

# Solid-State Transmitter for a 2 MW Klystron

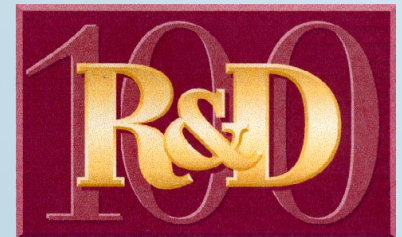
M. Kempkes, K. Schrock, T. Hawkey, M.P.J. Gaudreau

October 11, 2010

Diversified Technologies, Inc.

# About DTI

- Manufacturer & marketer of very high voltage solid-state pulse modulators, power supplies, & power converters
- Core technology allows high frequency switching at high power
- PowerMod™ technology comprised of an extensive patent portfolio developed over more than 20 years
- Company serves international commercial & defense markets in radar, power conversion, high energy physics, and compact high power switching
- ~\$14M revenue, ~75 employees, 10 PhDs



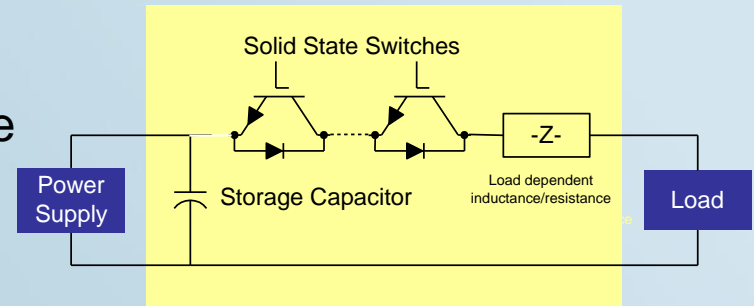
**Two-Time R&D 100  
Award Winner**

# Solid State Benefits

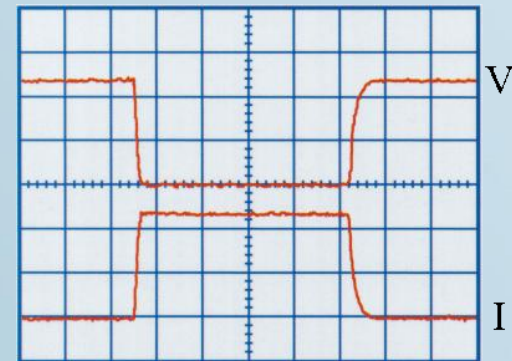
- Inherent Solid State Reliability
  - Replace Obsolescent Vacuum Tubes
  - High Voltage Switching With Low Voltage Devices
- All Major Modulator / Amplifier Combinations
  - Klystrons, TWTs, Magnetrons, IOTs
  - Cathode, Mod-Anode, Grid Pulsed
  - Pulsewidths 50 nS to CW; PRFs to >100 kHz
- Common Modules Across Multiple Systems
  - Lower NRE
  - Common Spares
  - Rapid Response to New Requirements
- MUCH Higher Transmitter MTBF

# DTI's Core Technology

- Series String of Transistors
  - All Operate Synchronously as a Single Switch
- Very High Voltage and Current
  - Up to 200 kV (200,000 Volts)
  - Up to 5 kA (5000 Amperes)
- Extremely Uniform & Reliable Pulses
  - Sub-Microsecond Switching
  - Arbitrary Pulsewidth & Frequency
  - 50 ns – CW; > 100 kHz Continuous



DTI's PowerMod™ Model



20 kV, 100 A 1 s/div

# Transmitter Specifications

Item	Requirement
Input Power	380 v, 3PH, 50 Hz
Avg Power	~250 kW
PRF	50 Hz
Pulse Width	20 $\mu$ S – 500 $\mu$ S
Duty Cycle	5% max
Droop	3% (3 kV)
Cathode Voltage	-100 kV
Cathode Current	45 A
Filament Voltage	20 V
Filament Current	20 A (< 30 A cold)
Rise Time	<10 $\mu$ S

