2010 Update Conference -
U.S. Department of Energy

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

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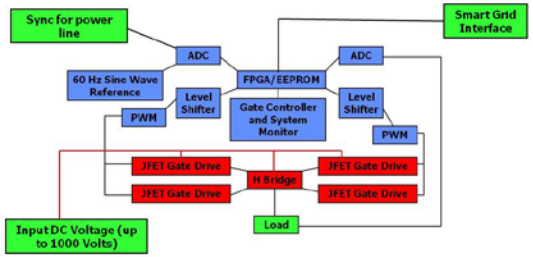

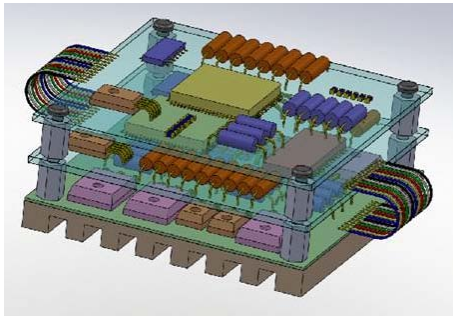

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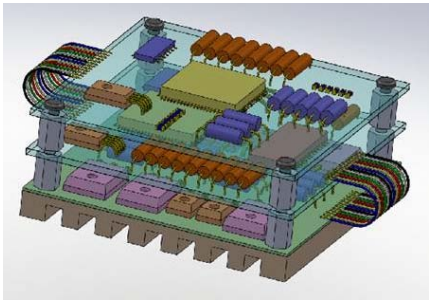
Overview

- Program Goals
- Accomplishments
- Design Details
- Test Results
- Conclusions
- Future work

Project Goals

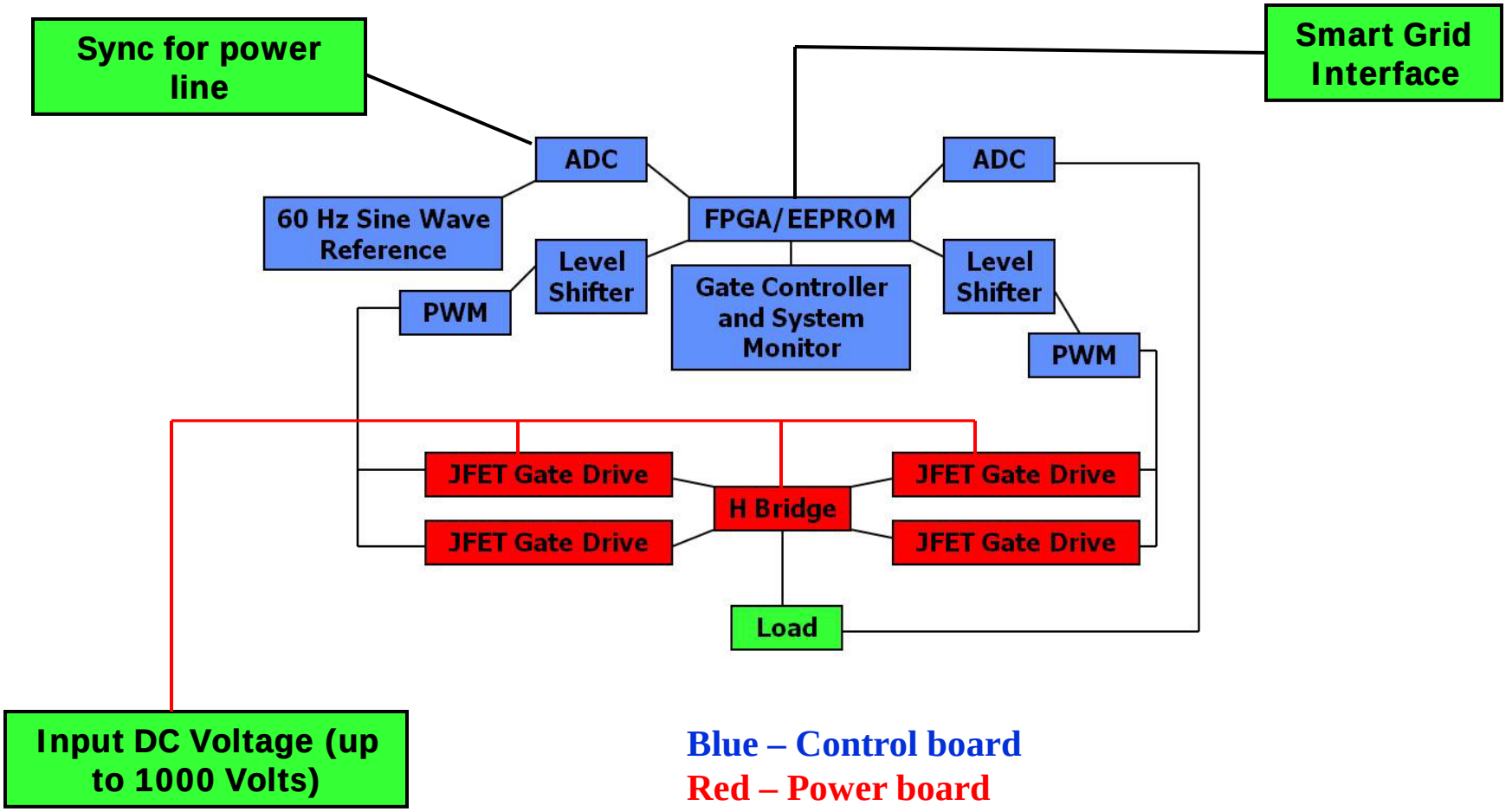
- **Design HT power controller that can be integrated into a single module**
  - **Benefits include:**
    - **Size reduction of power controllers**
      - **Integration of the SOI based controller with (near) SiC power devices**
    - **Ease thermal management requirements**
    - **Increase reliability**
      - **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**
        - **Can reduce energy losses by 3-4%**
    - **High voltage capable designs**
- **Establish commercialization path to quicken the adaptation of energy-saving SiC technology**

