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Performance of the Advanced Photon Source 350-MHz 1MW CW Klystrons

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PRESENTATION OUTLINE

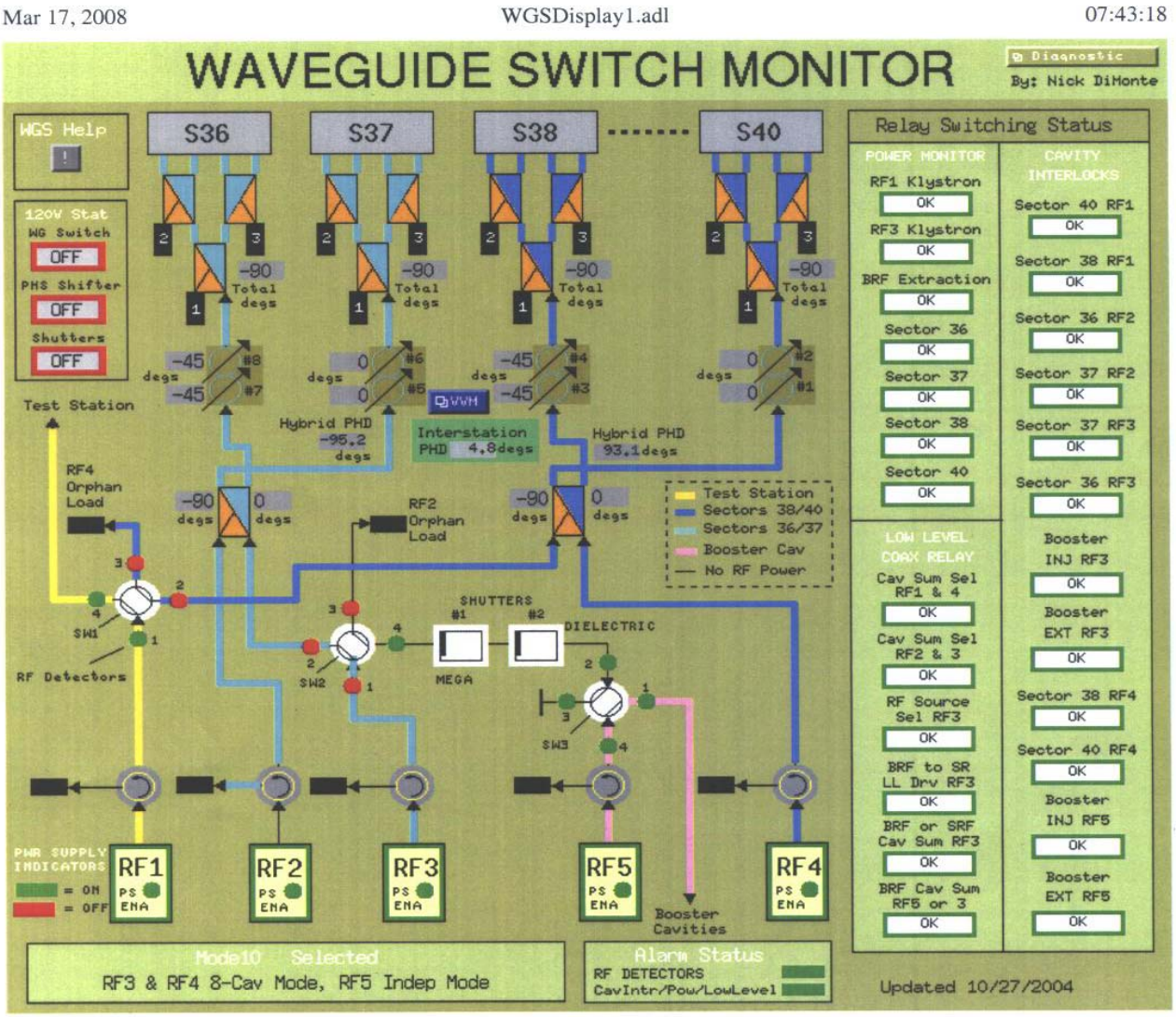
1. Review of APS 350-MHz RF System Topology
2. APS 350-MHz RF System Operation
3. APS 350-MHz Klystron Inventory
4. APS 350-MHz Klystron Operation 2006-2008
5. Klystron Problems and Corrective Action

