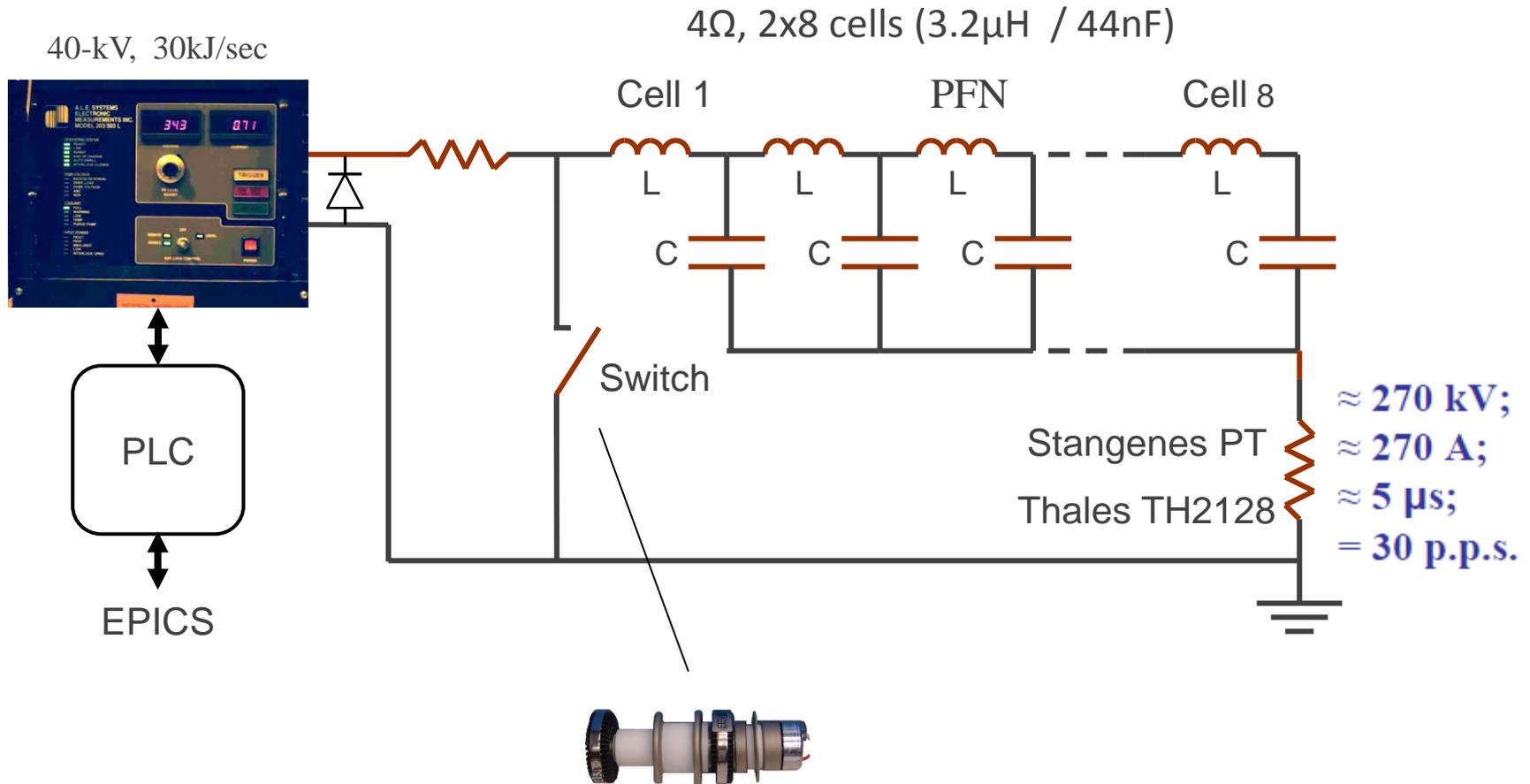


# Improvements to the APS LINAC and SR/Booster klystron HVPS, and Accomplishments of the 352MHz RFTS

G. Trento  
Accelerator Systems Division  
Argonne National Laboratory

Work supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11357.

