Inverter R&D

Madhu Chinthavali

Oak Ridge National Laboratory

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Project ID: APE053

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

- Start – FY13
- Finish – FY15
- 22% complete

Budget

- Total project funding
  - DOE share – 100%
- Funding for FY13: $ 500K

Barriers

- Availability and the cost of wide bandgap (WBG) devices will certainly be a barrier for achieving the cost target.
- Integrating the high temperature WBG module with the gate drive into the inverter.

Targets Addressed

- DOE 2020 Power Electronics Targets
  - Power density: >13.4 kW/l
  - Specific power: >14.1 kW/kg
  - Efficiency: >94%

Partners

- ORNL – Curt Ayers, Steven Campbell, Cliff White, Randy Wiles, Burak Ozpineci, John Miller
- NREL (Jason Lustbader)
- WBG manufacturers
- Inverter component suppliers

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Project Objective

- **Overall Objective**
  - Develop and design a WBG 55 kW inverter utilizing the WBG device attributes.
  - Reduce size, weight, and cost of the inverter to meet the 2020 inverter targets.

- **FY13 Objective**
  - Design, build, and test a 10 kW WBG based prototype using commercially available WBG modules.

Milestones

Date	Milestones and Go/No-Go Decisions	Status
August 2013	Go/No-Go decision: Perform design review of the 10 kW inverter to determine if design can meet the DOE 2020 Power Electronics Targets.	
September 2013	Milestone: Design, build, and test a 10 kW WBG based prototype using commercially available WBG modules.	On track.
September 2013	Milestone: Prepare a summary report that documents the results, findings, performance comparisons, and recommendations to be incorporated into the annual VTO report.	On track.

Approach/Strategy

Device Level Testing:

- Maintain cognizance of state-of-the-art WBG power devices and acquire, test, and characterize newer technology WBG power devices.
- Develop loss models and circuit models using the test data and understand inverter benefits.

Module Level Testing:

- Develop and build a single phase test bed based on conventional mid-point converter architecture to evaluate WBG module performance.

WBG Inverter Development:

- Design a 10 kW inverter using ***commercially available WBG devices/modules*** to demonstrate the performance targets scaled to 30 kW operation.
- Enhance the 10 kW inverter design using ***the high temperature packages and the gate drivers developed at ORNL*** to show the feasibility of achieving 2020 targets.
- Scale the low power inverter design to demonstrate the performance at 30 kW continuous and 55 kW peak power operation while meeting the 2020 targets.

