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U.S. Department of Energy

Development of an Integrated Power Controller Based on HT SOI and SiC

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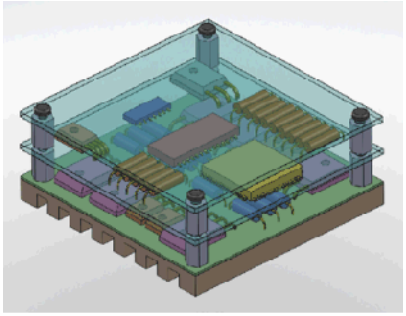

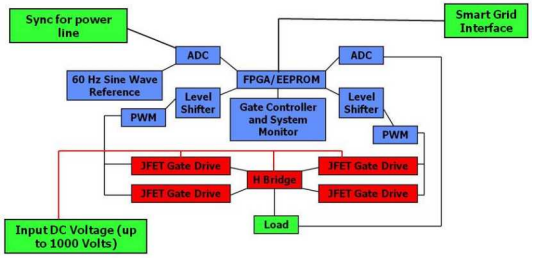

Sandia National Laboratories is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin company, for the United State Department of Energy under contract DE-AC04-94AL85000.

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Overview

- Program Goals for HT Power Controller
  - Size reduction of power controllers
  - Ultimately a single module solution
- Power Controller Design Details
  - Two options investigated
    - APEI's HT SOI MOSFET power module
    - Sandia's JFET power module
- Test Results
- Conclusions
- Future work

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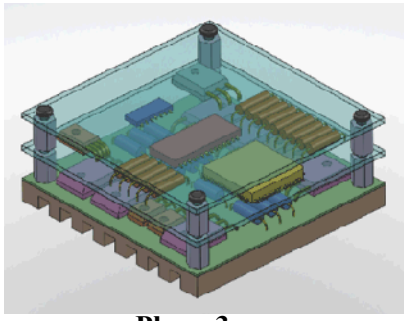
Project Goals

- Design HT power controller that can be integrated into a single module
  - Benefits include:
    - Size reduction of power controllers
      - Integration of the SOI based controller with (near) SiC power devices
    - Ease thermal management requirements
    - Increase reliability
      - Designed using HT components and elimination of board-level interconnects
    - Increase efficiency
      - Optimized to fully exploit the benefits of using SiC technology in power controllers
        - Higher breakdown voltage coupled with a lower "ON" resistance can reduce energy losses by 3-4%
    - High voltage capable designs (SiC JFET's rated at 1200 Volts)
- Establish commercialization path to quicken the adaptation of energy-saving SiC technology



Phase 3

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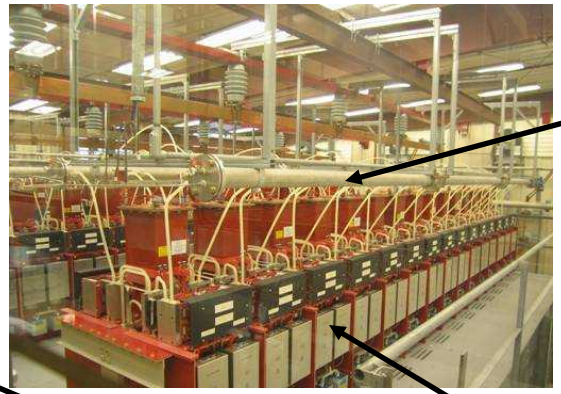
Why a Single Module Solution?

