ILC Marx Modulator Development Program Status

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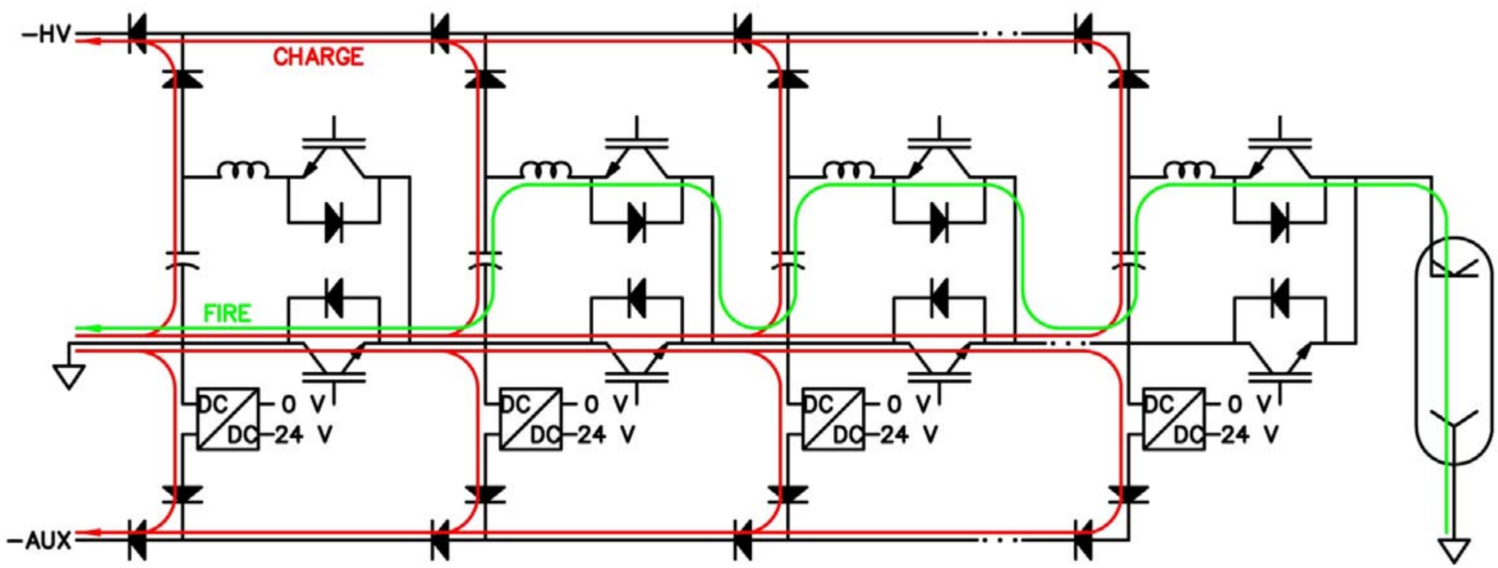
Overview

- Motivation for Solid-State Marx for ILC
- P1-Marx
- P2-Marx
- Summary

Solid-State Marx Topology

- Charge (parallel) – discharge (series) configuration controlled by solid-state elements, diodes and IGBTs
- Charge switch anti-parallel diode provides by-pass for delayed cells to compensate for voltage droop
- Highly evolved Marx (1924): well regulated output



ILC Klystron Modulator Parameters

• Pulse Voltage:	120 kV
• Voltage Regulation:	±0.5%
• Pulse Current:	140 A
• Pulse Length [flat-top]:	1.6 ms
• Total Pulse Energy:	27 kJ
• Repetition Rate:	5 Hz
• Average Output Power:	135 kW
• Total # of RF Stations:	576

Design Considerations (Why Marx?)

- Cost
  - Modular design simplifies fabrication
  - Active droop compensation reduced energy storage
  - Eliminate high voltage 1.6 ms-pulse transformer
- Reliability
  - Solid-state is intrinsically long-life
  - High Availability (HA) architecture: allows system MTBF to exceed component MTBF
    - Redundant, modular design
    - Intelligent control

Design Considerations (Why Marx?)

- Serviceability
  - Modularity reduces spare inventory and simplifies service
  - Intelligent control identifies eminent repairs and specific faults
  - Accessibility minimizes MTTR
- Performance
  - Active output regulation, compensate load variation
  - Eliminating transformer increases energy efficiency