# Long Pulse Modulator Options

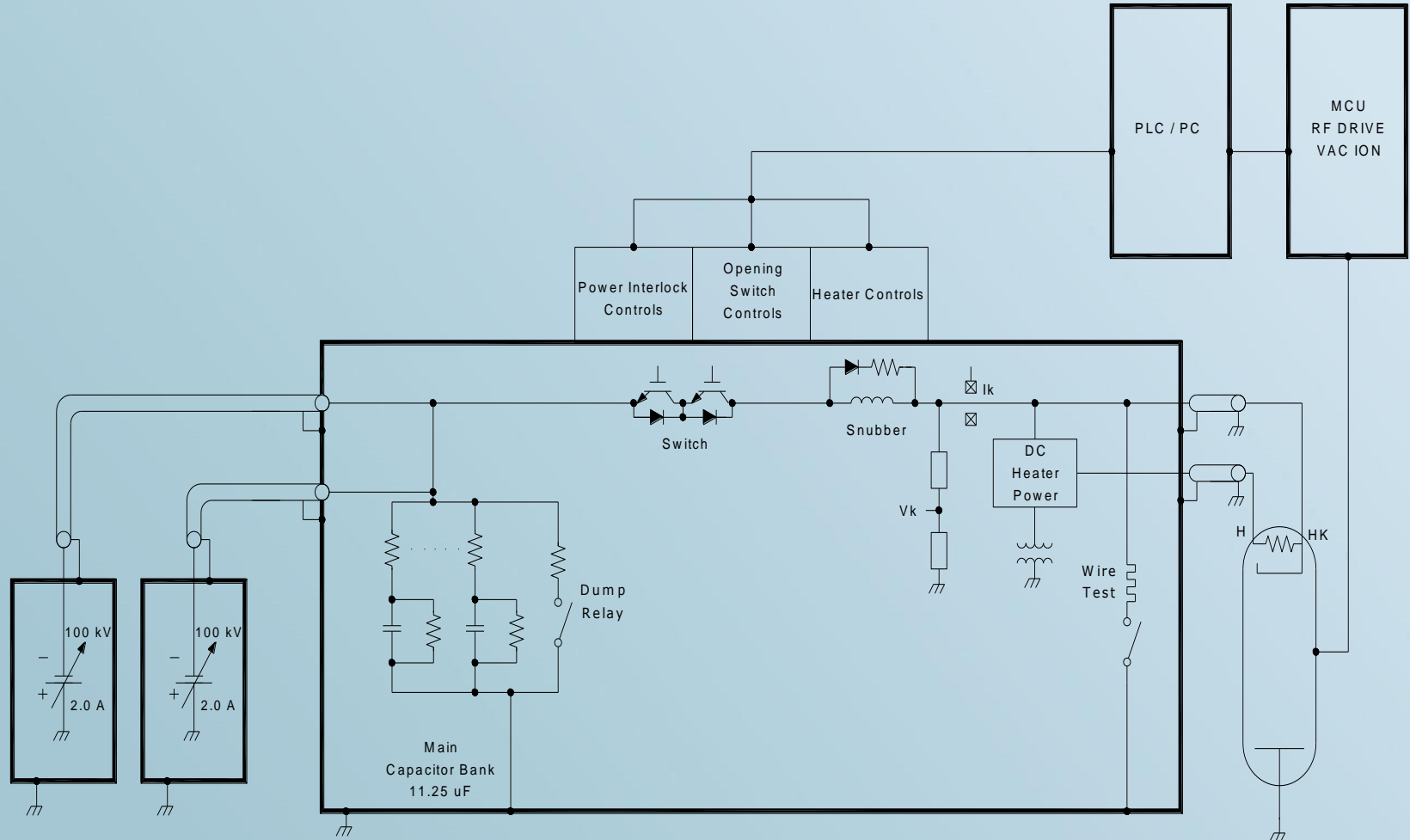
- High Voltage Hard Switch
- Hybrid Modulator (Hard Switch and Pulse Transformer)
- Low Voltage Switch / Bouncer / Pulse Transformer (DESY)
  - Typically Thyatron or Spark Gap
  - Modern Systems Use Solid State Switch
- Multi-Phase Resonant Converter (SNS)
  - Complex and Reliability Issues
  - Large Transformer
- Pulse Step Modulator (Thomcast / Continental)
  - Designed for CW Operation
  - Large and Complex Transformer
- Solid State Marx Bank

DTI Capabilities

# Hard Switch Advantages

- Switch Requirements (Peak Power) Similar Across Topologies
- No Pulse Transformer
  - Higher Efficiency
  - No Stored Energy After Switch (Less Arc Energy)
  - Flexibility
    - Pulsewidth (No Transformer Core Limitations)
    - Pulse Frequency (No Core Reset)
  - Smaller Footprint
- Pulsewidth Flexibility
  - No Tuned Components / Pulse Forming Network
  - Max Pulsewidth Limited By Energy Storage
- Pulse Energy Storage Options
  - Capacitor Bank
  - Bouncer
  - Switching Regulator
- Flat-Top Significantly Better

