Overview of

SLAC Marx
Modulator Design and Progress

Circulator-Less RF Distribution System with Adjustable Tap-offs

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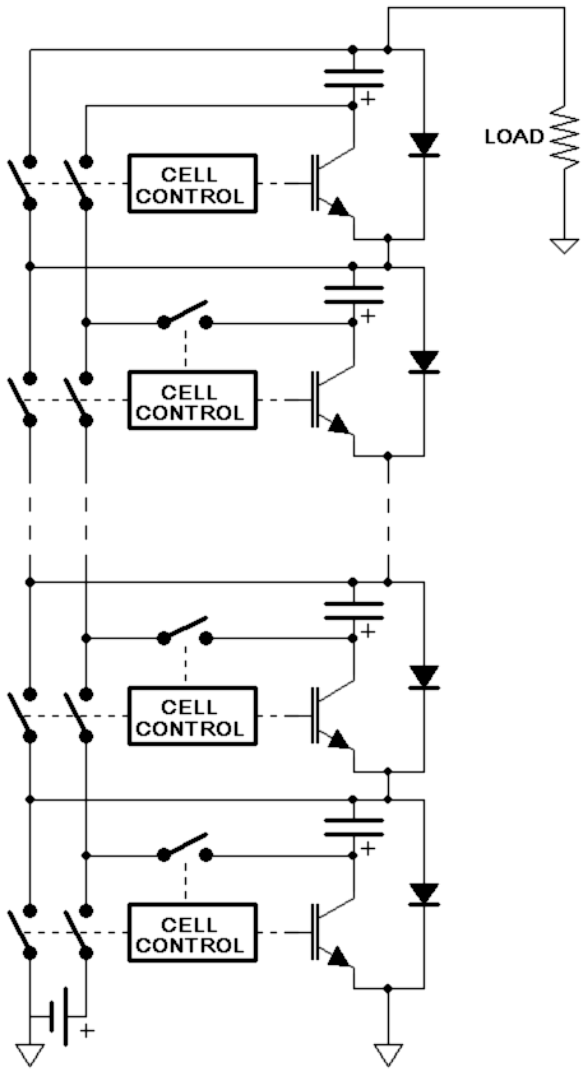
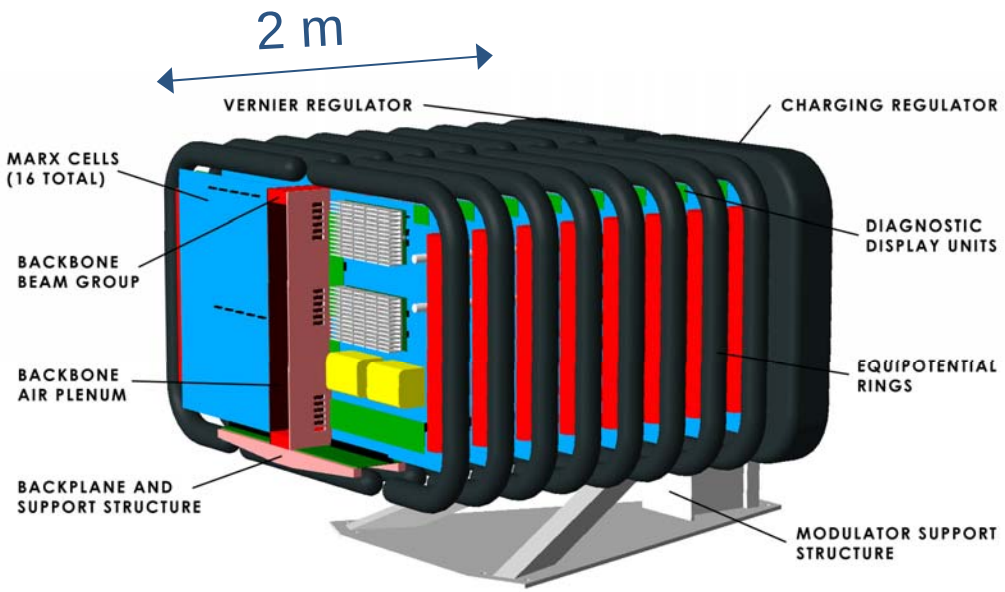
Jan 18, 2007

Acknowledgments

- A large team is contributing to the Marx project
  - **Greg Leyh – lead engineer** - has been responsible for the conceptual and detailed design of essentially the entire Marx circuitry, mechanics, electrical and thermal simulations, board level controls interface, test equipment, power and cooling systems and the test load.
  - Piotr Blum and Alfred Viceral - main frame, test equipment, production and assembly.
  - Ed Cook (LLNL) designed the vernier corrector unit.
  - Craig Brooksby (LLNL) designed the 150 kW load and enclosure.
  - Richard Cassel's group assembled the load.
  - Craig Burkhart is designing the vernier controls.
  - Jeff Olsen designed, built, tested and programmed the control system.

