DIVERSIFIED TECHNOLOGIES, INC.®

Solid State Thyratron Replacement

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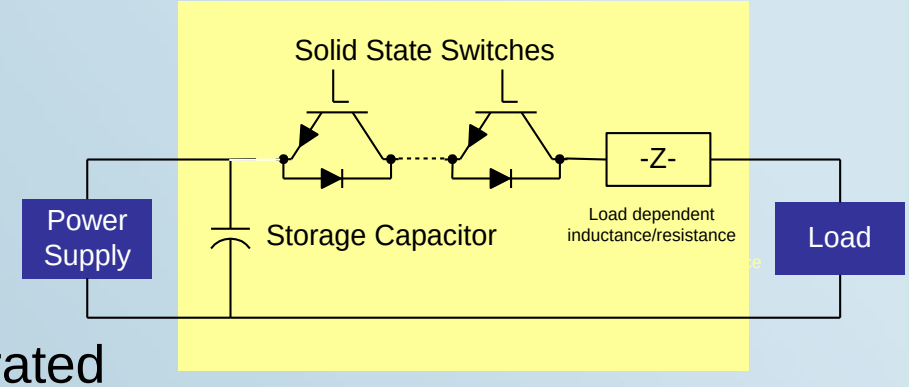
Diversified Technologies, Inc., Bedford, MA USA

Diversified Technologies, Inc.

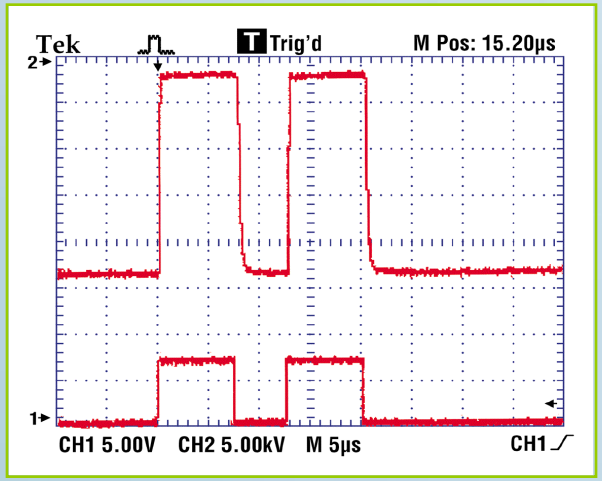
- Founded 1987 by Dr. Marcel Gaudreau (MIT)
  - 65 Employees
  - 6 PhDs (EE, Physics, Aero)
  - Diverse Technical Background
- Primary Business Areas:
  - High Power Electronic Systems
  - System Design and Integration
  - Manufacturing/Process Automation Systems
  - Consulting Engineering
- PowerMod™ Series
  - Solid State Pulse Modulators
  - High Voltage Power Supplies
  - RF Transmitters

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
  - Thyratron / PFN / XFMR
  - Operating Since 1963, Expected to Operate Until 2035+
  - Cost of Thyratrons Rising / Availability Decreasing

