Drivers Unlock SiC Power Device Capabilities

By Bill Schweber

(Photo source: Microsemi)

Electric motors are ubiquitous in our lives. With so many around us, we don't even realize their presence. Electric motors can range from small ones in toys and automobile power windows to midsize ones in appliances, and larger ones in industrial applications, electric vehicles, and train locomotives, to cite just some of the countless examples. Along with this span of applications comes a diversity of motor types. Going beyond AC and DC power for motors, many of these configurations include switched reluctance, synchronous, permanent magnet, brushless DC, and stepper.

What's the size of the motor market? It's difficult to provide a simple answer. The market can be segmented in so many valid ways: motor type, application, end-user situation, power rating, operating voltage, and global region. One thing is obvious, however. Regardless of a market study, the motor market is growing at a substantial rate, as advanced electronics combine with mechanical designs in almost every aspect of our society. According to one of the many market studies, **Fortune Business Insights** maintains that "the global electric motor market size stood at $108 billion (USD) in 2018 and is projected to reach $167 billion by 2026, exhibiting a CAGR (compound annual growth rate) of 5.7% during the forecast period."

Among the highest motor and related growth areas will be applications over 20kW, such as locomotive-engine traction motors, electric vehicles (a typical EV electric motor is rated at 250hp, about 200kW), and their chargers, and heavy-duty vehicles (**Figure 1**).

Figure 1: *Electric motors of all sizes are widely used in diverse applications, with significant market growth expected in motors rated at over 20kW. (Source: Microchip Technology)*

Efficiency, Smart Management Driving Motor-System Design

Regardless of size or application, an increasingly important priority for motors and their associated circuitry is greater efficiency (except for the very cheapest tiny motors in toys and similar applications). Although regulatory mandates are part of this imperative, two reasons stand out. First, the return on investment (ROI) on reduced energy-related operating costs is quantifiable and favorable. Second, inefficiency also results in added heat generation, and heat is among the major factors contributing to lower reliability and shorter operating lifetime.

Although motor speed and performance can be controlled to some extent by reducing the applied voltage or current, this is not acceptable for many reasons. Even motors that can still operate at lower levels usually can't develop the needed torque. Even if they do, their operation is highly inefficient. Instead, most motors are now driven by electronic on/off switches that rapidly throttle the applied voltage and current. By using electronic commutation or pulse width modulation (PWM) under sophisticated algorithms, the motor is managed to maximum possible efficiency, performance, and precision.

However, these electronic switches are not perfect. They have static losses because of their internal on-resistance (IR loss) and dynamic (switching) losses as they transition from on to off and vice versa. Minimizing these two losses is the primary goal for each generation of switches. Higher voltages are one efficiency strategy, as delivering a needed amount of power to a motor at a higher voltage requires less current, and less current means reduced IR loss. However, higher-voltage switching devices are more difficult to design and fabricate, yet significant progress has been made.

Silicon Carbide Devices Yield Substantial Improvement

Silicon-based MOSFETs have been the standard switching device for many years and have made great strides, but improvements have plateaued with gains coming slowly in recent years. Fortunately, newer process technology has been in development for several decades and has reached maturity in the past few years, with third- and even fourth-generation devices. These MOSFET switches use silicon carbide (SiC) rather than silicon (Si) alone as a base material.

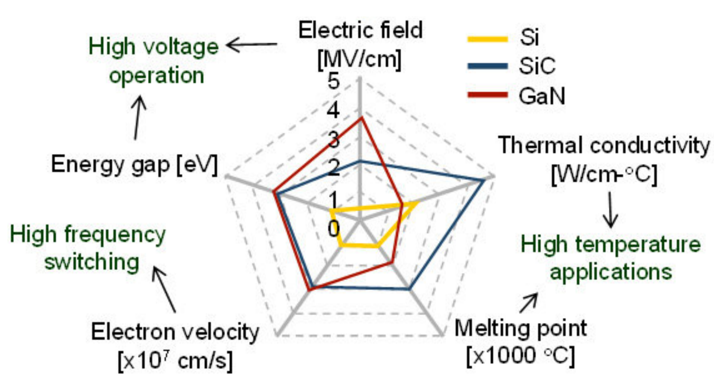

Figure 2: *Approximate comparison among key material properties of SiC versus Si (and GaN) solid materials (Source: ResearchGate).*

