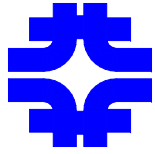


ILC Modulator Talk

C.C. Jensen

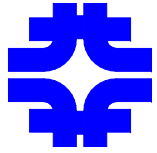
(Presented by O. Nezhevenko)

- Early FNAL Bouncer
- Optimization / Technology Upgrades
- Status



Bouncer Modulator Operation

- Switch connects main capacitor bank to transformer during 1.7 ms pulse.
 - Transformer steps up voltage to 120kV/130A (12:1)
 - 1400 uF cap bank voltage discharges by 20% during pulse
 - “Bouncer” resonant circuit compensates for cap bank droop.
- Switch **MUST** open during gun spark to remove transformer stored energy and limit energy at klystron spark site to < 20 Joules.



FNAL Modulator History at DESY

- First modulator has run for 30,000 hours (since 1993)
- Second and Third modulators have run for 23,000 hour each (since 1996)

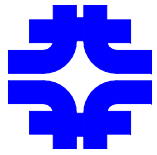
Pulse Transformer Failure (Secondary Short)

Snubber Resistor Failure (connector material problem)

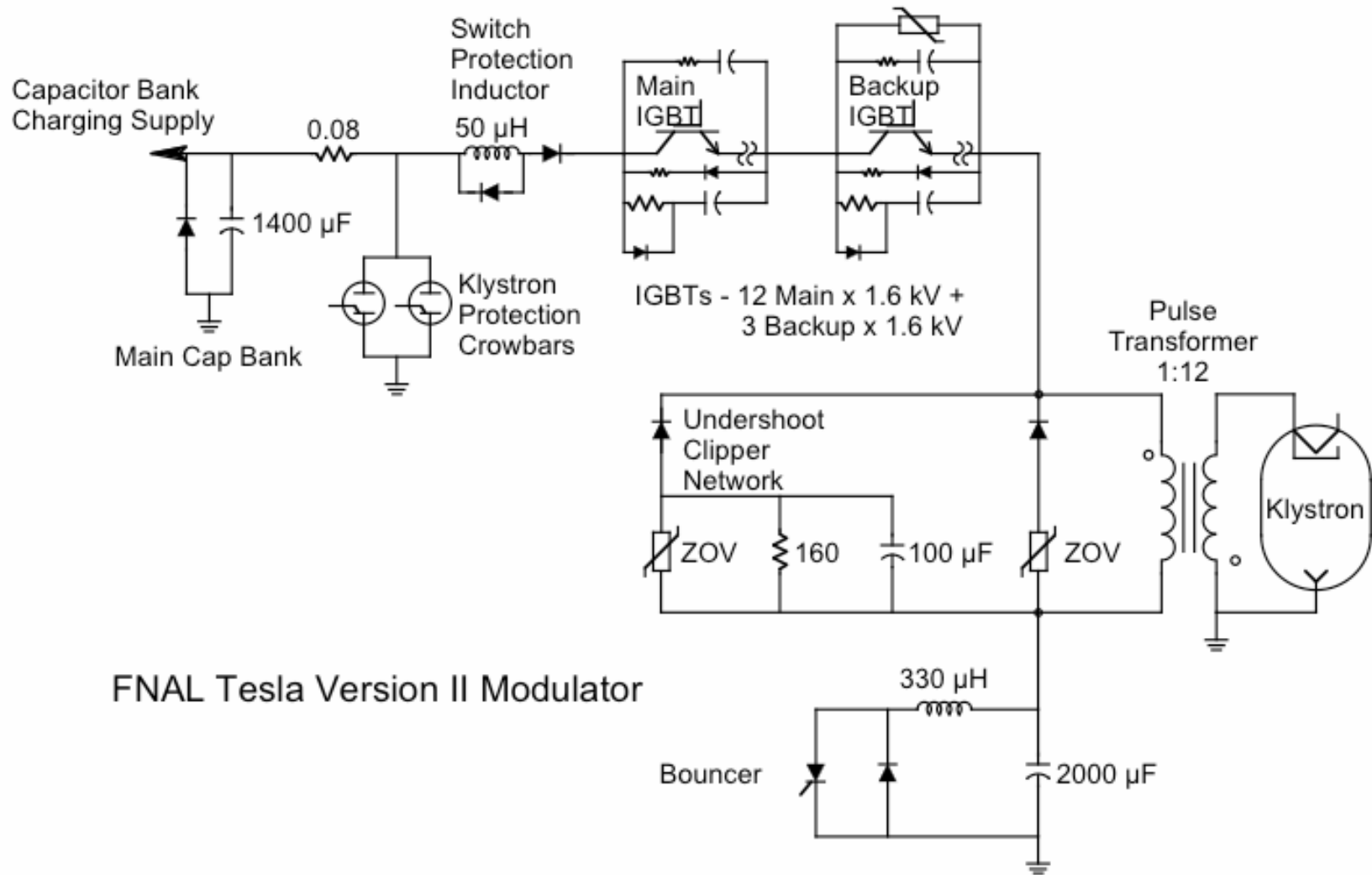
IGBT Driver Failure (dead chip)