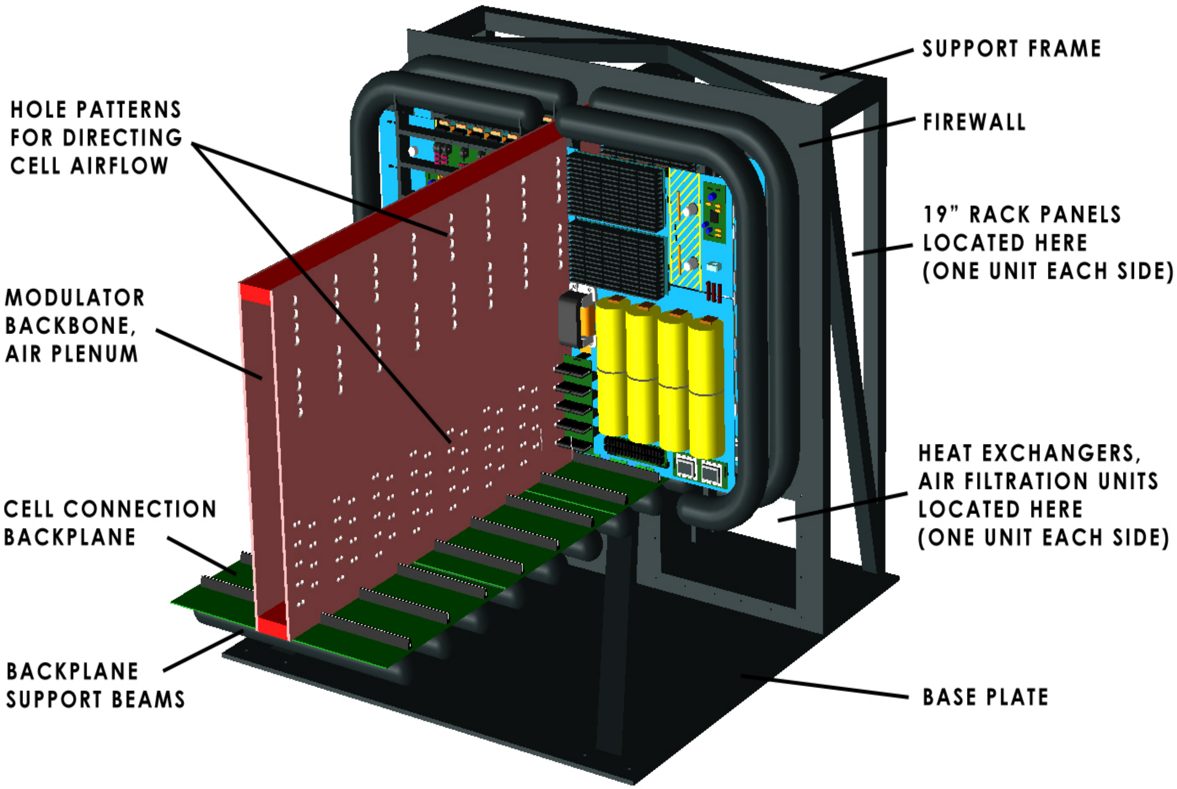
US-DOE Funded ILC Marx Modulators

	SLAC P1	Diversified Technologies	ISA Corp.	SLAC P2
Cell Voltage	11 kV	6 kV	3.5 kV	3.75 kV
Number of Cells	16 (11 prompt) (5 delay)	20	42 (35 prompt) (7 delay)	32
Redundancy	N+1	N+3	N+1	N+2
Regulation	Vernier (16) 1.2 kV + Delay	(16) 0.9 kV Correction cells	Vernier (16) 0.5 kV + Delay	Regulated cell (PWM correction)
Status	Extended life testing	→ SLAC for life testing	"Finished" full voltage, no correction	Testing prototype cell, complete FY11

SLAC P1-Marx

- 1st Generation SLAC Design for ILC Application
- Demonstrated Efficacy of the Marx for ILC
  - Active output regulation
  - HA features
  - 93% efficiency (modulator losses 7%)
- Undergoing Extended Life Testing

