Arkansas Power Electronics International, Inc.

High Temperature and High Power Density SiC Power Electronic Converters

DOE Peer Review
November 2-3, 2006

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Sandia National Laboratories

Energy Storage Systems Program

Overview

- APEI, Inc. Corporate Status
- Broader Impact of SiC-based Power Converter
- DOE Energy Storage System Program Phase I SBIR
  - SBIR Topic: Wide Band Gap Power Converter Application
  - APEI's Goals
  - Phase I Accomplishments
- DOE Energy Storage System Program Phase II SBIR
  - APEI's Goals
  - Research Team and Partners
  - Project Status

APEI, Inc. Mission Statement

We are a small business dedicated to developing and marketing the state-of-the-art technology in power electronics systems, electronic motor drives, and power packaging.

APEI, Inc. Company Information

- **Founded in 1997**
  - Original founder, Dr. Kraig Olejniczak left in 2002
  - We shifted emphasis from consulting to R&D product development in 2002
  - Moved out of Genesis in 2006 into the Innovation Center
- **Employees**
  - Have grown from 1 employee in 2002 to the present 19 employees
  - Includes 4 Ph.D.s, 5 M.S., 2 MBA, 4 BS, 4 Interns
- **Revenues**
  - Have grown from $14k in revenues in 2002 to the present $2+ million annually
  - $2 million in contracts secured for 2007 with projections to exceed $3 million
  - Revenues approximately 50/50 split between Federal and commercial R&D contracts
  - APEI, Inc. will release first “engineering sample” products in 2007
- **Facilities**
  - Have grown from 100 sq. ft. in 2002 to the present ~6,000 sq. ft. including 2 clean rooms and 2 test laboratories
- **Intellectual Property**
  - 1 patent has been awarded
  - ~ 6 patents are under filing and review
  - Trade secrets
  - ~ 150 international publications by company employees

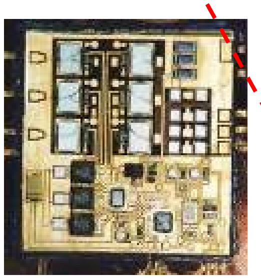
APEI, Inc. Technology

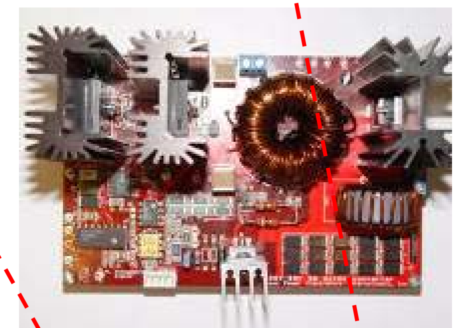
Multichip Power Modules (MCPMs)

