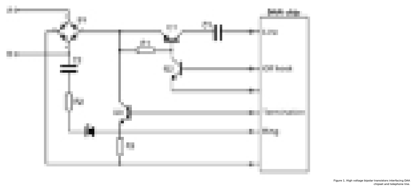
Optimizing the Power Switch in High Voltage Applications

Peter Blair, Zetex Semiconductors

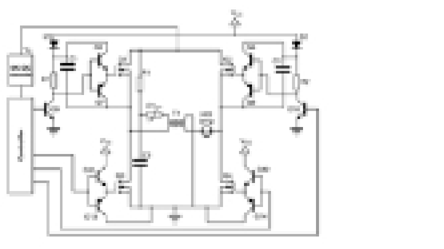
Small high voltage loads are found in abundance. Be they actuators, motors, solenoids or transformers, power supply or power conversion circuits, all are subject to the relentless quest for better energy efficiency, improved reliability and reduced cost and footprint. For the power switching element within such loads, these technical demands appear to manifest themselves as simply “increased switched power density!” In practice, how can this be best achieved?



To some extent, the demands listed above are contradictory. For instance, improving efficiency by increasing the power switching chip size can reduce conduction losses and improve reliability through reduced operating temperature, but this is at the expense of increased cost and a larger package size.

To satisfy the demands for increased switched power density, consider all aspects of power device manufacture, namely the design and construction of both chip and package. When considering breakdown voltages of up to 500V, there are three potential technologies to choose from: IGBT, MOSFET or BJT.

IGBT
IGBTs combine bipolar and MOSFET physics to create very efficient high power devices in larger packages. Unfortunately, the forward voltage drop of the additional emitter junction adds to the on-voltage so that even in a package such as DPAK the typical on-voltages achievable are >1.8V, and may reach 2.8V. While the additional off-set voltage may be feasible for large current devices, in heat-sinkable packages with thermal resistance values down to below 1°C/W it significantly increases the effective on-resistance for low current devices in small SMT packaging with typical thermal resistance values of 60°C/W to 200°C/W limits.



MOSFET

MOSFETs are certainly ubiquitous and have established a dominant position particularly in low voltage applications such as battery portable load switches due to the development of modern trench MOSFET processes. As such, they may appear at first sight to be the natural choice in the 200V to 500V range. However, they exhibit poorer area-specific on-resistance than bipolar transistors as breakdown voltage capability increases. This is because the contribution to resistance of the drift drain region increases rapidly with voltage, as resistivity and thickness are increased to support the voltage.

BJT

While the same must be true for bipolar junction transistors, the effect is mitigated by the bipolar phenomenon of conductivity modulation, whereby operation in the saturation region causes the injection of minority carriers into the collector region, resulting in a commensurate injection of majority carriers to preserve charge neutrality. The effect of this increase in charge carrier density is to dramatically reduce the resistance of the lightly doped collector region during the on-state, thereby reducing the area-specific on-resistance. The significant advantage of conductivity modulation does not, however, automatically lead to superior power density in bipolar transistors.

To deliver class-leading performance, a bipolar transistor must also be carefully designed to minimize series resistance and to ensure even current density across its active area. This must be combined with a compact chip termination, the function of which is to terminate the collector-base junction at the chip periphery while avoiding electric field crowding that will result in premature or unreliable breakdown.

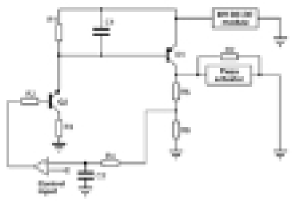
For low-voltage devices, the termination structure can be simple; but for higher voltage devices designed to fit in small footprint packages, it takes up a significant area. Considerable effort is necessary to achieve compact termination structures that maximize the active area of a chip, thereby allowing high power densities.

It is only when an optimized chip design is put together with a package that is engineered to maximize the chip-area-to-package-footprint ratio and achieve reduced thermal resistance, that the goal of high power density is realized. Careful internal design and selection of materials is required to ensure that package robustness is not compromised.

