Integrated Three-level GaN Inverter and PMsynRM Motor for Electric Passenger Vehicles and Medium/heavy duty Trucks (GaNIn_PMsynRM)

Project Lead: Kevin Bai (UTK), Daniel Costinett (UTK), Leon M. Tolbert (UTK) **Graduate Students and Research faculty/associates:** Niu Jia (UTK), Yicheng Zhang (UTK), Xianchao Liu(UTK), Anwesha Mukhopadhyay(UTK), Noah Wilding(UTK)
Project Duration: 6/2024 – 8/2027
Funding Source: DOE-VTO

Summary

The objective of this project is to develop and integrate an 800V/200kW Gallium Nitride (GaN_-based three-level high-power-density inverter and Permanent Magnet assisted synchronous Reluctance Motor (PMsynRM). The inverter will meet all performance targets of >99% efficiency at rated power, >110kW/L volumetric density, $2.2/kW cost. The novel PMsynRM using alternative magnet material and liquid cooling will achieve more than 55kW/l at <$3.3/kW. Together, this innovative, integrated electric traction motor and drive will meet the aggressive, >33 kW/L volume density and <$6/kW cost system targets.

The project will have three budget periods lasting 39 months. The University of Tennessee, Knoxville (UTK) is the project lead. In addition to the project management, UTK will develop the inverter packaging, control, and test. Four subrecipients include ABB Inc (motor design, control, and test), University of Michigan-Dearborn (UMD, topology selection and simulation), Rensselaer Polytechnic Institute (RPI, gate driver development) and Oak Ridge National Laboratory (ORNL, thermal solutions and dynamometer test). Lucid USA will provide contractual services, focusing on system specs, design guidance, reliability analysis and technology-to-market (T2M) plan.

In the present budget period, UTK packaged GaN based power module and processed the double pulse test (DPT). The test results indicated <100V voltage spike to secure the GaN reliability. In BP2, the team will start to package the whole inverter.

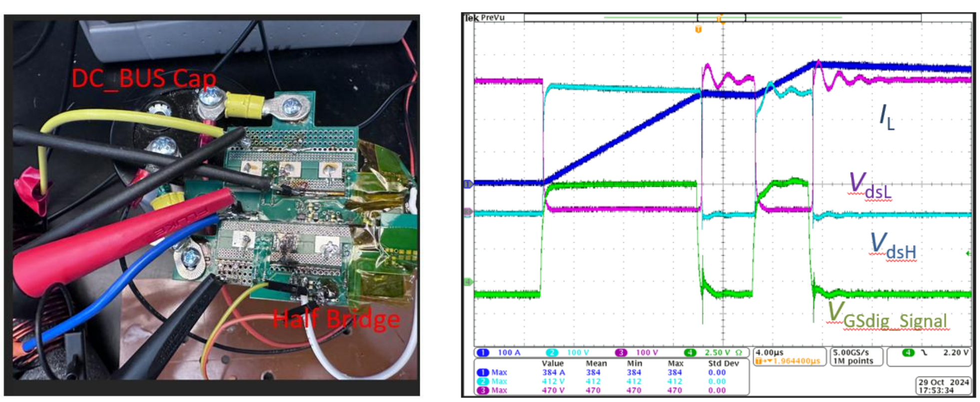

Fig.1. DPT results of the packaged GaN power module: (left) test bench and (right) switching waveform @400 V/385 A.

Characterization of DFPAK and Evaluation of DFPAK in an Inverter Application

Project Lead: Kevin Bai (UTK) **Graduate Students and Research faculty/associates:** Xin Xia, Yicheng Zhang, Saleh Khan (UTK)
Project Duration: 12/2025 – 6/2026
Funding Source: Diamond Foundry

Summary

This proposal will involve power electronics team from The University of Tennessee, Knoxville (UTK) to characterize DFPAK devices packaged by Diamond Foundry (DF) and build and test the inverter based on such device. Both electrical and thermal tests will be carried out by the UTK team to understand the benefits of using diamonds as thermal interface material, e.g., low thermal impedance thereby smaller footprint, as well as its system-level in electric vehicle (EV) drive inverters. At the end of the project, UTK team will carry out high voltage and high current test using an RL load. Voltage and current harmonics, efficiency/loss, as well as temperature profile of the DFPAK over the testing range will be recorded. A 800V/200kW EV inverter will be the final delivery.

Fig.2. Diamond Foundry Inverter (https://www.df.com/power-electronics)

Characterization of HV bi-directional GaN devices and development of 22kW bidirectional GaN devices based three-phase single-stage wireless battery charger for electric vehicles

Project Lead: Kevin Bai **Graduate Students and Research faculty/associates:** Xin Xia, Yicheng Zhang, Saleh Khan (UTK)	
Project Duration: 12/2025 – 12/2026	
Funding Source: BMW	

Summary

This project will involve graduate research assistant students of power electronics from The University of Tennessee, Knoxville to

1. Characterize high voltage bi-directional GaN devices based on test specification from BMW. The characterization will be carried out to evaluate different bi-directional GaN switches available. The auxiliary systems such as gate driver or sensing and protection circuitry needed for the characterization will either be purchased or designed and fabricated.
2. Design and develop three-phase single-stage wireless power transfer (WPT) system for BMW North America, using 650V bidirectional GaN devices on the grid side, 1200V SiC MOSFETs on the receiver side to accommodate an 800V battery. Based on the specifications provided by BMW, UTK team will study and simulate the best topology for a three-phase single-stage 22kW EV WPT, incorporate with bidirectional GaN and poly-phase WPT transmitters and receivers, lay out the circuit including magnetics, power electronics components and heatsink, etc, prototype the whole WPT and carry out the full voltage and power test. The project will evaluate the merits of bidirectional GaN enabled single stage wireless charging wallbox e.g., lower cost and smaller footprint thereby higher power density.