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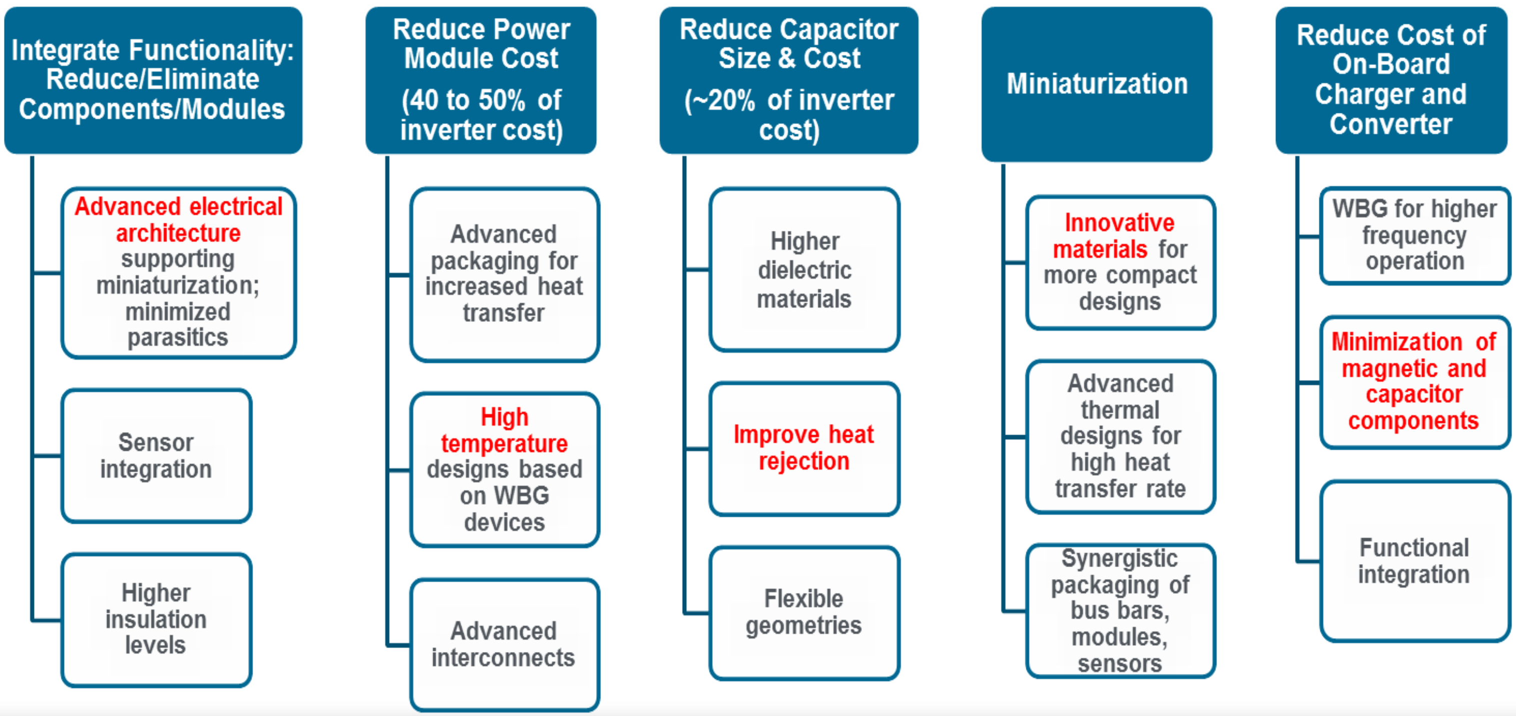
Approach/Strategy

- **The goal of this research is to reduce size and weight of the power converters to meet the 2020 inverter targets.**
- **Cost reduction can be achieved:**
  - reduce components by integrating functionality
  - eliminate/reduce the existing liquid cooling loops
  - decrease the manufacturing costs by reducing the part count and steps in manufacturing
  - minimize high cost materials, like copper, through bus bar optimization current reduction