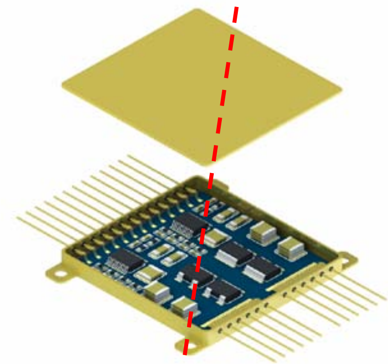
High Temperature Testing & Design

High Temperature Power Packaging

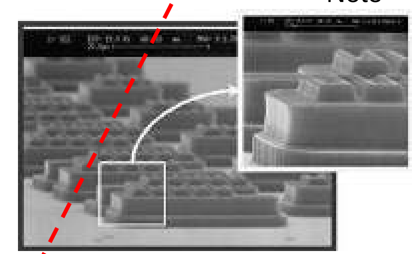
Silicon Carbide Electronics

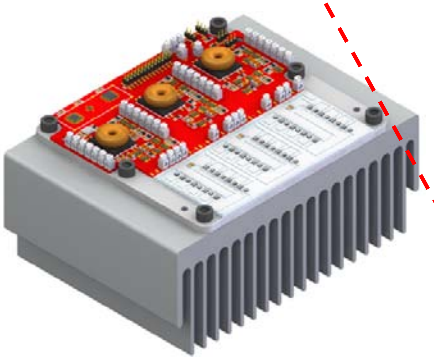


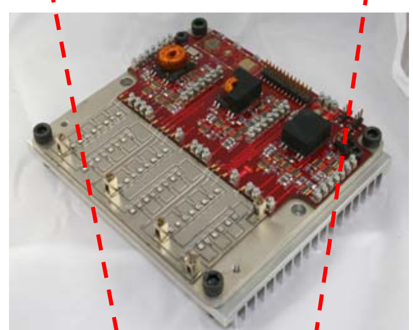


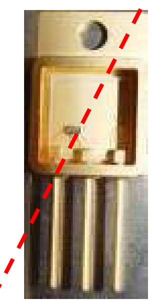


* Note







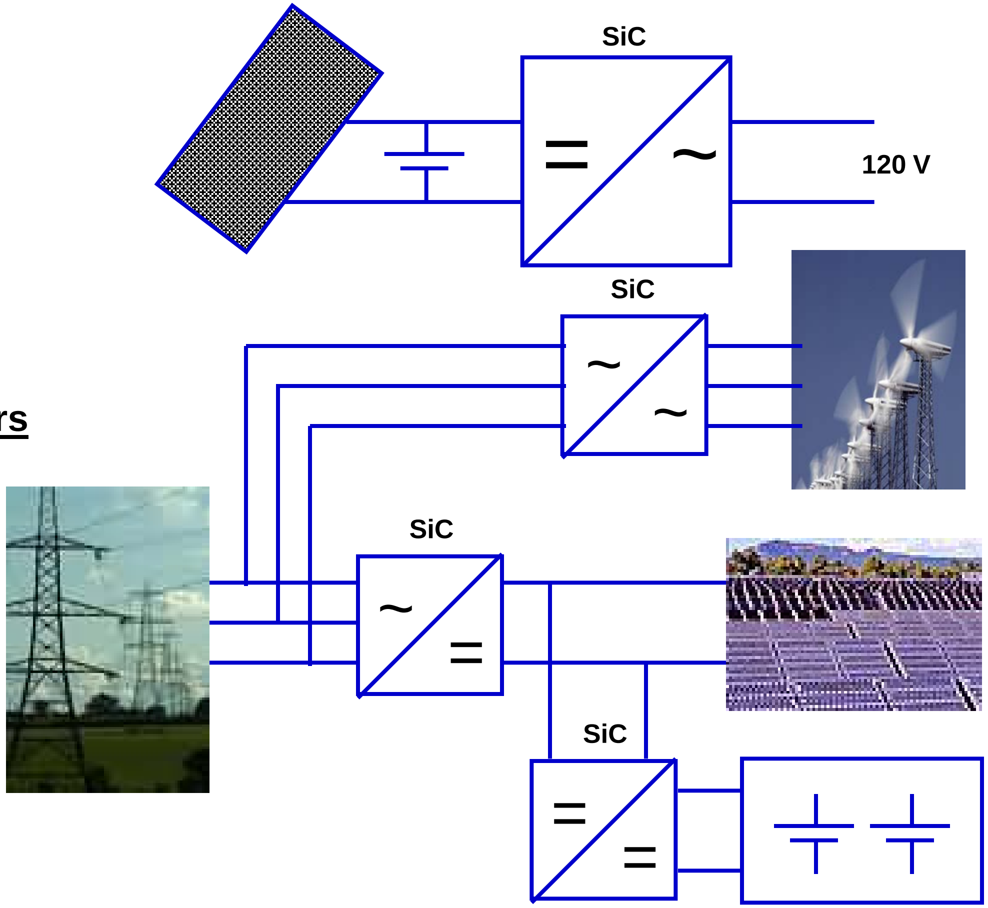


High Density Power Electronics

* Note: Semisouth LTSIT

Applications for SiC-based Power Converters

FY05 SBIR Topic: Wide Band Gap Power Converter Application



Single-Phase Inverter

- 3 kW proof-of-concept prototype
- Stand-alone application

Three-Phase Inverters and DC/DC Converters

- High-power applications
- Renewable energy sources

The Advantages of Silicon Carbide

Thermal Advantages

- SiC device theoretical limit exceeds 600 C

  Very high power densities can be achieved with these junction temperatures.
- SiC has a very high thermal conductivity— excellent for power devices and thermal transfer, increases power density
- **Disadvantage:** currently no device packaging technology exists to take full advantage of thermal capabilities.

  Requires packaging advances in die attach, interconnects, and reliability.

Electrical Advantages

- Very low switching losses (1/10th of Si) w/ smaller drive currents and smaller on-resistances
- Up to 10s to 100s of GHz switching range
- Very high voltage blocking

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DOE ESS Phase I SBIR Review

- **Phase I SBIR (FY05)**
  - **Partnership between APEI, Inc and GeneSiC**
  - **Goal: Demonstrate the advantages of a SiC-based power converter as interface for advanced energy storage systems**
  - **Technology Demonstrator: 3-kW 120V single-phase inverter capable of operating at high-temperature (250 ºC+)**

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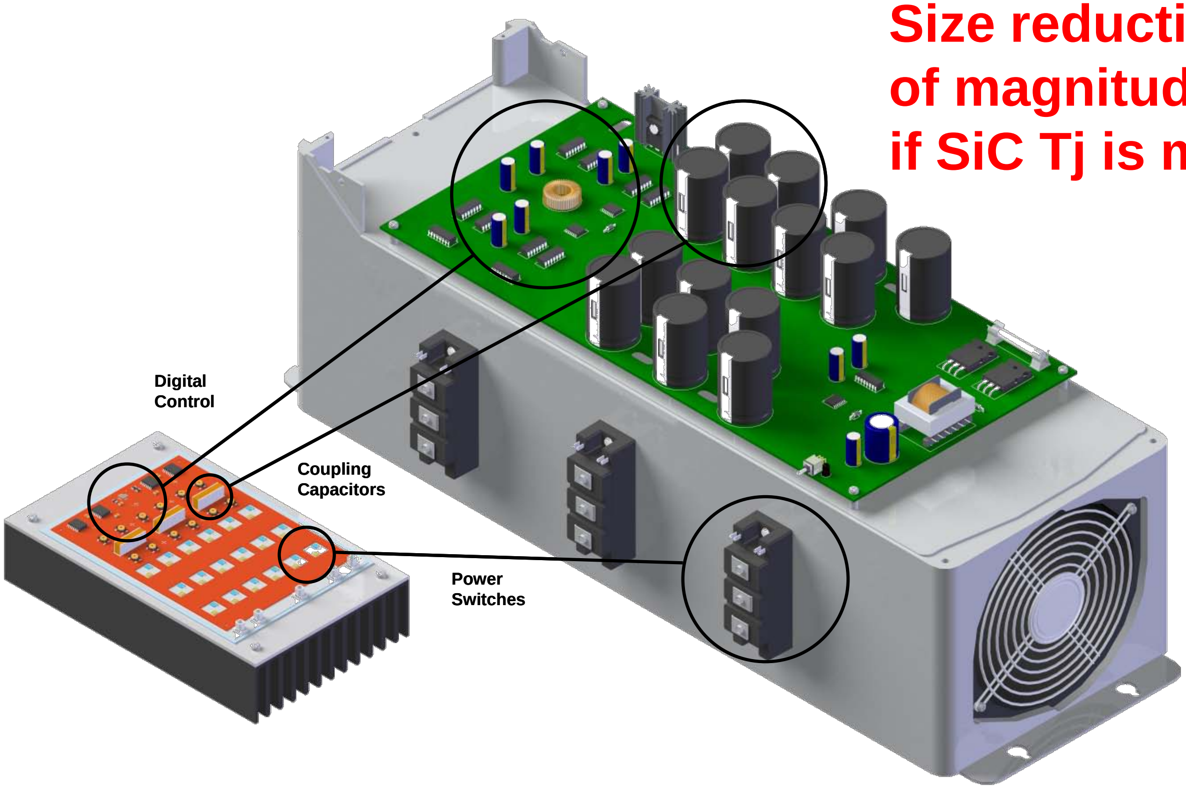
Potential Size Reduction Using SiC



