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Overcoming Design-in Challenges of SiC Devices Yields Impressive Power Amplifier Results

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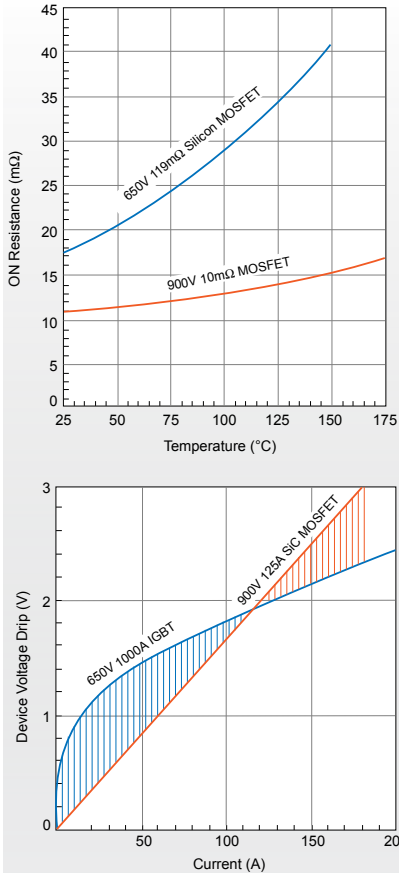


Fig 1. Compared to traditional silicon-based MOSFETs, wide-bandgap silicon-carbide power devices feature lower on-resistance versus both temperature and current levels, as well as better current-versus-voltage performance.

The availability of high-performance, reliable wide bandgap (WBG) power devices based on silicon carbide (SiC) processes is redefining the world of higher-power amplifier-design possibilities and products. The benefits of SiC across the parameters that are critical to these amplifiers: they offer lower on-resistance versus both temperature and current levels, better current versus voltage performance, **Figure 1**, and lower switching losses, **Figure 2**. These amplifiers, which deliver tens and hundreds of amps at higher voltage and speed, are critical but often underappreciated functions in industrial, avionics, and military markets for sonar, motor drive, and DC/AC inverters, to cite just a few of their many applications.

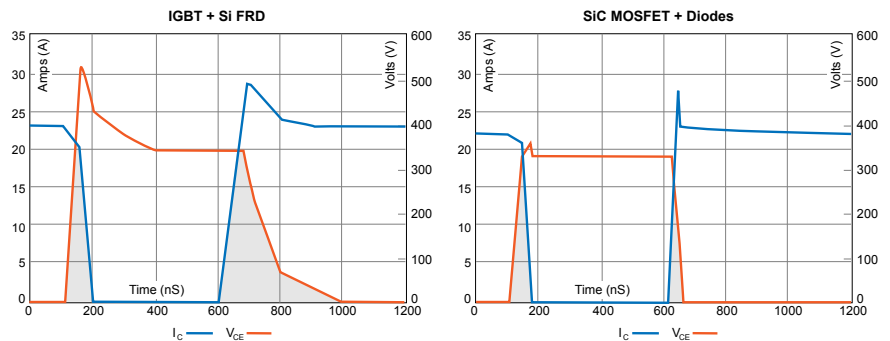


Fig 2: SiC power devices also offer lower switching losses, which is another key metric of power-device performance.

Of course, there are very few “free lunches” in engineering design. The apparent penalty for using SiC – at least for the foreseeable future – is their higher BOM cost, but this downside is outweighed by their greater efficiency and improved performance, and the many follow-on system-level benefits of those improvements including reduced thermal load, simpler cooling, greater reliability.

SiC devices are not the only power-device option, of course. Silicon-based insulated gate bipolar transistors (IGBTs) and superjunction FETs are proven viable power devices, **Figure 3**. (In contrast to planar MOSFETs, superjunction FETs use a structure which has a larger PN junction area than a planar MOSFET, and so reverse-recovery time is faster while reverse-recovery current is higher.)

IGBT	Super-Junction FETs	Silicon Carbide
<ul style="list-style-type: none"> • $P_{L, Cond} \sim I$ • Low device cost • Low conduction losses at high currents • High conduction losses for lower currents • High switching loss • High dependency of losses over temperature 	<ul style="list-style-type: none"> • Low switching losses • Low conduction losses for lower currents • $P_{L, Cond} \sim I^2$ • High dependency of RDS(on) over temperature 	<ul style="list-style-type: none"> • Low switching losses (~constant over temp) • Low conduction losses for lower currents • Low dependency of RDS(on) over temperature • $P_{L, Cond} \sim I^2$ • High device cost (5x-10x)

Fig 3: This brief chart summarizes the relative attributes of IGBTs, superjunction FETs, and SiC power devices.

