IWIPP 2019

Accelerating Commercialization of WBG Power Electronics: PowerAmerica Systems and Circuits impact

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PowerAmerica

PowerAmerica is Accelerating Adoption of WBG Power Electronics

- The U.S Department of Energy launched the PowerAmerica Manufacturing Institute to Accelerate Adoption of Wide Band Gap power electronics.

- PowerAmerica started operations in 2015 with $140M funds over 5 years, and is managed by North Carolina State University in Raleigh, NC USA.

- PowerAmerica addresses gaps in WBG power technology to enable <u>US manufacturing job creation</u> and <u>energy savings.</u>

PowerAmerica is Member Driven and Active in **All Areas** of the Power GaN-SiC Supply Chain

PowerAmerica

SiC Foundry

Wolfspeed

X-FAB MIXED-SIGNAL FOUNDRY EXPERTS

SiC Devices Circuits & Modules

USCi United Silicon Carbide, inc.

Wolfspeed

GeneSiC SEMICONDUCTOR

Sonrisa Research, Inc.

ry Innovation

ON Semiconductor

MONOLITH SEMICONDUCTOR INC.

Microsemi Power Matters.

GlobalPower TechnologiesGroup

GE

GaN Devices & Circuits

Navitas SEMICONDUCTOR

Infineon

HELLA

WBG Systems

GM

TOSHIBA

Raytheon

ATOM POWER

JENOPTIK

BAE SYSTEMS

ABB

JOHN DEERE

United Technologies Research Center

GE

LOCKHEED MARTIN

Academic

TT

UCDAVIS UNIVERSITY OF CALIFORNIA

UCSB UNIVERSITY OF CALIFORNIA SANTA BARBARA

AUBURN UNIVERSITY

VirginiaTech

KETTERING UNIVERSITY

Georgia Tech Center for Distributed Energy

M DEARBORN

UNC CHARLOTTE

SAN JOSÉ STATE UNIVERSITY 1857

ASU ARIZONA STATE UNIVERSITY

THE FLORIDA STATE UNIVERSITY

NC STATE UNIVERSITY

Rensselaer

THE OHIO STATE UNIVERSITY

The University of Akron

THE UNIVERSITY OF TENNESSEE KNOXVILLE

SUNY POLYTECHNIC INSTITUTE

A

University of Colorado Boulder

Gov. Labs

NAVAL RESEARCH LABORATORY WASHINGTON, DC

Argonne NATIONAL LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

Consortia

PEIC POWER ELECTRONICS INDUSTRY COLLABORATIVE

iNEMI Advancing manufacturing technology

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Electronics is the Foundation of High-Value Manufactured Products and Power Electronics is a Key Driver

Aerospace Sector

Global Market: US$700B

U.S. Exports: at US$120B is the largest US export market

Power Electronics Drivers: Sensors/Radar, Actuation, Propulsion

Automotive/Transportation Sector (Rail)

2nd largest U.S. export market

Power Electronics Drivers: Vehicle Electrification & Automation

Grid Infrastructure Sector

Power Electronics Drivers: Reliability, Sustainability, Flexible Resources

Electric Motor Drives

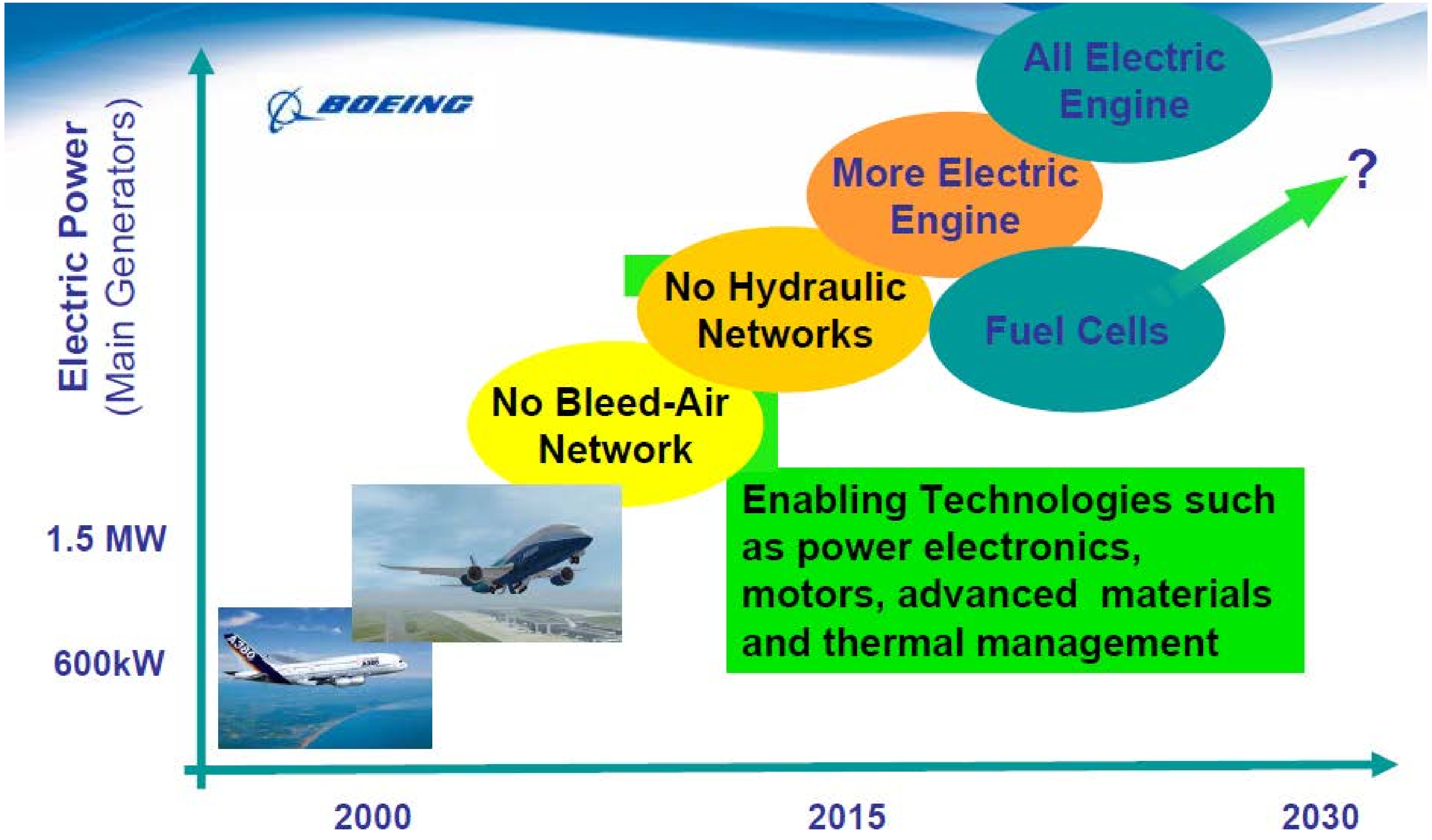
Power Electronics Drivers: Variable Speed Drives, Efficiency, Weight & Volume reduction

Information Technology Hardware Sector

Power Electronics Drivers: Efficiency & Bandwidth Growth

“More Electric Aerospace” is Primarily an Evolutionary Application of Power Electronics and Energy Storage

A more electric aircraft is a more energy efficient aircraft



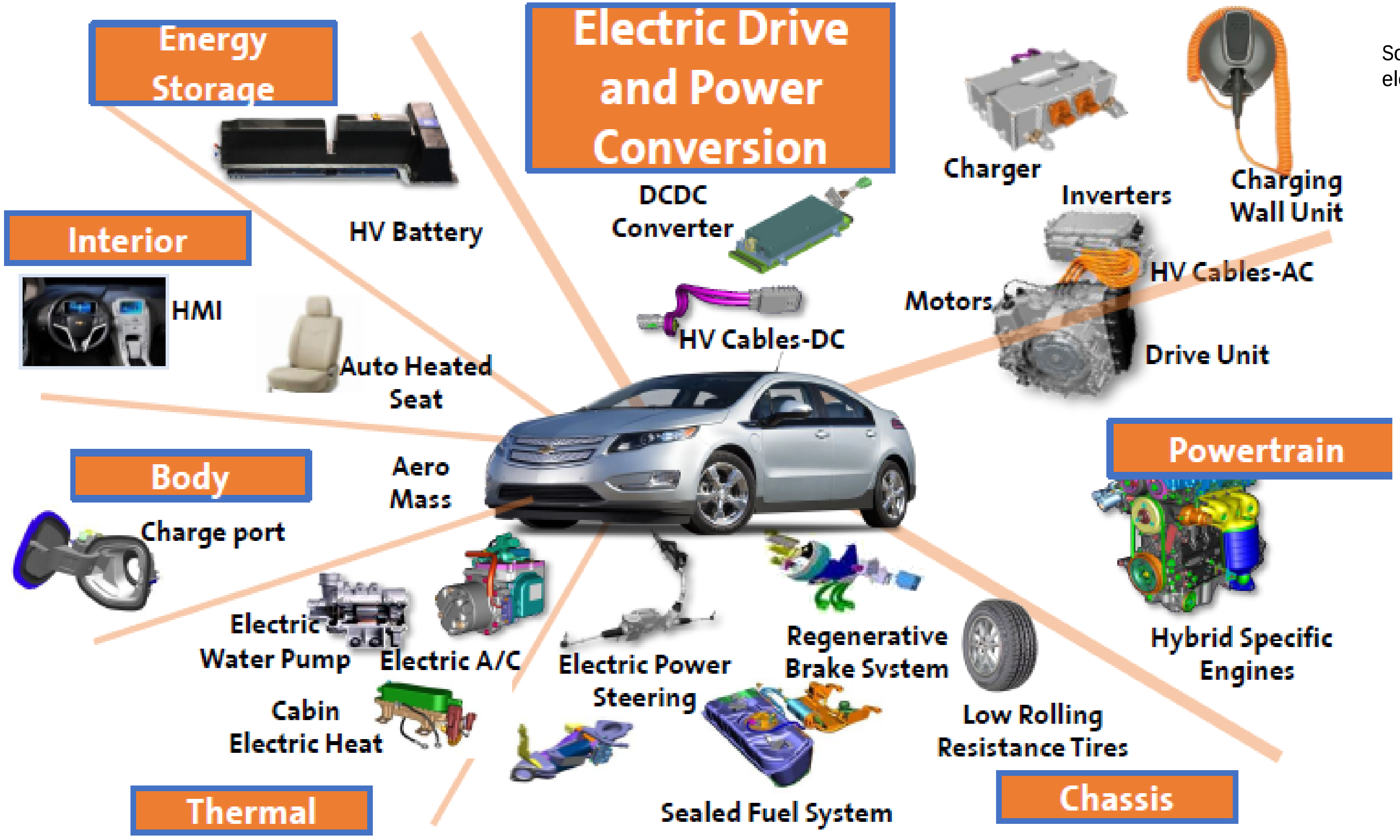
Power electronics innovations drive aerospace – aircraft, satellites, drones, rovers

- *Replace hydraulic systems with electrical*: lower fluid leak hazard, lower operation/maintenance cost, lower system complexity, higher reliability
- *Electrical generation/distribution systems replace electromechanical relays, pneumatics, and hydraulics*: reduce aircraft wiring and overall weight for fuel savings
- *Increased power electronics density*: reduces aircraft weight for fuel savings

Better fuel efficiency, lower maintenance/operation costs, higher reliability, less noise, lower NOx emissions