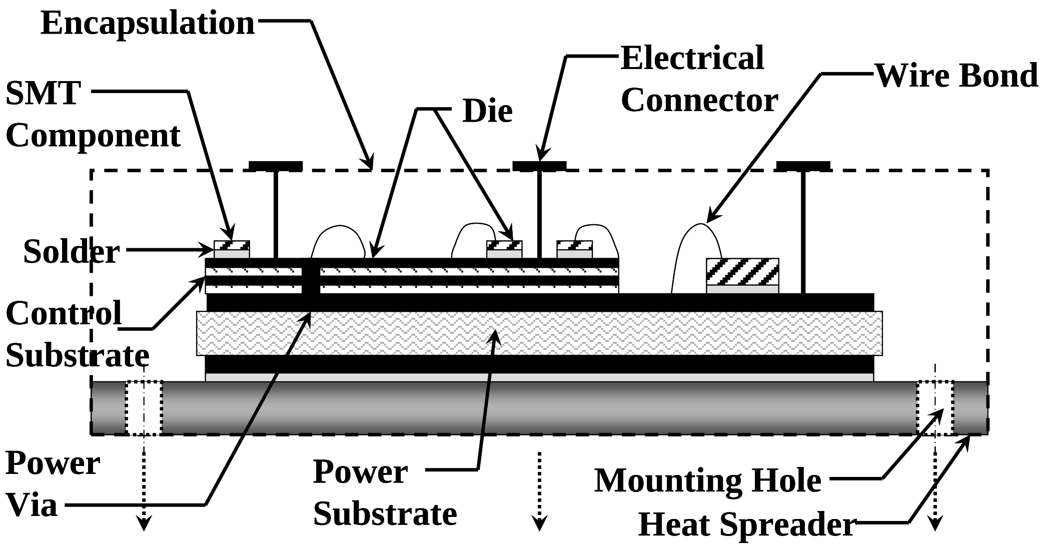
Size reduction of an order of magnitude achievable if SiC Tj is maximized

30 kW APEI SiC Power Module

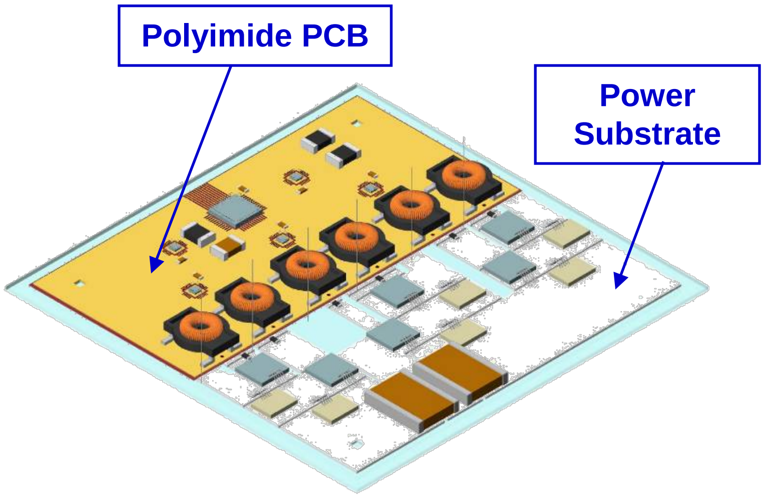
30 kW Standard Power Module

MCPM Packaging Approach

Cross-section of the SiC MCPM design (*)