SBIR - Thyratron Replacement

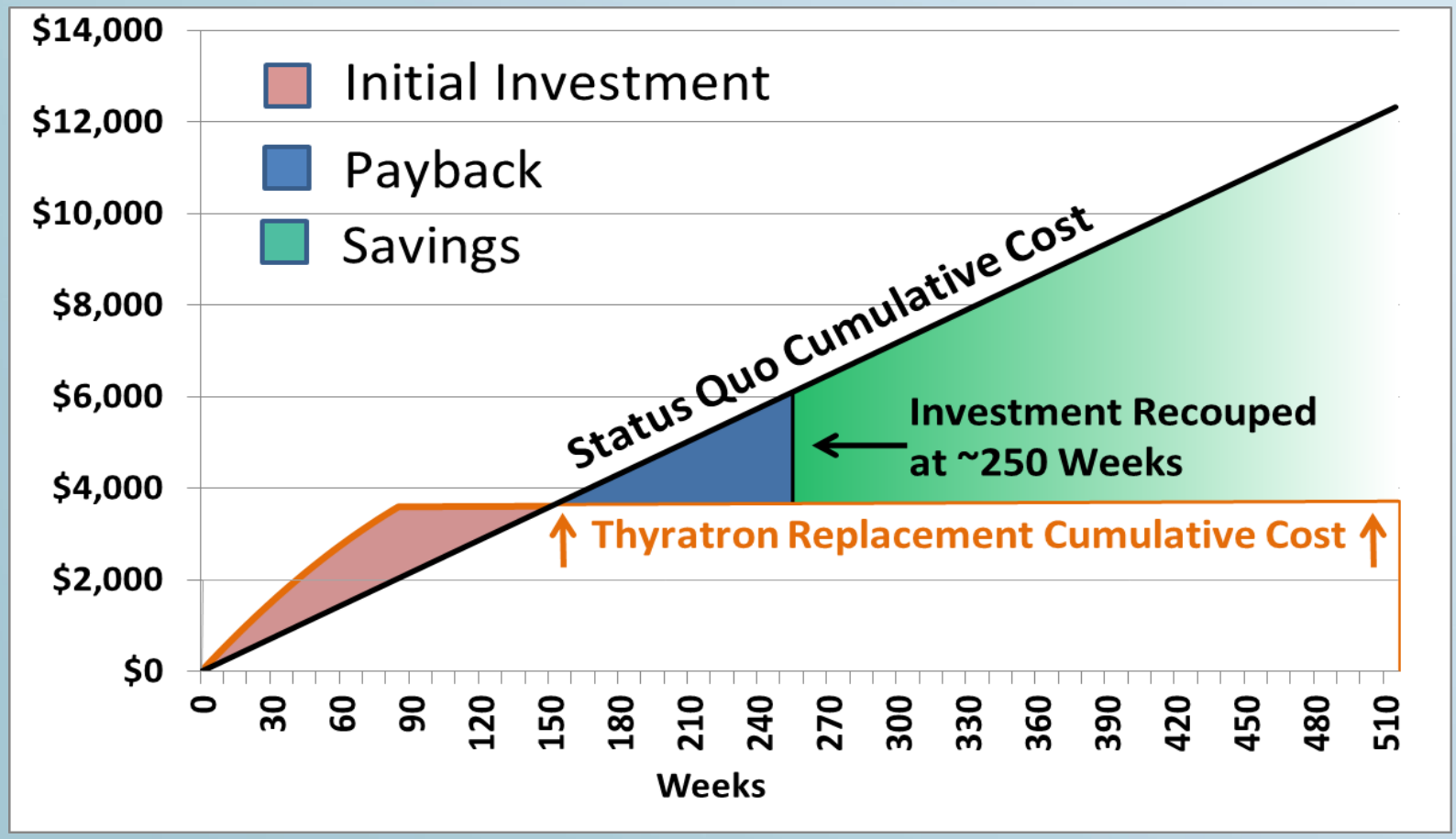
- SBIR Goals – Affordable, Solid State Replacement
  - Reliability > 20 Years
  - Cost << $100k; Goal is 2 - 3X Thyratron Cost (< $40k)
  - Savings > $1M/Year over 20 Years
- Motivation
  - Thyratrons Rated For Only 10,000 Hours
  - Heater Voltage Requires Adjustment Over Lifetime
  - Jitter Is 5 ns; Lowering Jitter Improves Stability
  - Significant Manpower Required for Thyratron Maintenance and Replacement
- Objective: Install and Demonstrate Prototype at SLAC

This Effort Was Funded under DOE SBIR Grant DE-SC0011292

SLAC Requirements

- 48 kV, 6.3 kA
- 6 µs pulsewidth
- 1 µs rise
- 120 Hz
- Survive klystron short (1 / month)
  - 13 kA, 10 A/ns
- Survive cable short (1 / 5 years)
  - 19 kA, 73 A/ns
- < 2 ns Total Jitter Spread
  - Thyratron Jitter 5 – 10 ns
- Fit In Existing Thyratron Cabinet
- Cost-effective Compared To ~ $15 K Thyratrons
  - Goal: < $40k To Build in Quantity