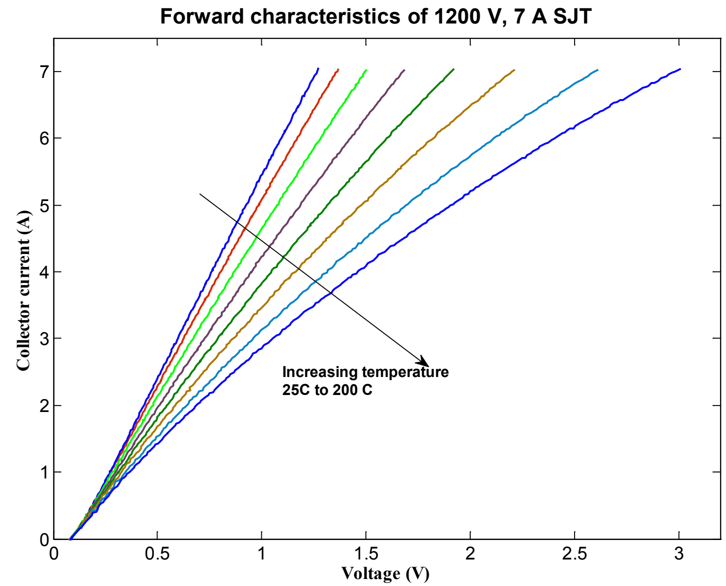


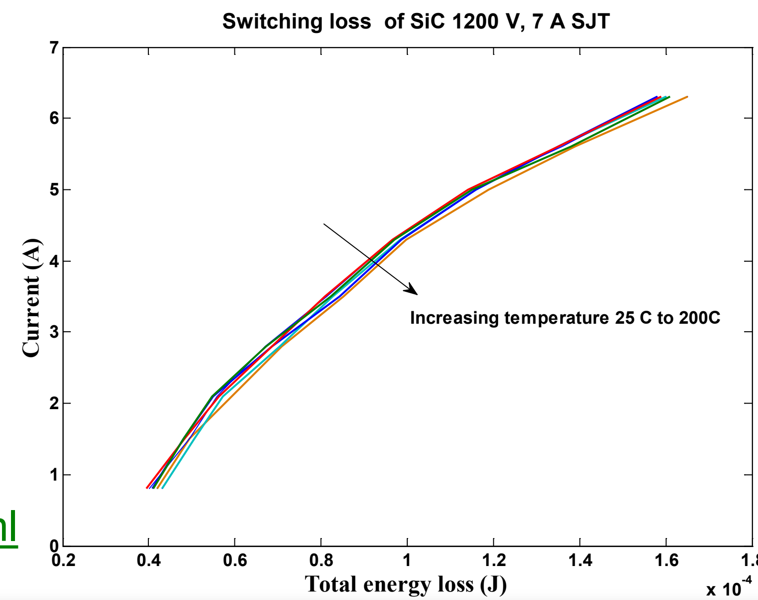
Technical Accomplishments and Progress

WBG device characterization and evaluation:

- **Acquired device prototypes from WBG manufacturers**
  - ✓ 1200 V , 7 A SiC super junction transistor (SJT)
  - ✓ 600 V, 5 A Gallium Nitride (GaN) field effect transistor (FET)
  - ✓ 1200 V 20 A normally-on junction field effect transistor (JFET).

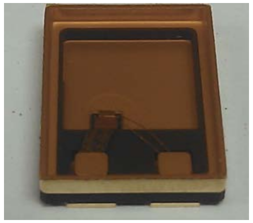
- **Evaluated 600 V, 7 A SiC SJT**
  - ✓ Obtained the static characteristics of a 600 V, 7 A SiC SJT over a temperature range of 25°C to 200°C at Ig= 200 mA.
  - ✓ Obtained the switching characteristics over a temperature range of 25°C to 200°C at 400 V dc up to 7 A.





1200 V, 7 A SiC SJT

1200 V, 20 A SiC JFET



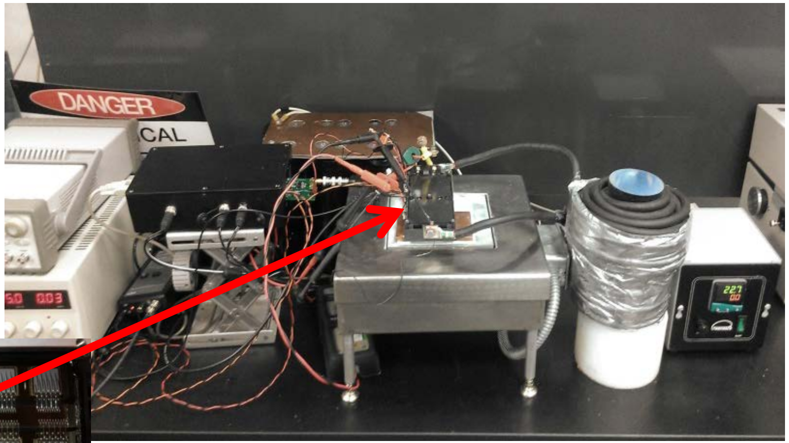
600 V, 5 A GaN FET

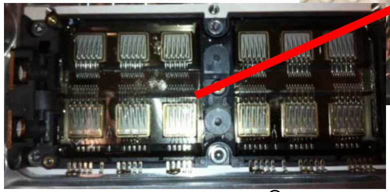
Device database:
http://www.ornl.gov/sci/ees/etsd/pes/device_testing.shtml

Technical Accomplishments and Progress

- Completed evaluation of 2012 Nissan LEAFÈ silicon (Si) power module.
- Tested the Si module over a temperature range of 25°C to 150°C, at 365 V and up to 200 A.
- Utilized the data in the LEAFÈ system simulation model by the APEEM team and in the future will also be to used compare with WBG devices.