P1-Marx Construction



MARX MODULATOR -- STRUCTURAL DETAIL

P1 Main Cell Construction

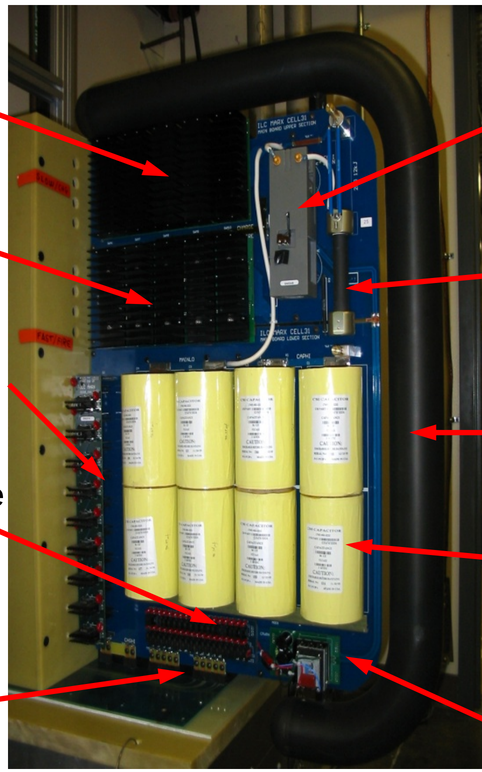
5 Charging SW Modules

5 Firing SW Modules

Charge Diode String

Bypass Diode String

Connector Group to Backplane



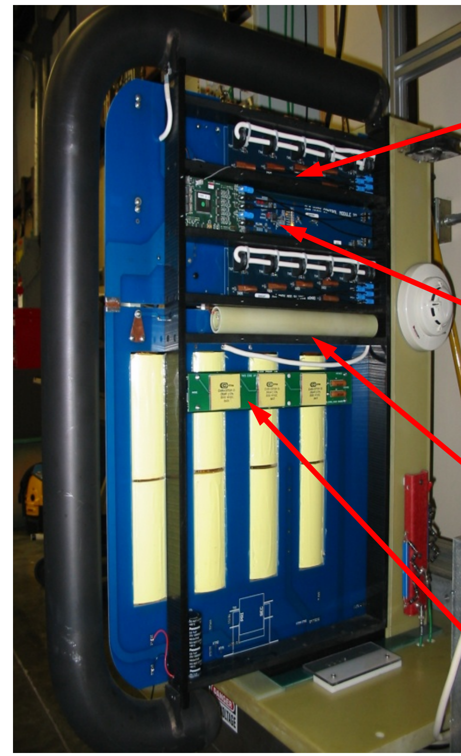
Cell Grounding Relay

Cap. Discharging Resistor

Equipotential Ring

Energy Storage Capacitors

Control Power Converters



11kV Isolated Power/Trigger Boards

Cell Control Module

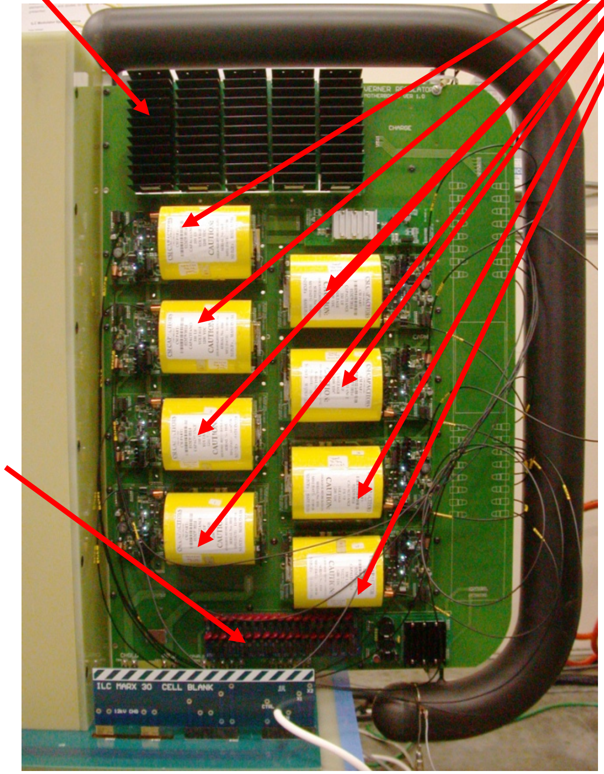
dI/dt Limiting Inductor

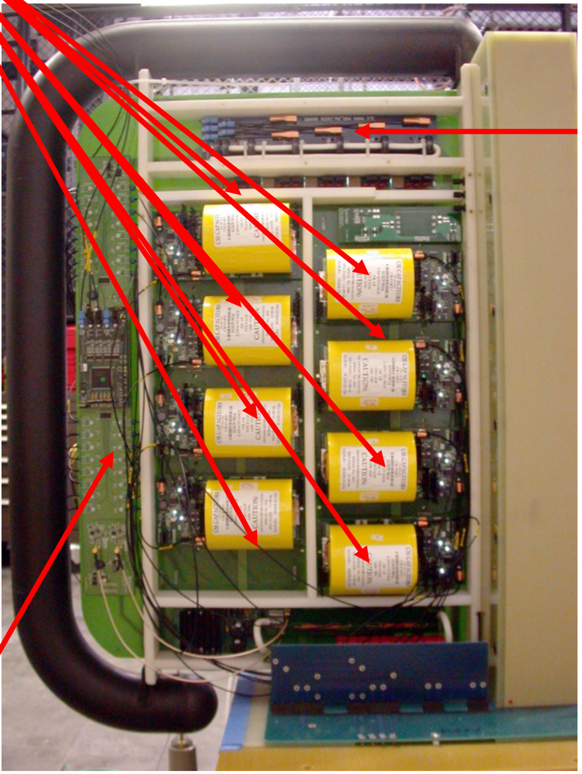
Charge Isolation Diode String

P1 Vernier Cell Construction

Charging IGBT Module X 5 ea (by-pass for main Marx)

Vernier cells (16)



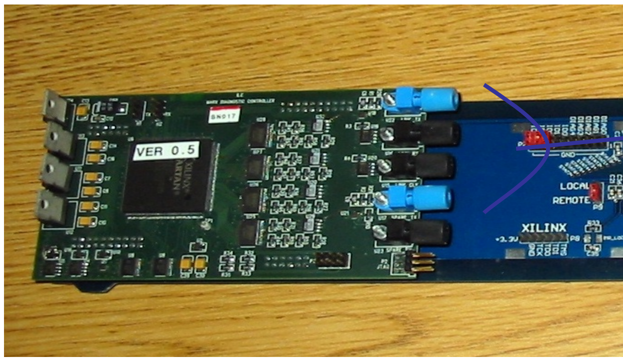


Charging Module - Control and Power Isolation

Forward Diode String (by-pass for main Marx)

