SiC and GaN Semiconductors in Modules for Higher Efficiency

With the increasing availability of new semiconductor materials such as SiC and GaN the opportunity to design higher switching frequency circuits at higher power levels has become possible for power electronics design engineers. Both SiC and GaN devices exhibit lower switching losses and higher switching speeds compared to existing Si devices. SiC offers the added advantage of higher operating junction temperatures. But present packaging limitations such as wiring inductance, module materials and bonding techniques prevent full exploitation of the operating temperature range and the maximum switching frequency advantages offered by these new semiconductor materials. This article discusses the advantages and disadvantages of using modules with SiC and GaN semiconductors in high efficiency and compact light weight applications. **Jerry Moudilos, Field Application Engineer, Vincotech, Munich/Unterhaching, Germany**

Existing low inductance module designs and wiring techniques using SiC and GaN semiconductors allow existing modules to be used efficiently with switching frequencies up to 150 kHz. Higher switching frequencies provide the designer with the ability to decrease the size, weight and cost for isolation and filtering components such as transformers, inductors and capacitors in applications which require compact and light weight designs. An added advantage of these semiconductor materials is their lower switching losses which allows their use in designs requiring higher efficiencies.

Applications requiring higher efficiency

In most cases, designers are required to meet minimum system efficiency levels for their designs. These minimum efficiency levels are becoming increasingly higher and more difficult to achieve. When these efficiency levels cannot be achieved by topology selection or by paralleling switching devices, designers may decide to replace existing Si devices with SiC or GaN devices to lower their switching losses. In these cases the switching frequency may remain the same as the original Si design to prevent redesigning the isolation and filtering components. The disadvantage of using more expensive SiC and GaN devices may be justified to meet these higher efficiency objectives.

An ROI or simple payback period calculation can be made to determine if the higher initial cost for the SiC and GaN devices will be returned over the operational life period of the product. In addition to the energy savings, cooling