Power Electronics is Increasingly Prevalent in Hybrid/Electric Vehicles

Source: SDRIVE, "Electrical and electronics technical team roadmap"



In 2014 >25% of all energy usage in the U.S. was consumed in transportation, 98% of that came from fossil fuels

Advances in Power Electronics and Control Systems Drive Efficient, Flexible, and Reliable Grid

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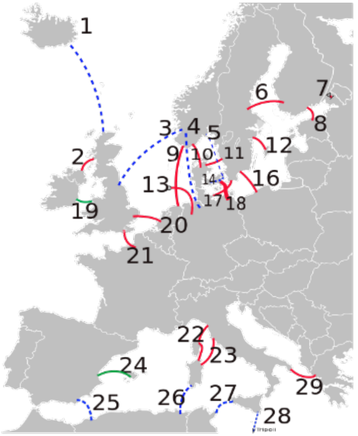
Electric Grid Applications

- HVDC Interface
- FACTS
- Microgrids
- Solar Interface
- Wind Interface
  (500 GW installed)
- Energy Storage Interface



Currently, ~40% of generated electric power passes through Power Electronics between generation and use

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Variable Speed Drives Enable Efficient Adaptation to Motor Speed/Torque and Reduce Energy Consumption



Traditional Motor Drives: 20-40% of energy is wasted with throttles and other mechanical devices

13.8 kV
3 phase
60 Hz

Big
60 Hz
Transformer

4.16 kV
3 phase
60 Hz

→

1-50 MW
60 Hz Motor

→

Gear
Box

→

Compressor
Fixed Speed

Across all sectors, electric motors account for approximately 40% of total U.S. electricity demand

https://arpa-e.energy.gov/sites/default/files/documents/files/ARPA-E_Power_Electronics_Paper-April2018.pdf

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SiC Based Variable Speed Drives have Volume, Weight, and Cost Advantages

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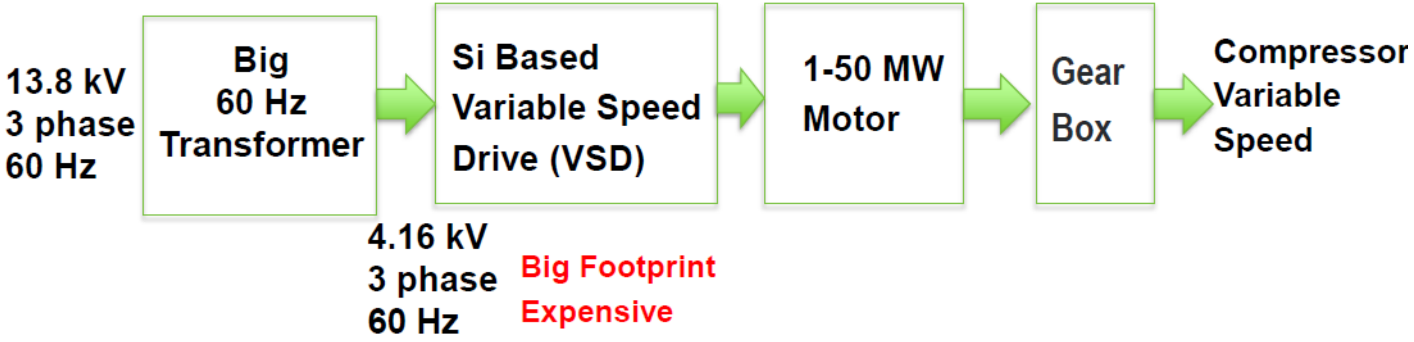
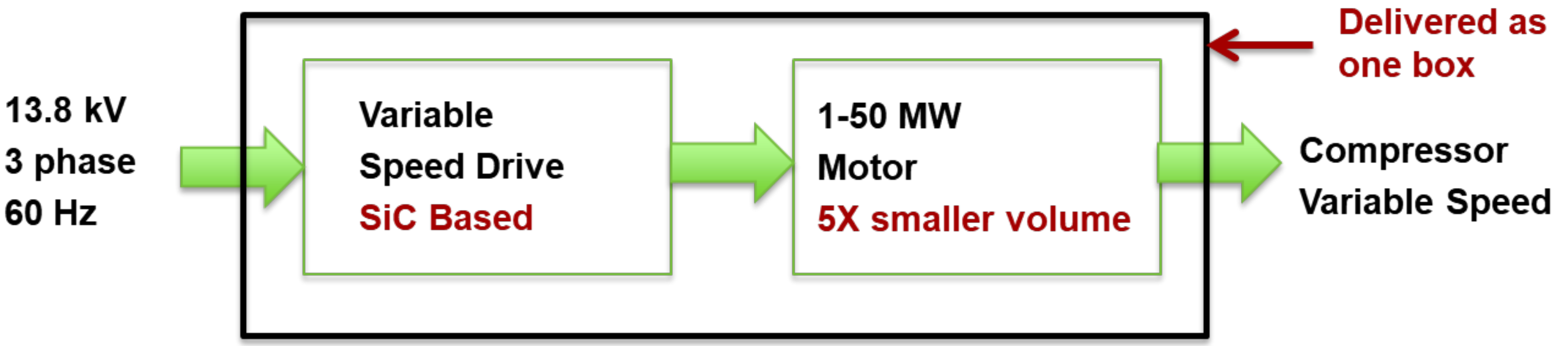
Si based VSD save energy but have limited adoption due to big footprint, weight, and cost



SiC based VSD use novel architectures to reduce volume, weight and cost, accelerating adoption



- Big 60 Hz Transformer replaced by small high frequency Transformer
- VSD system is reduced in size & weight and cheaper due to WBG devices
- Gear Box eliminated
- Motor size reduced by 5x – cheaper, less magnets

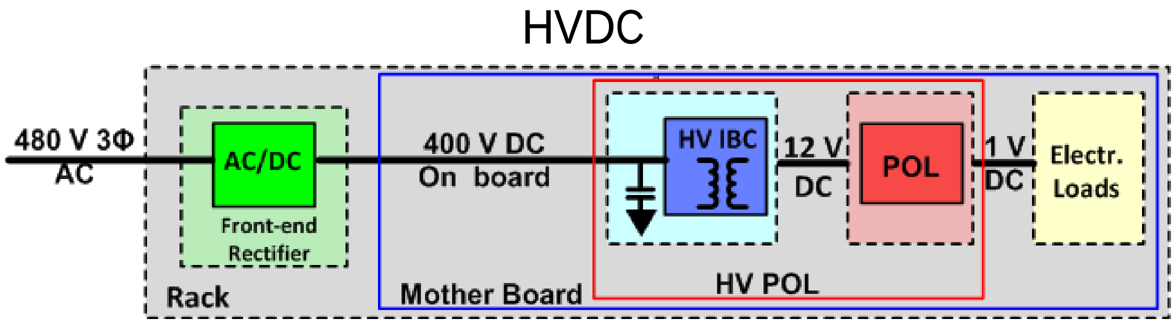
US Department of Energy (DOE), Next Generation of Electric Machines Program

The Range International Information Group Data Center in Langfang China is 6.3 Million Square Feet in Area

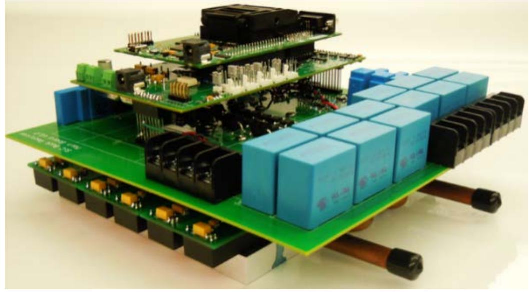
Waste Heat Management is Challenging!

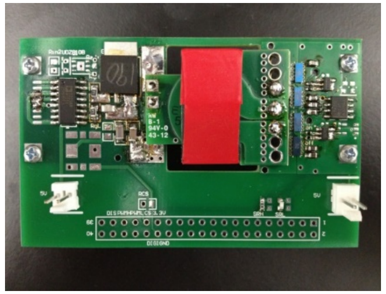
Data Center power consumption is projected to reach 10% of the total electrical power consumption by 2020

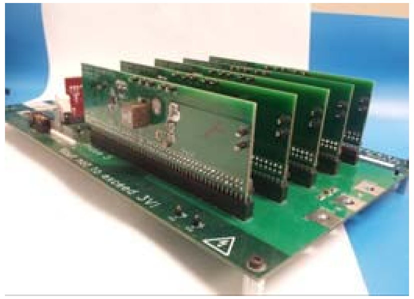
Efficient Data Center Architectures are Enabled by SiC/GaN Power Electronics Innovations



Full Load Efficiency: 98.5 % × 96.1 % × 94.0 % = 89.0 %







Front end rectifier:
7.5 kW, 480 Vac to 400 Vdc
SiC devices

HV IBC:
300 W, 400 V to 12 V
GaN devices

POL:
200 W, 12 V to 1 V
GaN devices

HV POL:
400 V to 1 V

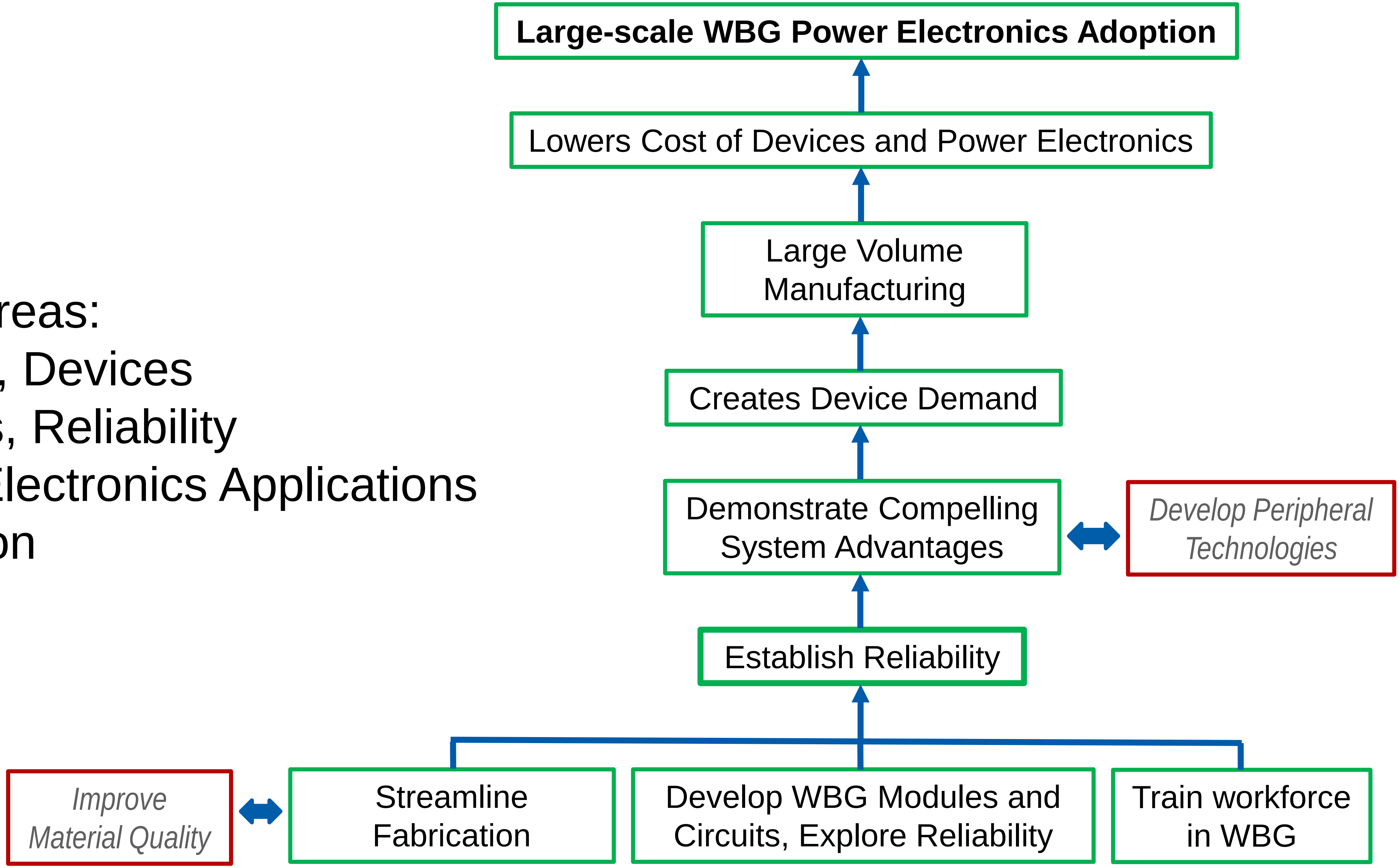
SiC/GaN Power Electronics simplify data center waste heat management