HT - High Temperature
SOI – Silicon-on-Insulator
SiC – Silicon Carbide
JFET – Junction Field-Effect Transistor
PWM – Pulse Width Modulation
MCM – MultiChip Module



Phase 3

Block Diagram of the Power Controller



Blue – Control board
Red – Power board
Green – Outside Components

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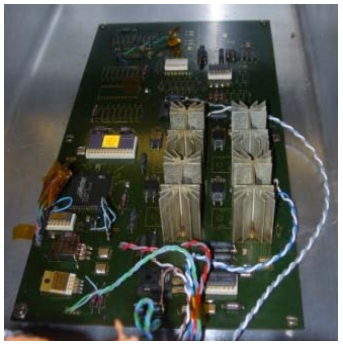
Phase I Accomplishments

Program Start Date FY09



- **Successfully demonstrated a prototype microcontroller-based HT power controller at 240C**
  - **Included basic safety functions to protect power devices**
- **Demonstrated SOI 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

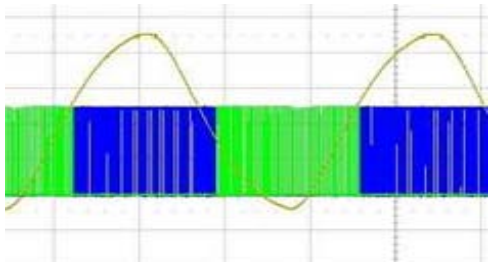
Phase II and III Accomplishments

- **"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**

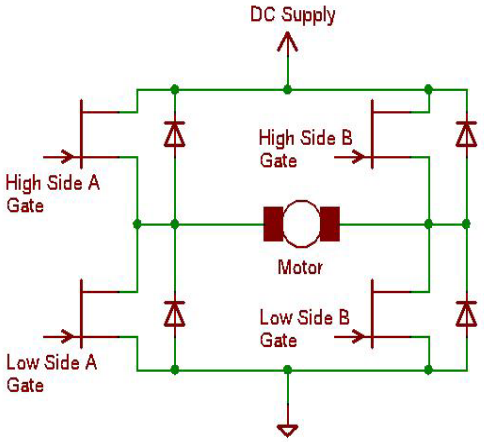
- **Started evaluation of APEI (Arkansas Power Electronics International) power module**
  - **Verified compatibility with Sandia's controller**
  - **Performed 5 kW tests at APEI (room temperature)**
  - **Initiated oven tests with modules**
- **Contracted with Honeywell to program HT FPGA (Field Programmable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

