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A High-efficiency Compact SiC-based Power Converter System

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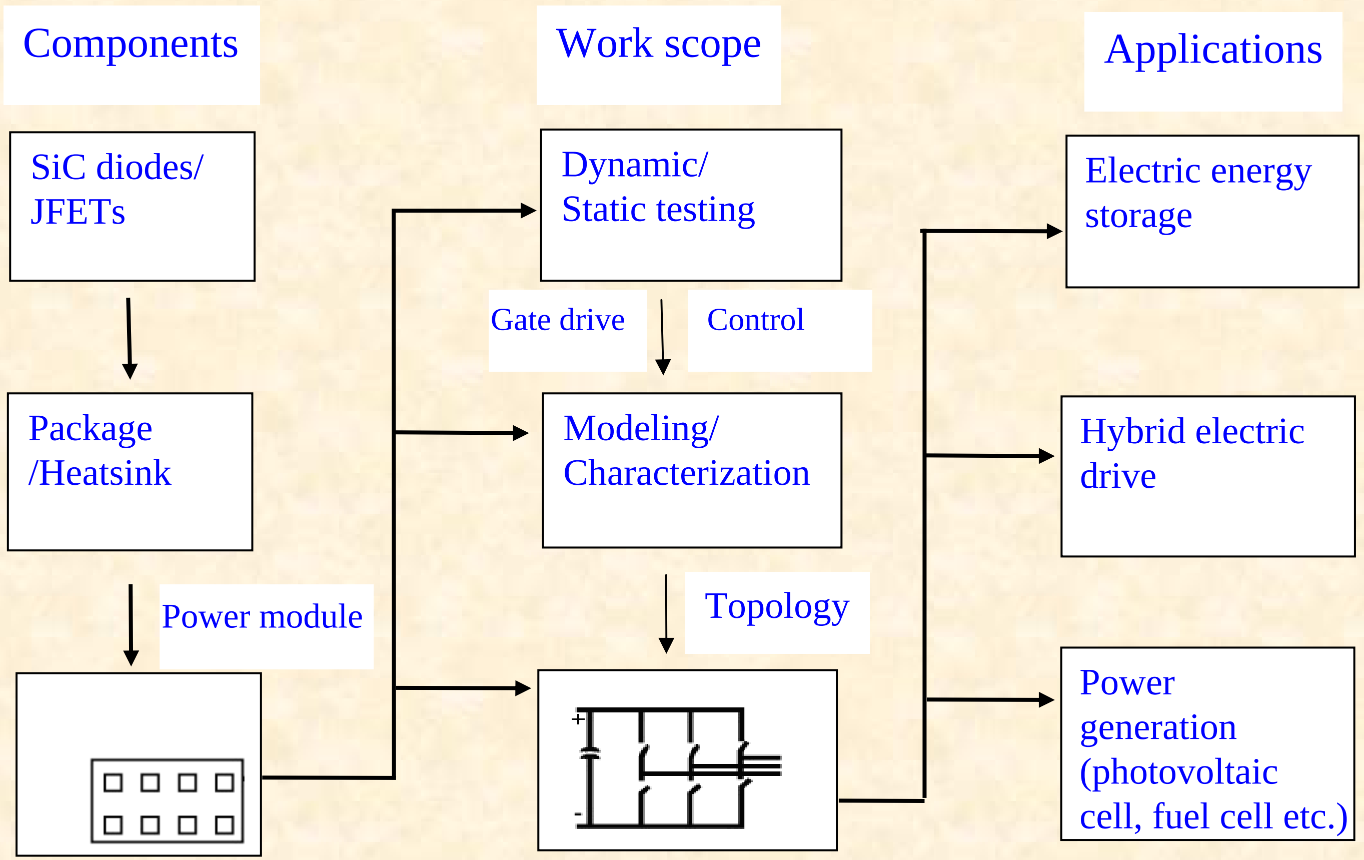
Significance and Challenges

