Possibilities of High Frequency Polyphase Resonant Converters for ILC Application*

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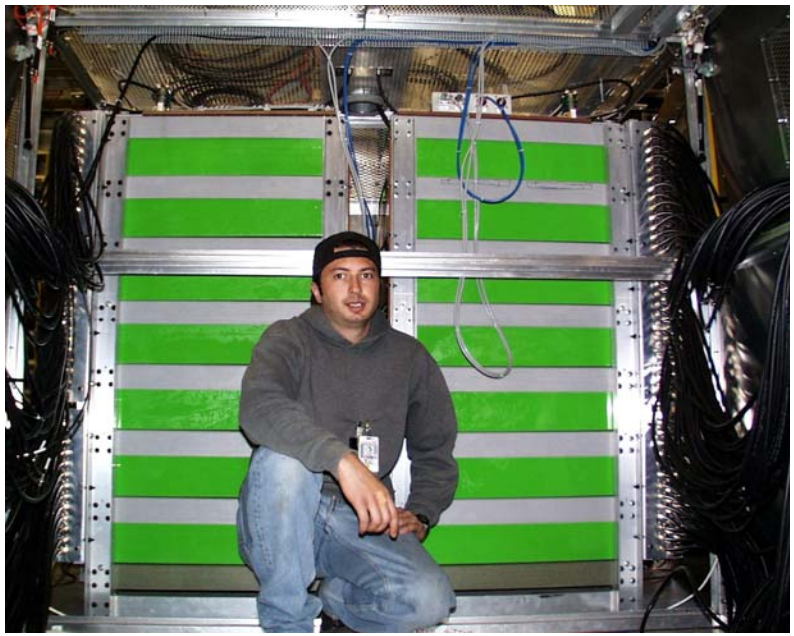
Los Alamos High Frequency "Polyphase Resonant Power Conditioning" Compared To Conventional 60Hz Technology Is Significantly Smaller

10 Megawatt Pulse, 20 KHz, 140 kV
Polyphase Resonant Converter-Modulator

- Developed for Oak Ridge SNS Accelerator
- All Components operate at 10 MW level
- Can be Optimized for 10 MW CW
- Can be Optimized for 30 MW Long Pulse
- Resonant Conversion is Fault Tolerant
- Small and Compact
- Reliable Components
- Can Operate With Kilometer Cable Lengths
- No Crowbars Needed

Los Alamos Low Voltage Energy Storage Compared To Conventional High Voltage Method Is Very Compact And Reliable

Self-Clearing Metallized Hazy Polypropylene



- 300,000 hour lifetime
- Graceful degradation
- High frequency design, variable rep-rate capabilities
- Extremely high volumetric efficiency
- High safety factor

Conventional
High Voltage Paper and Foil Capacitors

- Limited lifetime
- Explosive failure modes
- Highly frequency dependant and lossy
- Large footprint
- Poor safety factors and dangerous
- Crow Bar required

Nanocrystalline High Frequency Transformers Are Over 150 Times Lighter And Significantly Smaller

Typical H.V. Transformer

- 100 kV, 60 Hz
- 20 Amp RMS
- 2 MW Average
- 35 Tons
- ~30 KW Loss

HVCM Transformer

- 140 kV, 20 KHz
- 20 Amp RMS
- 1 MW Average (3) present use
- 450 LBS for 3
- 3 KW Loss At 2 MW