The Latest Bipolar Developments

Consider, for example, a 400V NPN transistor from Zetex Semiconductors that is capable of switching 500 mA continuously, 1A peak, within a SOT23 flat package less than 1 mm high and with a footprint of 7 mm^2. This equates to 200W of switched power and a maximum 28.5 W/mm^2 switched power density. The effective RCE(SAT) is down to 350 mW, a performance only previously available in the SOT223 package having six times the footprint and one-third of the power density.

Compared to this example, a typical MOSFET of an equivalent voltage rating can achieve continuous current ratings of approximately 3A in a DPAK package with a footprint of 64.3 mm^2, equating to a maximum switched power density of 19.3 W/mm^2 — only two-thirds that of the bipolar transistor. Despite the larger package and chip, the MOSFET RDS(ON) is typically more than four times the minimum RCE(SAT) of the bipolar transistor.

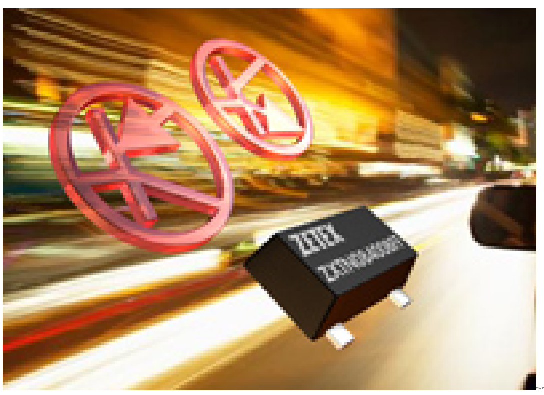


Other Selection Criteria

The illustration above does not tell the whole story. A designer must carefully consider other factors such as drive current capability, switching speed, nature of load and ambient temperature. A particular issue with the use of bipolar transistors in high voltage circuits is avoiding simultaneous high voltages and high currents that may lead to secondary breakdown failure. Unclamped inductive switching, for example, would require careful analysis. However, high voltage bipolar transistors in various small SMT package styles are available to suit a number of demanding applications, some of which are briefly outlined here.

Fax, modem and voice circuits require Data Access Arrangement (DAA) chipsets to interface with the Public Switched Telephone Network (PSTN). High voltage discrete transistors with breakdown voltages appropriate to the various national standards are used to connect the DAA chips to the telephone lines. Figure 1 shows a DDA chipset interfaced to the telephone line using bipolar transistors, Q1, Q2 and Q3. Typically 300V to 400V transistors are specified in SOT23, SOT89 and SOT223 outlines.

HID car headlamps require electronic ballasts that drive the lamp via a transformer (Figure 2). During start-up, the striking voltage may exceed 20 kV, which in turn requires the ballast and driving circuitry to withstand 350V. Typically 400V NPN and PNP bipolar transistors (Q5, Q6, Q7, Q8, Q9, Q10) are specified in the bridge high-side driver stage.
Piezo diesel injection valves are replacing traditional solenoid injectors driven by fuel emissions and efficiency considerations. Figure 3 shows a typical circuit using 300V to 400V bipolar transistors to switch the high-voltage supply to the piezo elements.



Conclusion
Bipolar technology provides designers with the ready means to achieve increased switched power density goals in high voltage load driving circuits. The advantages the latest bipolar transistors offer over MOSFET or IGBT alternatives, in terms of high breakdown voltage, switched currents up to an Amp and the smallest possible footprint, make them the power switch of choice in a wide range of demanding applications.

Peter Blair is Discrete Product Development Manager at Zetex Semiconductors plc. For more information, contact Ronnie Doctor, Zetex Semiconductors plc, Zetex Technology Park, Chadderton, Oldham, OL9 9LL, United Kingdom; +44 (0)161 622 4444; rdoctor@zetex.com [1]; *www.zetex.com* [2].

Links:
[1] mailto:rdoctor@zetex.com
[2] http://www.zetex.com/