Technical Article

Delivering on the EV Range Extension Promise of SiC in Traction Inverters

Timothé Rossignol, Marketing Manager

There are two major disruptions currently affecting the future of vehicular transport and semiconductor technology. We are embracing a new and exciting means to propel our vehicles cleanly with electrical power, while simultaneously re-engineering the semiconductor materials that underpin electric vehicle (EV) subsystems to maximize power efficiency and, in turn, EV driving range.

Government regulators continue to mandate that automotive OEMs reduce the overall CO_2 emissions of their vehicle fleets, with stringent penalties for noncompliance, and EV charging infrastructure is beginning to proliferate alongside our roadways and parking areas. For all these advancements, however, mainstream consumer adoption of electric vehicles remains stunted by lingering concerns over EV range limitations.

Complicating matters, the larger EV battery sizes that could extend EV range and neutralize consumers' range anxiety threaten to simultaneously increase EV prices—the battery accounts for more than 25% of the final vehicle cost.

Fortunately, the semiconductor revolution occurring in parallel has yielded new wide band gap devices such as silicon carbide (SiC) MOSFET power switches that can help shrink the gap between consumers' EV range expectations and OEMs' ability to satisfy them at competitive cost structures.

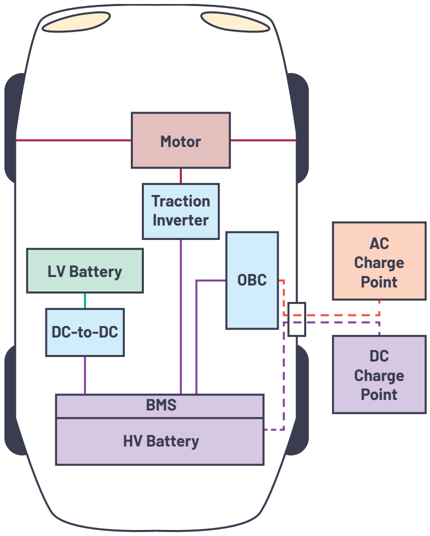

Figure 1. Power conversion elements in EVs. The traction inverter converts the HV battery's DC voltage into AC waveforms to drive the motor, which in turn propels the car.

According to Anuj Narain, a power platform manager at one of the leaders in SiC power devices, Wolfspeed, "SiC MOSFETs, on their own merit, are widely expected to add between 5% and 10% more range for a standard EV driving cycle as compared to existing silicon based technologies." Because of this, they are an important part of the next generation of traction inverters in the EV drive train. If properly exploited with supporting components, their power efficiency gain could represent a huge step forward in building consumer confidence in EV range and help to accelerate EV adoption.

Getting the Most from SiC Technology

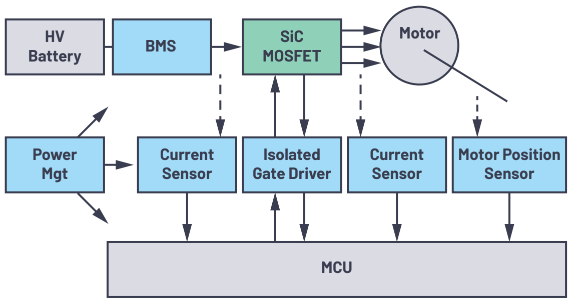

Figure 2. The battery to motor signal chain. To deliver on the range extension, each block should be designed for the highest efficiency level.

The inherent benefits of SiC-based power switches with regard to power density and efficiency are well understood, with key implications for system cooling and size. The evolution to SiC promises 3× smaller inverters at 800 V/250 kW, with additional significant size and cost savings on companion DC link film capacitors. Compared to conventional silicon, SiC power switches can enable better range and/or a reduced battery pack, giving the switches a favorable cost comparison from the device level to the system level.

At the intersection of these range and cost considerations, the traction inverter remains the epicenter for innovations aimed at unlocking further EV efficiency and range gains. And as the most expensive and functionally important element of the traction inverter, SiC power switches need to be controlled very accurately to realize the full benefit of the extra switch cost.

