Current Status of the APS LINAC and SR / Booster Klystron High-Voltage Power Supplies and the 352-MHz RFTS

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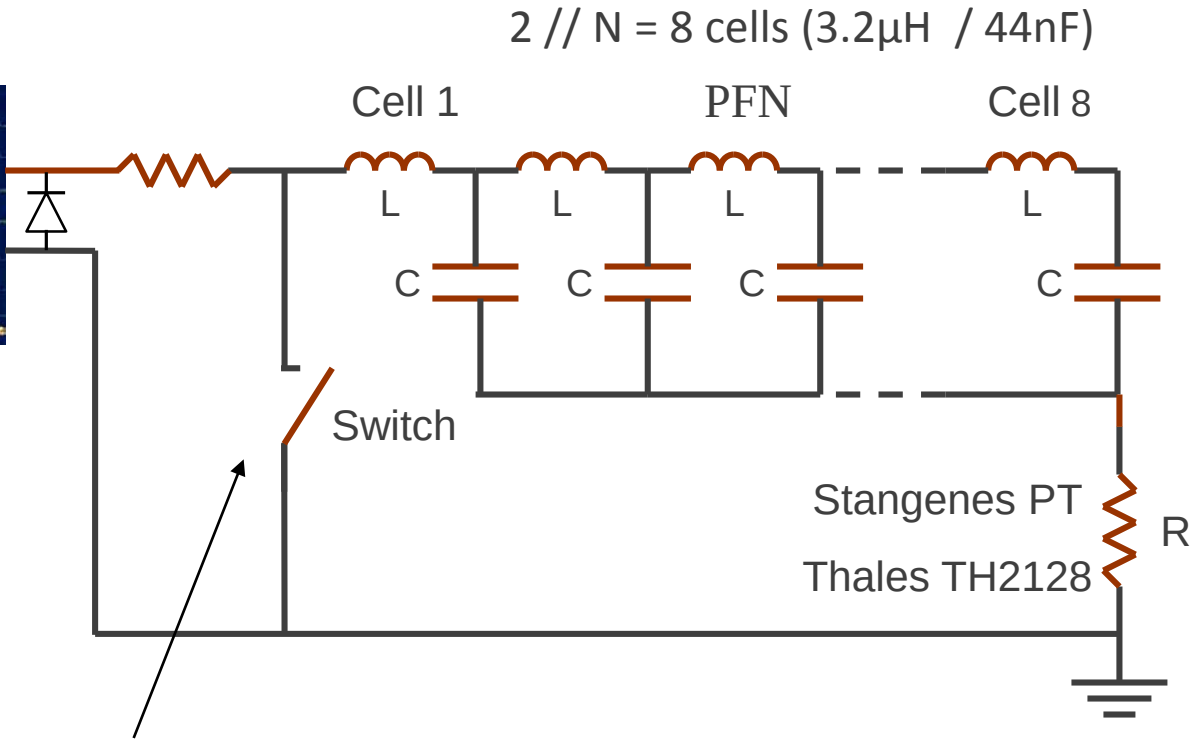
LINAC Modulator

