DIVERSIFIED TECHNOLOGIES, INC.®

Thyratron Replacement

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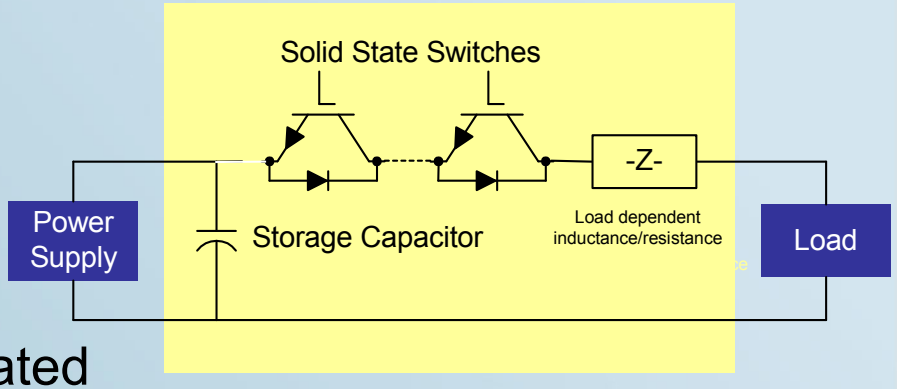
Diversified Technologies, Inc.

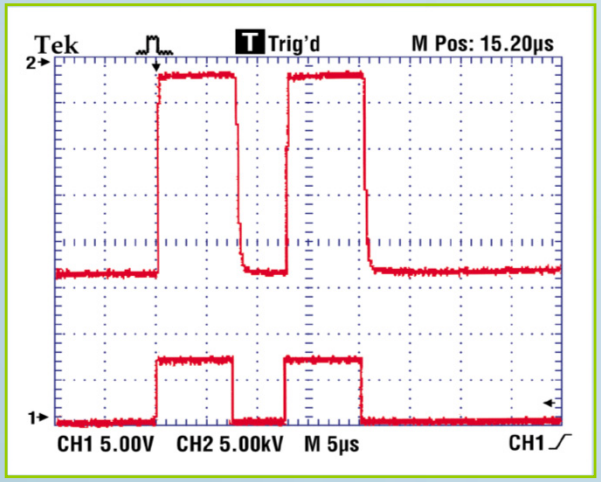
- Founded 1987 by Dr. Marcel Gaudreau (MIT)
  - 44 Employees
  - 4 PhDs (EE, Physics, Aero)
  - Diverse Technical Background
- Primary Business Areas:
  - High Power Electronic Systems
  - System Design and Integration
  - Manufacturing/Process Automation Systems
  - Consulting Engineering
- PowerMod™ Series
  - Solid State Modulators, Power Supplies
  - Two Time R&D 100 Award Winner
  - Multiple Patents

Solid-State Switching

- Series String of Transistors
  - All Operate Synchronously
  - Patented Design
- Very High Voltage & Current Demonstrated
  - Up to 500 kV (500,000 Volts)
  - Up to 20 kA (20,000 Amperes)
- Extremely Uniform & Reliable Pulses
  - Sub-Microsecond Switching
  - Arbitrary Pulsewidth & Frequency
  - 1 ns – CW; > 300 kHZ Continuous