Load Protection Networks Not Needed For Los Alamos Technology

Typical H.V. Crowbar Protect Network

- Large
- Reliability concerns
- Maintenance concerns

Resonant Converter Protect Network

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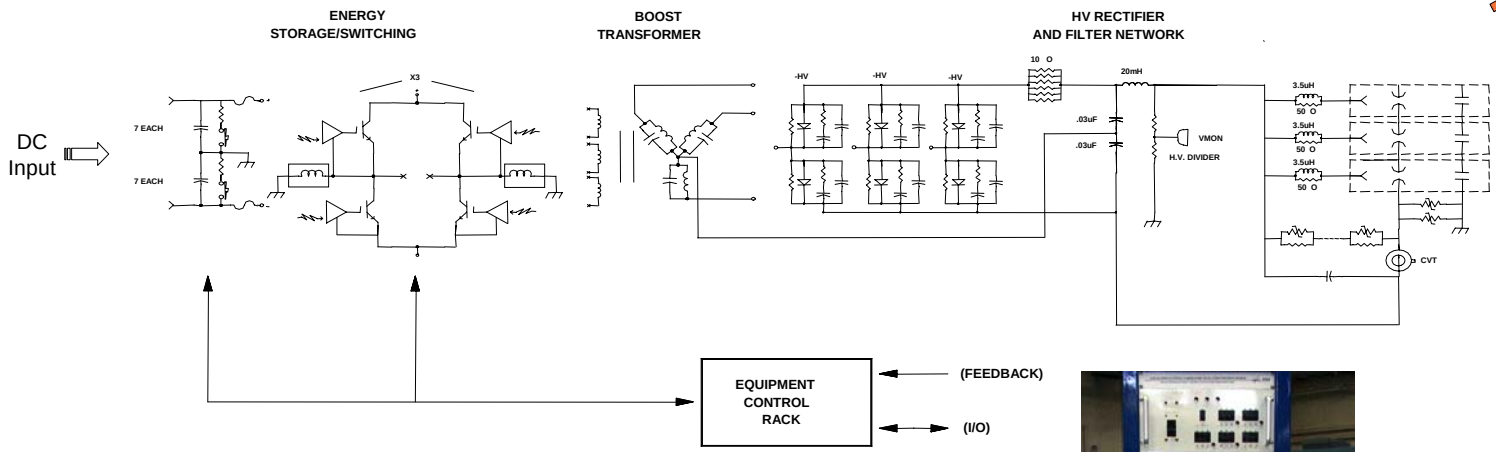
(none required)

- Converter-Modulator inherently self protective
- Automatic fault “ride-through”
- Safe for all components

Polyphase Resonant Power Conditioning Uses New LANL/LANL Funded Technology Developments

- Low Inductance Self-Clearing Capacitors
  - Thomson Passive Components (AVX), France
- Low Inductance High Power Capacitors
  - General Atomics Energy Products, San Diego, Ca.
- Amorphous Nanocrystalline Core Material
  - MK Magnetics (Stangenes), Adelanto, Ca.
- New Engineering Techniques
  - Polyphase Resonant Voltage Multiplication
  - Resonant Rectification
  - Self DeQing (No crowbars and self protective)
  - Snubberless IGBT Switching

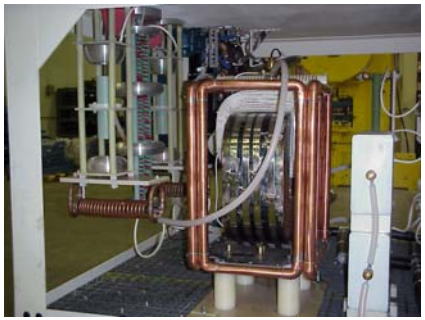
Simplified Block Diagram of Polyphase Resonant 10 MW Pulse Converter Modulator