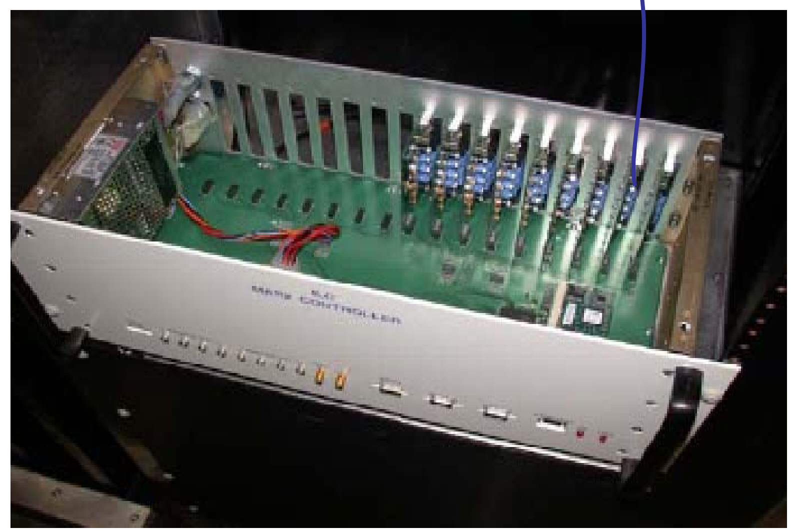
Control board

P1 Control System



CPLD-based Cell Diagnostic & Control Module

Fiber Optic Timing & Data Links



16-Channel FPGA-based Control System IOC

EPICS-based Modulator Control Interface

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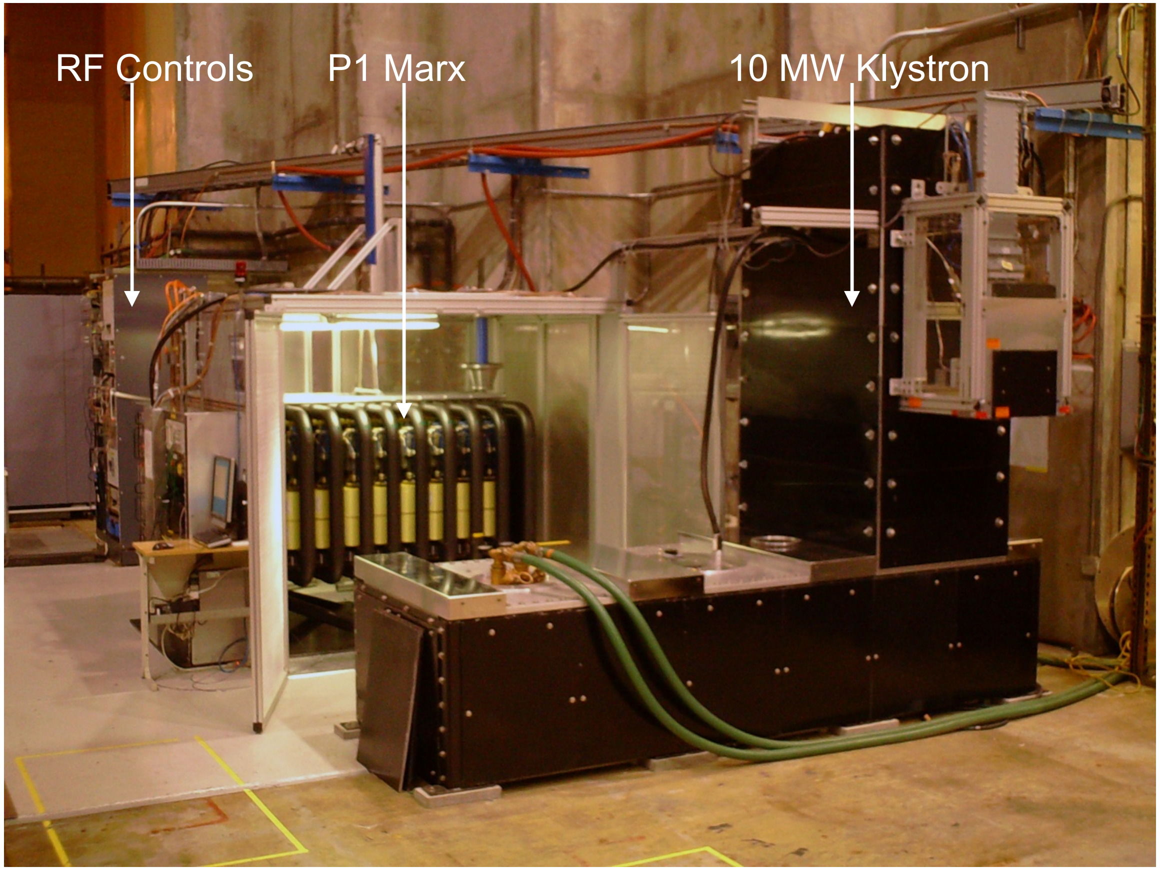
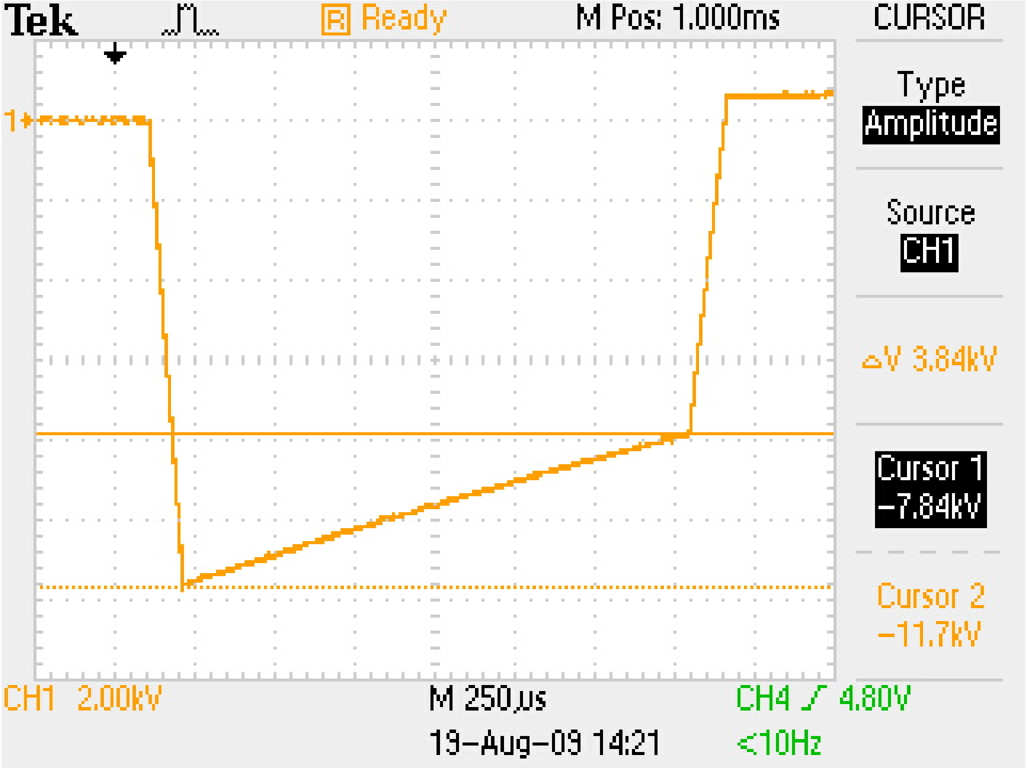
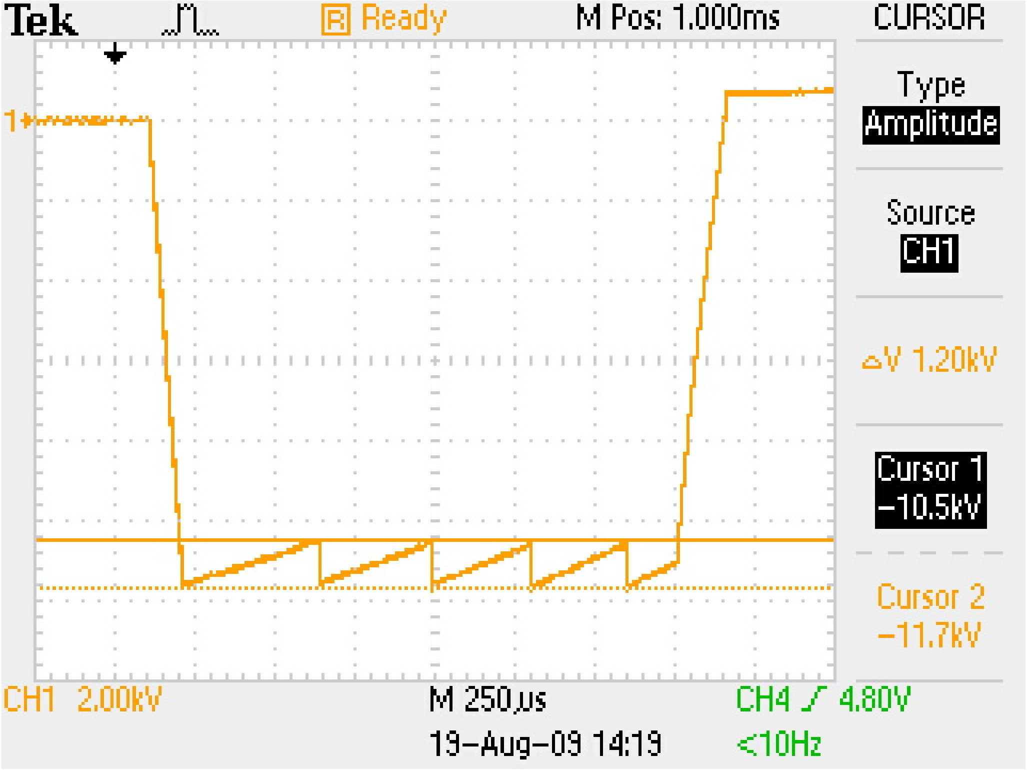
L-Band Test Stand