Enhanced Performance - Improved Gate Drive

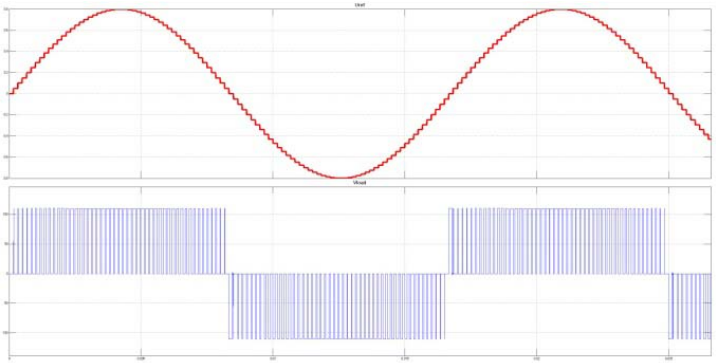
- **Enhanced switching methodology**
  - **Three-level continuous PWM**
    - **Voltage harmonics are both decreased in amplitude and increased in frequency**
      - **Reduced output filter size requirements (to achieve a given current THD)**
      - **Increased efficiency**



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



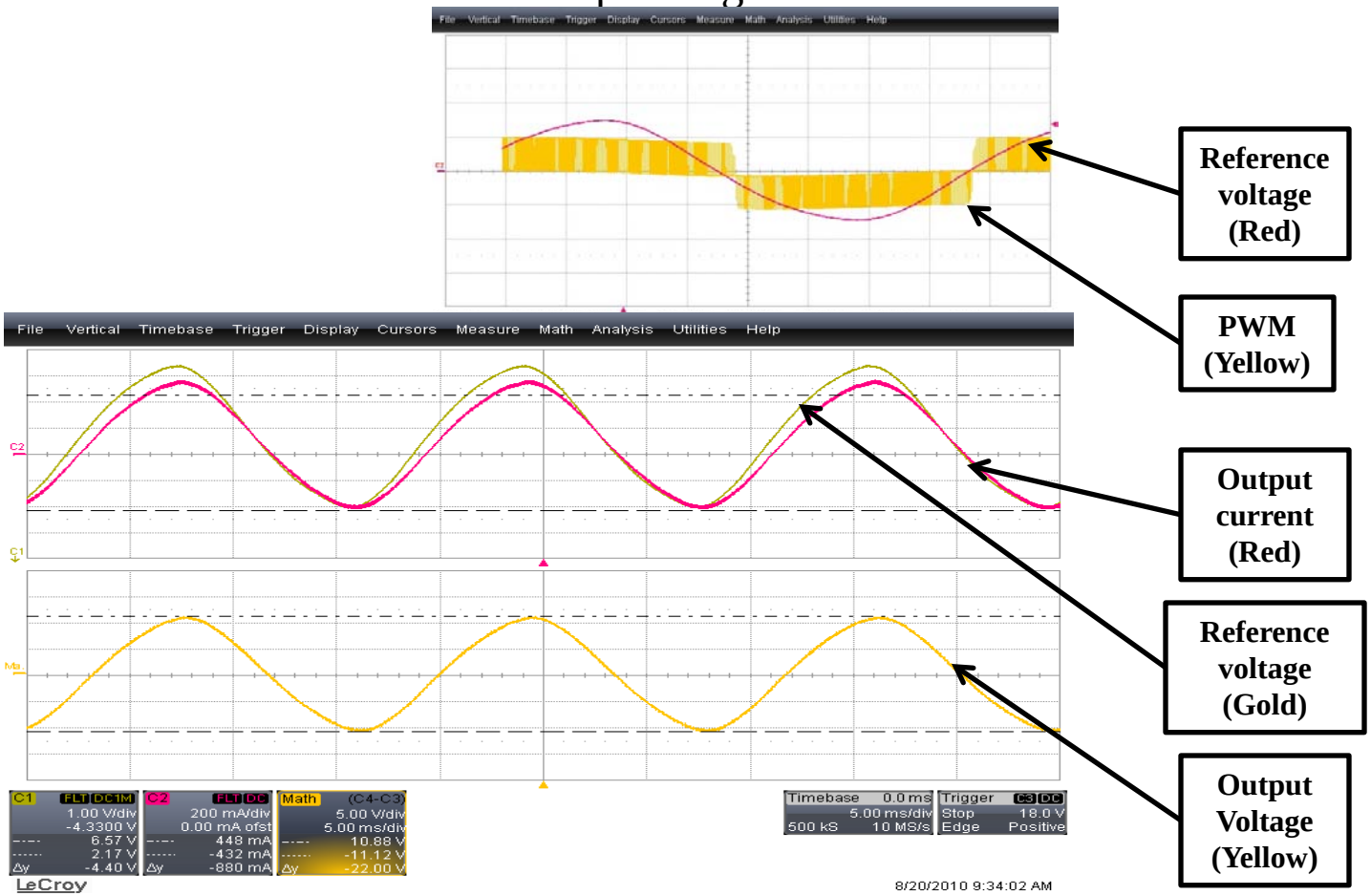
Simulink Simulation



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

Enhanced Performance - Improved Gate Drive

Scope Image of PWM



Scope Image of Output waveform

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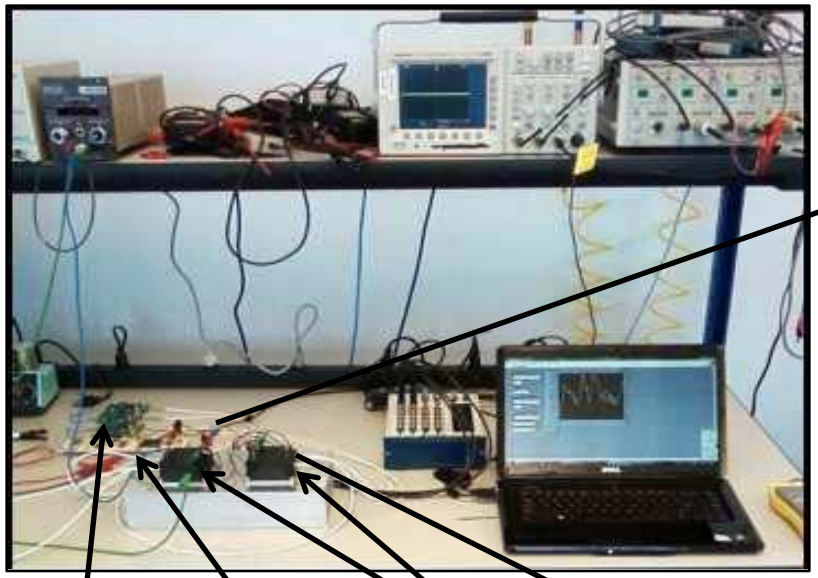
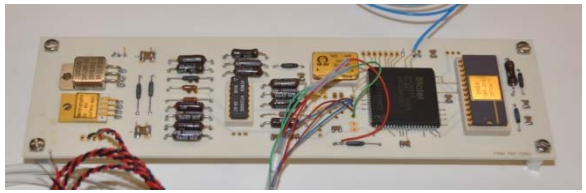
Test Results – Initial Testing at APEI