40-kV, 30kJ/sec

PLC

EPICS

E2V Thyratron CX1836A



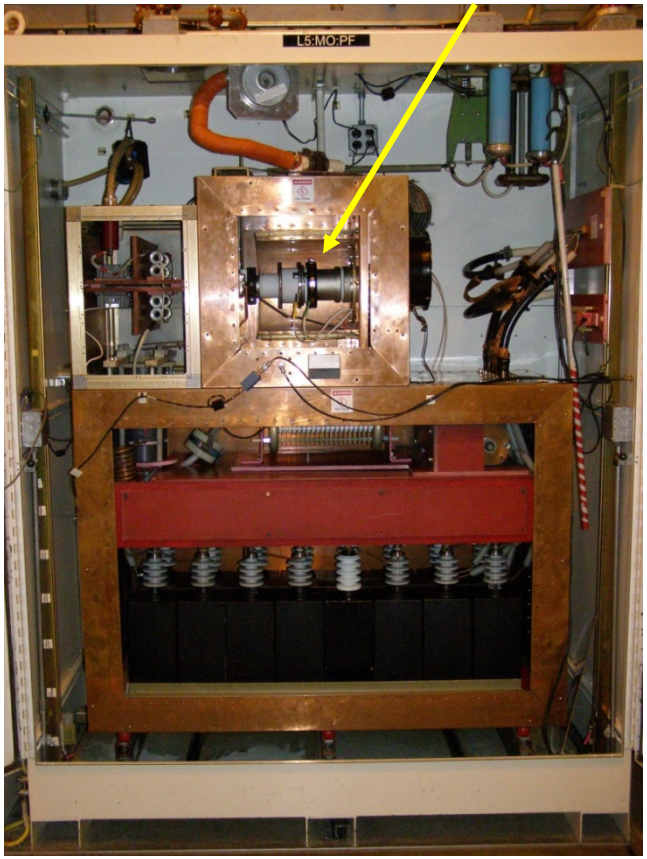
$$Z = (L/C)^{0.5}$$

$$\tau = 2N(LC)^{0.5} \text{ (output pulse length)}$$

$$VR = V\frac{R}{R+Z}$$

LINAC Modulator System

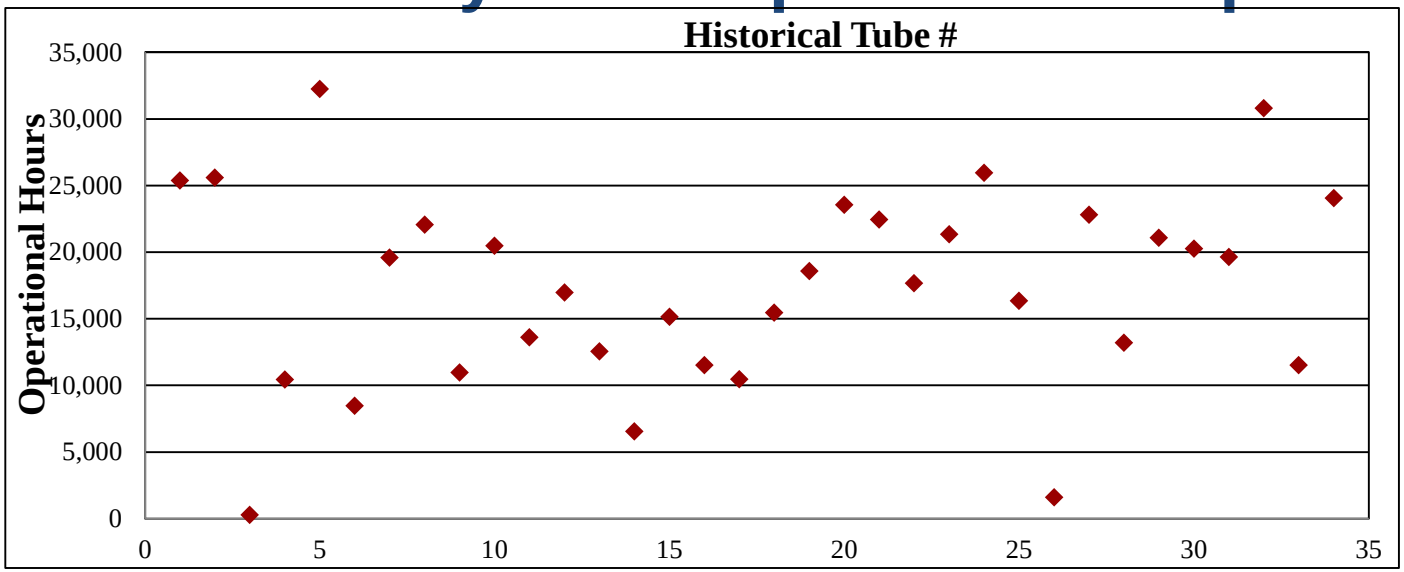
Thyratron



PFN Cabinet Internals

Klystron Tank Assembly

CX1836A Thyratron Operation Lifespan

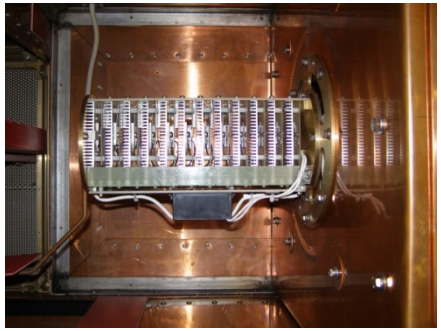


- Unpredictable life span
- Short average life time: 17,300 hrs.
- High tube consumption rate: 2.4 tubes/year
- Growing tube price: $18,300 as of April 2012
- High filament energy consumption: 26,000 kW*hrs./year
- 2012 operating cost: $45,200
- High-voltage triggering pulses: up to 1,500 V

Thyratron vs. Solid-State Switch

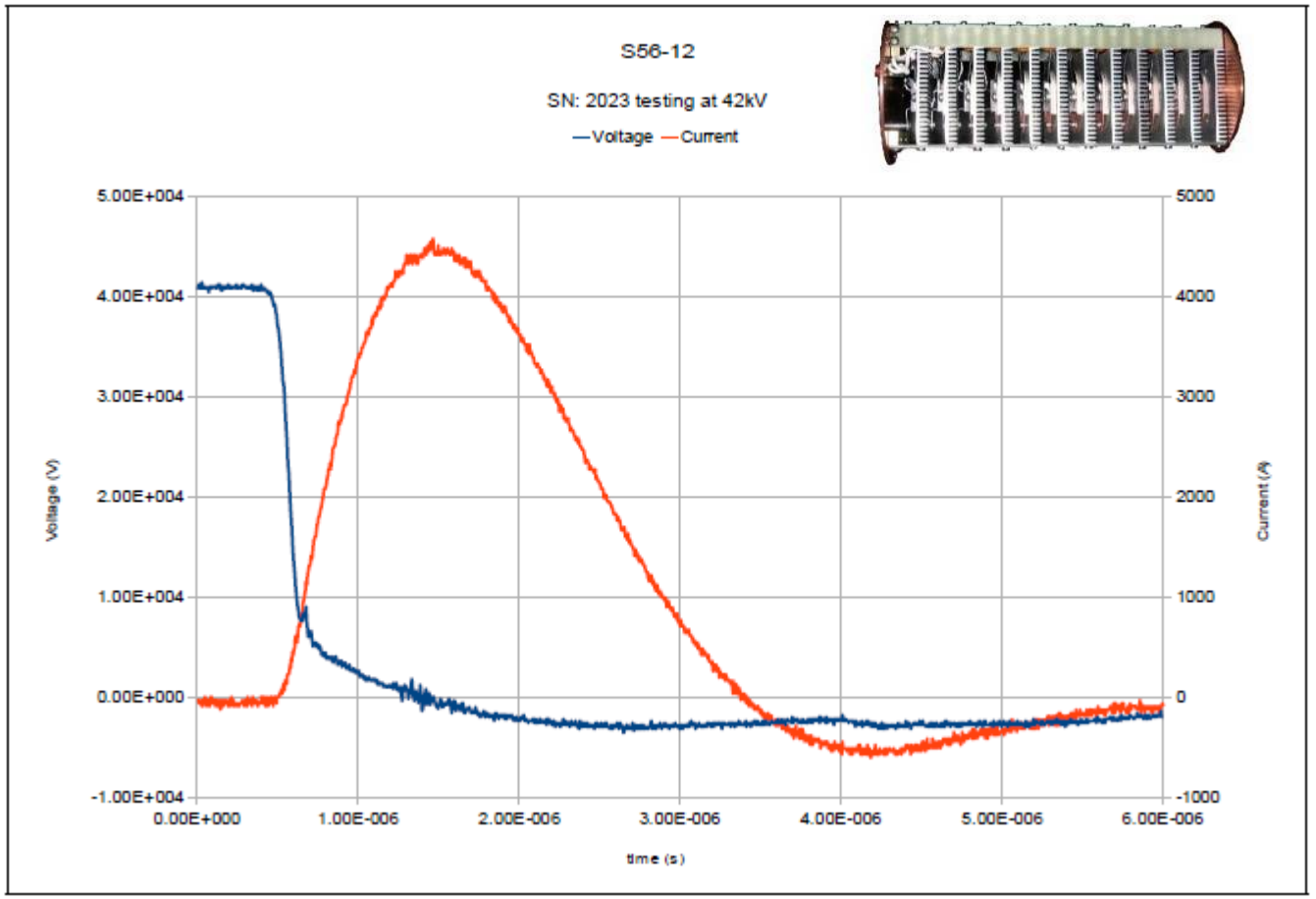
	Thyratron	Solid-State Switch
Peak Forward Voltage, kV	70	48 (60)*
Peak Anode Current, kA	10	7 (10)*
Rate of Rise (di/dt), kA/µs	10	30
Triggering Pulses	Up to 1,500 V	Fiber-optic
Filament Power, Watts	610	0

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



S56-12 Solid-State Switch

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



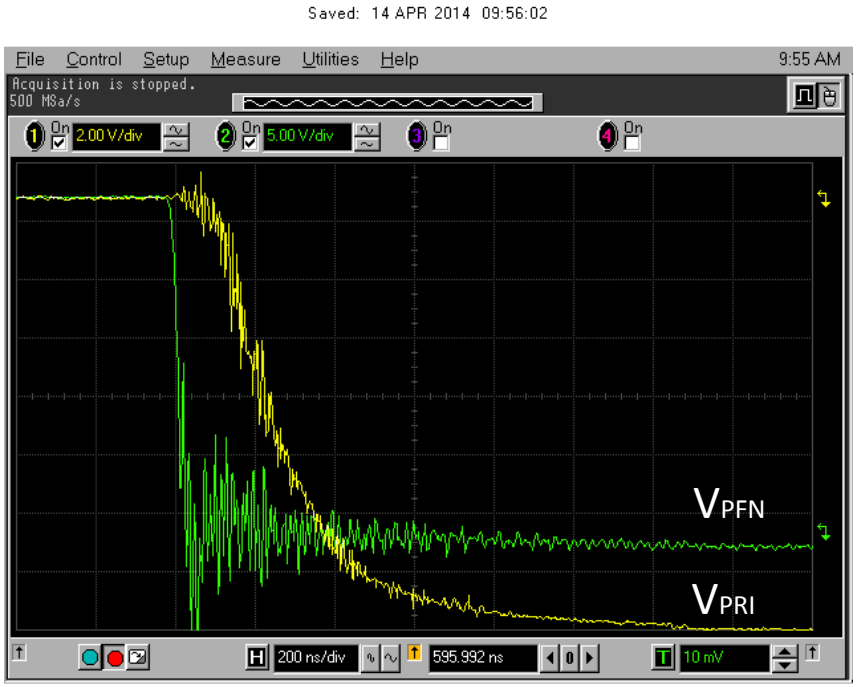
Courtesy of H. Sanders

Thyratron vs. Solid-State Switch cont.