Figure 3: *The deep-physics electrical characteristics of SiC ripple upward to yield tangible benefits for devices fabricated using that material and significantly affected system-level design issues. (Source: Mouser Electronics)*

Many in the industry refer to them as SiC devices and leave out the MOSFET part.

For various deep-physics reasons, SiC has important material and electrical characteristics that differ significantly from silicon alone, and each brings advantages. There are other, more subtle ones (**Figure 2**).

These key differences include:

- Higher critical breakdown electric-field voltage of about 2.8MV/cm for SiC versus 0.3MV/cm for silicon alone, so operation at a given voltage rating is possible with a much thinner layer and greatly reduced on-resistance.
- Higher thermal conductivity, enabling higher current density in a cross-section area.
- Wider bandgap (the energy difference (in eV) between the top of the valence band and the bottom of the conduction band in semiconductors (and insulators), resulting in lower leakage current at high temperatures. (For this reason, SiC devices are often referred to as WBG or wide bandgap devices.)

As a result of these differences, in approximate terms, SiC-based devices can block voltages up to 10 times higher than silicon-only ones, switch about 10 times faster, and have an on-resistance half or less at 25°C. At the same time, their ability to operate at much

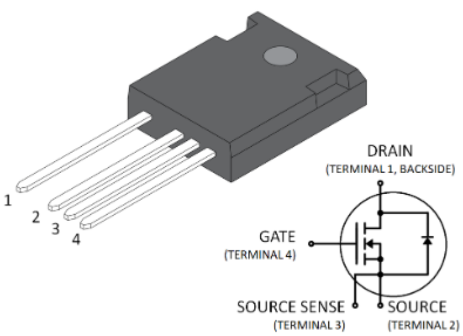

Figure 4: *The Microchip Technology 1200V, 40mΩ SiC MOSFET in a TO-247 package and rated for continuous drain current of 66 A at $T = 25^{o}C$, shows the level of performance possible with a SiC power device.*
(Source: Mouser Electronics)

higher temperatures of 200°C vs. 125°C eases thermal design and management, which are always issues with power devices (**Figure 3**).

For example, the Microchip Technology **MSC040SMA120B4** is a 1200V, 40mΩ SiC MOSFET in a TO-247 4-lead package with a source sense (**Figure 4**). It is rated for a continuous drain current of 66A at T = $25^{o}C$ and 44A at $100^{o}C$, along with a pulsed drain current of 105A. It features low capacitances and low gate charge, fast switching speed because of low internal gate resistance (ESR), stable operation at a high junction temperature of $175^{o}C$, and includes a fast and reliable body diode.

Why is SiC getting so much attention now? It's partially because of the self-reinforcing push-pull cycle between technology advances and application needs that's been seen so many times. The expanding user demands drive device technology advances. Those same advances, in tune, make further application opportunities possible–and back and forth, the cycle goes.

SiC Devices Need Their Drivers

As with silicon-only MOSFETs, it takes a properly designed and matched device driver to interface between the control processor with its algorithms and the SiC device. The driver must simultaneously reach several important goals. It must:

- Implement the basic function of driving current into the SiC device to turn it on, with proper slew rate and voltage. It must also pull current out of the device properly.
- Ensure that the driver's digital-control input and SiC-driving output are carefully matched to the power-device characteristics.
- Deal with driver-device issues such as overshoot ringing, slew rate management, electromagnetic interference (EMI) generation, among others.
- Properly respond to fault conditions associated with the power device, including short circuits or thermal overloads.