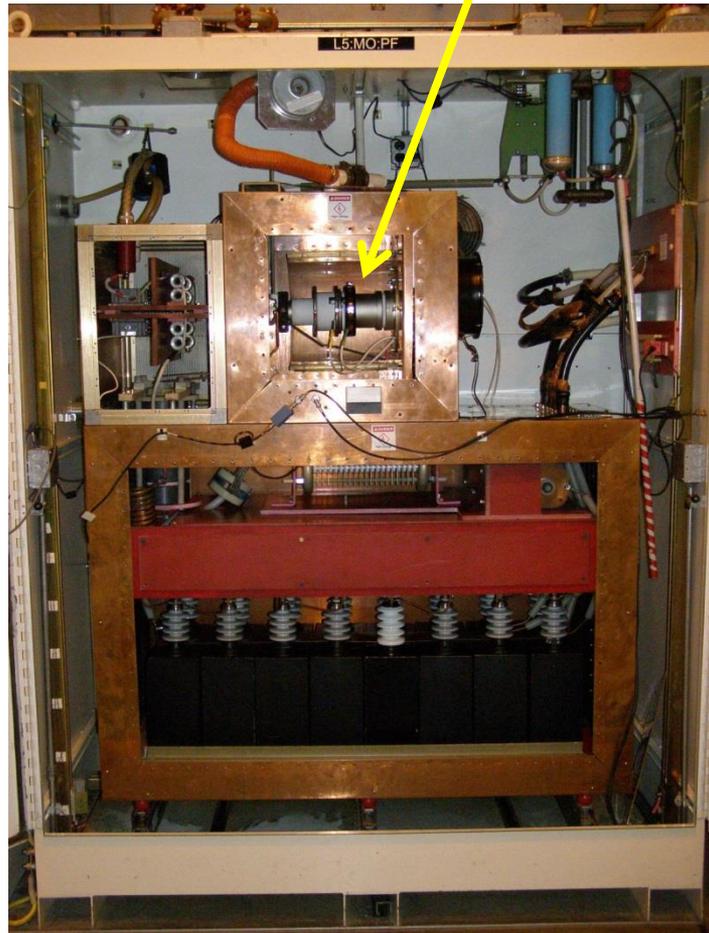
# LINAC Modulator



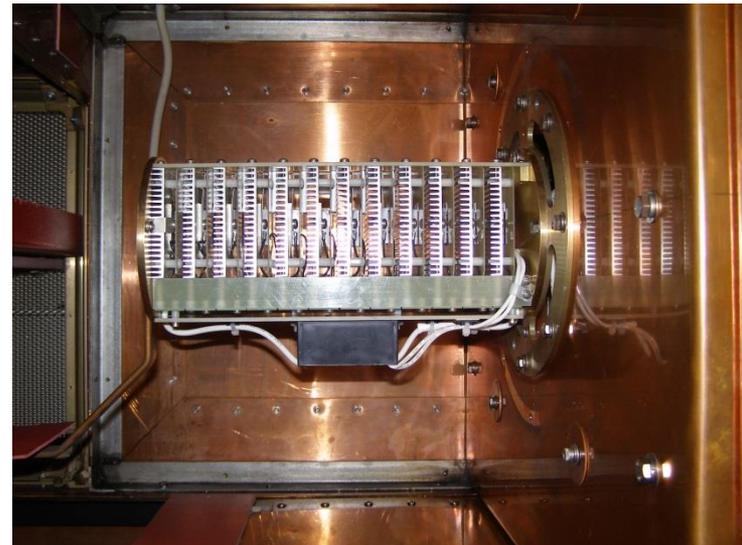
E2V Thyatron CX1836A

# Modulator PFN Cabinet Internals

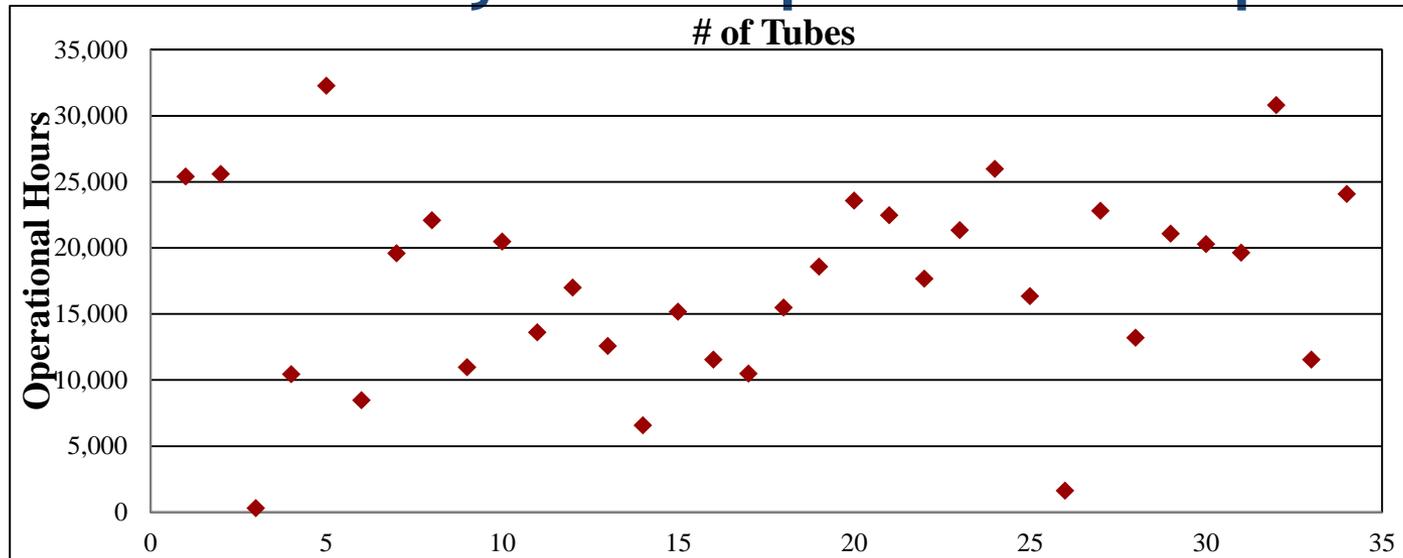
## CX1863A Thyatron



## S56-12 Thyristor



# CX1836A Thyratron Operation Lifespan



- Unpredictable life span
- Short average life time: 17,300 hrs.
- High tube consumption rate: 2.4 tubes/year
- Growing tube price: \$18,300 as of April 2012
- High filament energy consumption: 26,000 kW\*hrs./year
- 2012 operating cost: \$46,000
- High-voltage triggering pulses: up to 1,500 V