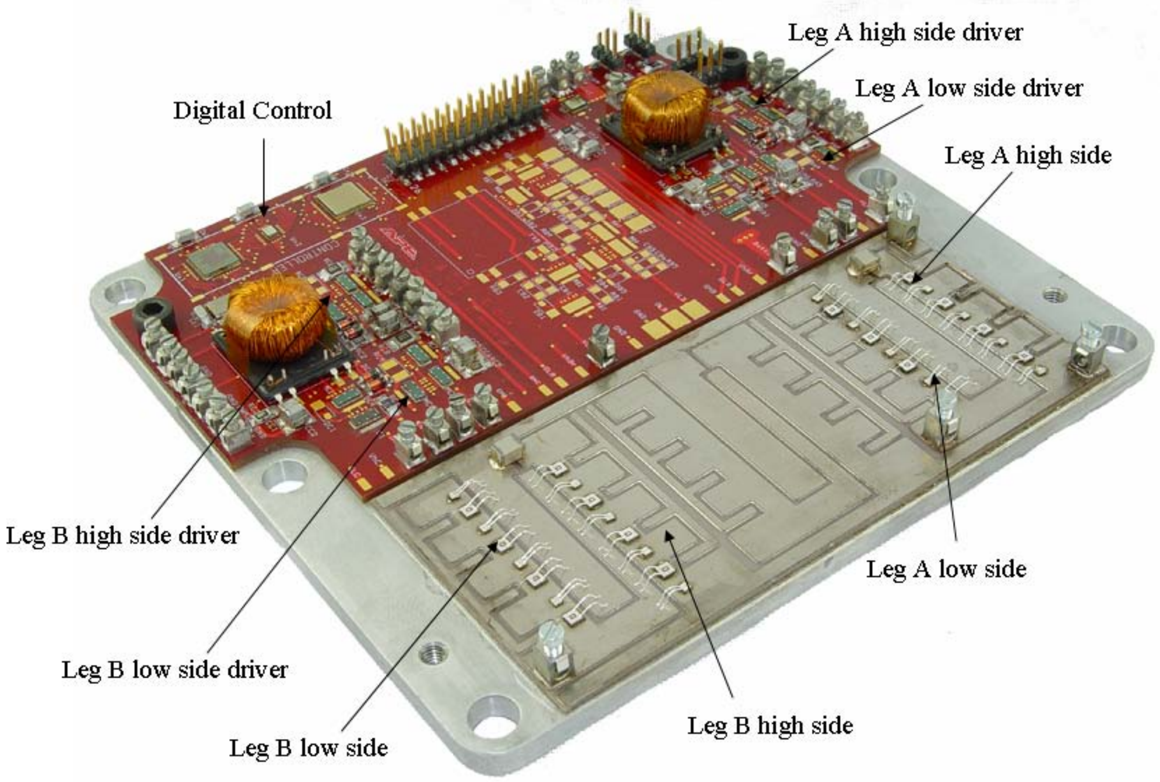
Isometric view of high-temperature MCPM



(*) **APEI, Inc. patented technology**

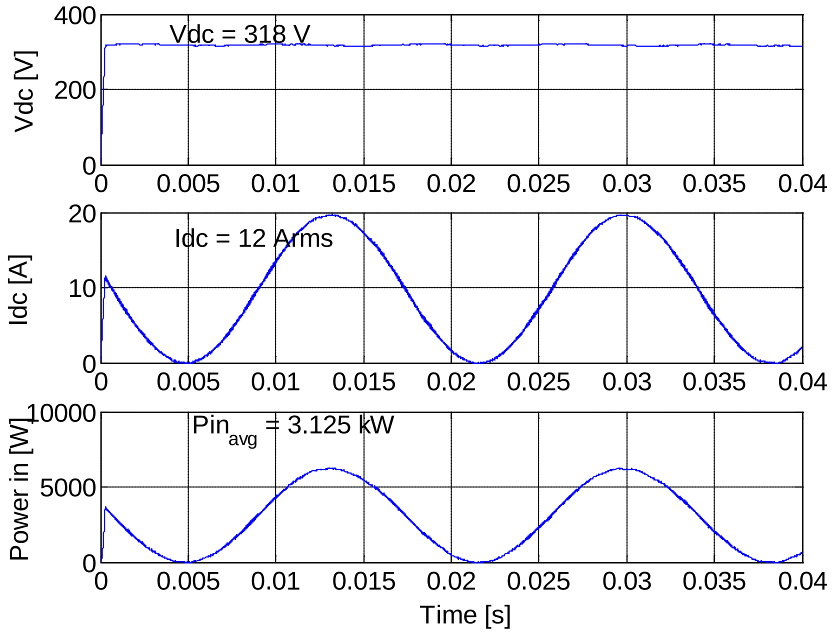
DOE ESS Phase I SBIR Review

- **Technology Demonstrator**
  - **3-kW 120V single-phase inverter (250 ºC+)**

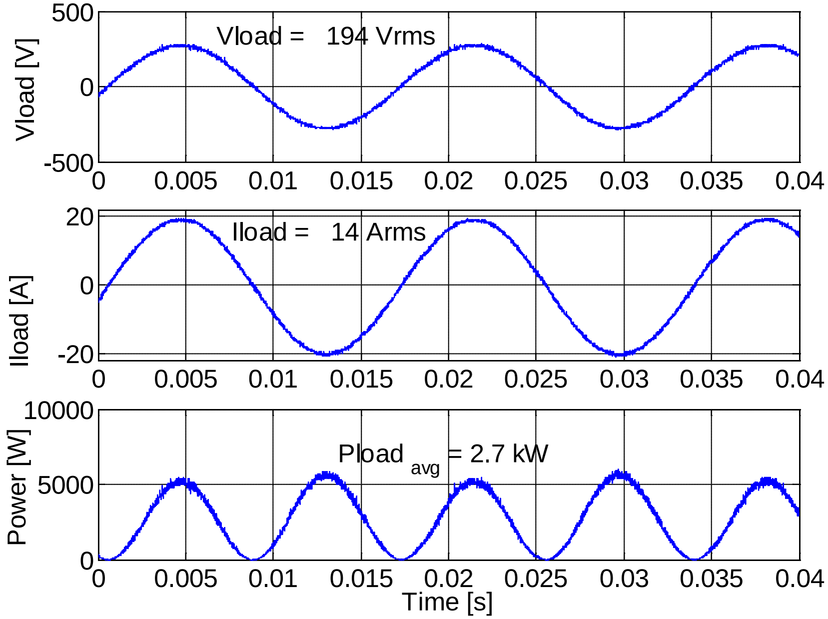


DOE ESS Phase I SBIR Review

Input Power



Output Power



Operation at ~ 3 kW

>90% efficiency

DOE ESS Phase I SBIR Review

APEI, Inc.'s SiC-based MCPM power inverter module has a power density of 11 W/in^3 (using only passive cooling). <u>This is an 85% volume reduction over current commercial Si-based power inverters</u>.