+/-15OMVAr STATCOM
Northeast Utilities' Glenbrook Substation in Stamford, CT

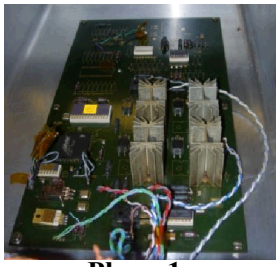


Cooling Pipes

Cooling System: Pump, Pipes

GTOs & Controls

7" x 12.5"

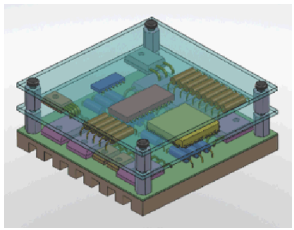


Phase 1

2.5" x 8.75" x 3.5"

Phase 2

4" x 4" x 2"



Phase 3

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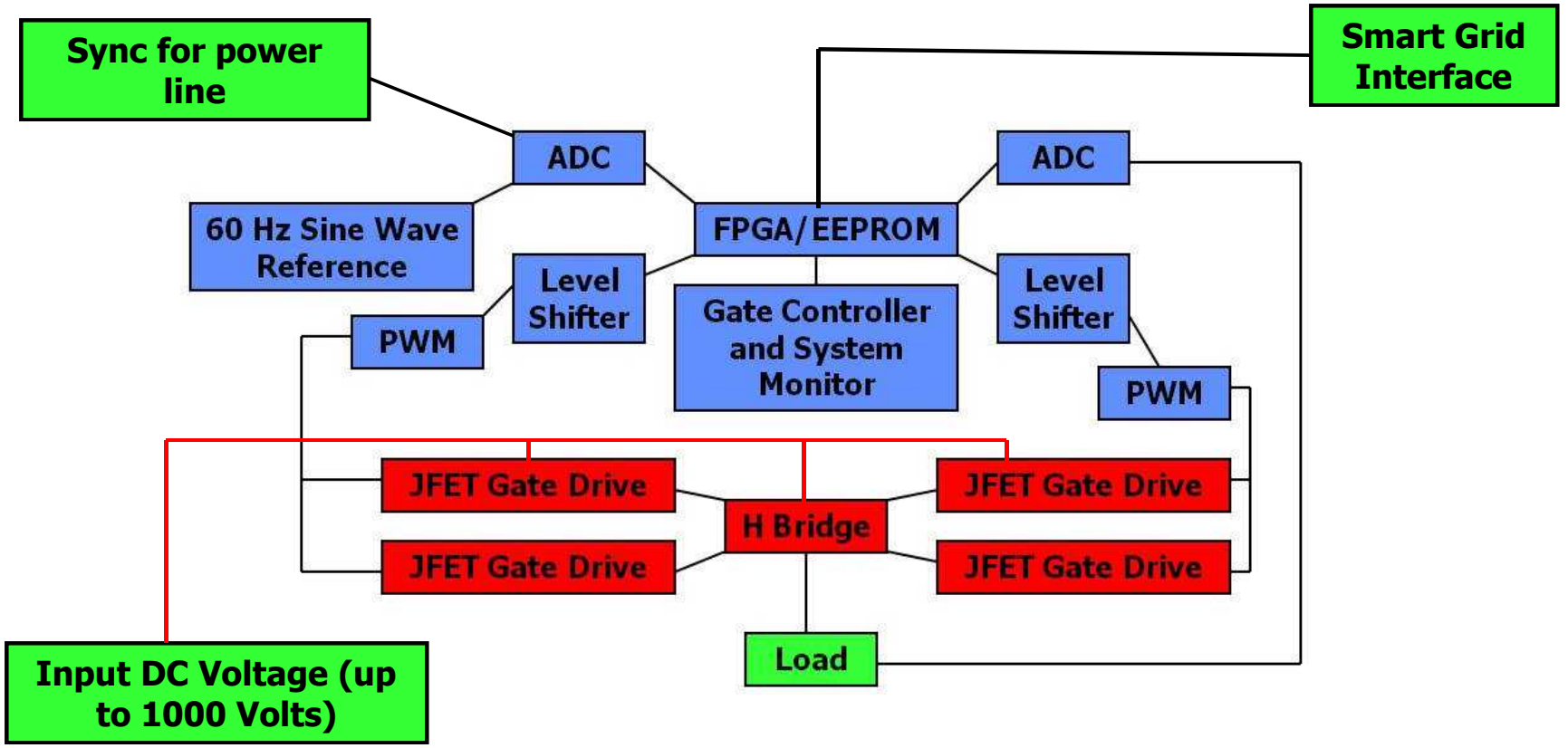
Block Diagram of the Power Controller



