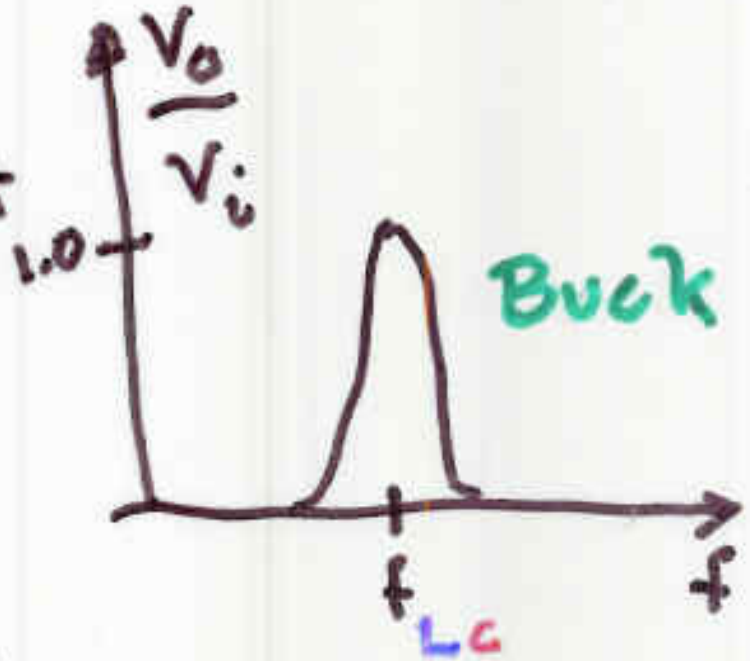
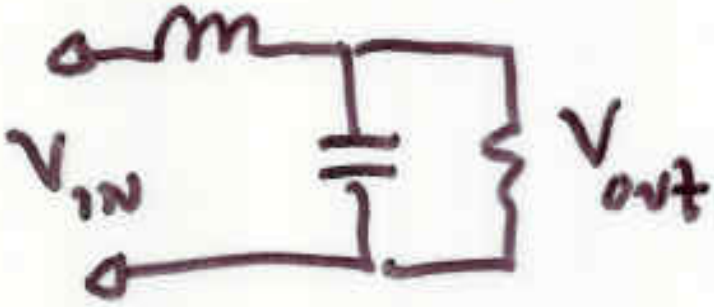
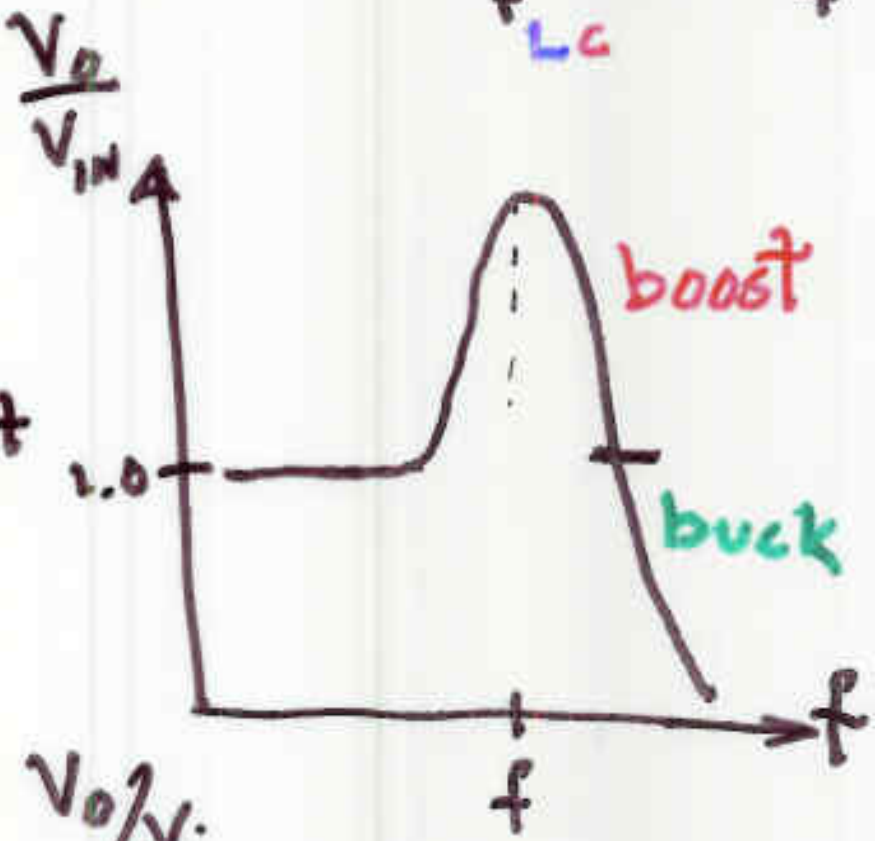
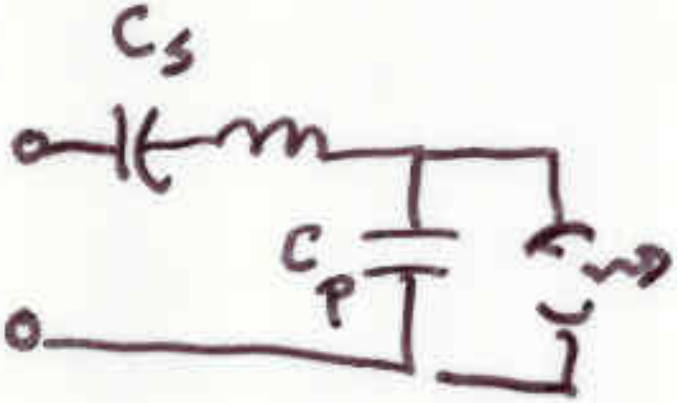