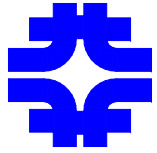
Main Capacitor Failure (case rupture)

Bad connection in main current path (loose bolted joint)



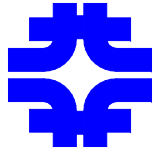
FNAL Original Modulator Circuit





Changes to Original FNAL Modulator Design

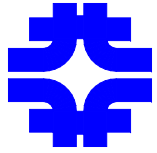
- **New Switch Philosophy:**
 - Design Single Switch for Fail Safe (i.e. OFF) Operation
 - No Backup Circuitry Required
 - No fast crowbar
 - No backup switch
 - Use of IGBT switch elements
 - Low turn off energy required
 - Design Switch with Extra Voltage Margin
 - 190% voltage margin over highest transient
 - MOV for each IGBT
 - 4 kV clamp voltage at rated current of 4.5 kV IGBT
 - Complete Redundant Control Design
 - No single failure can over ride switch off command
 - Double isolated gate power transformers with fault detection
 - Power loss detection at modulator controls, switch control or gate drive turns off switch
 - Redundant control paths and current sensors and loss of redundancy check



Changes to Original FNAL Modulator Design

- **New Switch Philosophy (continued):**
 - Slow, Low Current Crowbar Circuit
 - Mainly for personnel protection
 - Cost reduction in crowbar switch
 - Cost reduction in bus work size and clamping
 - Small efficiency gain
 - Eliminated 0.08 Ohm current limiting resistor

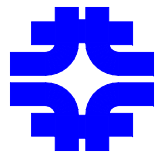
- **New Switch Technology:**
 - Using New Higher Voltage IGBTs
 - 50% reduction in physical size



