Analysis of Booster and Storage Ring RF System Reliability at the Advanced Photon Source

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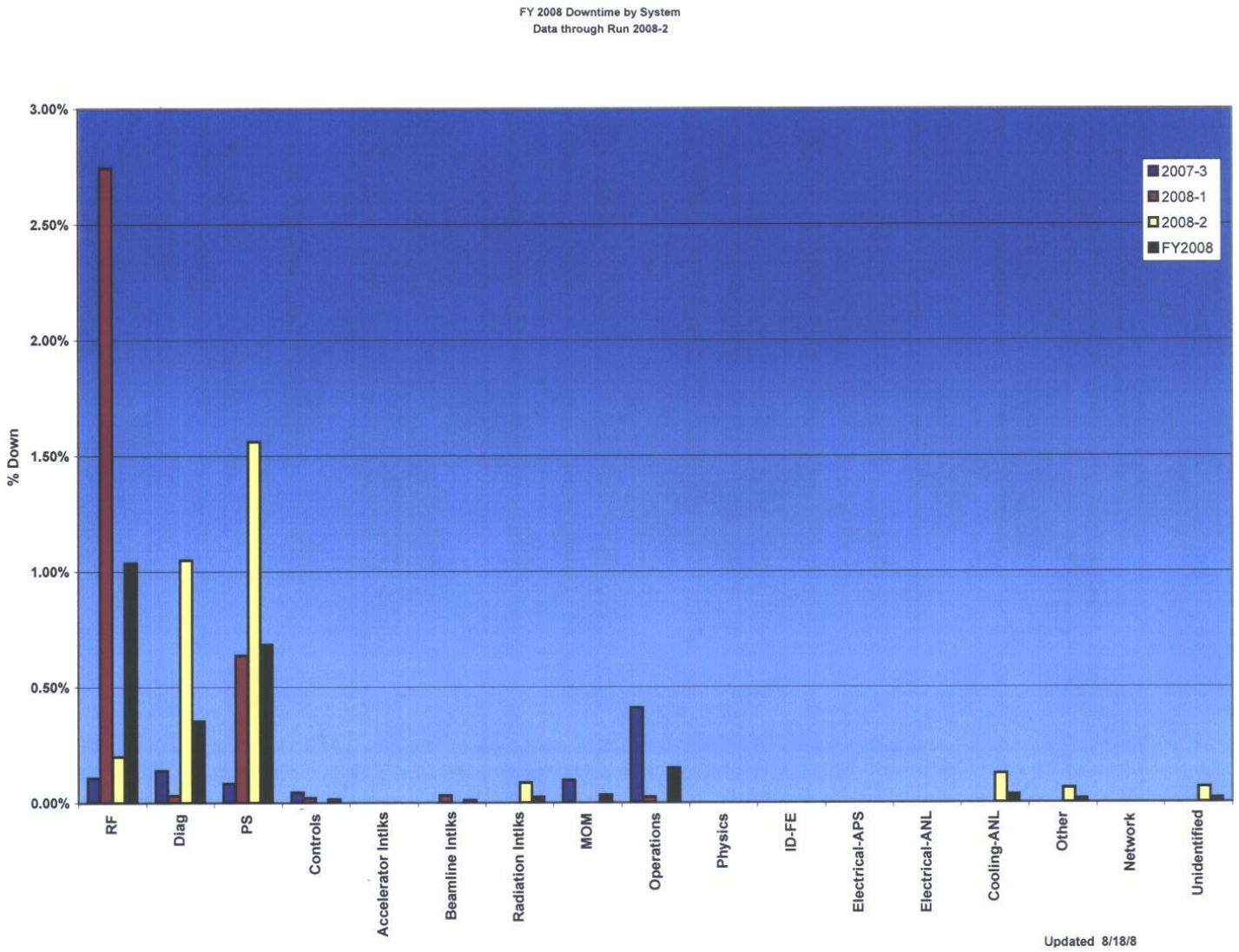
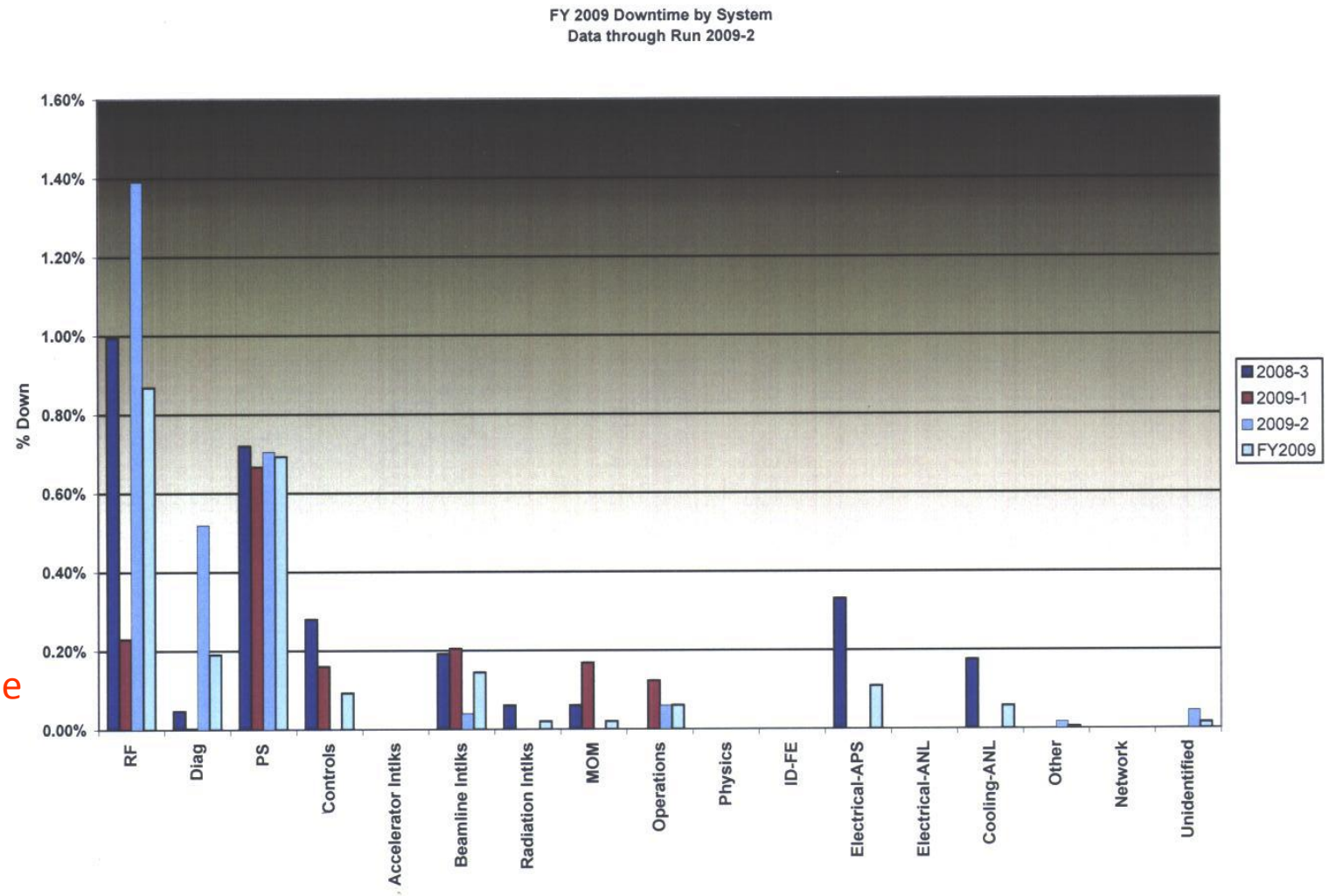
2008 APS Reliability Statistics By System