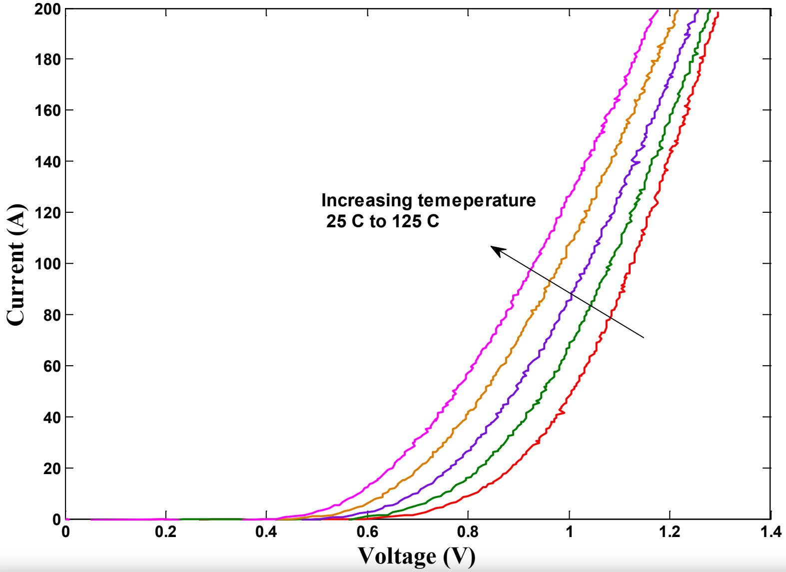
Test setup for evaluating 2012 Nissan LEAF® Si module