- **Advantages of SiC power electronics**
  - **SiC technology will enable less conduction loss, higher temperature operation (>175°C) and high frequency operation(100 to 500kHz).**
  - **Smaller volume, lighter weight, higher power density.**
  - **Higher efficiency.**
- **Challenge issues**
  - **Specially designed drive circuit because of its switching ON – OFF characteristics (normally ON for commercial SiC switch, JFETs).**
  - **High temperature packaging.**
  - **Limited current capability of SiC devices needing the paralleling of multiple devices.**

Objective

- Develop a high-efficiency compact power inverter based on SiC-based semiconductor technology
  - High efficiency, small size, and light weight.
  - High power density, high temperature, and high frequency.
  - Scalable current ratings and power levels.
- Address associated technical issues and supporting technologies
  - Design, modeling and simulation.
  - Power modules by paralleling multiple SiC devices.
  - High-temperature package and thermal management.
  - High-frequency gate driver suitable for SiC power devices.
- Integrate the technologies for demonstration/test of a SiC inverter that can operate at high junction/environment temperatures
  - Analyze the benefits of using SiC power devices in a systematic level.
  - Explore potential applications (e.g. electric energy storage).

Approach and Work Scope

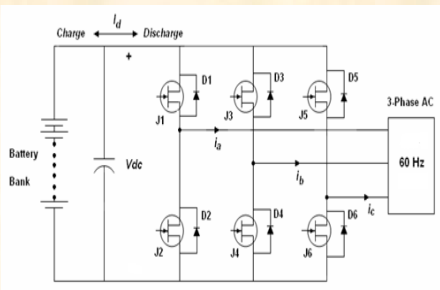


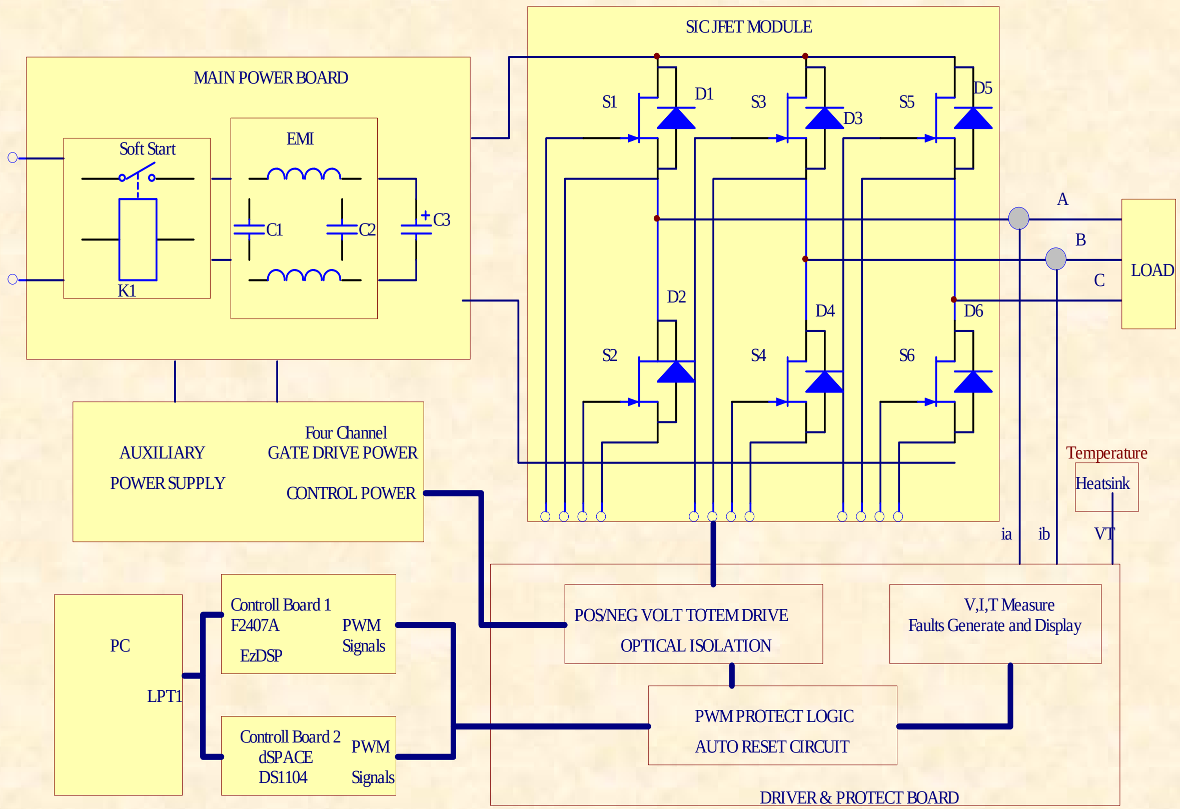
Up-to-date Accomplishments in Phase II

- ✓ DC-AC inverter design.
- ✓ Power module design/prototype.
- ✓ Packaging/Thermal management.
- ✓ Gate design/prototype.
- ✓ Modeling/characterization.
- ✓ Preliminary inverter prototype/testing.
- ✓ Preliminary commercialization.

Results – Inverter Design

Three-phase inverter





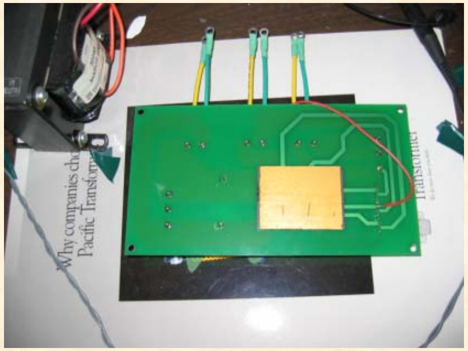
An inverter is interfaced with:

1) A large battery bank for energy storage.

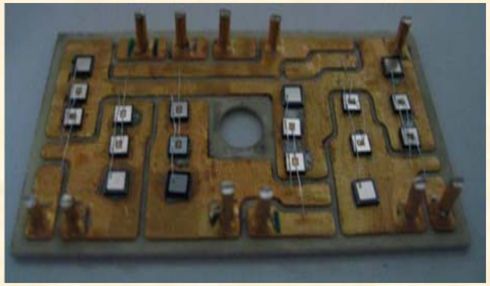
2) An AC system.

Power Module Design and Prototype

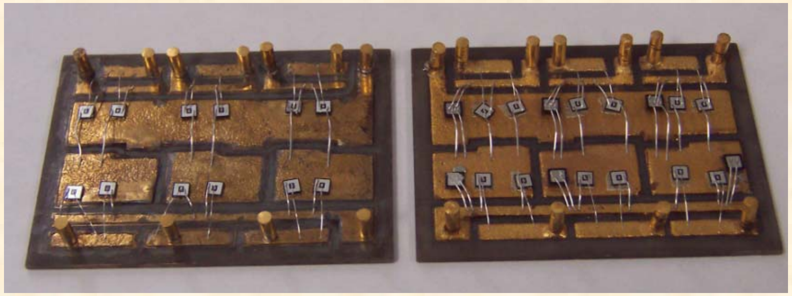
- **SiC power modules using commercial SiC devices**
  - SiC diodes and SiC JFETs
- **Device/module paralleling**
  - Low current rating (e.g. 15-30 A), 2-4 ps. devices parallel into an array (for a single gate drive) to form a unit power module
  - High current rating (e.g. 80-100 A), 4-6 ps. unit power modules parallel into an array of power modules