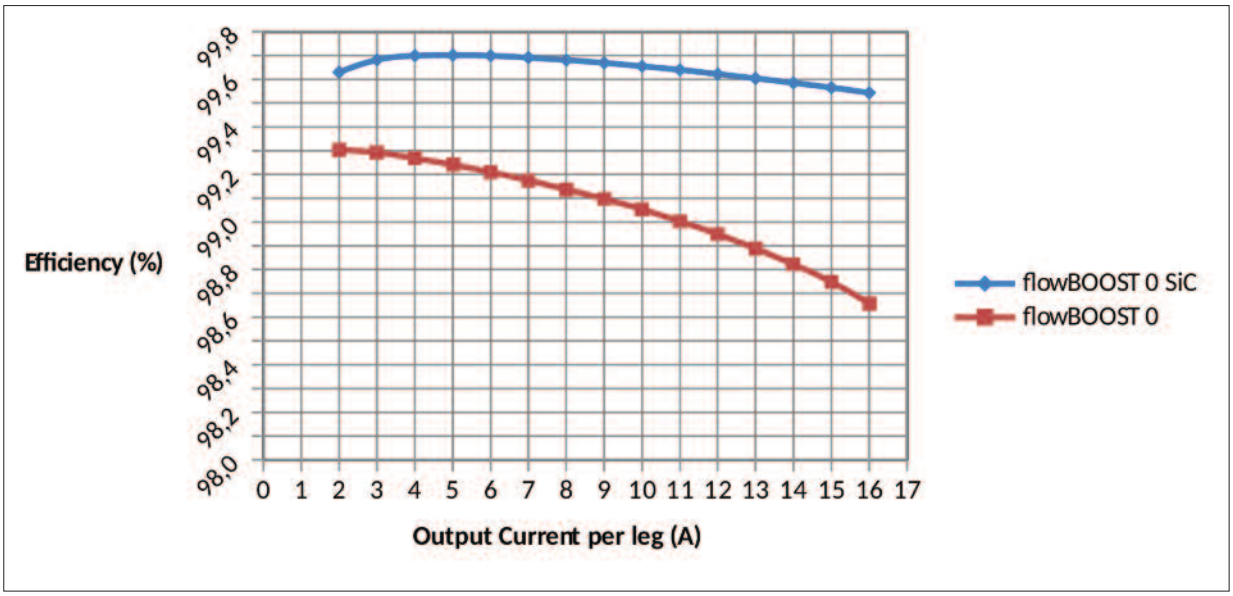

Figure 1: Efficiency comparison between flowBOOST 0 SiC and flowBOOST 0 modules

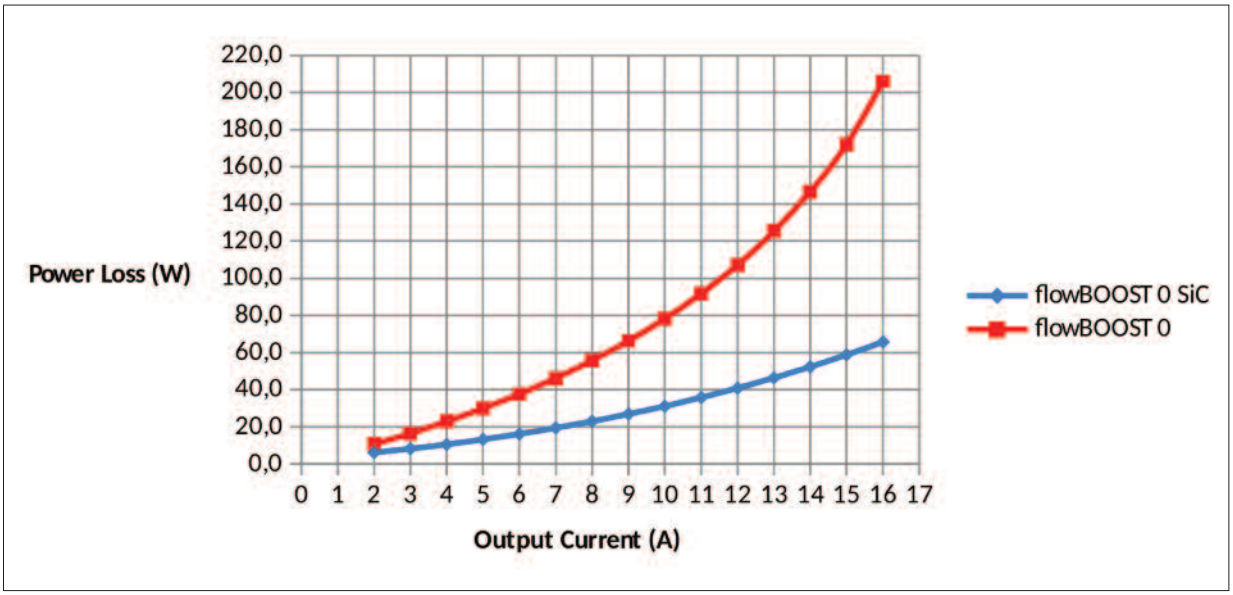

Figure 2: Power loss comparison between flowBOOST 0 SiC and flowBOOST 0 modules

requirements can be decreased since lower switching losses will result in cooler junction temperature when SiC and GaN devices are used at lower switching frequencies. The designer may decide to size down their thermal design to save size, weight, cost and run the module at higher temperatures or keep their existing thermal design and run the module cooler which will prolong the lifetime of the product. This decision will depend on the design's thermal derating criteria and the product's specified life expectancy.

Practical design example

As an example, we can consider the following Si IGBT boost stage design and comparison with an equivalent SiC MOSFET design. The preliminary boost design used Vincotech's flowBOOST 0 Si IGBT based module (V23990-P629-L49) in an application with the following operating conditions:

V_{in} = 500 Vdc, V_{out} = 900 Vdc @ 10 A per leg, R_{gs} = 4 Ω, F_{sw} = 20.0 kHz, $T_{heatsink}$ = 80°C

Using Vincotech's IES2 module simulator, these design and operating conditions resulted in the following output, losses, efficiencies and junction temperatures:

P_{out} = 18.0 kW, Losses = 86.8 W per leg, Efficiency = 99.053 %, Tjmax = 129.9°C

Higher efficiencies were required and the decision was made to replace the Si IGBT module with a SiC MOSFET module. The simulation was repeated with the flowBOOST 0 SiC MOSFET based module (PZ12B2A040ME01-M330L63Y) using the same operating conditions as were used for the Si module. The IES2 simulation software obtained the following results:

P_{out} = 18.0kW, Losses = 31.1 W per leg, Efficiency = 99.655 %, T_{jmax} = 92.2°C

The efficiencies and losses over different loads for the SiC and Si modules were simulated using IES simulator and are shown in Figures 1 and 2.

Both plots show the flowBOOST 0 SiC module has higher efficiencies and lower losses compared with the flowBOOST 0 module and that these differences increase as load current increases.

Although the 55.7 W per leg power saving using the flowBOOST 0 SiC module may seem small, this saving needs to be considered over the operational lifetime of the product. For example, each flowBOOST 0 SiC module consists of two boost stages which will double the power savings to 111.4 W. Assuming this boost converter is used in a solar PV application which will be operating at these operating conditions for 3 hours per day and the contract price of electricity is 0.20 €/kWhr, the additional revenue realized by the solar inverter over 15 years of operation is € 365.95. A more important figure of merit is the payback period which defines the amount of time required to recover the additional cost of choosing the more expensive flowBOOST 0 SiC module over the lower cost flowBOOST 0 module.