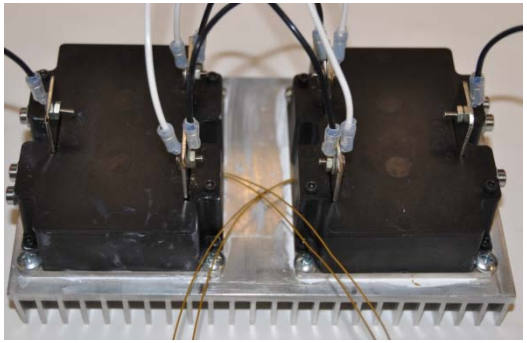
APEI Power Supplies

Sandia Controller

APEI Modules

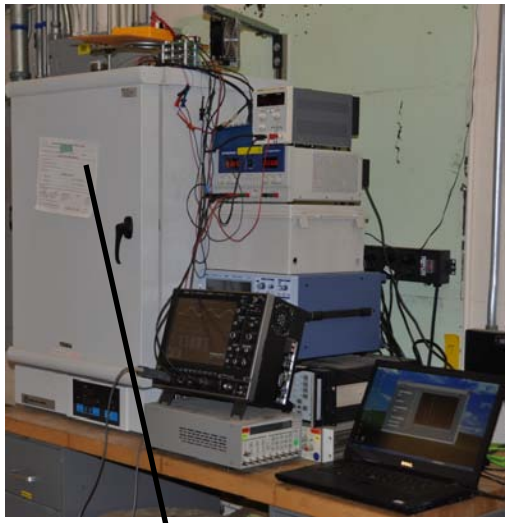


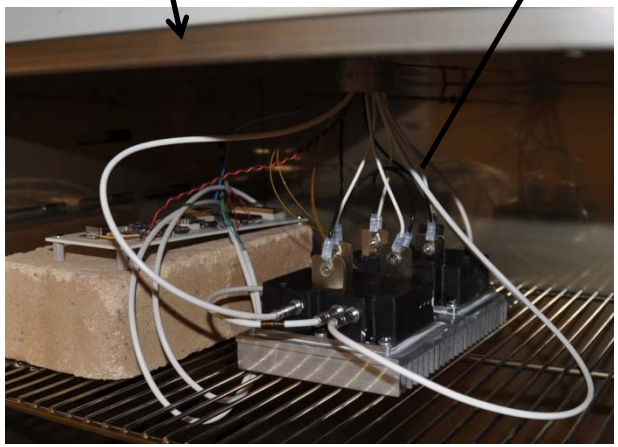
Sandia Controller

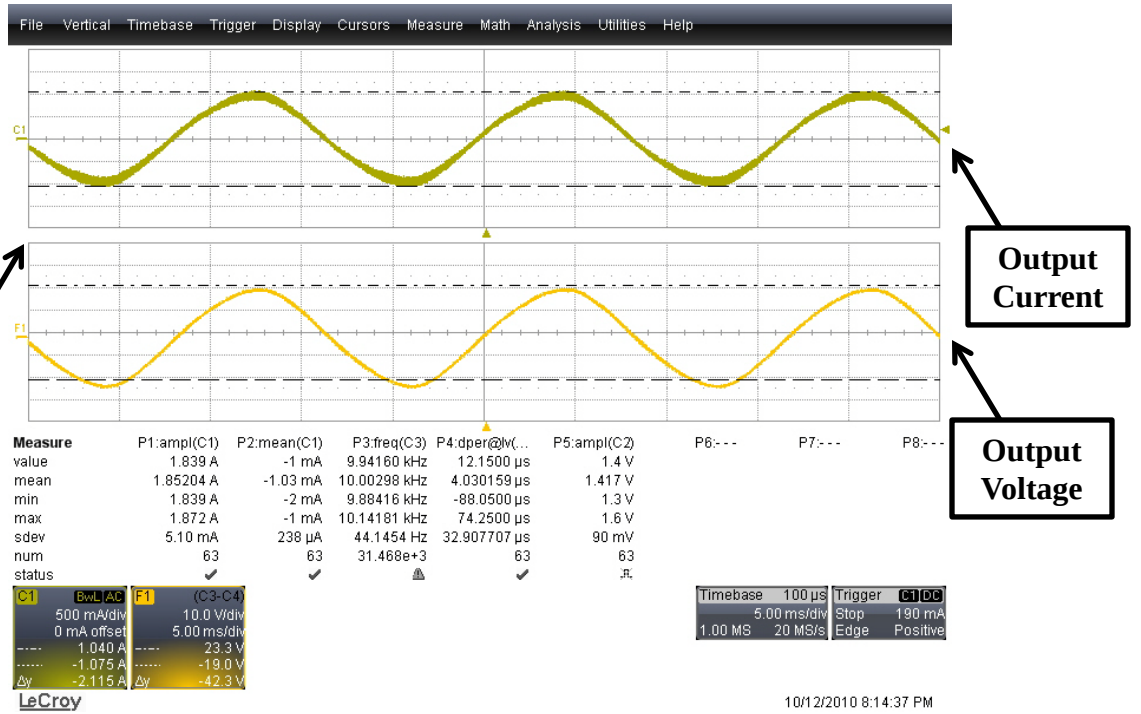


APEI Power module with integrated gate drive