Marx Generator Modulator



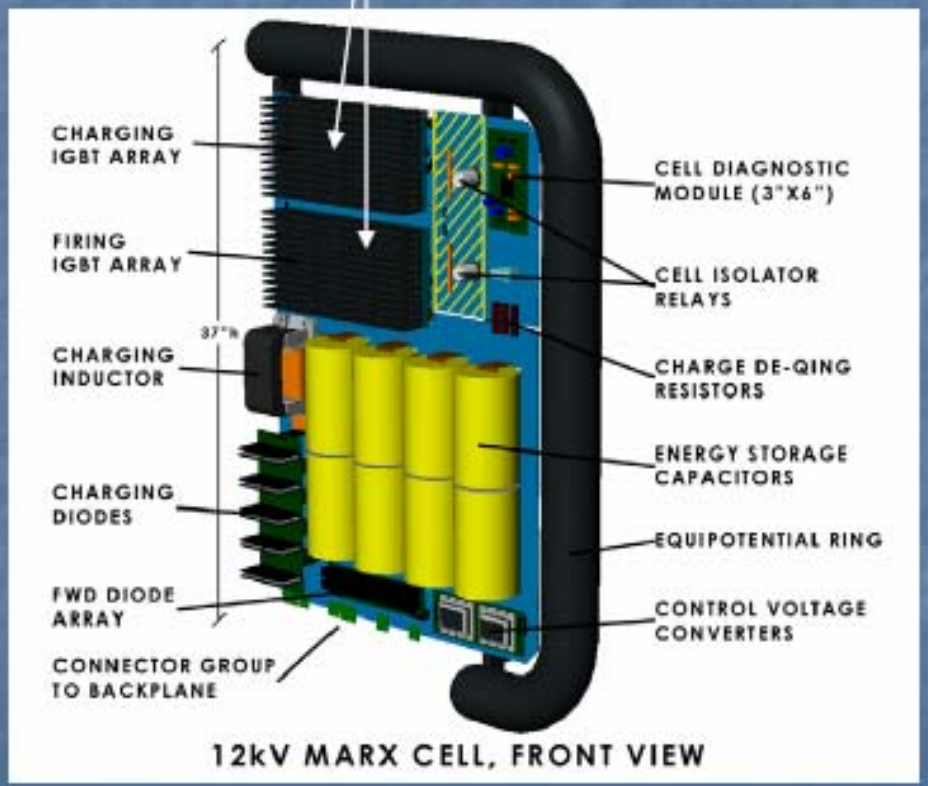


Stack of 12 kV Marx Cells

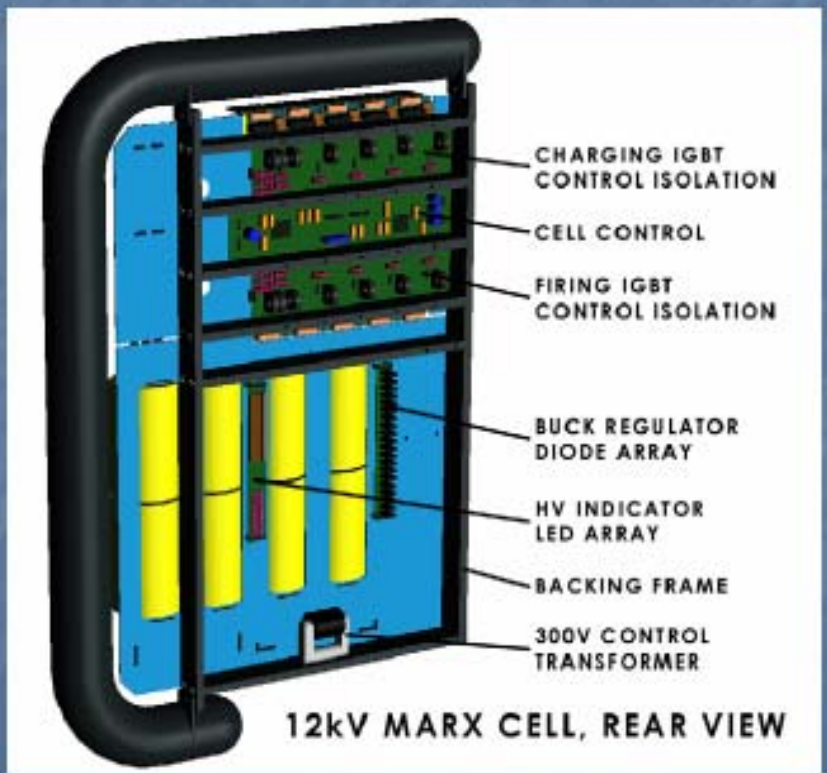
- IGBT switched
- No magnetic core
- Air cooled (no oil)

12 kV Cell Detail

N+1 Redundant Switch Arrays



12kV MARX CELL, FRONT VIEW

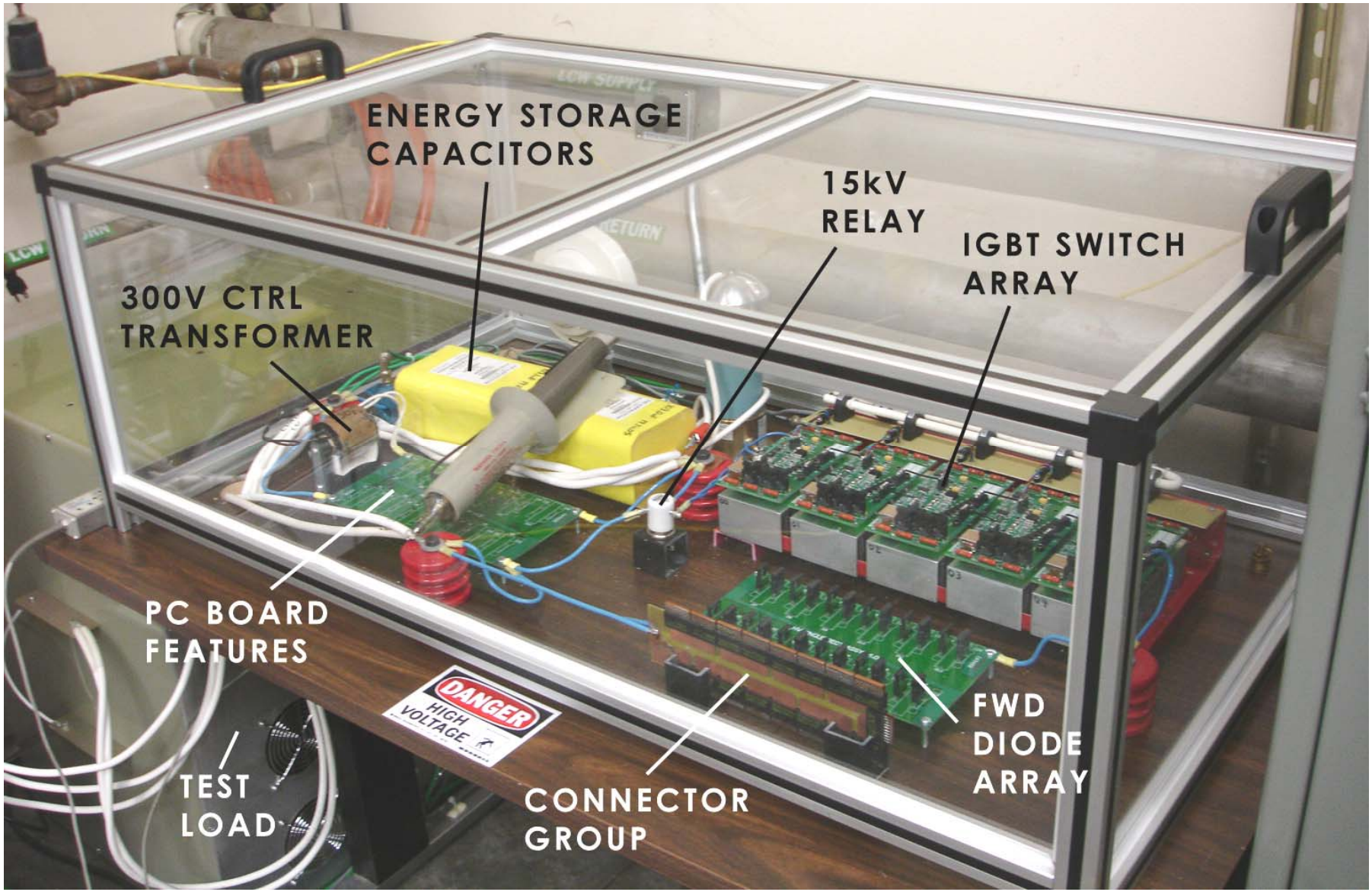


12kV MARX CELL, REAR VIEW

Marx Features

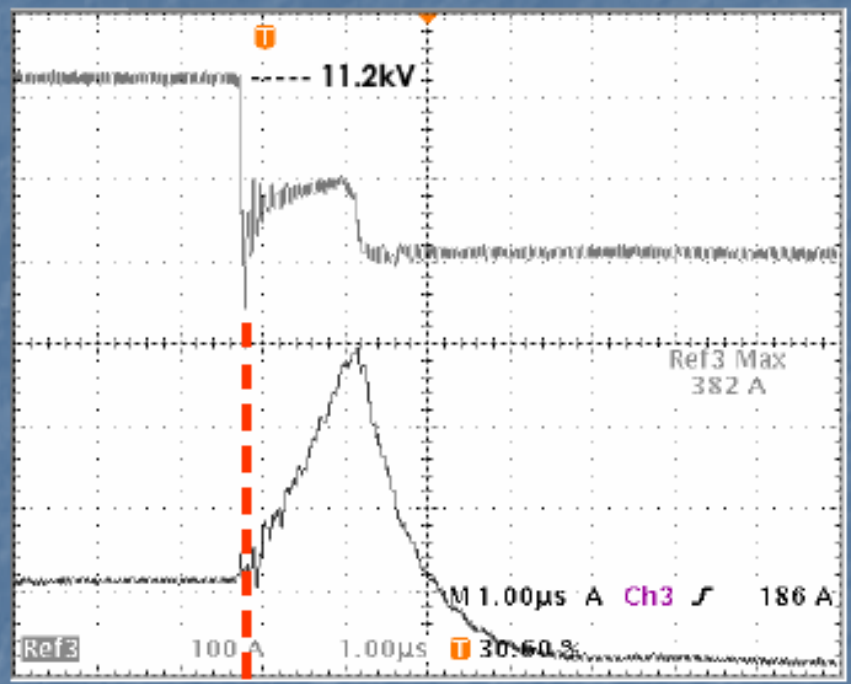
- Direct-coupled voltage stack of ten main 12-kV cells producing 140A pk @ 1.6 msec.
- Cell can operate with failed components.
  - 4/5 redundant solid state output, re-charging switch banks.
- Modulator functions with up to 2 failed drivers
  - 10 main cells needed, 12 available
- Vernier cells correct flat top to +/-0.5%.
  - Second stage correction also being studied to approach +/-0.1% if possible.
- Buck regulators (2) have 4/5 switch redundancy