The traditional all-analog driver used for silicon MOSFETs has limits and shortcomings in meeting the more-challenging needs of SiC devices. A new approach to driver design is needed. Using digitally

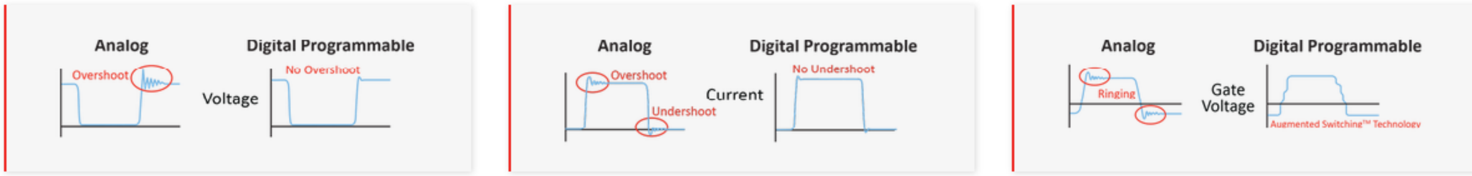

Figure 5: Analog MOSFET drivers have issues related to overshoot, undershoot, and to ring, each of which can have adverse effects on SiC-device performance, and which the digital AgileSwitch driver can overcome by its careful adjustment of the drive waveform. (Source: Microchip)

controlled circuitry rather than an analog approach, the AgileSwitch® High Performance SiC Gate Driver Core devices from Microchip Technology effectively address these issues. These can be precisely tailored to provide optimum driver performance concerning SiC devices and accommodate their unique needs in target applications.

The AgileSwitch driver cores address and solve three distinct but somewhat related problems among their many capabilities (**Figure 5**). These problems–overshoot, undershoot, and ringing (**Figure 5**)–are largely because of unavoidable parasitic inductances and capacitances and cannot be fully avoided using a traditional analog driver for the SiC device.

They are also partly responsible for excessive EMI, one of the most challenging problems to solve (and must be kept below specified levels to meet stringent regulatory standards). Together, these drive-waveform characteristics reduce efficiency and cause false and often catastrophic self-triggering of the power device.

That's where the patented Augmented Switching™ technology of the AgileSwitch plays a major role, as it provides for precise user-specified settings for turn-on and turn-off that soften the edges of a gate's output, thus reducing voltage overshoot and ringing while optimizing a system's efficiency and reducing EMI.

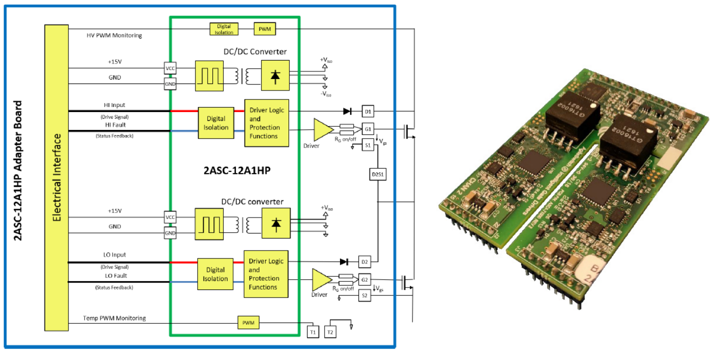

Figure 6: The Microchip Technology 2ASC-12A1HP is a 1200V/10A SiC driver with considerable internal complexity as seen by its block diagram (left) and physical construction (right). (Source: Mouser Electronics)

An example of an AgileSwitch driver core is the **2ASC-12A1HP**, a 1200V dual-channel augmented high-performance SiC Core 1, which enables superior control and protection of most SiC MOSFET-based power systems (**Figure 6**). It provides up to 10A of peak current at positive gate voltages (Vgs) from +15V to +21V and negative gate voltages from -5V to 0V, at frequencies up to 100kHz. The gate-drive core features high common-mode transient immunity (CMTI) and includes an isolated DC/DC converter and low-capacitance isolation barrier for PWM signals and fault feedback.