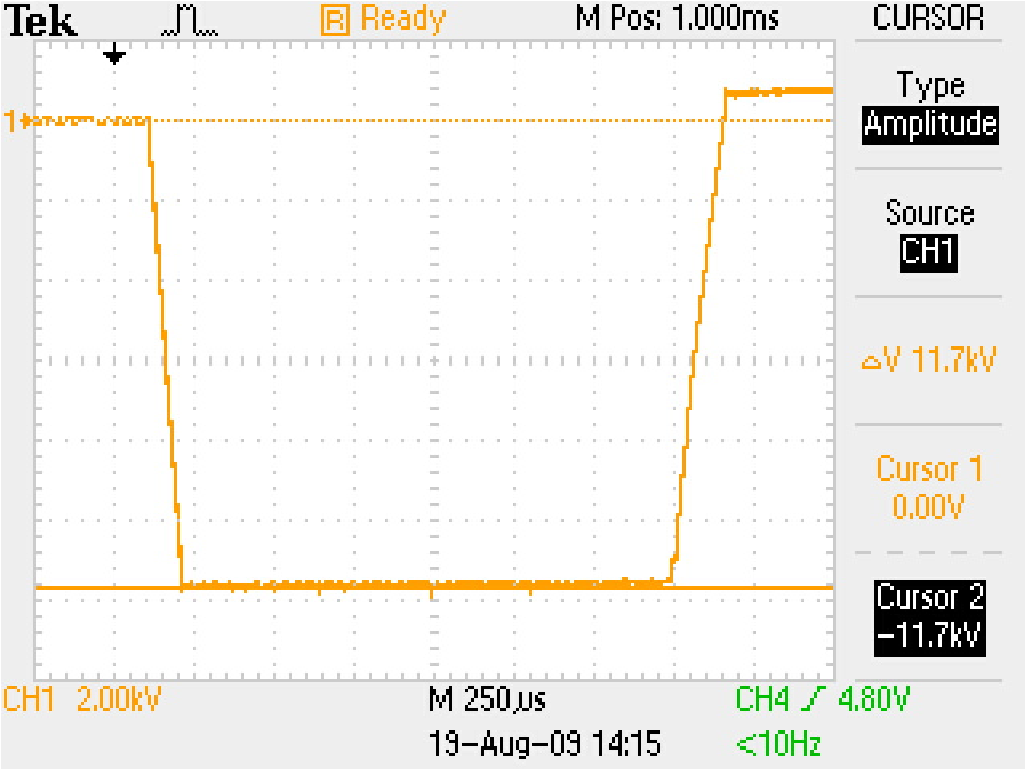
P1 Operation: Prompt-Main Cells Only



P1 Operation: Main Cells, Prompt+Delay

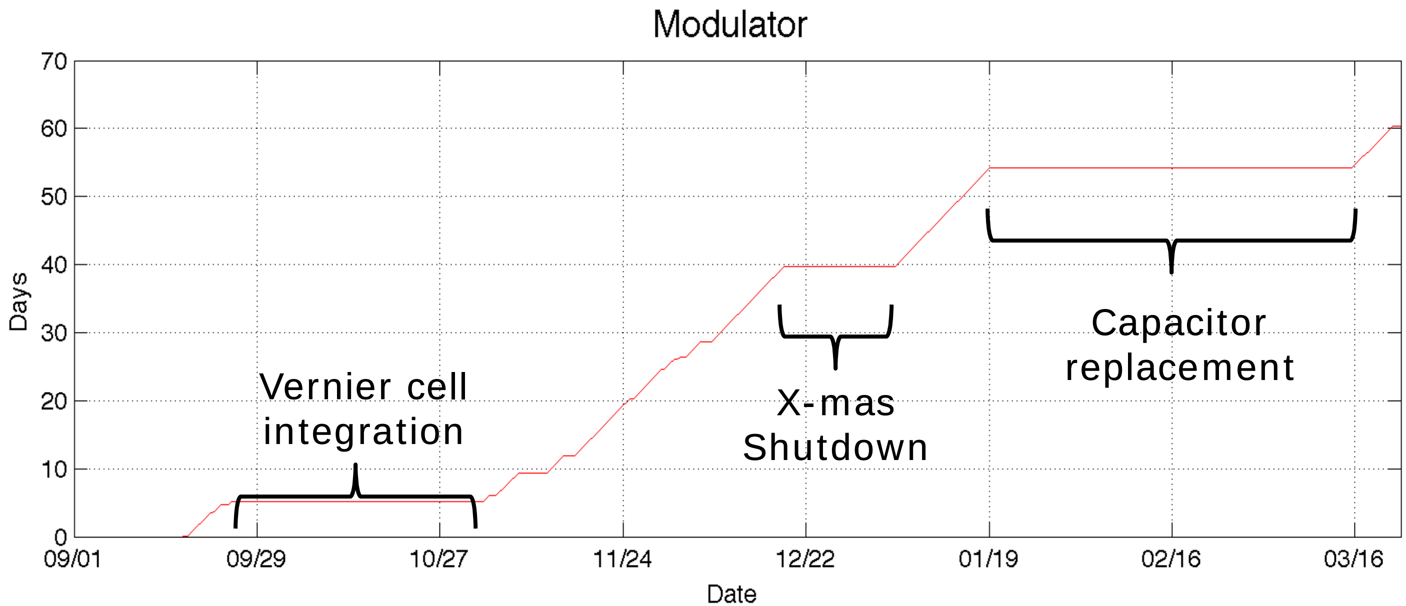


P1 Operation: Full Vernier Regulation



P1 Operational History

- 1450 hours (60 days) integrated operation with klystron [additional ~400 hours with test load]
- Maintenance downtime: replace energy storage capacitors damaged by improper voltage grading



