GaN Raises Electric Vehicle Powertrain Performance

In recent years, the number of electric vehicles (EVs) have multiplied on our global roads. Industry analysts expect that 56 million new EVs will be sold in 2040. The electricity consumption that accompanies this growth will rise to 1,800 TWh, representing 5 % of global power according to Bloomberg NEF's Electric Vehicle Outlook. A smart, smaller, lighter-weight powertrain is a key area in creating changes for the EV industry.

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The design challenge for tomorrow's generation of electric vehicles continues to intensify with a clear focus on the search for maximizing range, faster charging, and lower cost electrification systems. GaN power transistors are a significant part of addressing these current and future industry challenges by enabling the creation of smaller, lighter, lower cost, and more efficient power systems, especially in high-performance powertrain solutions. Thus GaN power transistors can open the market for more energy efficient and practical vehicles. Figure 1 shows a typical powertrain architecture for an EV system, which includes three main electrical sections:

- The AC/DC Bi-directional On-board Charger (OBC) charges or discharges the energy to the battery. A bridgeless totem pole PFC together with a Conventional LLC (CLLC) resonant converter are present as an example for OBC'

Type	GaN GS66508B	SiC MOSFET	Si SJMOS FET	Si IGBT+Anti-parallel diode
RDS(on), typ(mΩ) or Current (A)	50mΩ	55mΩ	40mΩ	40A
VDSS, max(V)	650	650	650	650
Qrr, typ(nC) @25°C	0	85	13000	1000
Qrr(nC) @ 100°C	0	139	Very high	High
Qg(nC)	5.8	73	93	95
td(on)/td(off), typ(ns)	4.3/8.2	16/35	20/82	20/157
tr/tf, typ(ns)	3.7/5.2	9/14	14/7	30/30
EOSS, typ@ 400 V (µJ)	7	12	12	-
RthJC(MAX)°C/W	0.5	0.72	0.55	0.6
Package type	GaNPX® embedded	D2PAK-7L	D2PAK	D2PAK

Table 1: Comparison of power transistors and

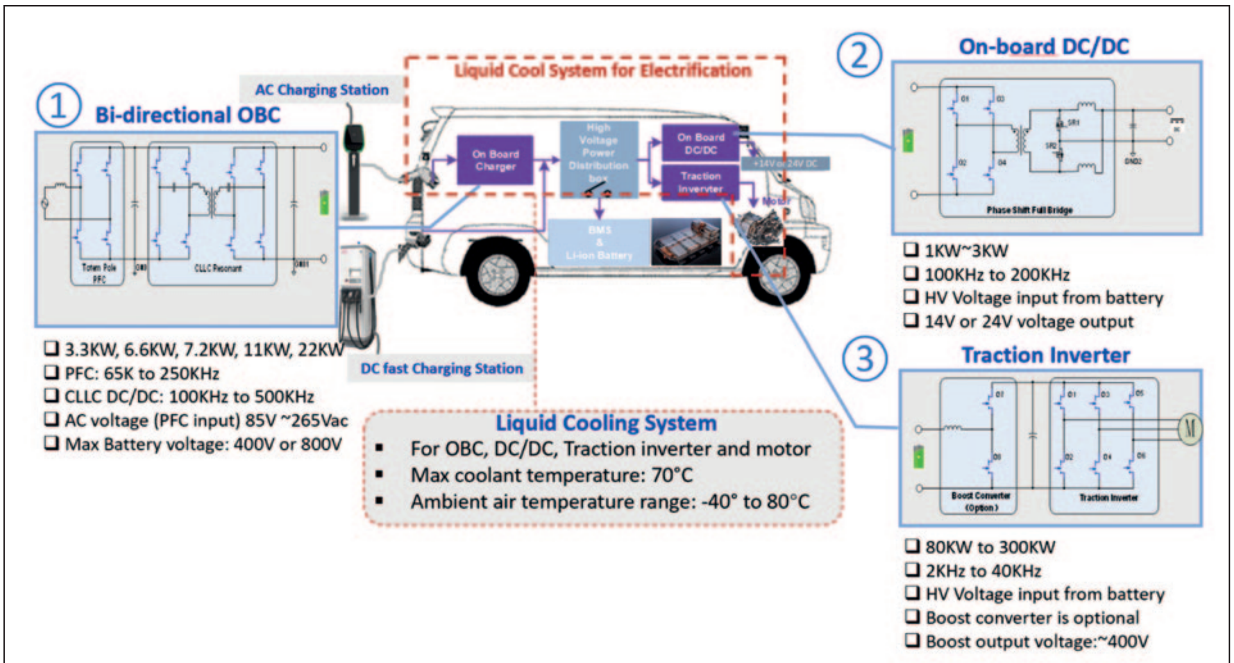


Figure 1: EV powertrain architecture and key specifications

topologies. The power rating ranges from 3.3 kW to 22 kW.

- An on-board DC/DC Converter converts the high voltage input from the battery to low output voltage (14V or 24V) for auxiliary systems. The power rating typically ranges from 1KW to 3KW.
- The Traction Inverter drives the motor through the high voltage DC battery pack. A 3-phase, 6-switch motor drive topology is present with a front-end boost converter as an option. The power rating normally ranges from 80 kW to 300 kW.

Normally the OBC, DC/DC converter, and traction inverter in an EV share one liquid cooling system where the maximum coolant temperature is 70°C with ambient air temperature ranging from -40°C to 80°C.