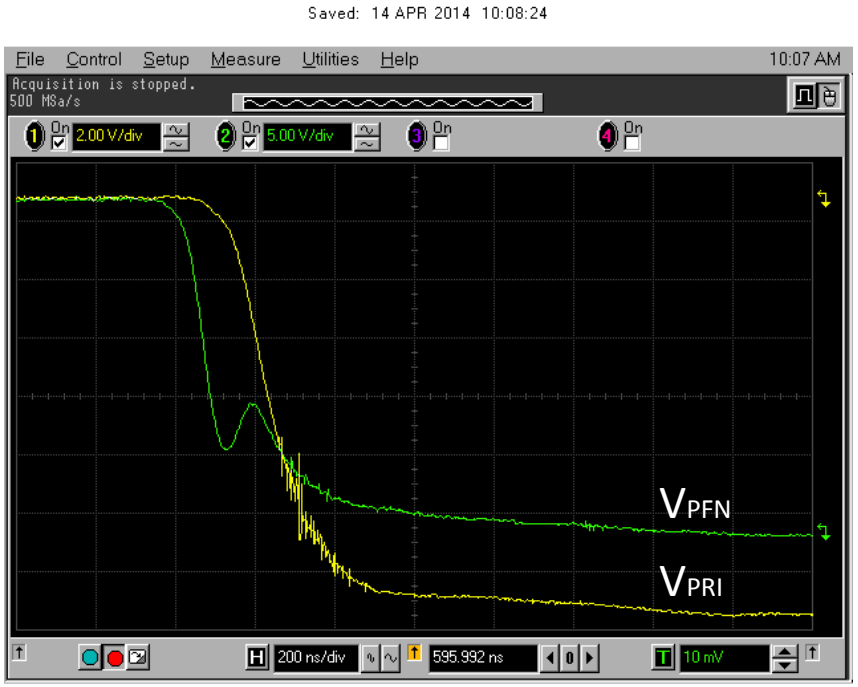
	Thyratron	Solid-State Switch
Unit Price	~ $18,300 US	~ $9,000 US
Average Life Time, hrs.	17,300	Theoretically much longer
Switch Failures per Year	2.4	--
Annual Operating Cost	~ $45,200 (6 RF Stations)	Theoretically much better
Triggering Pulses	Up to 1,500 V	Fiber-optic
Repairable	**No**	**Yes**
Chemical Waste Problems	**Yes**	**No**
Domestic Manufacturer	**No**	**Yes**

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

28KV PFN WAVEFORM
Thyratron versus Solid-State Switch



Modulator 4 Thyratron.



Modulator 3 Solid-State.

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.

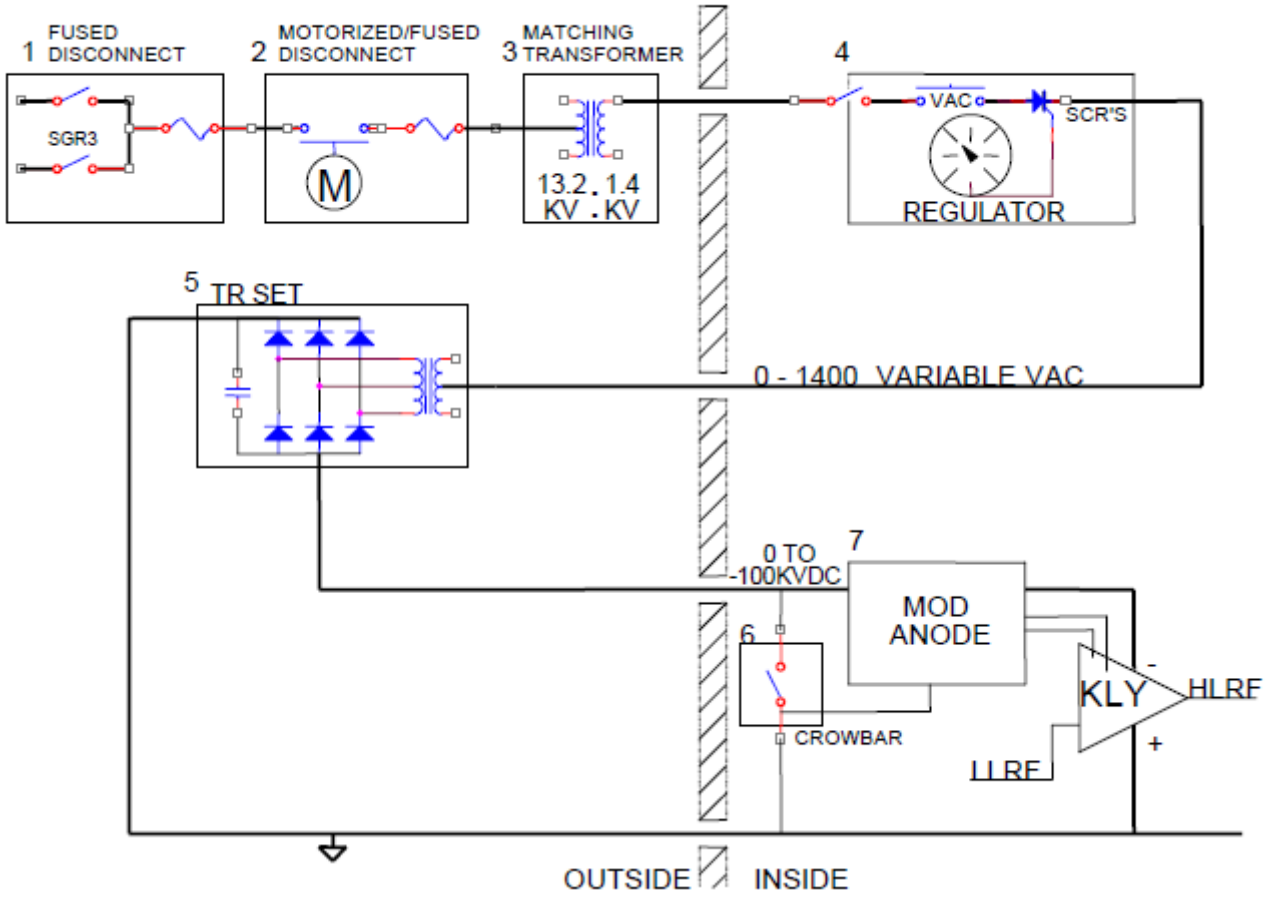
Old: Allen-Bradley Controller

- Limited amount of information transmitted PLC↔EPICS, quantity128 - 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