Marx Cell Component Testing



Cell Protection Response Time

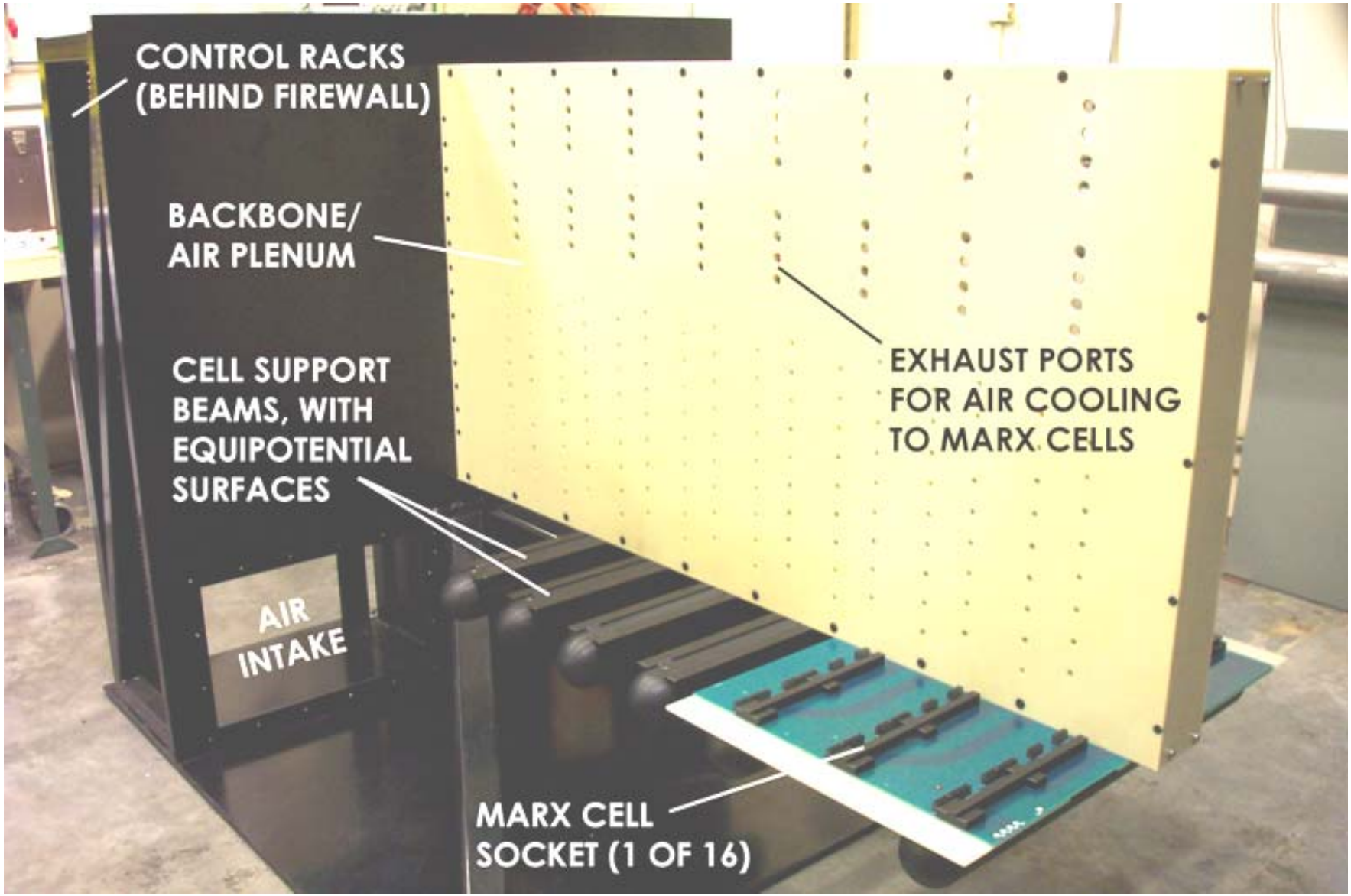
- Cell protection is fast turnoff of IGBT switch array and shunting stack current into bypass diode.
- Original 4usec – 32usec delay jitter fixed.
- Replaced current shunts, reduced physical size of detection circuitry, added shielding to achieve <1usec over-current response time.



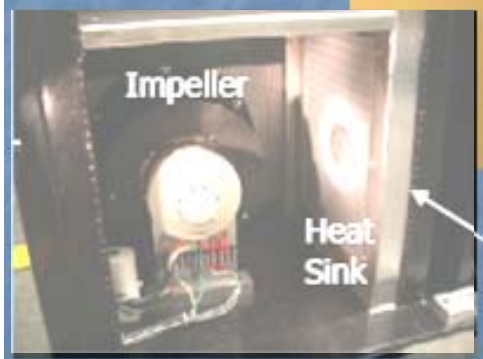
Spark-gap triggered short

Top: Collector voltage 11.2kV→0
Bottom: Output current 110A
Spikes to 382A peak when device shuts off, current decays to zero

Cantilever Backbone



4. Cooling System



Blower & Heat Sink (1 of 2)

- Dual fans, integral water heat exchangers pressurize hollow G10 girder
- Side holes direct air onto heat sinks for IGBT stacks, diode stack
- Require 600 lfpm; measure 1500 lfpm w/ 2 fans; no degradation in performance w/ 1 failed fan