Figures courtesy of
Dr. Leon M. Tolbert

PowerAmerica is a Catalyst in the Manufacturing of Low Cost SiC and GaN Power Electronics

Funding Areas:

- Foundry, Devices
- Modules, Reliability
- Power Electronics Applications
- Education



DOE/PowerAmerica Strategic Funding Allocation Accelerat
Commercialization of WBG Power Electronics

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33 NEW WBG Projects Annually
Industry/University/National-Lab

1 Management and Operations

1.1 Operations and Finance
1.2 Technology Roadmap
1.3 Sustainability
1.4 Device/Module Bank
1.6 Project Portfolio Management
1.7 Membership, Industry Relations and Communications

2 Foundry and Device Development

2.1 SiC Power Device Commercial Foundry Development **X-Fab Texas**
2.3 Development of a Manufacturable Gen3, 6.5 kV/100 mOhm MOSFET **Cree/Wolfspeed**
2.4 Commercialization of 1700V SiC Schottky Diodes **Monolith**
2.8A Lower Cost Foundry Process for 1.2 kV SiC Planar Gate Power MOSFETs and JBS Rectifiers **NCSU (Baliga)**
2.8B 1.2kV SiC Shielded Trench Gat PowerMOSFETs **NCSU (Baliga)**
2.14 3.3kV SiC MOSFET Dev **GeneSiC**
2.20 1.7kV/3.3kV SiC M up **Microsemi**
2.21A Developm 3.3kV/6.5kV/1 Diodes, ar MOSFE
2.21
D
ve,
SFETs
MHz DC-DC
*Circuit **Ricketts -***

3 Module Development & Manufacturing

3.1 High Voltage 6.5kV 8 10 kV Power Module Commercializatio Manufacturing **Fayettevill**
3.6 Dev Free A

4 Co A

4.1
shiba
ith Efficiency
a Tech
verter **FSU**
d Power Conditioning
connector to MicroGrid
a)
ion 350 kW Three-Phase Medium-
fficiency EV Fast Charger **NCSU**

Active Harmonic Filter for Variable
uency Drives **UTRC + Hopkins + Husain**
.24 65W High-Efficiency, High-Density Adapter with Improved Manufacturability **Navitas**
4.25 5 kV DC to LV DC or 3 Phase AC Microgrid Power Conditioning Modules **GA Tech**
4.26 High Frequency GaN Power Converter **LMCO + VPT + VA Tech**
4.27 SiC Based Power Electronic Motor Driver for Class-8 Mild Hybrid Truck **Bendix Corporation**
4.28 Multi-functional High-efficiency High-density Medium Voltage SiC Based Asynchronous Microgrid Power Conditioning System Module **University of Tennessee**
4.29A *Development of Active Harmonic Filter using Interleaved SiC Inverter **Husain-OIF***
4.29B *Modeling and Packaging Design of a High Power Density 150A SiC Inverter **Hopkins-OIF***
4.30 *High Power Density DC-DC Converter for Auxiliary Power in Heavy-Duty Vehicles **Bhattacharya-OIF***
4.31 *A High-efficiency Low-cost 22kW Fast On-board Charger for Electric Vehicles Using Hybrid Switches Combining GaN HEMTs with Si MOSFETs **Hella-OIF***

5 ucation and orkforce Development

5.1 Education and Workforce Pipeline Development
5.4 Undergraduate Research Scholars
5.5 Pre-College Education **5.6** WBG Short Courses
5.13 Documentation of Design and Process of GaN Power HEMTs **RPI**

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PowerAmerica Foundry Projects Enable Low-Cost Large Volume SiC Device Manufacturing in the U.S.

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1 Management and Operations

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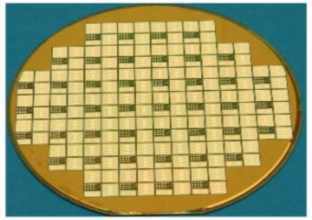

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2.14 3.3kV SiC MOSFET Development **GeneSiC**
2.20 1.7kV/3.3kV SiC MOSFET Scale-up **Microsemi**
2.21A Development of 3.3kV/6.5kV/10kV SiC MOSFETs, JBS Diodes, and JBS Diode Integrated MOSFETs **SUNY**
2.21B Development of 600V SiC JBS Diodes and MOSFETs **SUNY**
2.23 Advanced SiC Trench MOSFETs: A Path to Record-Low Ron,sp and Record-Low ($/A) **Sonrisa Research**
2.24 Manufacturable, Cost Effective, Low RON-SP 3.3 kV SiC DMOSFETs **Global Power**
2.25** 50 W GaN 15 -100 MHz DC-DC Converter Integrated Circuit **Ricketts - OIF

3 Module Development & Manufacturing

3.1 High Voltage 6.5kV & 10 kV Power Module Commercialization and Manufacturing **Cree Fayetteville**
3.6 Developing a BPD-Free Room Temperature Al Implant and Activation Anneal Process for P-Wells in SiC MOSFETs **NRL**
3.7 Reliability Analysis of Wide Band Gap Power Devices **Texas Tech**
3.8** 100A, 6.5KV Half-Bridge Module **USCI

4 Commercialization Applications

4.1 Design, Fabrication, and Vehicular Testing of SiC Inverter for Heavy-Duty Vehicles **John Deere Electronic Solutions**
4.3 SiC Device based Commercial Hybrid PV Inverter with Li-ion Battery Integration **Toshiba**
4.7 100 kW Commercial PV Inverter with Efficiency > 99 % Operating in iTCM **Virginia Tech**
4.10 100 kW Commercial PV Inverter **FSU**
4.11 Asynchronous Microgrid Power Conditioning System (Microgrid PCS) connector to MicroGrid **NCSU (Bhattacharya)**
4.13 Next Generation 350 kW Three-Phase Medium-Voltage High-Efficiency EV Fast Charger **NCSU (Lukic)**
4.23 SiC Active Harmonic Filter for Variable Frequency Drives **UTRC + Hopkins + Husain**
4.24 65W High-Efficiency, High-Density Adapter with Improved Manufacturability **Navitas**
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5 Education and Workforce Development

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5.13 Documentation of Design and Process of GaN Power HEMTs **RPI**

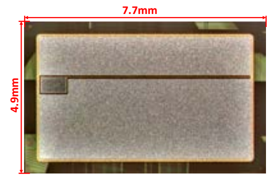
Cree-Wolfspeed Manufactures 3.3 kV, 6.5kV, and 10 kV SiC MOSFETs on 150 mm Wafers

2016 – Fabrication & JEDEC Qualification of New Design 3.3kV/45mOhm and 10kV/300mOhm SiC MOSFETs on 100 mm 4HN-SiC Wafers (Extend to BP3)

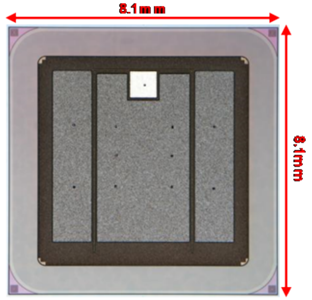
- High Temp Gate Bias (HTGB) - Completed
- Thermal Shock (TS) - Completed
- Body Diode Operating Lifetime (BDOL) - Completed
- Electrostatic Discharge (ESD) - Completed
- High Humidity High Temp Reverse Bias (H3TRB) - Completed
- Time Dependent Dielectric Breakdown (TDDB) - Completed

2017 – Fabrication & JEDEC Qualification of New Design 6.5kV/100mOhm SiC MOSFETs on 150 mm 4HN-SiC Wafers

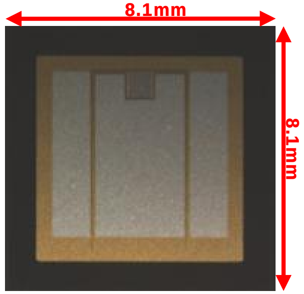
- Fabrication Lots #1, #2, #3, & #4 – 85 % Complete
- High Temperature Reverse Bias (HTRB) – Awaiting Devices
- High Temp Gate Bias (HTGB) – Awaiting Devices
- Time Dependent Dielectric Breakdown (TDDB) – Awaiting Devices



New Design 3.3kV/45mΩ SiC MOSFET



New Design 10kV/300mΩ SiC MOSFET



New Design 6.5kV/100mΩ SiC MOSFET

X-FAB 150-mm SiC Open Foundry Leverages Existing Si Economy of Scale to Reduce SiC Manufacturing Cost

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X-FAB/PowerAmerica Manufacturing Vision

SiC Open Foundry at the Economy Scale of Silicon

- Wafer fabrication dominated by fixed O/H costs (Management, Quality, EHS, IT)
- Economies of scale is the greatest factor in reducing cost: Use the scale established in Si to enable low-cost SiC manufacturing

X-FAB 150-mm SiC open Manufacturing is fully integrated within a high volume Si foundry

X-FAB/PA SiC Users: ABB, GeneSiC, Microchip, Monolith, USCi, Global Power, Sonrisa, SUNY, and NCSU

Module and Reliability Funding Bridges the Gap Between Device Readiness and Commercial Adoption

PowerAmerica

Funding Focus Areas

1 Management and Operations

1.1 Program and Financial Management
1.2 Technology Roadmap
1.3 Sustainability
1.4 Establish a Device Bank
1.5. Subawards Management
1.6 Open Innovation Fund
1.7 Membership and Industry Relations
1.8 Compliance Program
1.9 External Communications
1.10 Placeholder for Faculty Hiring for Sustainability
1.11 Metrics Reporting
1.12 Management of Foundry Process