V_{IN}
0

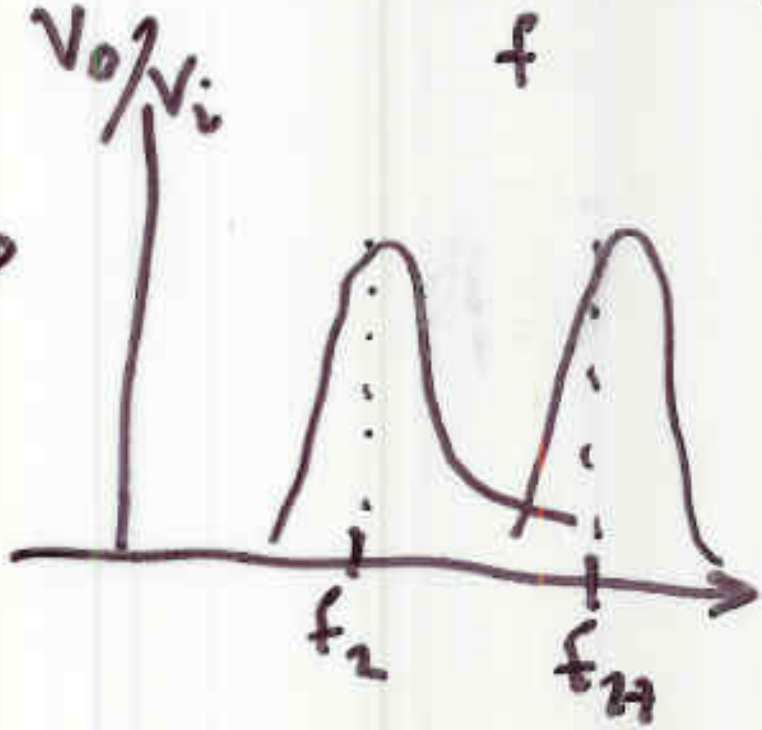
V_{out}


$\frac{V_o}{V_i}$
1.0
Buck
f_{LC}
f


V_{IN}
V_{out}
0


$\frac{V_o}{V_{IN}}$
1.0
boost
buck
f
f

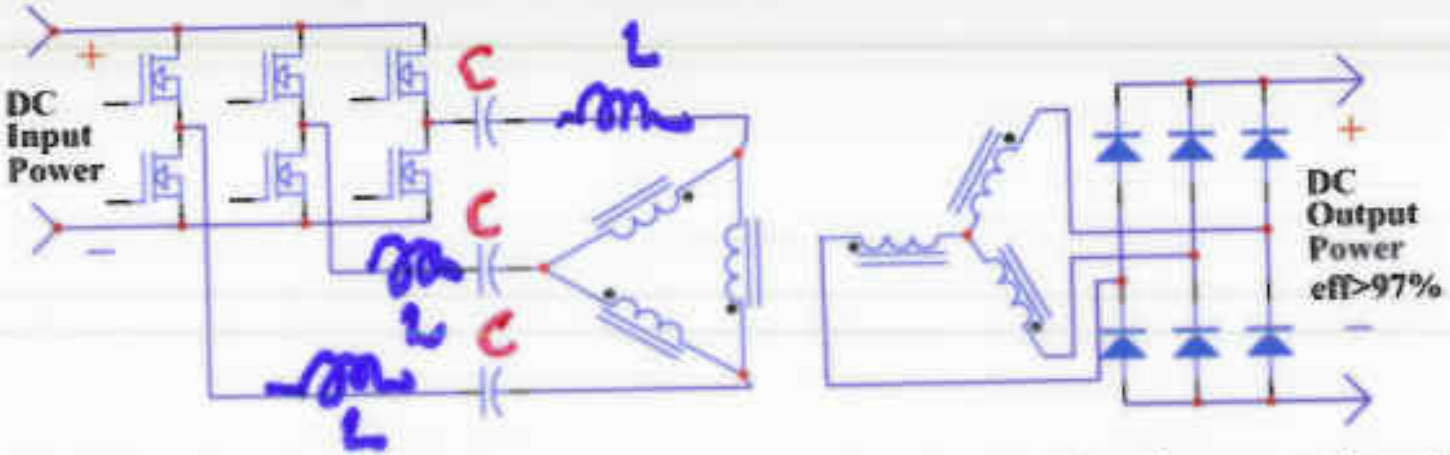

C_s
C_p
0


V_o/V_i
f_2
f_{24}

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

3PRC, The "Continuous Power" Converter



- MOSFET transistors produce square waves that have a fixed 120° phase shift.
- Square waves are converted to sine waves by the frequency selective resonant circuit.
- Three phase shifted sine waves produce a continuous flow of power to the load. The 120° of phase shift is maintained as the frequency is varied to control power flow.

461

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU
10KW Breadboard

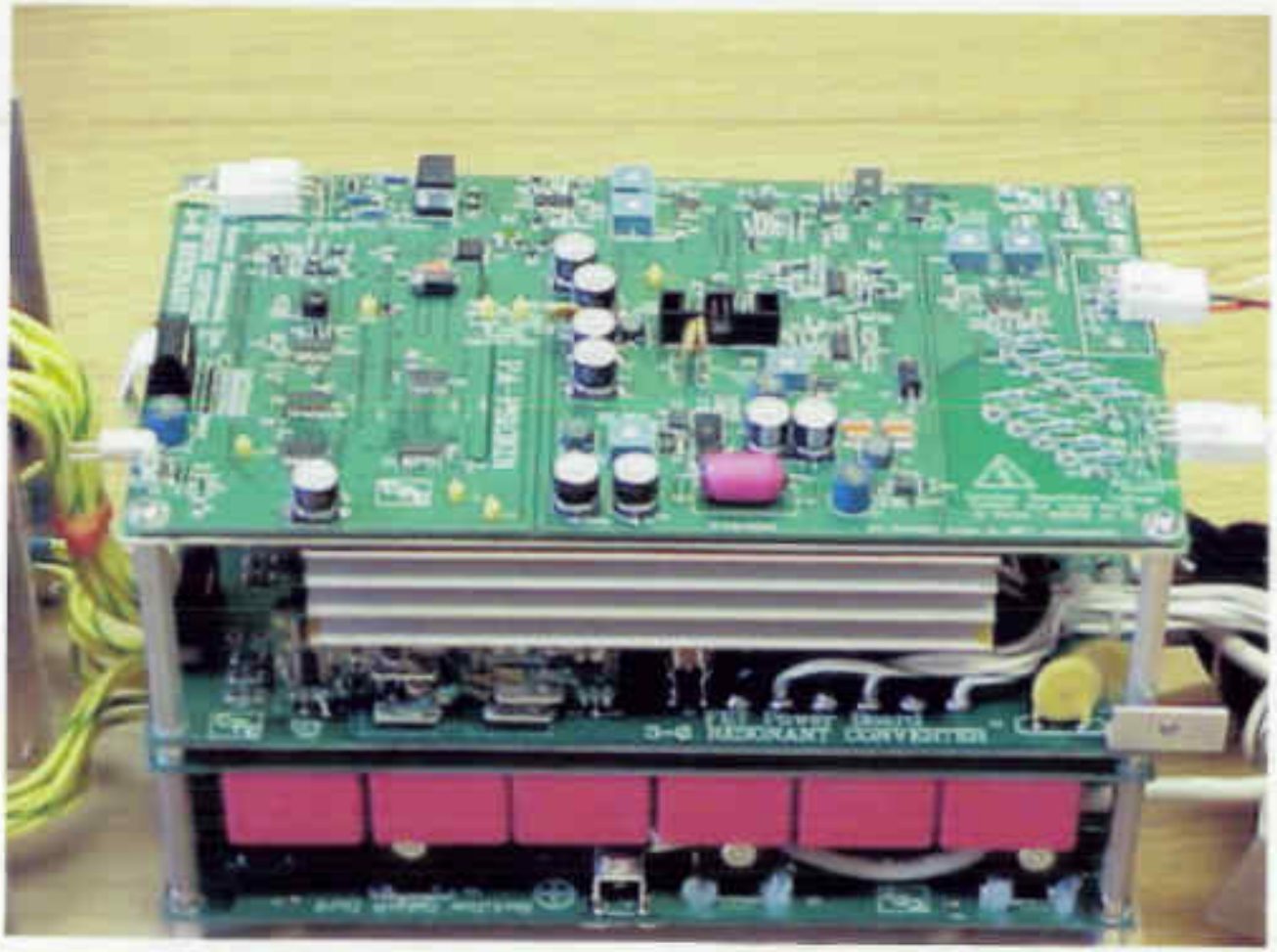
5"x7"

Six Transformer Magnetics, two different exposures of same object.

Wye secondary mags on the left, delta secondary mags on the right

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard



Three-Phase Resonant Converter PPU 10KW Breadboard

Design Objectives

- Develop gate drive circuitry for parallel (8) MOSFETs that conserves energy and is resistant to parallel FET oscillations.
- Design low inductance power interconnect wiring to minimize losses associated with magnetic stored energy.
- Scale magnetics of an existing 1KW design to 10KW.