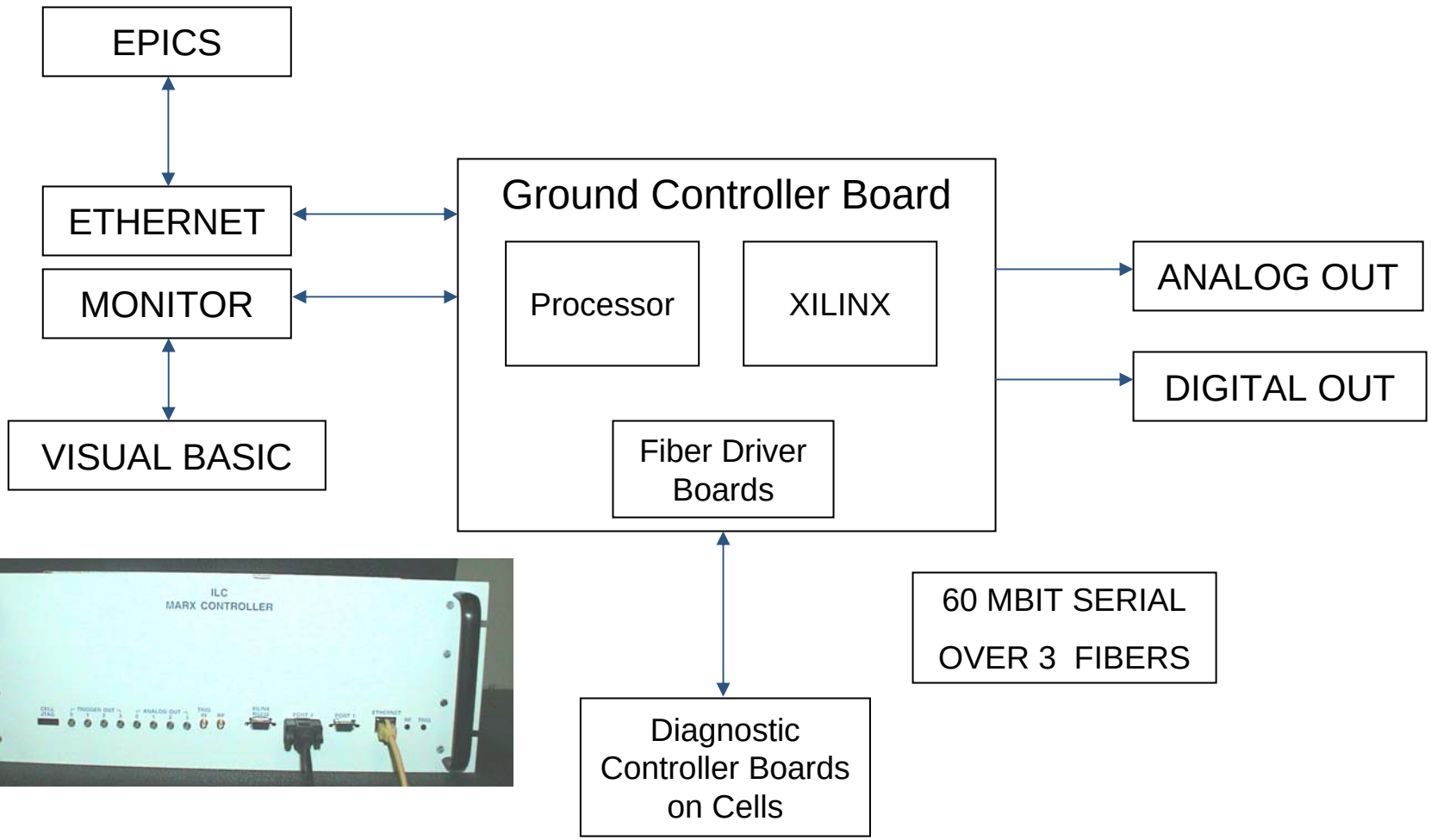
6. Vernier Cells

- Main Vernier Cells
  - Four cells programmed to correct for up to 30% droop of main waveform
  - Equivalent in action to "Bouncer" circuit of BCD
  - Leaves +/- 0.5% short ramps across waveform
  - Needs special timing program, under design
  - *Will not be implemented in first power tests*
- Second Order Vernier Corrector
  - Single rackmount unit at bottom of stack to correct small ramps, in effect programmable D/A Converter
  - Timing derived from Main Vernier timing
  - Designed by LLNL; first prototype under construction
  - *Will not be implemented in first power tests*

MARX Prototype

70 kV Achieved So Far with 6 Cells

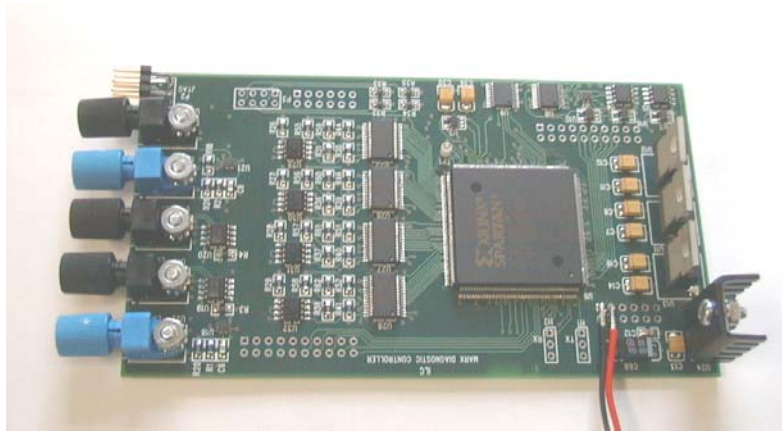
MARX Controls Block Diagram



Ground Controller Board

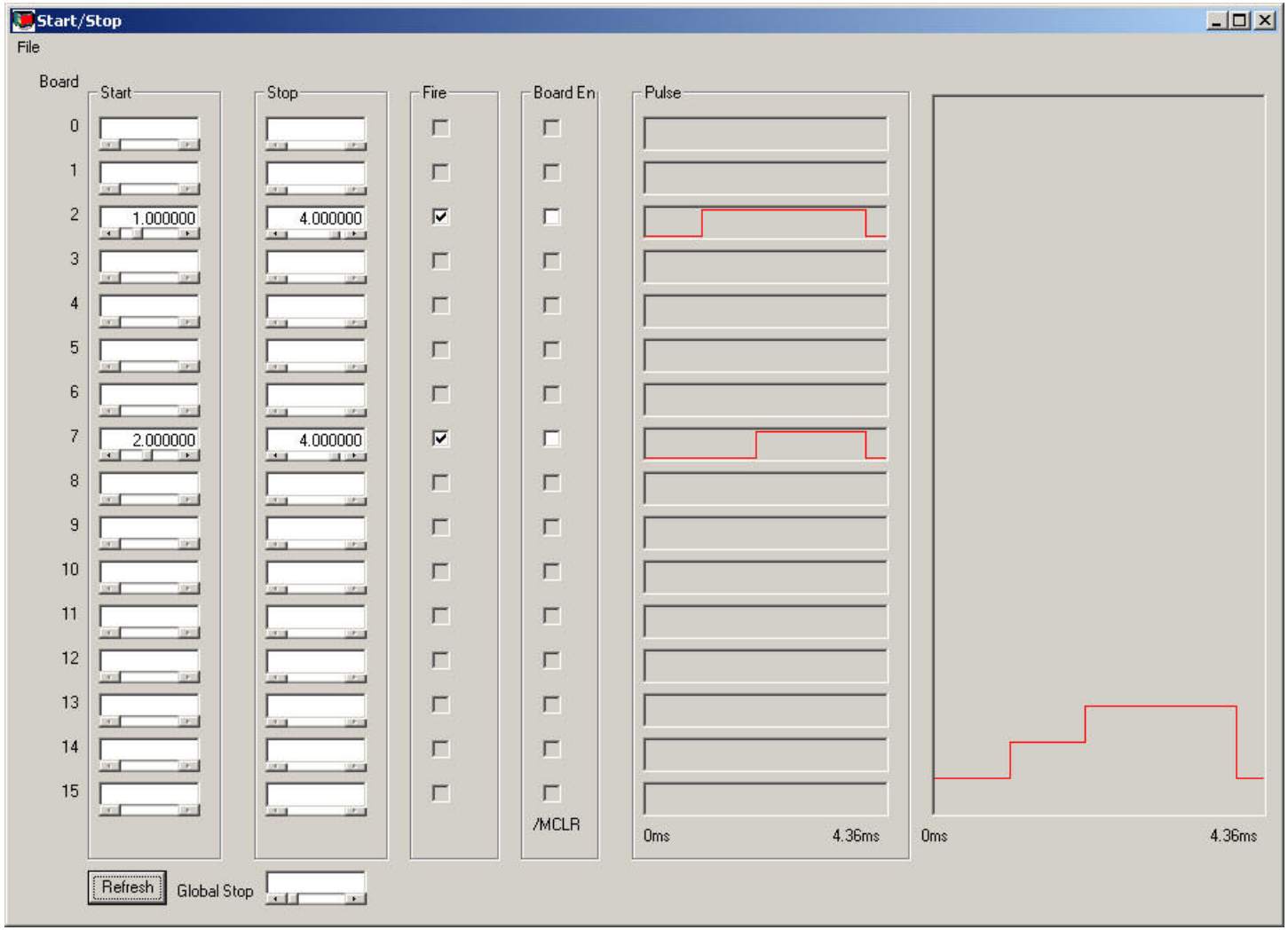
- Arcturus 5282 Coldfire processor
- XILINX Spartan 3-400
- 17 Fiber Driver Boards
- 4 Trigger Outputs (TTL)
- 4 DAC Outputs
  - Scope display of 4 slow ADC's on the Diagnostic Controller Boards
- Local 60Mhz oscillator
- Internal trigger generator