2 Foundry and Device Development

2.1 Ion Implanter and PDK **X-Fab Texas**
2.2 1.2 kV Diode and MOSFET Foundry Qualification of SiC 150mm line **USCi**
2.3A Qualification an testing of of Gen 3 3.3kV/40mOhm SiC MOSFETS **Wolfspeed/Cree**
2.3B Qualification and testing of Gen3 10kV/350mOhm SiC MOSFETS **Wolfspeed/Cree**
2.4 Diode Commercialization and Production **Monolith**
2.5 Manufacture Vertical GaN devices on bulk GaN wafers **Qorvo/Triquint**
2.6 N/A
2.7 N-Polar GaN Power Devices **UCSB**
2.8 High frequency 12kV SiC Planar gate Power MOSFETS **NCSU (Baliga and Misra)**
2.9 N/A
2.10 Examine Material Defects in SiC Epilayers by UV Photoluminescence **NRL**
2.11 GaN Power Device R&D **UC Davis**
2.12 & 2.13 N/A
2.14 Low Cost 1200V SiC JBS Rectifiers and SJT Dev. **GeneSiC**
2.17 Development of an open gate dielectric process for SiC MOSFET Manufacturing **Auburn University**

3 Module Development & Manufacturing

3.1 Power Module Development and Manufacturing **Cree Fayetteville**
3.2: Reliability benchmarking of SiC MOSFETs **Argonne National Lab**
3.3: Reliability Benchmarking of Lateral GaN Power HEMTs on Si **Rensselaer Polytechnic Institute**
3.4 Terrestrial Neutron Induced Reliability Concerns **CoolCAD**

4 Commercialization Applications

4.1 200 kW 1050Vdc SiC Dual-Inverter **John Deere Electronic Solutions**
4.2 Ultra-High Efficiency SiC Modular UPS **ABB**
4.3 SiC Small Commercial PV Inverters **Toshiba**
4.4: MV Power Module for High Density Conversion **NCSU (Hopkins)**
4.5 N/A
4.6 Comparison of SiC and GaN 7.2 kW Chargers **Kettering University**
4.7 EMI Mitigation and Containment in SiC Modular UPS **Virginia Tech (Burgos)**
4.8 DC Data Center with High Frequency Isolation **Virginia Tech (Lee)**
4.9 HybMic Converter **InnoCit**
4.10 SiC Commercial PV Inverter **FSU (Li)**
4.11A Hi Pwr Density DC-DC Conv. for Aux. Pwr. in H-D Vehicles **NCSU (Bhattacharya)**
4.11B Integrated Intelligent Gate Driver and Interface System for Med. V Appl. **NCSU (Bhattacharya)**
4.12 100kW SiC Inverter for EV Traction Drive **NCSU (Husain)**
4.13 WBG Med. V EV Fast Charger **NCSU (Lukic)**
4.14 TBD
4.15 High Perf. PV String and Micro Inverters **ASU**
4.16 MV Gate Drive with Comprehensive Protection Functions **Ohio State**
4.17: Mass Market SiC Solid-State Circuit Breaker Development **AtomPower**
4.18 Open-Source Compact Transformerless Grid-Tied 3kW GaN PV Inverters **Transphorm**

5 Education and Workforce Development

5.1 Program Management
5.2 Institutes, Workshops, Internships
5.3 Business Plan for Sustainability
5.4 Implement EWD Portal
5.5 Shared Specialty Courses

5.11 WBG Workshop Development and Teaching Modules **NCSU (Ozturk)**
5.12 Curriculum Dev. on WBG device Modeling, Simulation **FSU (Andrei)**
5.13: Documentation of Design and Process of GaN Power Devices (**Rensselaer)**
5.14 Technology Transition for the MV EV Fast Charger **NCSU (Lukic)**
5.15 Documentation of Design and Process for GaN Based Devices **UC Davis**
5.16 Technology Transition for SiC inverter for EV traction drive **NCSU (Husain)**

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PowerAmerica GaN Members Create High Frequency, High Efficiency, Compact Solutions with Very Large User Potential

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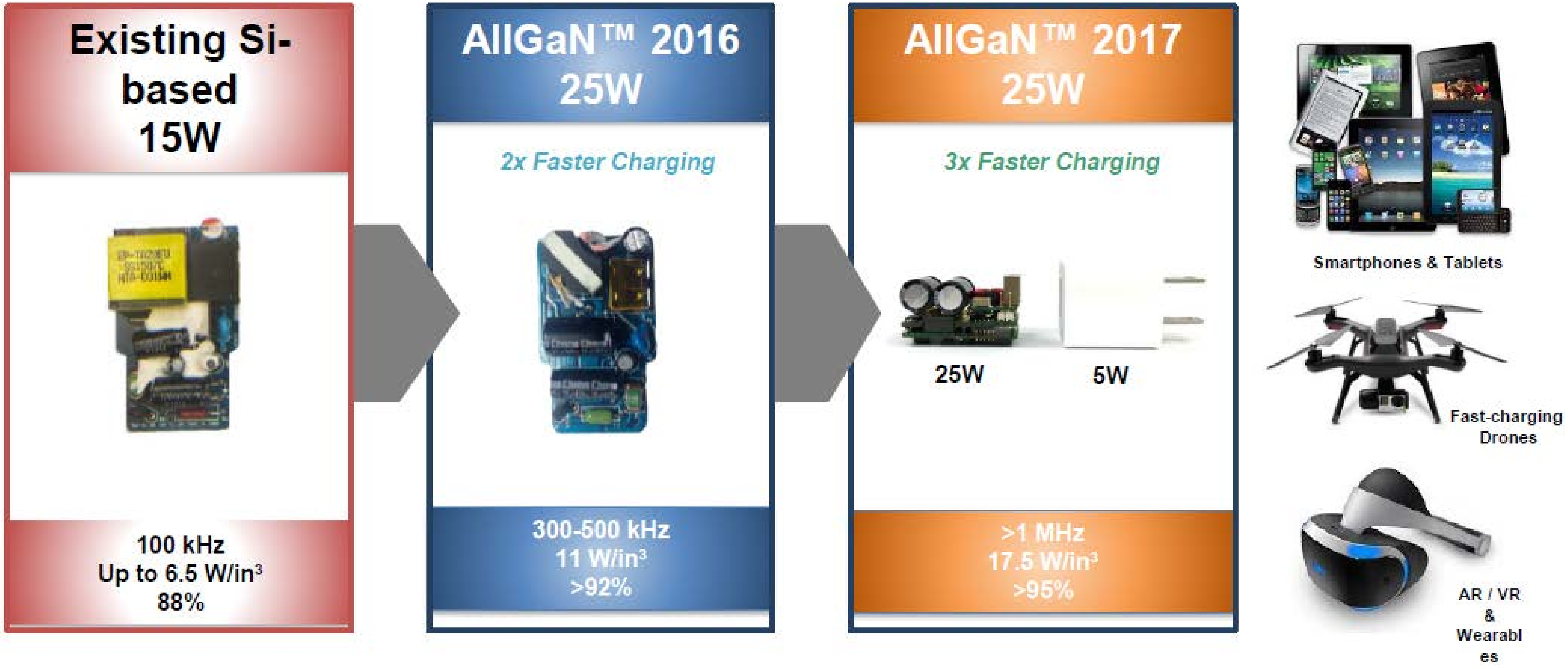
Power Supply market



2016: Navitas; 2017: Xiucheng Huang, "High Frequency GaN Characterization and Design Considerations," Ph.D Dissertation, Dept. Electr. Eng., Virginia Tech., Blacksburg, VA USA, 2016.

Courtesy of member Navitas

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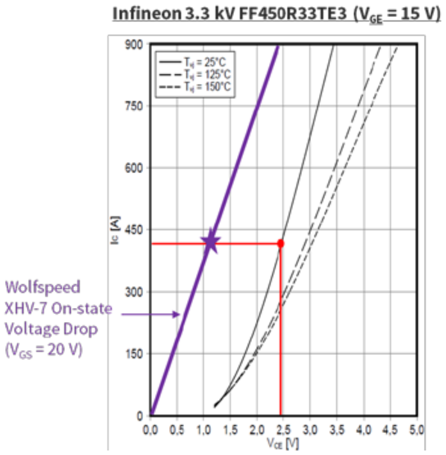
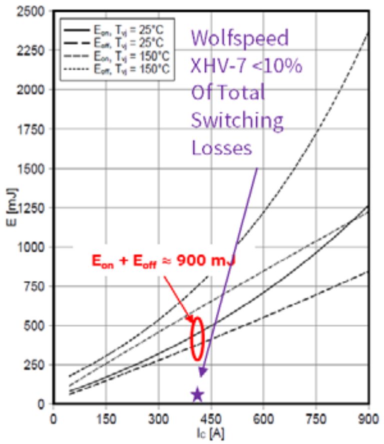
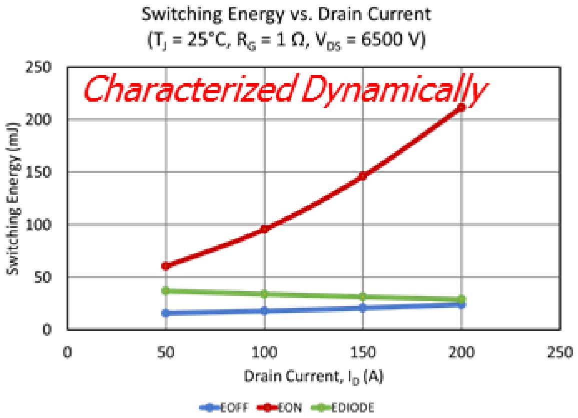
Wolfspeed Fay Develops 3.3-kV and 10-kV SiC Modules with Customizable Device Configuration

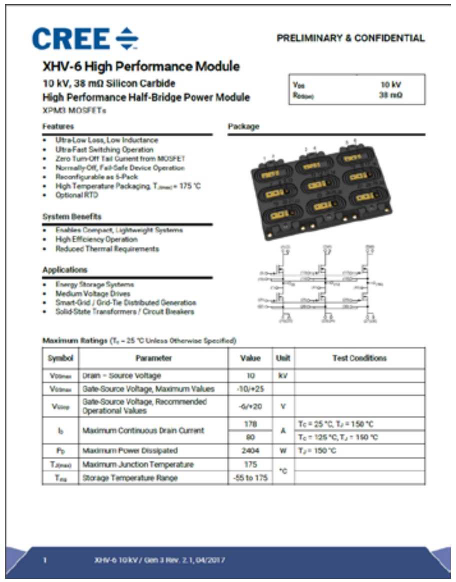
3.3 kV Industry Standard Footprint Module with Low Inductance <20 nH





10 kV Module with Low Loop Inductance <20 nH





CREE

PRELIMINARY & CONFIDENTIAL

XHV-6 High Performance Module

10 kV, 38 mΩ Silicon Carbide

High Performance Half-Bridge Power Module

XPM3 MOSFETs

V_{DS}	10 kV
$R_{DS(on)}$	38 mΩ

Features

- Ultra-Low Loss, Low Inductance
- Ultra-Fast Switching Operation
- Zero Turn-Off Tail Current from MOSFET
- Normally-Off, Fail-Safe Device Operation
- Reconfigurable as 5-Pack
- High Temperature Packaging, $T_{J(max)}$ = 175 °C
- Optional RTD

Package

System Benefits

- Enables Compact, Lightweight Systems
- High Efficiency Operation
- Reduced Thermal Requirements

Applications

- Energy Storage Systems
- Medium Voltage Drives
- Smart-Grid / Grid-Tie Distributed Generation
- Solid-State Transformers / Circuit Breakers

Maximum Ratings (T_C = 25 °C Unless Otherwise Specified)