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

- **10KW Breadboard Development**

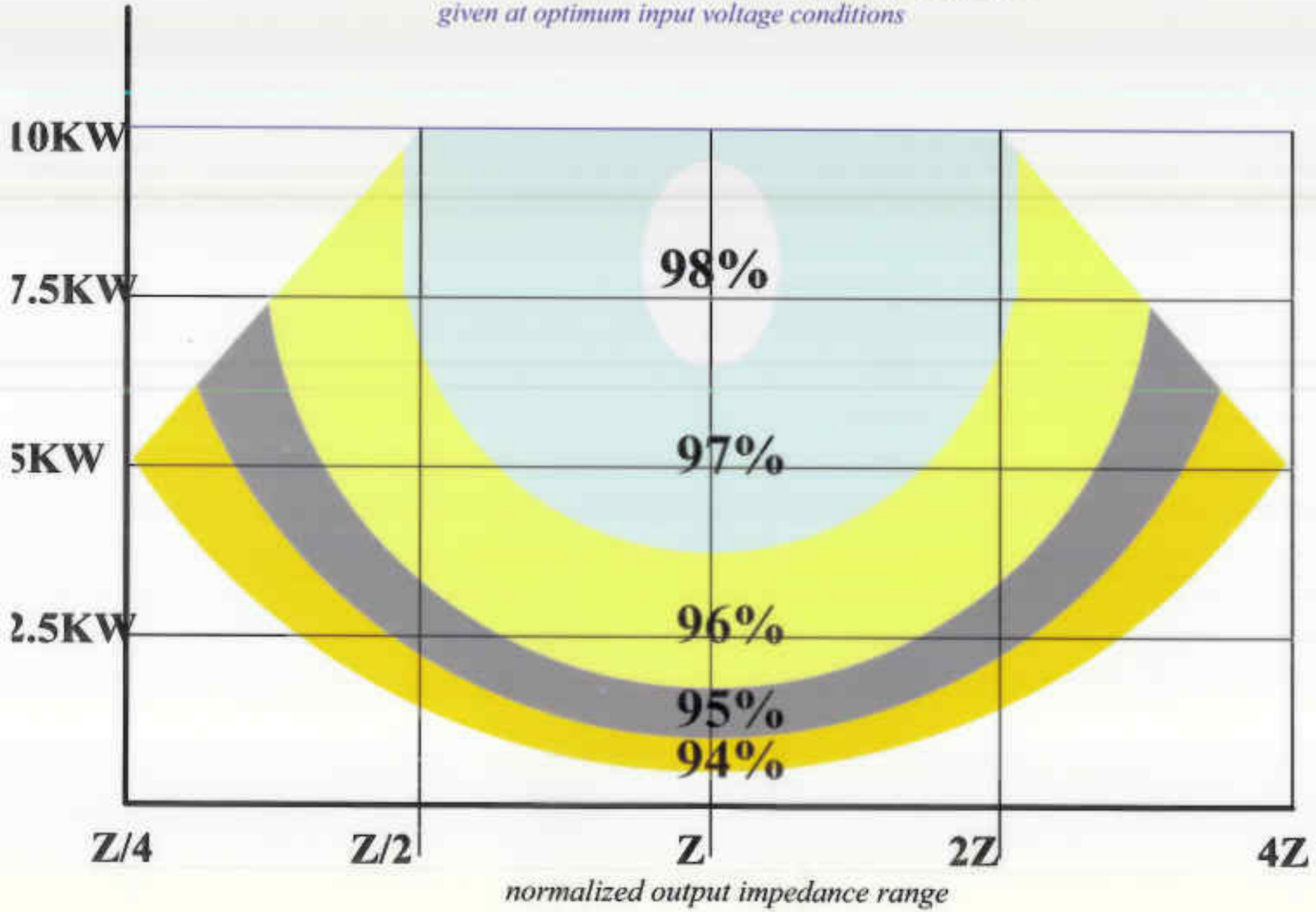
  Breadboard design parameters
  - 400V -800V DC, output at 10KW.
  - Input Buss 80V-120V DC.
  - >96% efficiency (97%+ achievable at 1KW).
  - Air-cooled for now to meet quick development schedule.

- Status - 6th month of a six month schedule
  - System verification and test
  - 97% + efficiency at both 400V and 800V, 10KW output with 100VDC input
  - specific mass <1.1g/W

10KW Breadboard efficiency for power versus output impedance

Three Phase resonant LCC Converter efficiency contours

given at optimum input voltage conditions



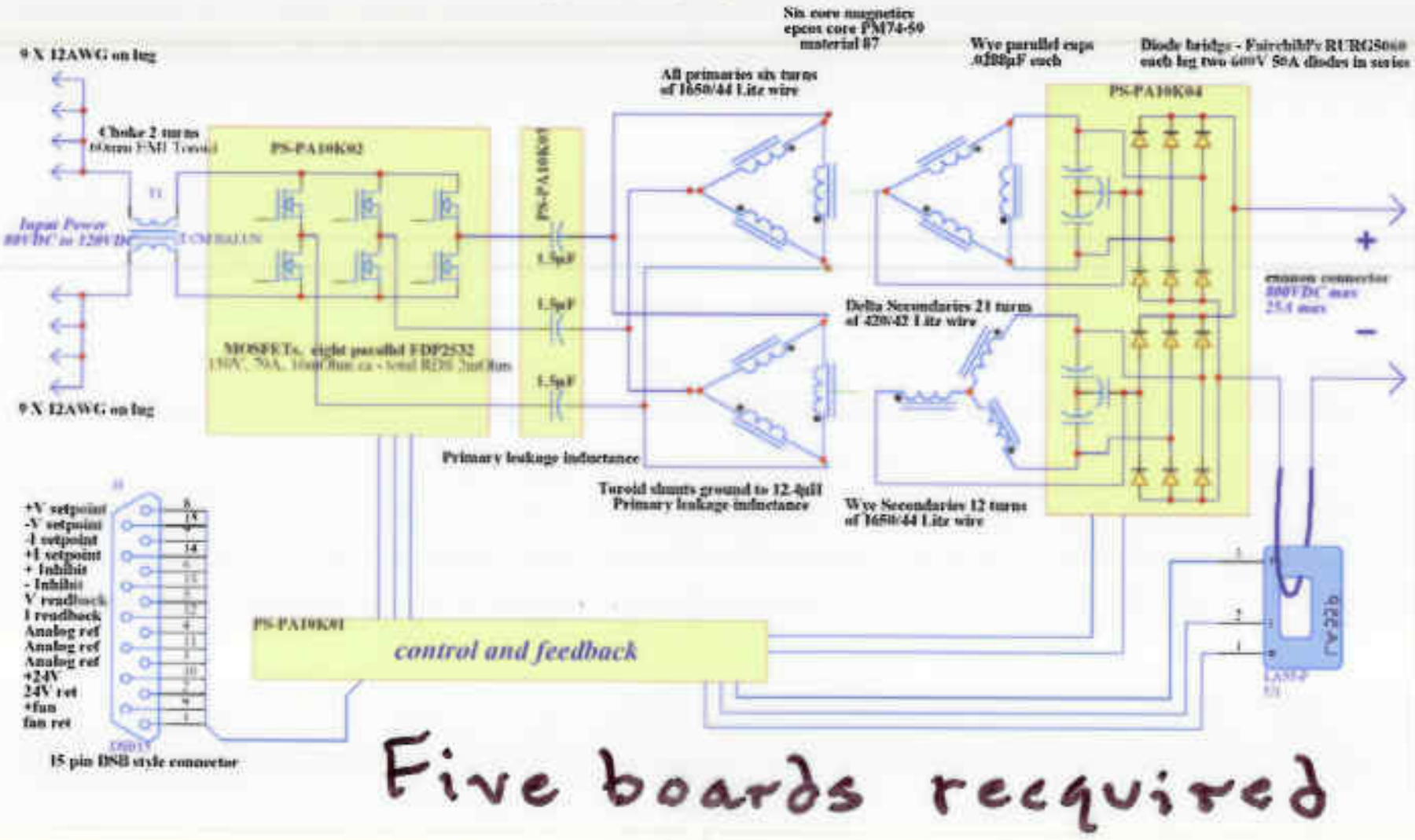
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

- Advantages of three-phase resonant conversion (3PRC) over current technology
  - High efficiency 97% demonstrated at 1 kW.
  - Wide full power load range 2:1 Voltage at >97% efficiency.
  - Low mass 1-kg/kW for a 10-kW converter.
  - Low stored output energy, <1 mJ/kW.
  - Low input ripple current.
  - Continuous power delivery – inherent to three phase topography.
  - Fastest full power to zero power response time.