Vout = Vin (1- Duty Cycle)

Blue – MCM 1
Red – MCM 2
Green – Outside Components

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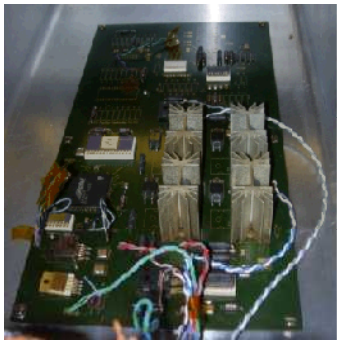
Phase I Accomplishments

Program Start Date FY09



- **Successfully demonstrated a prototype microcontroller-based HT power controller at 240C**
  - **Basic control capabilities including monitoring the JFET (Junction Field Effect Transistor) case temperature**
  - **Safely shutting the system down if a programmed temperature was exceeded**
- **Demonstrated high side / low side SOI (Silicon-on-Insulator) gate drive for the JFET power devices**
- **Successfully tested SOI MESFET (MEtal-Semiconductor-Field-Effect-Transistor) gate drive**

By combining SOI control and drive circuits with SiC, an intelligent system capable of operation up to 240°C (JFET junction temperature approaching 300°C) was successfully demonstrated

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Phase II and III Accomplishments

- "Fine-Tune" prototype design
  - Designed, fabricated and tested a version 2 board with optimized system efficiency
    - Enhanced high side gate drive of the H bridge
    - Mitigated the current spikes
    - Minimized the switching "dead time"
    - Optimized the output filter
    - Improved microcontroller design
      - Better control of the power devices
      - Active feedback investigated; refinement required

- Started evaluation of APEI's power module
  - Verified compatibility with Sandia's controller
  - Performed 5 kW tests at APEI (room temperature)
  - Initiated oven tests with modules
- Contracted with Honeywell to program HT FPGA with Sandia developed code – in progress
- Contracted with Life Bioscience to fabricate HT circuit board – in progress