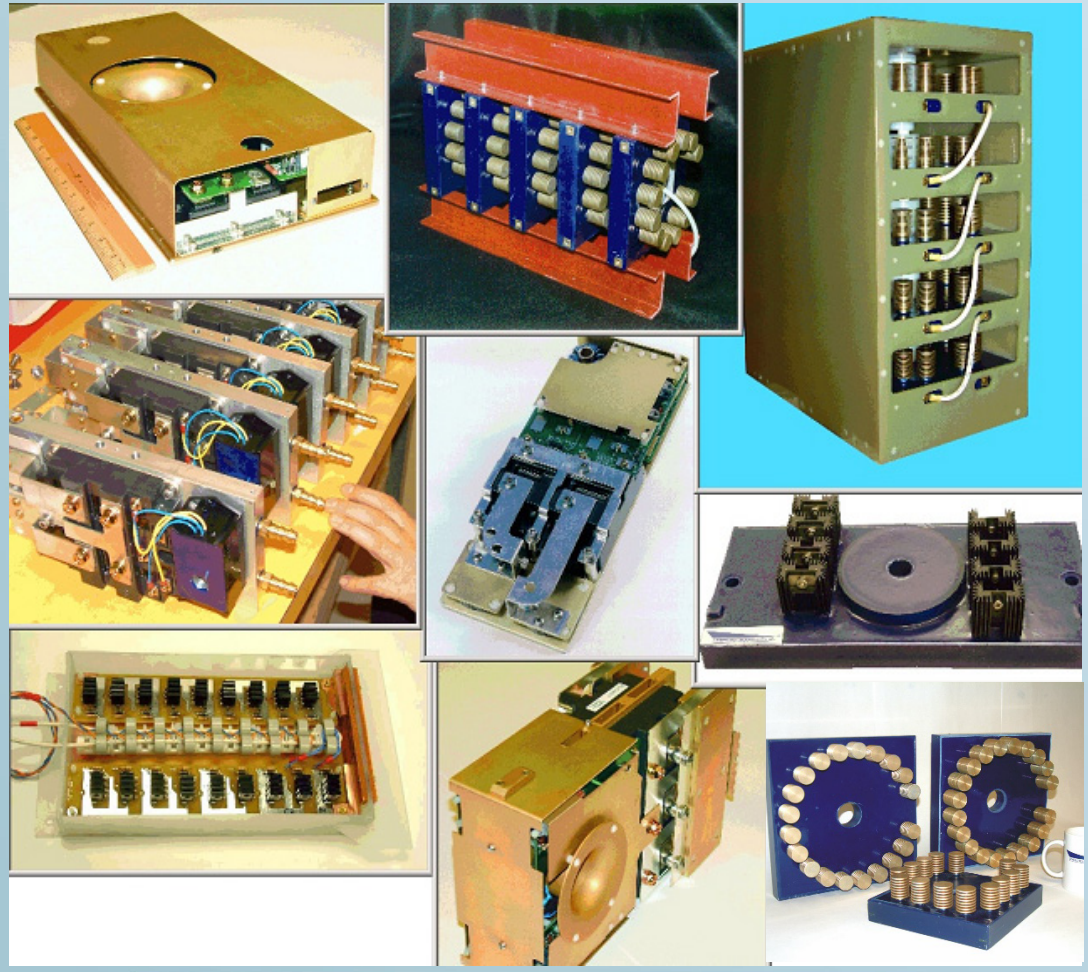


DTI's PowerMod™ Model



DTI's Core Technology

Product Examples



SBIR – Thyratron Replacement

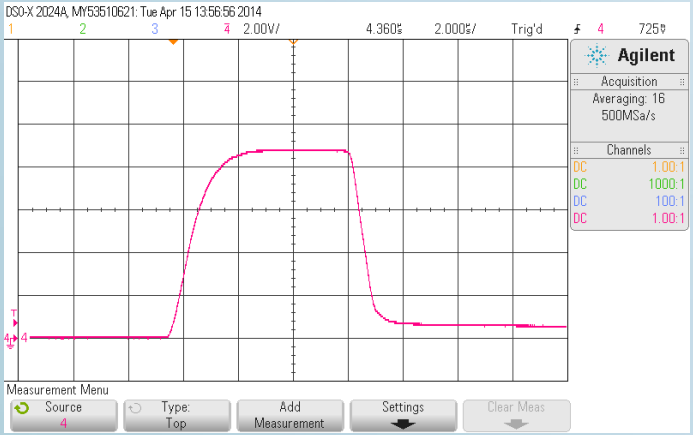
- Stanford Linear Collider Has 83 Modulators
- Requirements
  - 360 kV, 420 A
  - 3.7 μs, 180 Hz
- Existing Design
  - Thyratron / PFN / XFMR
  - Operating Since 1963, Expected to Operate Until 2035+
  - Cost of Thyratrons Rising / Availability Decreasing

This Effort Was Funded under DOE SBIR Grant DE-SC0011292

Options

- Hybrid Modulator
  - Solid State Hard Switch / Pulse Transformer
  - Very Similar to Daresbury Laboratory CLARA Modulator
    - 350 kV, 375 A
    - 3 μs, 400 Hz
  - Cost ~ $1M Per System (~ $80M)
- Replace Thyratron Only
  - Retain HVPS, PFN, Pulse Transformer
  - Cost < $50k Per System (~ $4M)

Daresbury CLARA Modulator



Switch Requirements

- Hybrid Modulator
  - Switch Rated at 40 kV, 4 kA
  - Opens and Closes
  - Peak Fault Current ~ 8 kA, < 1 μs
- Thyratron Replacement
  - 48 kV, 6 kA
  - Closing Only
  - Peak Fault Current 19 kA, 6 μs