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU
10KW Breadboard



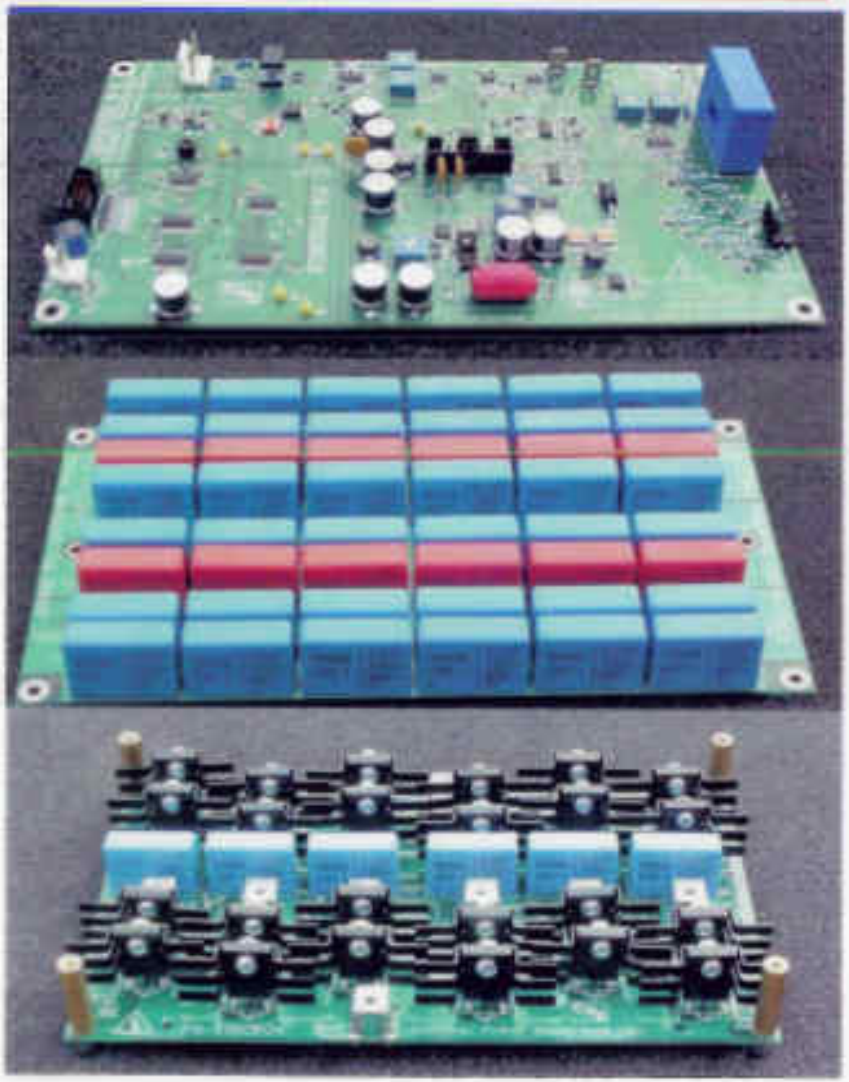
AEROJET LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

1. Control board
   - Three phase VCO
   - Control loops
   - User interface
   - Output measurement

2. Resonant capacitor board
   - Series resonant capacitors with low inductance foil PCB

3. Output diode board
   - Three phase full wave rectifier with parallel resonant capacitors

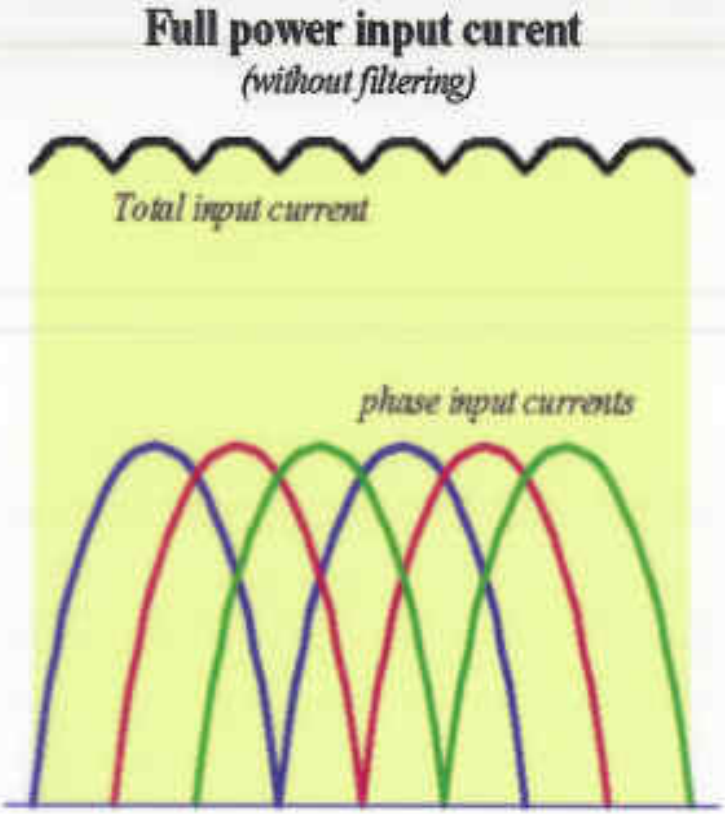


AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

Low Input Ripple Power Conversion

- When the three phase shifted currents are summed together they produce a low ripple input current.
- Input filter capacitors can weight as little as ten grams for a 10KW converter – this would not be possible with present power converters.
- The lower input buss energy improves the converter's survivability to flash x-ray events.



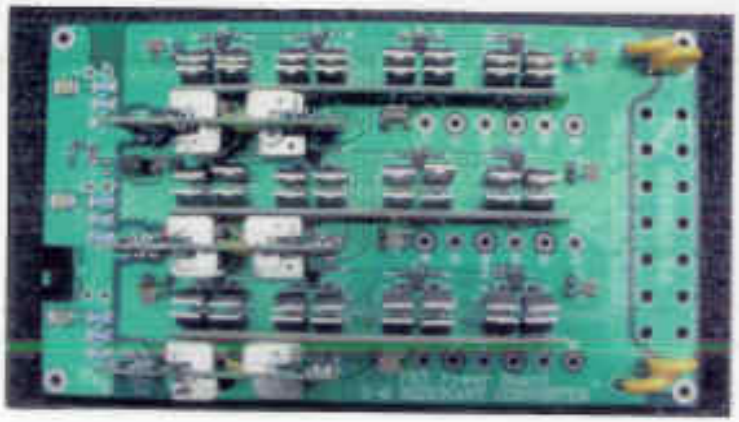
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

PCB design low inductance power interconnect

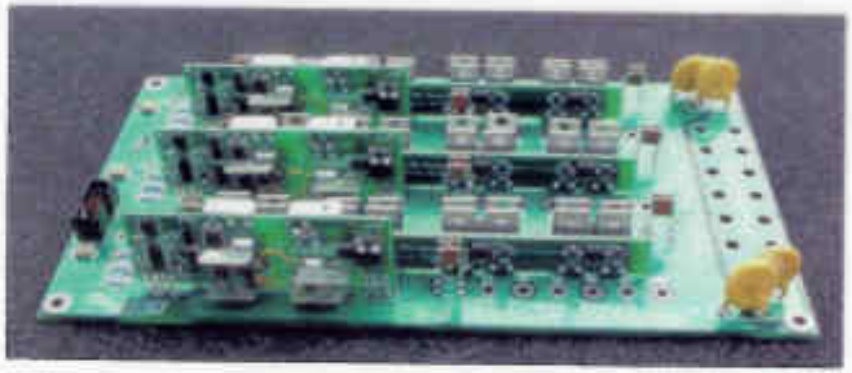
(4)

- MOFET power board is designed to carry 120Amps. A six layer PCB was chosen that had a copper thickness of four ounces of copper per square foot. The foils were interlaced to form low a low inductance power buss.



