By Bill Travis, Senior Technical Editor

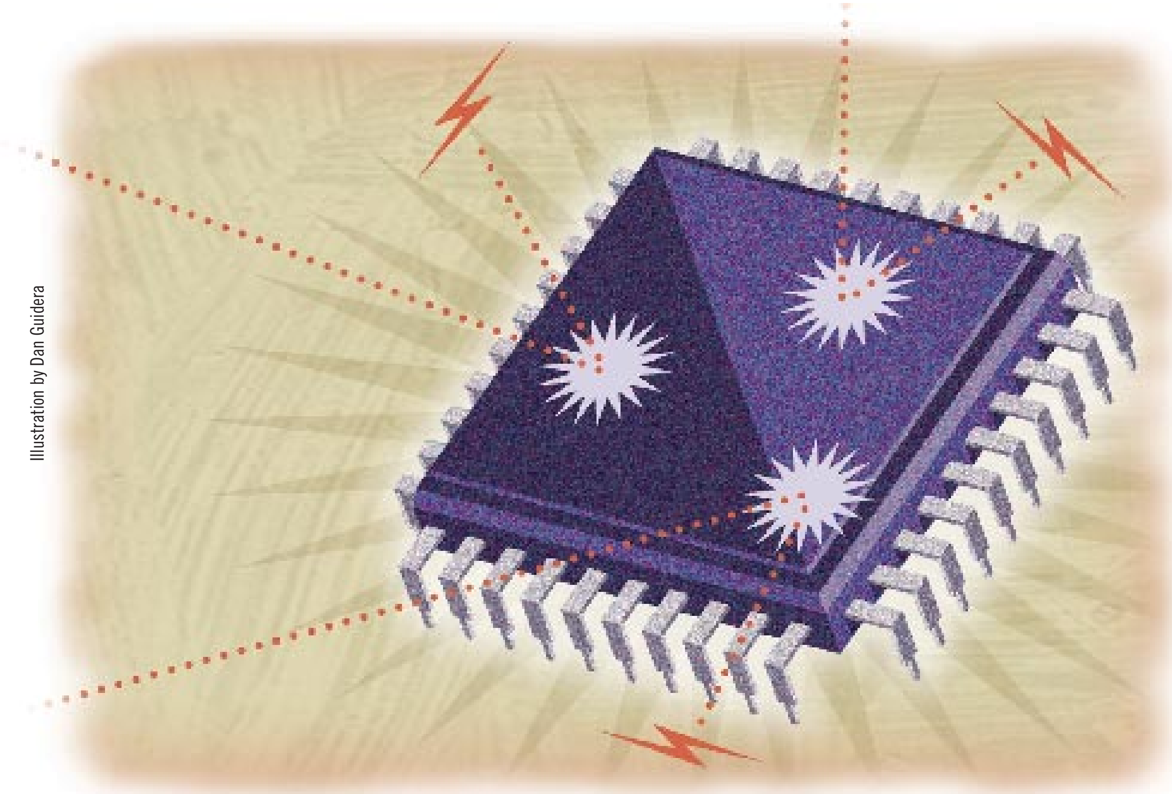


Illustration by Dan Guidera

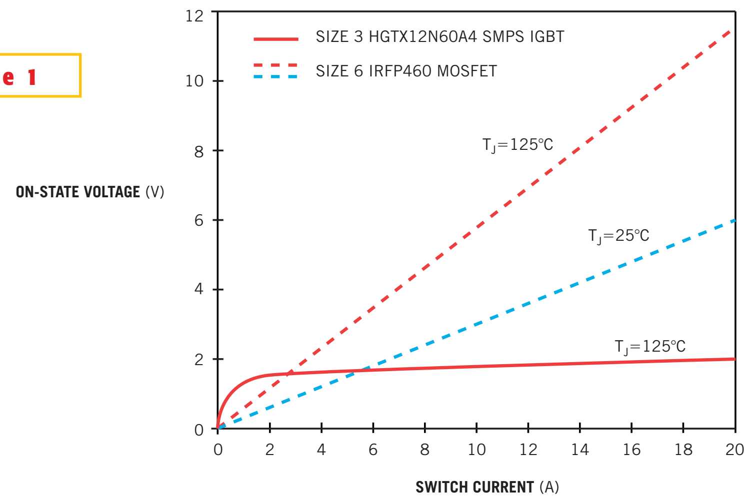
IGBTs come of age in switchers

NEW, HIGH-SPEED IGBTs CAN BEAT MOSFETs IN CONVERSION EFFICIENCY AND SILICON AREA IN SWITCHING SUPPLIES OPERATING AT 100 kHz AND FASTER.