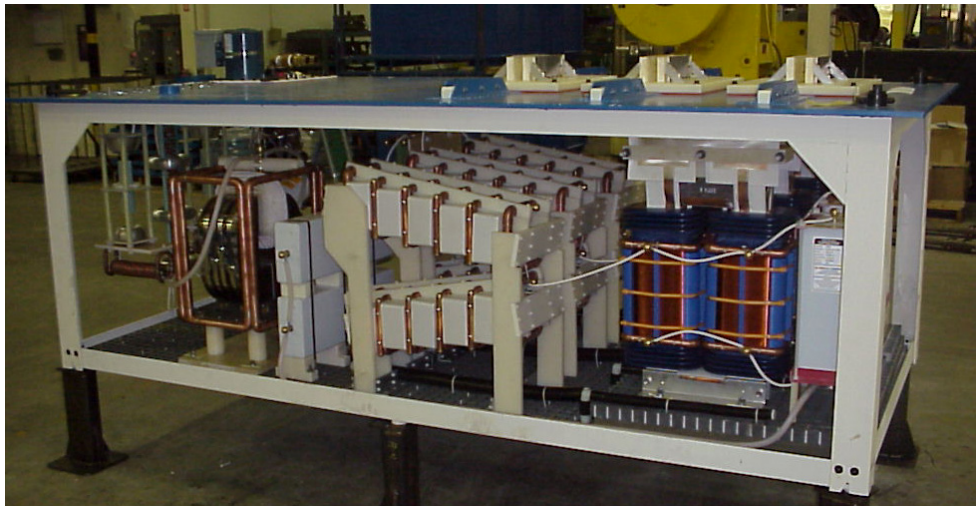
HIGH VOLTAGE
CONVERTER MODULATOR

EQUIPMENT
CONTROL RACK

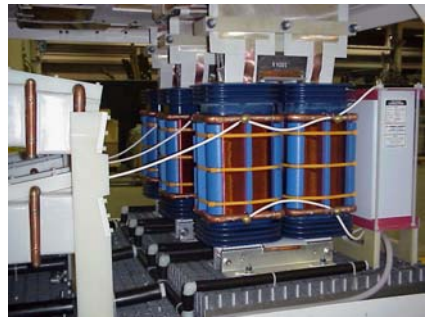
Tank Basket Assembly; 1 MW Average, 10 MW Long Pulse