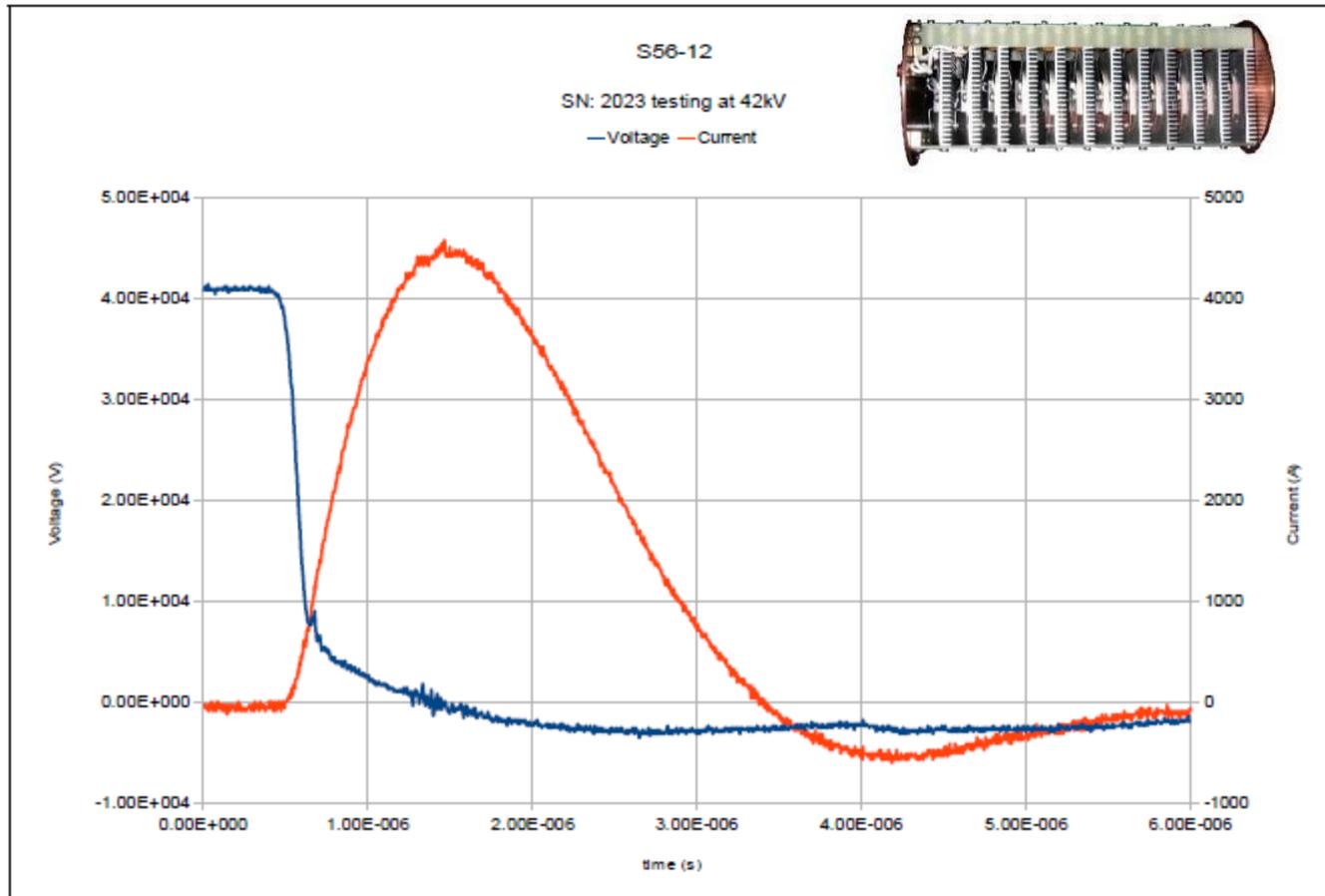
# Thyratron vs. Solid-State Switch

	Thyratron	Solid-State Switch
Peak Forward Voltage, kV	70	48 (60)*
Peak Anode Current, kA	10	7 (10)*
Rate of Rise (di/dt), kA/ $\mu$ s	10	30
Triggering Pulses	Up to 1,500 V	Fiber-optic & 24V
Filament Power, Watts	610	0

\* Numbers in the parentheses are for non-repetitive voltage or current.



# S56-12 Solid State Thyatron Replacement 10K Pulses @1pps, 42kV and 4500A



Courtesy of H. Sanders



# Thyratron vs. Solid-State Switch cont.

	<b>Thyratron</b>	<b>Solid-State Switch</b>
Unit Price	~ \$18,300 US	~ \$9,000 US
Average Life Time, hrs.	17,300	Theoretically much longer
Switch Failures per Year	2.4	~ 0 (?)
Annual Operating Cost	~ \$46,000 (6 RF Stations)	~ \$5 (?)
Triggering Pulses	Up to 1,500 V	Fiber-optic
Repairable	<b>No</b>	<b>Yes</b>
Chemical Waste Problems	<b>Yes</b>	<b>No</b>
Local Representatives	<b>No</b>	<b>Yes</b>

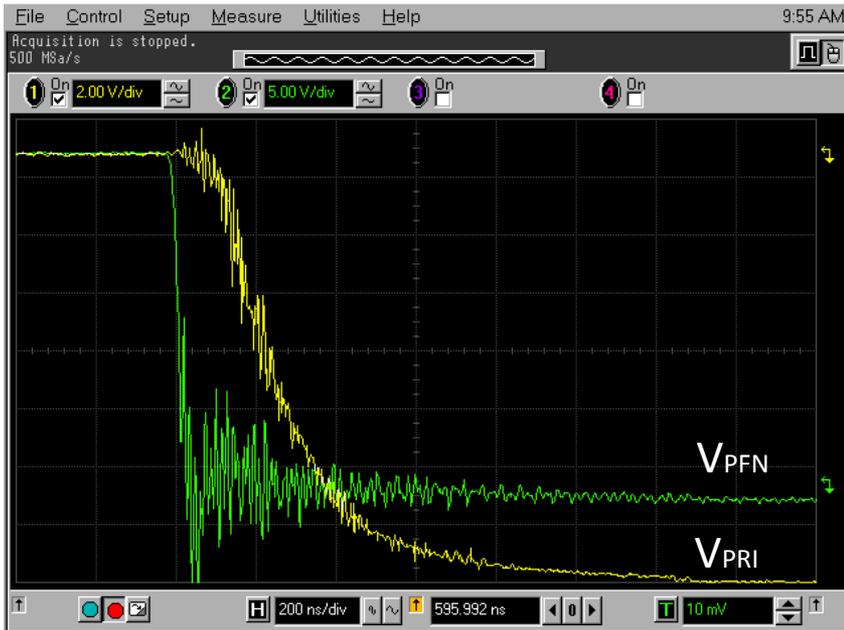
S56-12 Thyristor installed within Modulator L3 has ~ 9k hours of operation.