Power Board

- Three half brides with eight parallel FETs per switch



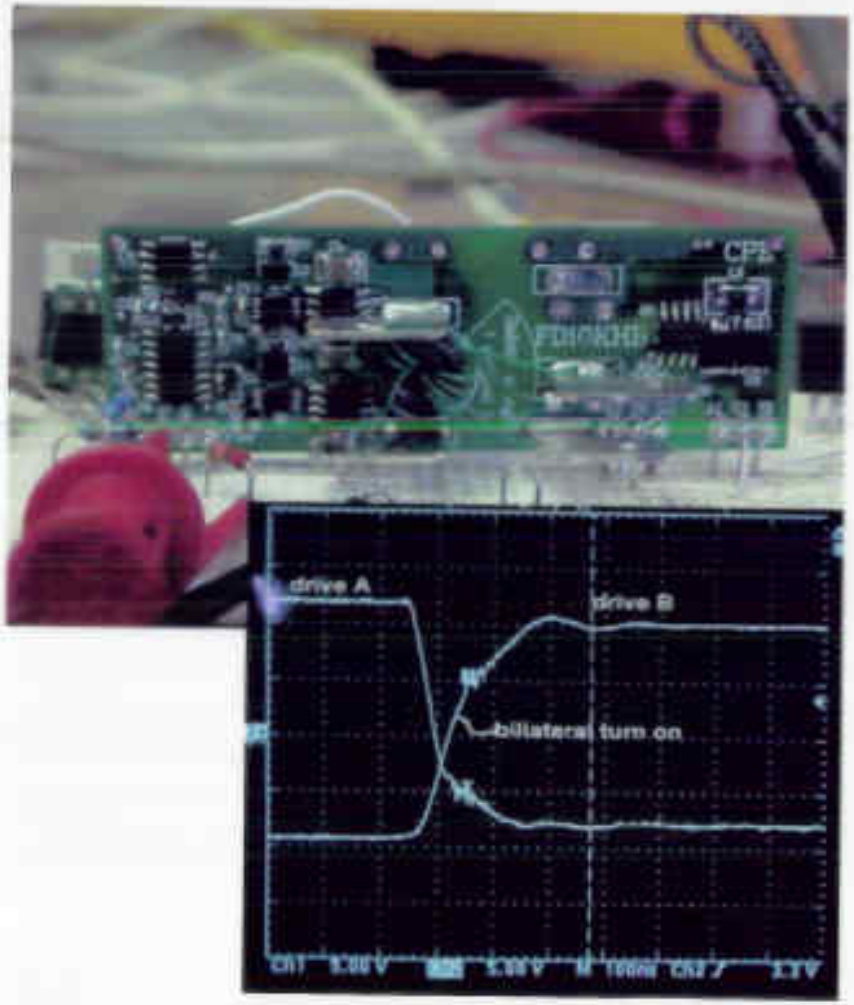
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

5

Isolated Gate Driver

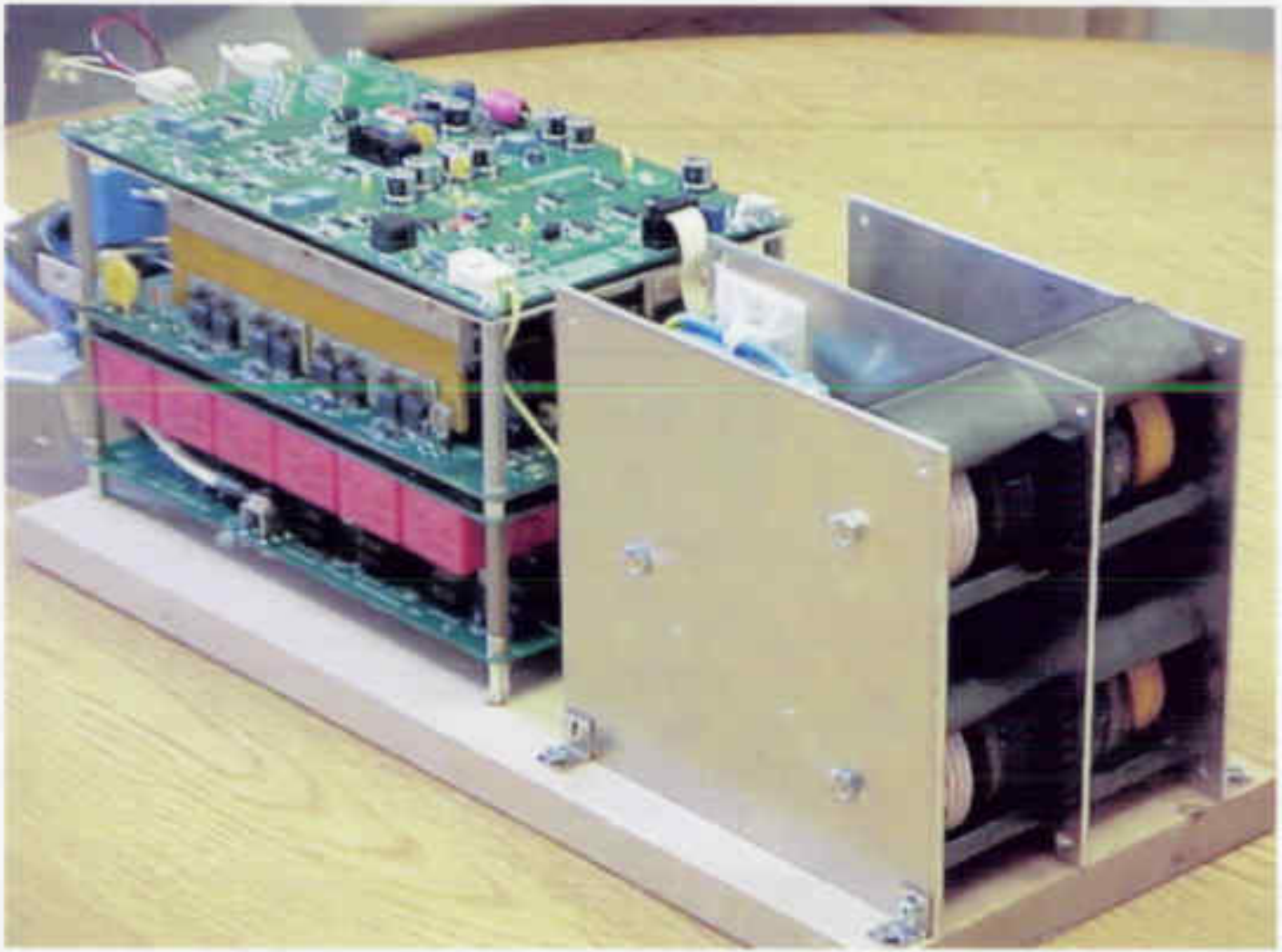
- A gate drive circuit was developed that used active shunt transistors for the following benefits;
  - Lower drive power. The shunt transistor current subtracts from the required drive current yielding lower input current to the driver.
  - The active shunt resistors drive to 0.05 Ohms. The lower impedance increases the insertion losses to the MOSFETs thus reducing the tendency for parallel FET oscillation.
  - 'On to off' gate transition is faster than with pure transformer derived gate pulses.



AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

Skinned 10KW Converter



AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

Breadboard with enclosure on test bench

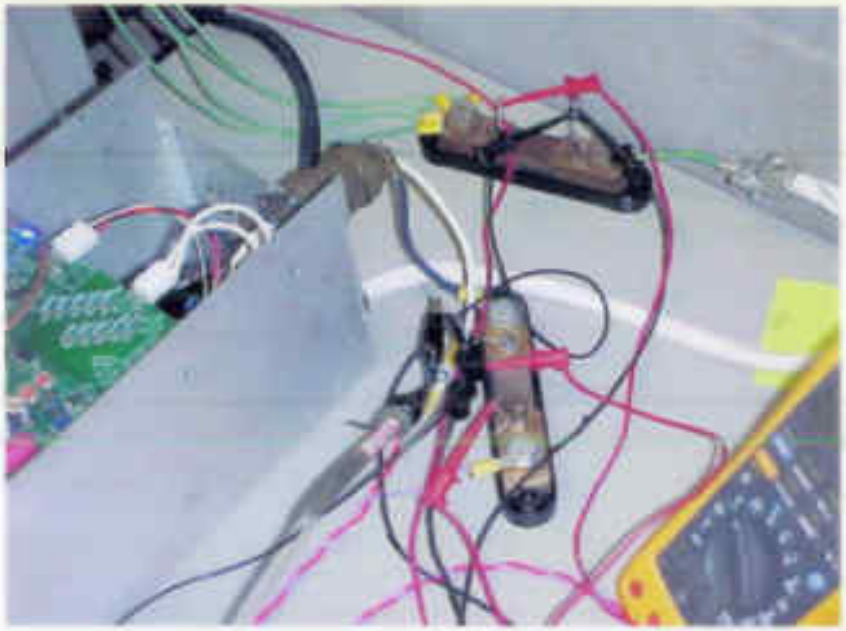
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

