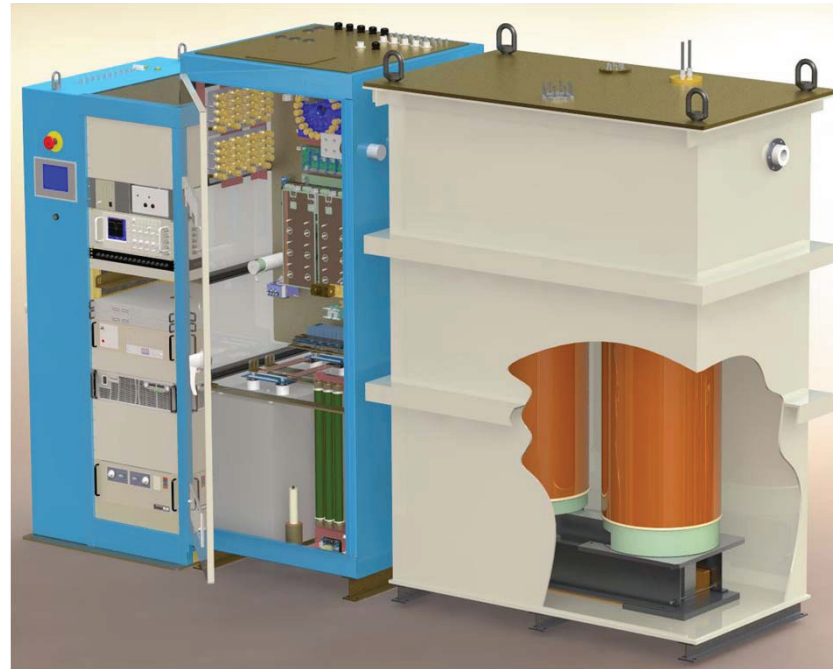


# *Regulator / Hard Switch Modulator*

Ian Roth, Neal Butler, Marcel Gaudreau, Michael Kempkes  
Diversified Technologies, Inc.



# *Modulator Specs*

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- 100 kV
- 50 A
- 3.5 ms
- 1% droop
- 14 Hz capability
  - Limited by 5 kW supply for tube conditioning
- Objectives
  - Condition klystron tubes for SNS
  - Demonstrate technology for ESS

# Modulators for SC Accelerators

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	Voltage (kV)	Current (A)	Time (ms)	E Pulse (kJ)	Freq (Hz)	P average (kW)
SNS	85	165	1.5	21	60	1300
ESS	115	50	3.5	20	14	280
XFEL	110	130	1.4	20	10	200
ILC	115	133	1.6	25	5	130
Project X	33	20	30	20	10	200

- All require 1% droop

# ***Drop Compensation Necessary***

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- Without compensation,  
20 kJ pulse, 1% droop  $\Rightarrow$  1 MJ capacitor
  - 3.2 m<sup>3</sup>, too large to be practical
- With compensation  
15% droop  $\Rightarrow$  67 kJ capacitor
  - 0.21 m<sup>3</sup>, reasonable size