Indeed, all the intrinsic advantages of the SiC switch would be negated by common-mode noise perturbations, as well as extremely high and destructive voltage overshoot due to ultrafast voltage and current transients (dv/dt and di/dt) generated in a poorly managed power switches environment. Broadly speaking, the SiC switch has a relatively simple function despite the underlying technology—it's only a 3-terminal device—but it must be carefully interfaced to the systems.

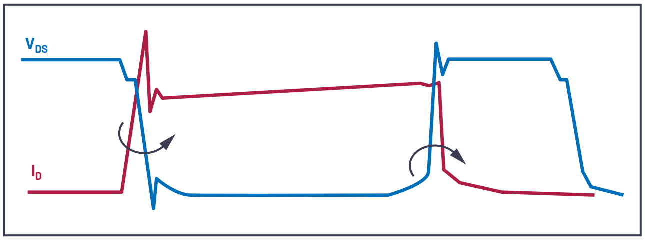

Figure 3. Voltage and current waveforms at turn-on (left) and turn-off (right). In SiC environments, dv/dt will exceed 10 V/ns, which means no more than 80 ns to switch an 800 V DC voltage. In a similar way, a 10 A/ns, meaning 800 A in 80 ns, type of di/dt can be observed.

Enter the Gate Driver

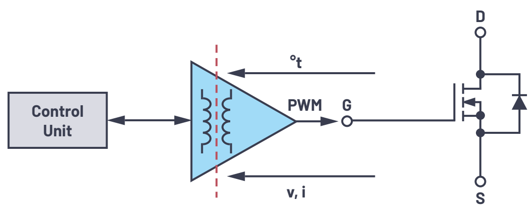

Figure 4. The isolated gate driver bridges the signal world (control unit) and the power world (SiC switch). Other than isolation and signal buffering, the driver performs telemetry, protection, and diagnostic functions, making it the key element of the signal chain.

The isolated gate driver will take care of setting the best switching sweet spot, ensuring short and accurate propagation delay through the isolation barrier, while providing system and safety isolation, controlling power switch overheating, detecting and protecting against short circuits, and facilitating the insertion of the sub-block drive/switch function in an ASIL D system.

The high slew rate transients introduced by the SiC switch can corrupt data transmission across the isolation barrier, however, so measuring and understanding the susceptibility to these transients is critical. *i*Coupler® ADI proprietary technology has shown leading common-mode transient immunity (CMTI) with measured performances up to 200 V/ns and beyond. This unlocks the full potential of SiC switching time under safe operation.

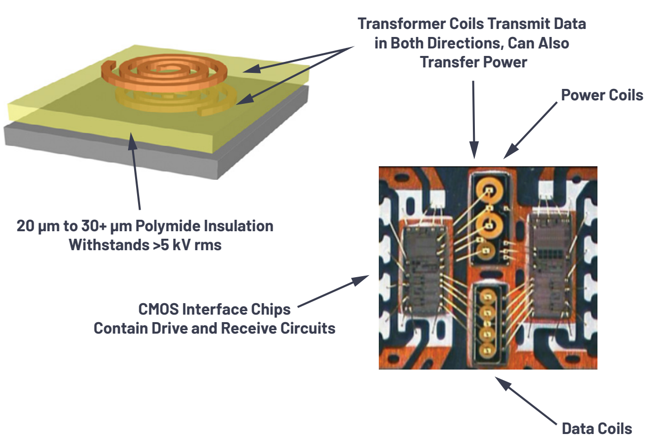

Figure 5. ADI has pioneered advances in digital isolation technology for over 20 years with iCoupler digital isolation ICs. The technology is comprised of a transformer with thick polyimide insulation. Digital isolators use foundry CMOS processes. Transformers are differential and provide excellent common-mode transient immunity.

Short circuits are another major challenge for SiC-based power switches, given the smaller die sizes and exacting thermal envelopes. Gate drivers provide the short-circuit protections essential for EV power train reliability, safety, and life cycle optimization.