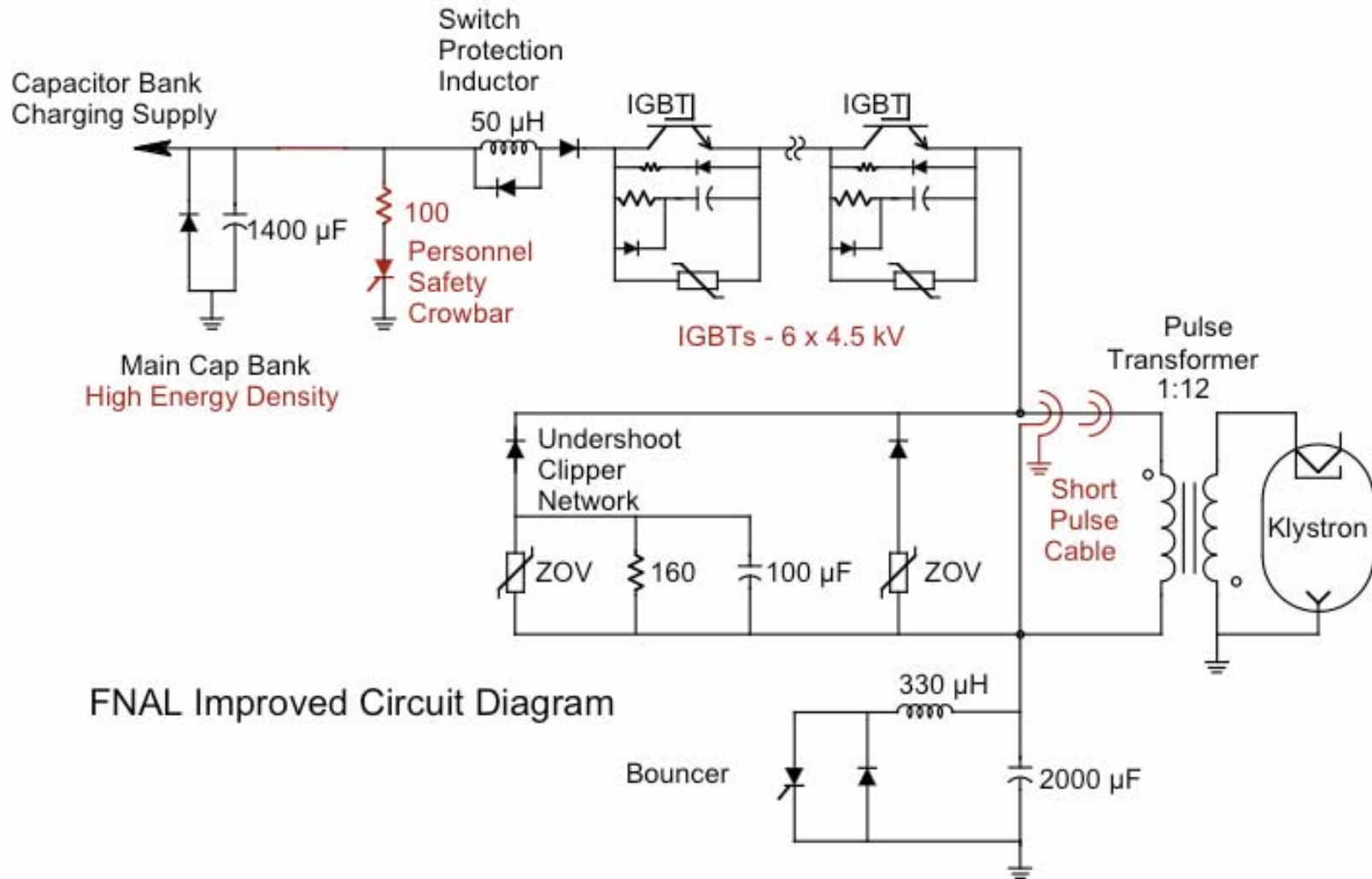
Changes to Original FNAL Modulator Design

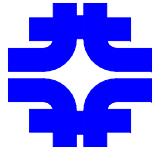
- **New Capacitor Technology:**
 - Volume is 20% of original film/paper
 - Cost is 50% of original film/paper
 - Use High Energy Density Capacitors for Main Capacitor Bank
 - Self Healing polypropylene / “HAZY” capacitors
 - Use of these capacitors requires low current crowbar
 - Presently also used in SNS modulator

- **Modulator Controls:**
 - Custom controls and backplane simplify interconnections
 - 25 % Reduction in Parts Cost / 50 % Reduction in Labor
 - Single board computer to interface with control system
 - Single Ethernet cable for control of modulator