Power module integrated with gate drive



Design 1- Six packed, 3 phase



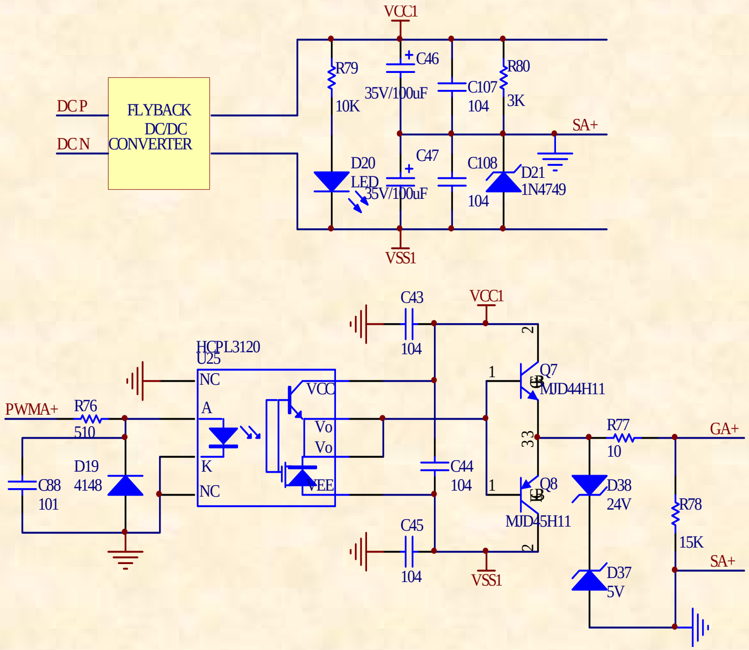
Design 2- Six packed, 3 phase

Packaging and Thermal Management

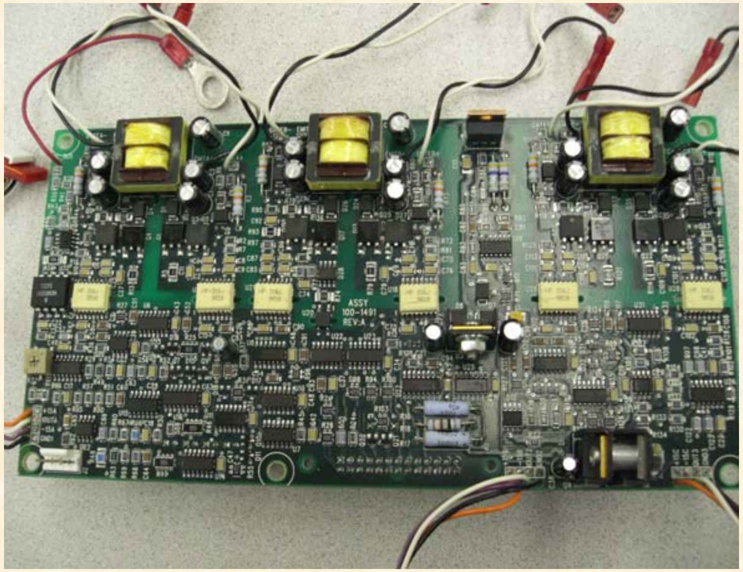
- **Thermal packaging**
  - **AlN package substrate for high temperature packaging**
  - **Networking microchannel cooling and graphite foam heatsink**
- **Metallization for interconnect, die attachment and joining**
  - **Active metallization on AlN (vs. commercial CB AlN)**
- **Die attachment of SiC devices**
  - **Au-Sn (280 C)**
- **Joining – Packaging and heatsink**
  - **Active brazing and metallization/soldering**
- **Wire bonding**
  - **Al or Au wires**

Gate Drive

- **Challenging issues/approach**
  - **Normally-on device of JFET for high frequency operation**
  - **Commercially available Si devices --> a Drive & Protect Circuit Board**