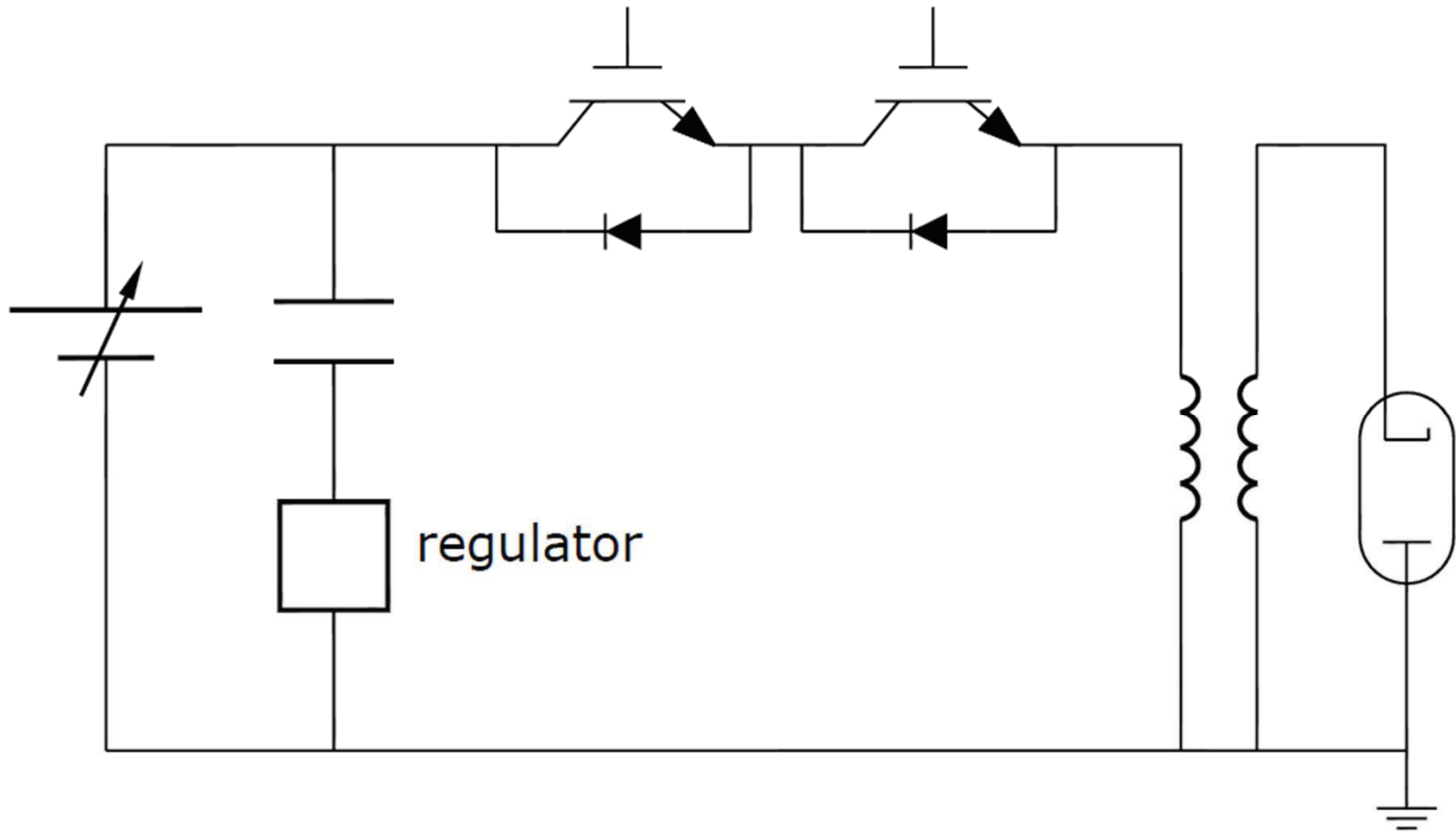
# ***Droop Compensation Architectures***

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- Converter Modulator, SNS
- LC Bouncer, FNAL / DESY / DTI
- Pulse Step Modulator, XFEL
- Marx, SLAC / DTI
  