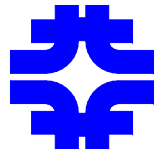
New FNAL Bouncer Circuit



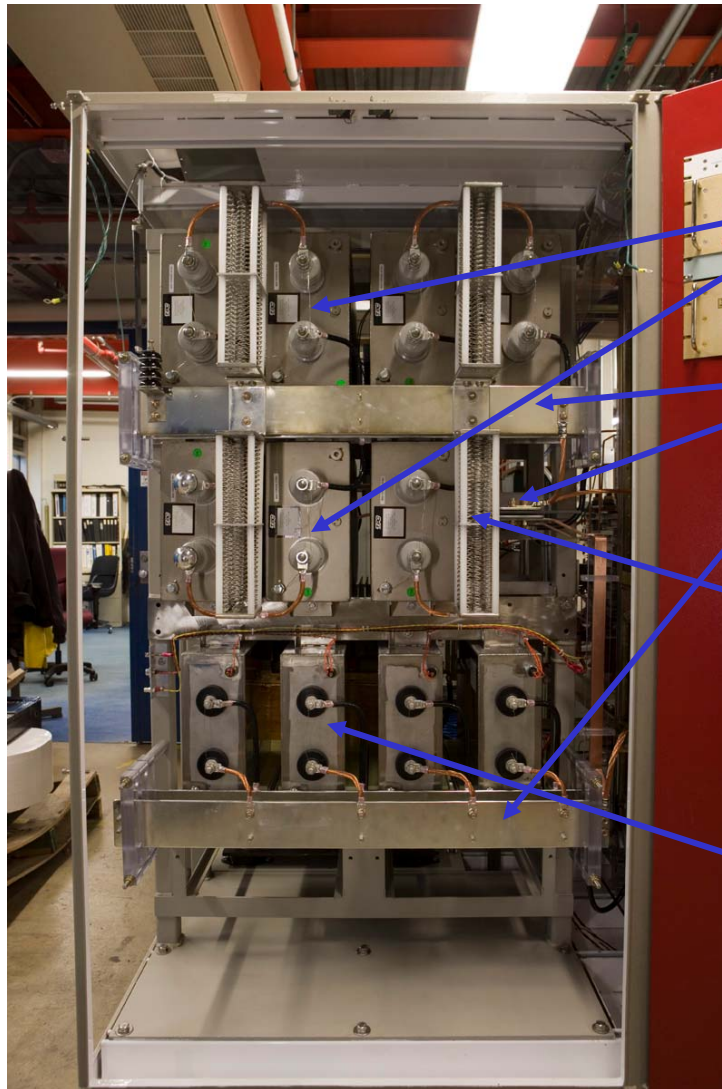


FNAL Modulator Status

- HINS Modulator pulse length is 4.2 ms
 - 325 MHz Klystron, 2.5 MW Peak
 - Running since February 2007
- ILC / NML Modulator under construction
 - Footprint is similar in size to SNS / HVCM
 - Pulse transformer in house
- NML / RF Gun Modulator
 - Parts on order
 - Pulse transformer on order