- Overall APS reliability was 97.6% with 91.4 hours mean time to beam loss
- Overall RF downtime was 1.04% with 319.9 hours mean time to beam loss
- 2.75% rf downtime in 2008 was due to booster coupler failure



2009 APS Reliability Statistics By System

- Overall APS reliability was 97.7% with 77.5 hours mean time to beam loss
- Overall RF downtime was .87% with 271.3 hours mean time to beam loss
- High rf downtime in 2009-2 due primarily to HVPS failures



2010 APS Reliability Statistics By System

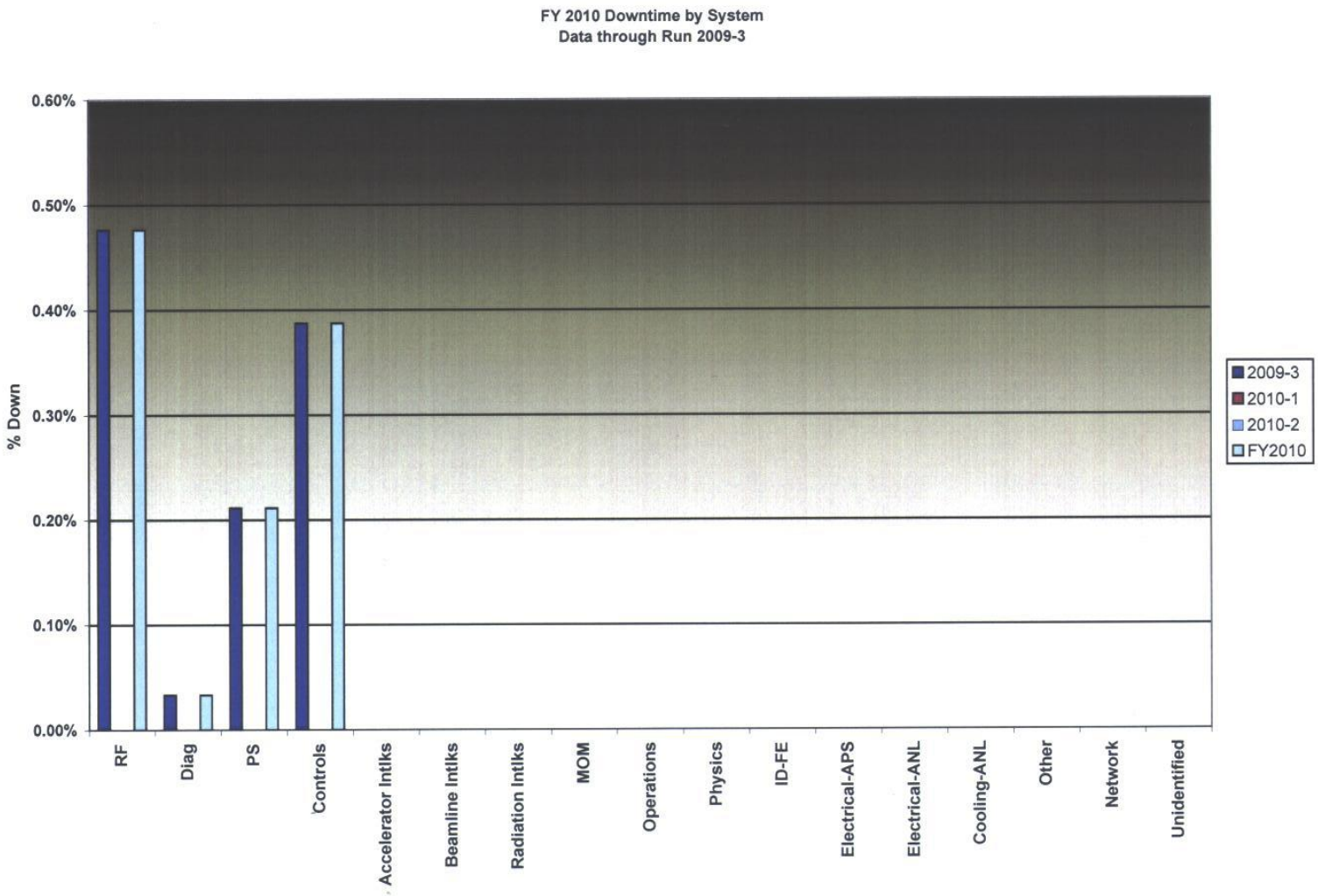
- **As of April 20th**

↓

….Overall APS reliability is 98.9% with 139.6 hours mean time to beam loss

….RF downtime is 0.48% with 383.9 hours mean time to beam loss

- Biggest problem in present run: klystron arc detector trips …..not real?



RF System Events Resulting in Beam Interruption - March 2008 to Present:

- High voltage power supply failures → 23
- Waveguide arc detector trips → 13
- LLRF hardware failures→ 6
- Cavity input coupler failures → 4
- Klystron instabilities and failures → 4
- Cavity tuners problems → 1
- Controls malfunction affecting rf systems → 1
- Broken coupler blower hose in tunnel due to radiation damage causing trip of wg air PSS system → 1
- Human error – loose waveguide air hose in test stand → 1
- Human error – opening test stand waveguide shutters with coupler blowers off causing trip of wg air PSS system → 1

HVPS is biggest cause of downtime!