- Regulator / Hard Switch Modulator, DTI
  - Less expensive
  - No flicker

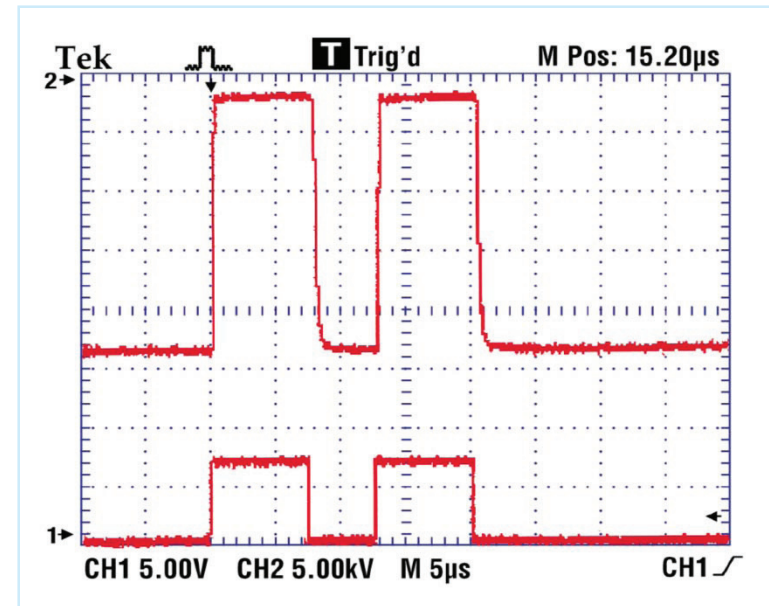
# Modulator Architecture

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# DTI Series Switch

- Series string of transistors
  - Operate synchronously
  - DTI-patented design
- Demonstrated
  - 200 kV
  - 10 kA
  - Pulse width 50 ns – DC
  - 100 kHz



# *Series IGBTs Redundant*

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- 20% more IGBTs than required
- Switch still operates when extra devices short
  - Short is failure mode
- Number of bad IGBTs monitored
  - Allows scheduling repairs



# ***Switch Option 1: Full Voltage***

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- Switch at 100 kV, 50 A
- Discrete IGBTs
- + / - Oil insulated
- + Fast rise
- + Compact



10 kV, 110 A plate

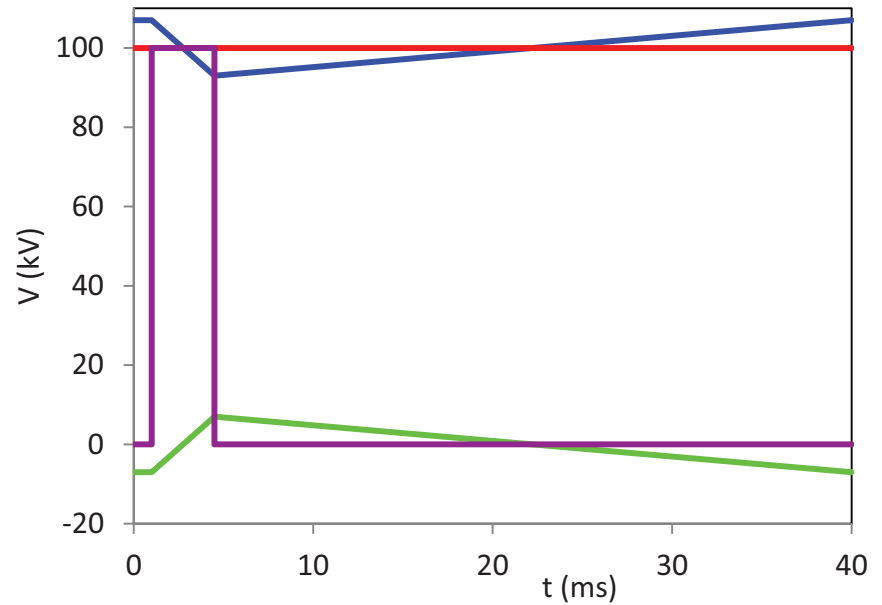
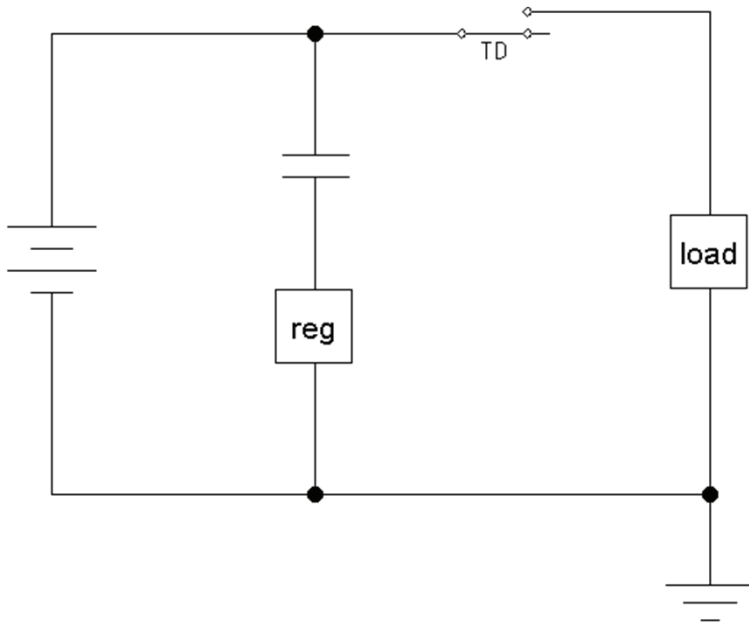
# Switch Option 2: With Transformer