APS 350-MHz RF System Topology

- **7GeV Booster-Synchrotron**
- **Electron Storage Ring capable of 300mA**
- **Five 350-MHz/1.1MW CW rf systems:**
  - → *four dedicated to Storage-Ring service (RF1, RF2, RF3, RF4)*
  - → *one dedicated to Booster-Synchrotron service (RF5)*
- **A waveguide switch system provides 12 different operating modes:**
  - → *Parallel-klystron configuration necessary for Storage-Ring currents greater than 150mA*
  - → *RF3 redundancy for RF5 (Booster-Synchrotron)*
  - → *Ability for RF1 to supply rf power for the 350MHz RF Test Stand*

APS 350-MHz RF System Topology

- **7GeV BOOSTER**
  - four 5-cell cavities, grouped in pairs
- **STORAGE RING**
  -16 single-cell rf cavities, grouped in four sectors



APS 350-MHz Klystron Installation

- **Al/Pb/Al "GARAGE" X-RAY SHIELD**

  - Movable half-shell for full access to klystron

  - Fixed half-shell fitted with two hinged doors to provide access for cavity tuning

  - X-ray levels normally less than 2mr at one foot from garage

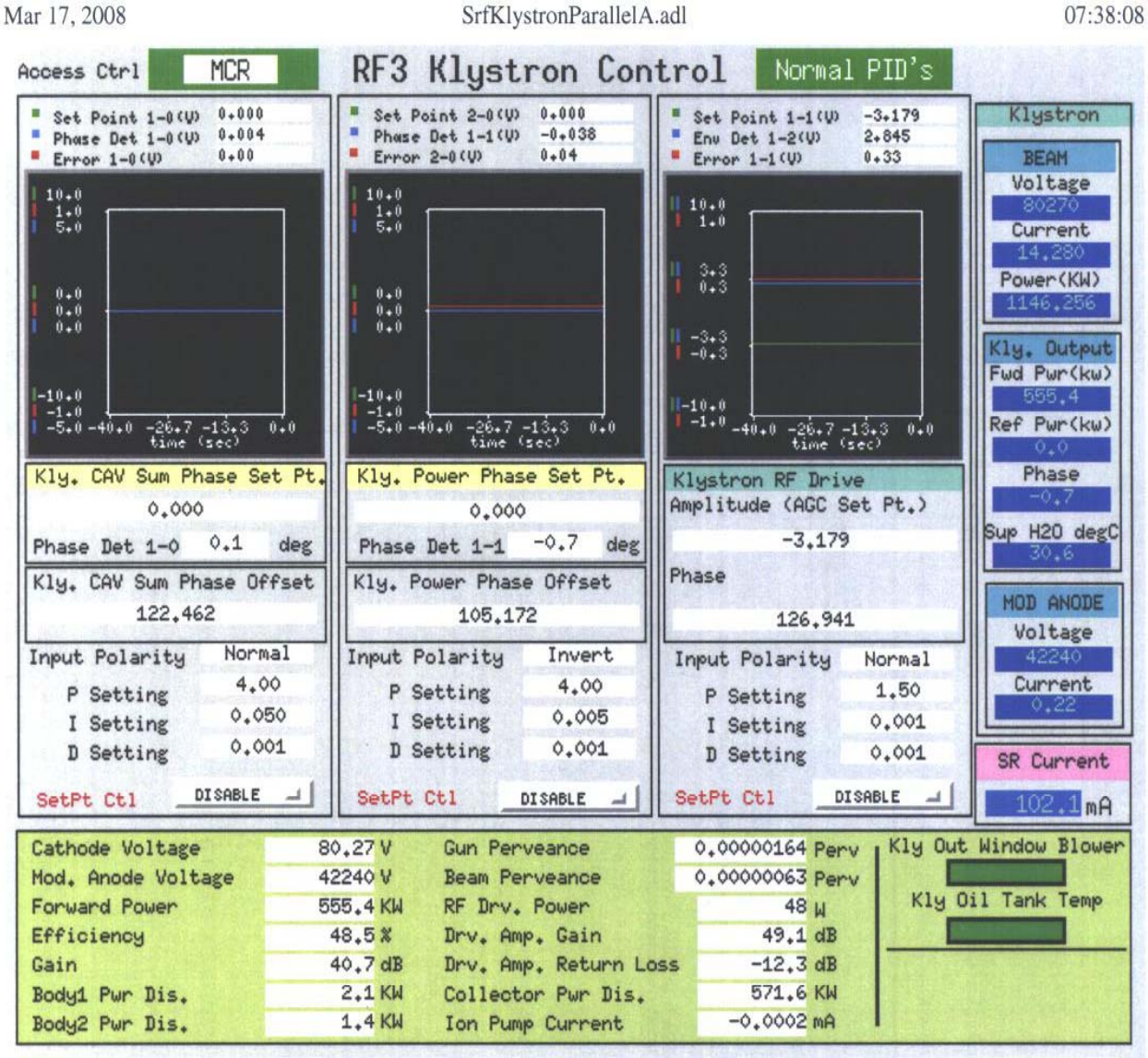
APS 350-MHz RF System Operating Levels

- **Normal Storage Ring operation is 103mA in "Top-Up" Mode**
  - *-- Requires two rf stations (RF1-RF4) operating at 600-700kW CW rf output, depending on gap voltage required*
  - *-- Beam voltage set to 80kV (where possible!) to improve operating efficiency*
  - *-- RF drive power as high as possible for highest efficiency (~ 50-52%), limited by klystron stability issues*

- **Normal Booster-Synchrotron operation at 7GeV**
  - -- Requires one rf station (RF3 or RF5) operating at 400-500kW peak rf power, depending on gap voltage required