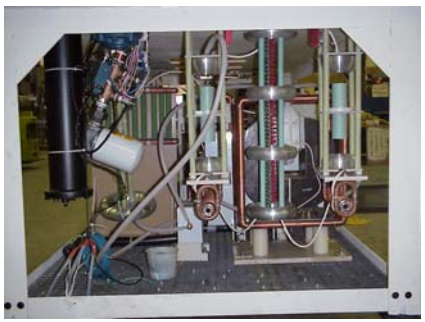
Filter Network



Tank Basket Assembly



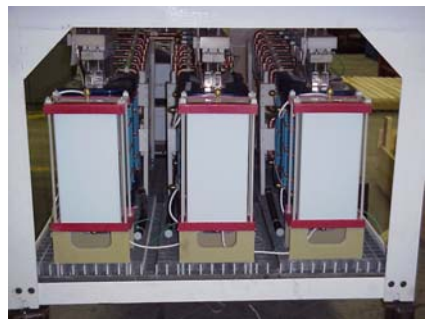
Transformers



Output Sockets
&
Varistor Assembly

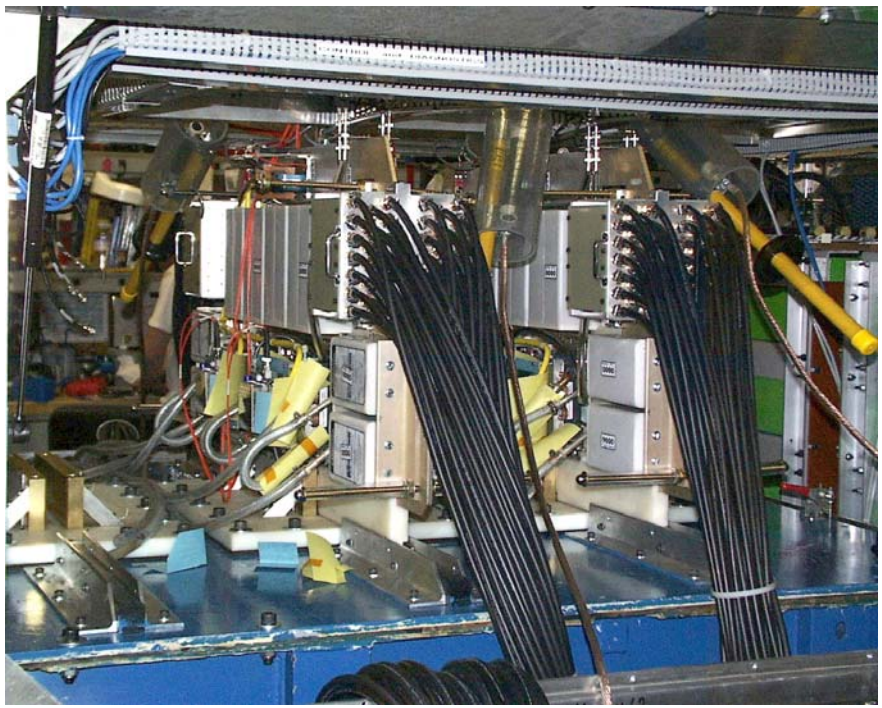
Oil Pump & Voltage Divider

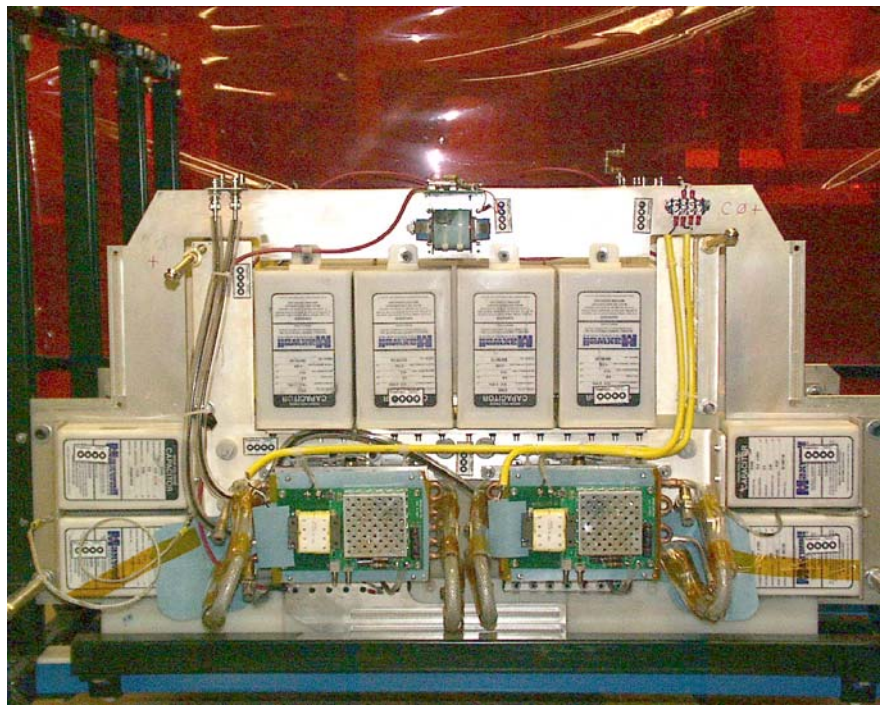
Diode Rectifiers



Transformer Resonating Capacitors

IGBT Switch Plate Assembly; 1 MW Average, 10 MW Long Pulse





- Already operates at 10 MW switching level

Installed HVCM Units

DTL-ME1 with Klystrons

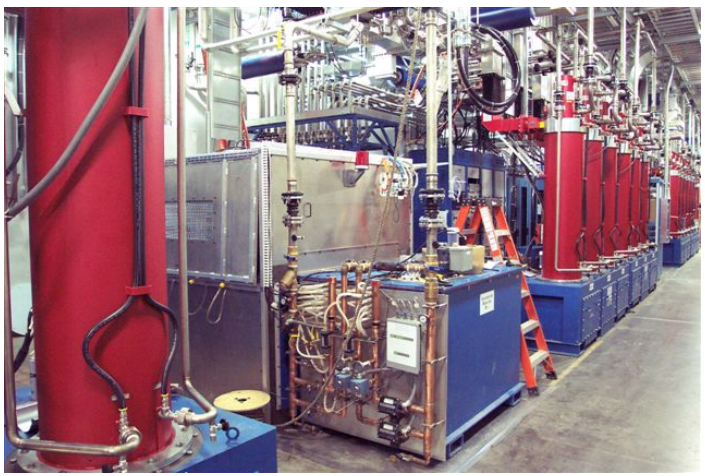
DTL-ME2 with Klystrons

DTL-ME3
with Klystrons
“The Workhorse”