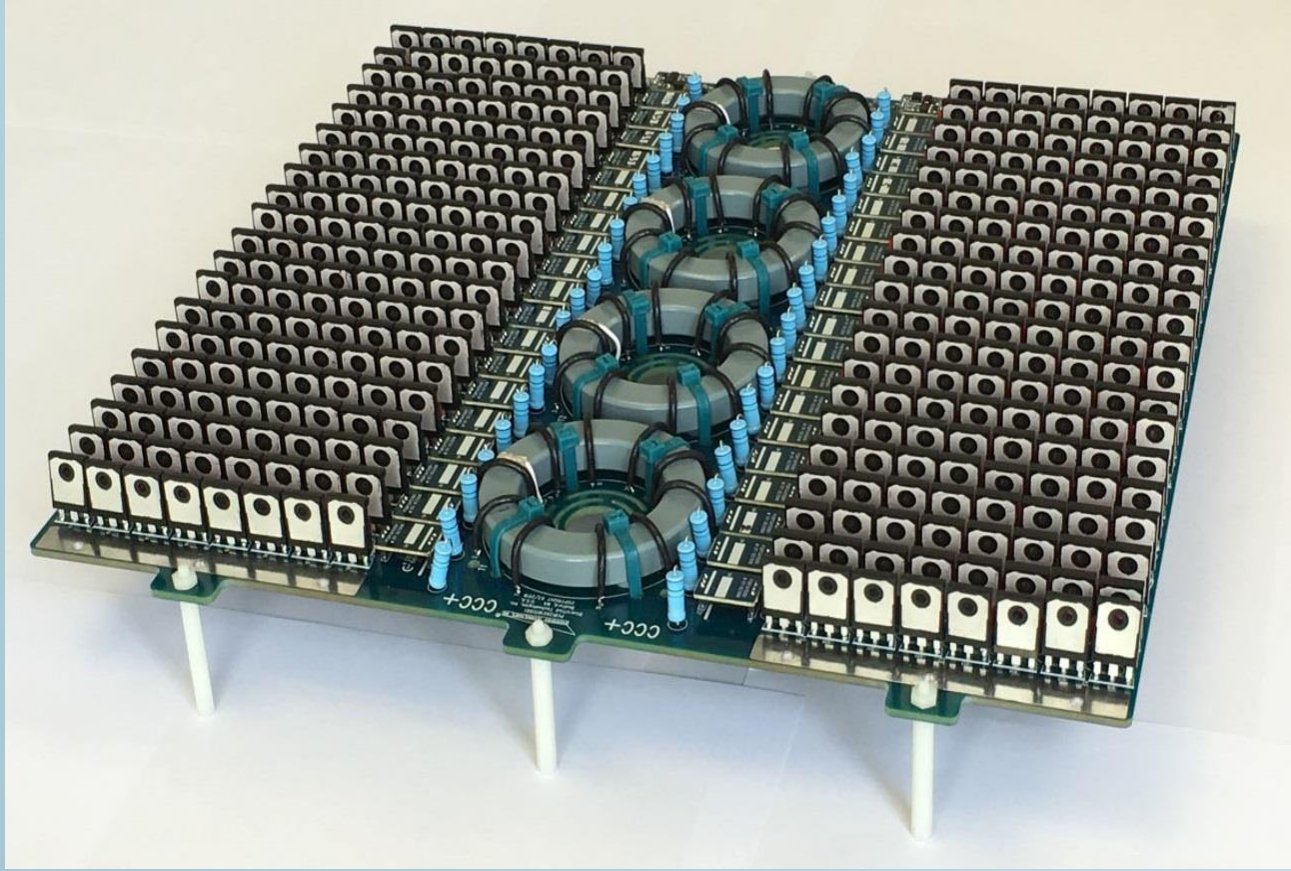
Cost Motivation



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

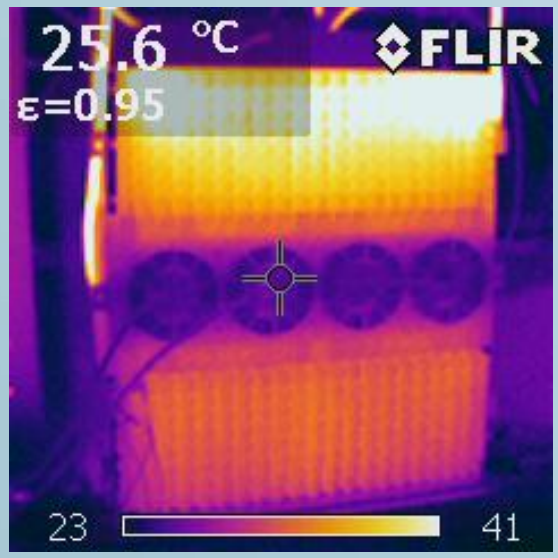


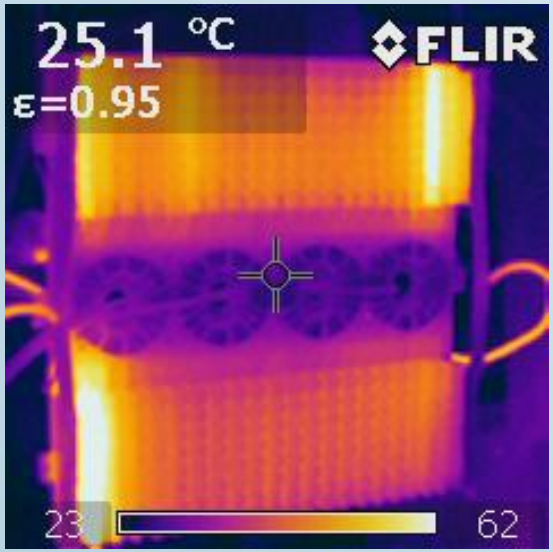
- 20 Devices in Series x 16 Devices in Parallel

Technical Issues Encountered

- dI/dt Capability of Commercial IGBTs
  - Required Additional Devices to Meet Speed Specifications
  - 3480 vs 2880 IGBTs Original Plan (1/3 More)
- Uneven Current Sharing
  - Board Layout Critical
  - Current Paths Between Rows Very Sensitive
  - Board Construction