RF System High-Voltage Power Supplies

- **Installed new in 1992-94……*approximately 90,000 average operating hours per system since 1995***

- **Conventional design, 95kV@20A maximum output:**

  → ***Transformer-Rectifier***

  → ***SCR voltage control***

  → ***Ignitron crowbar***

  → ***Tetrode mod-anode modulator***

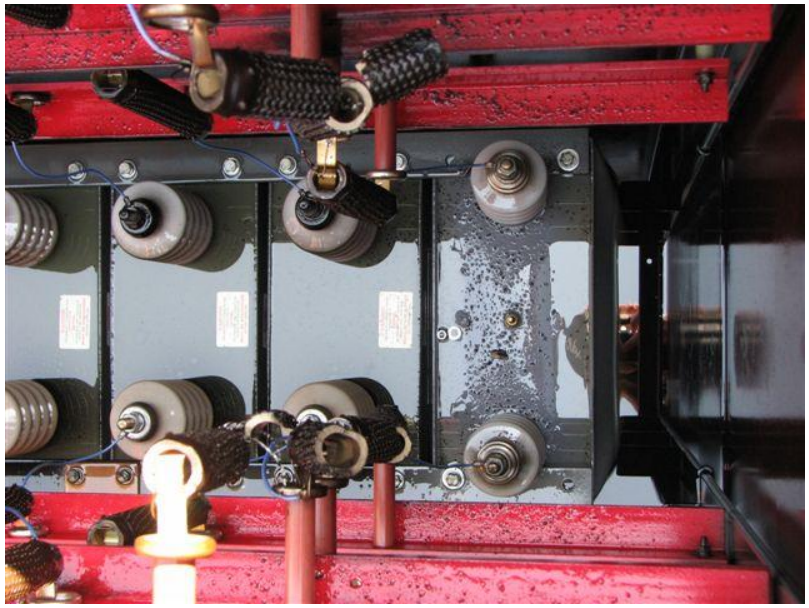
→ ***Most frequent cause of downtime in the last two years***

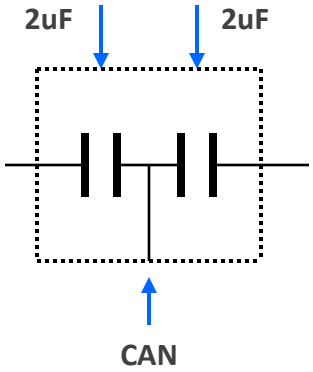
HVPS Sub-System Problem Areas

- Transformer-rectifier set capacitor bank
- Mod-anode regulator
- Pantak cable connectors and sockets
- Control system
- Cathode voltage regulator (SCR's)
- 13.2kV Fused Disconnect Switch

Transformer-Rectifier Set Capacitor Failures

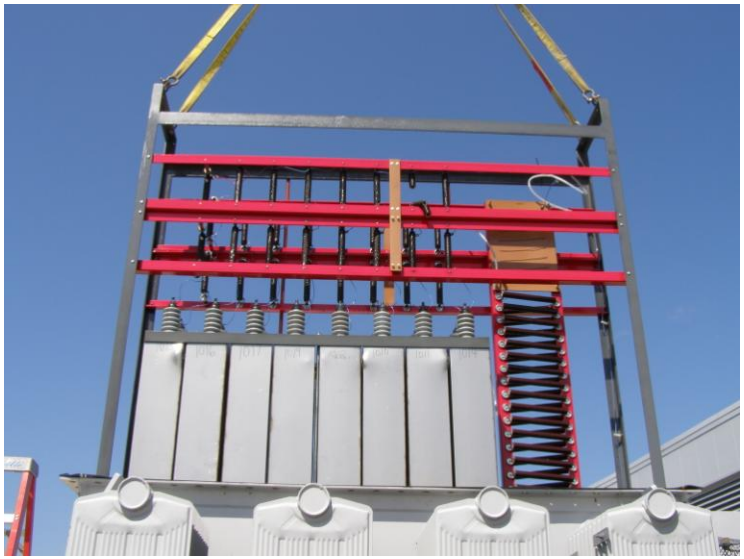
- T-R set capacitor bank consists of eight 2x2uF capacitors arranged in series/parallel:
  → Ct = 8uF at 95kV max
- Routine inspection of the RF5 T-R set in May 2008 revealed several failed capacitors – ***predicted lifetime was 20 years***
- Original capacitors were obsolete and out of production by manufacturer
- **Replacement capacitors were second-sourced to another manufacturer, *hipot tested twice*, and installed in the RF4 T-R set in May of 2009**

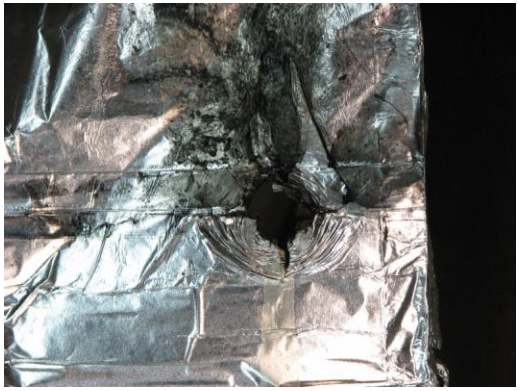




Transformer-Rectifier Set Capacitor Failures

- **Most of the new caps failed after approximately one week service!**
- **The cause of the failures was determined to be incomplete oil impregnation to all sections of the capacitor:**





Transformer-Rectifier Set Capacitor Failures

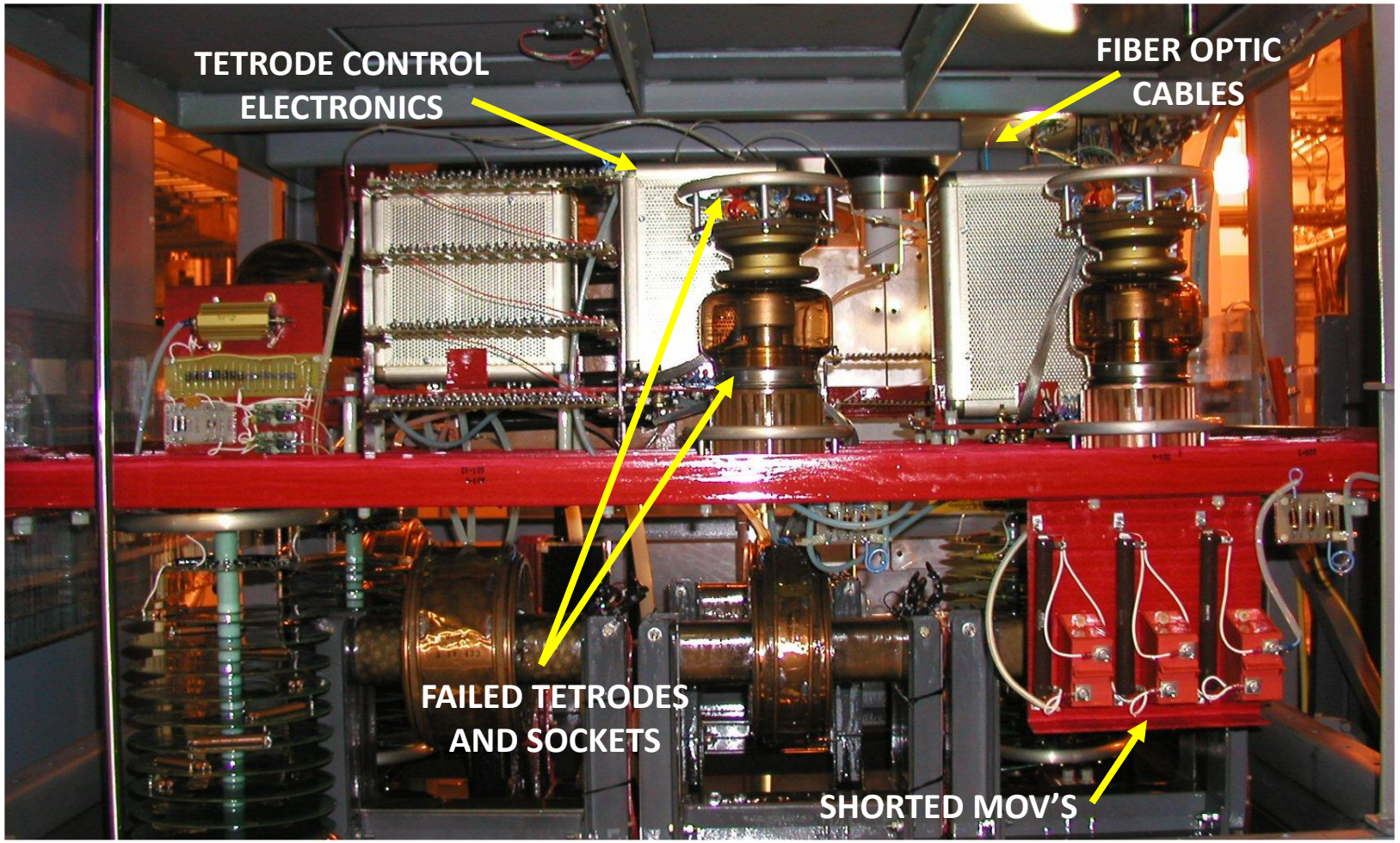
- The original caps were re-installed in the RF4 T-R set so operation could resume
- A search for a second vendor was started
- New caps were ordered from Vendor #2 and were installed in RF4 during the August 20090 maintenance shutdown
- No further problems with caps from vendor #2
- Lessons learned:

  → *"old-school" high-voltage components may not be so easy to get nowadays*

  → *try to secure two vendors for such parts, and maintain adequate spares*

Mod-Anode Regulator Failures

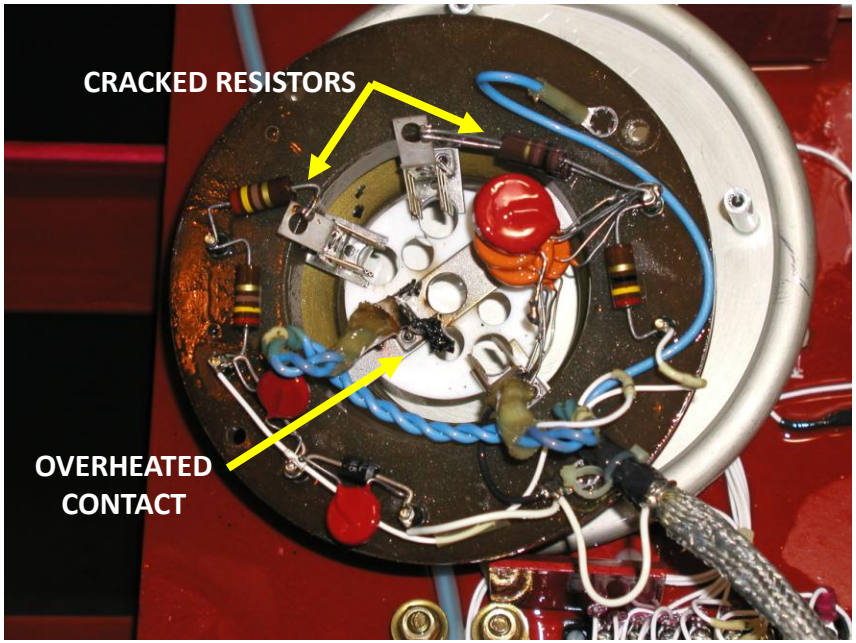
- Many component failures resulting in significant downtime:

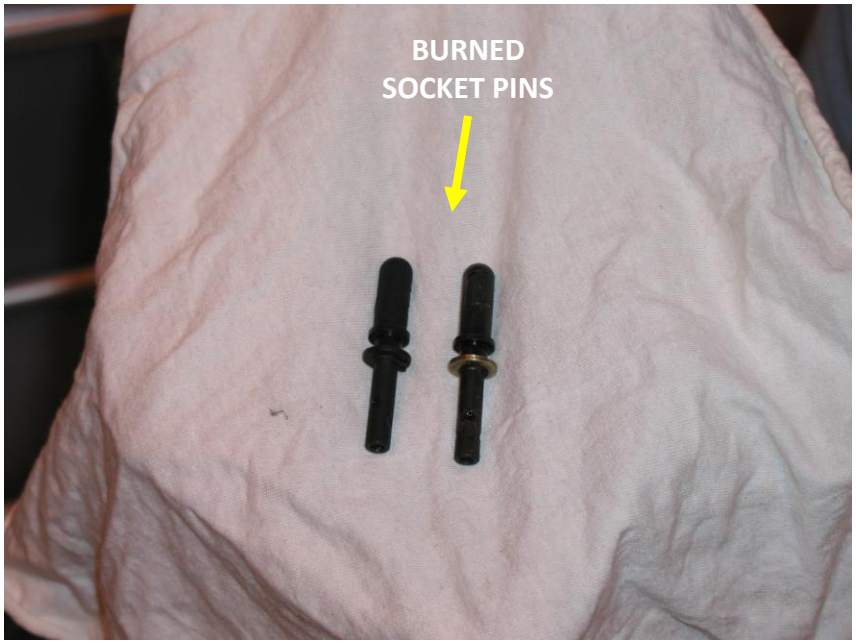


Mod-Anode Tetrode Socket Failures

- Over-heating of center pin tetrode contact due to trapped oil, causing intermittent loss of heater power
- 2-watt carbon composition resistors cracking