Installed HVCM Units Continued

CCL-ME1 with Klystron

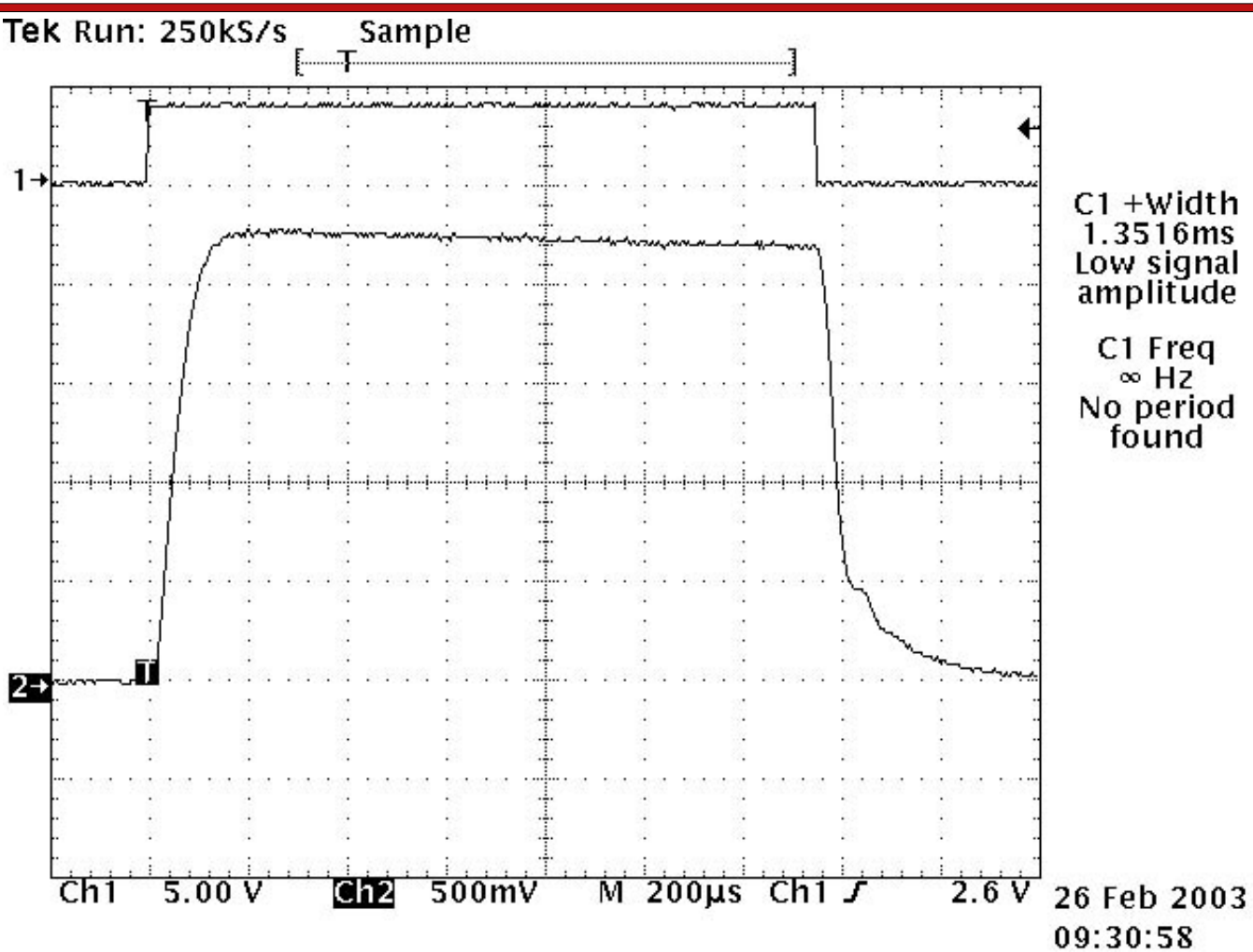
RFTF-ME with Beamstick



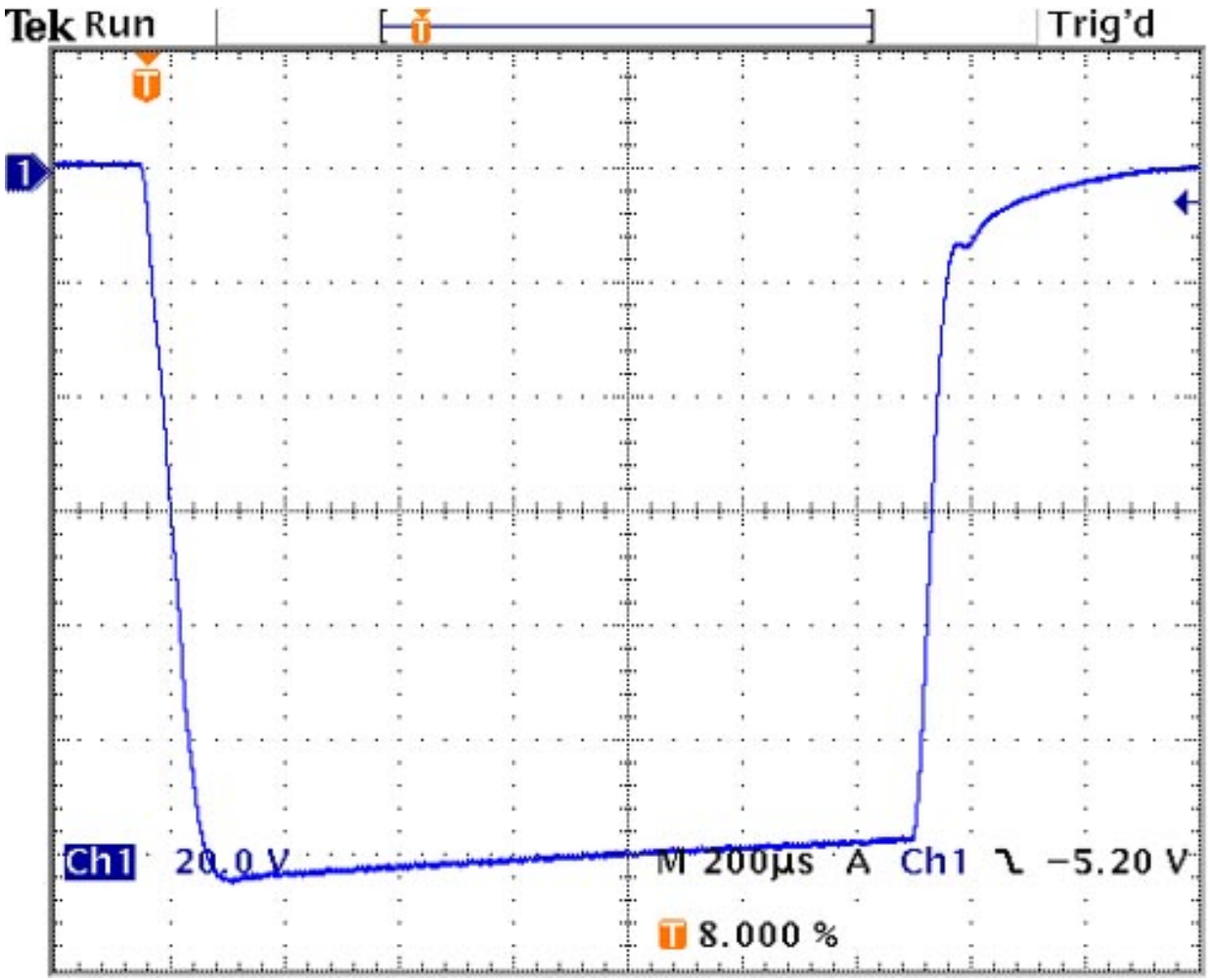
SCL-ME1
with 12 pack

Other units not shown

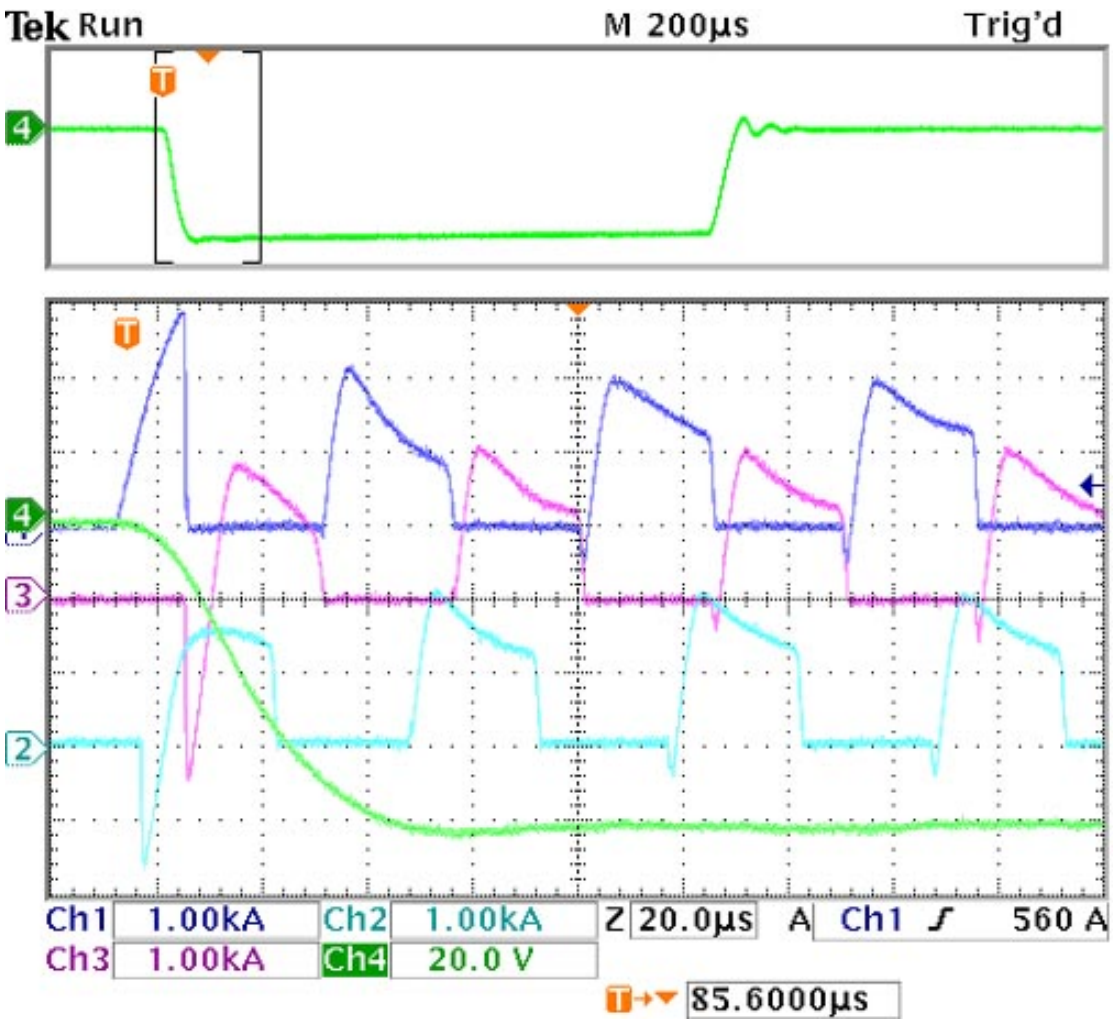