# 28KV PFN WAVEFORM

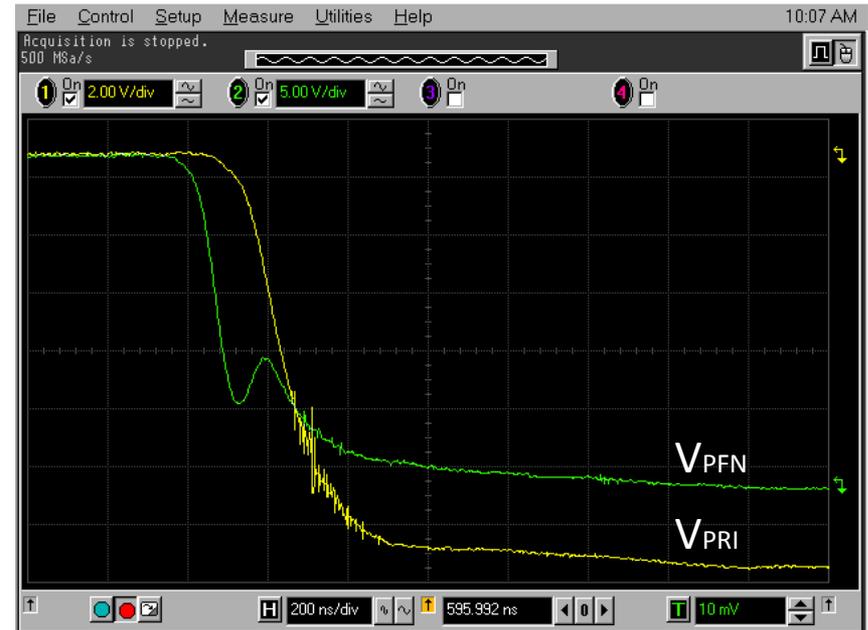
## Thyratron versus Solid-State Switch

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Modulator 4



Modulator 3

# PFN Capacitor - Original Exceeded 100x Lifetime Specification



Old & New PFN Capacitor

# Modulator Control System

## Old: Allen-Bradley Controller

- Obsolete PLC hardware & chipset.
- Obsolete cathode ray tube HMI.
- Obsolete PLC software.
- Obsolete HMI software.
- Communication protocol no longer supported by EPICS.



## New: Automation Direct Controller

- New PLC hardware & chipset.
- LCD HMI – long lasting.
- Current PLC low cost software.
- Free HMI software.
- EPICS supported driver.
- Low cost hardware.



# Modulator Control System cont.

## Old: Allen-Bradley Controller

- Limited amount of information transmitted PLC↔EPICS, quantity 128 - 16 bit words.
- Table transfer - discrete and integers (16 bit).
- Open Frame.



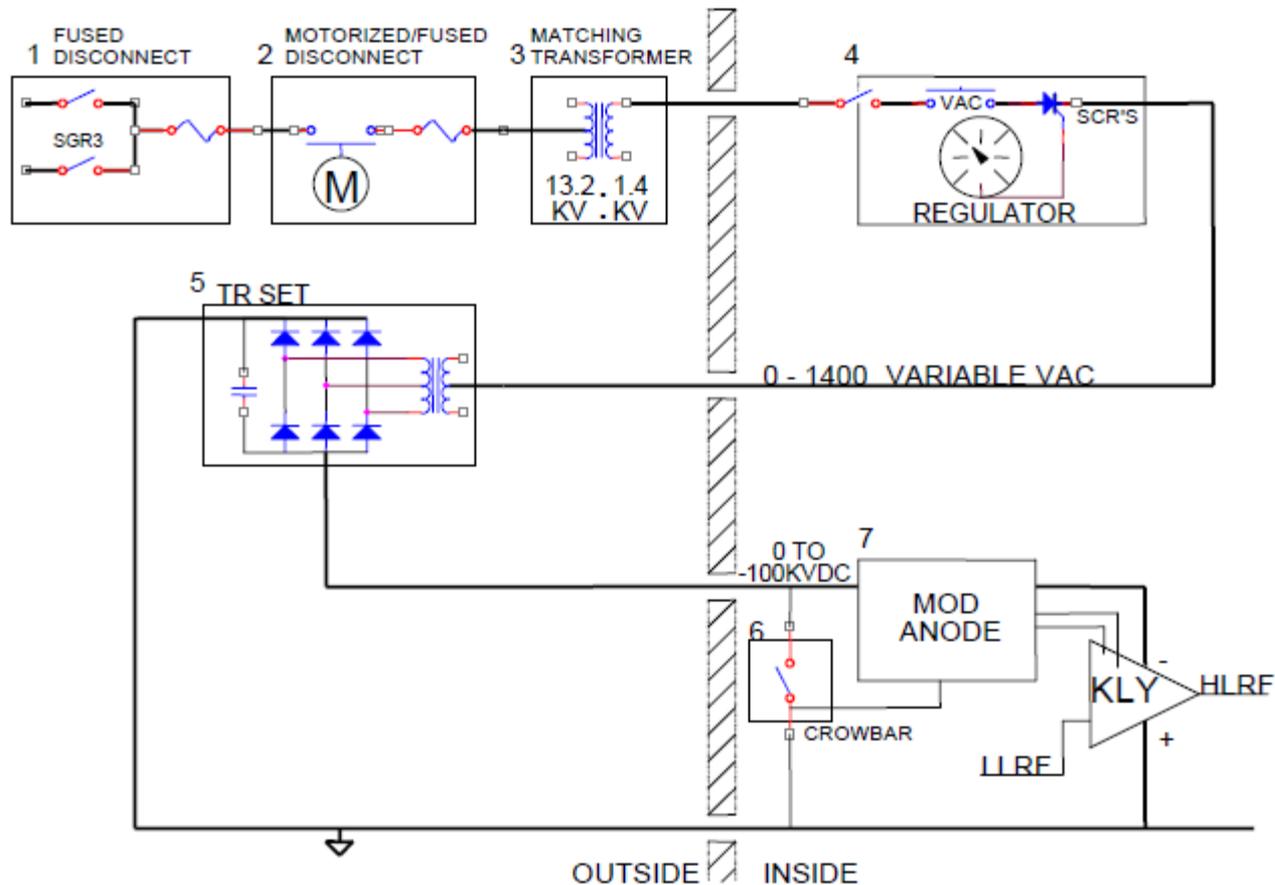
## New: Automation Direct Controller

- Large amount of information transmitted via floating point (32 bit) and discrete.
- Microprocessor monitored by EPICS.
- RF Group standardized PLC.
- Chassis construction with filtered connectors.
- Last unit installed May 2014.