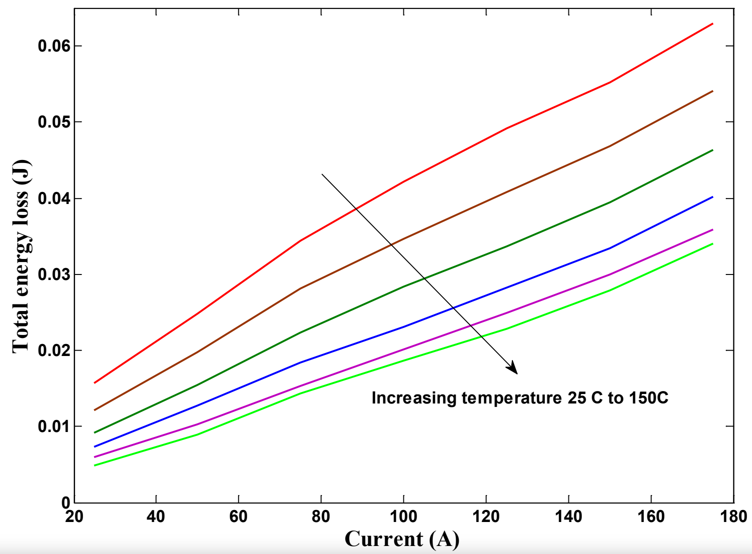


Single phase Si LEAF® module

Forward characteristics of 600 V Si IGBT



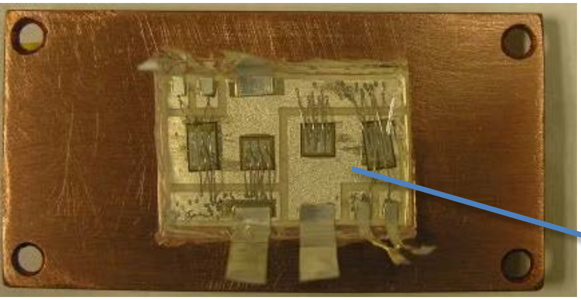
Switching loss of 600 V, Si IGBT



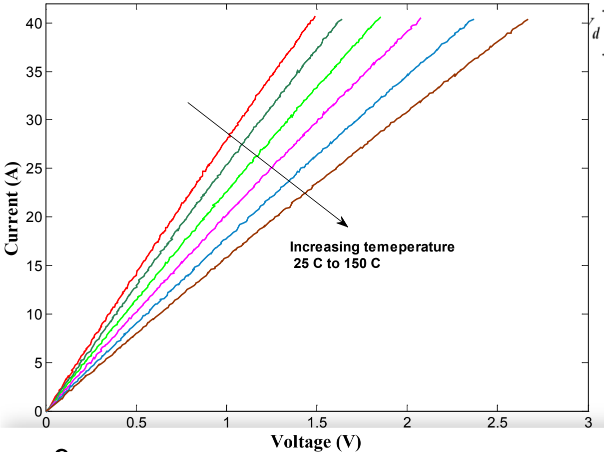
Technical Accomplishments and Progress

Single Phase Test Bed for component evaluation

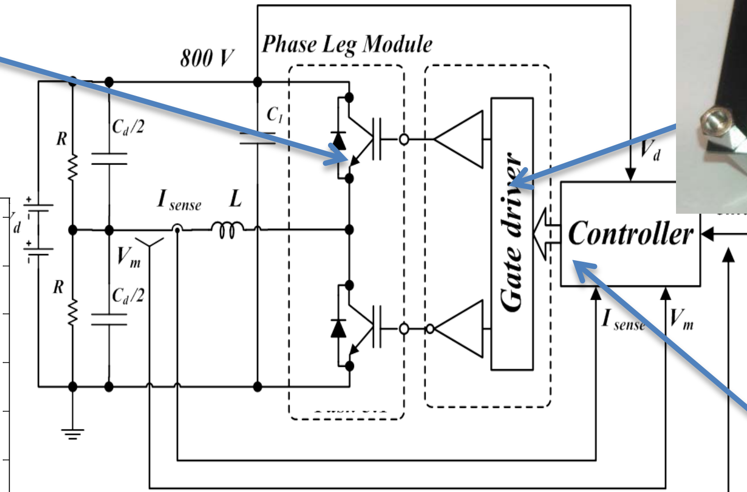
- Acquired the silicon-on-insulator (SOI) latest generation gate driver
- Completed the data acquisition system in lab view for the test bed
- Completed the gate driver board and the control board design using commercially available component.
- Completed the static characterization of ORNL high temperature SiC MOSFET package



ORNL high temperature SiC phase leg module

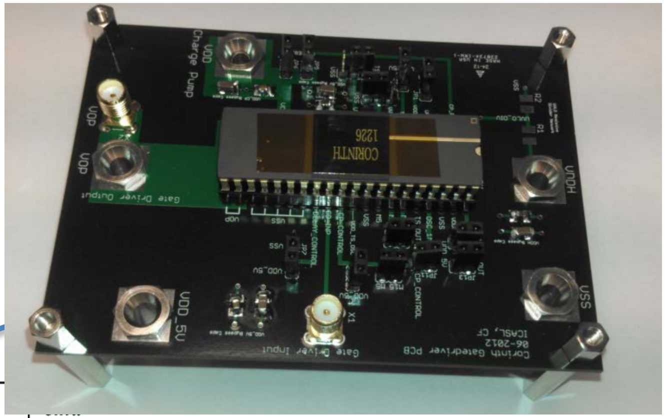


Forward characteristics of ORNL 1200 V SiC MOSFET module



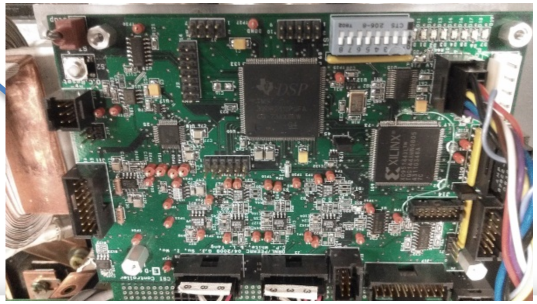
ORNL Systems Modeling, Mapping, Identification
ORNL Traction Drive Electric Motor Development