→ *temperature?.....old age?*

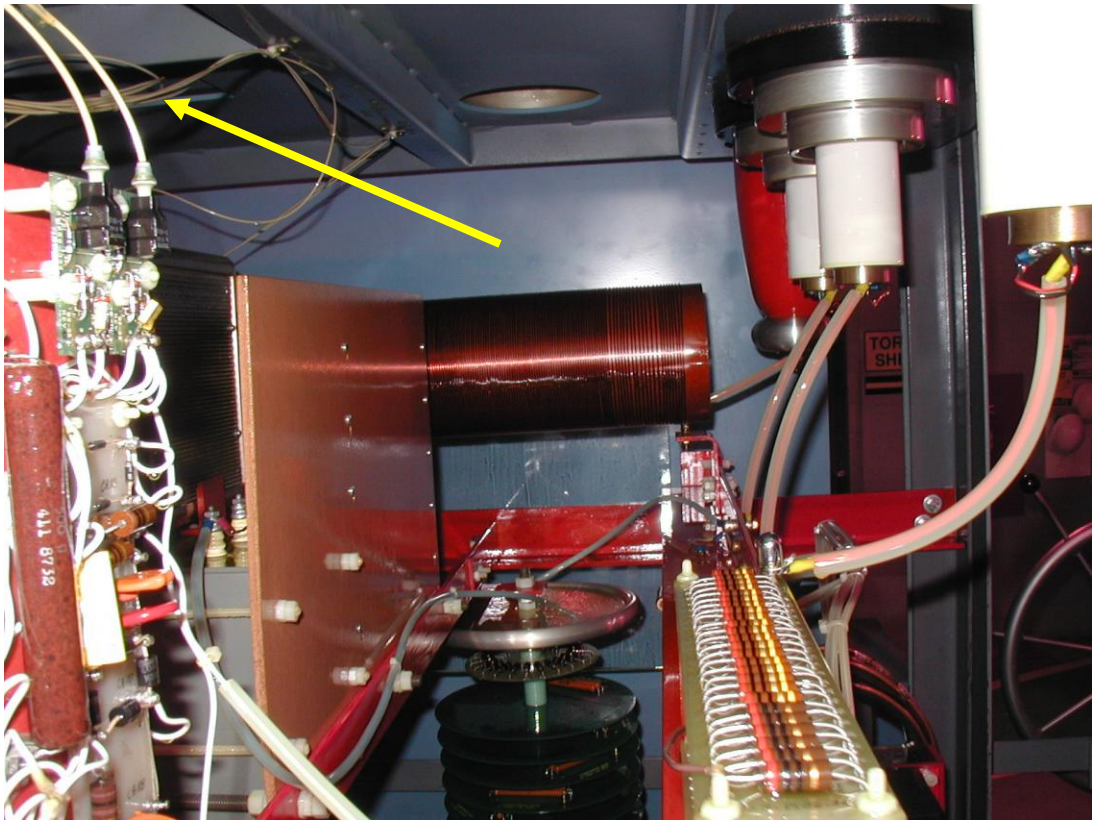




Solution: Drill oil escape hole in center of socket cover, and replace all carbon composition resistors with 3-watt metal film

Mod-Anode Fiber Optic Cables

- X-rays from tetrodes degrade fast glass fiber optic cables, impeding analog communication with tetrode control electronics cages and resulting in loss of anode regulation



Solution: Convert to radiation-resistant plastic fiber cables with larger active area

Tetrode Failures

- Two Thales TH5188 tetrodes are used as an active voltage divider in mod-anode regulator
- Production of TH5188 ceased approximately five years ago – *we made bulk purchase for spares*
- *Approximately 5 verified failures in the last ten years*

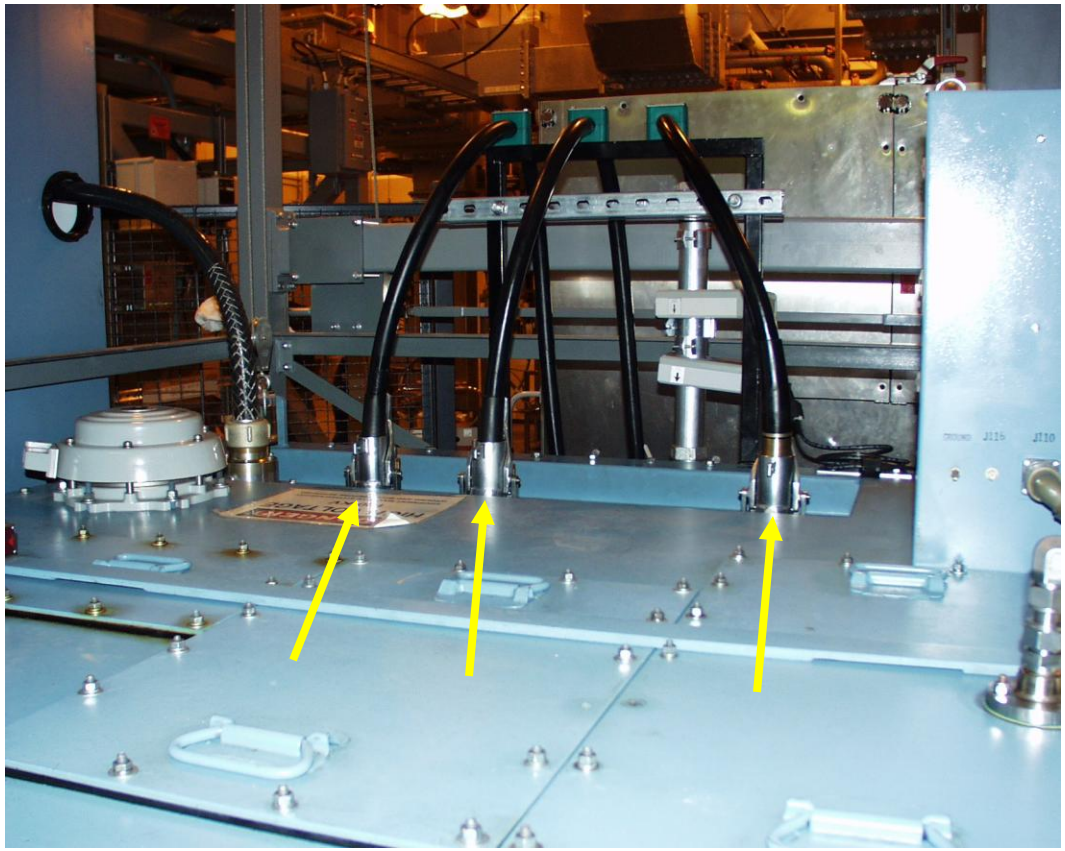
Solution: A tetrode test set was constructed to evaluate and test new and used tetrodes and other mod-anode electronics modules under high-voltage operation conditions

Problems with Pantak Cable Connections Between HVPS and Klystron

- **Numerous HVPS system failures have occurred due to:**

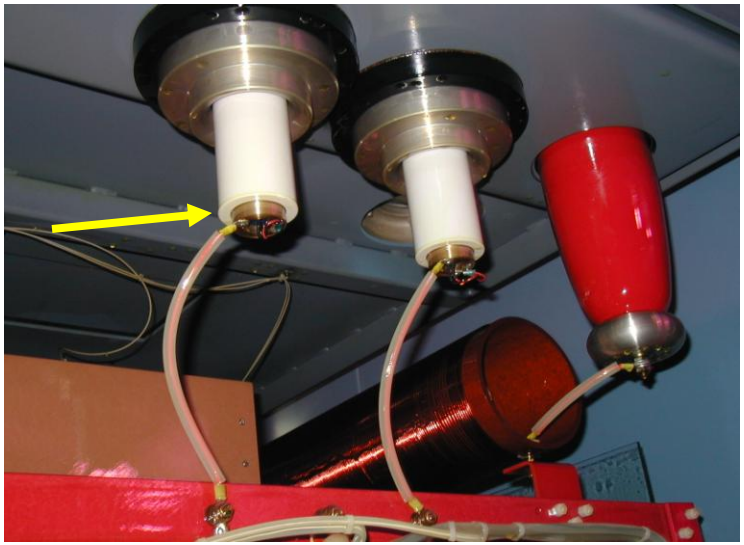
  → ***cable failures due to high voltage breakdown***