Motorized Fused Disconnect

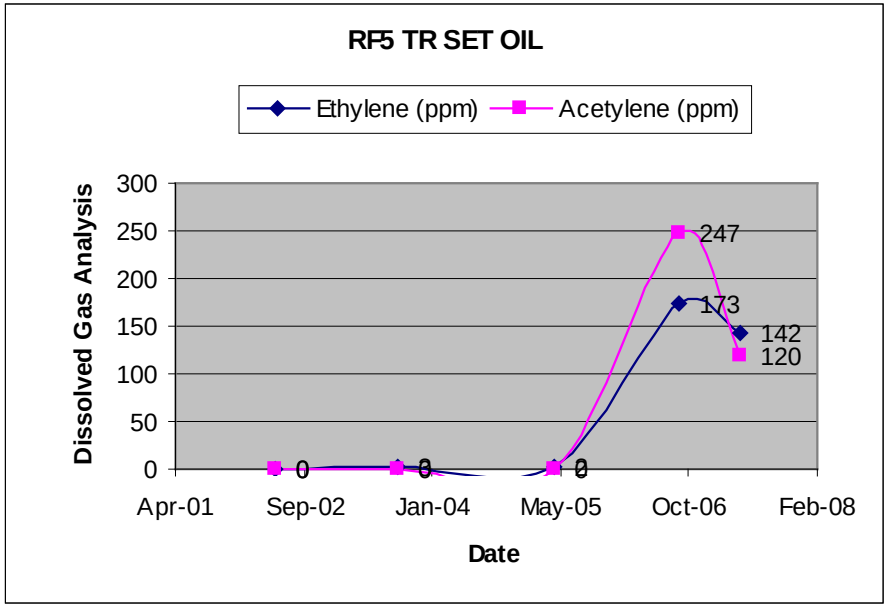
Old- ABB

- OEM disavowed knowledge of its existence yet sold replacement parts at a premium price.
- Obsolete.
- Averaged 2 failures / year after sacrificial rollers installed. This actually increased reliability!
- Concrete foundation deteriorated and sourced moisture to GPO3.
- Violent open / close action wore out the mechanical components.

New - SQD

- Unit available from OEM.
- Specified to operate 750 X prior to maintenance.
- Installation completed 11/2011.

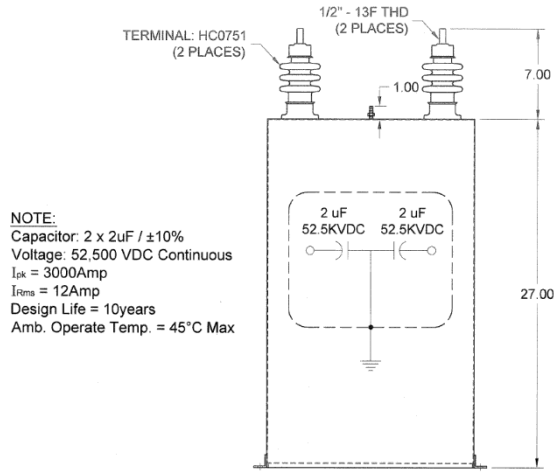
Transformer / Rectifier Analysis

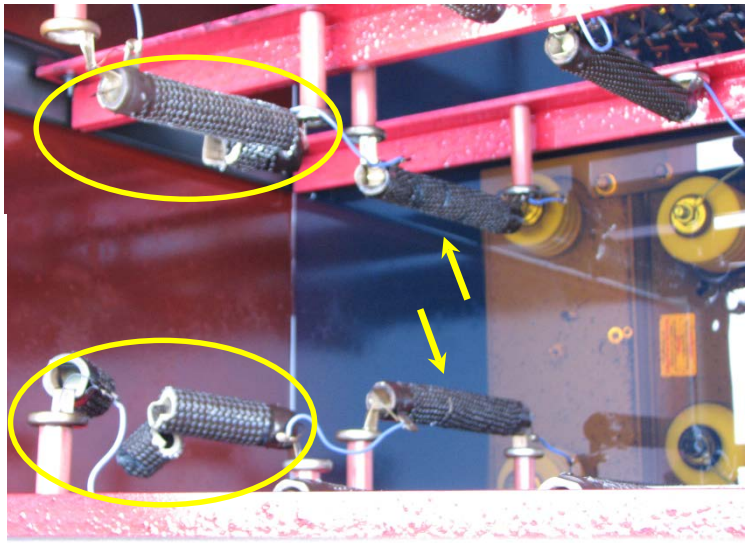


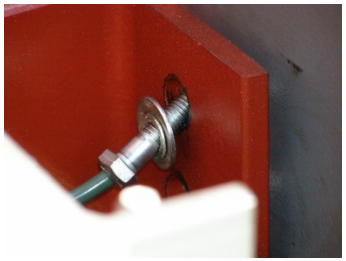
Dissolved Gas Analysis
Acetylene – severe arcing activities
Ethylene – overheated oil