Diagnostic Controller Board

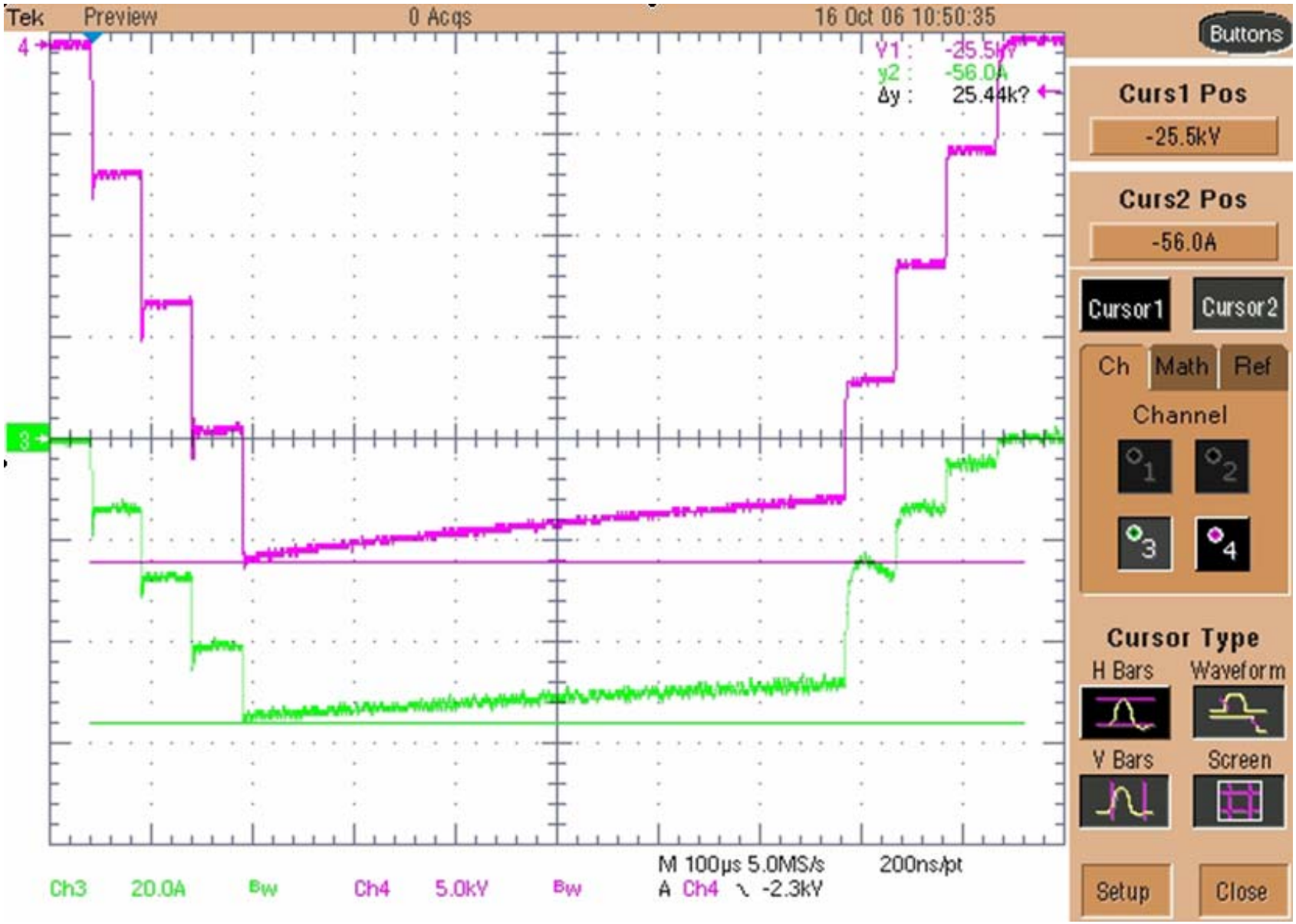


- XILINX Spartan 3 - 400
- 16 Fire outputs
  - Programmable Delay and Width
- 4 Slow 16 Bit ADC's constantly monitoring CT1, HVD1, HVD2, HVD3 from the Cell
  - 200Khz, 50Khz per channel
- 4 Fast 8 Bit ADC's monitoring CT1, HVD1, HVD2, HVD3 from the Cell
  - Programmable clock from 30Mhz to 200Khz
  - Programmable delay from trigger
- Reprogrammable secondary boot prom
  - Reprogrammable from serial interface

Visual Basic GUI



4-Cell Output Waveforms



150 kW Air-Cooled load

Disc Resistor Stacks (2)

120 kV Input Cable

Rear View Axial Fans

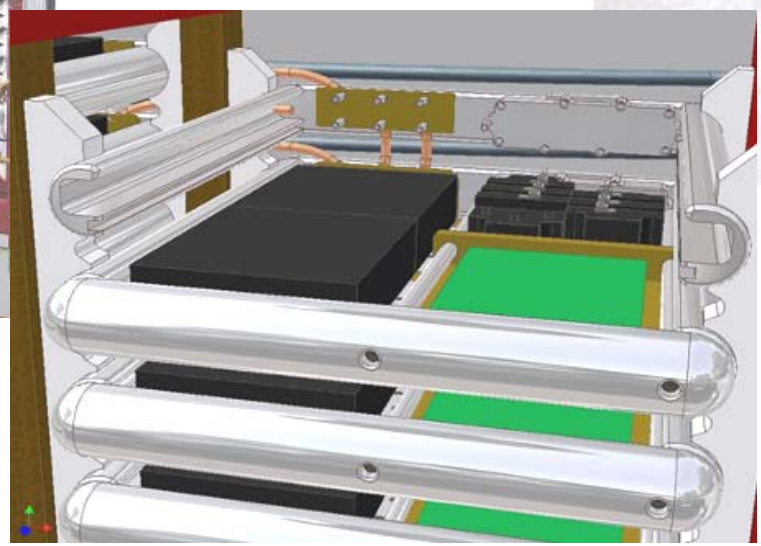
Disc Resistor & Cooling Fin Stacks

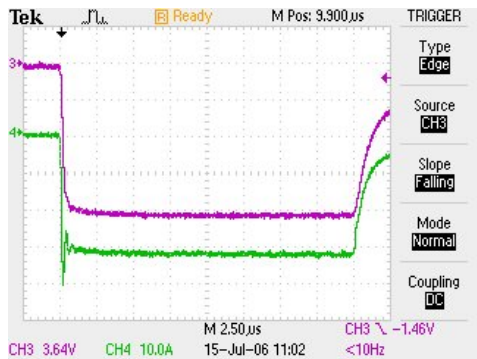
Stangenes Marx Generator for NATO Radar Systems

- Peak Operating Voltage: 90 kV
- Peak Operating Current: 50-150 A
- Pulse Width: 110 microseconds
- Duty Cycle: 4.8% (Short Burst)
- Continuous Duty Cycle: 2.5%
- Pulse Droop: 3% max, 1.5% desired
- Input power: 120 kW
- Input voltage: 416 volts AC 60 Hz