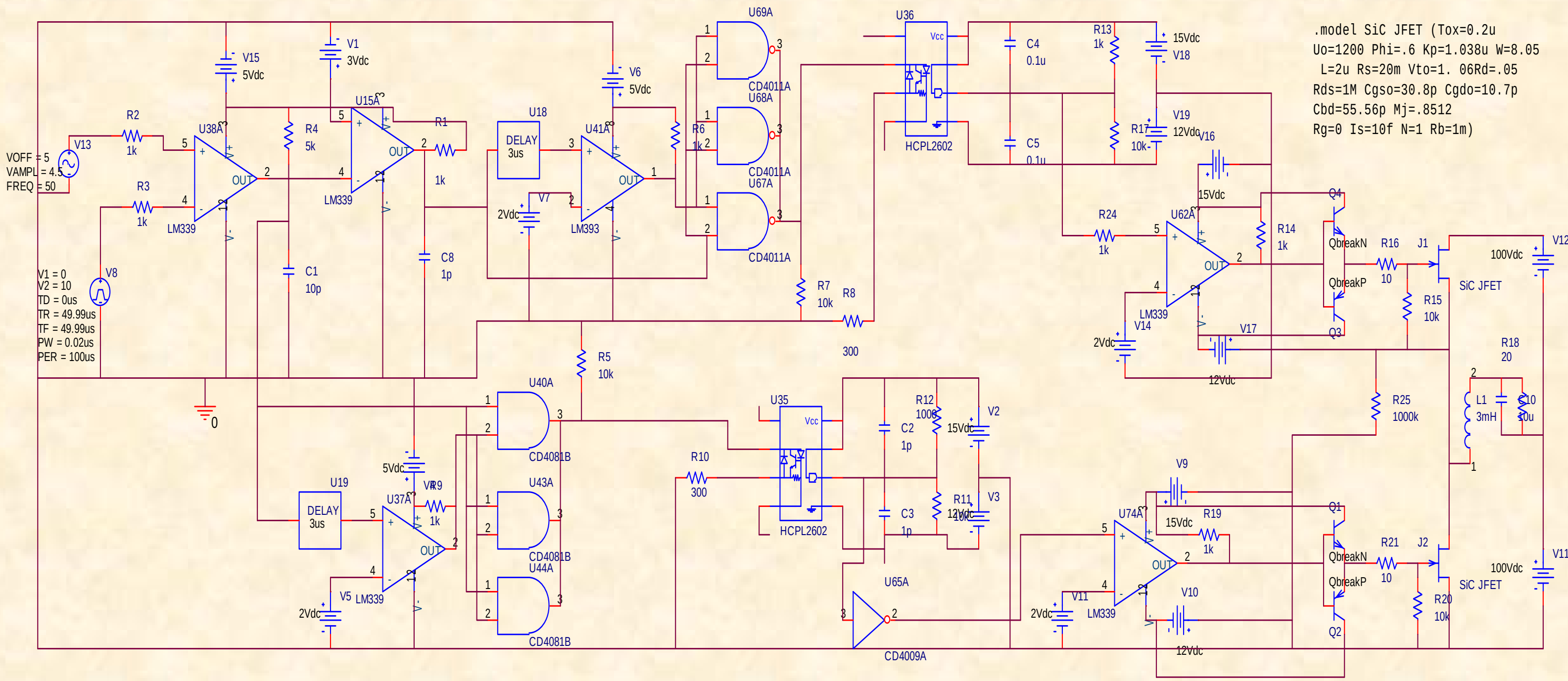
A gate drive circuit design



A drive & protect circuit board

Modeling and Simulation

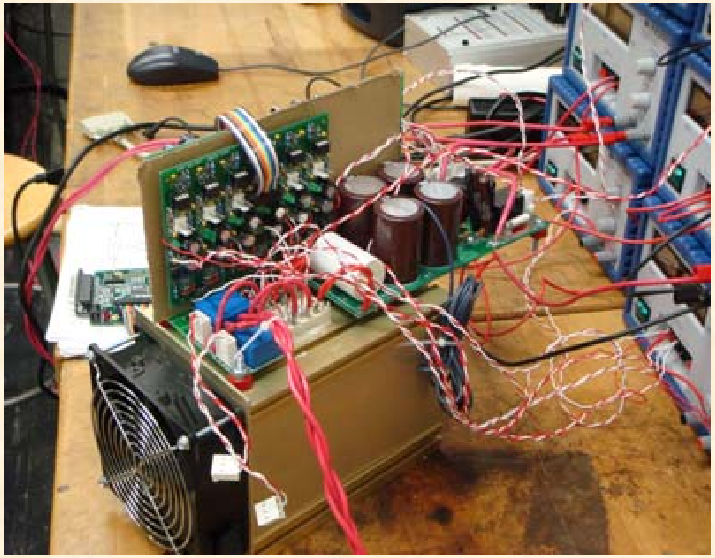
- Model power module/inverter performance (circuit/thermal modeling).
- Analyze system-level impacts of using SiC power devices compared with using Si power devices.