RF5 Service Report

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

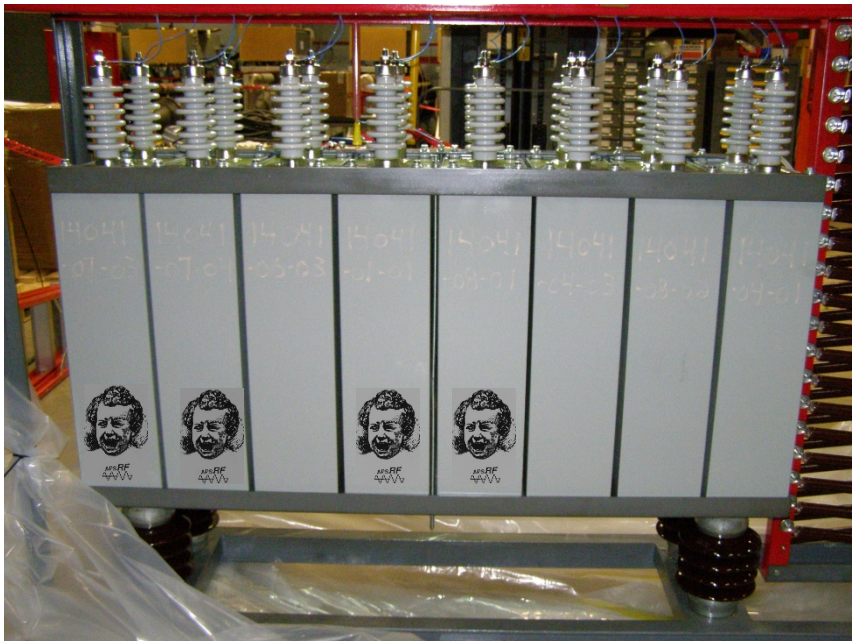






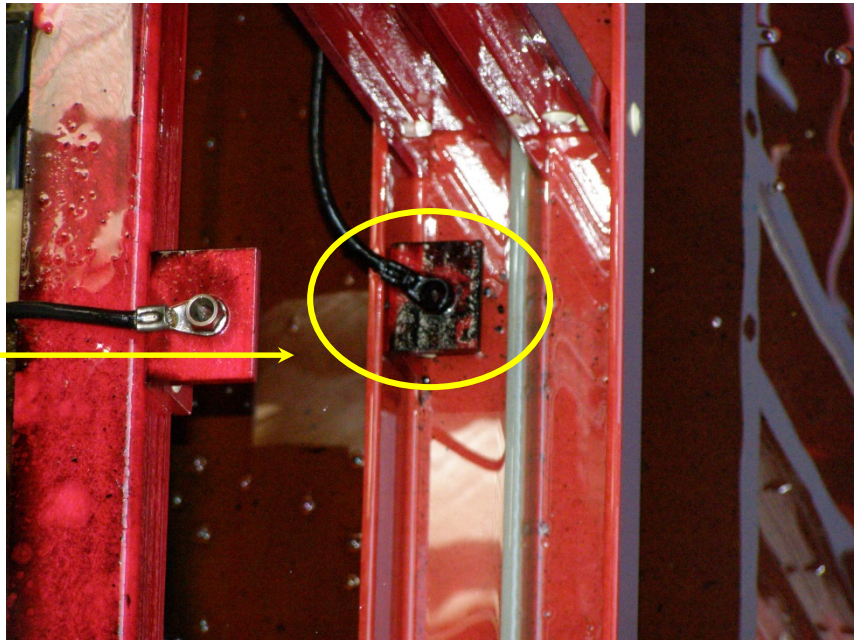
May 2014 Maintenance Period – RF2

TR Set capacitor bank removal.



4 Failed Capacitors.

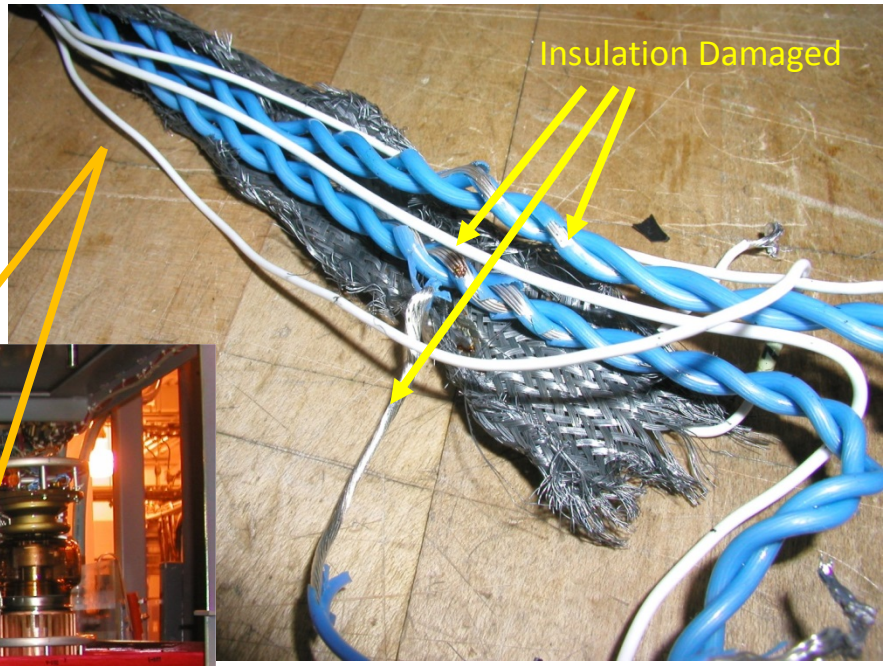
May 2014 Maintenance Period – RF3

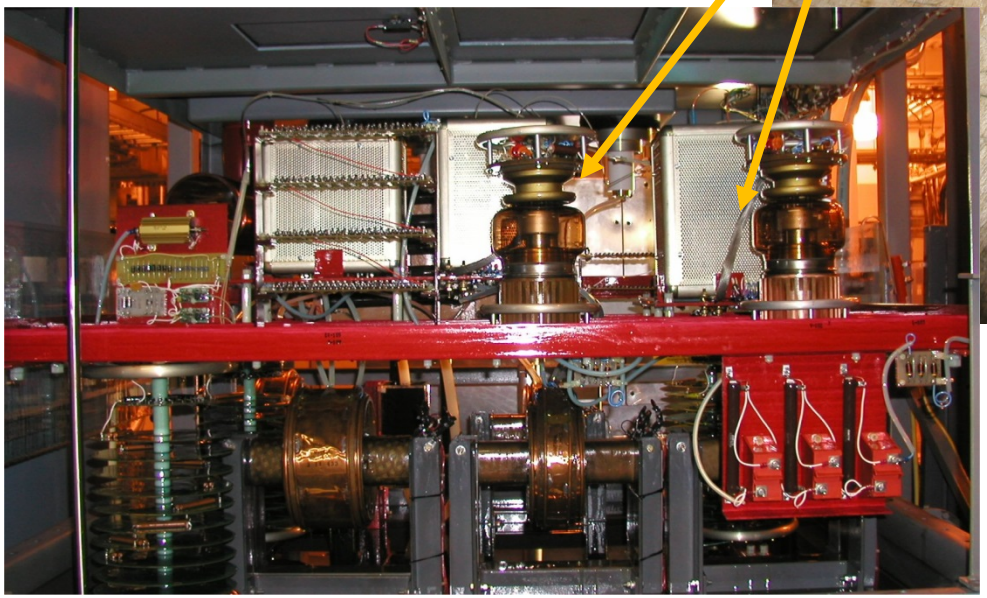


RF3 TR Set diode stack connector fault.

- Plagued by intermittent crowbars during 2014-1.
- Oil Acetylene Content = 878ppm.
- Root Cause: poor banana jack / plug mechanical connection.

Radiation Aged Tetrode Cable





Mod-Anode Tank Internals

- Caused intermittent mod-anode regulation.

2-MW DC KPS Control Interface

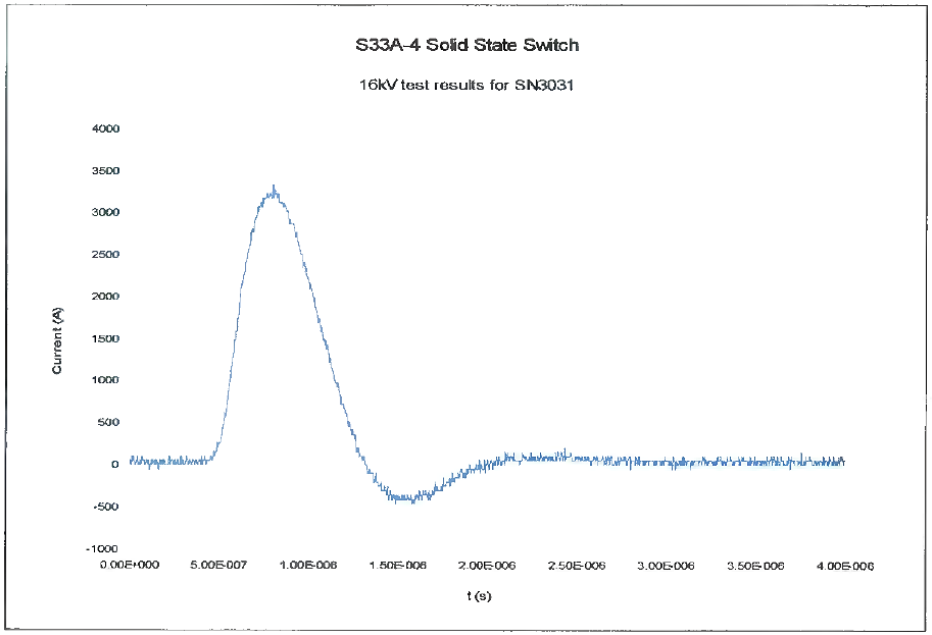
Old: Manufacture Design

- Obsolete boards and ICs.
- 486 PC running Windows95 GUI.
- Proprietary E²PROM program.
- GPIB communication error.
- No longer supported by OEM.