Main and Bouncer Capacitor

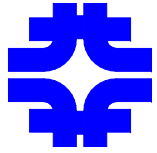


Main Capacitors

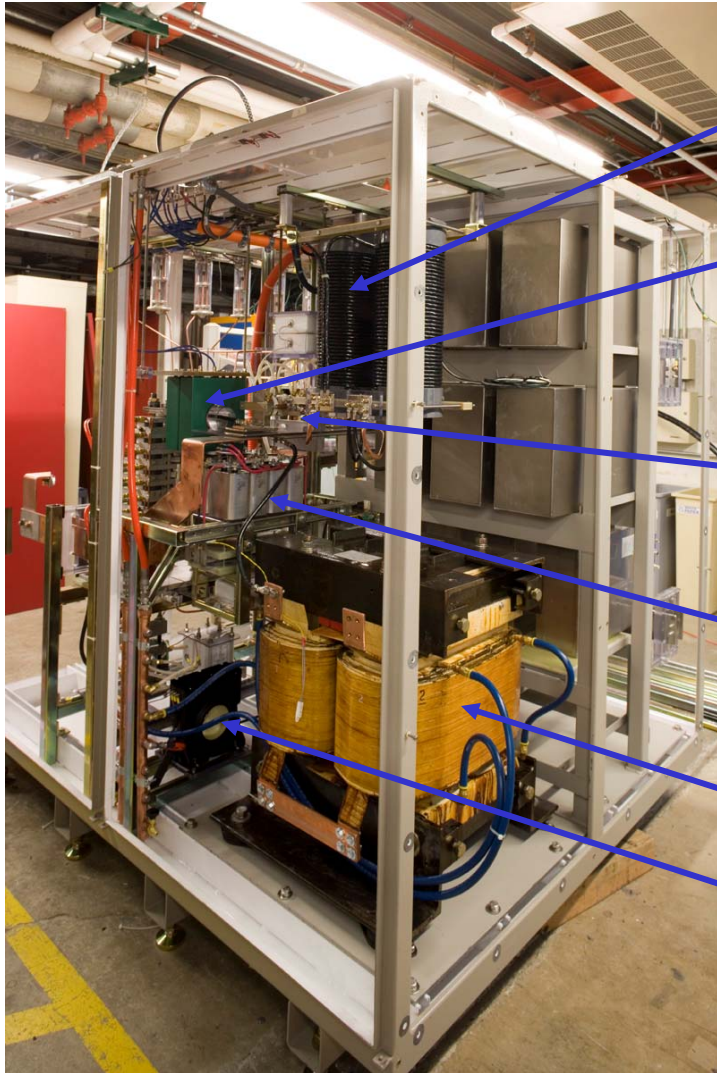
High Voltage, Low Inductance Buswork

Current Limiting Resistors

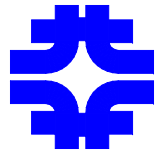
Bouncer Capacitors



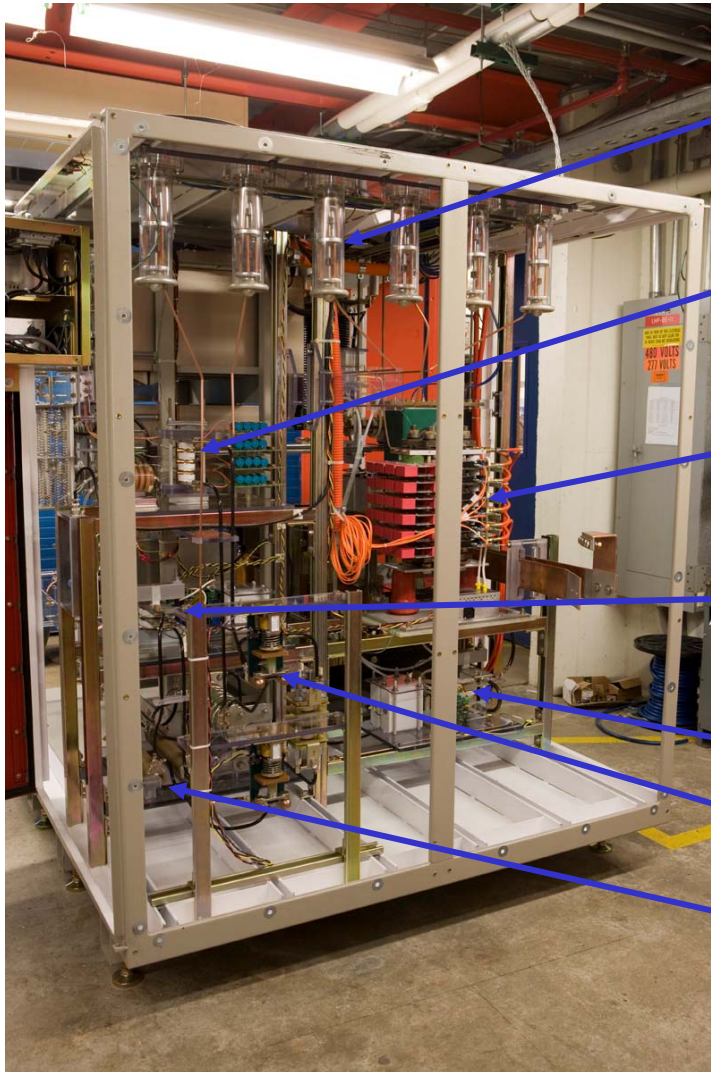
Bouncer and Switch Chokes



- Switch Protection Inductor
- Main Switch Current Transformers (2)
- Switch Protection Inductor Diodes
- Undershoot Network
- Bouncer Inductor
- Bouncer Current Transformer