# Schematic

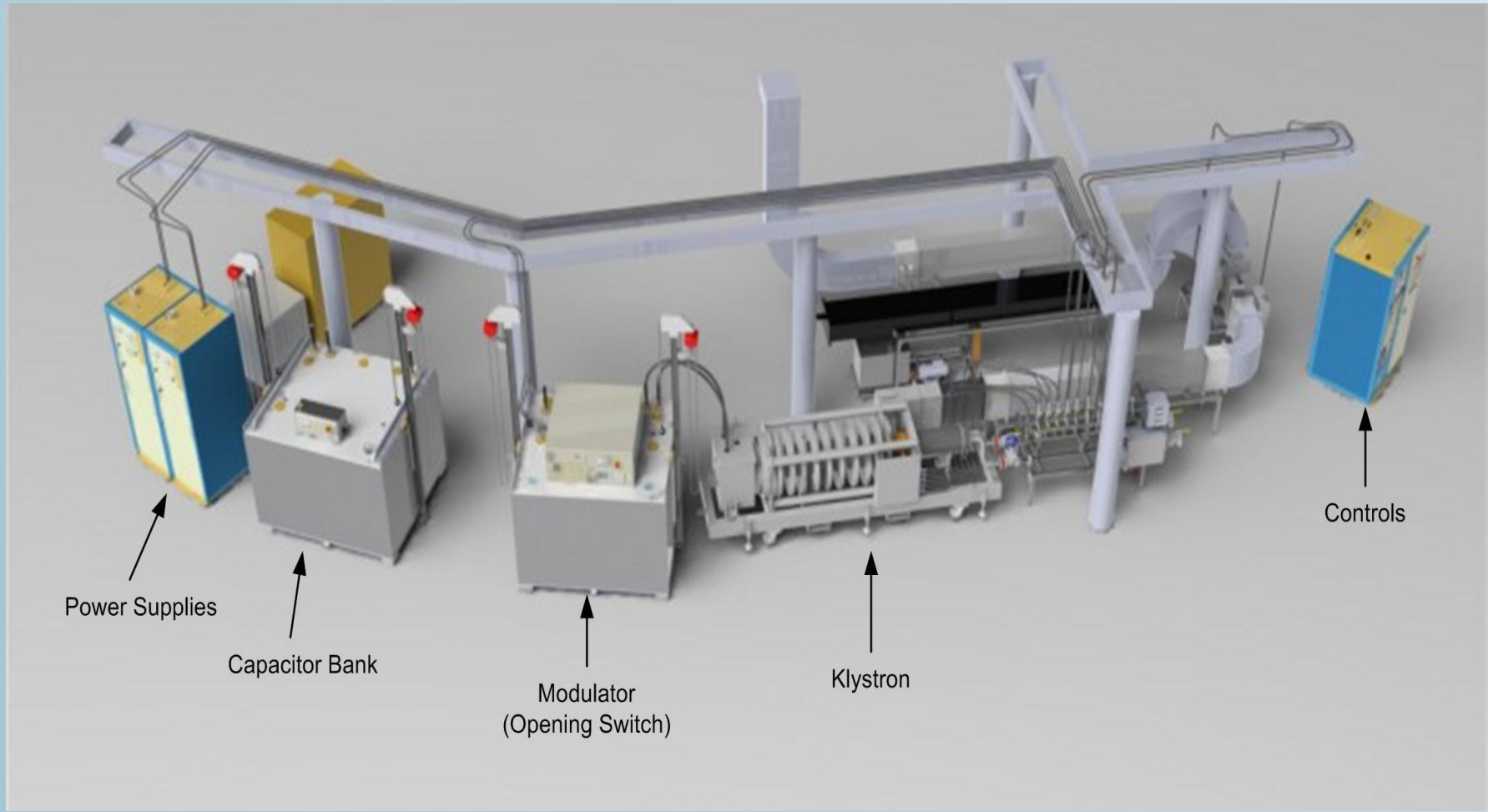


Prime Cathode 20 kHz  
Switching Power Supplies

# Project Scope

- CPI – Prime Contractor
  - Klystron (Primary and Spare)
  - RF Testing
- DTI – Subcontractor
  - Power Supplies / Modulator
  - Transmitter Controls
  - RF Driver & Controls
  - Cooling / Manifold
  - Circulator / RF Loads / Waveguide
- Site
  - Prime Power / Distribution
  - Cooling Water