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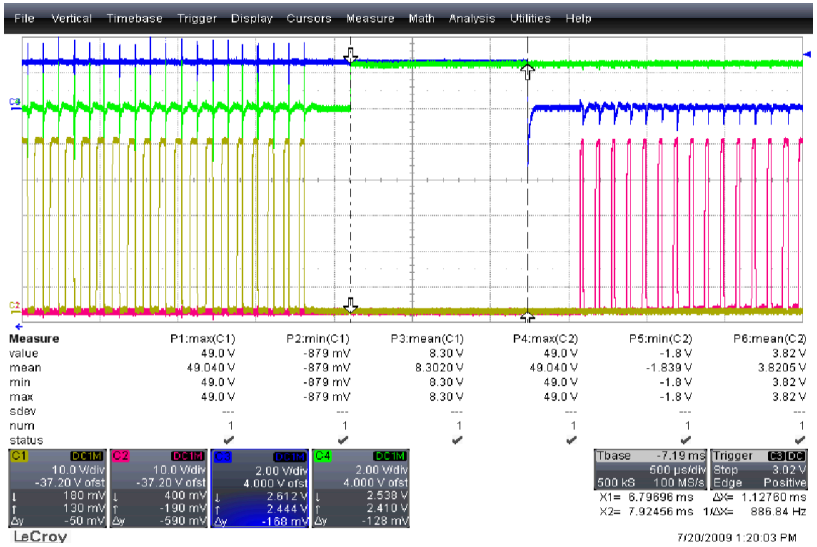
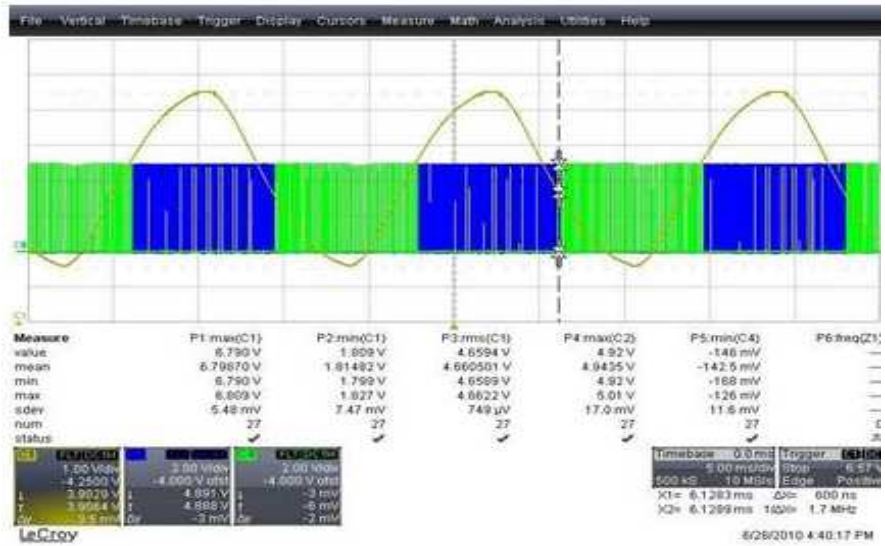
Enhanced Performance – Reduced Dead Band



Scope image depicting the gate drive for the H bridge: Yellow trace is high side A, blue is low-side B, red is high-side B and green is low-side A



Present design has a 600ns dead band

Prototype design exaggerated the dead band between cycles to ensure the JFETs were not damaged due to timing issues. This substantially reduced the overall efficiency.

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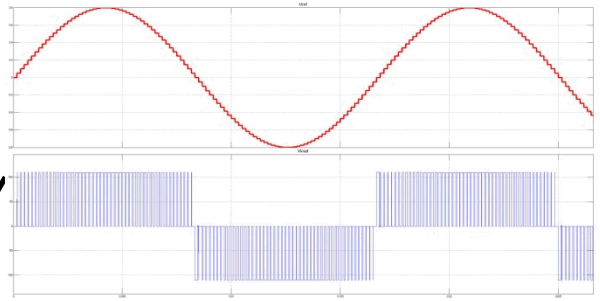
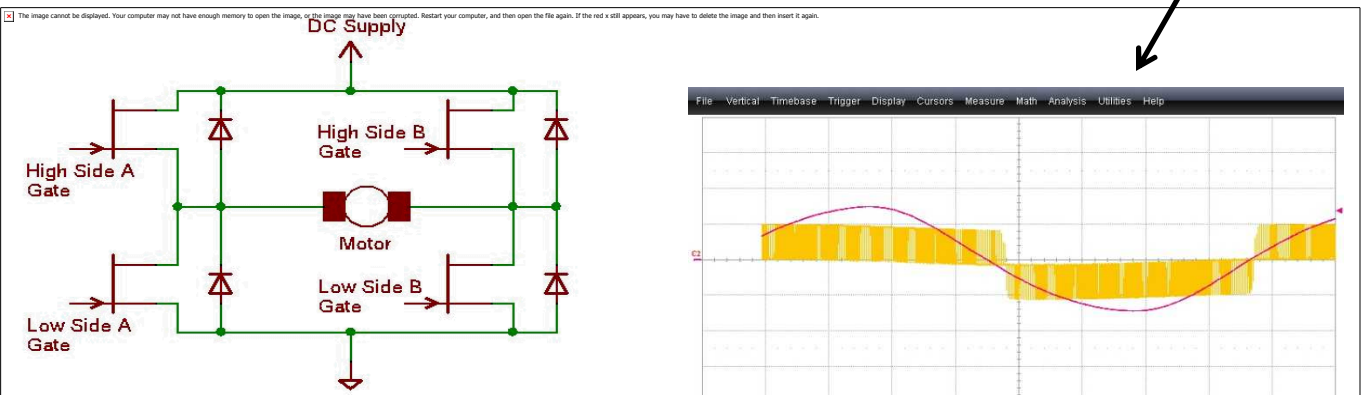
Enhanced Performance - Improved Gate Drive