Technology innovation is happening quickly and new requirements of future powertrain systems need to consider:

Reliability. This is a key factor affecting the adoption of new technologies in EVs. For automotive power semiconductors, the Automotive Electronics Council (AEC) establishes baseline reliability testing requirements (AEC-Q101) however, further assessment is required. Semiconductor vendors must implement testing procedures that extend stress testing beyond standard qualification conditions to predict Time-To-Failure (TTF). Automotive customers target a 15+ years lifetime in their specific mission profiles for products with far lower Failure in Time (FIT<<1) rate. Stress testing involves switching accelerated lifetime testing with hard switching to provide a direct demonstration that lifetime requirements are achieved.

Recharge mileage. Longer range and fewer charging cycles are now must haves in EVs. To extend the mileage range per one charging cycle, higher efficiency and lower weight is required in powertrain systems especially for 100 kW and above traction inverters. The target peak efficiency for current traction inverters is above 99.5% with power density beyond 15 kW/l.

Smart charging. A unique aspect of an EV battery powered system is that it requires multi-directional power flow. With OBCs, the battery loading should be able to interconnect between power systems from power grids, solar panel systems, and other standalone loads such as home appliances. The energy is distributed based on the end user's requirements. EV traction inverters also require bidirectional power transfer unlike traditional industrial motor drives. During regenerative braking,

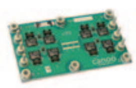
Powertrain Type	Manufacture and form factor	Features
7.2KW OBC	canoo  	• High, flat efficiency over wide input and load range • Low switching losses • Small device package/footprint increases power density • Efficient thermal management • GaN transistors mounted on IMS to maximize performance
15KW 1-phase and 22KW 3-phase compatible bi-directional OBC	HELLA 	• 3-Phase and 1-Phase options • 50% less volume • Significantly improved efficiency (98%) • >2X power density increases versus silicon
All GaN vehicle with Traction Inverter, OBC, and DC/DC	ALL GaN VEHICLE  	• 20% extended mileage for driving range on one charging cycle • 3%-5% efficiency improvement
4.8KW On-board DC/DC	BrightLoop CONVERTERS 	• 3X smaller size • 60% decrease in weight • 25% reduction in power losses • Dual outputs with 10-52 V_{DC} each

Table 2: **Examples of OBC, DC/DC converter, and traction inverter products featuring GaN power transistors**

switches are controlled to allow the same inverter to act as a rectifier, while the motor acts as a generator, thereby allowing power to flow back to the battery pack for fuel economy.

System cost reduction. About 70-80% of overall electrification costs in EVs are due to the battery and power electronics. Reducing costs in this area can be done by increasing the efficiency of the traction inverter. Therefore, the capacity of the battery can be drastically reduced while maintaining the same driving mileage. Moreover, higher efficiency means the ability to downsize the cooling system, again lowering overall system cost with less heatsinks. Besides bringing the component costs down, the integration of an all-in-one OBC, DC/DC converter, and traction inverter into one cooling case is also a cost effective and reliable approach.

Power transistors for EVs

So far, EV powertrain systems have used Silicon solutions. For OBCs and DC/DC converters where the normal operating frequency is about 100 kHz, Si MOSFETs were used and Si IGBTs were the main switching device traction inverters. But that is changing. Wideband Gap (WBG) devices such as GaN and SiC are the most promising power semiconductors set to improve overall efficiency and meet future demands of EV powertrains. Table 1 shows GaN, SiC, Si MOSFET, and Si IGBT comparisons. The GaN transistor shows some impressive advantages:

Zero reverse recovery charger (Q_{rr}): for hard commutation topology such as a totem pole PFC and a traction inverter, the larger Q_{rr} for Si MOSFET and Si IGBT's anti-parallel diode bring a large turn-on loss on the transistors, thus limiting the switching frequency and efficiency improvements. GaN's zero Q_{rr} means lower switching loss which is ideal for OBCs and traction inverters. Especially in OBC topology, the totem pole PFC with GaN transistors can achieve high efficiency and bi-directional operation. A SiC MOSFET also shows fairly lower Q_{rr} compared to Si. But at high temperature with its intrinsic bipolar body diode characteristics, the SiC MOSFET also has switching losses due to Q_{rr}, which limits the switching frequency improvement for the OBC and traction inverter, impeding further power density and weight improvements.

Switching speed: GaN transistors allow fast switching with lower switching turn-on and turn-off losses, so it is extremely effective to reduce the volume and weight for some passive components, such as OBC and DC/DC inductors and transformers. For the traction inverter, the higher switching frequency is also favorable because it results in reduced THD of the motor current at high RPM.

Low Q_g and Q_{oss}: GaN transistors show very low gate charge (Q_g) and output charge (Q_{oss}). These values are important for soft switching Zero Voltage Switching (ZVS) achievement on soft switching topology, such as an OBC's CLLC converter. With lower Q_{oss} and Q_g, ZVS operation is easier to achieve without a large magnetizing current on the transformer. Also, it is evident that GaN transistors can increase the operating frequency range to support a wide output battery range for an OBC's CLLC topology.

All of these parameters demonstrate that GaN is an optimal choice with respect to high power density, high efficiency, and system cost.

GaN transistors are being implemented more and more in EV powertrain systems which highlight confidence in its reliable outperformance and benefits on system cost, density, efficiency, and weight. Examples of OBC, DC/DC converter, and traction inverter products that demonstrate the GaN's high performance advantages according to Table 2.