  → ***Intermittent socket connections***

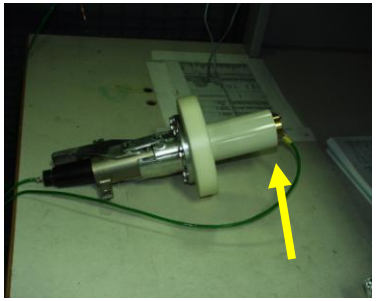


Improved Pantak Socket Tip Connector

- Original tri-axial tip connector was sensitive to insertion force and would result in intermittent filament contact



Solution: Re-designed one-piece tip contact with fingerstock provided positive contact to tip and ring bushings on plug



TESTED AT 50A!

Pantak Cable High Voltage Failures

- Suspect causes include defects in connector or plug molding, potting, or material, incorrect plug insertion force, insufficient grease, undetected HV damage to the mating socket

Solution: Increased awareness of proper insertion force, improved technician training on Pantak connector inspection and maintenance

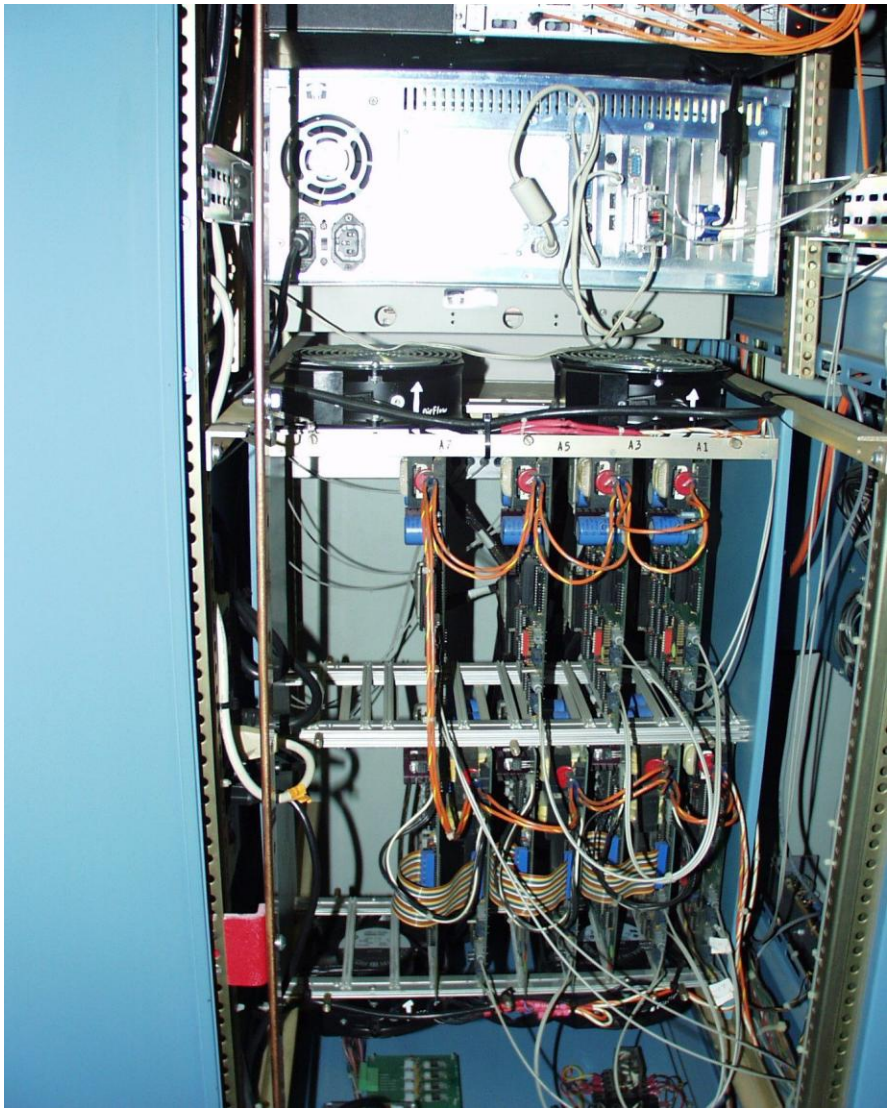
Failures in HVPS Control System

- **Original control system, circa 1990:**

  → ***many obsolete parts***

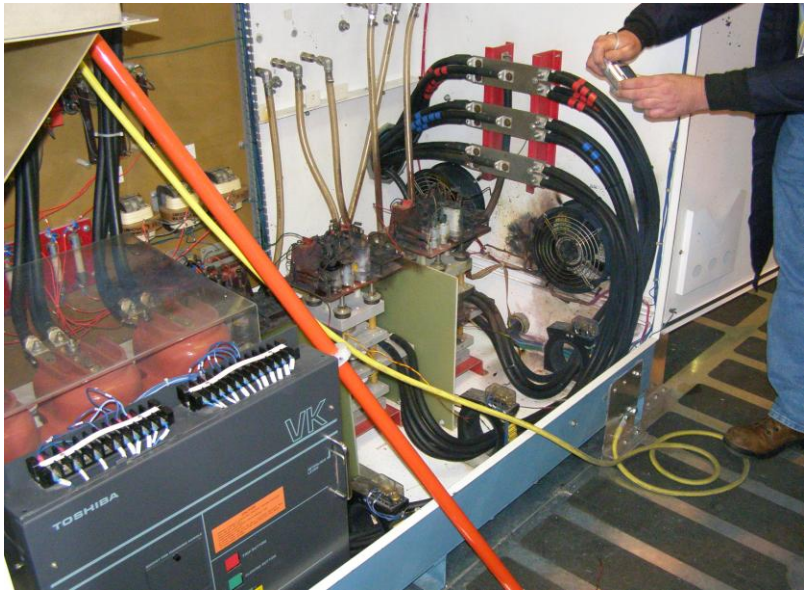
  → ***PC computer interface program written in Windows 3.1, running on Windows 95 OS!***