Initial Tests with APEI Power Module







Output Current

Output Voltage

Testing APEI modules with Sandia's controller at elevated temperatures

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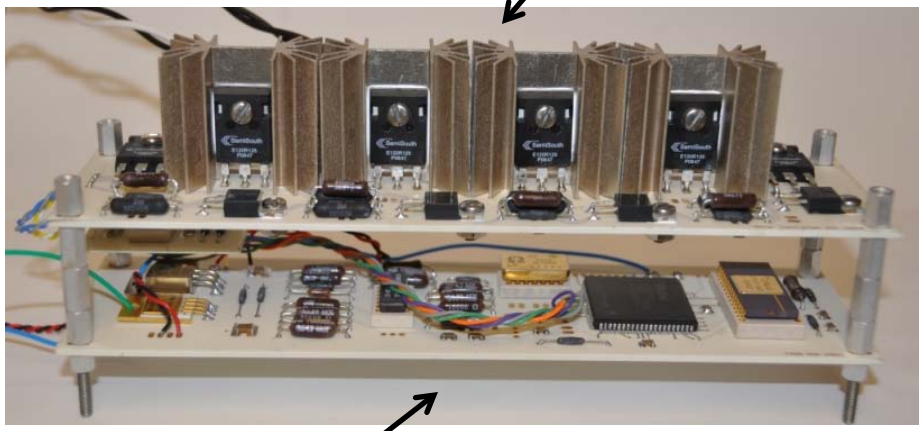
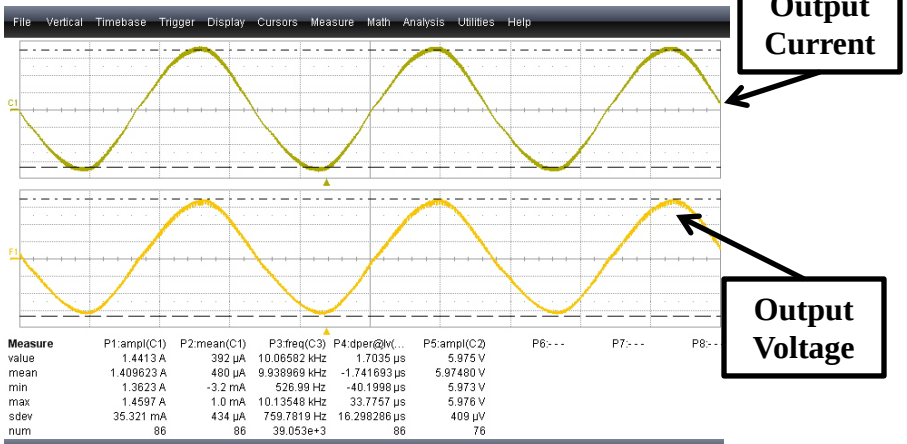
Tests with JFET Power Board