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- Switch at 6 kV, 830 A
- Module IGBTs
- Cold plate cooling
- + Air insulated
- Large transformer
- Slow rise
- European Spallation Source prefers using transformer



# Regulator Waveforms

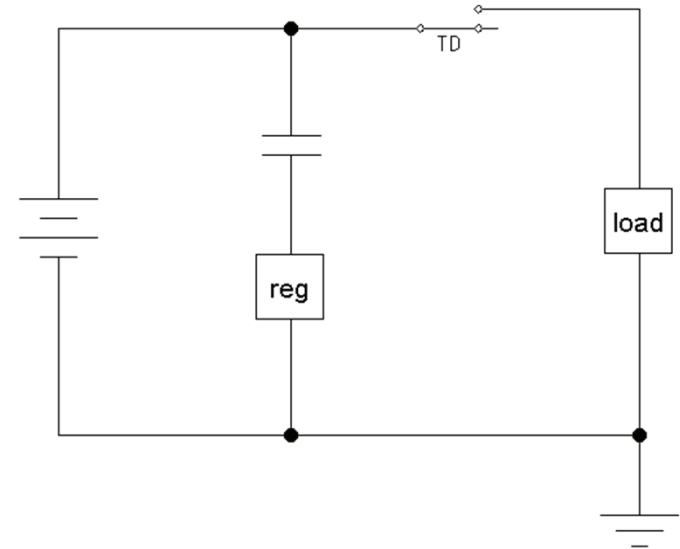


- Regulator keeps  $V_{\text{load}}$ ,  $V_{\text{power supply}}$  flat

# Regulator Properties

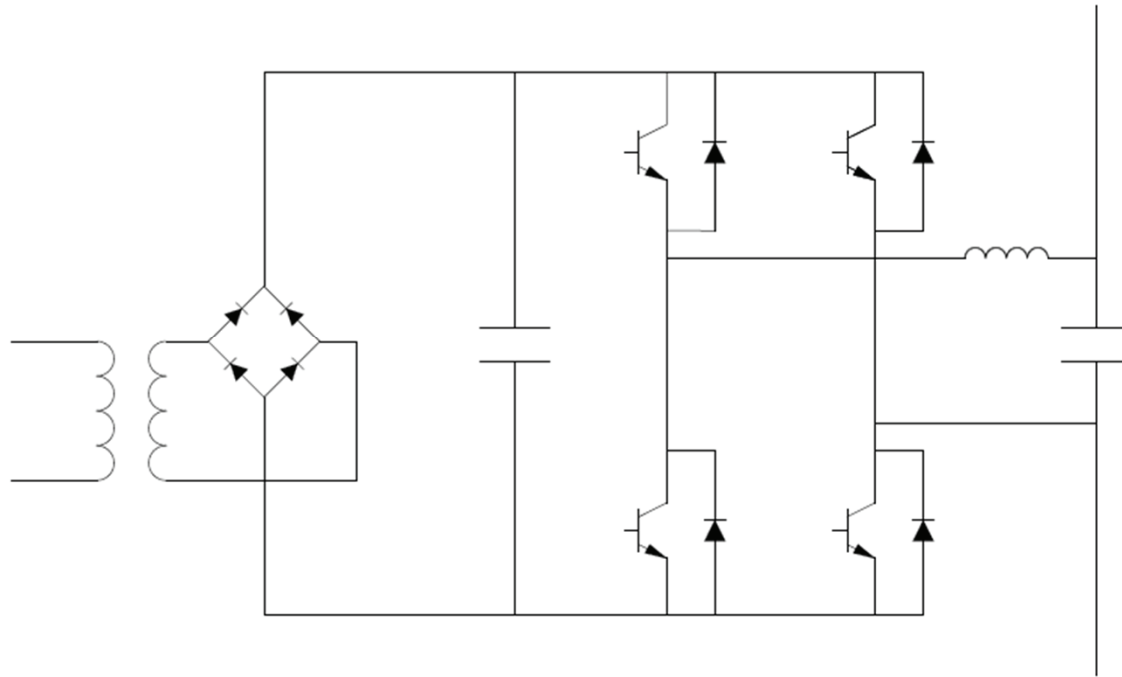
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- Regulator output  $\leq 7.5\% V_{\text{load}}$   
 $\Rightarrow$  small regulator
- Constant voltage, power supply charges continuously  
 $\Rightarrow$  no flicker
- Regulator does not supply net power
- Patent applied for