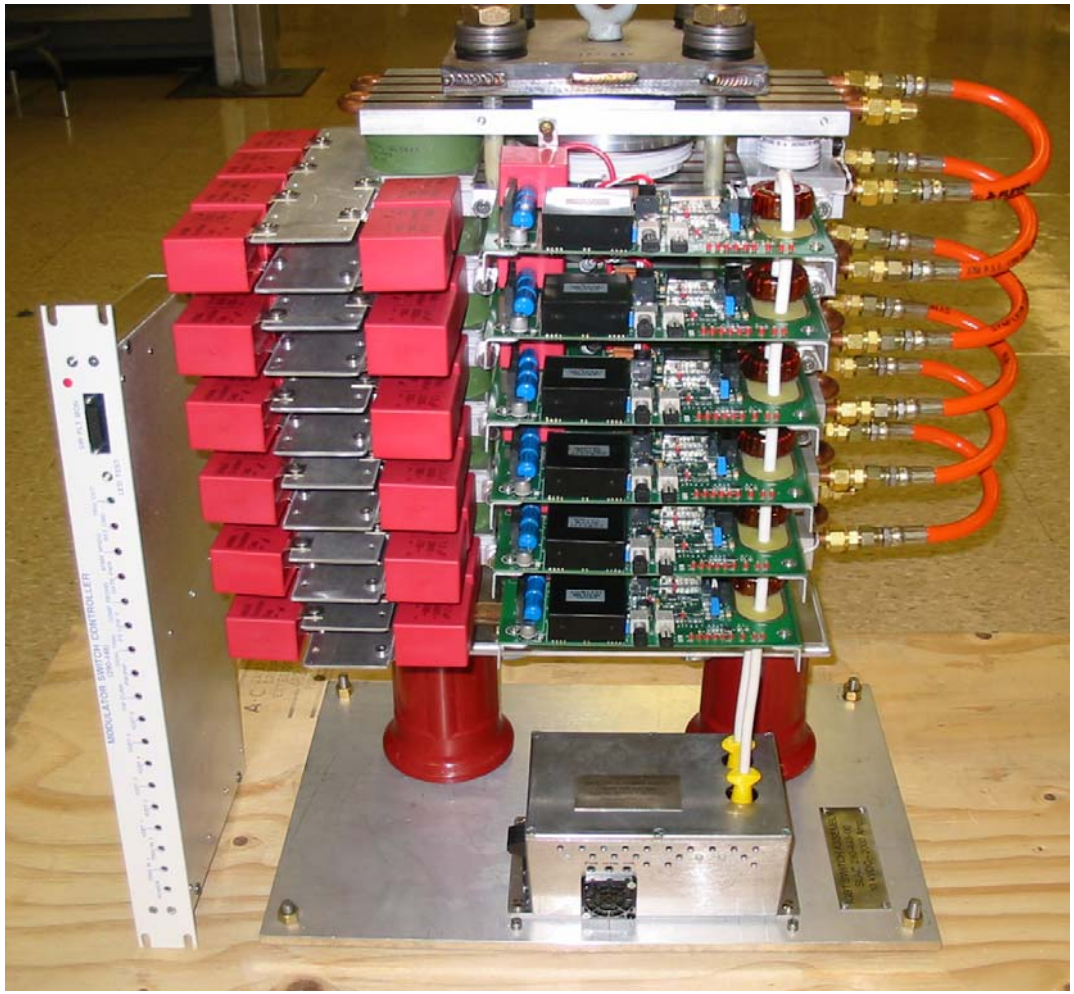
Stangenes Marx Generator

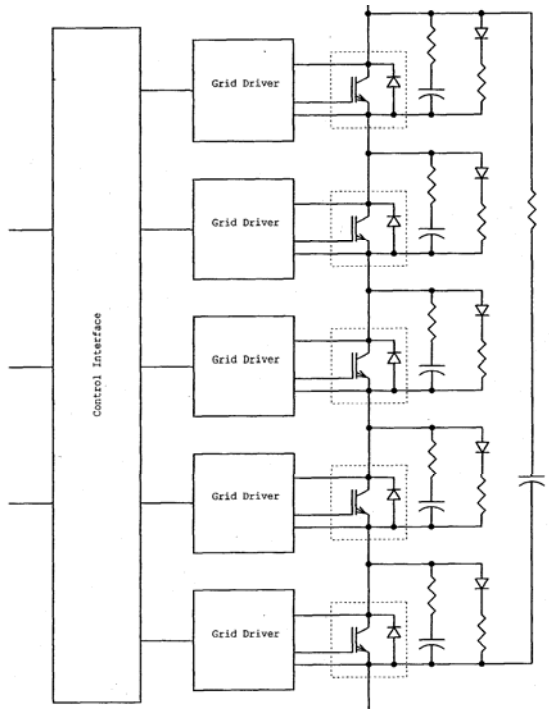
(Produced 30*3 = 90 kV, 50A, 100 μsec Pulses)





New Switch Design for Baseline Modulator Provided by SLAC

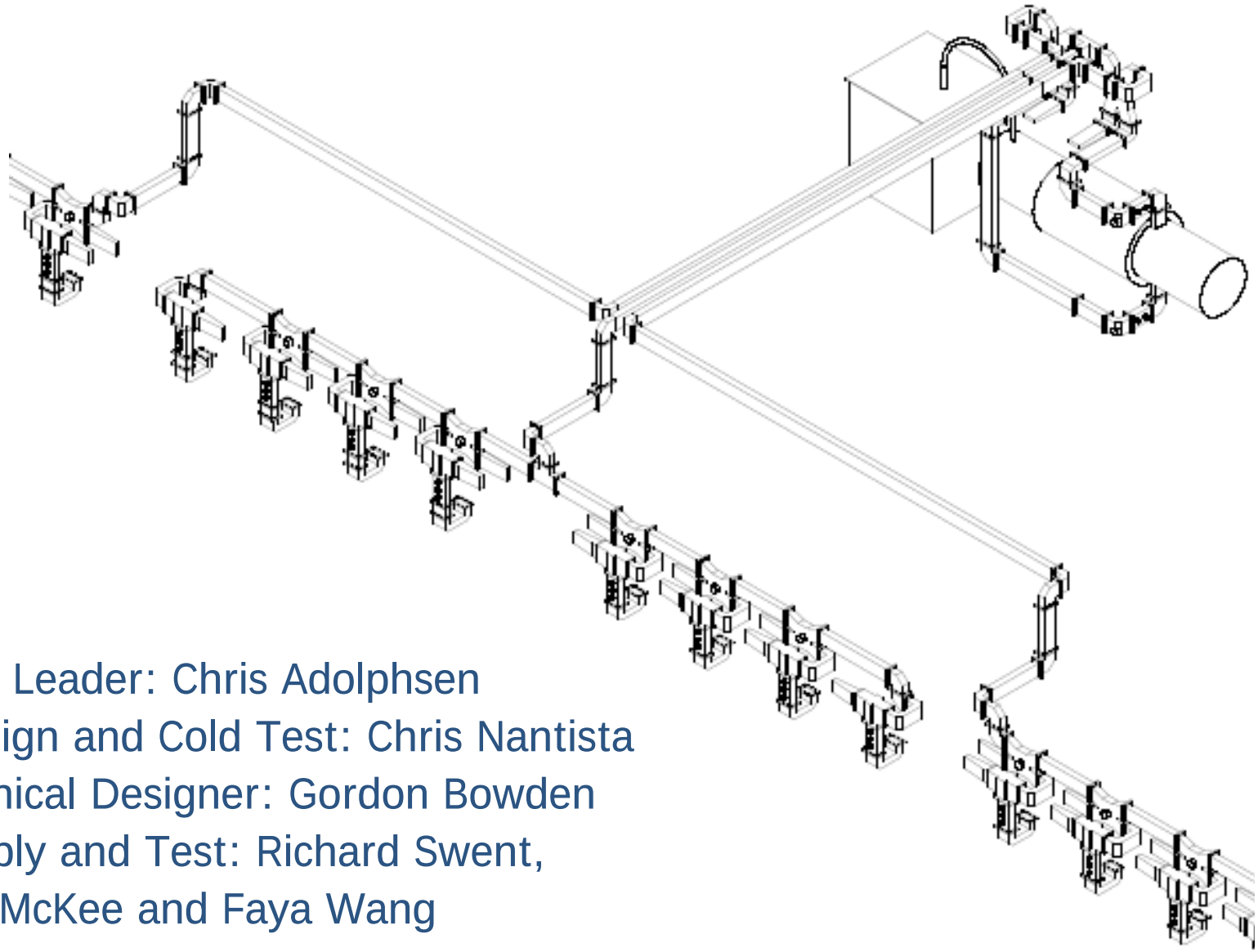




Switch Schematic

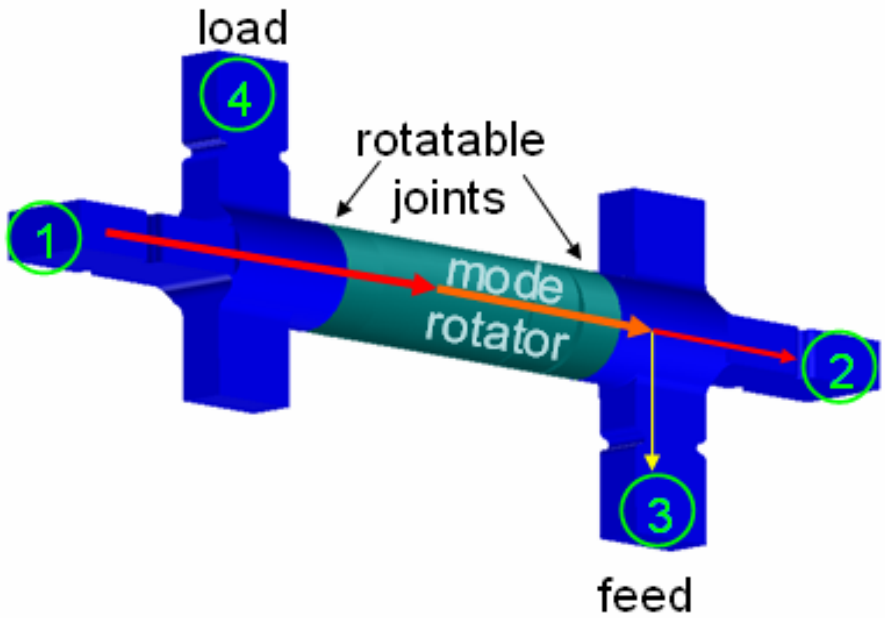
- 10 kV nominal operation
- Redundant drive
- Independent snubbers