# Transmitter Layout



# Modulator

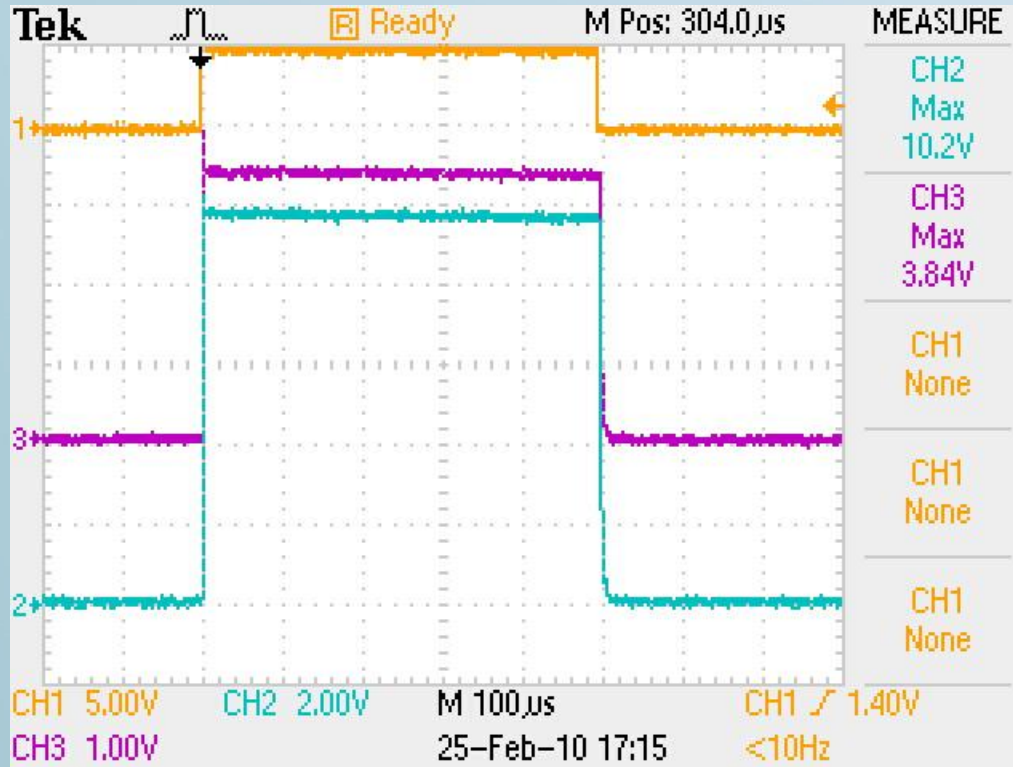


Cathode Switch  
40 – 3 kV Switch Modules in Series



Complete Modulator

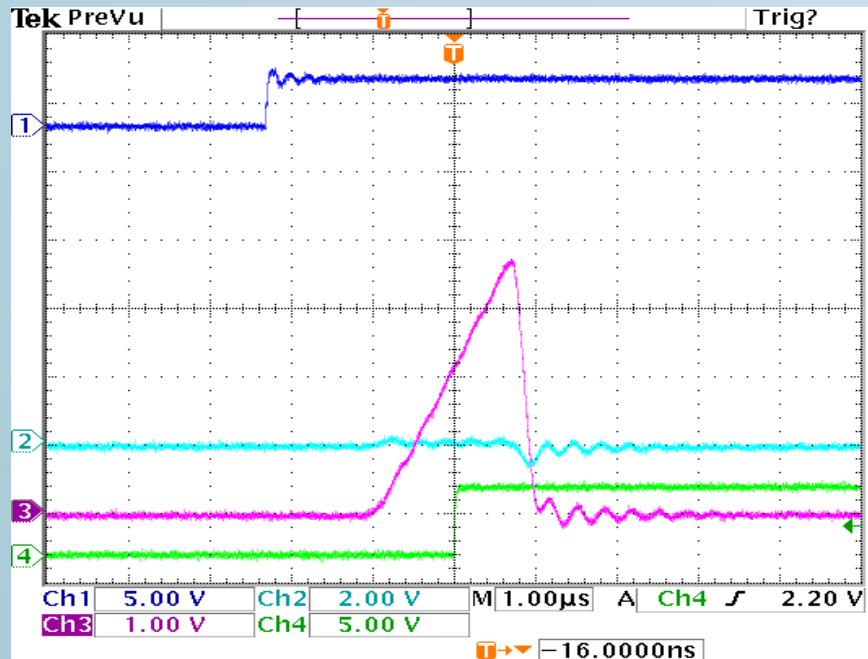
# Cathode Pulse



100 kV, 35 A, 500 µs into Resistive Load

- CH1 – Pulse Command
- CH2 – Cathode Voltage
- CH3 – Cathode Current

# Arc Response



- Arc Threshold (200 A) Crossed at Center Line (Ch 4)
- Cathode Switch Opens ~ 700 ns Later
- Peak Current < 350 A (Ch 3)