The insulated-gate bipolar transistor (IGBT) is a workhorse of a semiconductor. Capable of blocking extremely high voltages and conducting high currents with low losses, it is the switching element of choice for rugged applications. Motor control, one such application, demands high voltage and current capabilities. Motor drive places no stringent demands on the switching speeds of its drivers. That's not the case with switchmode power supplies (SMPSs), in which the slow speed of the switching elements contributes directly to a loss of efficiency. Until now, the use of IGBTs in switching supplies has been limited to slow switchers (50 kHz and less), mainly because of the switching losses that arise from the slow turn-off times of the IGBTs. A new generation of fast devices from Intersil, "SMPS IGBTs," capably competes head-on with MOSFETs in switchers operating at 100 kHz and faster (www.intersil.com). Moreover, they outperform the nearest equivalent MOSFETs on the basis of silicon efficiency, thermal characteristics, and power-conversion efficiency.

A little history on the IGBT might prove edifying. In 1982, RCA and General Electric virtually simultaneously announced the discovery of the device. RCA dubbed the invention the conductivity-modulated FET (COMFET); General Electric called it the insulated-gate rectifier (IGR); and Motorola followed with the GEMFET. RCA and General Electric found that using a p+ substrate in a basic MOSFET structure resulted in an entirely new class of semiconductor. Instead of a MOSFET drain, the substrate connection electrically resembled the emitter of a bipolar transistor. The conduction characteristics of IGBTs also proved drastically different from those of MOSFETs. Whereas MOSFETs' on-state voltage drops are the product of the conducted current and the on-state resistance ($R_{DS(ON)}$), IGBTs' on-state drops resemble those of a saturated bipolar transistors. So, the new devices have the high-impedance input characteristics of MOSFETs and the current-invariant saturation characteristics of bipolar transistors. **Figure 1** shows the on-state voltage versus current for a Size 3 (0.148-cm^2) SMPS IGBT and a Size 6 (0.654-cm^2) MOSFET.

Figure 1

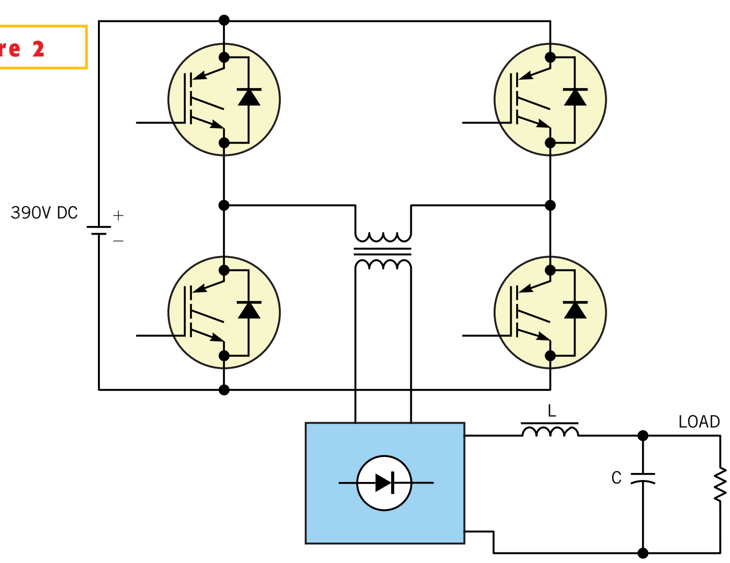


The IGBT exhibits the flat voltage-versus-current characteristic of a saturated bipolar transistor.

IGBTs offer much greater silicon efficiency, so they seem to render MOSFETs obsolete. However, that's not quite the case. First, p-channel, opposite-polarity IGBTs do not exist, whereas p-channel MOSFETs are readily available. Also, early IGBTs were prone to latch-up problems if you tried to switch them too quickly—so they required extensive snubbering to limit the rate of switching. Processing improvements have virtually eliminated the latch-up problem. IGBTs' relatively long turn-off time is another traditional shortcoming. If you provide enough drive to discharge the gate capacitance of a MOSFET, the device turns off almost instantaneously. Early IGBTs required as much as 2 msec to turn off; modern fast IGBTs can turn off in less than 200 nsec. The new generation of SMPS IGBTs can turn off in less than 100 nsec. This high speed enables the new device to compete with MOSFETs in switching power supplies that operate at 100 kHz and faster. Previously, the switching losses from slow switching speeds limited IGBTs to supplies operating around 50 kHz.