*Note: this portion of the Si inverter was **not** included in the calculations.

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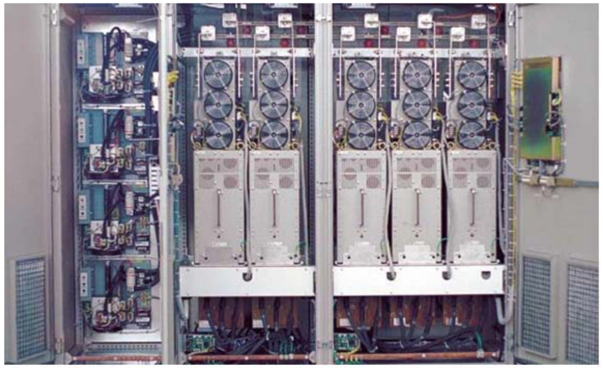
DOE ESS Phase II SBIR

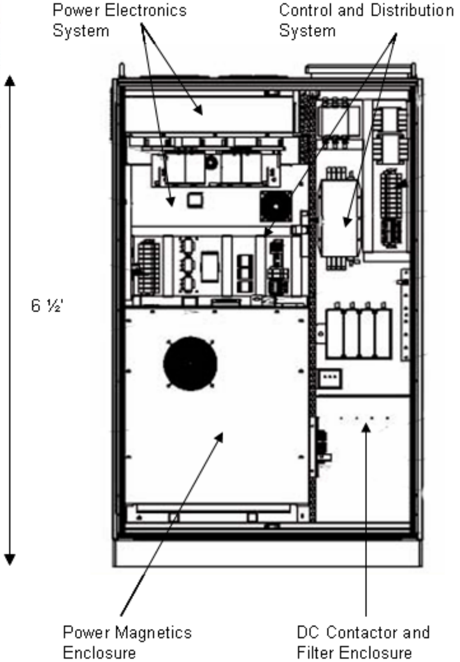
- Phase II SBIR (FY06)
  - Phase II started on August 2006
  - Goal: In Phase II, APEI, Inc. will take the concepts demonstrated in Phase I and develop a fully-functional multi-purpose 100 kW SiC-based DC/AC power converter prototype with 75%+ volume reduction over silicon equivalent systems.
  - Industry and Governmental Support:
    - State of Arkansas
    - Baldor Motors and Drives
    - Northrop Grumman
    - National Center for Reliable Electric Power Transmission (NCREPT)

DOE ESS Phase II SBIR

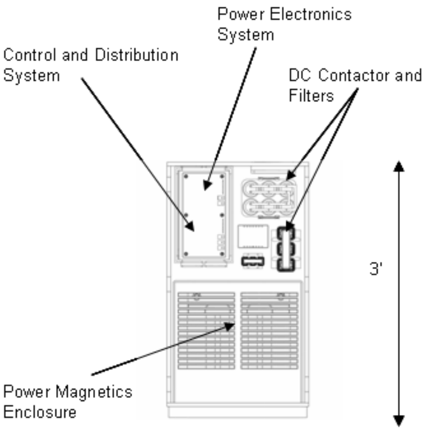
Commercial Si based Photo-
-Voltaic Grid Tie Three-Phase Inverter
(100 kW)



Commercial Si Based Three-Phase Motor Drive (400 kW)