Uneven IGBT Heating





Even Current Sharing

- Two plates visible

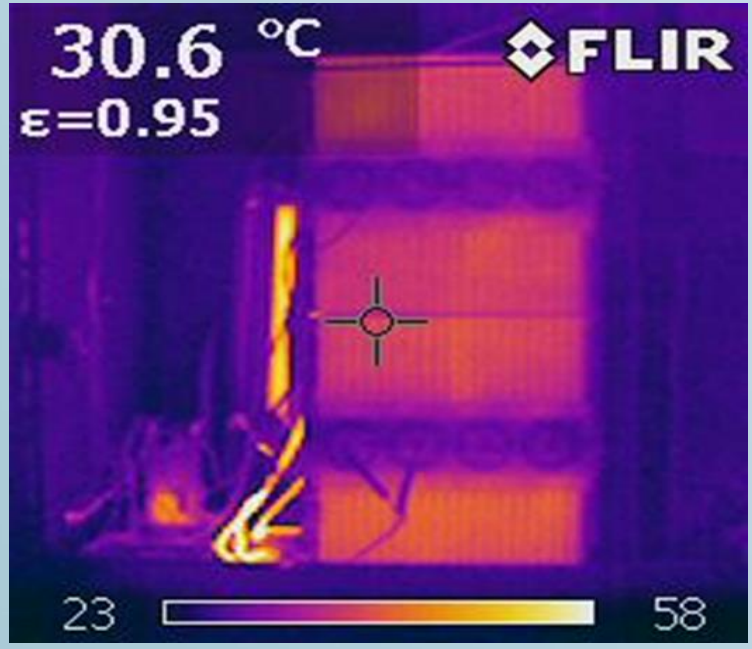
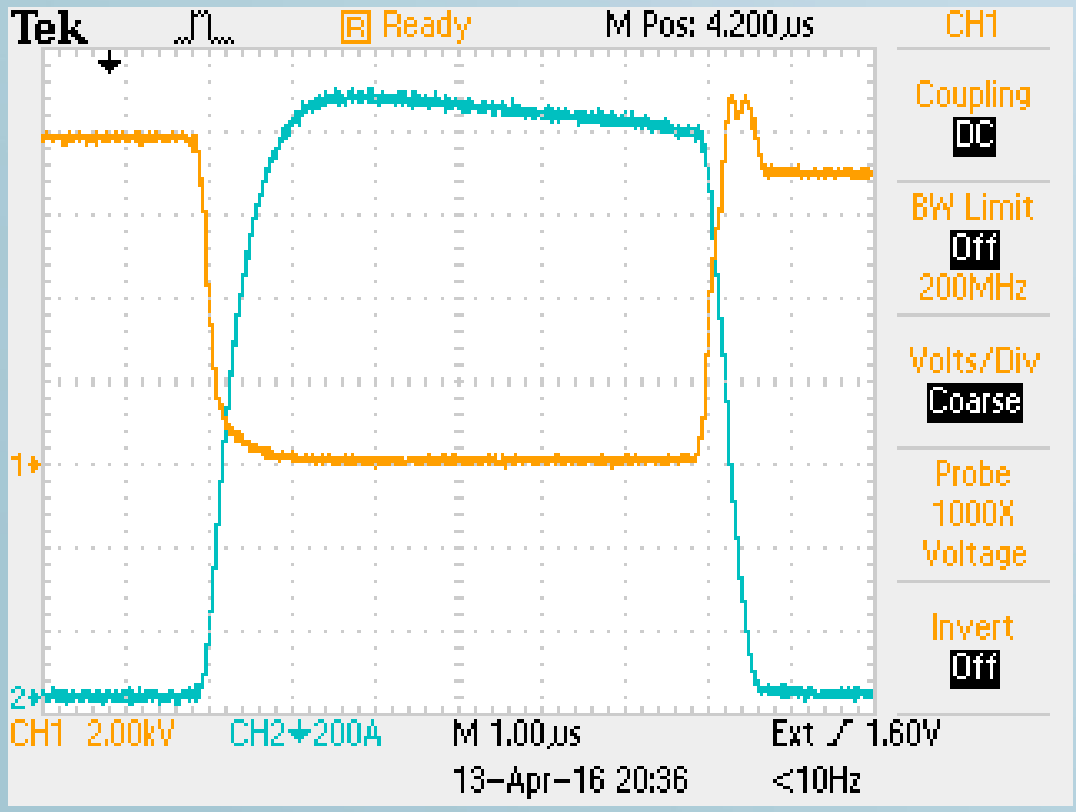