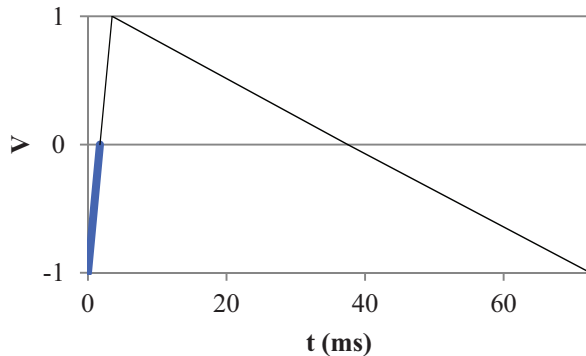
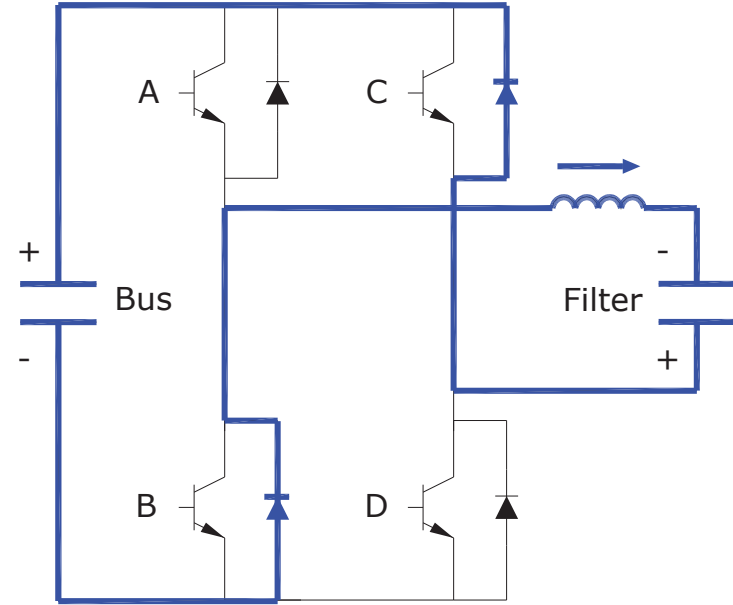
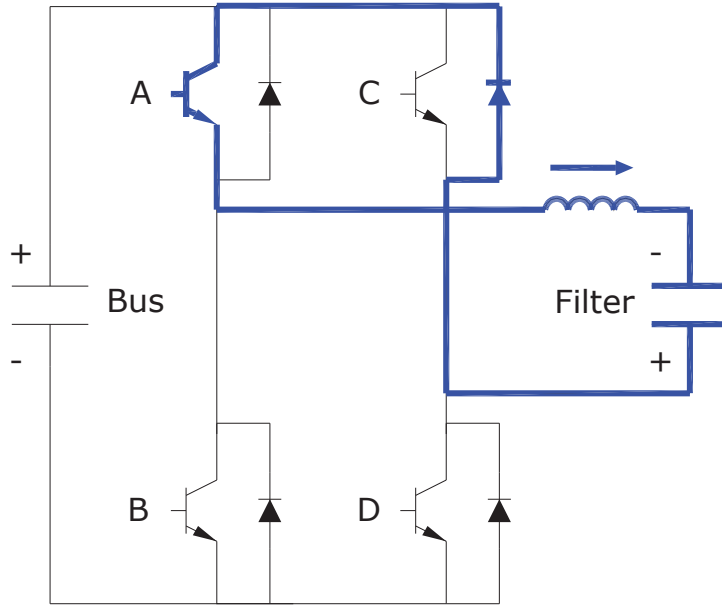
# *Regulator is Full-Bridge*