- **Enhanced switching methodology**
  - **Three-level continuous PWM**
    - **Voltage harmonics are both decreased in amplitude and increased in frequency**
      - **Reduced output filter size requirements (to achieve a given current THD)**
      - **Increased efficiency**

Simulink Simulation





Prototype had PWM Gate Drive at Q1 and Q3; 60Hz at Q2 and Q4; Discontinuous PWM

Gold – Reference signal,
Red – current waveform,
Yellow – resulting voltage waveform

Enhanced circuit has PWM Gate Drive at Q1,Q2, Q3 and Q4; Three-level continuous PWM

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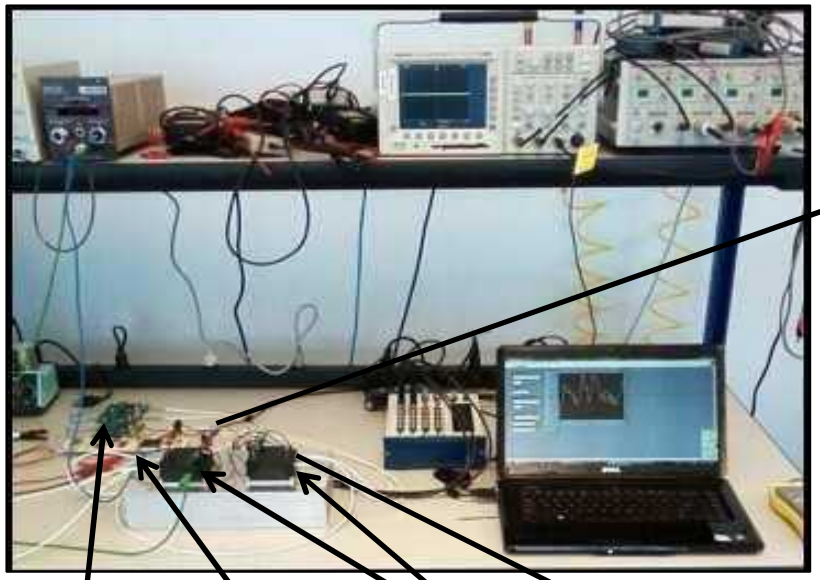
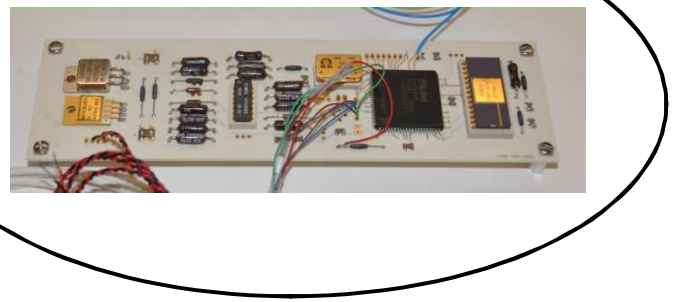
Test Results – Initial Testing at APEI