  → ***many intermittents on board connectors***

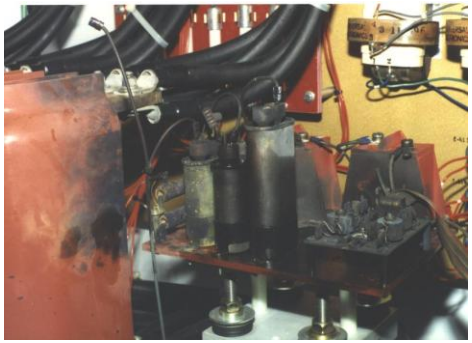


Solution: **Replace entire control system with a modern PLC……..*project currently underway***

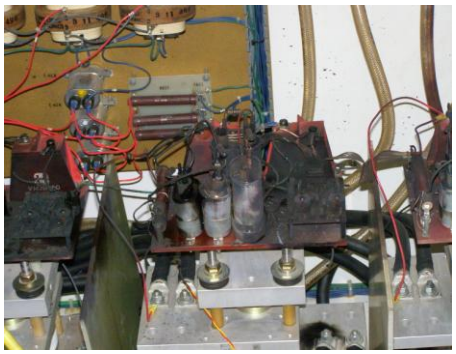
Cathode Voltage Regulator - SCR Cabinet Failures

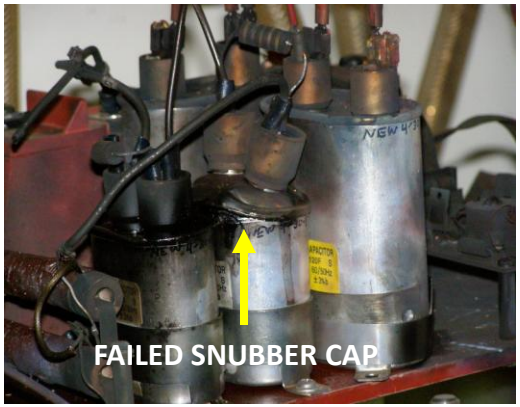


1996 EVENT



2007 EVENT





2007 EVENT

- Three catastrophic events have occurred: 1996, 2003, 2007
- Root cause in 1996 and 2007 events was traced to failure of SCR snubber capacitors

Solution: Replace original capacitors, and re-configure wiring between SCR stacks to reduce possibility of phase-to-phase shorts when components fail

13.2kV Fused-Disconnect Switches

- **Original switches *notoriously* unreliable**
  - → Failure rate as high as once every 10 operations!
  - → Would stick in both open and closed positions!
  - → Switch was obsolete at time of installation….1992!

- **Replaced by new switch that is more robust and easier to maintain, with improved personnel safety features**

Waveguide Arc Detector Trips

- **Typically occur once every 2 months per rf system, roughly 5-6 total per year…….*are they real or false*?**

- **Typical causes *when arcs are considered real*:**

  → Humid air from storage ring tunnel blown into waveguides by coupler blowers -- *common when weather is wet, rainy……. tunnel air is not controlled for humidity or temperature*

  → Arcing between ferrites in circulators coming out of a shutdown…….*dust settling on ferrites*?

- ***Typical causes when arcs are considered false*:**

  → Radiated electrical noise coupling into arc detector electronics

- **Number of arc detector trips since January 2010 is very high….7 total!**

  → Radiated noise suspected……*arc detector trips occurred on klystrons that were in standby diode mode*!

Solution: Find noise source…….*investigation ongoing!*

Cavity Input Coupler Failures

- **Four coupler failures in the last two years:**

  → 3/22/08 – Booster C1 -- sudden pinhole leak in ceramic

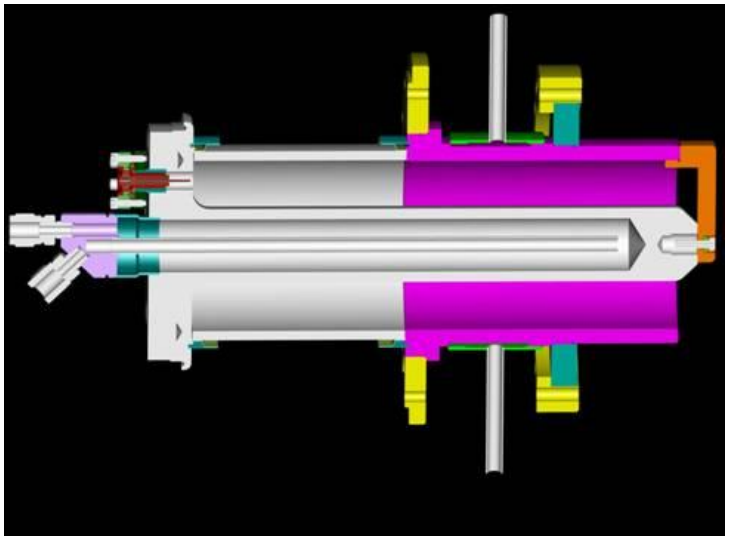
  → 4/25/08 – S40/C2 – intermittent vacuum trips

  → 6/04/08 – S40/C2 – new coupler destroyed by overpower accident during beam studies

  → 6/17/09 – S40/C2 – sudden pinhole leak in ceramic

- **Operating data before failure and post-mortem analysis did not find a definite cause for ceramic pinhole leaks**

FAILED BOOSTER C1 COUPLER



STORAGE RING COUPLER DESIGN

Klystron Trips and Instabilities

- Only two *verified* klystron-related beam losses in the last two years:

  → klystron vacuum trip (1)

  → sideband instability (1)

  …….a relatively low number considering the accumulated operating hours:

RF1 → EEV s/n 01 = 73,409 hr

RF2 → Thales s/n 089041 = 56,231 hr

RF3 → EEV s/n 089041 = 57,548 hr

RF4 → Thales s/n 089030 = 29,757 hr

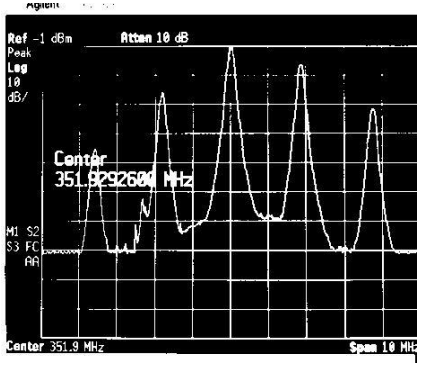
RF5 → Thales s/n 089026 = 48,073 hr

EEV K3513A → most reliable, free of instabilities

Thales TH2089A → reliable, but can become unstable at certain operating points

Klystron Instabilities

- The common sideband instability seen in the TH2089A results in very strong sidebands spaced ~ 2MHz from the carrier:



- Typical remedies:
  - → change cathode voltage by 1-3kV
  - → adjust circulator bias to increase reflected power in the direction of *slightly lower efficiency*

- In most cases sidebands can be suppressed

Klystron sidebands can occur without warning and typically result in beam loss during a fill