JFET Power Devices and Gate Drive



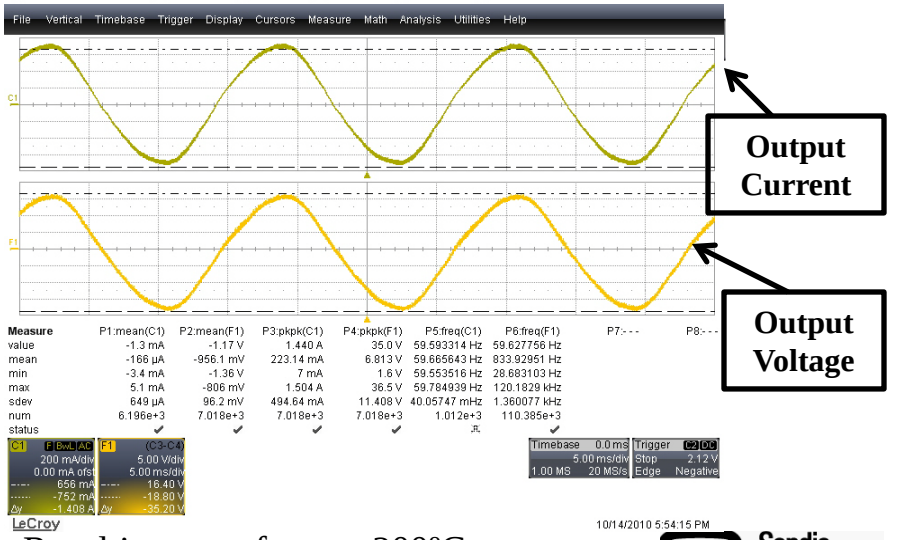
Controller

Resulting waveform at room temperature



Output Current

Output Voltage



Output Current

Output Voltage

Resulting waveform at 200ºC

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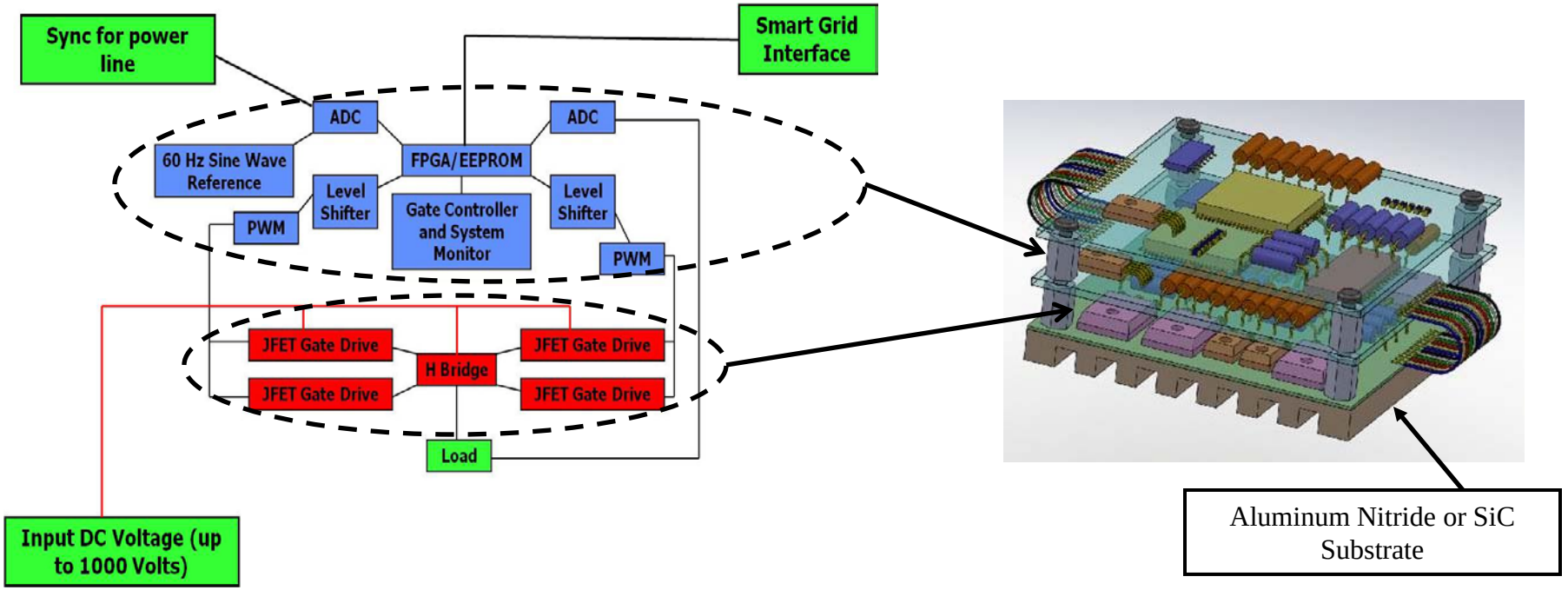
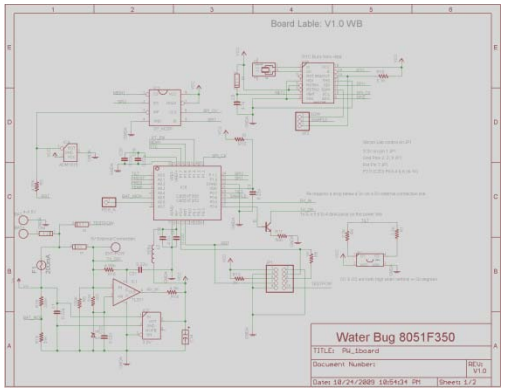
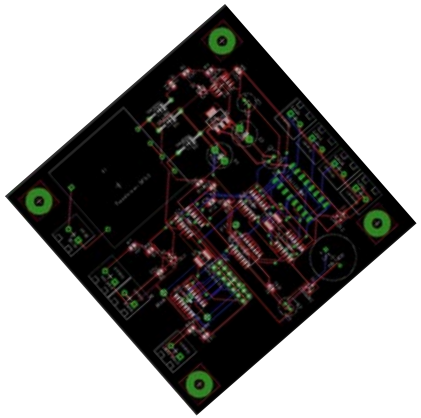
Single Module Solution