# Controls

- Fast controls ( $\mu\text{s}$  timescale) - Dedicated analog electronics
  - Cathode overcurrent
  - Over voltage
  - RF Fault
  - Input pulse protection
  - Internal controls fault
  - Internal modulator fault
  - Vaclon current
- PLC - Slow controls & Monitoring
  - Filament
  - Solenoid faults
  - Cooling
  - Temperature
  - Interlocks
- Remote Operation Possible over Ethernet



# Display Screen

**OVERVIEW** 2:52:43 PM March 17, 2010

EXIT APPLICATION	PRIOR DISPLAY	ALARMS SEVERITY 1-3	ALARMS SEVERITY 4-5	ALARMS SEVERITY 7	NAVIGATION
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<b>Transmitter Room</b>		<b>RF Signal</b>		<b>CONTROL POWER</b>		<b>System Power Supply</b>	
Temperature	5.0 F	RF OUT AVG	0.0 dbm	Voltage		-9770 V	
Humidity	0.0 %	RF OUT PEAK	0.0 dbm	Current		-0.42 A	
<b>Transmitter Cooling</b>		<b>TRANSMITTER CONTROL ROOM</b>		Peak Power		Data Not Available	
Supply Temp	32.0 F	PS 1	PS 2	Login		MODES	
Supply Press	0.0 PSI	CAP BANK		Logout		MODULATOR	
Return Temp	32.0 F	MODULATOR		Current User		POWER SUPPLIES	
Return Press	0.0 PSI	MCU		engineer		COOLING	
		COOLING					

CONTROL POWER FILAMENT HIGH VOLTAGE BEAM

ALM HISTORY  
ACK ALARM  
MASTER RESET

Overview

**SEVERITY ALARMS 1-2-3** 11:01:12 AM March 22, 2010

NAVIGATION	PRIOR DISPLAY	ALARMS SEVERITY 4-5	ALARMS SEVERITY 7	OVERVIEW
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<b>SEVERITY # 1</b>		<b>SEVERITY # 2</b>		<b>SEVERITY # 3</b>	
E-Stop CR Rack	DNet Buss OFF	MOD CTRL PWR	FIL Power Supply	TR Temperature	TR Humidity
E-Stop CAP Bank	DNet No Power	Diode I Fault	Filament Manual	VMOD HV I LOCK	HV Manual
E-Stop Modulator	DNet TCR Node	MOD Switch Driver	FIL Temperatura	MOD HV not OK	No PS Selected
E-Stop TC Rack	DNet Other	MOD Oil OT	FIL Current	MOD Switch Leak	Site Cooling
TCR KIRK Key	DNet Reset	MOD Oil Level Hi	FIL Current Hi	VMOD > SP	DNet Node COOL
		MOD Oil Level Low	FIL Run	WT ROSS AUX	CAP HV Dump
		Vac Ion PS HV On	FIL Voltage	CW Supply Temp	CW Return Temp
		Vac Ion HV	FIL Voltage Hi	MOD Pump I Hi	MOD Pump I Lo
		WT Switch	Filament CDM		
		DNet CAP	DNet Node MOD		
		CAP Oil High	MCR		
		CAP Oil OT	SWSNS HV		
		CAP Oil Low	SWSNS Beam		

CONTROL POWER FILAMENT HIGH VOLTAGE BEAM

ALM HISTORY  
ACK ALARM  
MASTER RESET

Alarm Status

# Status

- Transmitter and Klystron Independently Tested at Factory (DTI & CPI)
- Equipment In Transit to User Facility
- Installation / Integration Starting Late October '10

# Thank You

**Diversified Technologies, Inc.**  
**35 Wiggins Avenue**  
**Bedford, MA 01730**  
**(781)-275-9444**

**[www.divtecs.com](http://www.divtecs.com)**