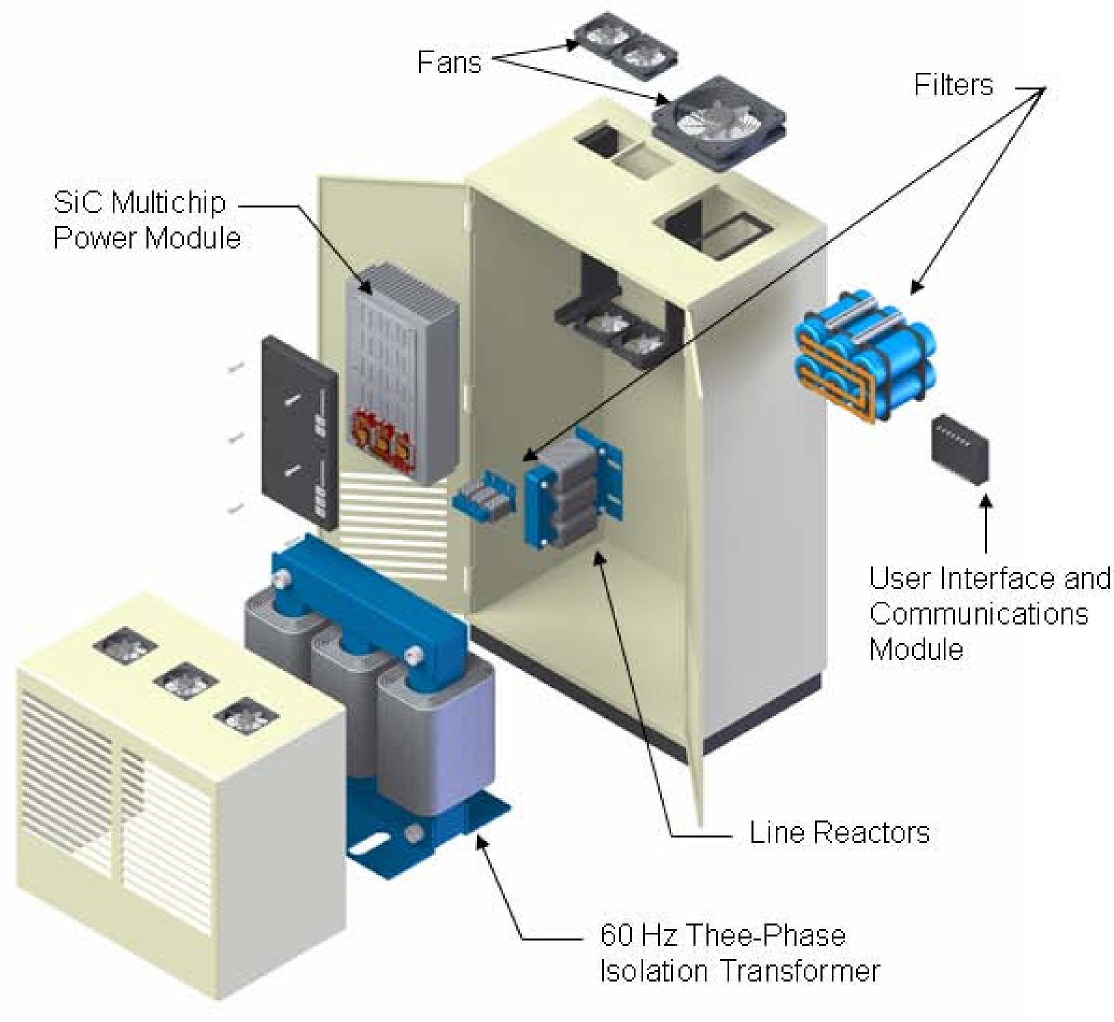


Xantrex GTE100 Three-phase Inverter
(100 kW)



APEI, Inc. SiC Three-phase Inverter
(100 kW)

DOE ESS Phase II SBIR



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DOE ESS Phase II SBIR

- **Phase II SBIR Tasks/Current Status**
  - Task One: Overall Mechanical Design and Layout (Started)
  - Task Two: SiC Multichip Power Module Packaging (Started)
  - Task Three: Electric Design of a Switch Position (Started)
  - Task Four: Electrical Design of the Power Stage
  - Task Five: Electrical Design of the Control Stage
  - Task Six: SiC JFET Fault Limiter (GeneSiC)
  - Task Seven: SiC Inverter Fabrication and Testing