SBIR - Thyratron Replacement

- SBIR Topic – Affordable, Solid State Replacement
  - Reliability > 20 Years
  - Cost << $100k; Goal is 2 - 3X Thyratron Cost
  - Savings > $1M/Year over 20 Years
- Thyratron Replacement Switch in Development Now
  - Phase I: Awarded 2/14, 9 Months
  - Phase II: Awarded 4/15, 24 Months
- Goal is to Install and Test Prototype at SLAC In 2016

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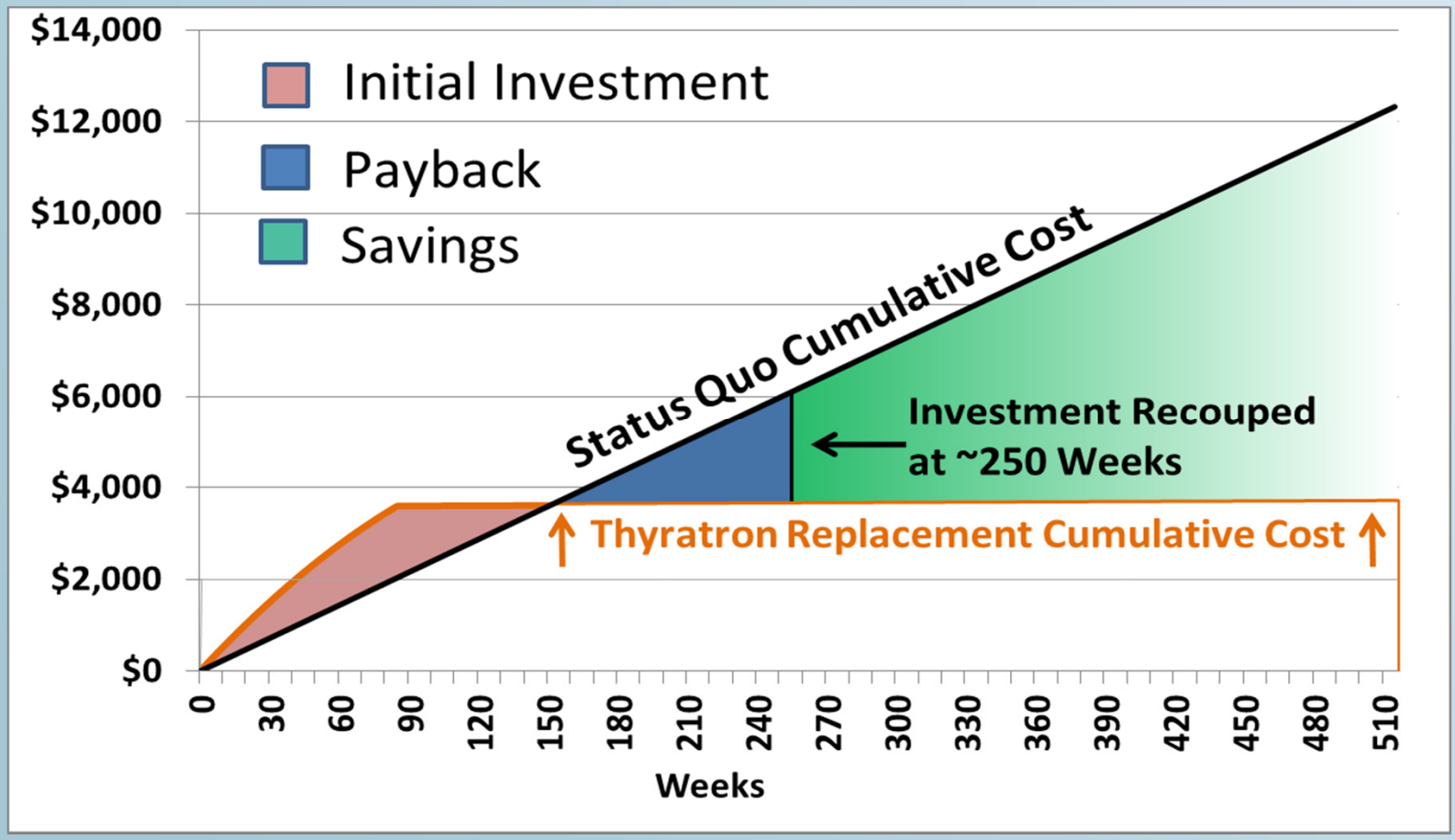
SLAC Modulators

Motivations for Replacement

- Thyratrons Rated For 10,000 Hours; Longer Is Desirable
- Heater Voltage Requires Adjustment Over Lifetime
- Jitter Is 5 Ns; Lower Is Desirable
- Significant Manpower Required for Thyratron Maintenance and Replacement