To evaluate the efficacy of SMPS IGBT high-frequency switchers, Intersil ran tests on several configurations of power supplies. The first configuration was the 1700W full-bridge converter shown in **Figure 2**. The company compared a Size

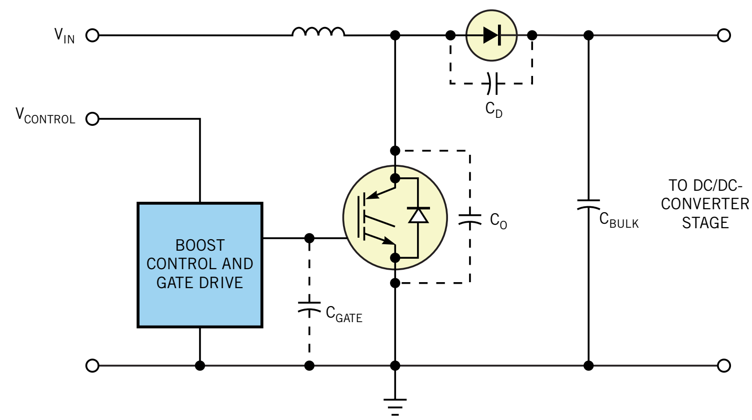
Figure 2



NOTES:
TOPOLOGY=FULL BRIDGE.
SWITCHING FREQUENCY=100 kHz.
MAXIMUM DUTY CYCLE IS 0.45 AT BUS=300V (LOW BUS VOLTAGE).
NOMINAL BUS VOLTAGE=390V.
MAXIMUM DUTY CYCLE IS 0.346 AT BUS=390V.
t_{ON}=3.46 μSEC.
T_JMAX=125°C.
IC_{AVG}=11A.
TURN-OFF CURRENT=12A.
TURN-ON CURRENT=10A.

This full-bridge converter delivers 1700W at 100 kHz, using either IGBTs or MOSFETs.

Figure 3



Intel requires power-factor correction for the company's servers; this typical configuration drives the dc/dc converter for the computer's supply.

3 HGTG12N60A4 with a Size 6 IRFP460 MOSFET. Because of the IGBT's low 1.75V saturation voltage, its on-state losses in the supply are much less than those in the MOSFET: 6.7 versus 20.5W. Because the turn-on characteristics of the two classes are roughly equal, the turn-on losses are equal at 5.5W. The MOSFET beats the IGBT in turn-off losses, 13.6 versus 17.5W. Total power loss is 29.7W for the IGBT versus 39.6W for the MOSFET. Junction-to-case temperature rise is 22.3°C for the IGBT and 19.8°C for the MOSFET. In this configuration, the IGBT clearly emerges as the winner:

- Total power dissipation for the IGBT is 25% less.
- Thermal design is easier (smaller fan size, smaller heat sink).
- You can increase the switching frequency (smaller magnetics).
- The IGBT uses much less silicon (ergo, lower cost).

Power-factor-corrected boost-mode dc/dc converters represent another SMPS IGBT application. **Figure 3** shows a typical configuration. Intel now specifies power-factor-correction requirements on server power supplies with a norm that limits mains harmonics. Intersil compared an HGTG12N60A4D IGBT with an MTY30N50E MOSFET (**Figure 3**). In the converter, the diode and switching transistor share a common heat sink. The results of operating the 850W converter at 62.5 kHz are shown in **Table 1**. Note that the comparison used a Size 3 (0.148 cm^2) IGBT and a Size 7 (1.03 cm^2) MOSFET. The test used both ultrafast STA2006 and hyperfast RHRP1560 diodes. With the ultrafast diode, the IGBT runs 7° cooler than the MOSFET. You can lower the costs by reducing the size of the heat-sink extrusion. Alternatively, you could increase the output power with the same-size heat sink. The cooler-running IGBT also leads to improved transistor and system reliability.

The SMPS IGBT is only the first in a series of planned enhanced-performance IGBTs. To help you design with the devices, Intersil offers advanced Saber/Spice/Mathcad models for circuit and device simulation. The models include full temperature performance, including self-heating effects and transient thermal impedance. They also provide full characterization of transient speed performance. Intersil claims to have validated the models across variations in temperature, voltage, and current.□

You can reach Senior Technical Editor Bill Travis at 1-617-558-4471, fax 1-617-558-4470, e-mail b.travis@cahners.com.

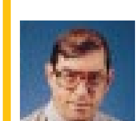


TABLE 1—COMPARISON OF TEMPERATURES IN A POWER-FACTOR-CORRECTION CIRCUIT

Diode	Switch	Temperatures (°C) Switch	Diode	Heat sink
STA2006	MTY30N50E	92	95	92
RHRP1560	MTY30N50E	87	84	87
STA2006	HGTG12N60A4D	85	90	85
RHRP1560	HGTG12N60A4D	84	79	83