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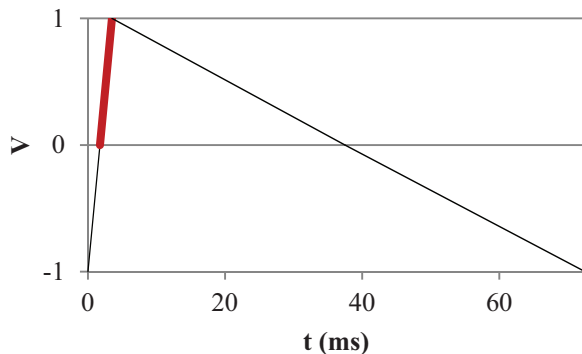
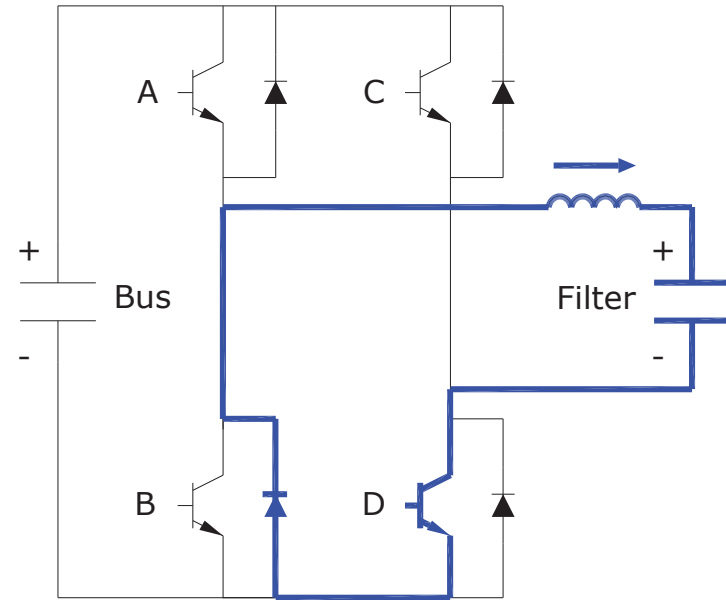
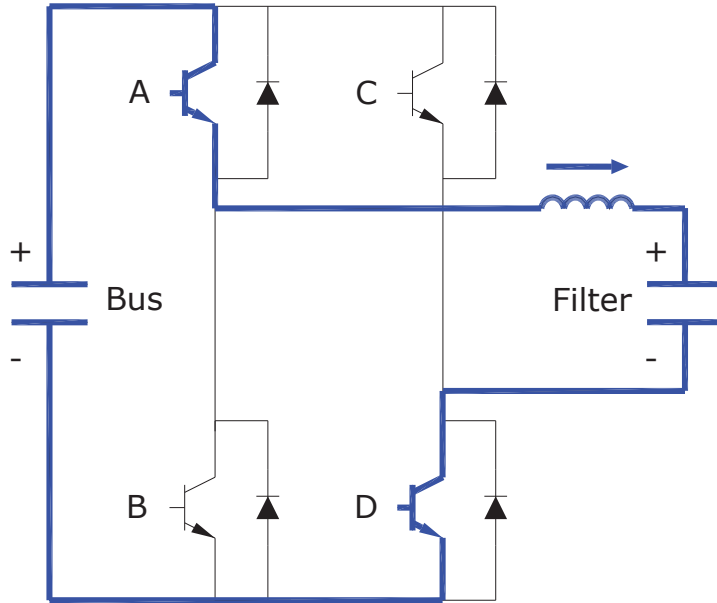
- Two bridges in parallel
- Regulator output  $\pm 500$  V
- 100 kHz during pulse, 5 kHz during charge