Cost Motivation



SLAC Requirements

- 48 kV
- 6.3 kA
- 6 μs pulsewidth
- 1 μs rise
- 10 A/μs
- 120 Hz

- Survive klystron short (1 / month)
  - 13 kA, 10 A/ns

- Survive cable short (1 / 5 years)
  - 19 kA, 73 A/ns

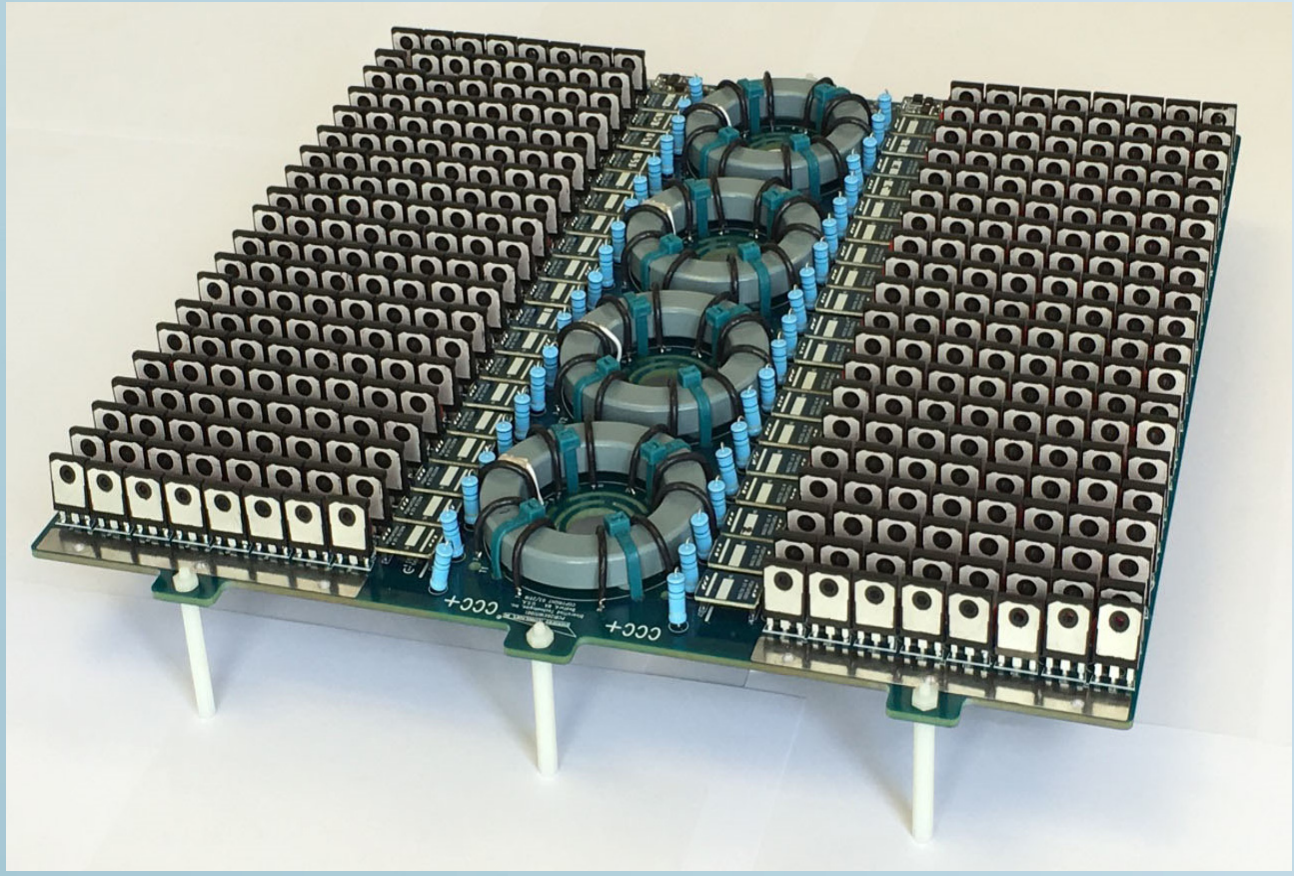
SLAC Requirements (2)

- < 2 nS Total Jitter Spread
  - Thyratron Jitter 5 – 10 nS.
- Fit In Existing Thyratron Cabinet
- Cost-effective Compared To ~ $15 K Thyratrons
  - Minimize Number Of Devices ⇒ Max Current, Voltage Per Device