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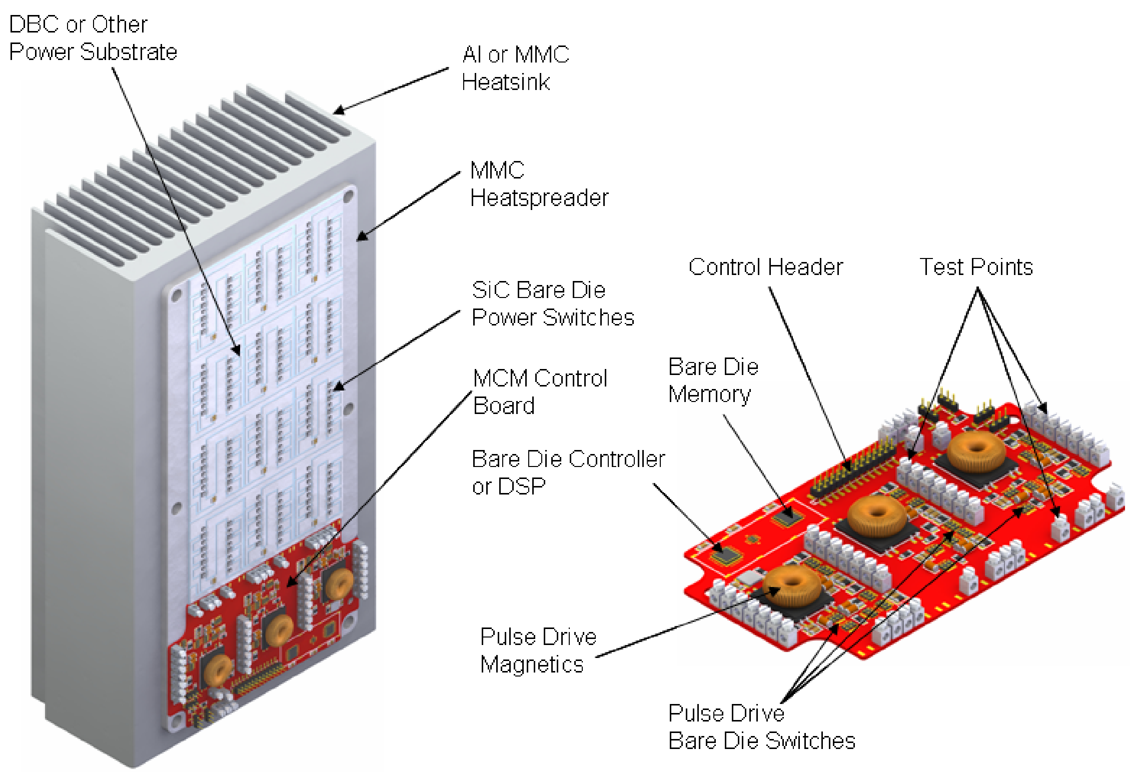
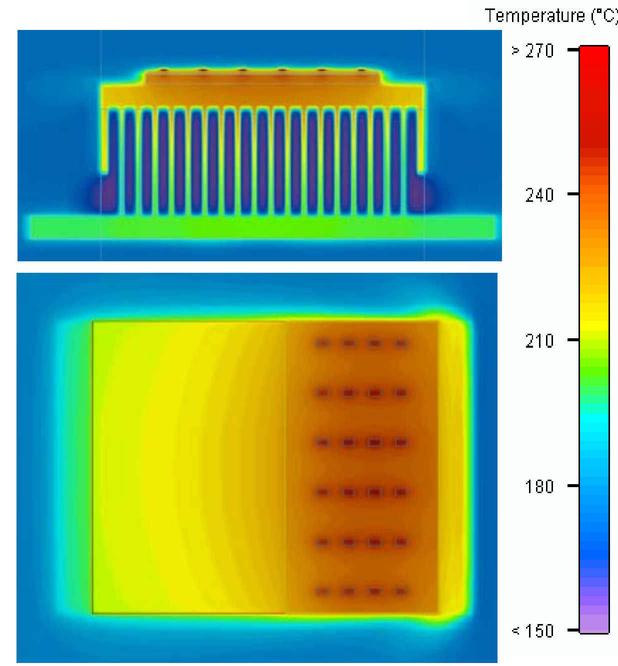
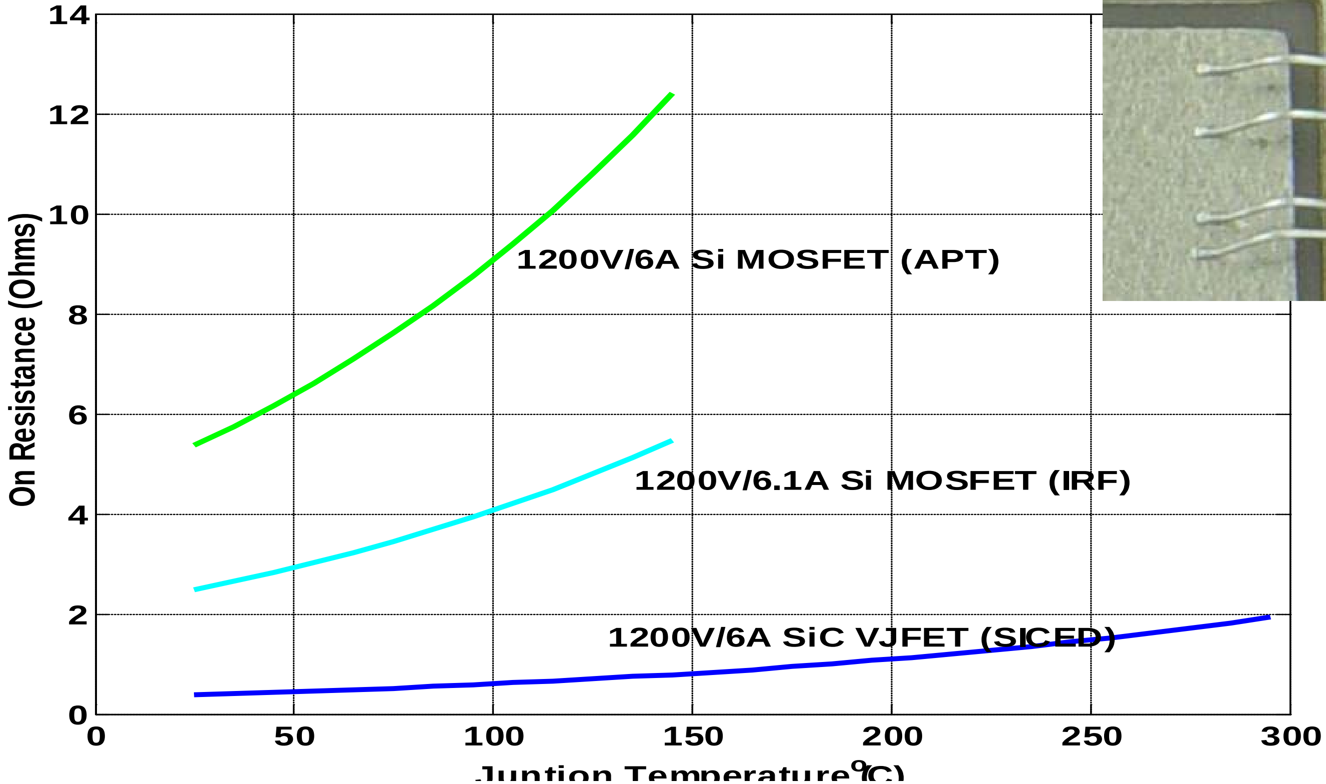
SiC MCPM Mechanical and Thermal Design