SLAC P2-Marx

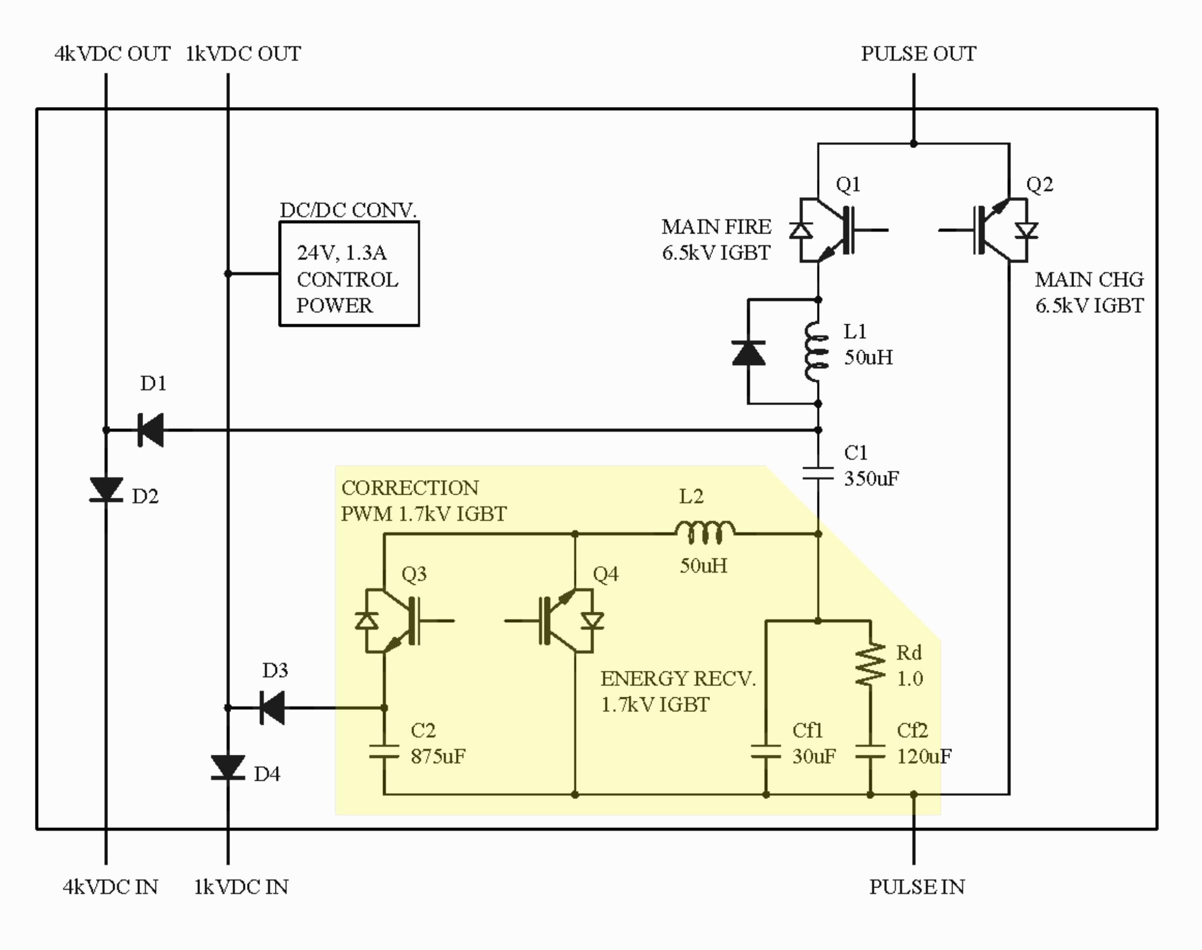
- 2nd Generation Design Builds on P1 Experience and Success
- Prototype Cell Undergoing Testing
- Expected Completion in FY11

Design Evolution to the P2-Marx

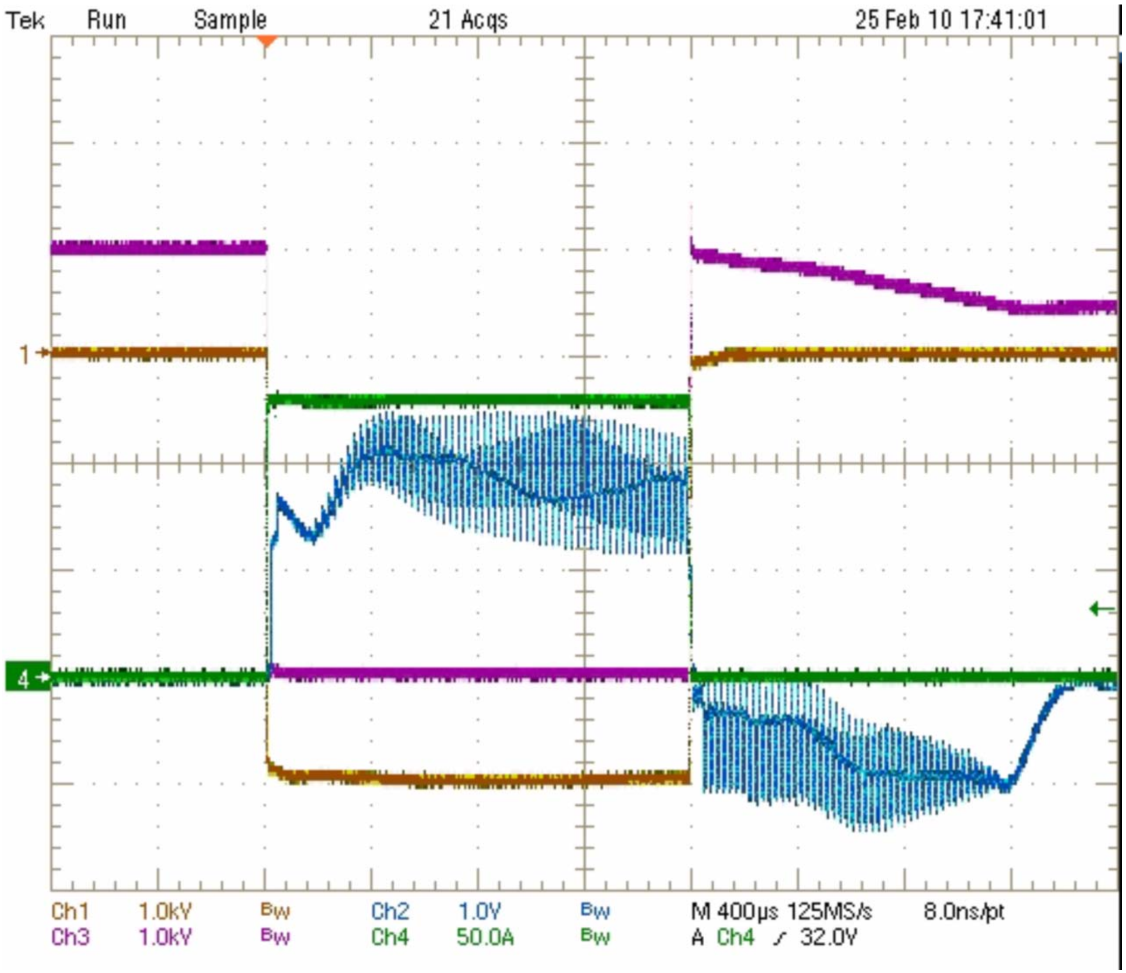
- Improved HA architecture
  - Truly modular topology; single repeated cell design
  - Droop compensation (via PWM) integrated into each cell
  - Cells fail to by-pass mode
  - 4 kV cell voltage eliminates series switch arrays
  - Enhanced control system with increased diagnostic and prognostic capabilities
- Engineering refinements
  - Reliability evaluation: 10^5 hour life
    - Voltage margin on silicon
    - Capacitor energy density
  - Decreased overall size by ~20%