Technical Approach

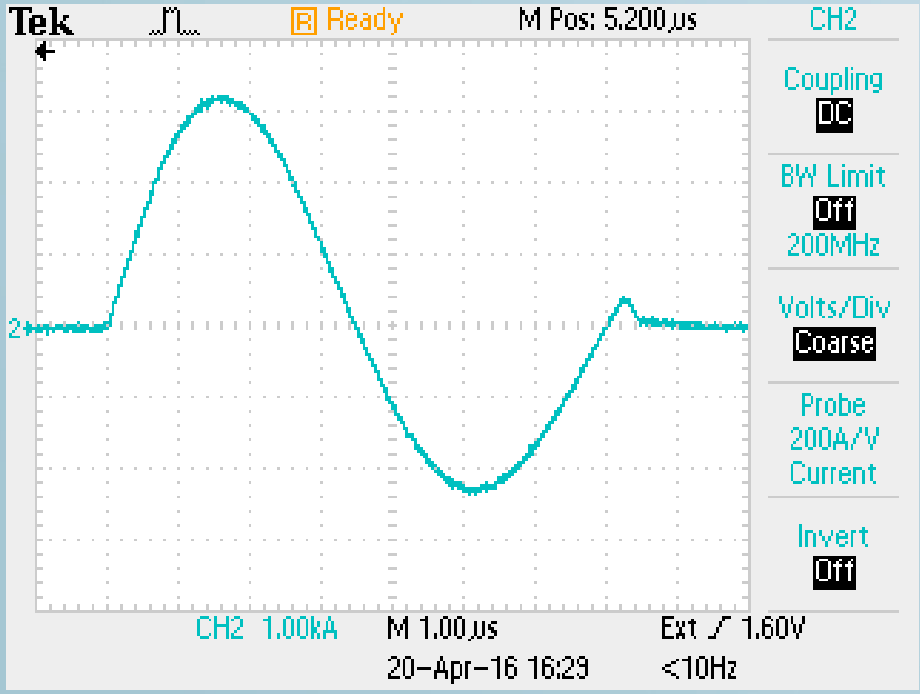
- Large Array Of IGBTs
  - Can Handle dI/dt, Unlike Thyristors
- Series Connected For Voltage
  - DTI Core Technology
- Parallel Connected For Current
- TO-247 Packages For Low Cost
  - Modules More Expensive
- Oil Cooled For Compactness

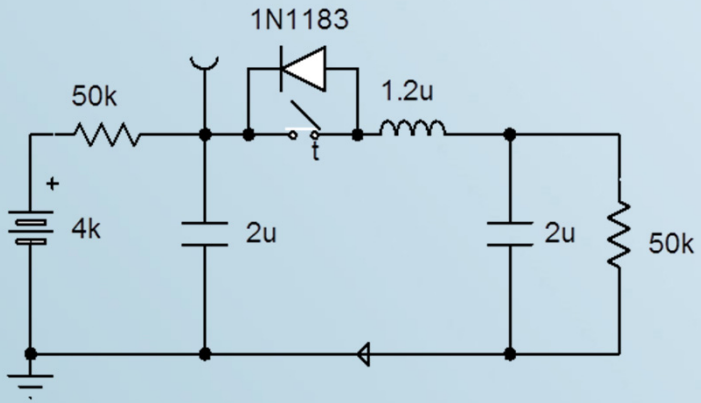
Switch Plate: 8 kV, 3.2 kA



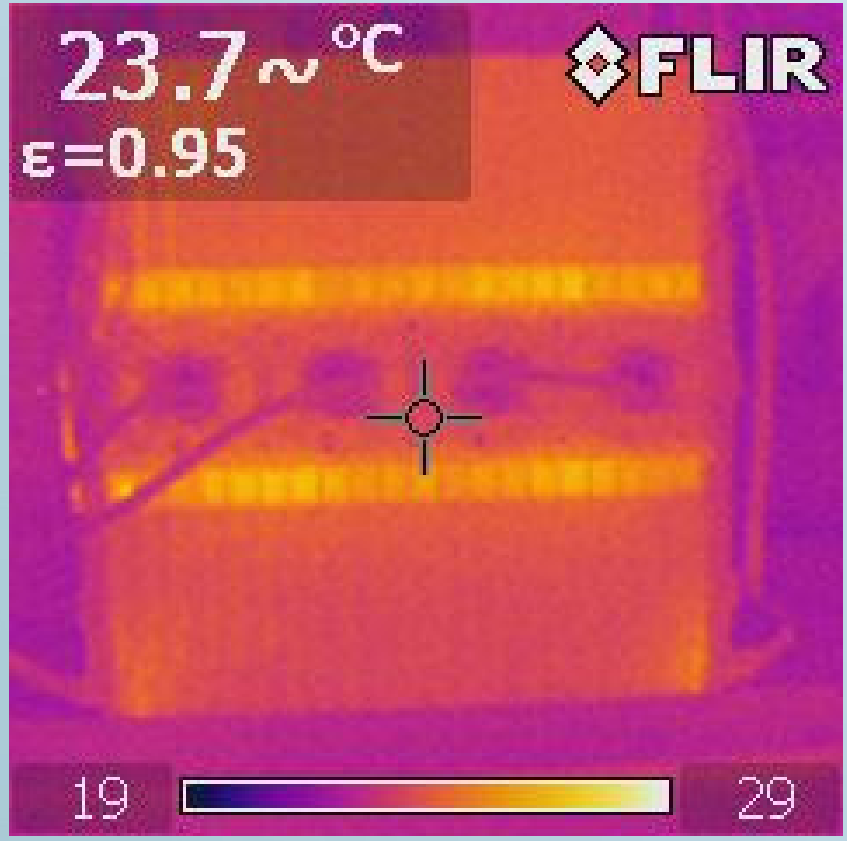
- 20 Devices in Series x 16 Devices in Parallel