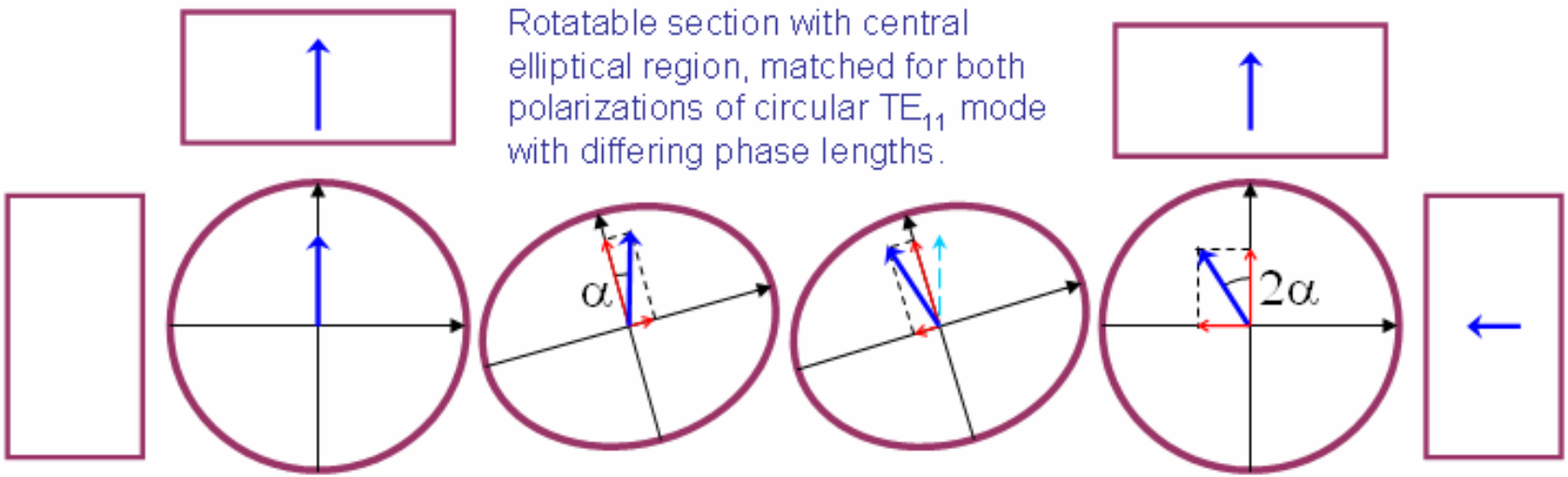
RF Distribution Development



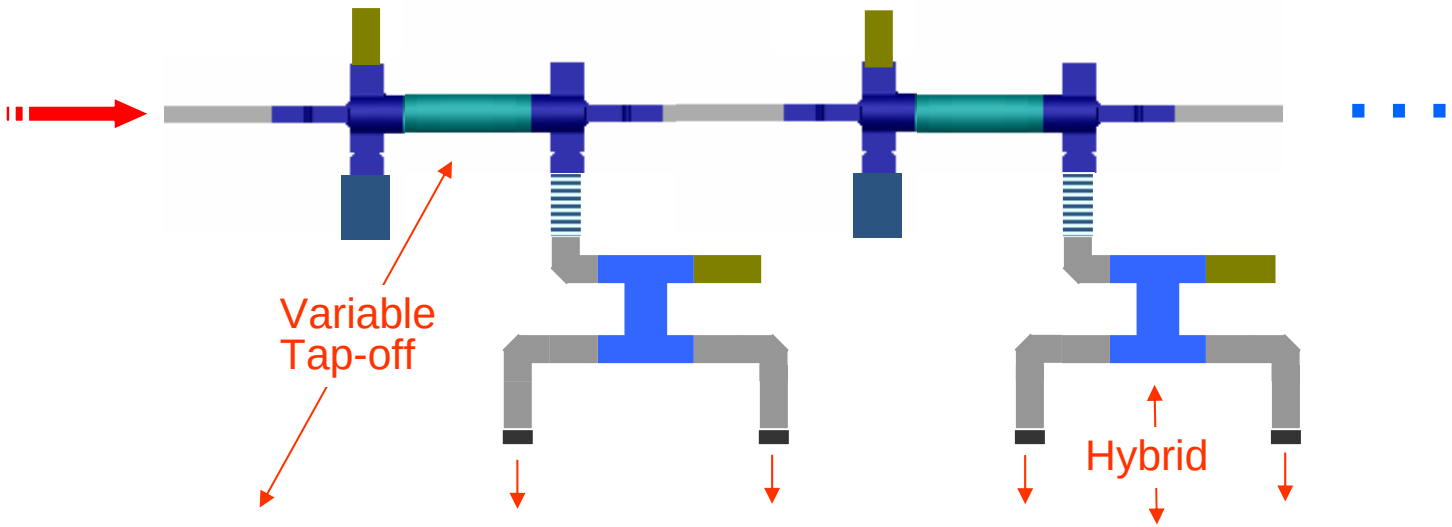
Project Leader: Chris Adolphsen
RF Design and Cold Test: Chris Nantista
Mechanical Designer: Gordon Bowden
Assembly and Test: Richard Swent,
Bobby McKee and Faya Wang