New: Automation Direct Controller

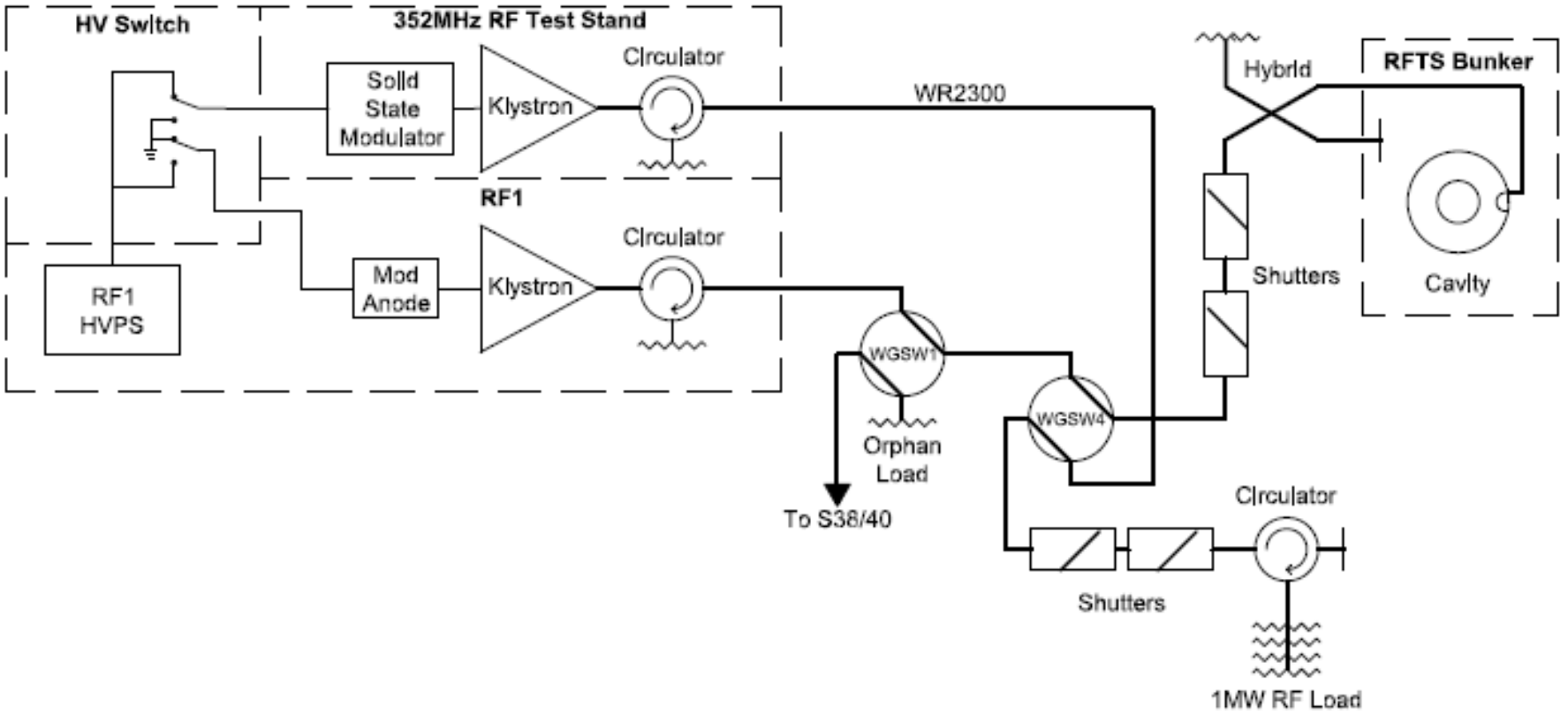
- Same details as LINAC Modulator Controller.
- Installation complete.