Plate Test at 4 kV, 3.2 kA



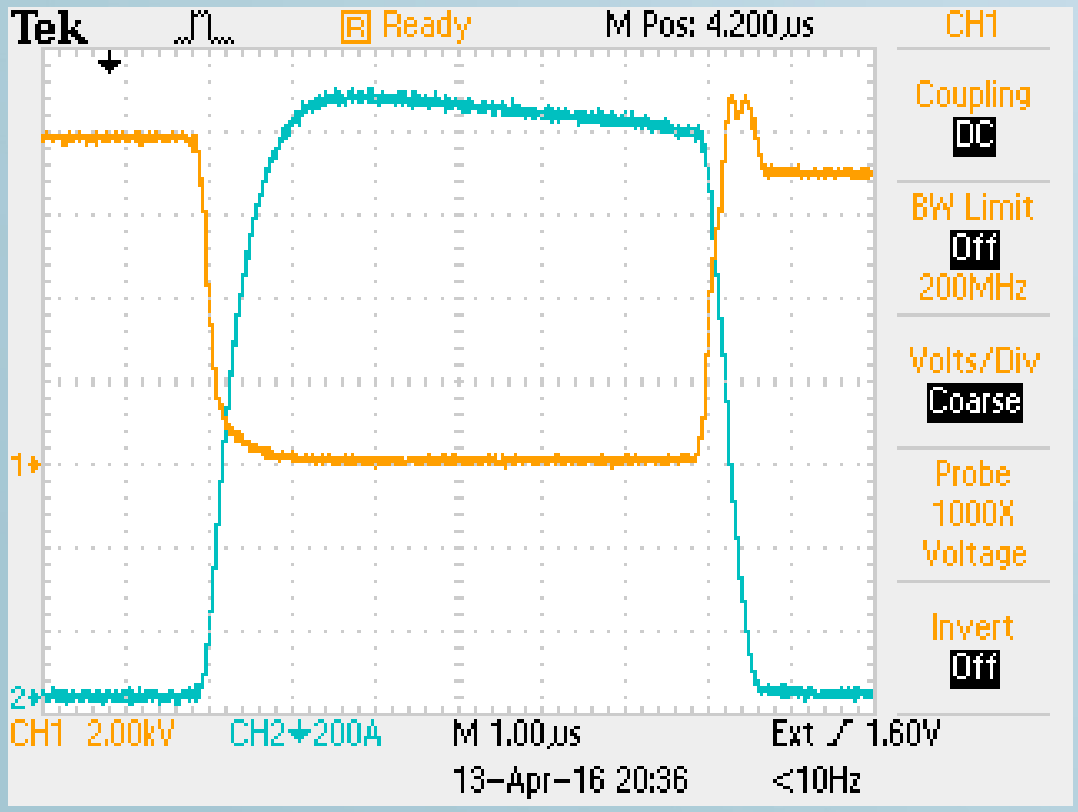


Thermal Imaging



- No Hot Spots – Gate Drives are Warmer than IGBTs
- Excellent Current Sharing

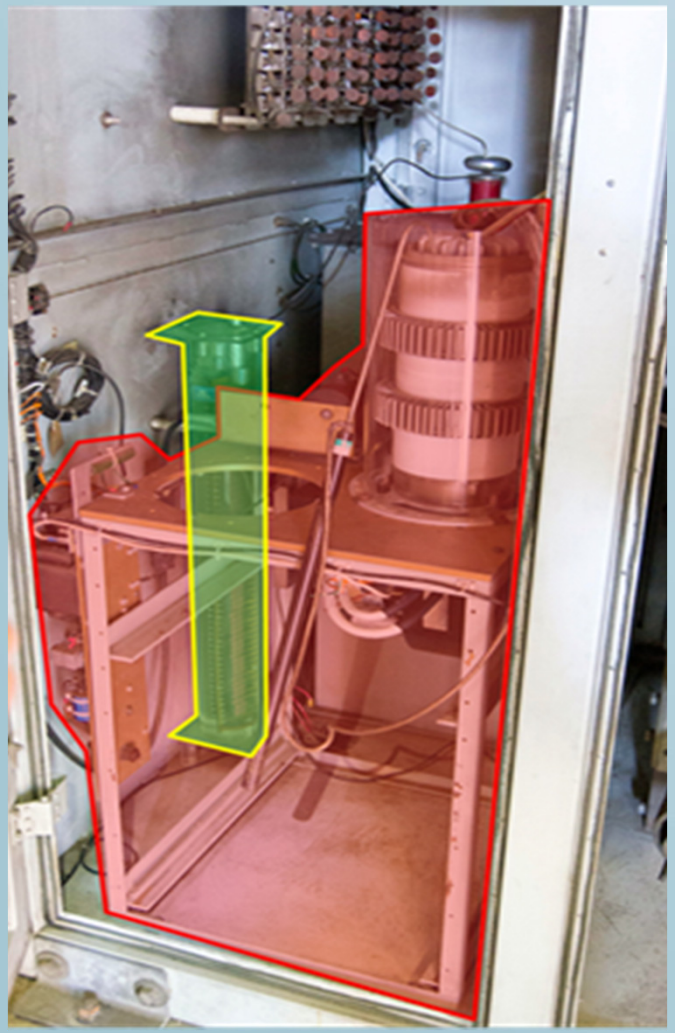
Plate Test at 8 kV, 1.8 kA

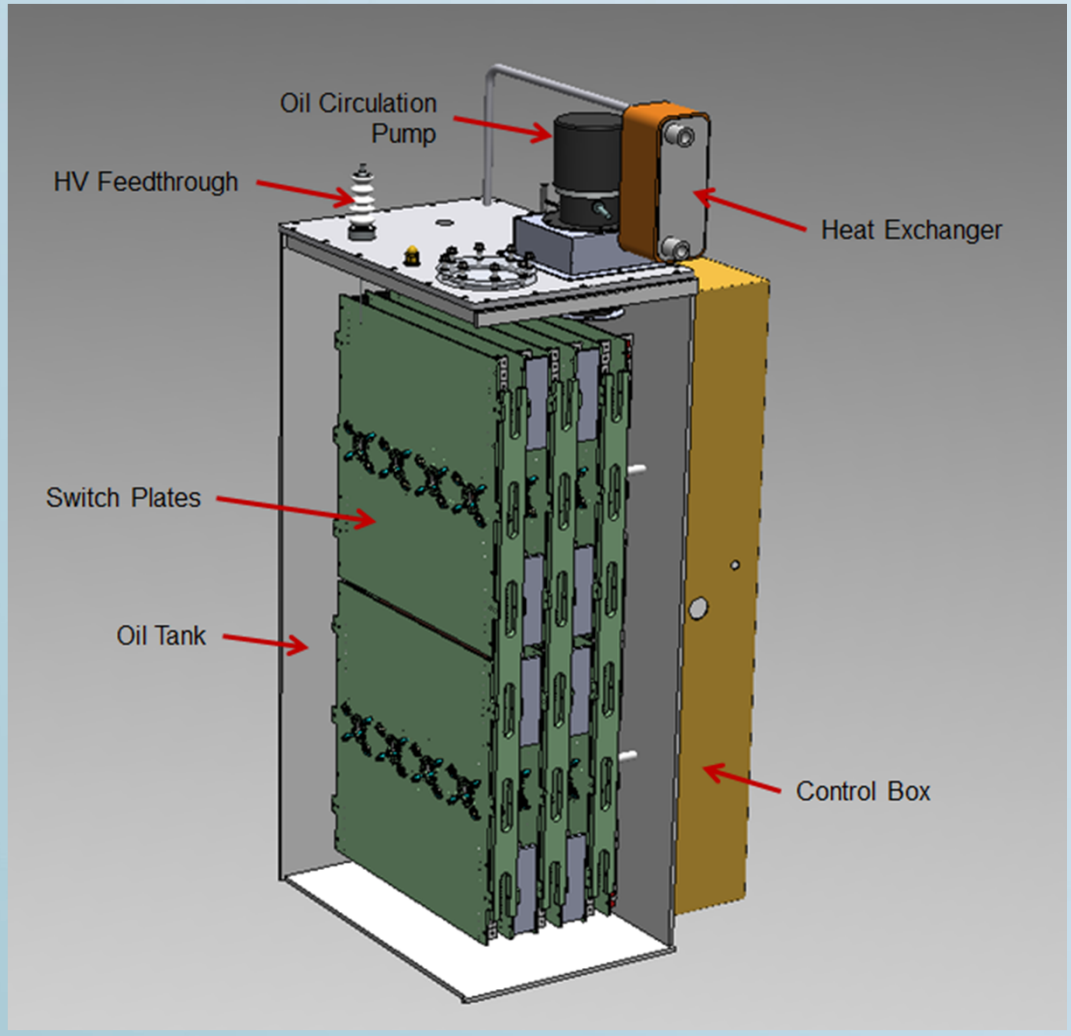