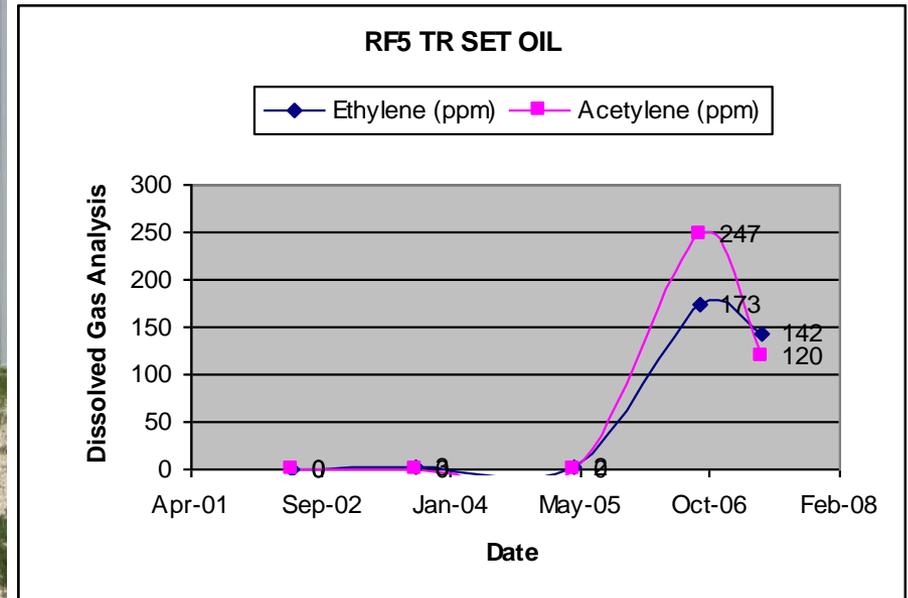
# 2MW DC POWER SYSTEM FOR SR / BOOSTER

## 116k → 150k Hours of Operation



# Transformer / Rectifier Capacitors

## Completed T/R Set Repairs 2013

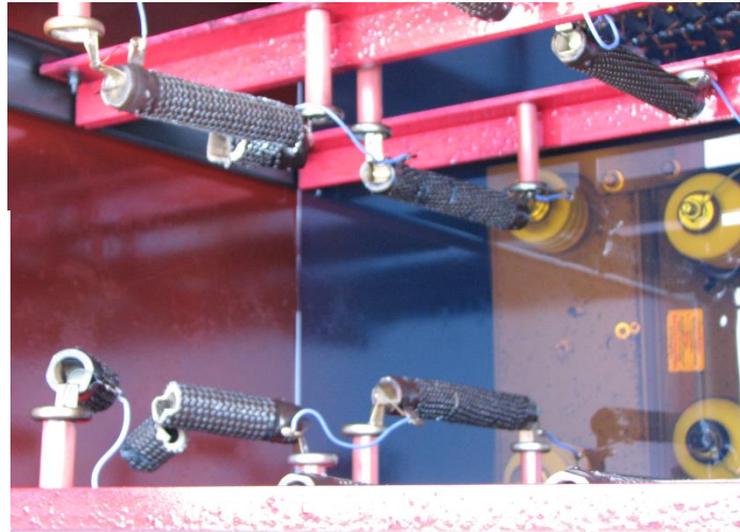
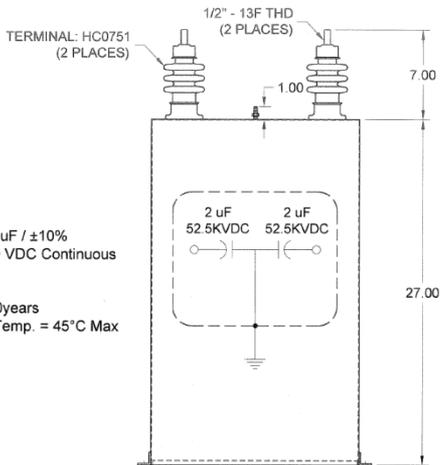


Acetylene – severe arcing activities

Ethylene – overheated oil

# RF5 Example

- 1 Failed capacitor.
- 4 Damaged 16Ω, 300W resistors.
- Loose transformer ground connection.
- Carbon deposits on components and walls.
- Loose transformer core block hardware.
- ~1% of diodes damaged.



# 2MW DC KPS Control Interface

## Old: Manufacture Design

- Obsolete boards and ICs
- 486 PC running Windows95 GUI
- Proprietary E<sup>2</sup>PROM program
- GPIB communication error
- No longer supported by manufacture



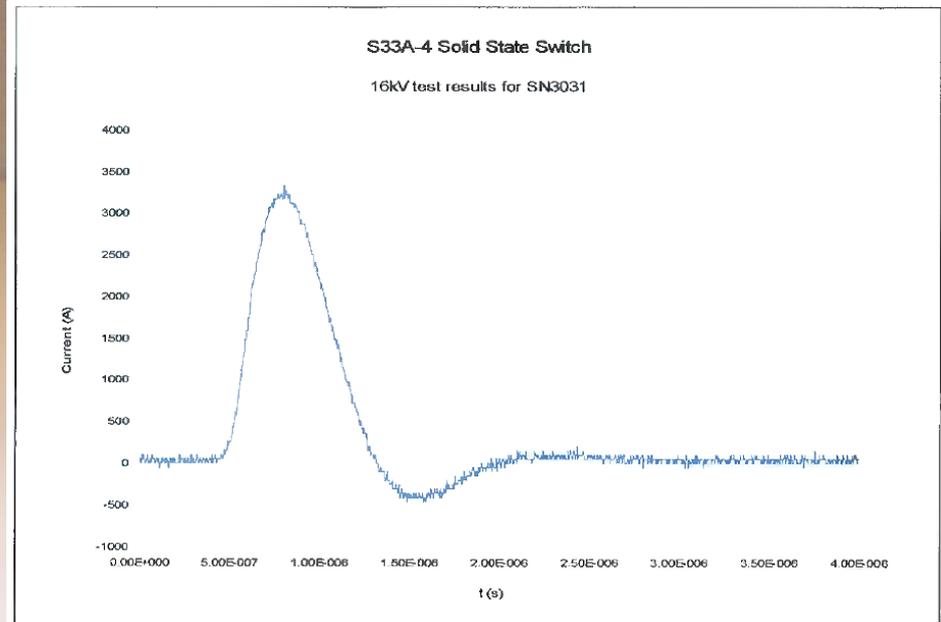
## New: Automation Direct Controller

- Same details as LINAC Modulator Controller
- Final unit installed 2013.



