How SiC Is Enabling Next Generation Automotive Power Electronics

EV Power Electronics Challenges and the Role of SiC

Electric vehicles impose strict and often competing constraints on power electronics design. Limited installation space, weight targets, efficiency requirements, thermal limits, safety standards and cost-reduction pressure must all be addressed simultaneously within a vehicle platform expected to operate reliably for many years. As EV architectures evolve toward higher battery voltages and increased onboard power, managing these trade-offs becomes one of the central challenges for OEMs and Tier-1 suppliers.

Silicon carbide (SiC) has emerged as an important wide bandgap (WBG) enabler for addressing these challenges in high-voltage (HV) power electronics. While conventional Si super-junction MOSFETs and IGBTs have served automotive applications well for decades, they show limitations in some applications as power levels rise. Higher switching losses and constraints on switching frequency set by semiconductors physics, increased cooling overhead and the resulting penalties in size and weight. These are some of the inputs in the trade-offs equation that calculates modern EV performance targets.

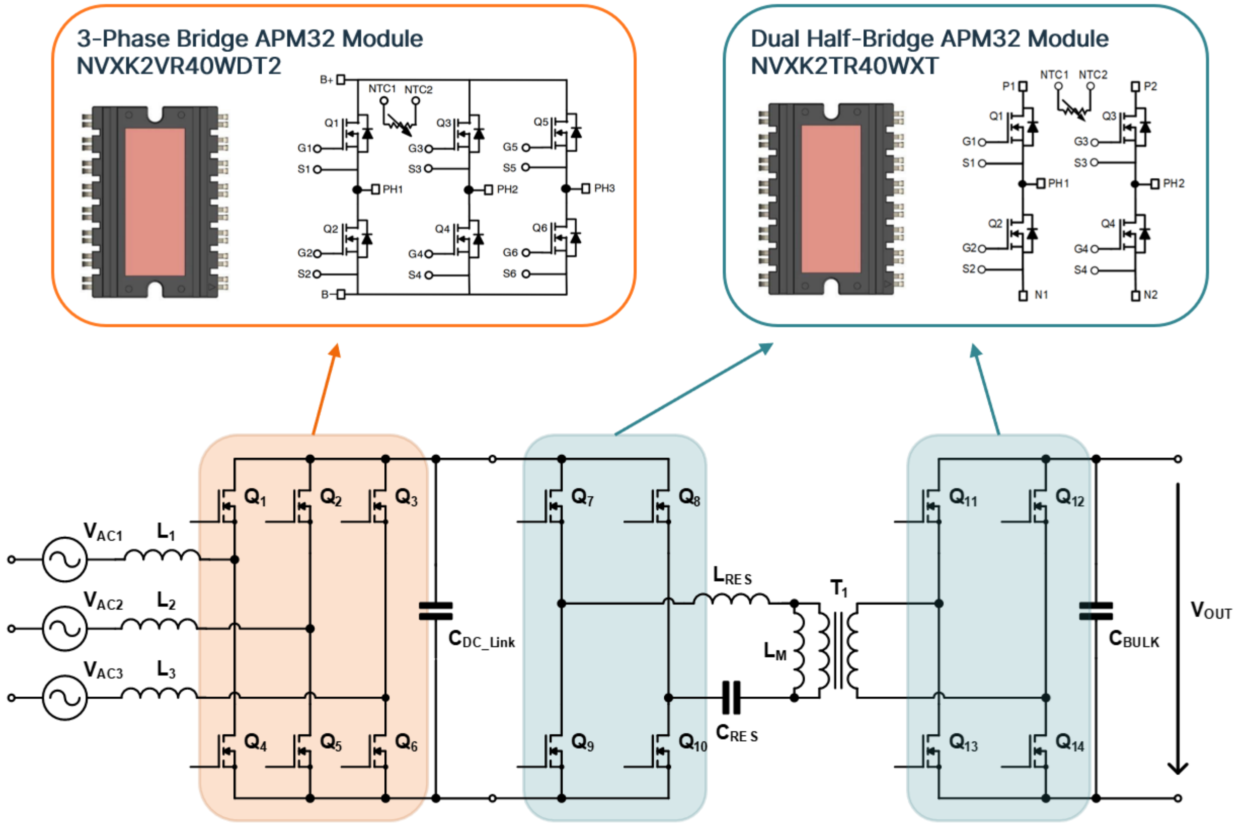
These challenges are most visible in the vehicle’s HV power conversion stages, where energy must be converted efficiently between AC and DC or between different DC voltage levels. One such subsystem is the On-Board Charger (OBC), an essential component in every battery electric vehicle. The OBC converts AC power from the grid into DC power suitable for charging the HV battery pack, while operating under tight constraints on efficiency, power density, thermal performance and electromagnetic compatibility.