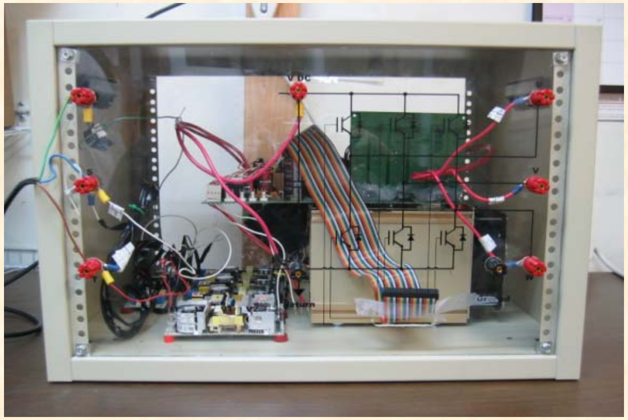


SiC JFET inverter simulation circuit

Inverter Prototype

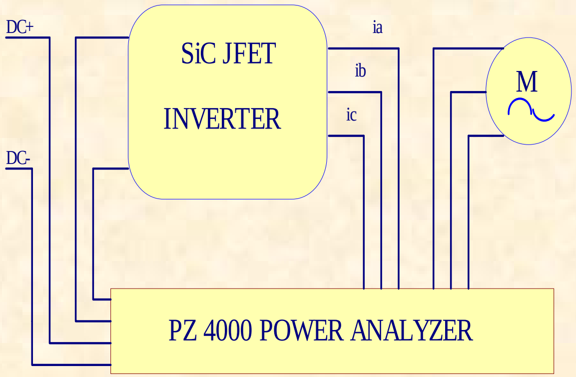
- A 5 kVA DC-AC inverter prototype
- Integrate power module, package, and gate drive