(Inputs from APEEM team)



ORNL SOI dual output gate driver

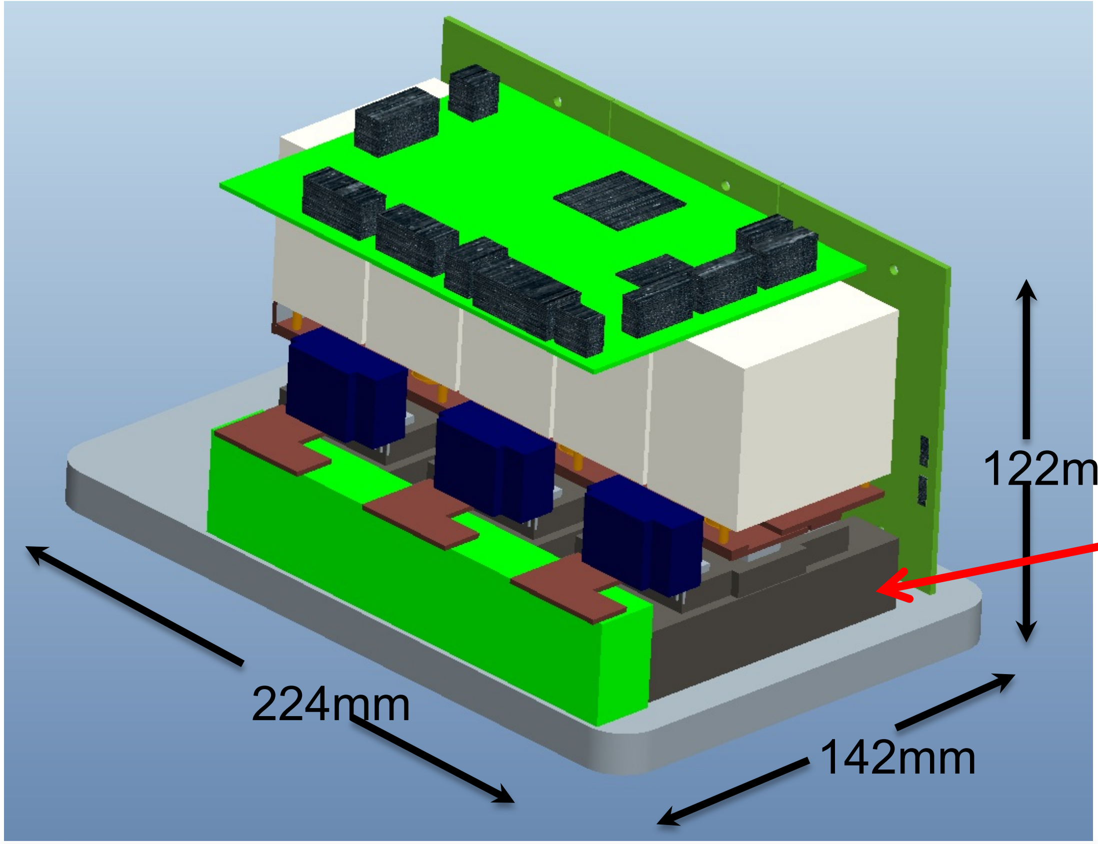
Control board built at ORNL



Technical Accomplishments and Progress

- Completed the inverter design using commercial SiC 1200 V, 100 A MOSFET modules.
- Completed the gate driver and control board design for the inverter using commercial components.