Main and Crowbar Switches



■ Voltage Dividers

■ Main Cap Bank
Crowbar Switch

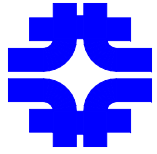
■ Main Switch

■ Bouncer Cap Bank
Crowbar Switch

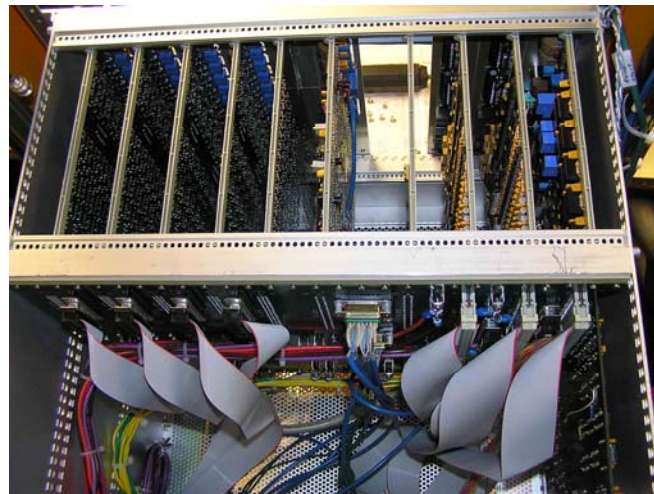
■ Bouncer Switch

■ Shorting Relays

■ Crowbar Resistors



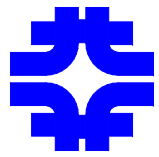
Controls



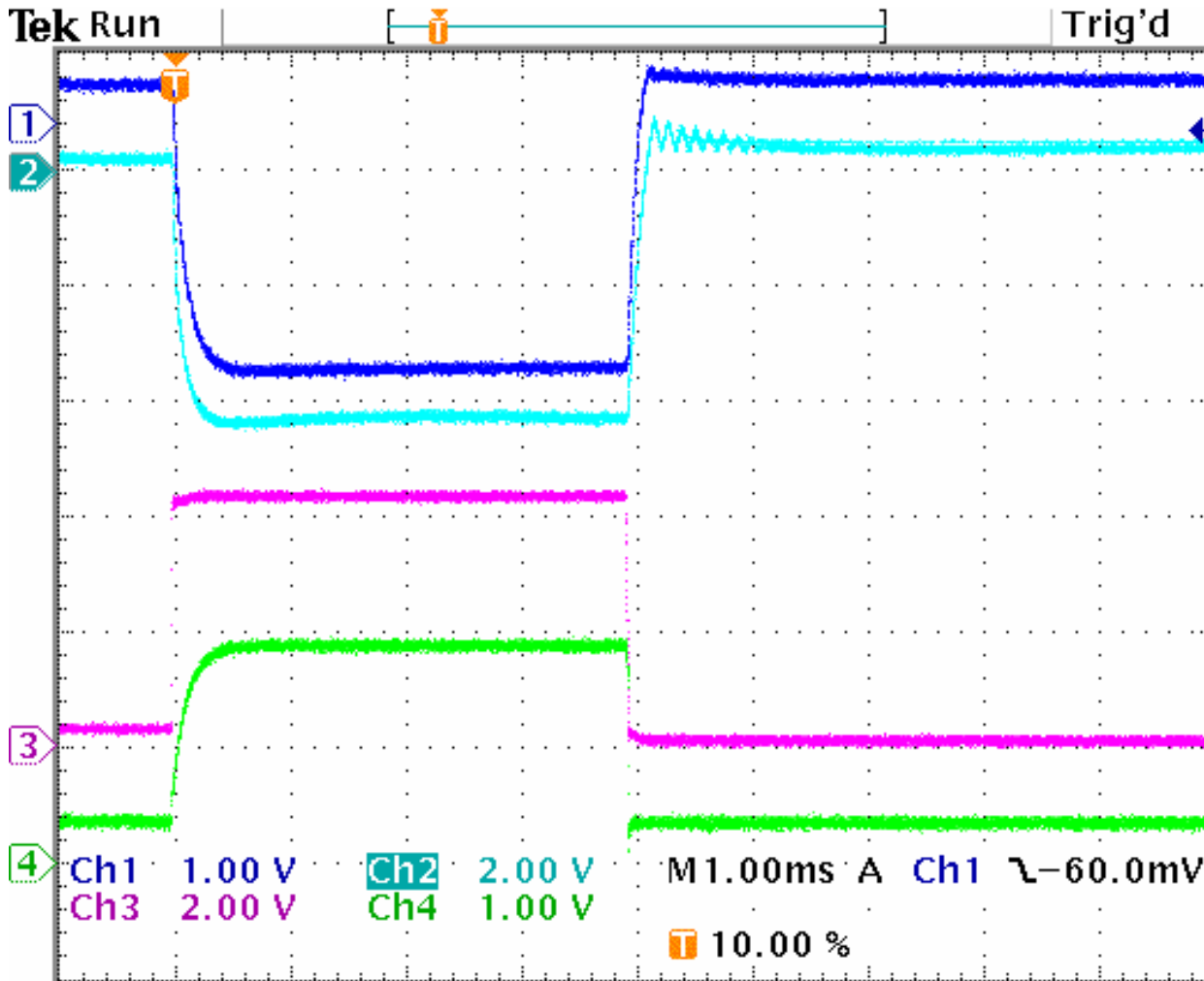
October 1, 2007

HLRF KOM

13



HINS Waveforms (Normal)

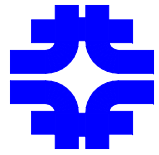


- Klystron Voltage (20 kV/V)