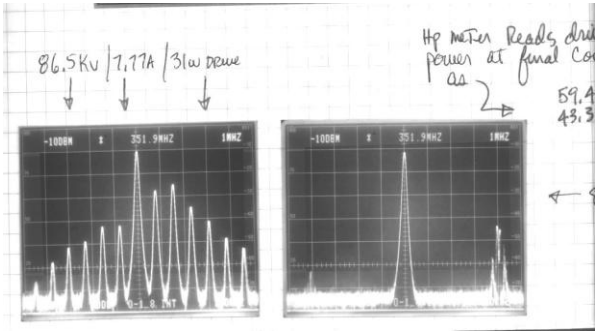
Recent Failure of a Klystron

- TH2089A, s/n 089043, failed after approximately 1,850 hours of operation
- Purchased new in 2001, sat in storage for eight years
- Was installed at RF2 in January of 2010 and ran normally in storage ring service for approximately three months
- On April 6th it suddenly developed severe sideband instability that could not be corrected by normal means
- Preliminary investigation indicates severe dc leakage across mod-anode/cathode ceramic (~ 2.5mA at 60kV)
- No crowbar or HV breakdown events were logged

Investigation is ongoing……

Klystron Instabilities

- Suspected multipactor losses in klystron C1 and/or C2 can result in sudden loss of efficiency and erratic rf power output, and have produced 800kHz sidebands:



- Typical remedy:

  → Adjust rf drive power to avoid multipactor region -- ***penalty:*** *loss of efficiency*

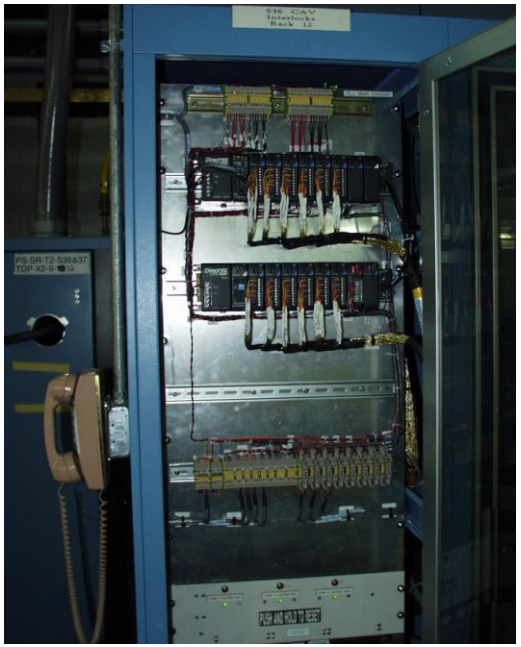
- In most cases the instability can be avoided without excessive loss of efficiency

C1/C2 multipactor can severely limit useful operating parameter range

Upgrade of Legacy RF System Hardware to Improve Reliability

- **Replacement of original process meter-relay logic interlock systems with modern PLC hardware:**

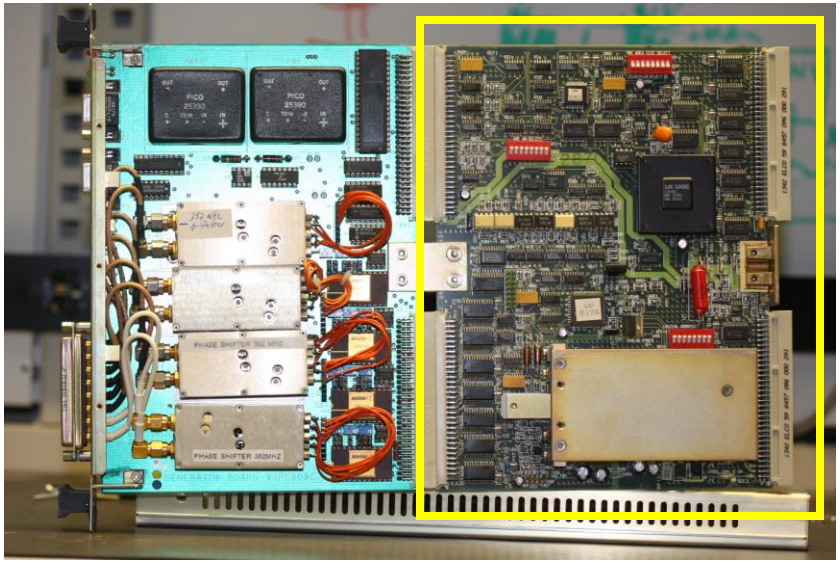
ORIGINAL SYSTEM WITH INDIVIDUAL PROCESS METERS



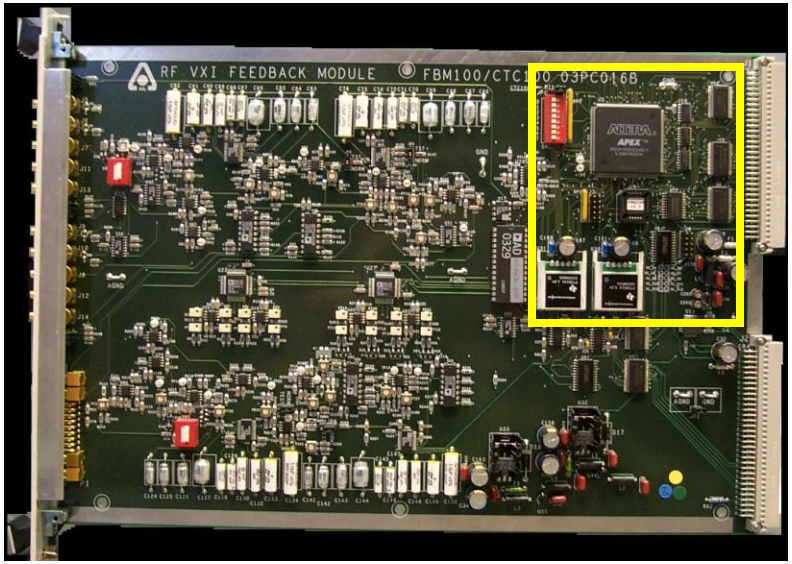
NEW PLC INTERLOCK SYSTEM INSTALLATION

Upgrade of Legacy RF System Hardware to Improve Reliability

- Upgrade of original low-level rf boards (circa 1990) with new data acquisition hardware:



LLRF BOARD WITH ORIGINAL DATA ACQUISTION HARDWARE



NEW LLRF BOARD WITH UPDATED ACQUISTION HARDWARE

Ongoing Effort to Maintain and Improve RF System Reliability

- Maintain adequate spares and avoid reliance on obsolete hardware wherever possible
- Implement design improvements on input couplers
  → Work underway; see D. Bromberek talk
- Increased attention paid to HVPS systems
  → Routine close visual inspection of system components to detect age-related defects…….*replace anything suspect!*
- Investigate *every* fault to determine the root cause…….. then implement change to prevent a future occurrence

THE PLACE IS GETTING OLD!…….THE FIGHT NEVER ENDS!