P2 Cell: Simplified Schematic

- Basic cell circuit similar to P1
- Correction circuit (shaded) PWM compensates droop as C1 discharges
- Output=∑C1+Cf1
  = constant



P2 Output Voltage Regulation

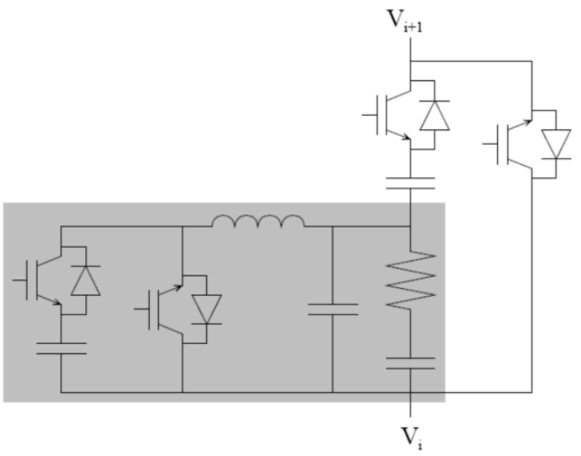


Cell Output Current

Cell Output Voltage

Main IGBT V_{ce}

PWM Inductor Current



P2 Cell Control System

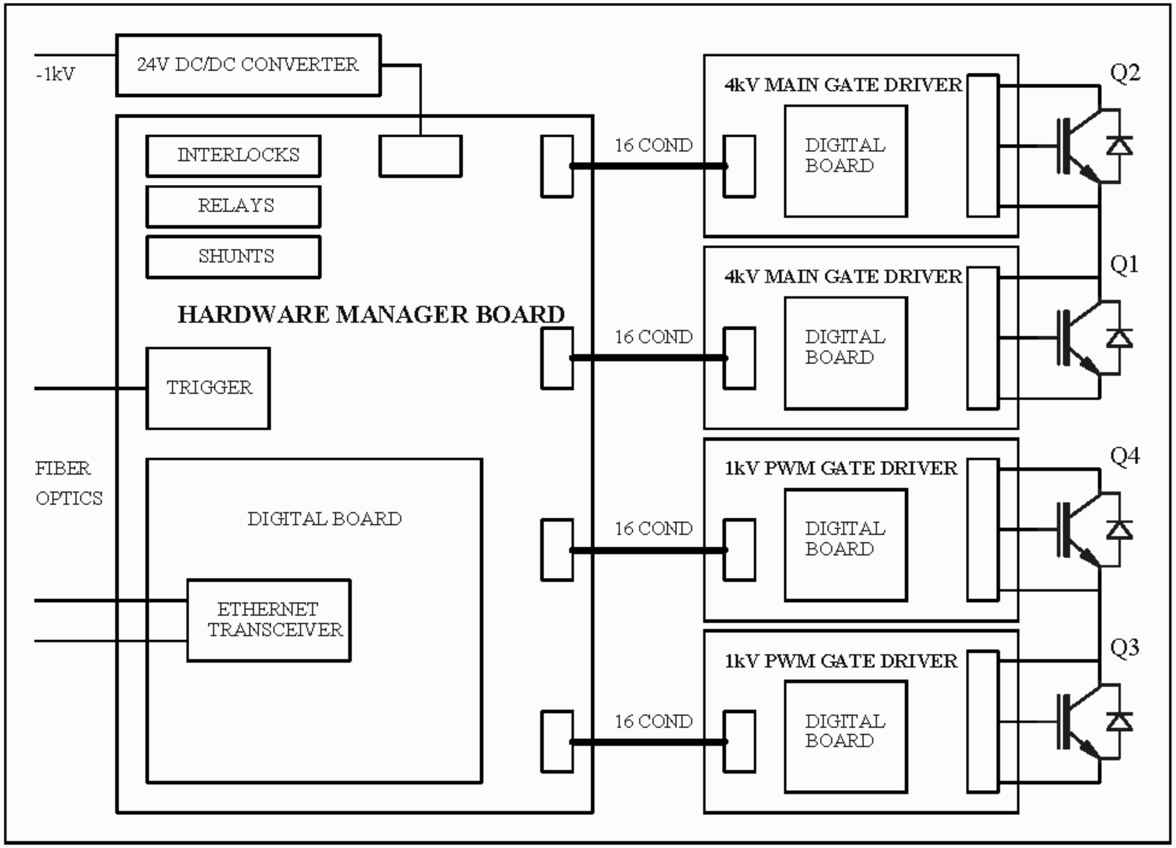
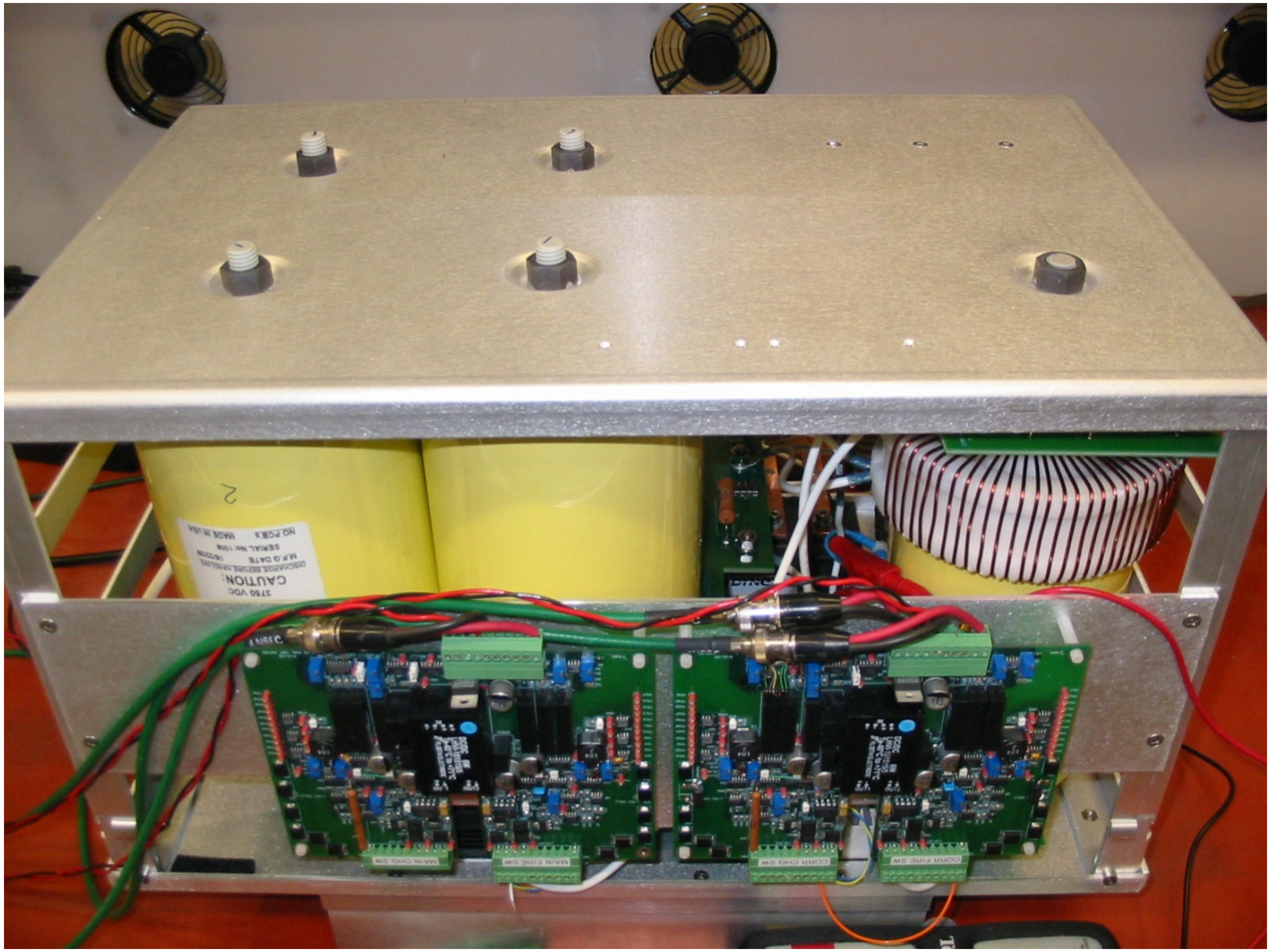
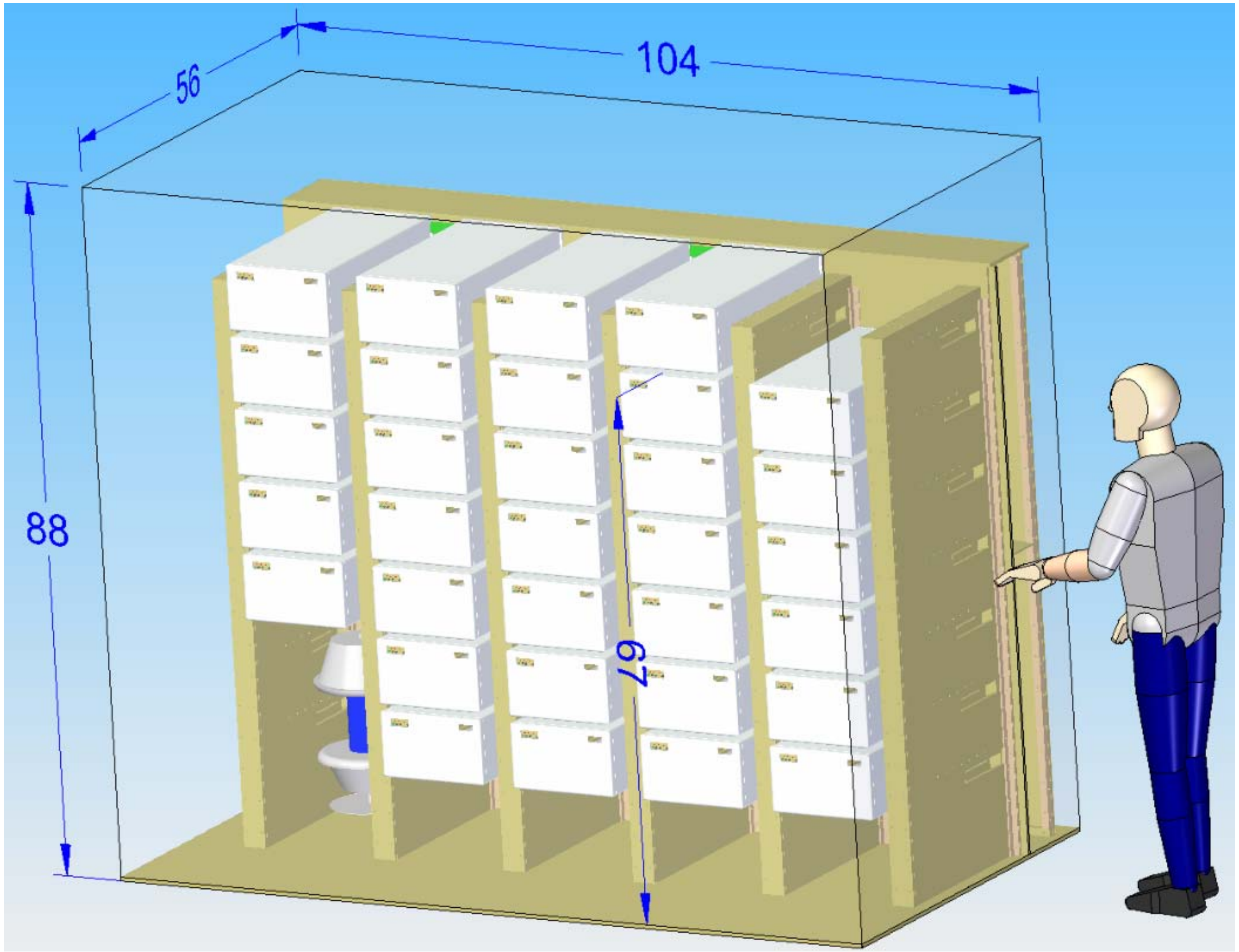


Photo of P2 Cell



Conceptual Design of P2-Marx



Summary

- Performance improvements achieved with solid-state modulators offsets increased development costs for a broad range of applications
- 1st generation modulator validates benefits of Marx topology for ILC application
- Subsequent generations of solid-state modulators will deliver enhanced performance with improved sustainability

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