# Reg Operation First Half of Pulse



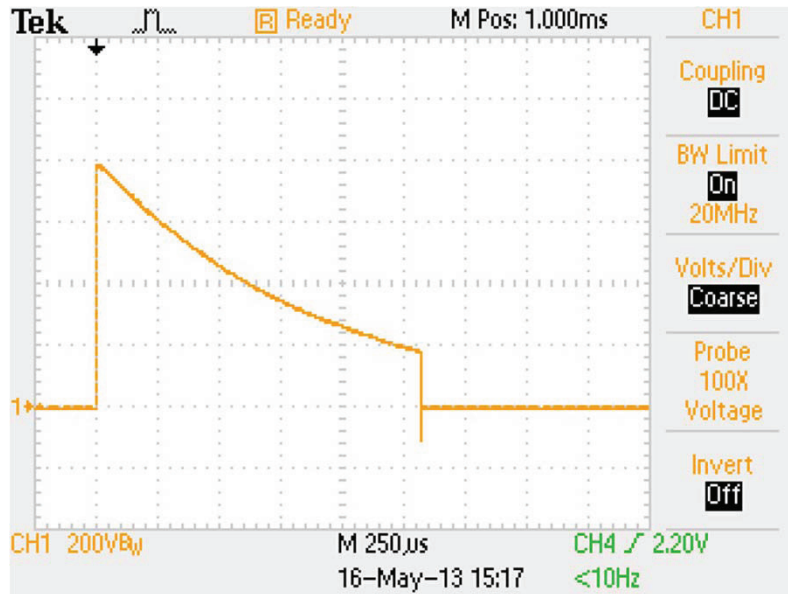
- Acts as boost regulator
- Transfers energy from filter cap (main cap) to bus cap

# Reg Operation Second Half of Pulse

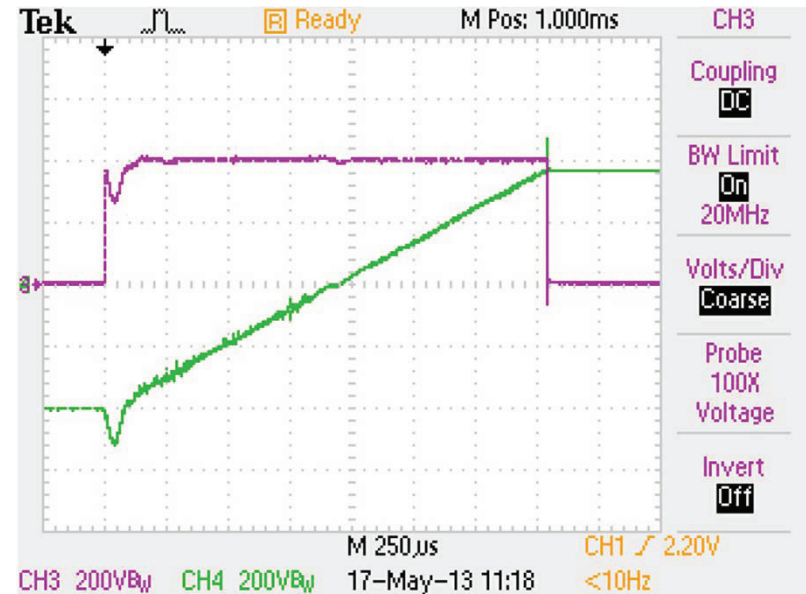


- Acts as buck regulator
- Transfers energy from bus cap to filter cap (to load)

# Regulator Full-Output Tests



V output, no regulator  
200 V/div  
250  $\mu$ s/div  
50 A



V output with regulator (purple)  
V regulator (green)  
 $\pm 400$  V regulator authority  
Dip from initial drop across switch;  
adjust feedback



# *Power Supply*

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- 5 kW Glassman supply for this tube-conditioning modulator
- For large modulator, 280 kW
  - Switching supply or
  - T/R set with SCR controls (no flicker)
    - Much less expensive, but worse power factor