Configuration Tool Simplifies AgileSwitch Optimization

User configurability is a major benefit, but it must be supported by powerful and convenient tools to tailor that configurability optimally. For that reason, Microchip offers the AgileSwitch Intelligent Configuration Tool (ICT) with multiple levels of software configurability to allow designers to fine-tune performance to their

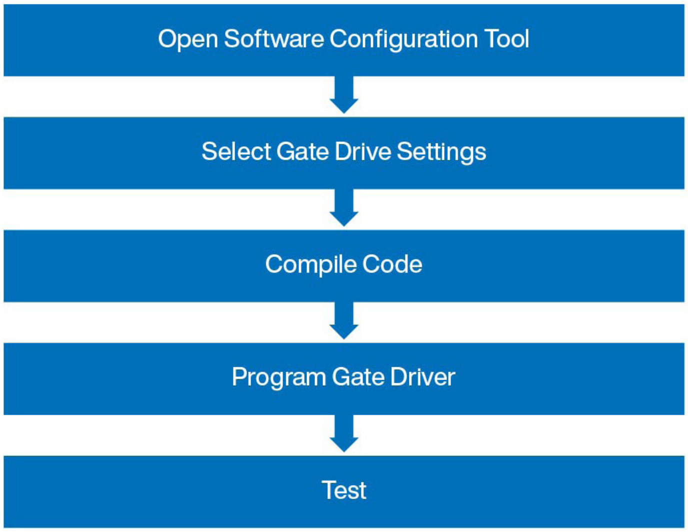

Figure 7: The Microchip Technology Intelligent Configuration Tool (ICT) steps the designer through a sequence that eases the selection of optimal driver parameters. (Source: Microchip Technology)