OBC requirements vary by vehicle class and regional infrastructure. Premium EVs target onboard charging power of up to 22 kW to reduce charging time, driving higher design stress and more complex thermal solutions. EVs in the mid-price range typically target 11 kW, offering more flexibility in power conversion topologies and electronic components selection, thus providing more options between cost and performance. By enabling higher switching frequencies, significantly lowering power losses, providing low reverse recovery body diode and improving thermal performance, SiC devices expand the OBC design space. This allows designers to reduce the size of magnetics and passive components, simplify thermal management and improve overall system efficiency. To support EV performance targets, **onsemi** offers a broad portfolio of automotive qualified SiC solutions for OBCs and other high power EV subsystems. This includes both discrete SiC MOSFETs, diodes and integrated power modules that allow designers to scale performance, optimize layout and meet automotive reliability targets.

OBC Architectures: Power Stage Topologies and Semiconductors

Conventional OBCs are typically implemented as two-stage power converters, consisting of a bridgeless PFC stage followed by an isolated DC-DC stage, commonly based on LLC or CLLC resonant topologies. As EV platforms transition to 800 V battery architectures and higher onboard charging power, these stages require SiC devices rated up to 1200 V and capable of higher frequency operation.

To support OBC designs in the 11 kW to 22 kW range, **onsemi** offers SiC APM32 power modules optimized for both PFC and DC-DC stages. For example, 3-phase bridge modules such as the NVXK2VR40WXT2 (1200 V, 40 mΩ) are well suited for bridgeless PFC implementation, while full-bridge and dual half-bridge modules like the NVXK2TR40WXT address the demands of faster DC-DC conversion. These modules are automotive qualified under AEC-Q101, AQG-324 and meet creepage, clearance and reliability IEC standards, supporting robust OBC designs in demanding vehicle environments.



Example schematic of a power stage design with APM32 modules for 11kW – 22kW OBC solution. Bridgeless PFC topology and LLC topology for DC-DC.

Extending OBC Functionality with Bidirectional Charging (V2H)

Beyond unidirectional charging, modern OBC designs are increasingly expected to support bidirectional energy flow, enabling vehicle-to-home (V2H) operation. In this mode, the EV battery can act as a mobile energy storage system, supplying power back to a home during grid outages or when paired with local generation such as solar. From a power electronics perspective, this capability is typically realized using a bidirectional CLLC DC-DC topology combined with an active PFC stage. SiC power modules from **onsemi** already used in high efficiency OBC designs are well suited to support these bidirectional operating modes, enabling efficient, compact implementation and seamless transitions between charging and discharging operation.

Optimizing OBC Designs with Top-Side Cooled SiC MOSFETs

In 400 V battery architectures, OBC designs are increasingly challenged by rising power density targets, tighter thermal limits and the need for high efficiency across a wide operating range. To address these requirements, SiC MOSFETs are becoming the preferred switching devices in both OBC power stages and other HV DC-DC converters.