136 kV and 10 MW Output Pulse, 800 KW Average Power



125 kV, 10 MW Pulse for 402 MHz Klystrons



12 Klystron, 75 kV Operation (9.25 MW)



Output Voltage
(~75 kV)

IGBT Switch Current
(1 kA/Div)

Operational Efficiency

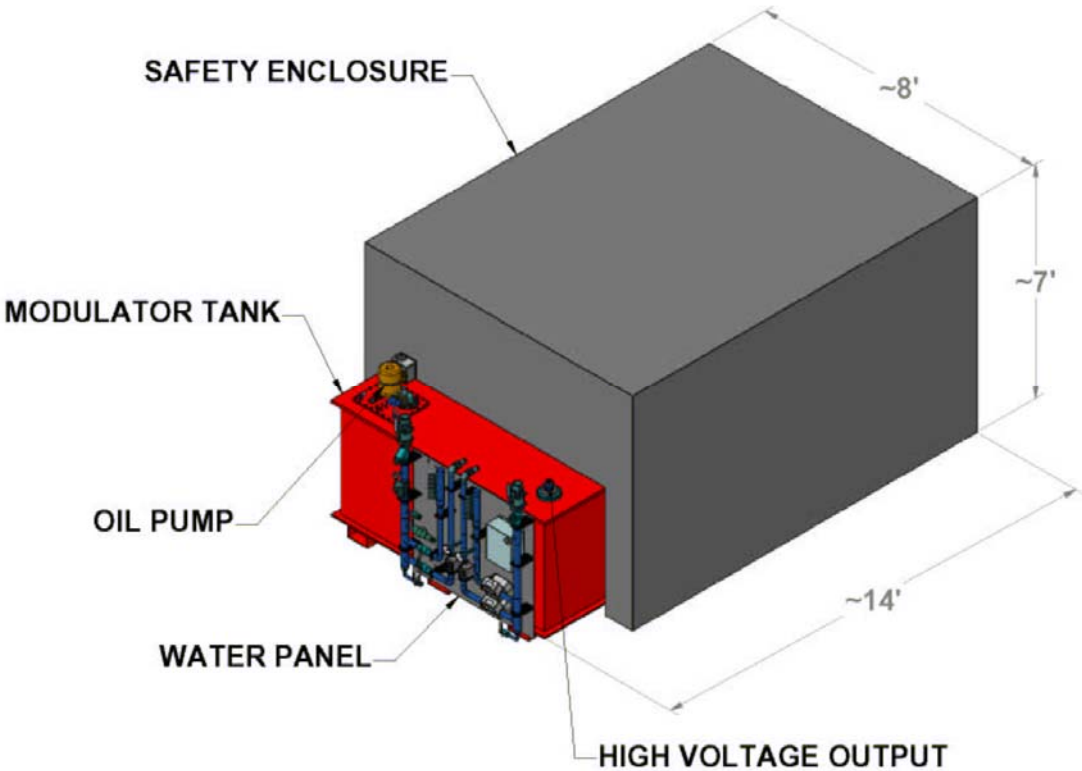
- 140 kV (5 MW Klystron), 800 kW Average Power
  - ~94% efficient
- 75 kV, “12 Pack” (550 kW klystrons)
  - ~93% efficient
- “Zero-Voltage-Switching” works
- Can be optimized to ~96% efficient for ILC Application
- Can Achieve ~90% Overall System Pulse Utilization Efficiency