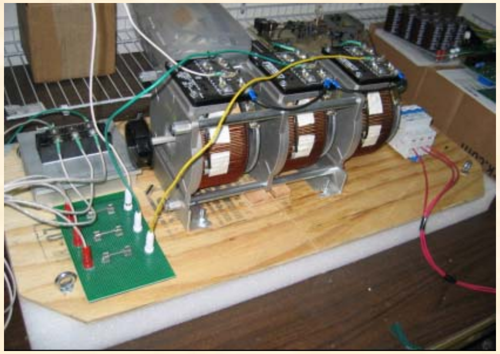


A prototype of a 5 kVA SiC inverter

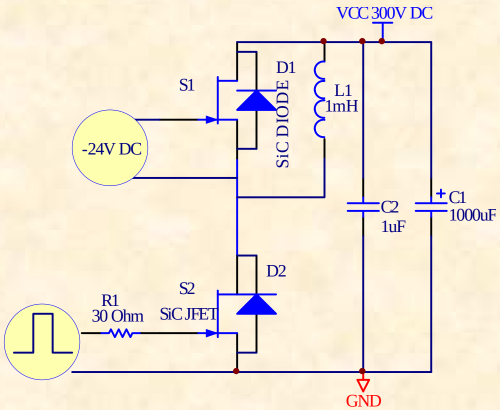
Characterization



Inverter power measurement circuit



DC power source



Switching time measurement circuit

Motor drive

Commercialization Efforts

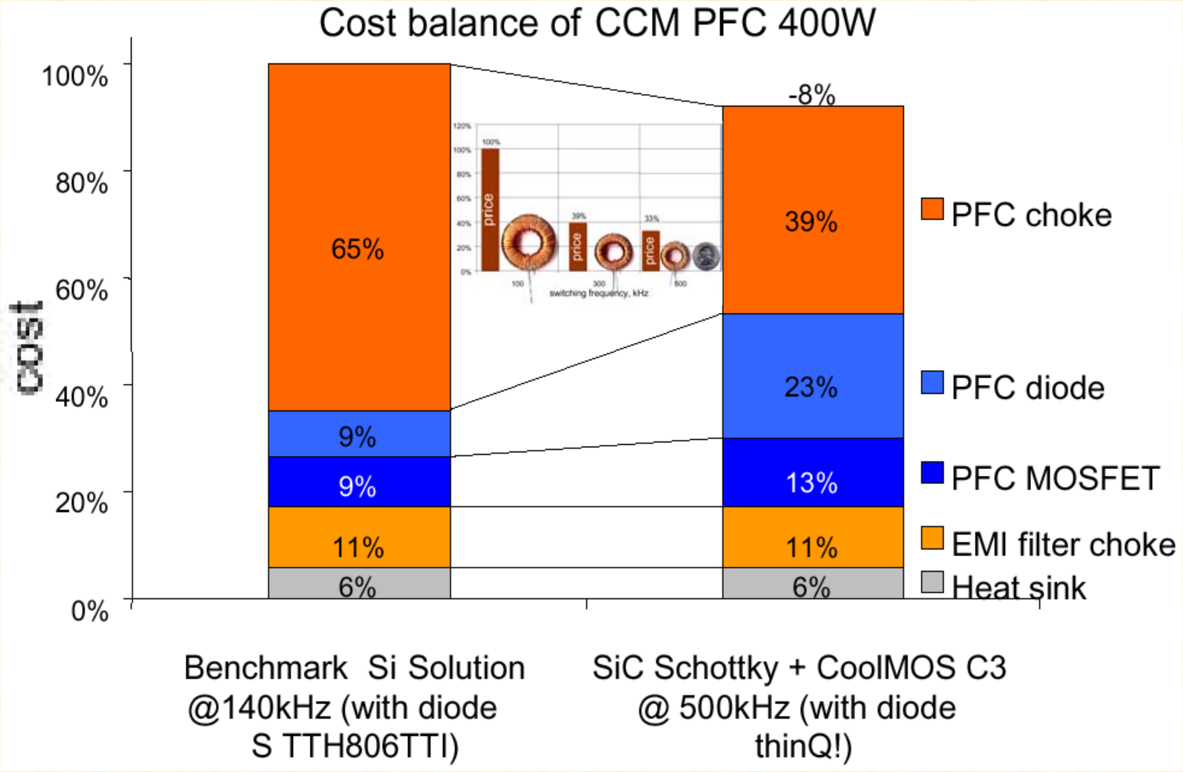
- **Commercial Companies**
  - BSST (a subsidiary of Amerigon), brazing/packaging thermoelectrical (TE) modules for waste heat recovery in vehicles.
  - Hamilton Sundstrand (a United Technologies Company), joining/high-efficiency heat exchanger for aerospace application.
  - Ceradyne (a major ceramic company for armor, energy and engine applications), High-temperature bonding technology for oil-drilling ceramic parts.
- **Government Contracts**
  - NASA SBIR Projects on SiC inverters (Phase I and now II).
  - Navy SBIR Project on SiC inverter for motor control (Phase I).
  - Army SBIR Project on high-efficiency thermal management (Phase I and Phase II pending).
  - DoE SBIR Project on an Innovative bonding method for high temperature, high power density SiC devices

Ongoing Work

- *Converter fabrication, characterization and demonstration*
  - Fabricate, test and characterize inverter
    - A power module array (1200V, 120 A) by paralleling module units of 1200 V, 20 A
    - Gate drive (Honeywell SOI-based high temperature drive)
    - High- temperature thermal packaging
  - Analyze system-level impacts of the SiC inverter with similar Si inverters
    - Advantages of operations at high temperatures (smaller heatsink), power densities and frequencies (smaller passive component)
    - Technical/economical benefits in terms of performance and cost
- *Application and commercialization*
  - Electric storage system (battery, capacitors)
  - Transportation (traction drive, hybrid electric vehicles)
  - Distributed power systems (Fuel cells, micro turbine, nuclear energy, and renewable sources)
  - Potential products: SiC power modules and converters

Through this project, a high-efficiency compact affordable SiC inverter can be anticipated.

Appendix – Benefits of Using SiC devices



Provided by SICED, Germany

	Si inverter	SiC inverter
Energy efficiency	~ 95%	98-99%
Size/weight	SiC inverters with 25-50% size/weight of Si ones depending on power levels.	

Predicted by Modeling