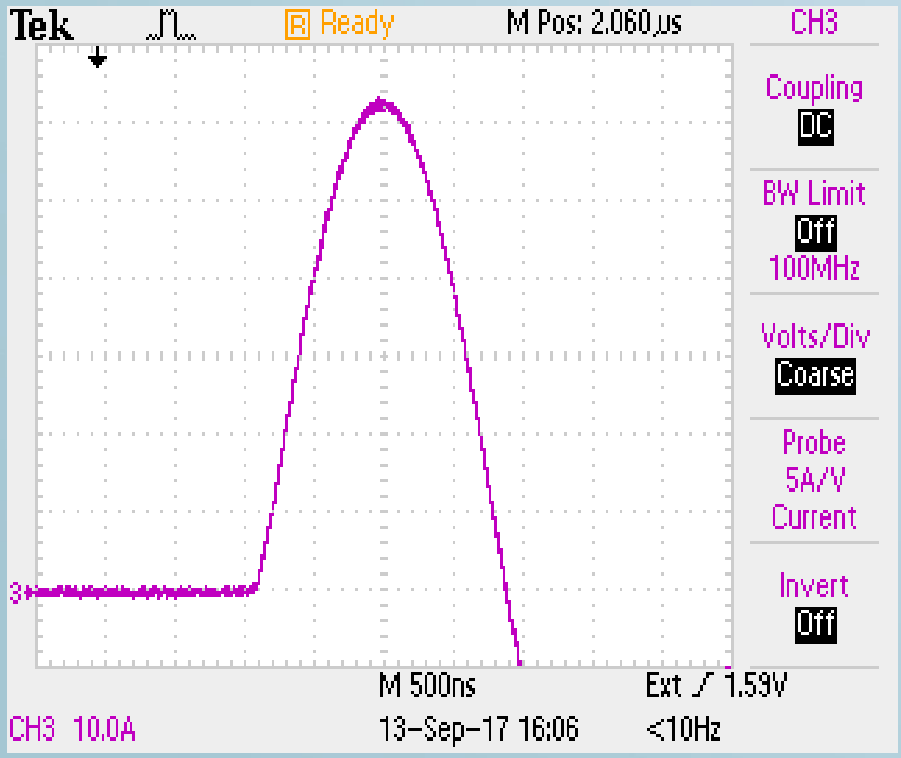
Plate Test at 8 kV, 1.8 kA

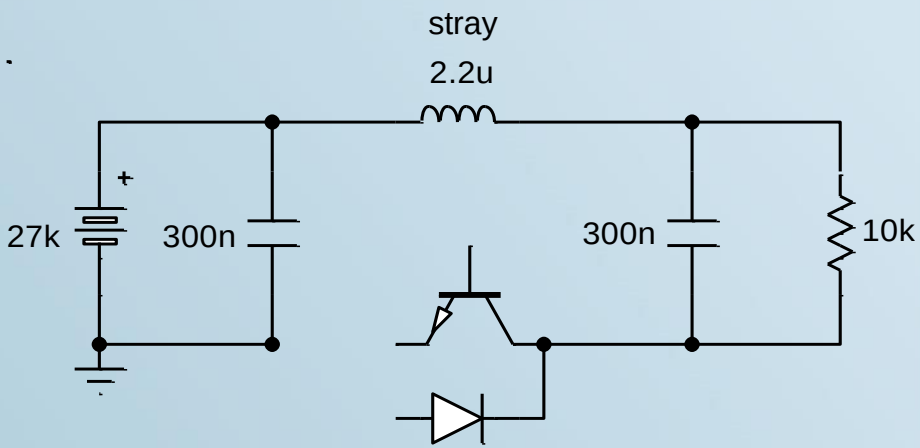


(Yellow) Voltage 2 kV/div (Blue) Current 200 A/div