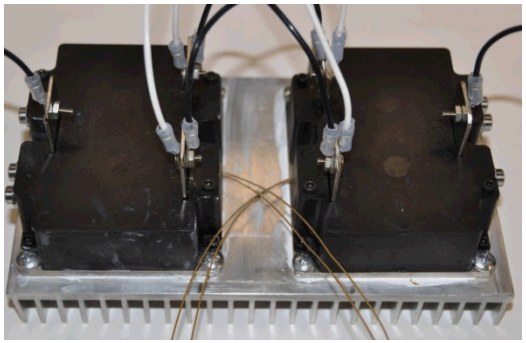
APEI Power Supplies

Sandia Controller

APEI Modules



Sandia Controller



APEI Power module with integrated gate drive

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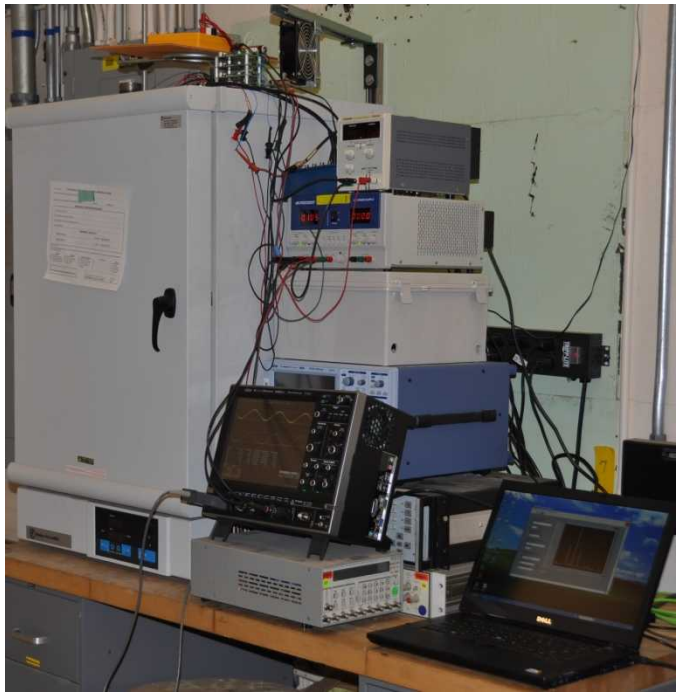
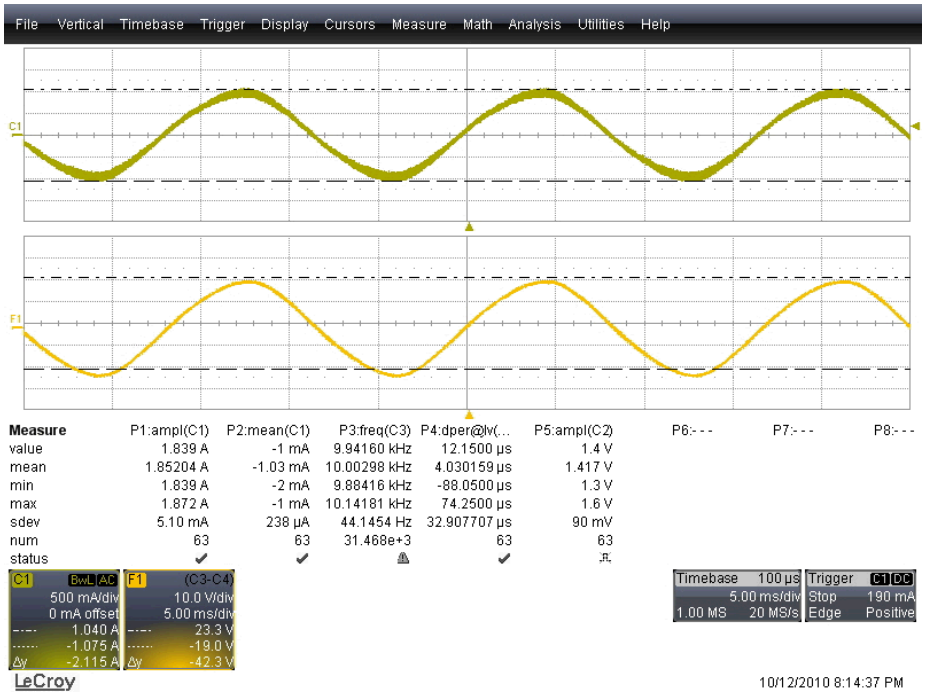
APEI Test Results