Symbol	Parameter	Value	Unit	Test Conditions
V_{DSmax}	Drain - Source Voltage	10	kV	
V_{GSmax}	Gate-Source Voltage, Maximum Values	-10/+25		
V_{GSop}	Gate-Source Voltage, Recommended Operational Values	-6/+20	V	
I_D	Maximum Continuous Drain Current	178	A	T_C = 25 °C, T_J = 150 °C
		80		T_C = 125 °C, T_J = 150 °C
P_D	Maximum Power Dissipated	2404	W	T_J = 150 °C
$T_{J(max)}$	Maximum Junction Temperature	175	°C	
T_{stg}	Storage Temperature Range	-55 to 175		

1 XHV-6 10 kV / Gen 3 Rev. 2.1, 04/2017

GE is Developing SiC and GaN Modules with Danfoss in Utica NY as Open Volume Production Facility

POWERAMERICA

GE SiC MOSFET Module Portfolio

600A, 1200V
½ bridge HTMP

400A - ½ bridge

200A, 1200V Dual

1600A, 1200V
½ bridge

250A, 1700V – 6 pack

250A, 1700V - Dual

300A, 1200V
3 Channel SSPC

550A, 1700V – Dual
650A, 1200V - Dual

Texas Tech/NIR Member Project: Establish an **Independent** Facility to Perform Reliability Analysis of WBG Semiconductor Devices

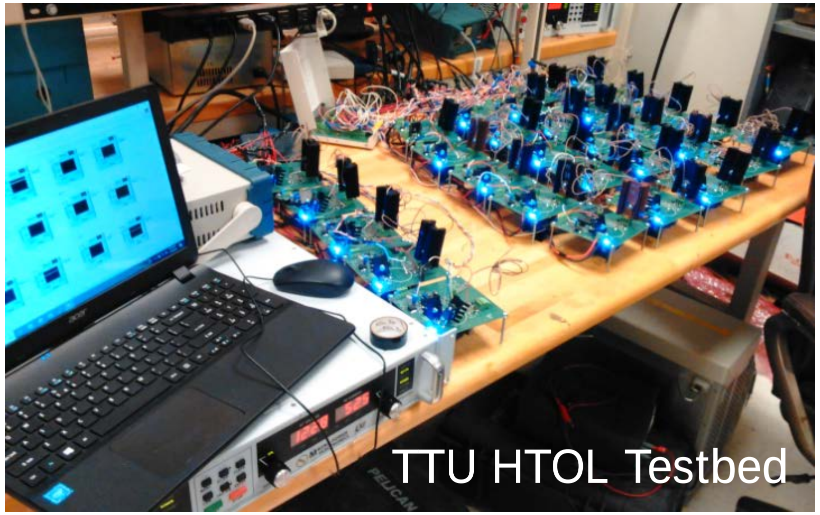
PowerAmerica

NIR Group Renewable Energy Solutions

Texas Tech University

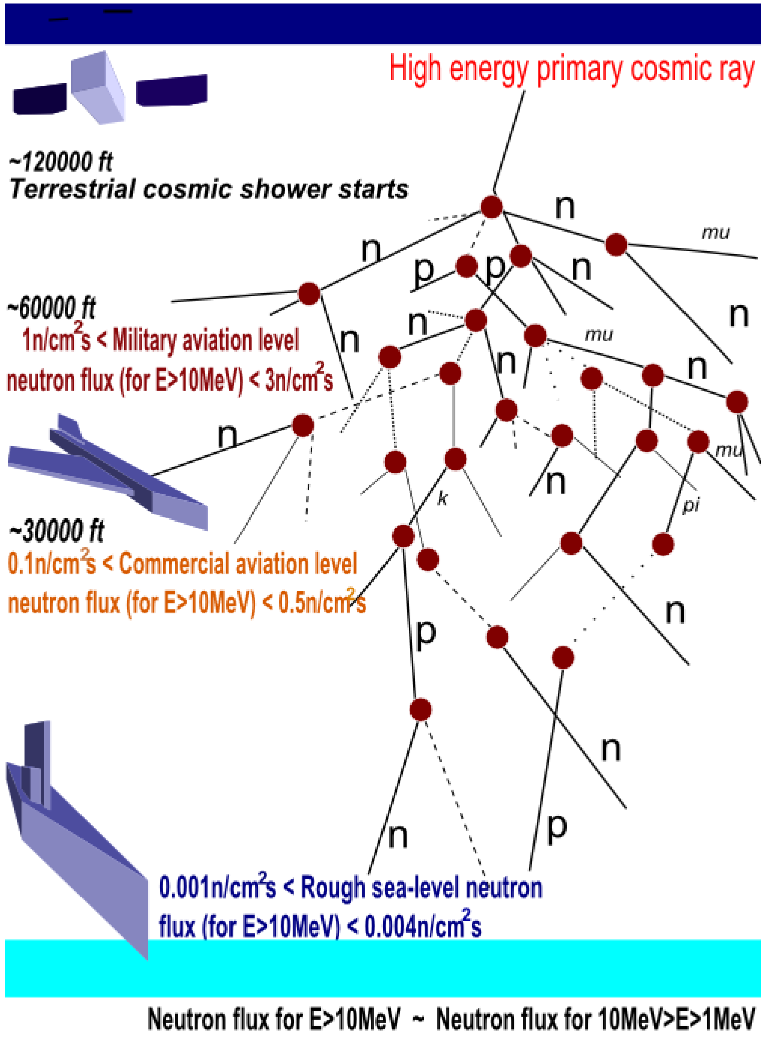
Tests and Services offered

- High temperature reverse bias (HTRB)
- High temperature gate bias (HTGB)
- High temperature operating life (HTOL)
- Temperature humidity biased test (THBT)
- Intermittent operating life (IOL)
- Time dependent dielectric breakdown (TDDB)
- Avalanche (MOSFET and diode)
- Diode surge current
- Short Circuit
- di/dt and dV/dt
- Continuous switching

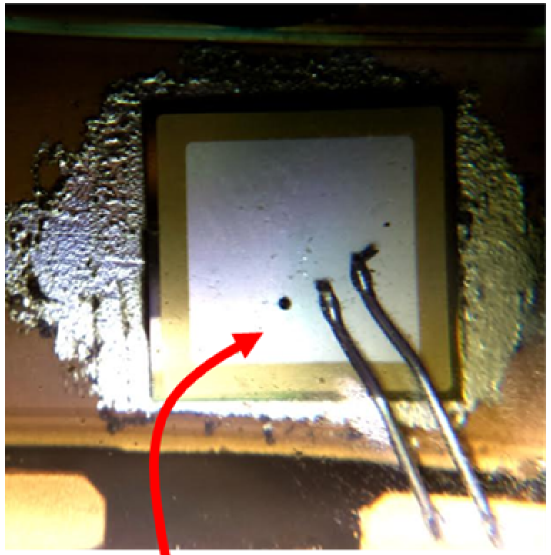

TTU HTOL Testbed

TTU HTRB and HTGB Testbed

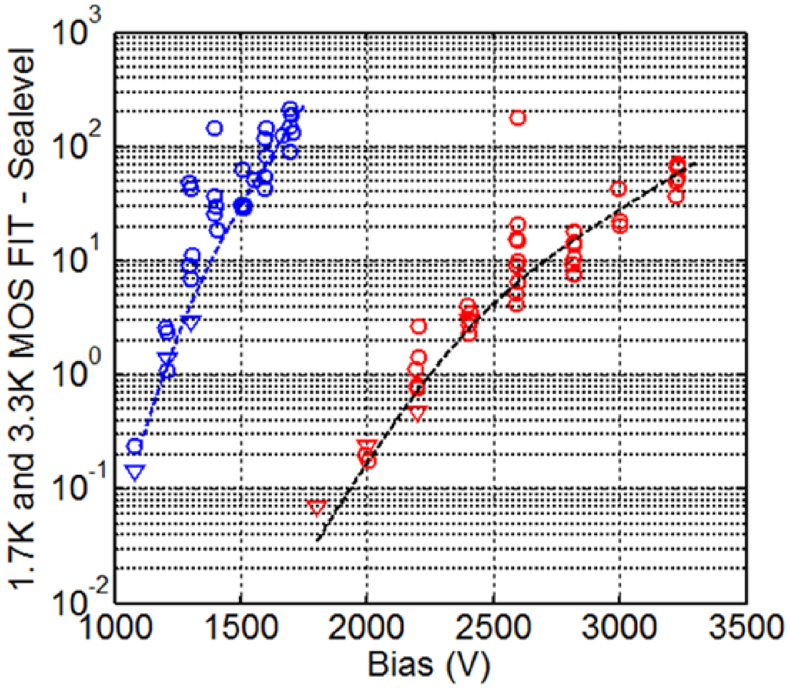
CoolCad Member Project: Evaluate WBG Power Device Reliability Under Terrestrial and Other Radiation Exposure



Terrestrial neutron irradiation is a reliability concern for power devices even at the Sea Level!

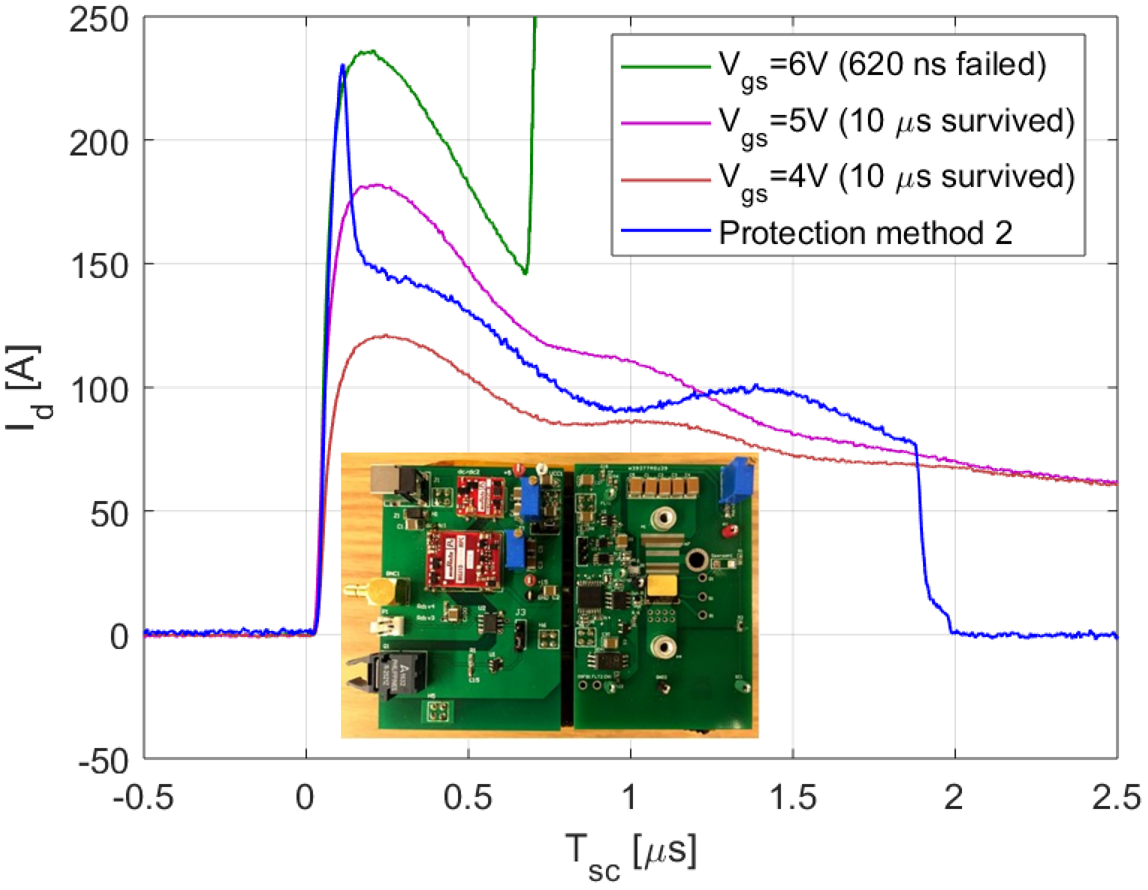


Neutron induced failure resulting in damage site.