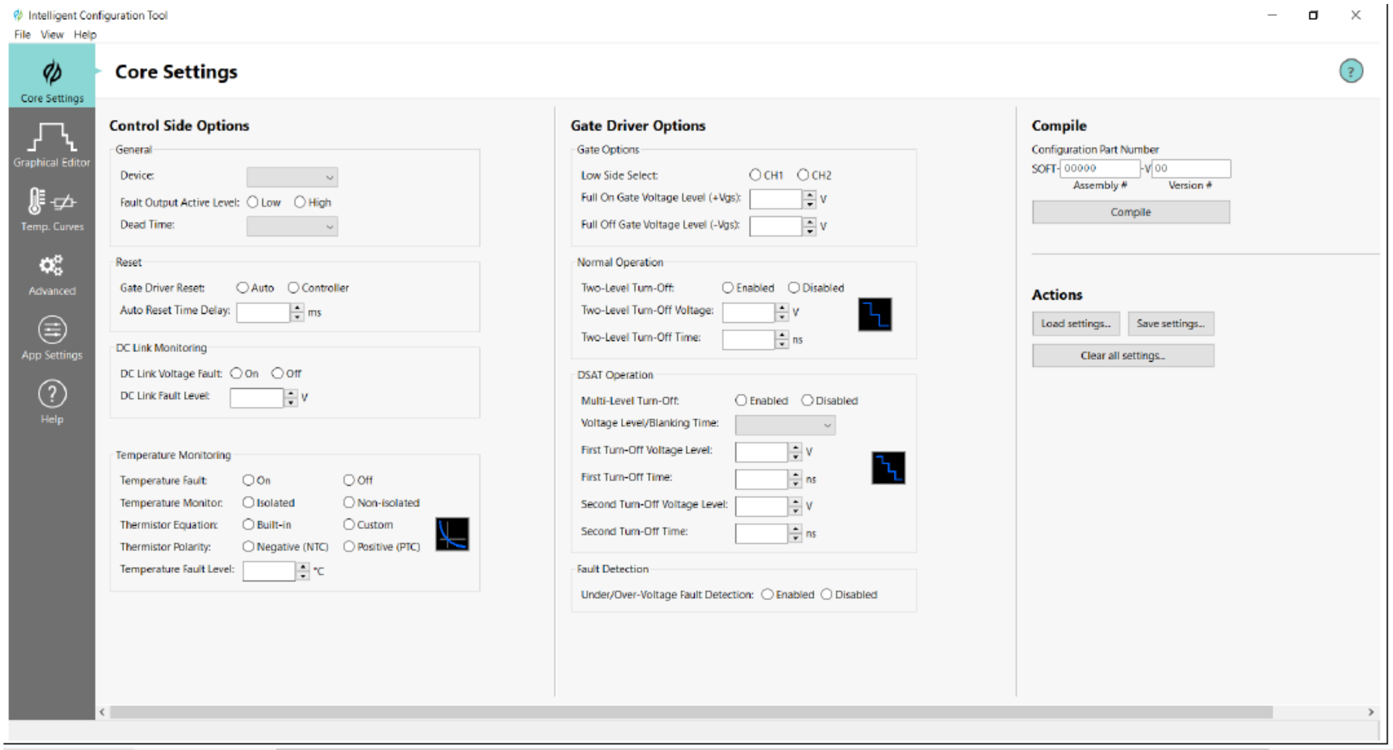

Figure 8: *Using the ICT, designers can easily enter critical driver parameters to understand their effect on driver and SiC-device performance. (Source: Microchip Technology)*

specific system and application. Using this Windows/PC-based tool, designers can adjust settings for the patented Augmented Switching profiles, fault reporting, on- and off-gate voltages, and DC link and temperature trip levels. They can also quickly and easily characterize new devices, including changing driver settings from benchtop using a defined, multistep process (**Figure 7**).

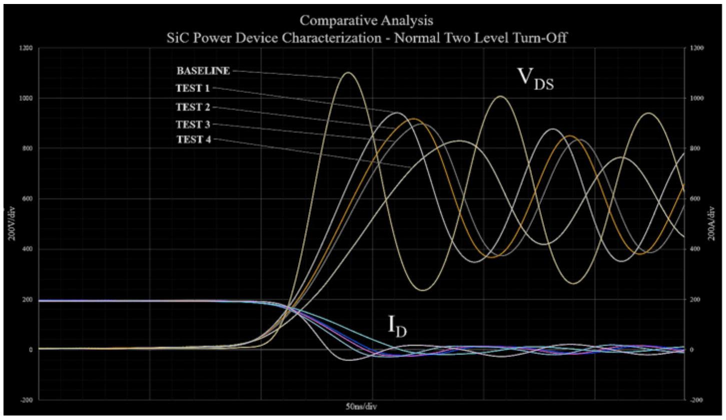

Figure 9: *The ICT provides easily understood and informative images showing SiC device performance corresponding to different driver settings. (Source: Microchip Technology)*

Use of the tool begins with a basic screen with parameter values left blank. The user can enter their configuration parameters, load the default settings, select settings from a list of tested SiC modules, or load in previously saved parameter settings (**Figure 8**).

The tool is well suited for device and system characterization and can be used to quickly assess the system's performance (**Figure 9**). This includes optimizing the overshoot voltage and switching efficiency to meet system requirements and customizing temperature profiles specific to the driver-module type.

Conclusion

SiC-based devices are mature, providing significant efficiency and performance benefits in motor-drive applications, and so are getting major design-ins. However, to fully realize the SiC devices' benefits and achieve consistent performance and reliability, their drivers also need to be properly and carefully matched to the SiC-device characteristics to minimize well-known power-waveform issues that degrade performance and can even result in false triggering. The Microchip Technology AgileSwitch and its configuration tool are addressing and meeting these challenges of SiC drivers.