT. The conditions are 400V$_{out}$, 18A switched, 125ºC junction temperature, 15V gate drive, 10Ω gate resistance for each APT5024BLL MOSFET and the APT30GP60B, and 5Ω gate resistance for the APT5014B2LL. The results are shown in Figure 3. Note that the simulations were also verified in a hard switched boost converter operating at 50, 100, 150, and 200kHz with an insulating pad installed between the devices and the heatsink.

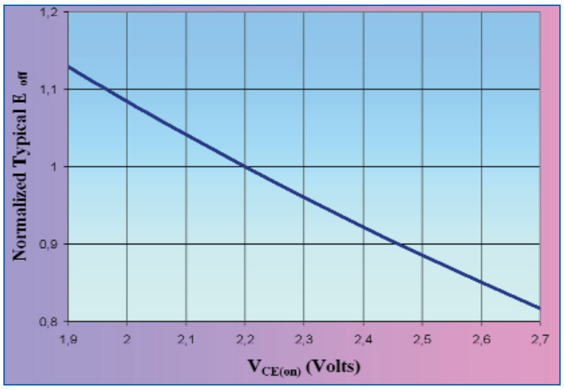


Figure 2 (right). Normalised turn-off energy versus $V_{CE(on)}$ at 25°C for 600V Power MOS7 IGBTs

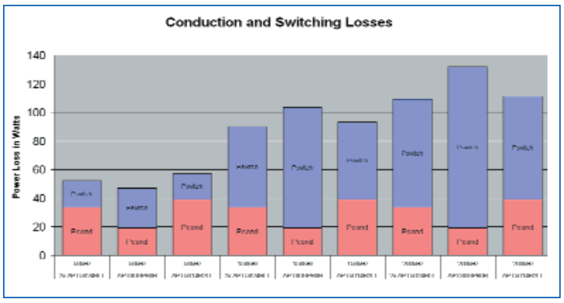


Figure 3 (right). Conduction and switching losses for two parallel MOSFETs versus a single IGBT of different types

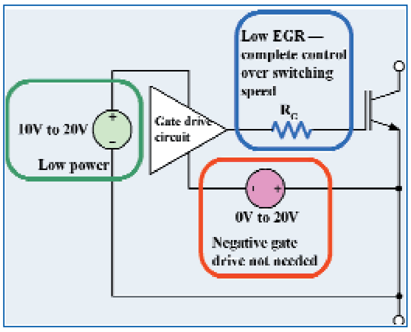


Figure 4 (left). Gate drive requirements

The IGBT of course has the lowest conduction loss because of its conductivity modulation (bipolar current flow). The low conduction loss of the Power MOS7 IGBT effectively offsets its higher switching losses. Total power losses are very similar for the IGBT and the MOSFETs up to about 150kHz. The higher IGBT switching losses are due to higher turn-off energy, the turn-on energy is almost identical for the MOSFETs and the IGBT.

The IGBT could certainly be used in this application, even at 200kHz and at much lower cost than the MOSFETs. The APT5024BLL has about the same die size as the APT30GP60B, and since two APT5024BLL devices are required above about 50kHz, it is a more costly option. The same is true of the single APT5014B2LL MOSFET. One thing to keep in mind is the smaller size of the IGBT causes its temperature rise to be higher than that of the MOSFETs if the total power loss is about the same.

Notice in Figure 3 that the conduction loss of the IGBT is a very small portion of the total losses above about 150kHz. Choosing a larger IGBT does not reduce switching losses but rather can increase them unless the gate resistance is adjusted to compensate for the higher gate charge. Therefore, choosing a larger IGBT to reduce total losses in a hard switched application operating at 150kHz or higher would result in very little reduction in total losses. This is not the case for the MOSFETs since conduction loss is still a significant portion of the total loss, even at 200kHz. So the optimum frequency range for these IGBTs to replace MOSFETs is generally at or below about 150kHz in hard switched applications, and below about 300kHz soft switched.

GATE DRIVE

Power MOS7 IGBTs utilise a unique metal gate with a planar striped layout. The planar stripe layout has proven to have superior reliability at high temperature and to be very tolerant of manufacturing defects. The metal gate results in very low equivalent gate resistance in the device, enhancing immunity to dv/dt induced turn-on in bridge circuits and enabling fast, uniform excitation of the gate. The overall result is exceptional reliability and the ability to control switching speed over a wide range by adjusting the value of gate resistance and/or a ferrite bead. Other distinguishing features of Power MOS7 IGBTs are extremely low gate charge and reverse transfer capacitance, features derived from Power MOS7 MOSFET technology and resulting again in industry leading switching speed.

These IGBTs were designed to be driven similar to MOSFETs. Negative gate bias is not required but may be used, just as with MOSFETs. Low gate charge by design combined with smaller die size IGBTs displacing larger sized MOSFETs results in a very low gate drive power requirement.

Enquiry No: 255