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

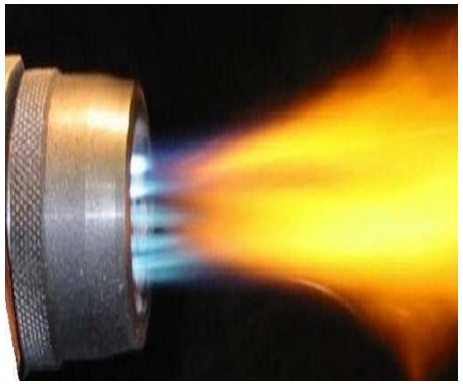
New Extreme HT-HV Circuit Boards

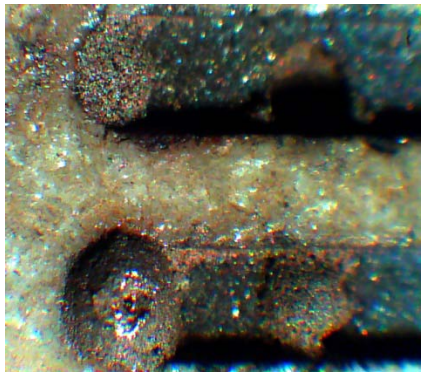




- % start
- G90,G71,G54
- M5, M6
- G92 0.001,0.200,-0.200
- G1 0.001,0.570,-0.200
- G1 0.456,0.200,-0.200
- G1 0.456,0.234,-0.200

Standard Schematic → Optical Image → NEW Convert Image to CNC G-Codes





New Fab SiC Circuit Board

New Metalize Circuit Traces

New HT Lead Free Solder

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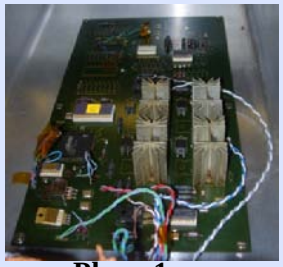
Conclusion

- 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

7" x 12.5"

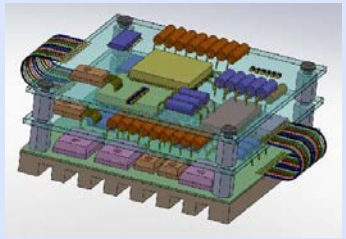


Phase 1

2.5" x 8.75" x 3.5"

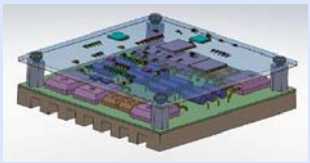
Phase 2

4" x 4" x 2.5"



Phase 3

4" x 4" x 1"



Phase 4

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 the design for MCM controller
- Evaluate Honeywell HT SOI FPGA
- Evaluate HT circuit board
- Demonstrate "next step" in single module solution (Sandia or APEI power boards)

Collaborative Effort with Academia and Industry

- **DOE Funded**
  - **Participants include:**
    - **Sandia (Lead)**
    - **Arizona State University (Circuit simulation, fabrication of test circuits using HT) MESFET – JFET gate drive) - Phase I**
    - **University of Maryland – HT lead attach**
    - **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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