High performance gate drivers have proven their value in real-world testing with leading SiC MOSFET power switch providers like Wolfspeed. Across key parameters, including short-circuit detection time and total fault clearance time, performance can be achieved down to 300 ns and 800 ns, respectively. For additional safety and protection, test results have demonstrated the adjustable soft shutdown capabilities essential for smooth system operations.

Switching energy and electromagnetic compatibility (EMC) can likewise be maximized for improved power performance and EV range. Higher drive capability allows users to have faster edge rates and therefore reduces switching losses. This not only helps with efficiency but also enables board space and cost savings by eliminating the need for external buffers allocated per gate driver. Conversely, under certain conditions, the system may need to switch more slowly to achieve optimal efficiency, or even in stages, which studies have shown can increase efficiency further. ADI provides an adjustable slew rate to allow users to do this, and the removal of external buffers eliminates further obstacles.

Elements in a System

It's important to note that the combined value and performance of the gate driver and SiC switch solution can be completely negated by compromises and/or inefficiencies in the surrounding components. ADI's heritage in power and sensing, and our system-level approach to performance optimization, encompass a wide range of design considerations.

A holistic view of the EV reveals additional opportunities for optimizing drive train power efficiencies, which are critical for exploiting the maximum usable battery capacity while ensuring safe and reliable operations. The quality of the BMS directly impacts the miles per charge an EV can deliver, maximizes the battery's overall lifetime, and, as a result, lowers the total cost of ownership (TCO).

In terms of power management, the ability to overcome complex electromagnetic interference (EMI) challenges—without compromising BOM costs or PCB footprint—becomes paramount. Power efficiency, thermal performance, and packaging remain critical considerations at the power supply layer, regardless of whether the layer is for an isolated gate driver power supply circuit or auxiliary high voltage-to-low voltage DC-to-DC circuit. In all cases, the ability to neutralize EMI issues takes on greater importance for EV designers. EMC is a critical pain point when it comes to switching for multiple power supplies, and superior EMC can go a long way toward shortening testing cycles and reducing design complexities, thereby accelerating time to market.

Deeper into the ecosystem of supporting componentry, advancements in magnetics sensing have yielded a new generation of contactless current sensors delivering no power loss with high bandwidth and accuracy, as well as accurate and robust position sensors for end-of-shaft and off-shaft configurations. There are between 15 and 30 current sensors targeted for deployment in a typical plug-in hybrid EV,[1] with rotation and position sensors monitoring traction motor functions. Sensing accuracy and robustness to the stray field are critical attributes for measuring and maintaining efficiencies across EV power subsystems.

End-to-End Efficiency

Looking holistically at all elements in the EV power train—from the battery to the traction inverter to the supporting components and beyond—ADI sees myriad opportunities to improve EV in a manner that enhances overall power efficiency and extends EV driving range. Digital isolation is one of the many important parts of the equation as SiC power switching technology penetrates the EV traction inverter.

Likewise, automotive OEMs can leverage a multidisciplined approach to EV optimization to help ensure that all available power monitoring and control devices are working in close concert for maximum performance and efficiency. In turn they can help to overcome the last remaining barriers to mainstream consumer EV adoption—vehicle driving range and cost—while helping to ensure a greener future for all.

References

[1] Richard Dixon. "MEMS Sensors for the Car of the Future." 4th Annual Automotive Sensors and Electronics Summit, February 2019.

About the Author

Timothé Rossignol holds master's and Ph.D. degrees in electrical engineering from Toulouse University. He has been working in the automotive industry for the last 10 years, with experience throughout the entire supply chain. Timothé started his career at OEMs and Tier 1 suppliers in France, then worked in the UK as a hardware design leader. He joined Analog Devices in 2018 in Limerick, Ireland, as a system engineer and recently moved back to France to take on a broader role as marketing manager for e-mobility power conversion systems. He can be reached at timothe.rossignol@analog.com.

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