Bread board with power system

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

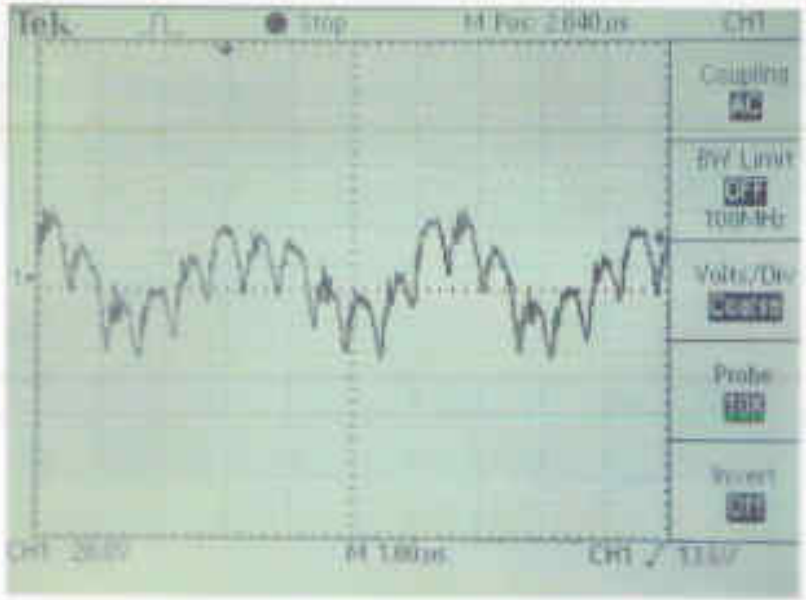


Current measuring shunts for input and output currents (top)

Load Bank (left), 22 piece array of 600W IR heaters

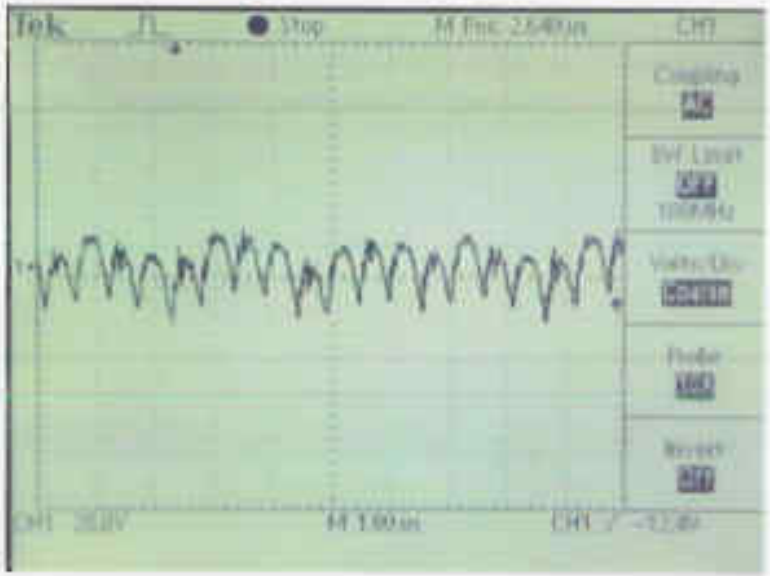
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard



Output ripple on at 500V output (left) before balancing

Twelve point ripple shown with single phase imbalance



Output ripple on at 500V output (right) after balancing

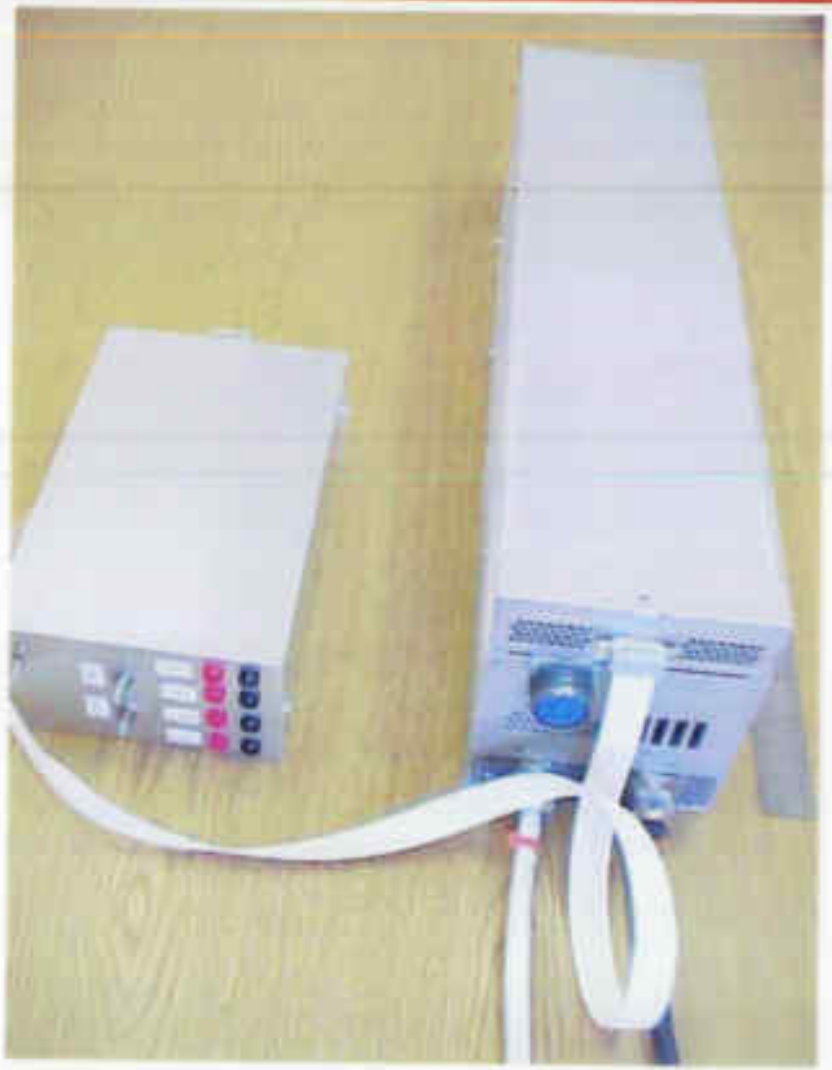
Three-Phase Resonant Converter PPU 10KW Breadboard

Efficiency Measurements

- 400V/10KW output, Converter losses
  - 261W at 100V input
  - 271W at 110V input
  - 279W at 120V input
- 800V/10KW output , Converter losses
  - 261W at 100V input
  - TBD at 110V input
  - TBD at 120V input