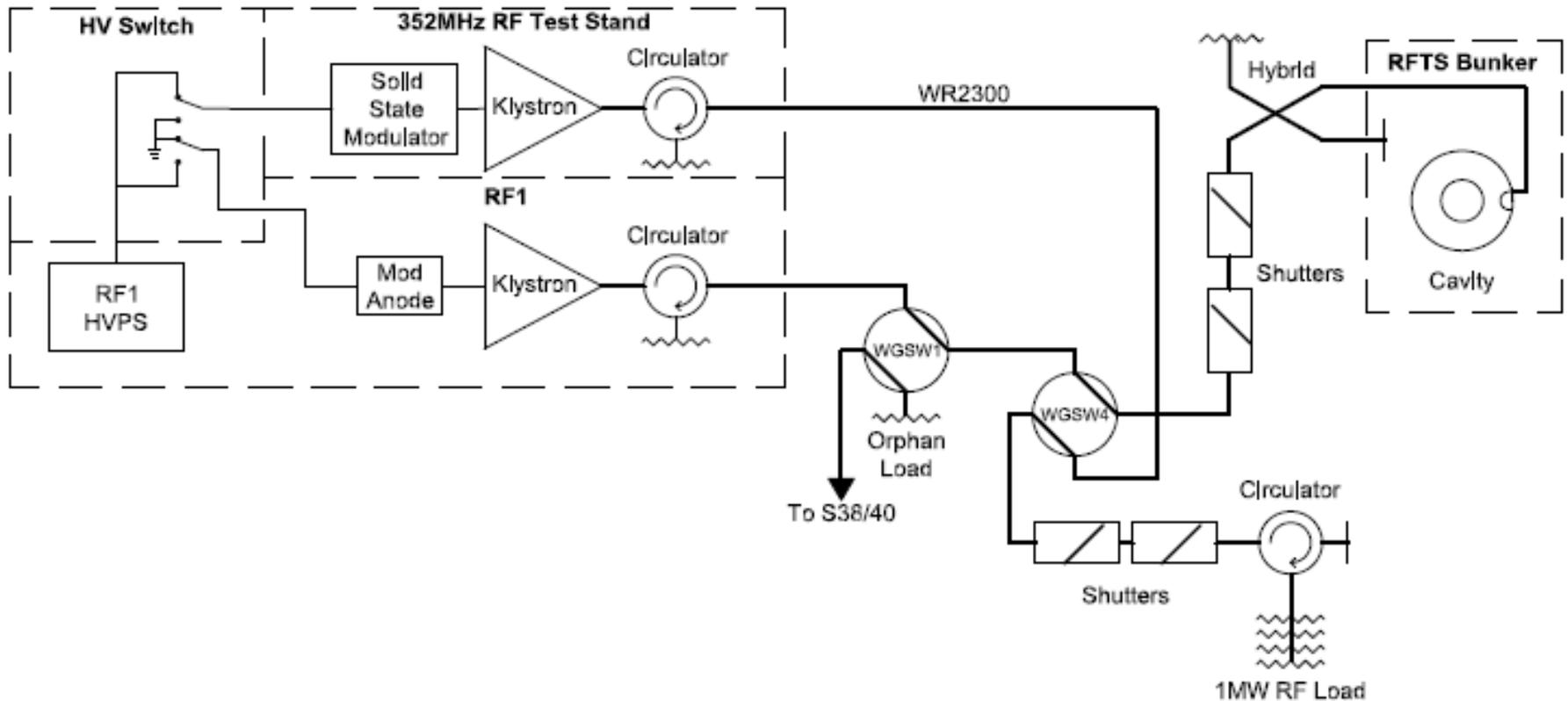
# Crowbar Ignitron Trigger

5C22 → JAN8613 → S33A-4



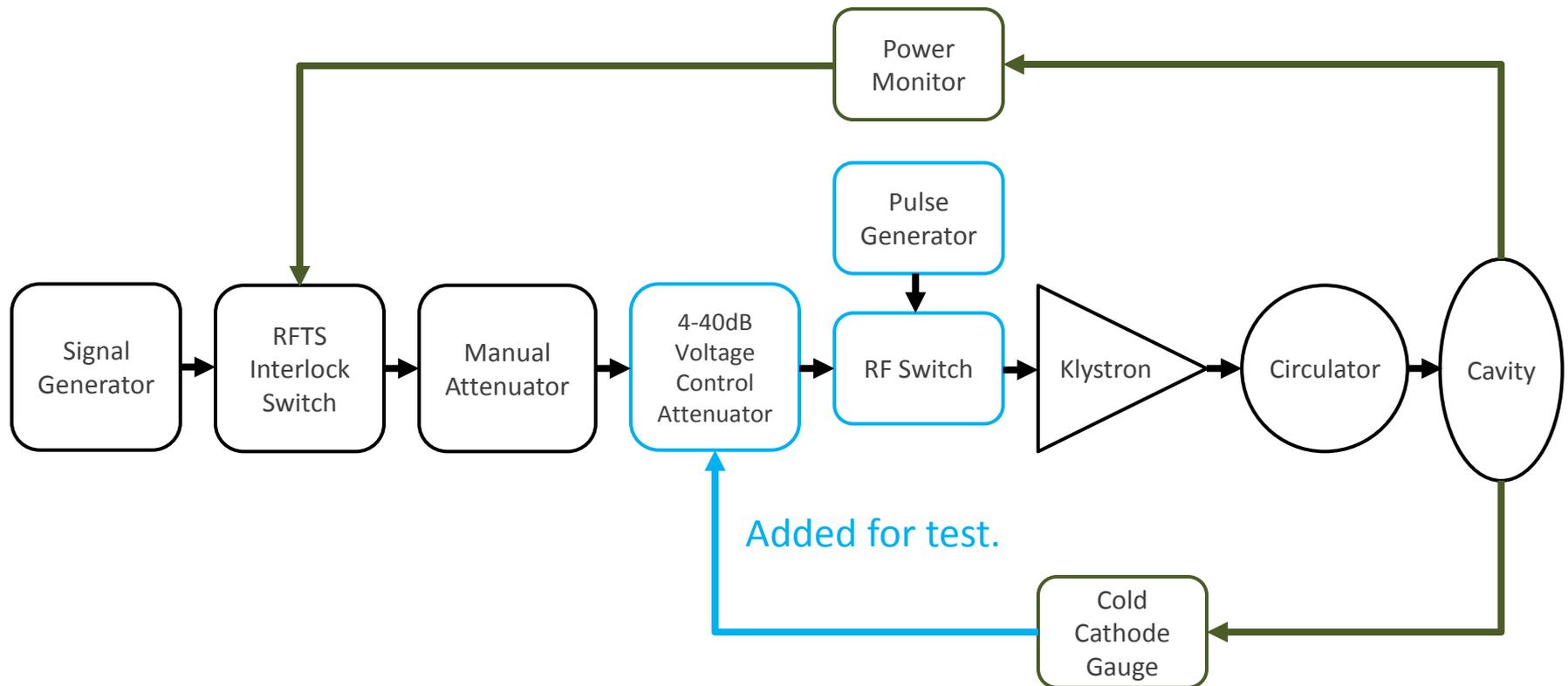
Vendor's test data 16-kV @3.2-kA<sub>pk</sub>