To support these demands, **onsemi** has introduced advanced SiC MOSFETs in a top-side cooled T2PAK package. Compared to conventional bottom-cooled packages, T2PAK enables direct thermal contact between the device's exposed drain pad and an external heatsink or metal chassis. This significantly improves heat extraction from the die, reduces thermal stress on the PCB and enables higher continuous power operation within the same footprint. As a result, designers can achieve higher power density while maintaining robust thermal margins, an increasingly critical requirement in compact OBC enclosures.

Achieving peak system performance requires careful attention to the complete thermal stack-up, including heatsink, mounting pressure, and the selection of high conductivity thermal interface material (TIM). Proper TIM application ensures consistent thermal resistance beyond the device's junction-to-case resistance ($R_{\theta JC}$), supporting long-term reliability under harsh operating conditions.

Pin-Out for EliteSiC MOSFET T2PAK

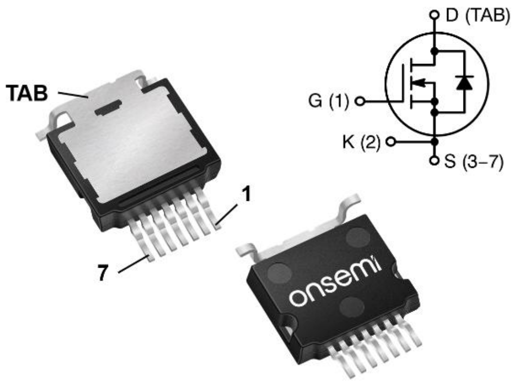


Table: Key specifications of onsemi SiC MOSFETs in T2PAK package

Part Number	V_{DSS}	V_{GS_OP} [V]	$R_{DS(ON)}$ [mΩ]	$Q_{G(TOT)}$ [nC]	$R_{\theta JC}$ [°C/W]
NVT2012N065M3S	650 V	-3 / +18	12.7	135	0.35
NVT2016N065M3S	650 V	-3 / +18	16	100	0.45
NVT2023N065M3S	650 V	-3 / +18	23	74	0.52

In addition to thermal advantages, the T2PAK package minimizes parasitic stray inductance by eliminating long leads and enabling tighter commutation loops compared to traditional D2PAK or TO-247-4L packages. This design feature enables more flexible electrical routing on the PCB and directly contributes to reduced switching losses, reduced voltage overshoot and higher overall system performance. Combined with **onsemi's** M3S SiC technology, top-side cooled SiC MOSFETs provide a compelling solution for high performance OBC designs in 400 V EV platforms.

From Devices to Systems: Building SiC-Based Solutions

To fully leverage the benefits of SiC MOSFETs, galvanically isolated gate drivers must be optimized for this technology, including fast switching capability and robust protection. SiC MOSFETs are susceptible to parasitic turn-on due to Miller capacitance C_{DG}, which couples drain voltage to the gate during switching events. This can occur during the MOSFET turn-off phase, because of the remarkably high di/dt. This can lead to shoot-through currents and device failure if a direct short from the high voltage rail to ground appears during the parasitic turn-on. One highly effective mitigation against this issue is to swing V_{GS} below 0V, typically down to -3V or even -5V during turn-off phase. The NCV51152 isolated gate driver enables this protective feature and can generate a negative V_{GS} swing during turn-off, by supporting external negative bias or negative power supply.

These system concepts come together in **onsemi's** 11 kW Matrix OBC demonstration design, which shows how SiC technologies can be combined into a complete OBC solution. SiC MOSFETs in top-side cooled T2PAK packages form the core of the power stage, enabling switching performance, efficient thermal management and robust implementation. When paired with galvanically isolated gate drivers, the design achieves robust control, fast switching and reliable operation. This demonstration design highlights a system level approach, showing how advanced semiconductors, packaging, thermal management and control algorithms can be integrated into a working OBC platform that addresses real EV design constraints.

11 kW Matrix OBC (Demonstration Design)