- Switch Closes and Opens (Conventional Hard Switch)
- Opening Not Required for SLAC – Higher Stress on IGBTs

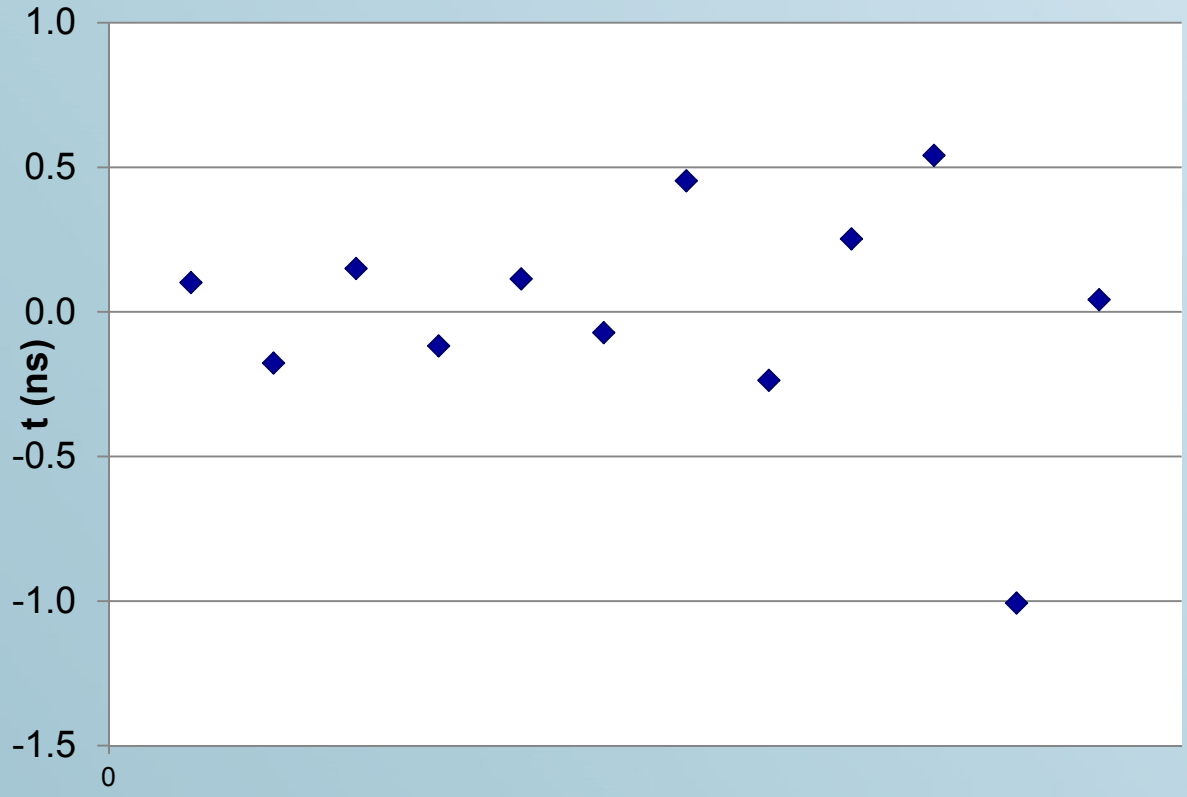
(Yellow) Voltage 2 kV/div (Blue) Current 200 A/div

Mechanical Design





Total Jitter Spread: 1.5 ns



Test used single devices
Thyratrons: 5 – 10 ns

Summary

- Solid State Switch Provides Cost Effective Thyratron Replacement
- Design Status
  - Electrical Design Complete
  - Plate Testing Complete
  - Mechanical Design Complete
- Prototype Construction Underway
- Initial Installation at SLAC Late Summer 2016

Thank You

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