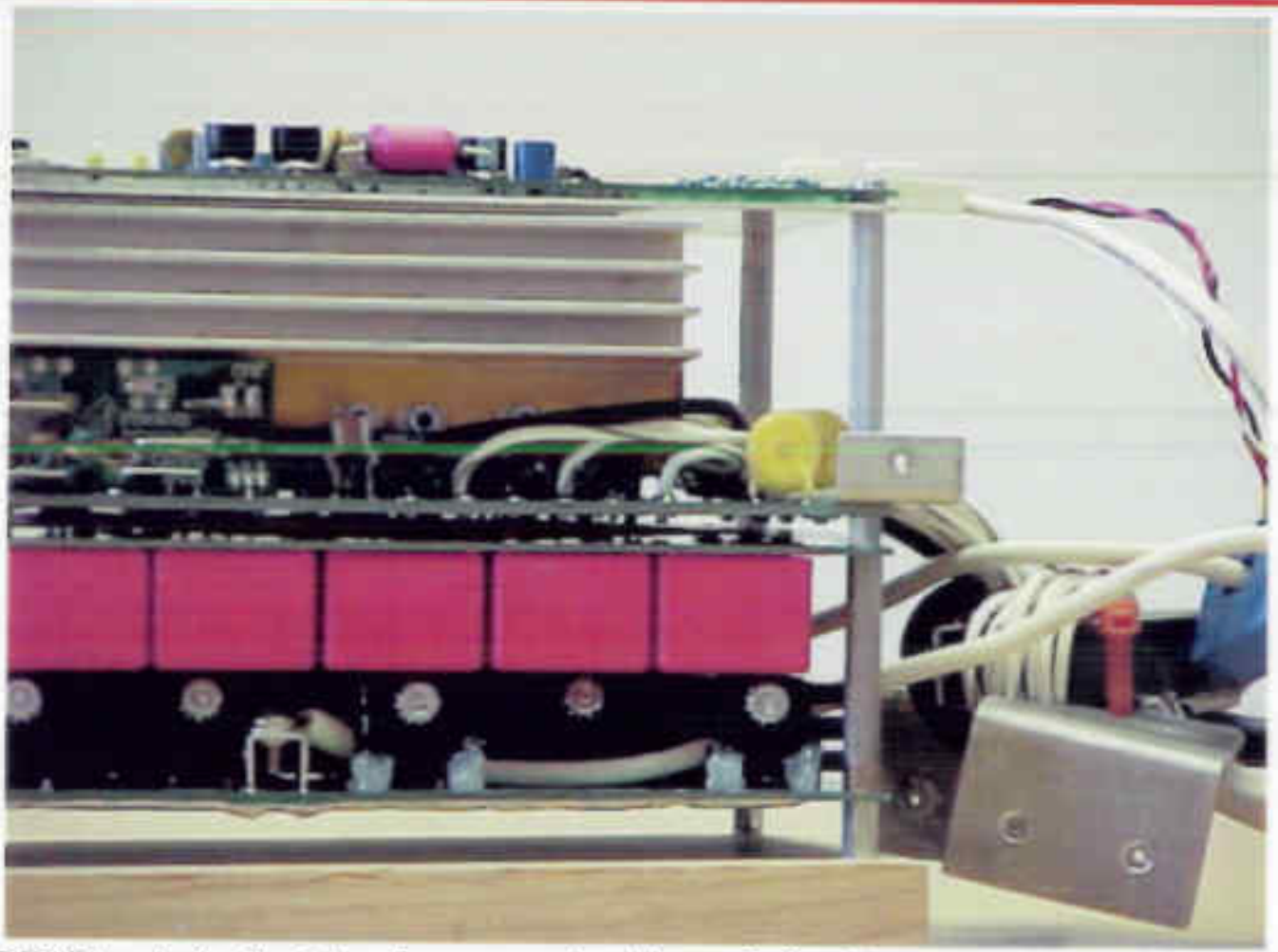
AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU
10KW Breadboard



AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

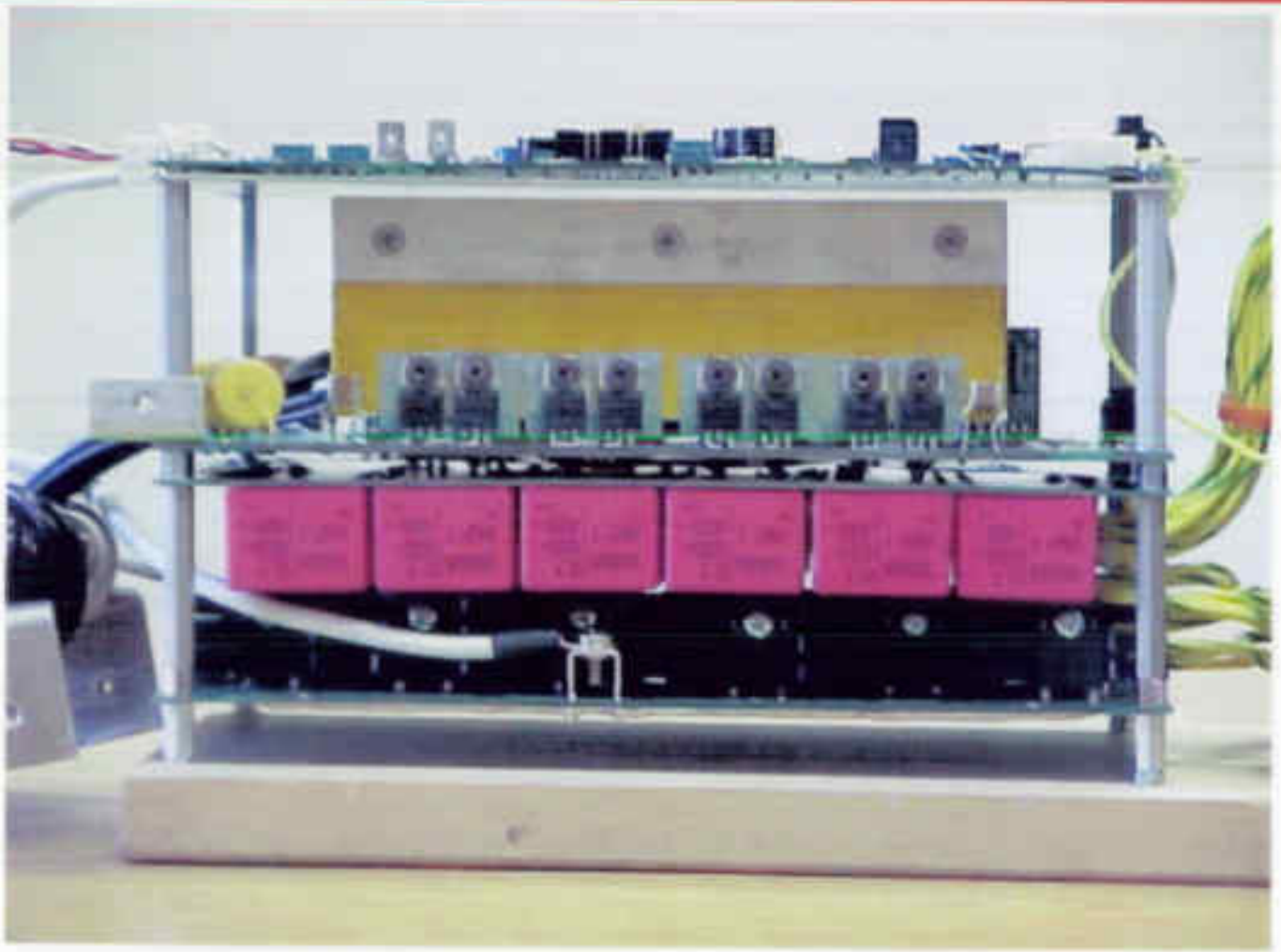
Three-Phase Resonant Converter PPU 10KW Breadboard



- PCB Stack Left side view; control board (top), power board (second) series resonant cap board (third), and rectifier board bottom