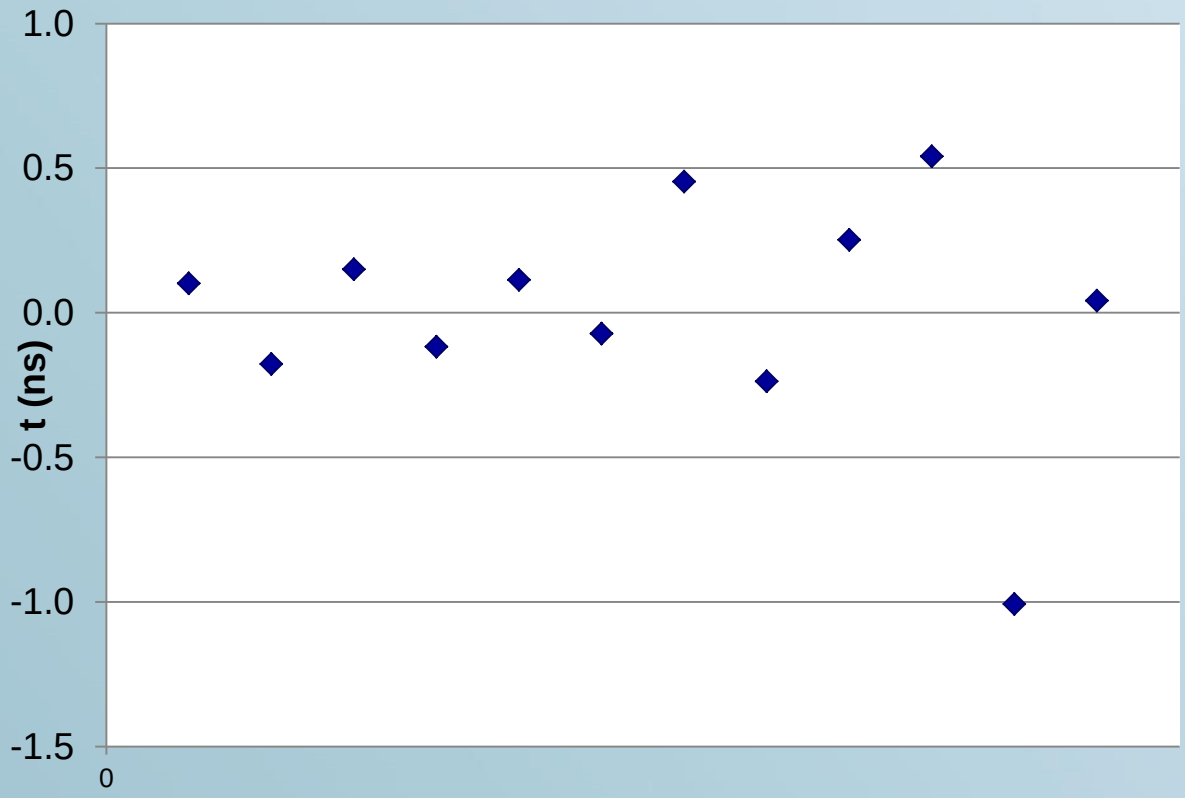
- Switch Closes and Opens (Conventional Hard Switch)
- Opening Not Required for SLAC – Higher Stress on IGBTs