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The Path from Better Components to Viable End Product

Of course, improved components can be a major benefit when developing a higher-performance product, but using them effectively is often a challenge. Apex Microtechnology's objective was to leverage the virtues of SiC in new, higher-power product designs while avoiding or overcoming the inevitable design-related issues associated with almost any new, better component. While SiC has potential to redefine design constraints, power and thermal concerns are always important issues with amplifiers such as those from Apex.

To do so while also benefitting from a cross-product learning curve, Apex defined several target products using SiC components:

- a half-bridge switching amplifier with integrated gate driver (SA110), **Figure 4**.

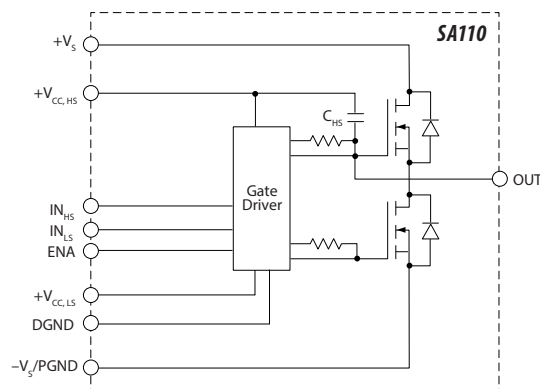


Fig 4. The Apex SA110 is an SiC-based half-bridge switching amplifier with integrated gate driver.

- and a family of fully integrated, high-voltage, high-current drivers rated at 30/100/200 amps per switch (the Apache Peak family), **Figure 5**.

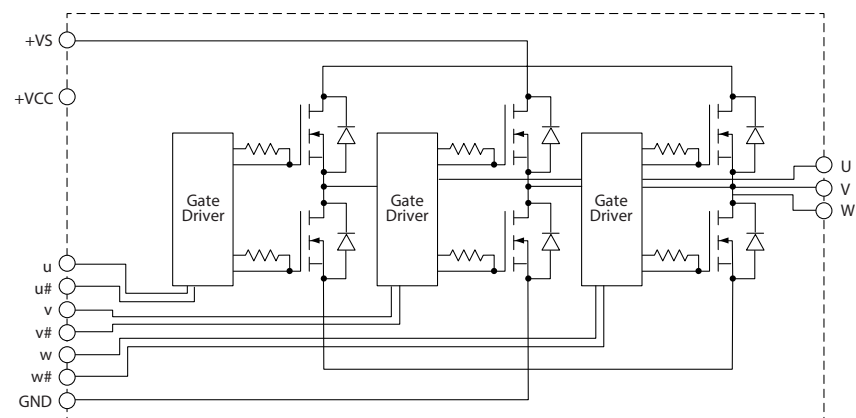


Fig 5. The Apex Apache Peak family of highly integrated, high-voltage, high-current drivers is available with ratings of 30, 100, or 200 A per switch.ure and current levels, as well as better current-versus-voltage performance.

The product design process obviously begins with the data sheets of the selected SiC devices, as these provide critical details about the parts, their capabilities, minimum/maximum ratings, applications tips, and safe operating area (SOA). Well-written data sheets give you the facts about how to drive and use the parts, but don't tell the whole story, as they cannot show how to use them in your specific component design.

While using SiC in a new design brings opportunities, it also brings challenges. The benefits of SiC can be negated due to packaging, parasitics which can exceed on-resistance $R_{DS(ON)}$, trace inductance, or the simple reality of Ohm's Law that trace and interconnect resistance is significant at these high current levels.

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Fig 6. Packaging and thermal issues are major considerations for any high-power amplifier design; the SA110 features dissipation of 75 W and is rated for operation from -40°C to +125°C.



Fig 7. The smallest member of the Apache family, the SA310CR, is packaged as a Power DIP device to allow it to deliver 30 A of continuous current per switch, and up to 80 A peak current.

Overcoming the Impediments

Apex employed several tactics to minimize the design issues associated with SiC devices and in return, realized the benefits they can bring, beginning with co-packaging of the MOSFET driver with MOSFET gate drivers.

At the switching speeds of these devices, the current slew rates (di/dt) are very high. This results in circuit cross-coupling and noise, so the designer's combined tactics include detailed analysis, experience, and judgment with extra attention to routing of PC board traces. In addition, the well-known "skin effect" is a major factor at the operating frequencies, as it reduces the effective cross-sectional area of the package's input/output connections, which increases IR drop and changes the parasitics situation from what it initially appears to be. To overcome these issues, the team used an advanced thick-film technology on substrate, with double-printing of traces to thicken them and so reduce their impedance. While they did not do detailed modeling, they relied instead on extensive prototyping and measurements. In addition, they already had suitable packaging technology, but the output current was limited, so adjustments had to be made.