Crowbar Ignitron Trigger
5C22 → JAN8613 → S33A-4

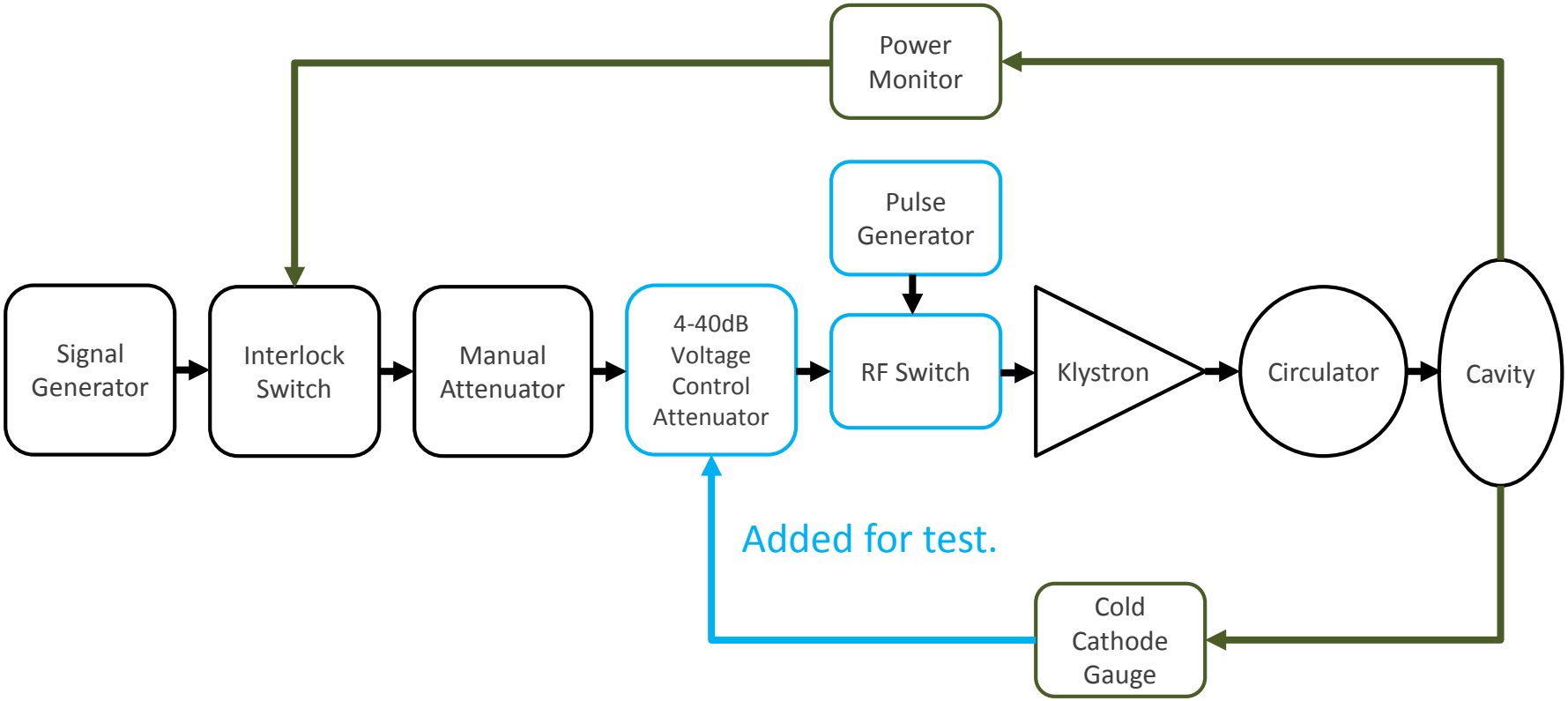


Vendor's test data 16 kV @3.2 kA_{pk}

352-MHz RFTS Line Diagram



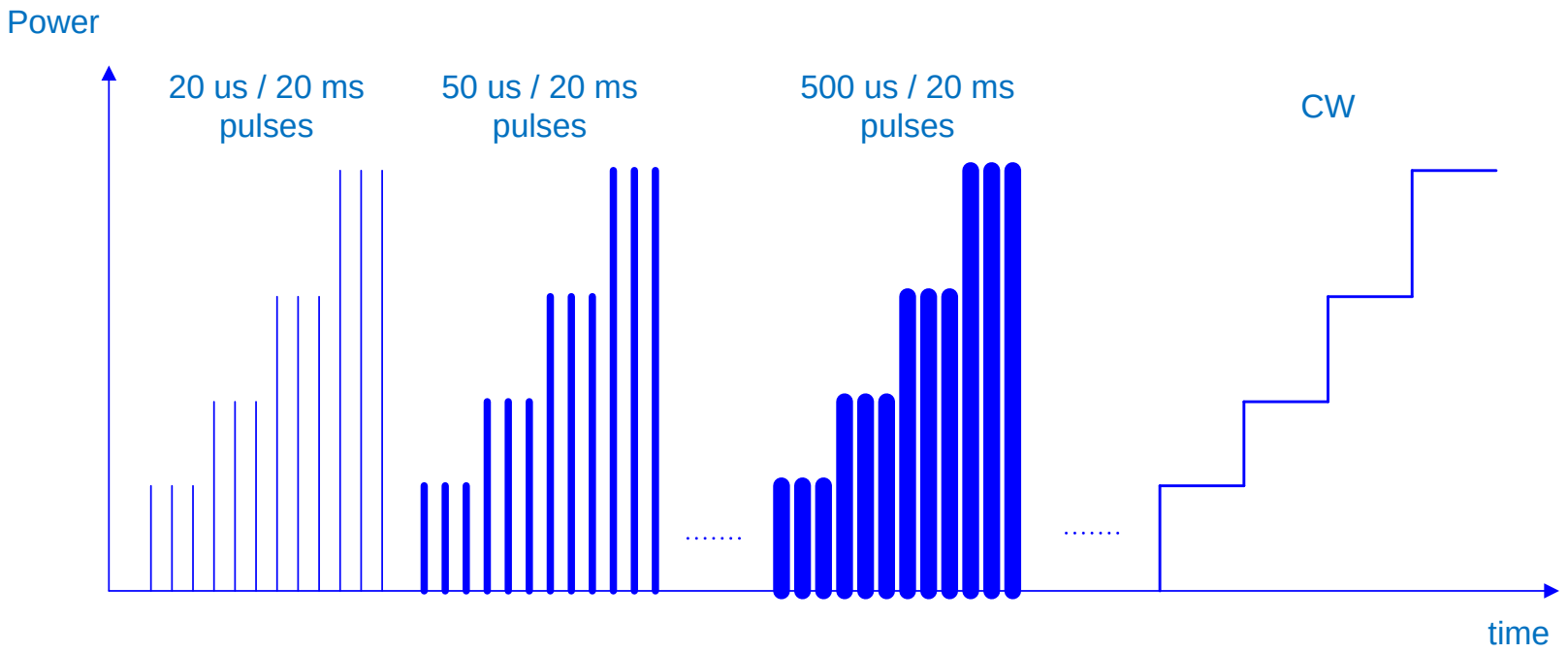
Pulsed-Mode Conditioning Principle



RF Conditioning - The objective is always to “touch” surface area with RF; “burn” particulates and induce controlled gas layers desorption (they enhance the secondary electron emission coefficient and cause “local desorption outbursts” which could facilitate arcing events). -Mircea Stirbet

Methodology

Pulse length of 20-50-100-200-500us-1-2-5-10ms with fixed repetition time of 20 ms and finally CW



- Regulate rf power as a function of vacuum.
- Apply a longer repetition rate than the vacuum reading delay.
- Reduce average power and minimize energy delivered to an unconditioned coupler with rf pulses, then increase duration.