System Test at 27 kV, 6.2 kA



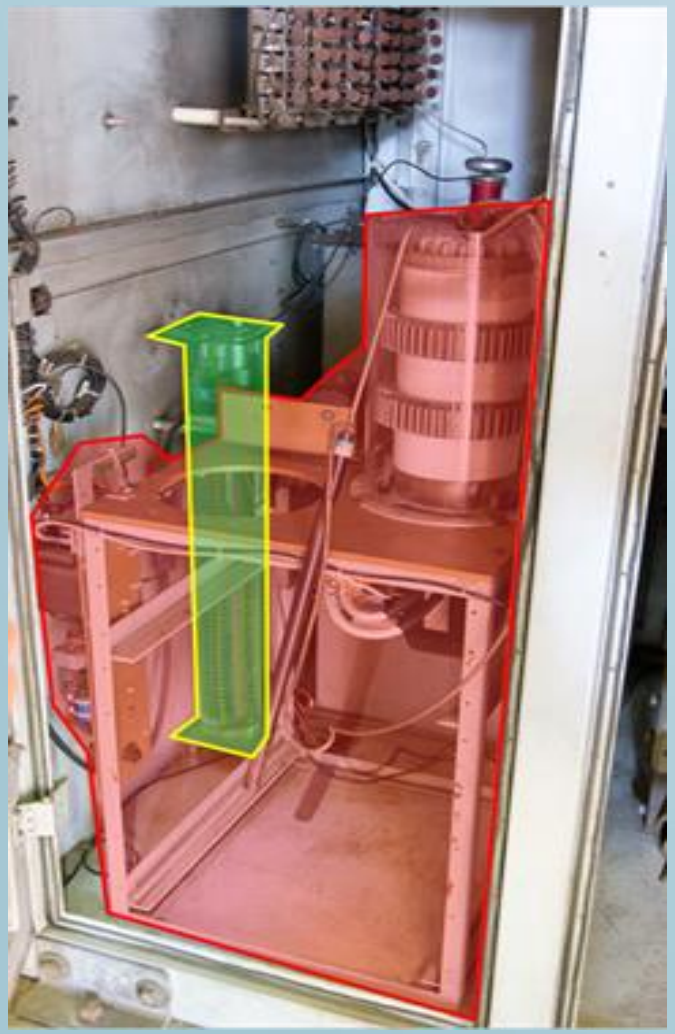


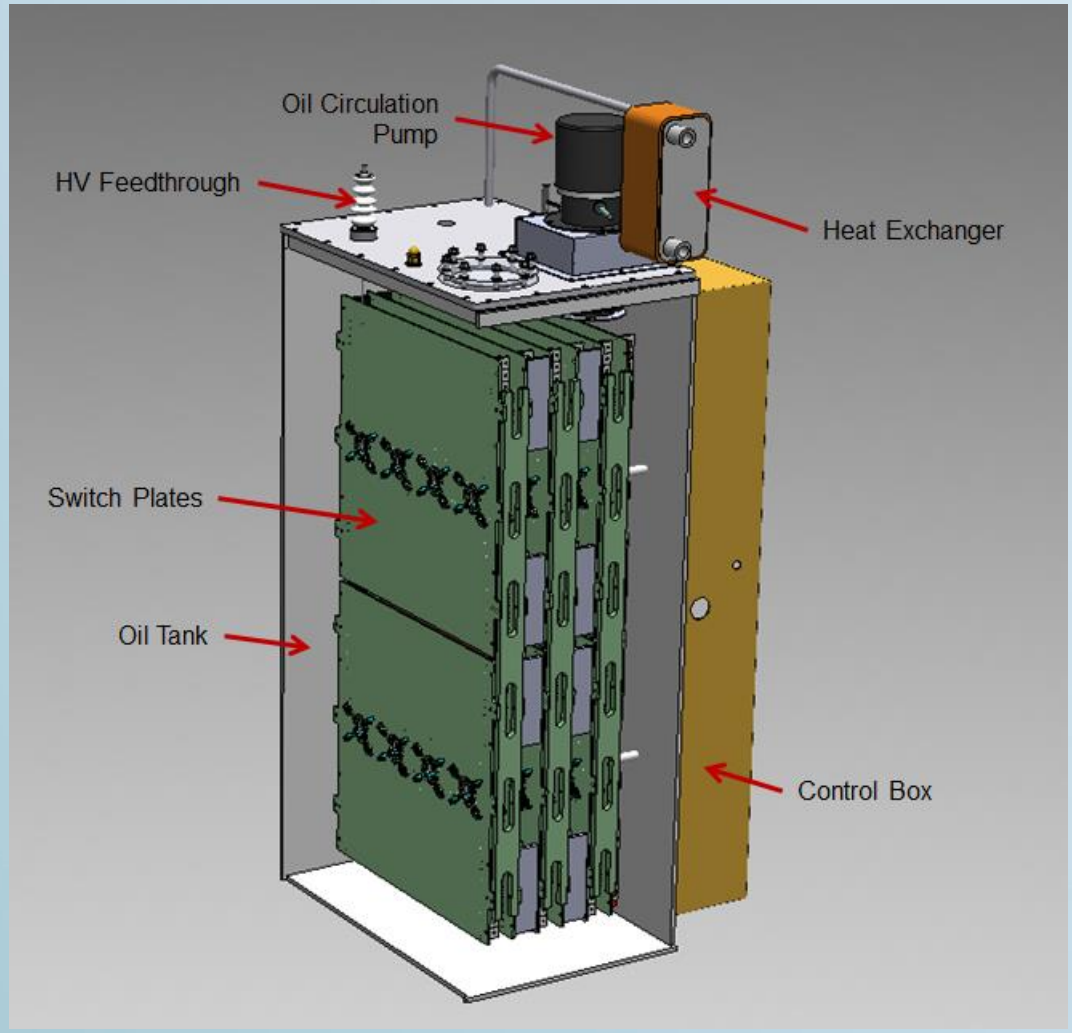
Total Jitter Spread: 1.5 ns



Test used single devices
Thyratrons jitter 5 – 10 ns

Mechanical Design





Final Assembly

- Fits in Modulator Volume
- Interfaces Directly with SLAC Controls
- Utilizes Klystron Cooling Loop

Summary

- Thyratron Replacement Built and Tested at DTI
  - Meets All Specifications
  - Passed All Operating Tests
- Switchplate Development More Complex Than Expected
  - dI/dt Limitations of Commercial IGBTs
  - Current Sharing In Parallel Strings
- Funding & Time Expired Prior to SLAC Testing
- Estimated Production Cost Higher Than Expected
  - Not Cost Effective for SLAC or DTI to Move Forward
  - Low Additional Value to Test at SLAC
- Smaller Variants Deployed Already

Conclusion

- Solid State Thyratron Replacements Are Feasible
  - Can Be Retrofit Into Existing Volume
  - Performs Above Thyratron Specifications
- Economically, Not Quite There (for SLAC)
  - Challenging Payback Requirements
  - Upfront Costs Count More than Long-term Savings
  - Other Applications Can Be Cost Effective
- Future Systems Will Be Less Expensive
  - Lower IGBT Costs
  - Higher dI/dt Performance
- Capability to Upgrade High Value Systems Now

Thank You

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