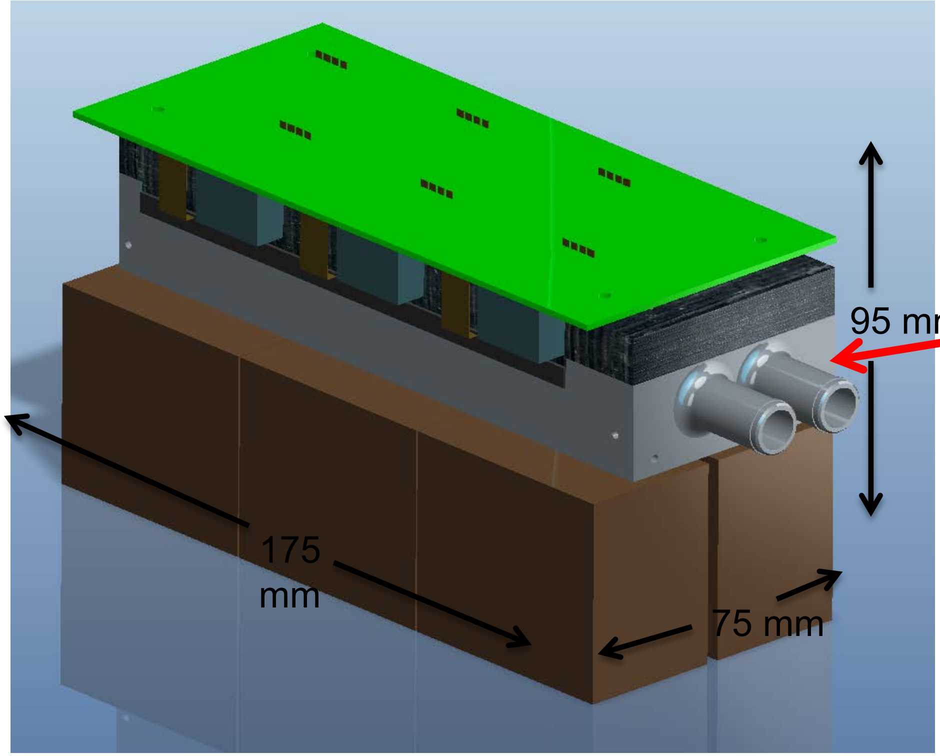
Power density : 10 kW/3.88 L = 2.6 kW/L.

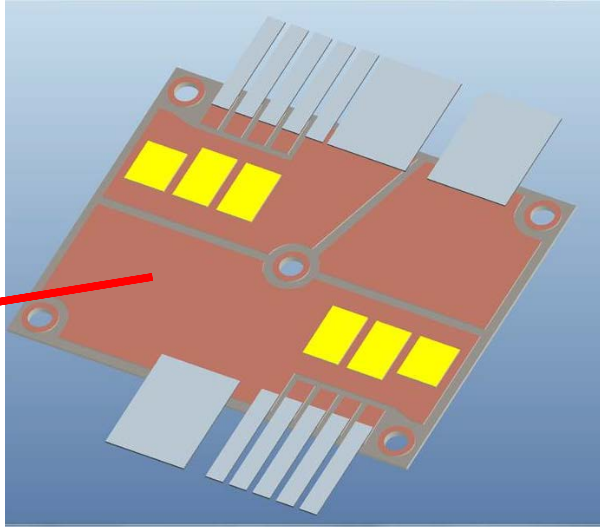


1200 V, 100 A SiC MOSFET commercial single phase module

Technical Accomplishments and Progress

- Completed the initial design of 10 kW WBG inverter with ORNL high temperature SiC 1200 V, 100 A module layout.





1200 V, 100 A SiC MOSFET single phase module layout designed at ORNL

Power density : 10 kW/1.24 L = 8.1 kW/L ~ 3.11 times higher than the commercial module based design.