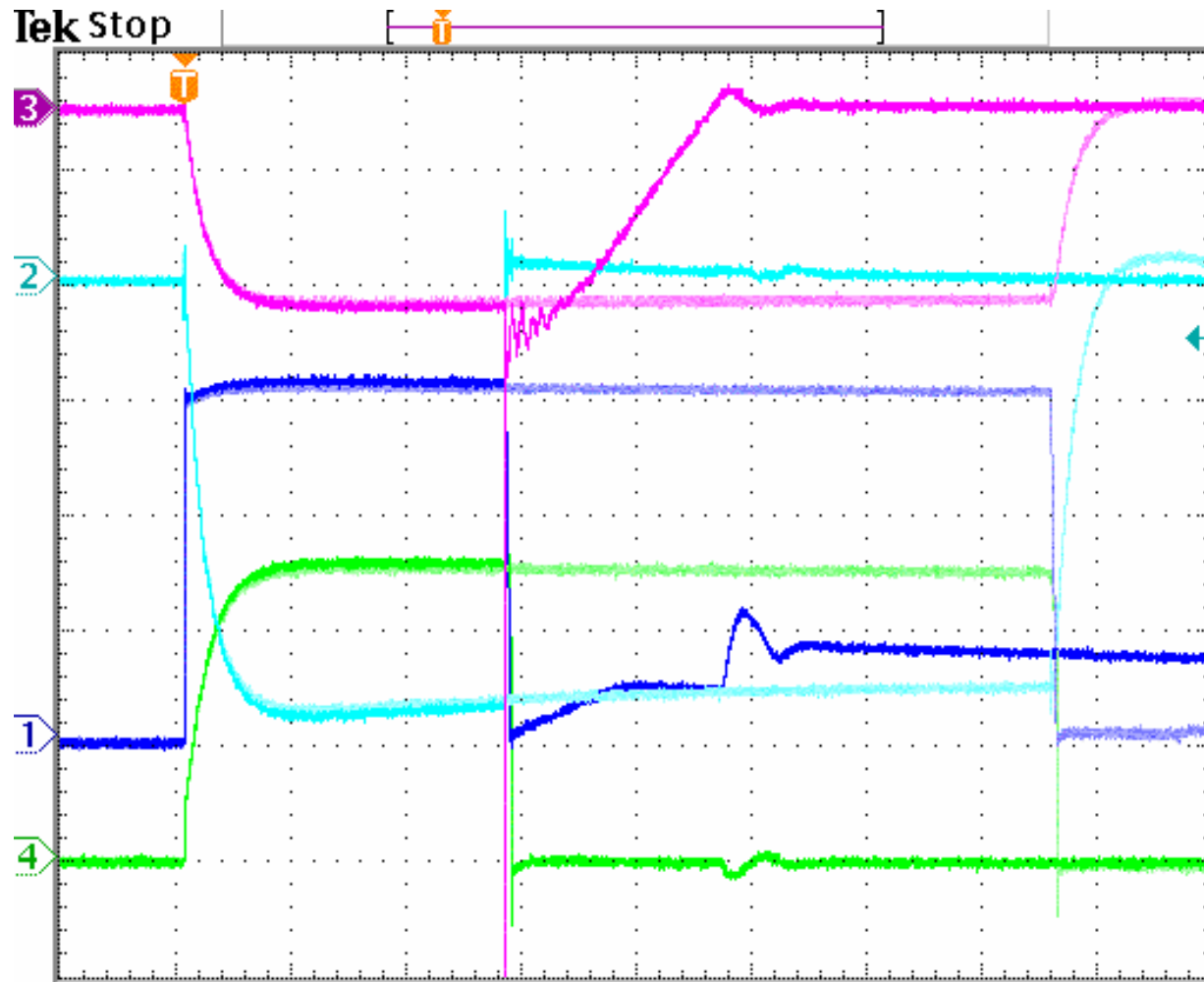
- Klystron Current (20 A/V)

- Transformer Primary Voltage (2 kV/V)

- Main Switch Current (400A/V)



HINS Waveforms (Gun Spark)

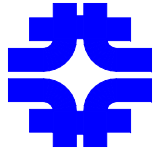


•Klystron Voltage
(20 kV/V)

•Klystron Current
(20 A/V)

•Transformer
Primary Voltage
(2 kV/V)

•Main Switch
Current (400A/V)



Conclusions

- Have implemented all of these changes
- One modulator has been commissioned and is running (4.2 ms)
- Two further bouncer modulators are being built