Beyond the challenge of using bare die for the critical isolated gate drivers, they devised new techniques to use packaged components instead of bare die, as bare die were unavailable for some needed components. Inductance in the gate drive have a greater effect at higher switching speeds. Reducing these effects by co-packaging gate drivers with the SiC MOSFETs by locating the gate drivers very close to the SiC MOSFETs.

To mitigate the thermal concerns, Apex took advantage of existing technologies by extending their capacity to the limits via additional attention to thermal paths, packaging, and materials.

SiC Proof Is In the Products

The result of the effort to use SiC power devices included multiple successful products as well as lessons for the future. The SA110, **Figure 6**, is housed in a 12-lead PSIP package, and includes critical protection features such as undervoltage lockout (UVLO) and active Miller clamping. Operating from a +400 V supply (maximum) and switching at up to 400 kHz, the device delivers 40 A (Peak) and up to 28 A (continuous). Dissipation is just 75 W, and case operating-temperature range is a wide -40°C to +125°C.

Looking to the future of additional Apache devices, the smallest family member (Model SA310CR) will potentially deliver 30 A continuous per switch (up to 80 A peak) from a Power DIP package, **Figure 7**, with just 30 mΩ RDS(on) per switch at 25°C (650 V version) and rising to 40 mΩ at 125°C.

Switching performance and associated losses are also impressive, with fast rise/fall times of 41/27 nsec (for 300 V/18 A waveform) and low turn-on/off losses of 168/112 μJ (300 V/27 A), **Figure 8**.

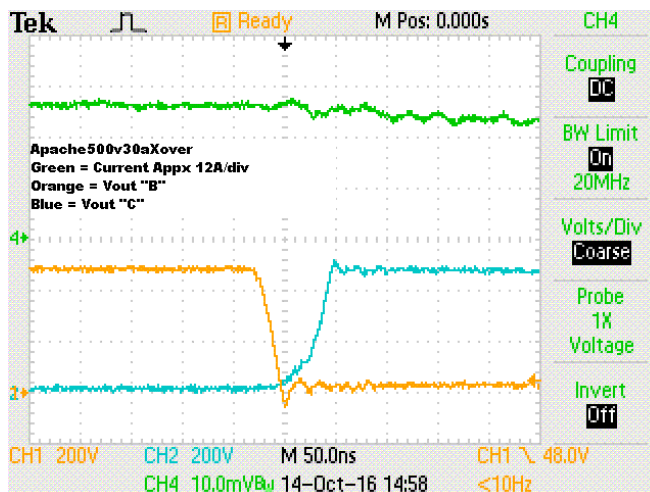


Fig 8. Despite its small size, the Apache series features impressive switching performance, with rise and fall times of 41 nsec and 27 nsec, respectively, when driving 300 V at 18 A.

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Looking Back: Lessons Learned

The first lesson is one that is common when trying to use a new device and process technology that does not have a depth of applications history: it's easy to underestimate the number and subtlety of the issues. Hardware prototyping and iterations are critical, as models and simulation cannot provide the fidelity needed when working at the leading edge, or for very important corner cases

Keep in mind that the increased efficiency of SiC-based designs is all-important because it brings multiple design and operating benefits, beyond the obvious one of electric-power cost savings. First, there's less heat and therefore less need for cooling of the module itself, while the module can be smaller and reduce precious real estate needs. Similarly, the power supply for the module can be smaller and dissipate less heat, and likely be less expensive as well.

Careful thinking about the implication of SiC benefits is needed, but it is a best choice right now for solutions where the focus is on performance and efficiency over temperature and compact design, despite the penalty of higher module cost. Due to the opportunities which are inherent in SiC-based high-power amplifier design, Apex is looking at new packaging to handle higher currents and speeds, and so make maximum use of the new possibilities.

Compared to existing Apex devices using silicon MOSFET and IGBT devices, the performance and efficiency demonstrated with our SiC based devices have shown measurable improvement in efficiency. Increase in speed and efficiency is beyond any of the silicon MOSFET and IGBT devices.

Beyond the improvements seen compared to our silicon-based offerings, the improvement in switching characteristics and waveforms achieved by co-packaging MOSFETs with gate drivers further enhances efficiency over what we have seen in discrete implementations. Add to that the advantages to the end customer of designing in one integrated device compared to multiple discrete devices, the value of using these integrated solutions makes the switch to WBG devices attractive for more applications.

As packaging technology advances Apex plans to offer devices delivering the same speed and efficiencies at much higher output current and voltage supporting many more customer applications.

About the Author

Kirby Gaulin has been with Apex Microtechnology for over 35 years in the roles of IC design, quality engineering, process engineering, analog design engineer, and now fellow. He holds a BS degree in electronics from Chapman University.

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