# 352MHz RFTS Line Diagram



# Pulsed-Mode Conditioning Test

20,50,100,200,500 $\mu$ S; 1,2,5,10mS with 20mS R.R.  
...Then CW



# RFTS Conditioning Method Comparison to Achieve 100kW CW

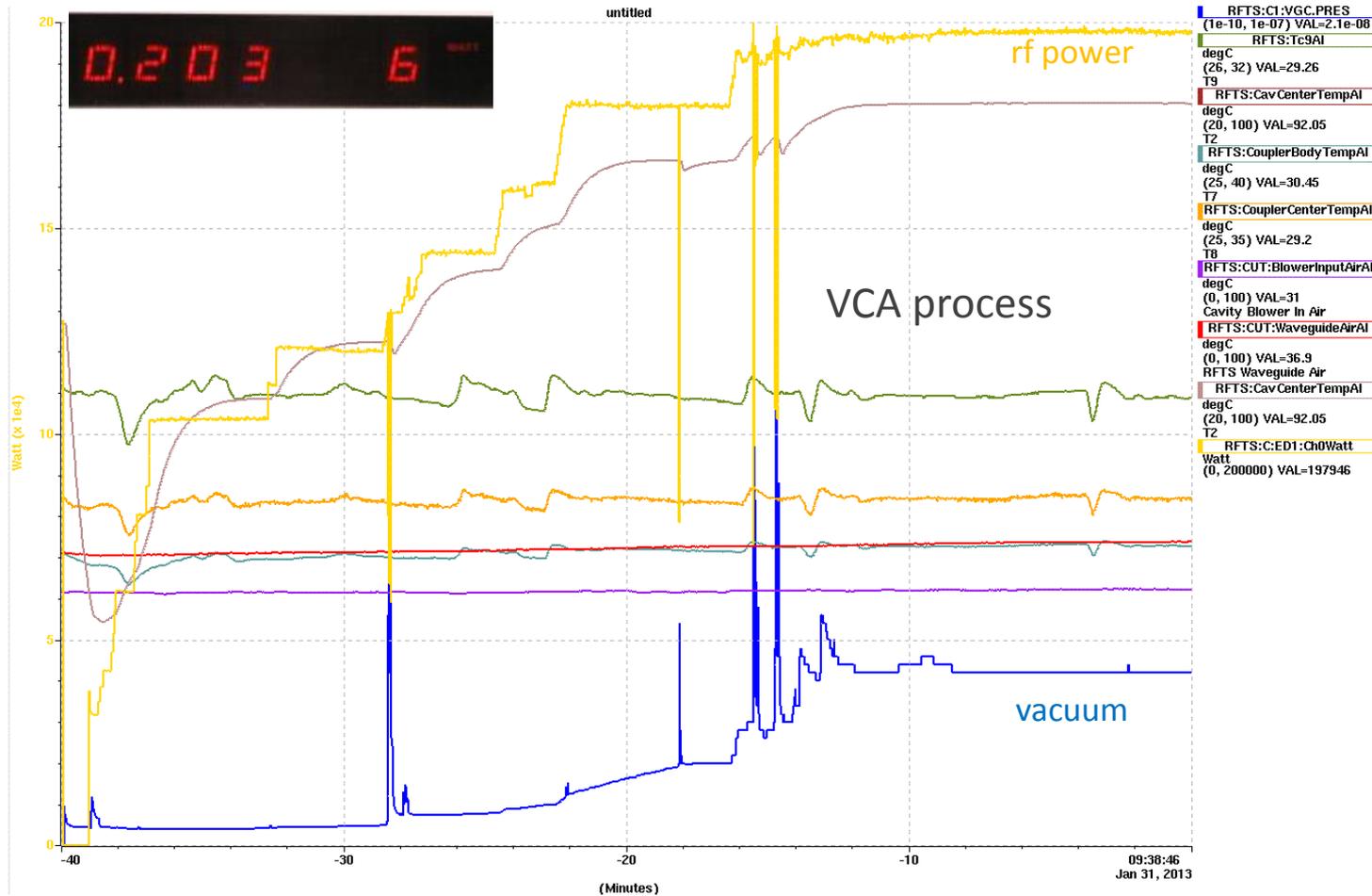
## CW ONLY

FPC ID#	Conditioning Hours
ANL-B01	453
ANL-22	496
ANL-23	473

## Pulsed → CW

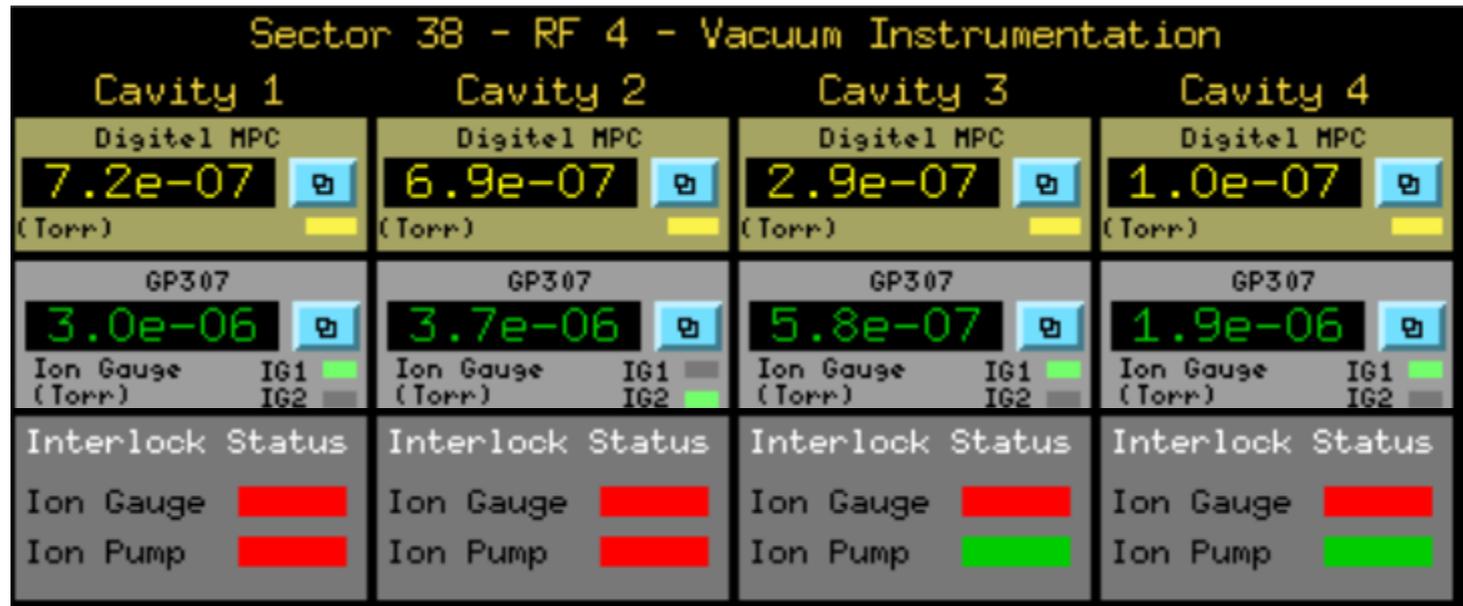
Component	Conditioning Hours
FPC C2	48
Tuner ANL-09	54
FPC ANL-25	44
FPC ANL-26	53

# FPC C2 & RFTS CW Test



RFTS Shielding -TLD Deep Dose 11 mR/h at door/window.

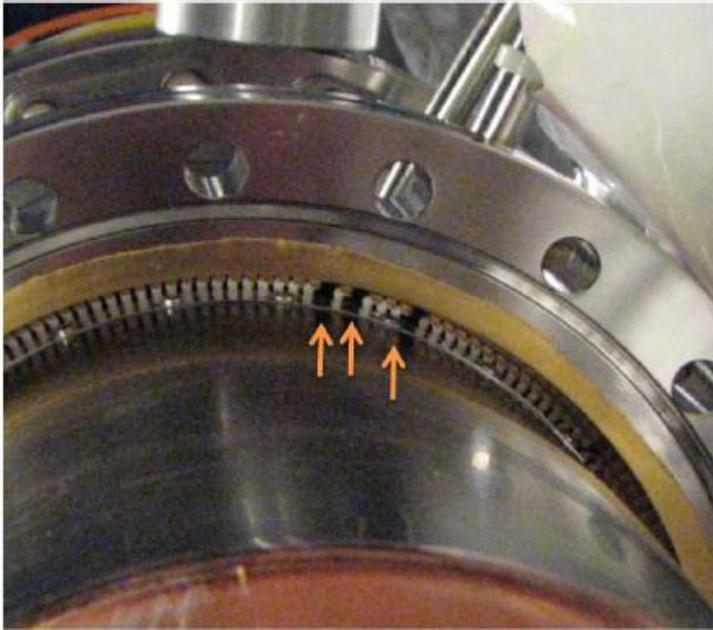
# S38 Cavity Pressure Run 2013-2 Machine Start-up Trip Levels are 5e-8 Torr



S38 Cavity 1	Fundamental Power Coupler	Mechanical Tuner	High Order Mode Damper
Component Removed	MTM-11	ANL-21	535ED-05
Component Installed	ANL-24	ANL-25	535ED-01
S38 Cavity 2	Fundamental Power Coupler	Mechanical Tuner	
Component Removed	MTM-05	ANL-13	
Component Installed	ANL-22	ANL-26	

# S38 Component 100kW Test Results

## C1 Mechanical Tuner ANL-21



- Conditioning terminated at 82kW @1mS pulse.
- RF Fingers and Bellow temperatures  $\geq 100^{\circ}$  C (US, DS and Aisle), not during operation(?).
- No finger stock found in cavities (?).