Presently, the cost of the flowBOOST 0 SiC module is € 30.29 more than the cost for the flowBOOST 0 module. In this example, the additional cost of selecting the higher efficiency flowBOOST 0 SiC module will be recovered in 1.24 years by the added revenue generated due the lower PV inverter losses. More detailed calculations can be performed which take into consideration the portion of the product's final price which is attributed to the power module and the cost of money if the product was purchased and financed through loans. Exact operating conditions for PV solar inverters will vary for different installation sites. The effects of these site specific parameters should also be considered to obtain more realistic payback periods.

Another design approach to is to determine the additional price one is willing to pay for these higher efficiencies. Payback period can be selected to be aggressive (less than 2 years), moderate (3-5 years) or less aggressive (5+ years) depending on the lifetime of the product and the market's focus on price. Given the energy savings per year, the additional cost one is willing to pay for the SiC devices can be approximated for a desired payback period. In general, if more aggressive payback periods are required, higher prices should be paid for modules with higher efficiency gains. If less aggressive payback periods are acceptable, lower prices can be paid for modules with lower efficiency gains. In either case, comparative simulations should be performed to obtain the new losses and efficiencies which are necessary to calculate the energy savings and payback periods.

Applications requiring smaller and lighter products

Designers in these cases increase the design's switching frequency to decrease the size and weight of the isolation and filtering components to meet the desired size and/or weight requirements. In certain applications such as motor drives

the gains using this design strategy are minimal. Inverters for solar applications, battery chargers and power supplies on the other hand may achieve substantial space, weight advantages with higher switching frequencies. Operating expenses will increase due to the higher switching losses but these costs could be offset if the application is mobile such as a portable variable frequency generator or a portable power supply.

An added advantage of switching at higher frequencies is faster feedback loop responses to load changes which are desirable for power supplies but of little advantage for larger motor drives other than to minimize over- and under-voltages. The designer of these applications may choose SiC and GaN devices to achieve the higher switching frequencies required to obtain the smaller size and lighter weight targets required. Although losses will also increase at higher switching frequencies for SiC and GaN devices, these losses will be much less than those exhibited by Si devices.

For example, if it is determined that the flowBOOST 0 Si IGBT design used in the PV inverter design described above needs to be switched at 60 kHz instead of 20 kHz to achieve the desired size and weight reductions, the simulated losses will increase from 86.8 W per leg at 20 kHz to 253.34 W per leg (506.68 W per module) at 60 kHz. These higher losses will force the flowBOOST 0 module to operate at a prohibitive junction temperature of 265.5°C if the thermal designed for the lower switching frequency is left unchanged.

To maintain the design's maximum derated junction temperature specification, additional cooling requirements such as larger heatsink size and higher airflow will be required for the flowBOOST 0 module to operate at this higher switching frequency. The additional cooling effort could offset any size and weight advantage derived from the smaller filter components. If the flowBOOST 0 SiC MOSFET module is used in this higher frequency design, the losses at 60 kHz will be 46.36 W per leg or 299.73 W less per leg (599.46 W per module) than the flowBOOST 0 module design and the component junction temperatures will be 104.5°C. Using the flowBOOST 0 SiC module in this case will help decrease the size and weight of the filter components without increasing the size of the heatsink and fans required for the original 20 kHz design.

ROI and payback period calculations for these smaller size and lighter weight designs can be performed but are complicated by the fact that the savings are not solely dependent on electrical considerations such as component costs and the cost of electricity. In the case of mobile applications, non-electrical operational parameters such as how often and how far the product will be moved as well as the mode of transportation used will result in fuel savings and will differ for each application.

Conclusion

SiC and GaN semiconductor switching characteristics allow designers to benefit from lower switching losses and higher switching frequencies. These characteristics allow designers the flexibility to use the same switching frequency to increase system efficiencies, or to increase the switching frequency and minimizing the size, weight and the cost of filtering components. Efficiency and loss differences between Si and SiC modules can easily be obtained with Vincotech's IES simulator which can be used to perform ROI and payback period calculations to determine if the selection of these higher cost SiC devices was justifiable for the application.

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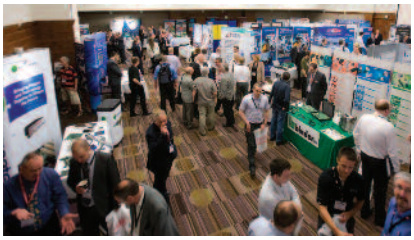

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