Solid State Thyatron Replacement

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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 – Thyatron Replacement

- Stanford Linear Collider Has 83 Modulators
  - Thyatron / PFN / XFMR
  - Operating Since 1963, Expected to Operate Until 2035+
  - Cost of Thyatrons Rising / Availability Decreasing
SBIR - Thyatron Replacement

• SBIR Goals – Affordable, Solid State Replacement
  – Reliability > 20 Years
  – Cost << $100k; Goal is 2 - 3X Thyatron Cost (< $40k)
  – Savings > $1M/Year over 20 Years

• Motivation
  – Thytragons Rated For Only 10,000 Hours
  – Heater Voltage Requires Adjustment Over Lifetime
  – Jitter Is 5 ns; Lowering Jitter Improves Stability
  – Significant Manpower Required for Thyatron 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

Status Quo Cumulative Cost

Initial Investment

Payback

Savings

Investment Recouped at ~250 Weeks

Thyratron Replacement Cumulative Cost
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

• dl/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

- 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
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

- Oil Circulation Pump
- Heat Exchanger
- HV Feedthrough
- Switch Plates
- Oil Tank
- Control Box
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 Thyatron Replacements Are Feasible
  – Can Be Retrofit Into Existing Volume
  – Performs Above Thyatron 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 dl/dt Performance

• Capability to Upgrade High Value Systems Now
Thank You

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