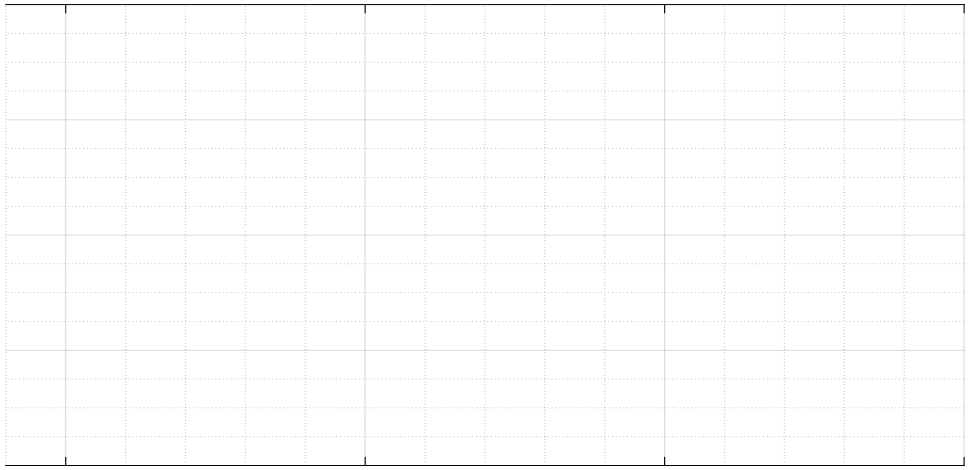
Reliability of WBG power devices under various background radiations will be quantified to determine SOA

OSU Member Project: Develop Short-circuit Ultra-fast Protection Gate Drives to Overcome a Critical Barrier to SiC Commercialization



Short Circuit Protection verified with 650 V rated GaN Devices

1200 V commercial SiC MOSFET SC test at V_{gs} = 20 V, V_{ds} = 800 V

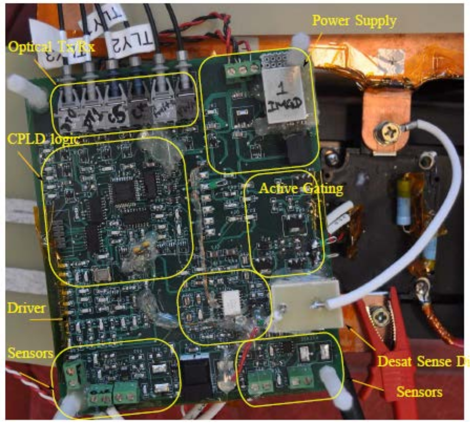


- SiC Power modules provided by Wolfspeed
- SiC TO247 packaged devices provided by GeneSiC, Microsemi, Monolith Semiconductor, and United SiC

NCSU Develops Integrated Intelligent Gate Driver and Interface System for Medium Voltage Converter Applications

POWERAMERICA

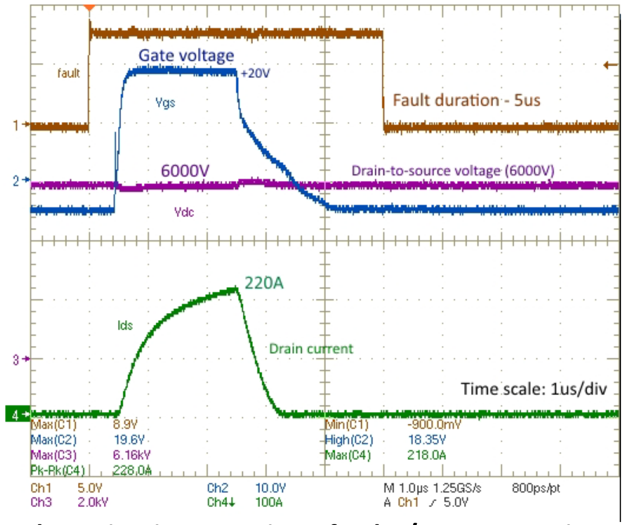
NC STATE UNIVERSITY



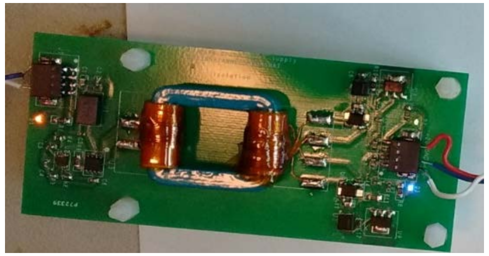
Intelligent Gate Driver

Specification	Value
Turn-on Voltage	18 V -> 20V
Turn-off Voltage	-5 V
Supply Input Voltage	9-10 V
Switching Frequency	Up to 20 kHz
Turn-on Gate Resistance	10-33 Ω
Turn-off Gate Resistance	10-15 Ω
Isolation Voltage	Up to 15 kV
dv/dt capability	> 50 kV/μs
Isolation Transformer Coupling Capacitance	< 5 pF (1- 100 MHz)

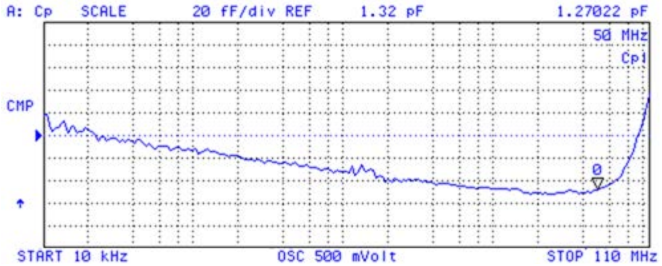
With short circuit protection and diagnosis features



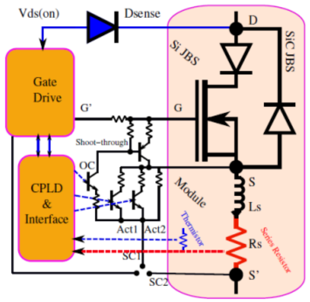
Short circuit protection of 10kV/10A Gen-3 SiC MOSFET at 6kV, 220A current, Trip time: 2.4μs



15kV isolated DC power supply

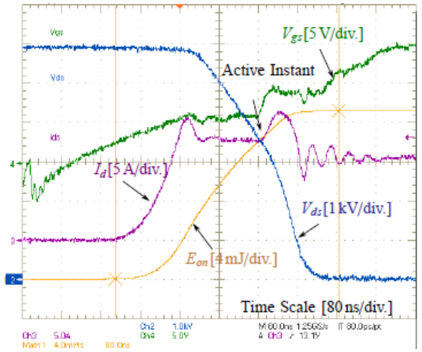


Isolation transformer coupling capacitance: 1.43pF

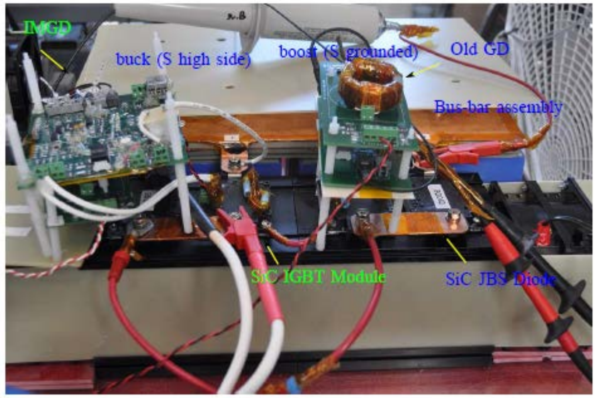


Dynamically changing effective gate resistance during module switching

Gate-voltage level reduction



Active gating and protection circuit



Gate driver validation: Boost-buck setup

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PowerAmerica Applications Funding Boosts WBG Manufacturing by Showcasing Compelling System Advantages

Funding Focus Areas

1 Management and Operations

1.1 Program and Financial Management
1.2 Technology Roadmap
1.3 Sustainability
1.4 Establish a Device Bank
1.5. Subawards Management
1.6 Open Innovation Fund
1.7 Membership and Industry Relations
1.8 Compliance Program
1.9 External Communications
1.10 Placeholder for Faculty Hiring for Sustainability
1.11 Metrics Reporting
1.12 Management of Foundry Process

2 Foundry and Device Development

2.1 Ion Implanter and PDK **X-Fab Texas**
2.2 1.2 kV Diode and MOSFET Foundry Qualification of SiC 150mm line **USCi**
2.3A Qualification an testing of of Gen 3 3.3kV/40mOhm SiC MOSFETS **Wolfspeed/Cree**
2.3B Qualification and testing of Gen3 10kV/350mOhm SiC MOSFETS **Wolfspeed/Cree**
2.4 Diode Commercialization and Production **Monolith**
2.5 Manufacture Vertical GaN devices on bulk GaN wafers **Qorvo/Triquint**
2.6 N/A
2.7 N-Polar GaN Power Devices **UCSB**
2.8 High frequency 12kV SiC Planar gate Power MOSFETS **NCSU (Baliga and Misra)**
2.9 N/A
2.10 Examine Material Defects in SiC Epilayers by UV Photoluminescence **NRL**
2.11 GaN Power Device R&D **UC Davis**
2.12 & 2.13 N/A
2.14 Low Cost 1200V SiC JBS Rectifiers and SJT Dev. **GeneSiC**
2.17 Development of an open gate dielectric process for SiC MOSFET Manufacturing **Auburn University**

3 Module Development & Manufacturing

3.1 Power Module Development and Manufacturing **Cree Fayetteville**
3.2: Reliability benchmarking of SiC MOSFETs **Argonne National Lab**
3.3: Reliability Benchmarking of Lateral GaN Power HEMTs on Si **Rensselaer Polytechnic Institute**
3.4 Terrestrial Neutron Induced Reliability Concerns **CoolCAD**

4 Commercialization Applications

4.1 200 kW 1050Vdc SiC Dual-Inverter **John Deere Electronic Solutions**
4.2 Ultra-High Efficiency SiC Modular UPS **ABB**
4.3 SiC Small Commercial PV Inverters **Toshiba**
4.4: MV Power Module for High Density Conversion **NCSU (Hopkins)**
4.5 N/A
4.6 Comparison of SiC and GaN 7.2 kW Chargers **Kettering University**
4.7 EMI Mitigation and Containment in SiC Modular UPS **Virginia Tech (Burgos)**
4.8 DC Data Center with High Frequency Isolation **Virginia Tech (Lee)**
4.9 HybMic Converter **InnoCit**
4.10 SiC Commercial PV Inverter **FSU (Li)**
4.11A Hi Pwr Density DC-DC Conv. for Aux. Pwr. in H-D Vehicles **NCSU (Bhattacharya)**
4.11B Integrated Intelligent Gate Driver and Interface System for Med. V Appl. **NCSU (Bhattacharya)**
4.12 100kW SiC Inverter for EV Traction Drive **NCSU (Husain)**
4.13 WBG Med. V EV Fast Charger **NCSU (Lukic)**
4.14 TBD
4.15 High Perf. PV String and Micro Inverters **ASU**
4.16 MV Gate Drive with Comprehensive Protection Functions **Ohio State**
4.17: Mass Market SiC Solid-State Circuit Breaker Development **AtomPower**
4.18 Open-Source Compact Transformerless Grid-Tied 3kW GaN PV Inverters **Transphorm**