**C2 Mechanical Tuner ANL-13** would not achieve vacuum  $< 3.5 \times 10^{-8}$  Torr yet conditioned to 100kW CW.

**C1 FPC MTM-11** no issues.

**C1 HOM Damper 535ED-05** no issues.

## C2 FPC ANL-21



- Prior arcing noted & continued.

# References

Cours A., Trento G., “Replacing Thyatron in the APS LINAC Modulators with Solid-State Switches and Allen-Bradley Controllers with AD PLC”, RF-TN-2013-011.

Sander H., Glidden S., “Compact, High Current, High Voltage Solid State Switches for Accelerator Application”, Applied Pulsed Power, 2014.

Montesinos E. (CERN); Trento G. (ANL-APS), “Optimal RF Conditioning of the Advanced Photon Source (APS) Fundamental Power Coupler”, CERN-ATS-Note-2013-031 TECH.

Trento G., Bromberek D., Morrison L., “Sector 38 Cavity Tuners and High Order Mode Damper RF Test Stand Conditioning Results”, RF-TN-2013-012.

# Acknowledgement

Our gratitude goes to ASD-RF Group and AES-MOM & MED personnel for their efforts.

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AES-MED: Andre McKenzie and John Pace.

ANL-HP: David Fieramosca and John Vacca

**GRAZIE MILLE**

Alessandro Fabris

CWRF Committees

Audience

# Any Questions?