Test Results at 150 C



Testing APEI modules with Sandia's controller at elevated temperatures

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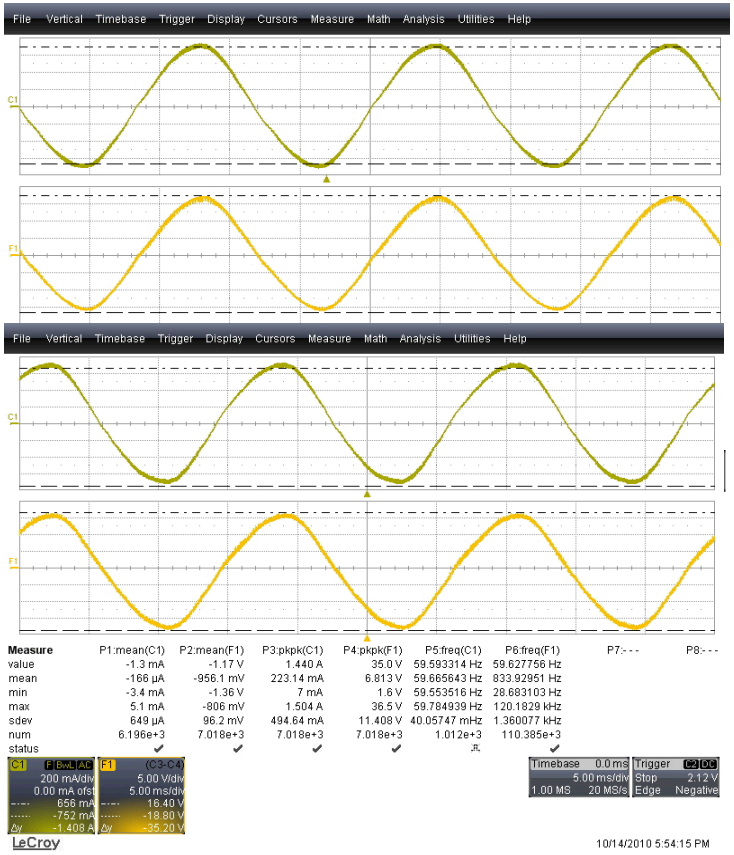
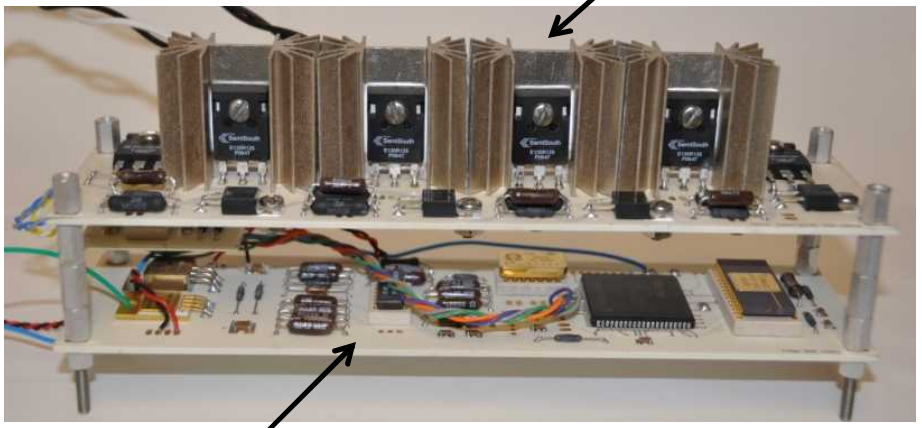
Testing Sandia's Controller with JFET Power Devices