Capabilities of Polyphase Resonant Conditioning

- Long pulse systems demonstrated
  - 140 kV, 1 MW Average (10 MW Long-Pulse)
  - Efficiency >94%
- CW systems to 10 MW would be reliable
  - Efficiency >97% possible
  - Similar footprint to SNS system
  - Does not require increase in component current or voltage ratings
- ILC Dual Klystron (30 MW) operation is viable
  - Similar footprint as SNS system
  - Can drive standard HV cables over 1 KM
  - Good pulse fidelity and minimal fault energy (see handouts)

View of Proposed 30 MW ILC Pentaphase Converter-Modulator System

Size: 7’ X 8’ X 14’



- Suitable for large high power systems
- Fault tolerant, automatic fault “ride-through”
- Can operate with long output cables (over 1 kilometer)
- Cannot harm klystron
- Multiple units operate from common DC bus

A Historical Perspective of the SNS Project

- SNS had many delays and changes as project started
  - 7 changes in leadership management
  - 2 year delay in determination of LINAC configuration

- This resulted in a very compressed schedule for design, testing, and fabrication
  - Linac installation schedule did not change.

- Converter was in production before it was tested at full average power
  - achieved full average power 2 weeks after 5 MW tube installed

- NO DOUBT, THERE ARE MANY THINGS WE HAVE LEARNED
  - … and now would optimize differently!!!

What I Would Do Differently For the ILC Application (and have solutions for)

- Optimize IGBT Switching Conditions to Minimize Losses
  - More than just resonant tuning changes
- Use New IGBT Control Method to Achieve Perfect “Flat-Top”
  - Present method (PWM) does not work at high average power
- Improve IGBT Fault Protection Methodology
- Solve 75 kV Modulator Acoustic Noise (Loud!!)
  - Change METGLASS choke core
  - METGLASS has highest magnetostriction
- Reduce Harmonic Content of Converter Output
  - Now it is -55 dB, should achieve -65 dB
- Improve Mechanical Assemblies
  - (reduce required assembly skills)

What I Would Do For a Single Tube SLAC Test Stand From an ORNL "Spare"

- Optimize IGBT Switching Conditions to Minimize Losses
  - More than resonant tuning changes
- Rewind Nanocrystalline Boost Transformer
  - Can Also Reduce Winding Peak Field Stress by ~35%
- Redo Resonant Rectifier Racks
- Incorporate (as many) Improvements as Indicated From Previous Slide
  - Budget dependant
- Team as Required to Efficiently Complete Job

Conclusion

- Polyphase Resonant Power Conditioning design topology and techniques now proven
- Designs can be optimized for any load
- Inherently self and load protective
- Significant change in high power, power conditioning topology
- Testing, teaming, and prototypes desired for ILC application
- Design is very cost effective and efficient