5 Education and Workforce Development

5.1 Program Management
5.2 Institutes, Workshops, Internships
5.3 Business Plan for Sustainability
5.4 Implement EWD Portal
5.5 Shared Specialty Courses

5.11 WBG Workshop Development and Teaching Modules **NCSU (Ozturk)**
5.12 Curriculum Dev. on WBG device Modeling, Simulation **FSU (Andrei)**
5.13: Documentation of Design and Process of GaN Power Devices (**Rensselaer)**
5.14 Technology Transition for the MV EV Fast Charger **NCSU (Lukic)**
5.15 Documentation of Design and Process for GaN Based Devices **UC Davis**
5.16 Technology Transition for SiC inverter for EV traction drive **NCSU (Husain)**

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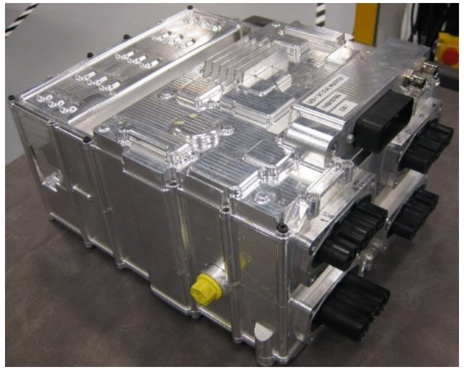
Heavy-Duty Vehicle SiC Inverter Has Performance and System Advantages over Si-IGBT Inverters

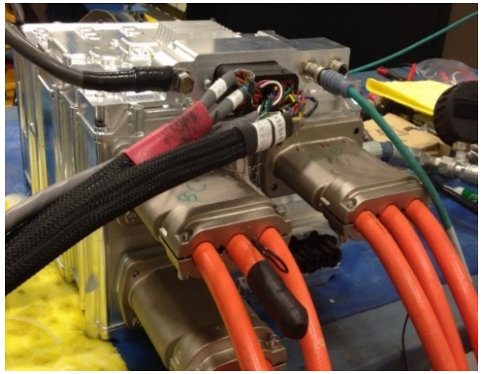
PowerAmerica

Advantages of SiC Inverter

- 18 kW/L power density vs. 9kW/L for IGBT inverter
- Up to 25% more work per gallon of fuel
- > 97% SiC inverter efficiency compared to < 95% for IGBT inverter
- SiC systems benefits and advantages
  - Reduction in engine size and hence lower fuel consumption
  - Elimination of dedicated cooling system/loop for inverter, uses radiator fluid

John Deere

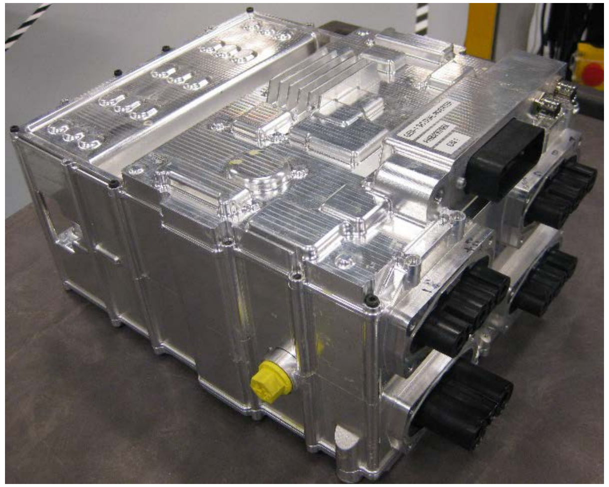


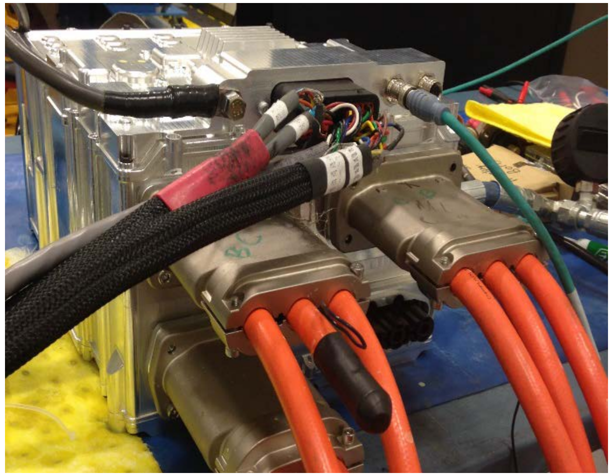


JDES 644K Loader with SiC Based Inverter Driven by DOE and PowerAmerica Personnel

PowerAmerica

Gen-1 Inverter (18 kW/L) - Apr 17, 2017





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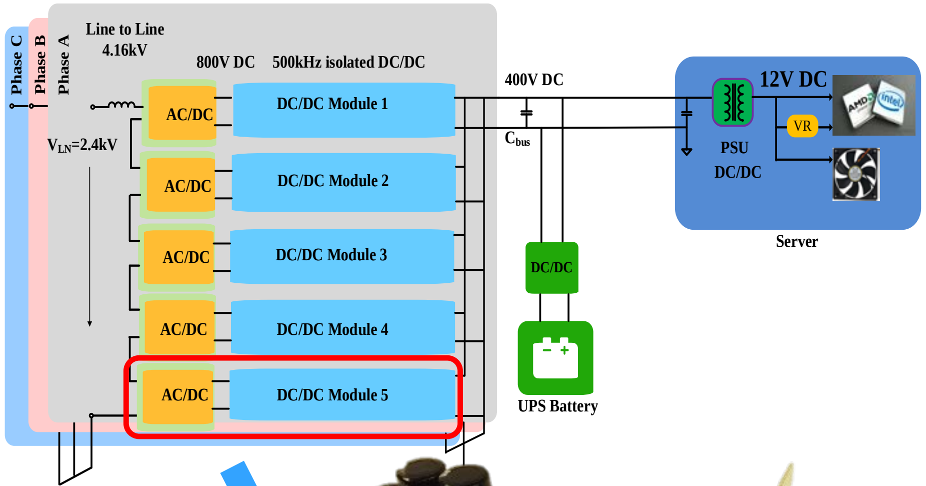
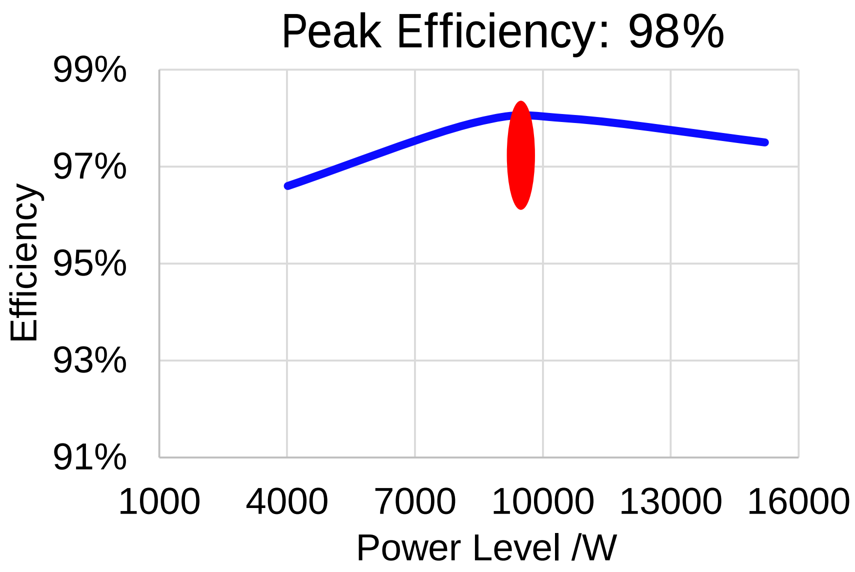
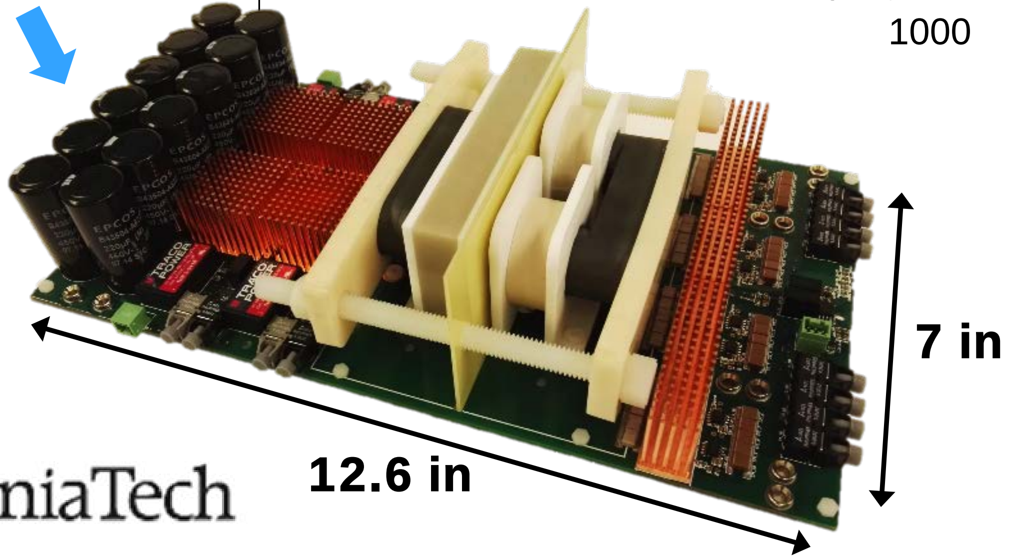
Develop SiC Based DC Data Center with High Frequency Isolation to Dramatically Reduce Power Conversion Loss

PowerAmerica

Objective: Develop a SiC based power conditioning building block, which converts 4.16 kV AC directly to 400 V DC bus with 500 kHz magnetic isolation to dramatically reduce power conversion loss of data center







15kW module with shoe box size

$48W/in^3$

VirginiaTech

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FSU is Developing SiC Based PV Inverters with Mass/Volume/Efficiency Advantages Over Si

State of art 100kW PV inverter

550 kg, 0.18 kW/kg, 98% peak efficiency, 97.5% weighted efficiency

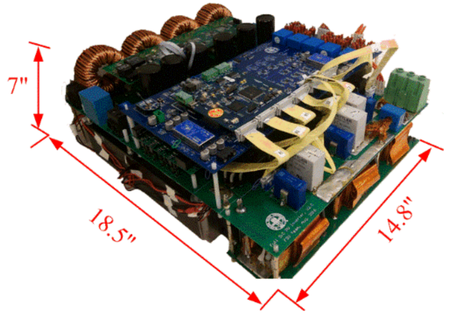
FSU Gen I 50kW SiC PV inverter

13x power density

20 kg, 2.5 kW/kg, 99.2% peak efficiency, 99.0% weighted efficiency, transformer-less, filter-less (grid side)