A High-efficiency and High-power-density 48/12V DC/DC Converter for Electric Vehicles

Project Lead: Kevin Bai (UTK), Daniel Costinett (UTK) **Graduate Students and Research faculty/associates:** Saleh Khan (UTK), Yicheng Zhang (UTK)
Project Duration: 11/2024 – 12/2025
Funding Source: Hella/Fovia

<u>Summary</u>

The final deliverable of this project is a 48V/12V DCDC converter used for electric vehicles (EVs), with the input range of 36V~60V and the output voltage of 12V. The UTK team will offer the modular design of 1kW, 2kW and 4kW. It is desired to use wide-bandgap devices particularly GaN to reach high efficiency (>97%) and high-power density (>13kW/L). The goal is to reach high compactness and low cost.

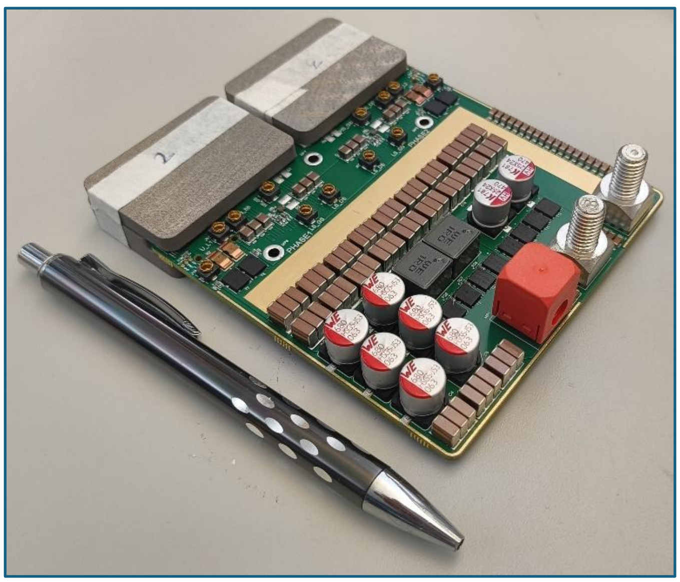

Fig.3. UTK developed 4kW dc-dc converter

A GaN based DC/DC Converter Using Planar Technology for Electric Vehicles

Project Lead: Kevin Bai (UTK), Daniel Costinett (UTK) **Graduate Students and Research faculty/associates:** Saleh Khan (UTK), Yicheng Zhang (UTK)
Project Duration: 11/2024 – 12/2025
Funding Source: Hella/Fovia

<u>Summary</u>

The final deliverable of this project is a DCDC converter used for electric vehicles (EVs), with the input range of 180V~940V and the output voltage of 6V~16V. The rated power is 4kW. It is desired to use wide-bandgap devices to reach high efficiency (>95%) and high-power density (>5kW/L), such as 1200V GaN with two level design, or 650V GaN with a three-level topology.

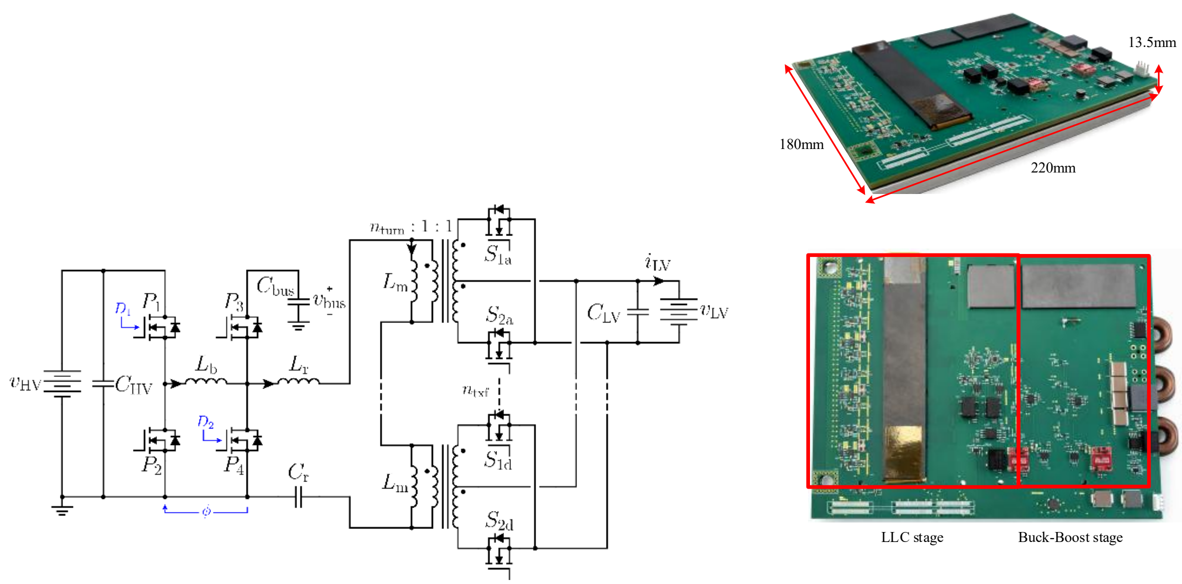

Fig.4. UTK developed dc-dc converter: topology (left) and prototype (right)