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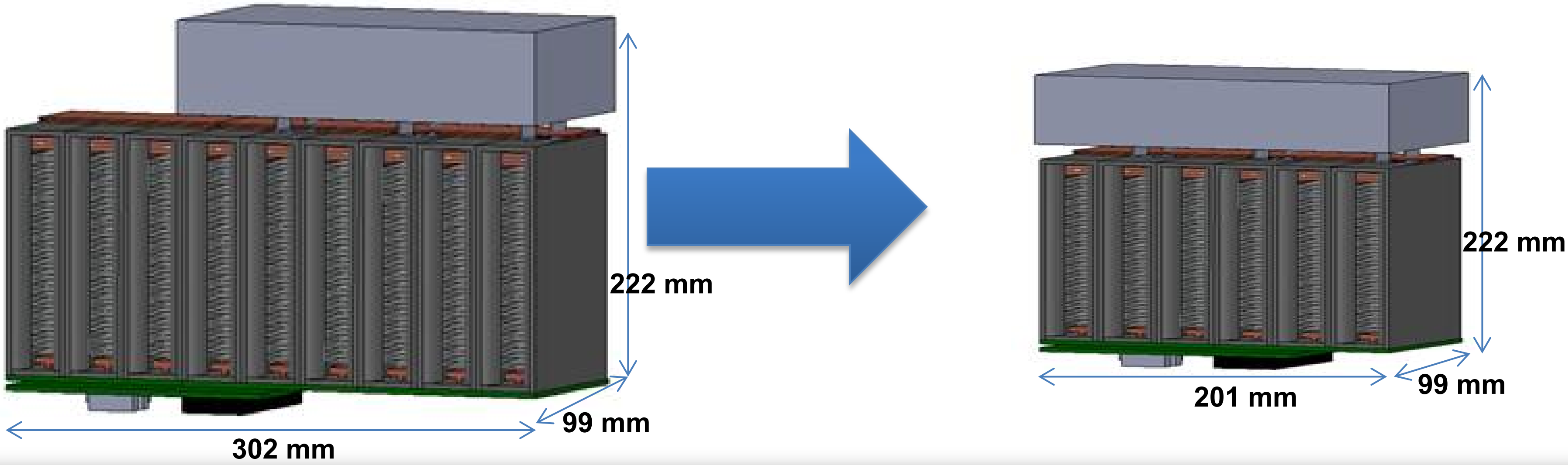
Technical Accomplishments and Progress

Enhanced air cooled inverter design

- Redesigned the inverter developed in FY11 using the thermal simulation results from NREL.
- Reduced the size of the initial inverter design by 33% with of fin design optimization.
- Balance of plant analysis is currently being conducted to establish the feasibility of air-cooling at system level.
- For results on thermal analysis refer to NREL's presentation APE019 (Jason Lustbader)



Collaboration and Coordination

Organization	Type of Collaboration/Coordination
NREL	Thermal analysis
WBG manufacturers: GeneSiC, CREE, USiC, General Electric, Infineon, HRL, International Rectifier	Device prototype supply
Capacitor manufacturers: KEMET,SBE, AVX	Custom capacitor supply

Proposed Future Work

- **Remainder of FY13**
  - Complete evaluation of the WBG device and develop loss models.
  - Complete the single phase test bed and evaluation of the high temperature SiC module and SOI gate driver.
  - Build and test the 10 kW commercial SiC module based inverter.
- **FY14**
  - Develop, design, and test a 10 kW prototype WBG inverter with high temperature module and high temperature gate driver.
- **FY15**
  - Develop, design, and test a 55 kW prototype WBG inverter with high temperature module and high temperature smart gate driver and integrate the novel protection and sense controls.

Summary

- **Relevance:** This project is targeted toward reducing volume, weight and cost of the traction drive inverter.
- **WBG inverter development approach:**
  - Design a 10 kW inverter using commercially available WBG devices/modules to demonstrate the performance targets scaled to 30 kW operation.
  - Design 10 kW inverter using the high temperature packages and the gate drivers developed at ORNL to show the feasibility of achieving 2020 targets.
  - Scale the low power inverter design to demonstrate the performance at 30 kW continuous and 55 kW peak power operation while meeting the 2020 targets.
- **Collaborations:** Collaborations with WBG device manufacturers, inverter component suppliers, and NREL are being used to maximize the impact of this work.
- **Technical Accomplishments:**
  - Completed evaluation of 600 V, 7 A SiC SJT.
  - Completed evaluation of 2012 Nissan LEAF Si power module.
  - Completed data acquisition system in lab view and the gate driver board and the control board design with DSP interface for the single phase test bed.
  - Completed the 10 kW inverter design using commercial SiC 1200 V, 100 A MOSFET modules.