RFTS Conditioning Method Comparison to Achieve 100-kW CW

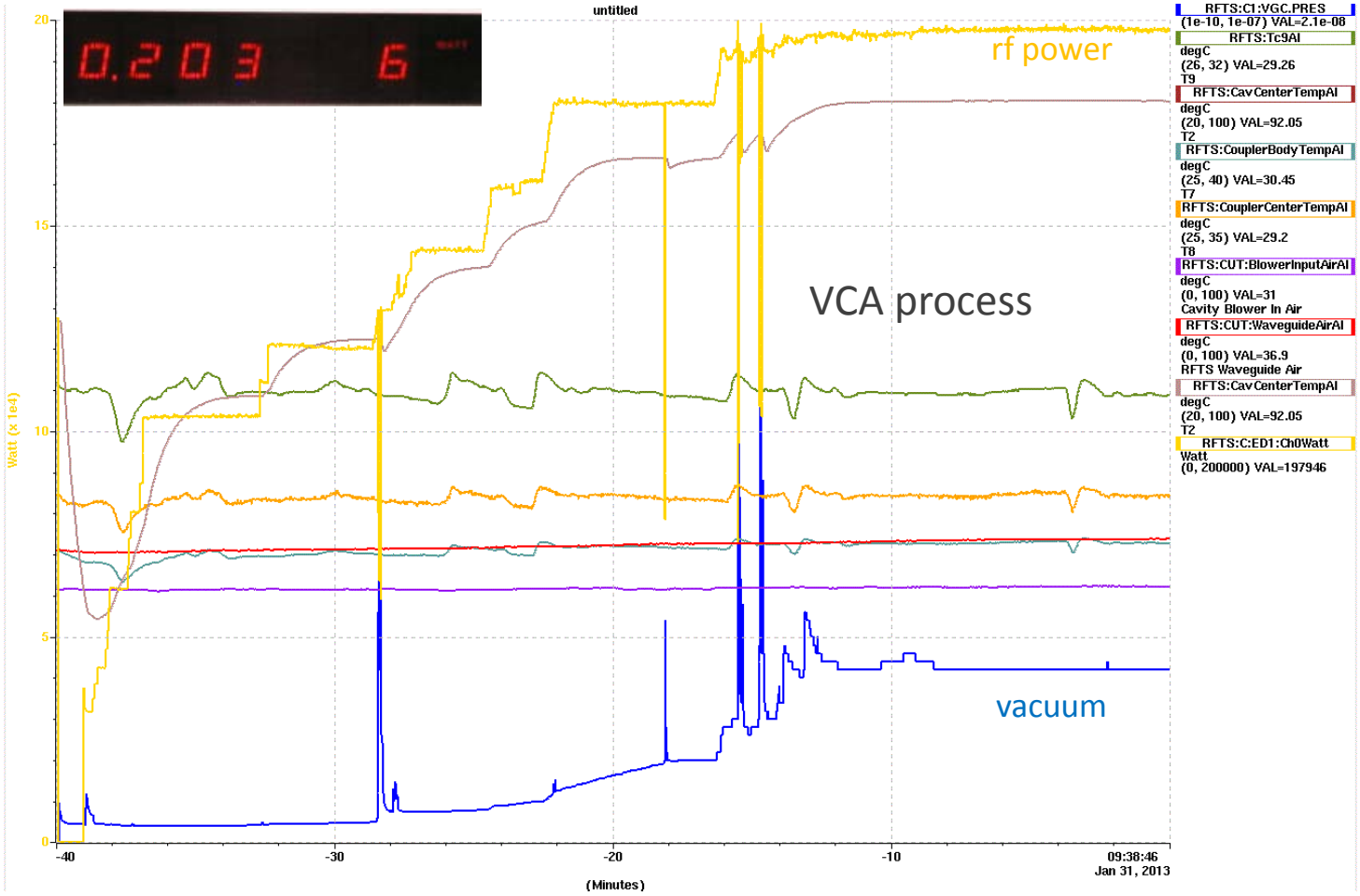
CW ONLY

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

Pulsed → CW

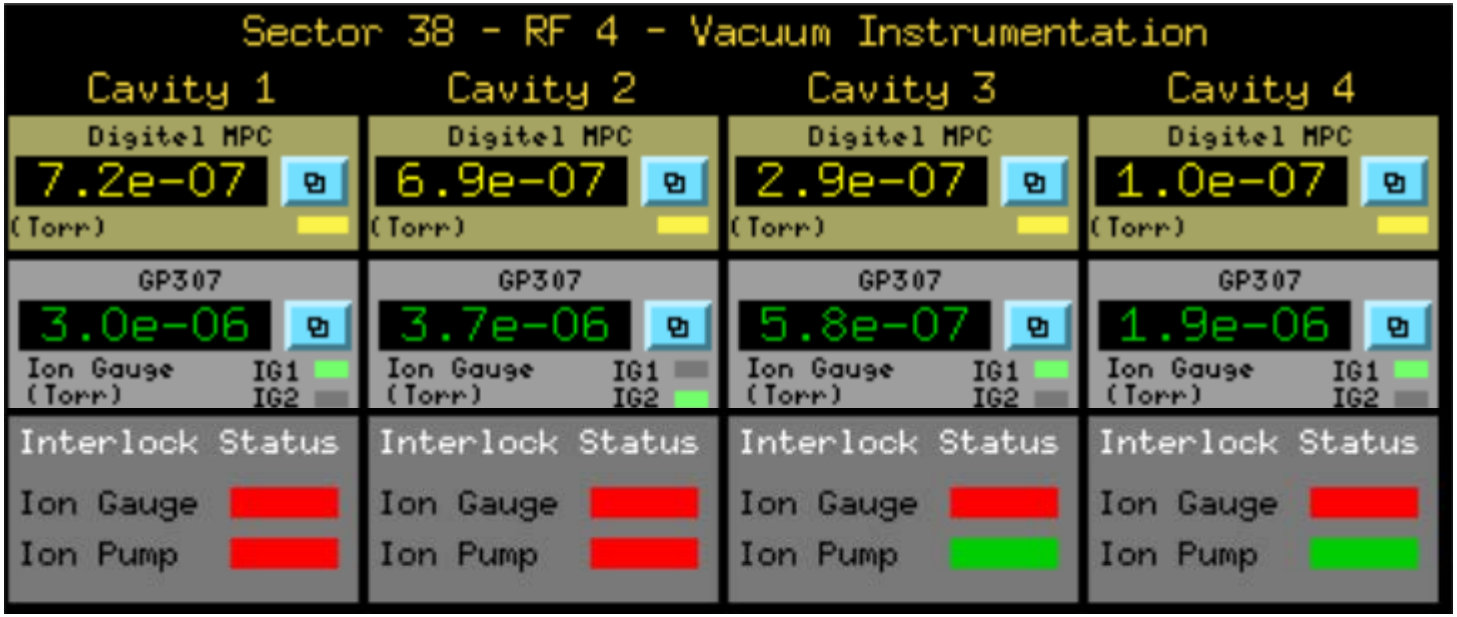
Component	Conditioning Hours
FPC C2	48
Tuner ANL-09	54
FPC ANL-25	44
FPC ANL-26	53

FPC Prototype & RFTS 200-kW CW Commissioning



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

S38 Cavity Pressure Run 2013-2 Machine Start-up



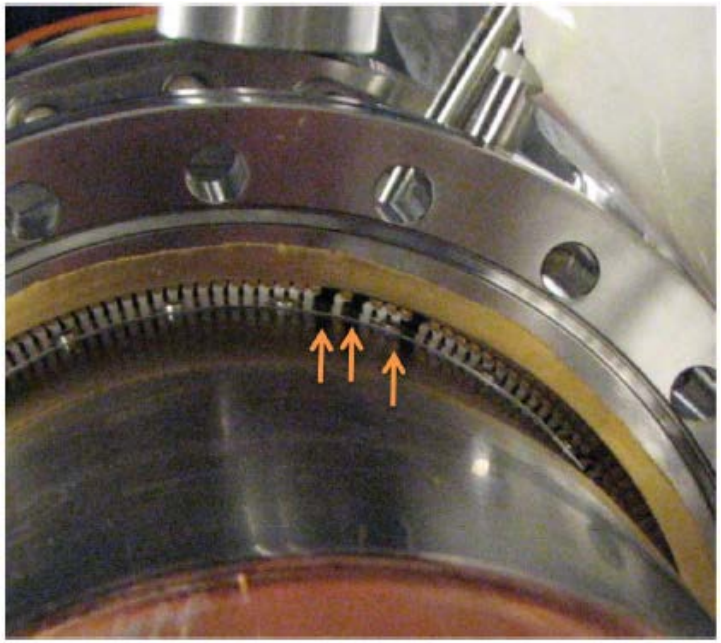
Vacuum Trip Levels are 5e-8 Torr.

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 100-kW Test Results

C1 Mechanical Tuner ANL-21



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

C2 Mechanical Tuner ANL-13 would not achieve vacuum < 3.5×10^{-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 Thyratron 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.

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Thank you for your attention.

Questions?