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

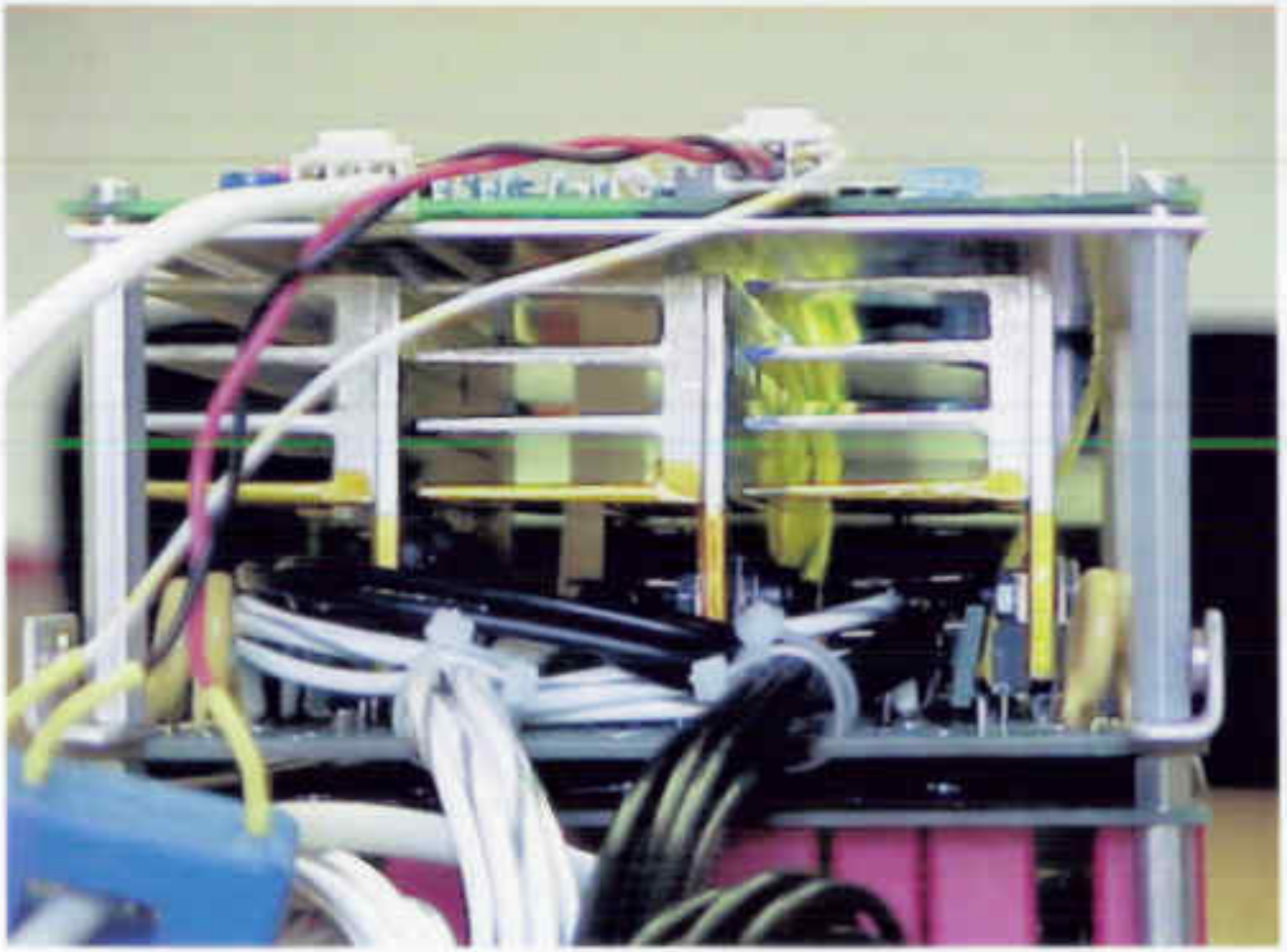
Three-Phase Resonant Converter PPU 10KW Breadboard



PCB Stack right side view

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

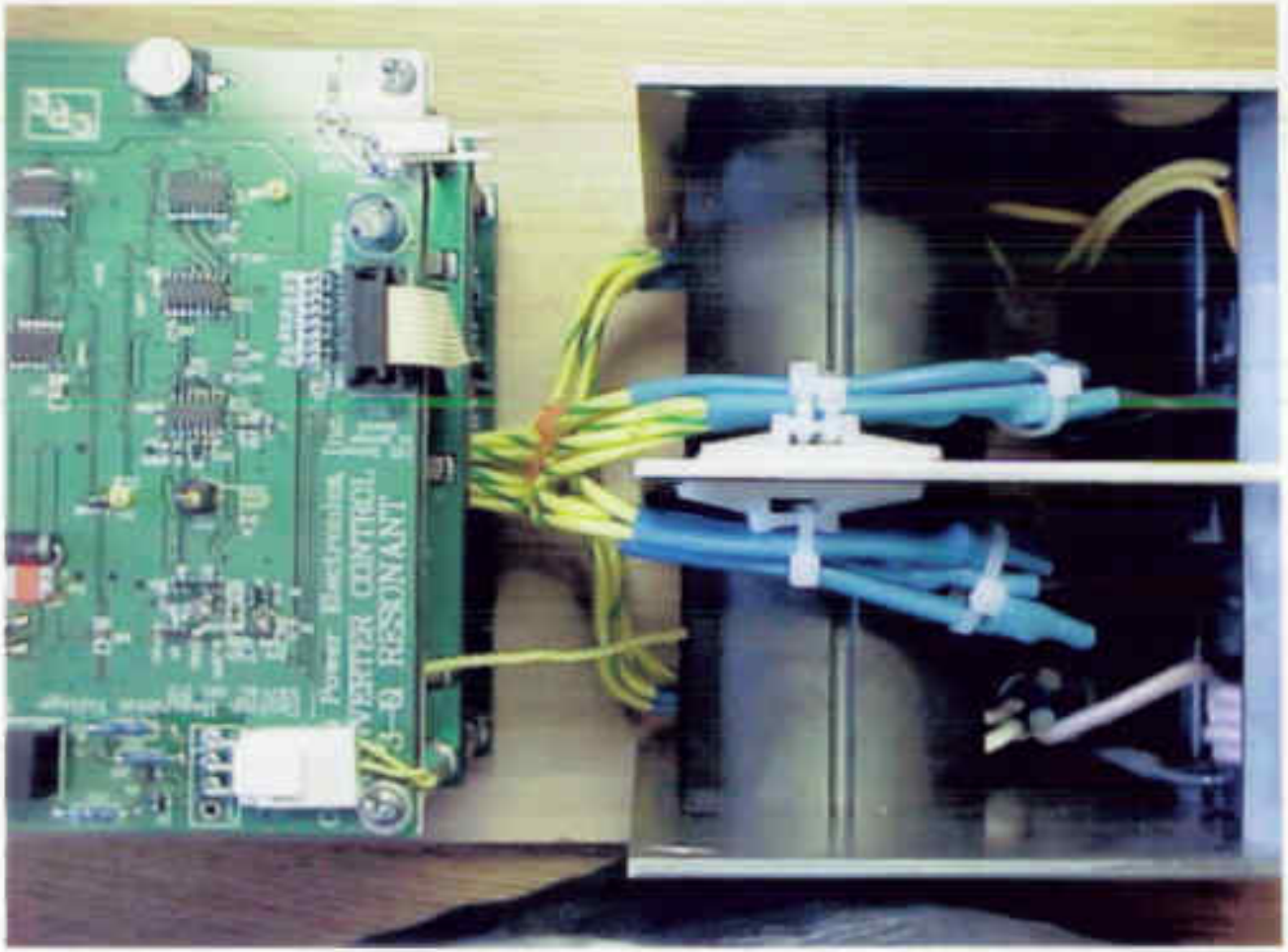
Three-Phase Resonant Converter PPU 10KW Breadboard



Bread board front view, Input power feed and Switch heatsinks in fore front

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU
10KW Breadboard




AEROJET
LOCKHEED MARTIN
NASA
Glenn
Research
Center
10KW Breadboard
10-27-05
Three-Phase Resonant
Converter PPU

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

Program Objectives

1. Develop scalable 10KW three-phase DC converter for 600KW PPU.
2. Develop highly efficient resonant power train, which yields total converter efficiency in excess of 96% while maintaining a low specific mass.
3. Build a 10KW DC converter Breadboard, which demonstrates objectives 1 and 2.

AEROJET
LOCKHEED MARTIN
Glenn Research Center
Colorado Power Electronics, Inc.

Three-Phase Resonant Converter PPU 10KW Breadboard

- Modular Designs using the 3PRC as standardized power module
  - Low heat flux designs reduce loading on cooling components which allows for greater flexibility in thermal management and converter placement.
  - The wide output range of the 3PRC means one part number converter can take the place of multiple part number converters.
  - The smooth input and output current characteristics reduce parallel converter cross-talk and sympathetic oscillations.