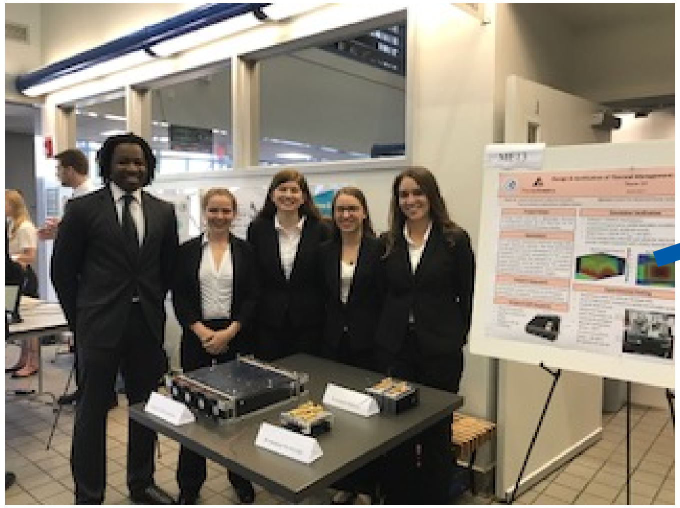
FSU Gen II 100kW SiC PV inverter

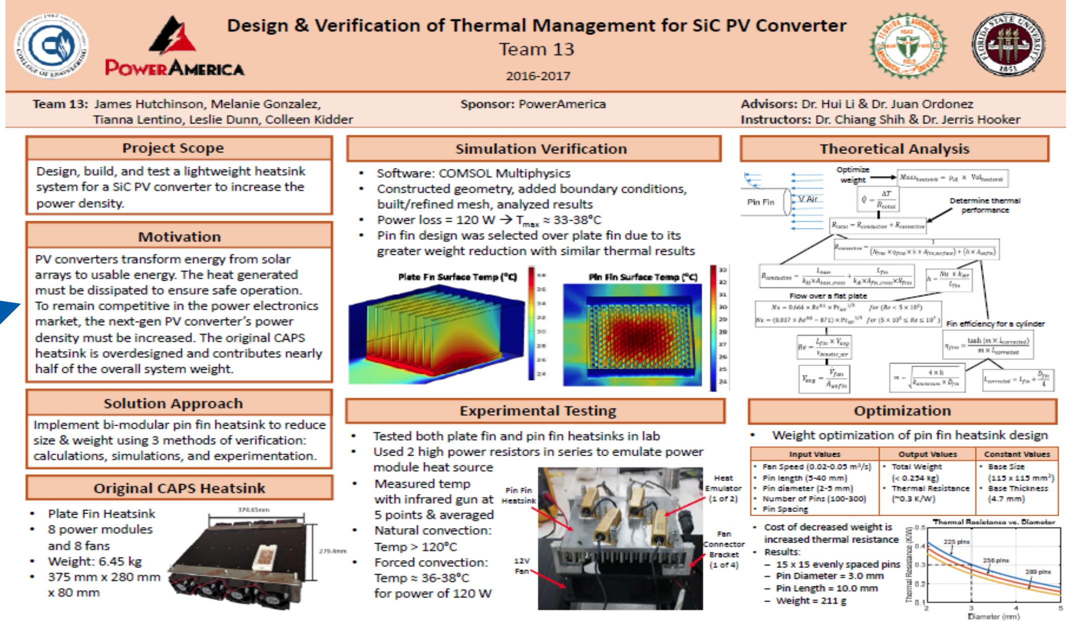
27x power density



20 kg, 5 kW/kg, 98.7% peak efficiency (derived), transformer-less, filter-less (grid side)

Under graduate education/training





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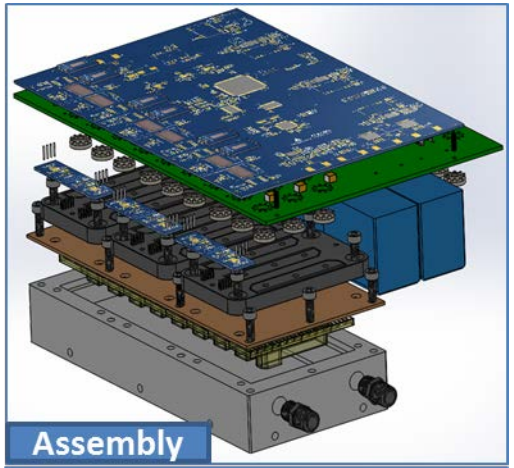
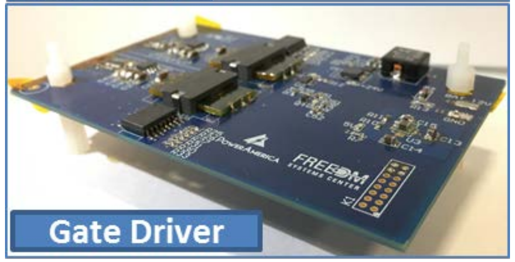
NCSU SiC Based EV Traction Inverter has Mass, Volume, and Efficiency Advantages

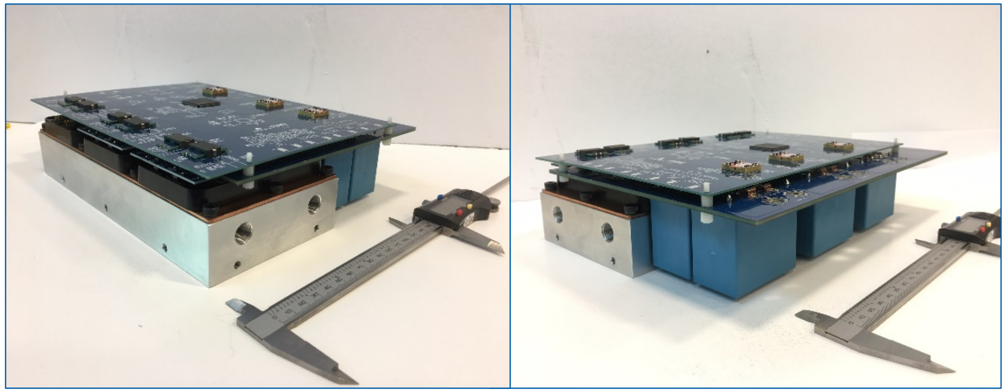
Objective: Develop a 135 kW EV traction inverter with high efficiency and high power density using SiC devices

- **135 kW** Boosted Inverter with **1 kV** DC-link
- 1.7 kV/7.5 mΩ Wolfspeed HT-3231 Power Modules
- Planarized design for High Power Density with High Voltage PCB-based Busbar (**<13 nH** loop inductance), innovative heavy duty connector, and 3D cooling
- Ultra Low-profile (**4 mm**) Gate Driver – **70%** height reduction
- Inverter Stage: Volume - 3.9L; Power Density – 26kW/L





	2016 Chevy Volt Si-IGBT Inverter	NCSU SiC-based Boosted Inverter
Peak Power	135 kW	**135 kW**
Volume	10.4 L	**7 L**
Power Density	13.1 kW/L	**19.3 kW/L**
Efficiency	97.5 %	**99%**



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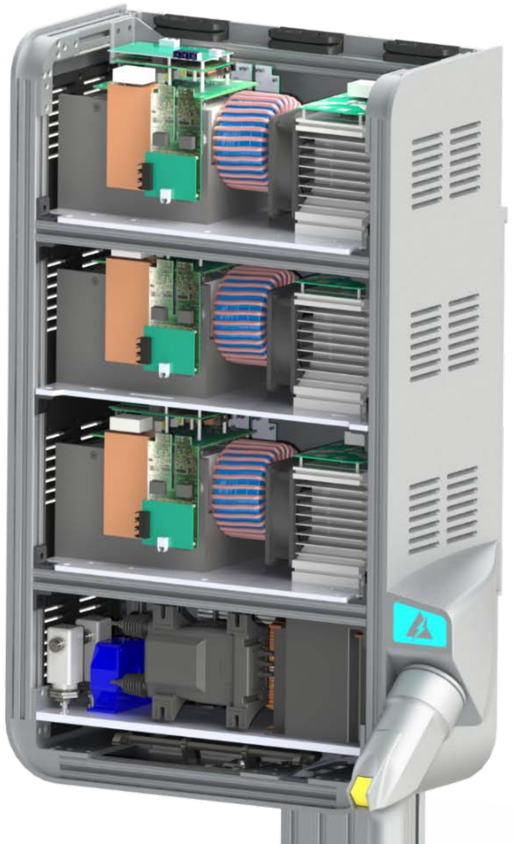
NCSU SiC-Based MV Fast Charger is Smaller, More Efficient, and Cheaper to Install Compared to SOA

Objective: Develop a modular Medium-Voltage Fast Charger using commercial 1200 V SiC devices.

- On Track for System Deployment by end of BP2
- Ready for business model based on subscription parking, monetizing data and advertising on charger displays

MVFC Basic Features

- 50 kW
- 2,400 Vac to 400 Vdc
- 1200 V SiC devices
- η ≥ 96%,
- PF ≥ 0.98, THD ≤ 2%
- 10x size reduction
- 4x weight reduction
- 40% installation cost reduction
- No step-down service transformer



Commercial Fast Charger
V = 800 L
m = 400 kg
η ~ 93.5%

NCSU MV Fast Charger
V = 82L
m = 100 kg
η ≥ 96%

University of Tennessee SiC Medium Voltage Power Conditioning System Has US Manufacturing Partners

Project Objective:

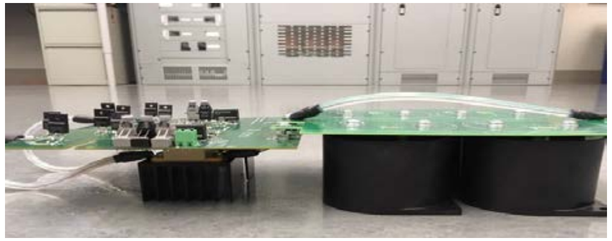
Develop a multi-functional high-efficiency high-density power conditioning system (PCS) module at medium voltage level (13.8 kV AC) using 10 kV SiC power semiconductors, satisfying related requirements (i.e. specific power, power density, efficiency, control bandwidth and grid requirements)

Achievements:

1. Specification and grid requirements determined for the PCS module with help of EPB and SCS
2. Latest generation 10 kV SiC MOSFET characterized, and test report completed
3. PCS phase-leg designed including topology and PWM strategy, passives, cooling, gate drive & isolated power supply
4. PCS controller designed including control and interface board, sensor board and control algorithm
5. 25 kV DC, 35 kW phase-leg prototype and test platform building in progress
6. PCS module controller demonstrated with grid-emulation Hardware Testbed

Impacts on WBG Manufacturing and Jobs

1. Address challenges for MV SiC converter design, and accelerate the commercialization for MV SiC converter
2. Increase the market of asynchronous microgrid with developed SiC PCS, which allows more integration of renewable energy sources
3. With U.S.-based HV SiC device, the project will have a positive impact on U.S. competitiveness and leadership in MV converter, renewable energy and microgrids
4. Collaboration with utility (EPB and Southern Company) and manufacturing partners (EPC Power) will help the product transition to market, creating a complete chain and more jobs from converter manufacturing to grid integration



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PowerAmerica accelerates WBG commercialization

WBG device fabrication in large-volume Si foundries exploits economies of scale and is key in lowering cost.

Minimizing capital expenditures by exploiting the mature Si-processing capability lowers fabrication costs.

A workforce well trained in WBG power electronics is key in creating the large device demand that will spur volume manufacturing with its cost-lowering benefits.

PowerAmerica funds building-block projects in multiple areas of the WBG supply chain that synergistically culminate in large-scale WBG power electronics adoption.

PowerAmerica

IWIPP 2019

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