# 67 kJ Capacitor

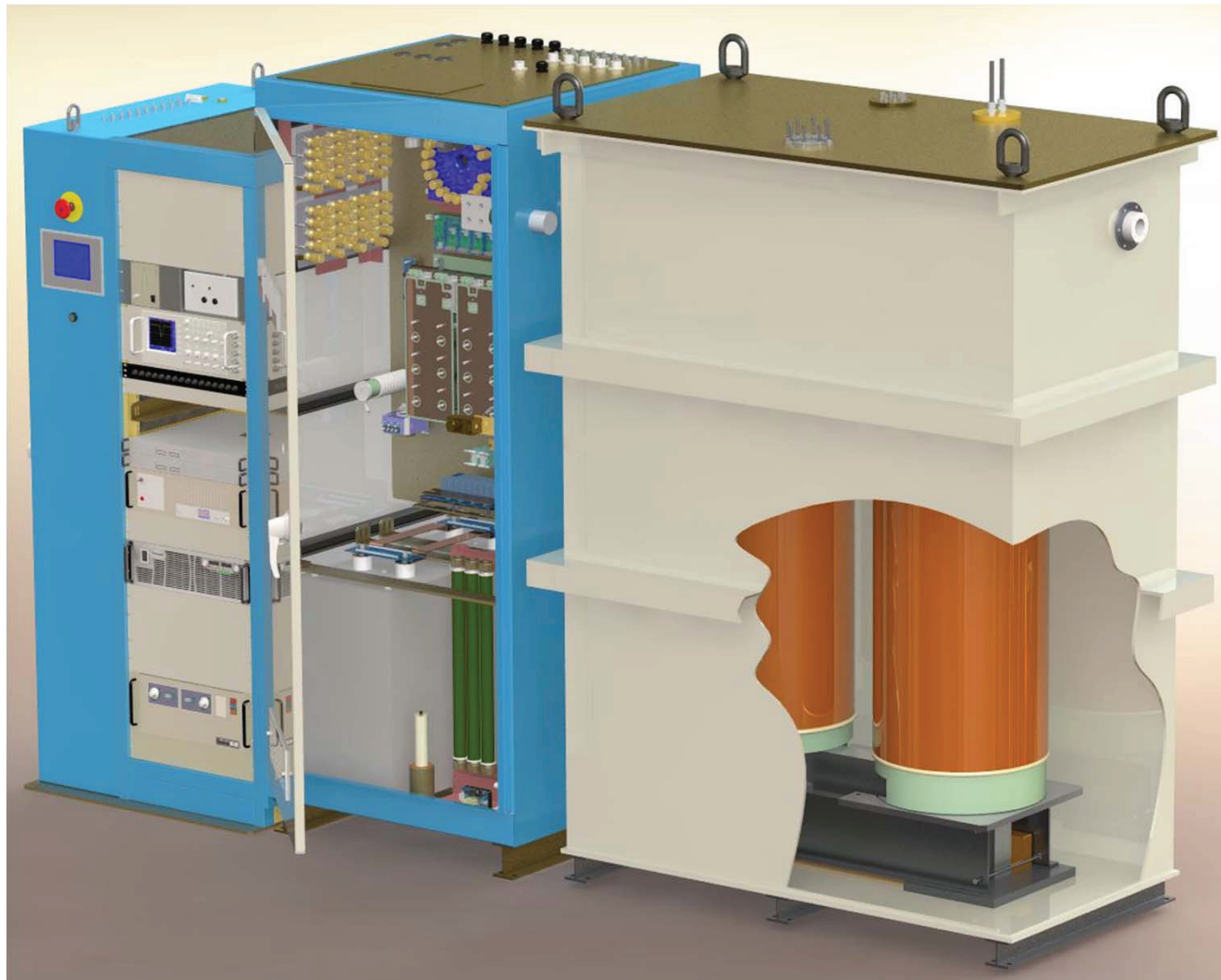
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- Capacitor uses metallized film
  - Lower cost than film-foil
  - Possible since RMS current is low



# ***Mechanical Layout***

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# *Status*

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- Regulator control demonstrated
- Switching cabinet being assembled
- Transformer ordered
- System to be installed at SNS / Oak Ridge in early 2014

# Conclusions

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## Series switch

- Redundant devices  $\Rightarrow$  high reliability

## Regulator

- Only  $\pm 7.5\%$  voltage  $\Rightarrow$  small, lower cost
- Eliminates flicker
- Allows low-cost T-R / SCR power supply

# ***Acknowledgements***

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- Eliane Lessner, DOE
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- David Anderson, SNS

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DE-SC00004254

# ***Thank You For Listening***

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