Resulting waveform at room temperature



Resulting waveform at 200ºC



JFET Power Devices and Gate Drive

Controller

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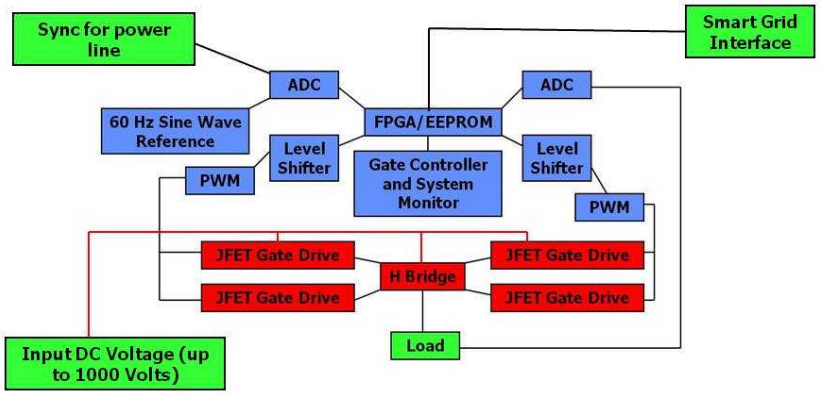
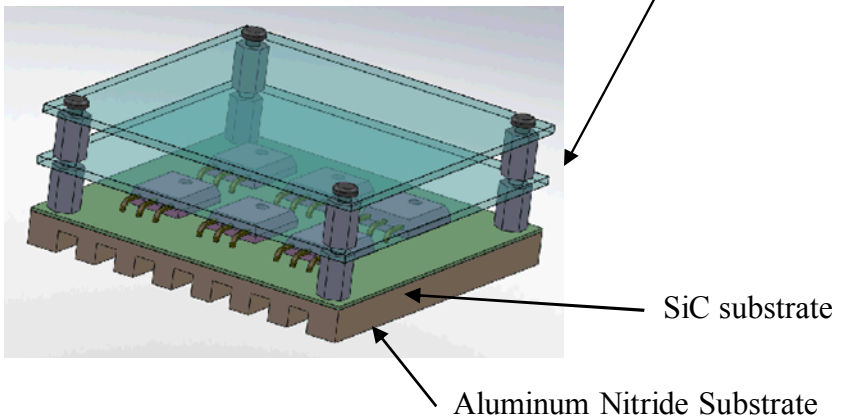
Updated Concept of the Power Controller Module





Investigating potentially utilizing same substrate for power devices and MultiChip Modules (MCM)

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Future Plans

- Evaluate APEIs HT gate drive power supplies
- Investigate utilizing APEI's JFET power module with HT gate drive power supply and steps required to integrate into single module
- Refine feedback control
- Complete MCM design of controller
- Evaluate Honeywell HT SOI FPGA
- Evaluate HT circuit board
- Demonstrate "next step" in single module solution (Sandia or APEI power boards)

Conclusion

- Lab tested an enhanced controller board and a power board consisting of JFET power devices with gate drive
- Completed initial testing at APEI using APEI's power modules, LT gate drive power supply and Sandia's controller; 5kW tests
- Completed initial testing at Sandia at elevated temperatures
- In progress: conversion of Sandia code into a HT FPGA (Honeywell)
- In progress: fabrication of HT circuit board

Collaborative Effort with Academia and Industry

- **DOE Funded**
  - **Participants include:**
    - **Sandia (Lead)**
    - **ASU (Circuit simulation, fabrication of test circuits using HT MESFET – JFET gate drive) - Phase I**
    - **PermaWorks (Inverter design simulation and fabrication of HV supply) – Phase I**
    - **APEI (Power modules, HT power supplies, thermal analysis) – Phase II, III**
    - **Life BioScience (HT circuit boards) – Phase II, III**
  - **COTS suppliers**
    - **Honeywell SSEC**
    - **Cissoid**
    - **SemiSouth**

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