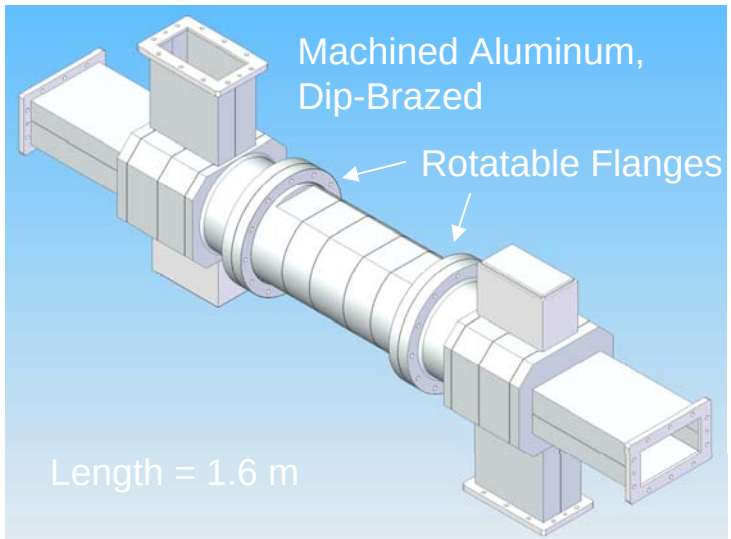
Adjustable Tap-Offs Using Mode Rotation

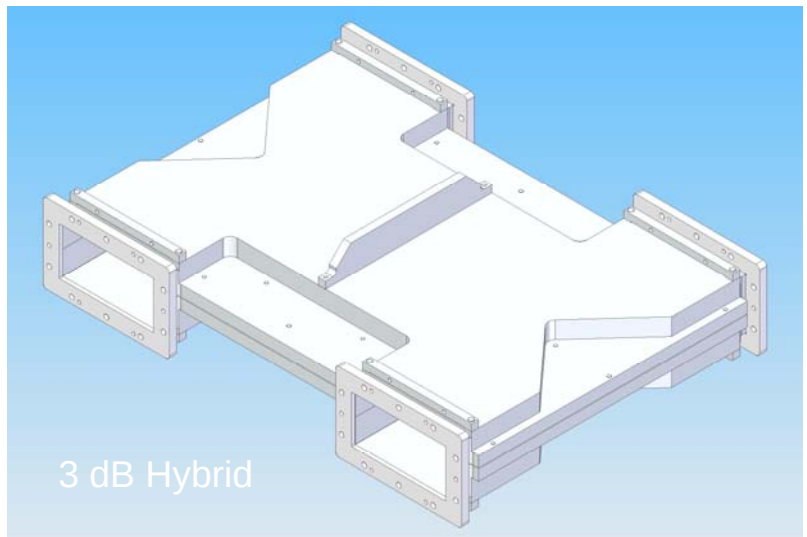




RF Distribution System without Circulators and with Variable Tap-offs

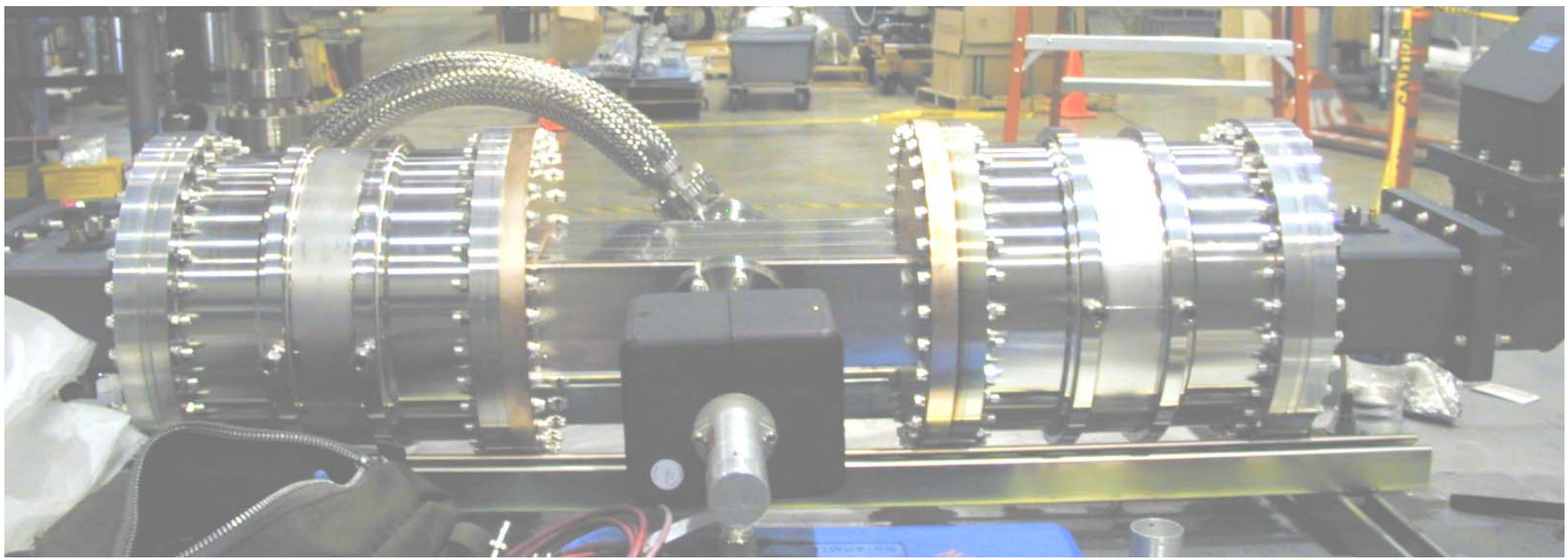




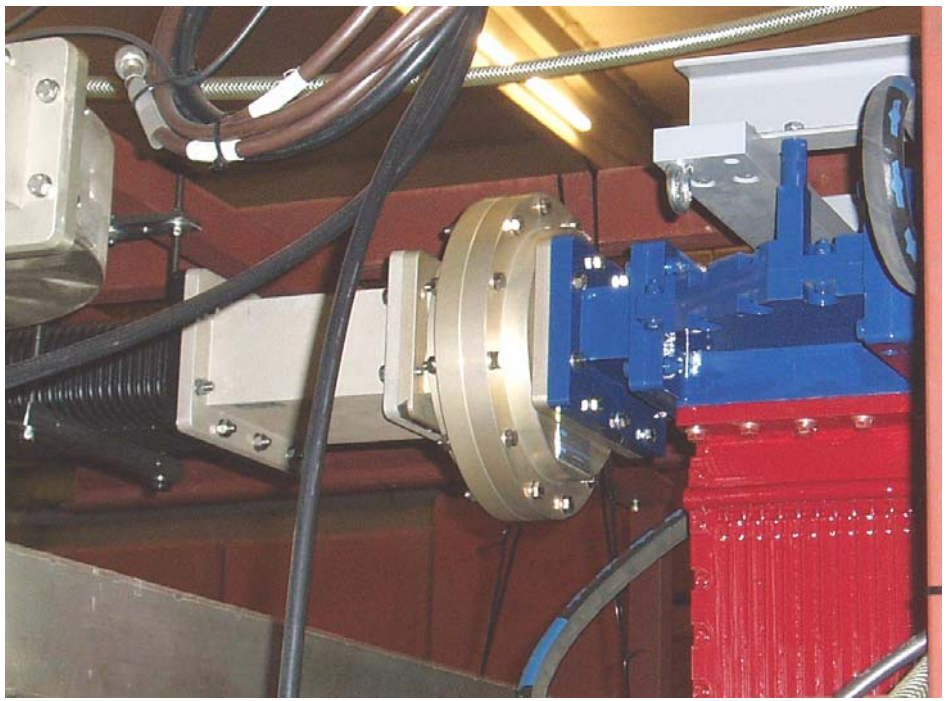


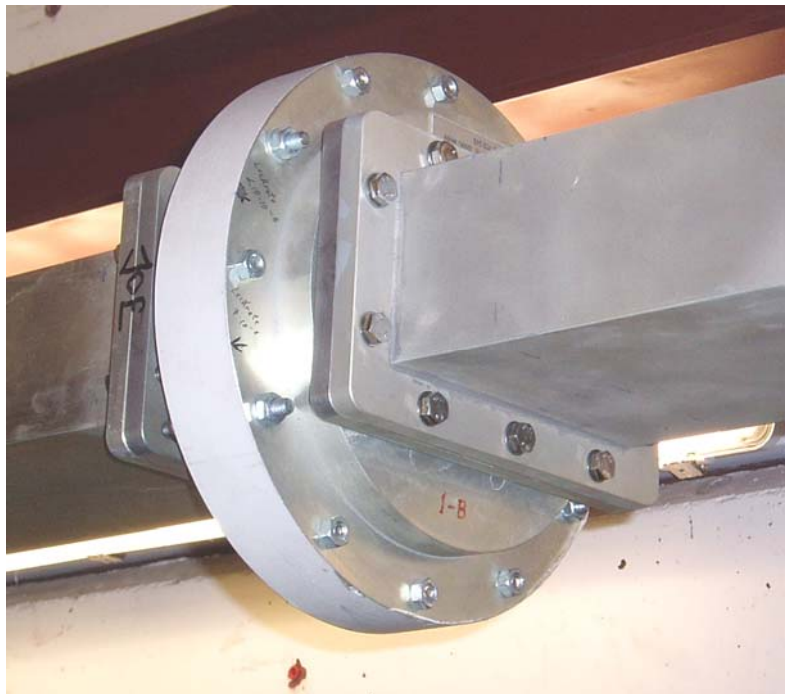
High Power Vacuum Windows

Work well in tests so far to
4.5 MW, 1.4 ms



Seeking Air-to-Air Windows (2 bar differential pressure)





S-Band BPM Triplet Results

(0.5 micron resolution, 1.4e10 electrons, Q of 500 for clean bunch separation)