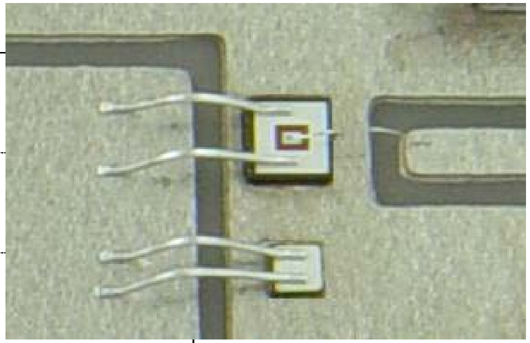




DOE ESS Phase II SBIR

Electrical Design of SiC Switch Position

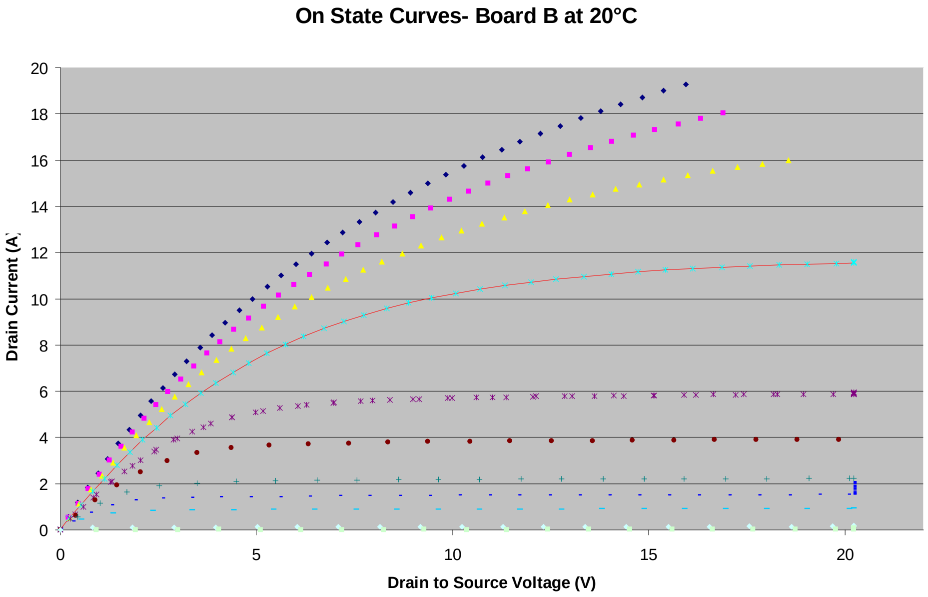


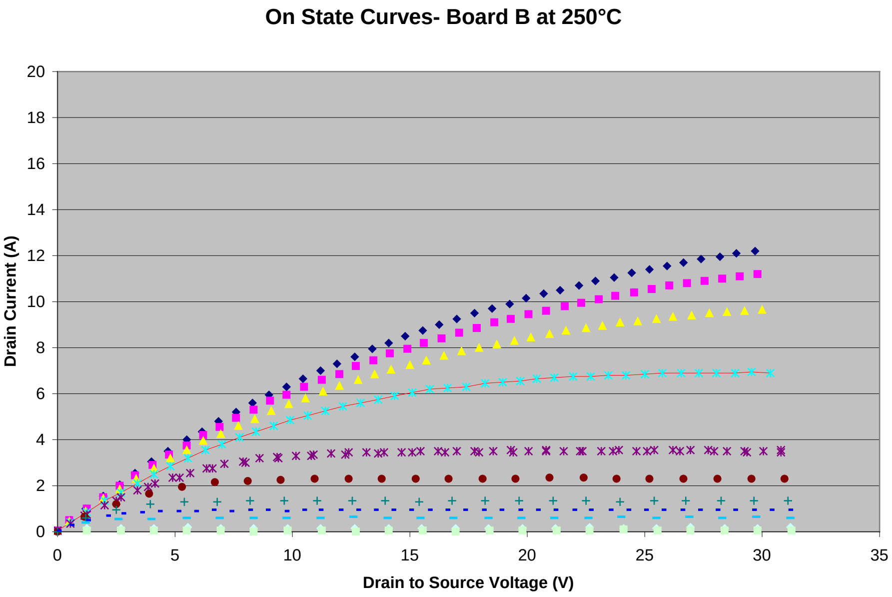


DOE ESS Phase II SBIR

Electrical Design of SiC Switch Position

- Characterization of devices over temperature





Summary

- SiC has the potential of greatly increase the performance power converters enabling distributed generation
  - Higher efficiency
  - Smaller size
  - Higher reliability
  - And ultimate lower cost

- Phase I work focused on prove-of-concept
  - 3-kW/120V single-phase inverter
  - Great volume reduction
  - Demonstrate high-temperature operation (250 ºC)

- Phase II work focus on higher power level and high integration of complete system
  - 100 kW 3-phase inverter
  - 75%+ volume reduction of complete system

DOE ESS Phase II SBIR

- **Phase II SBIR Future Work**
  - Task Two: SiC Multichip Power Module Packaging
    - Thermal analysis based on switch position loss estimation (Task Three)
    - Optimization of temperature rise vs. losses
    - Thermal-stress analysis based on maximum temperature rise
  - Task Three: Electric Design of a Switch Position (Started)
    - Final selection and characterization of power devices (VJFET/Diode)
    - Optimization of "device paralleling"
  - Task Four: Electrical Design of the Power Stage
    - Begin the selection/sizing of DC link capacitors and output/input filters
  - Task Five: Electrical Design of the Control Stage
    - Design of gate drive circuitry
    - Begin the development of the digital controller

Acknowledgments

- Department of Energy (DOE)
  - Energy Storage System Program, directed by Dr. Imre Gyuk
  - Sandia National Labs, Stan Atcitty

- APEI's Partners
  - GeneSiC
  - State of Arkansas
  - Northrop Grumman Advanced Technology Center
  - Baldor Motors and Drives