  - -- 253ms ramp from 5kW to 420kW, at 2Hz rate
  - -- Klystron operating class A, ramped rf drive, 68kV@~12.5A.

APS 350-MHz RF System Operating Levels

- Klystron control screen for RF3 – ***EEV s/n 01***
- Efficiency lower than 50% due to low rf power requirement *(reduced storage ring gap voltage)*
- Approximately 330kW rf required with no SR beam
- RF power is controlled by an AGC loop that varies mod-anode voltage in response to storage ring beam loading



APS 350-MHz RF System "Hot Standby" Mode

- **RF stations not providing rf power to the storage ring or 350-MHz RF Test Stand are operated in "diode mode" (no RF) at 70kV/5A**

  -- RF stations are routinely switched in/out of standby mode approximately every 30 days

  -- Maintains gun conditioning and vacuum in klystron

  -- Maintains HVPS crowbar conditioning and general reliability

  -- Ok with all klystrons except Thales s/n 089041; a problem with excessive body power dissipation requires 70kV/6.2A diode operation.

APS 350-MHz Klystron Inventory

- **Total of ten klystrons tuned to APS RF Frequency – *351.93MHz***
  - → Present Five Operating Klystrons:
    - *-- Three Thales TH2089A, two EEV K3513A*
  - → Five Spare Klystrons:
    - *-- All Thales TH2089A……one new, four rebuilt*

- **One Philips YK1350 klystron tuned to *352.21MHz***
  - → Less than 500 hours of operation
  - → Recently tested into rf load to full 1MW CW after ten years of storage
  - → Under consideration for retuning to APS frequency

APS 350-MHz Operating Klystrons

EEV K3513A s/n 02

- Presently in service at **RF1**
- **59,014 hours** as of March 13, 2008
- No operational problems noted; *absolutely trouble free!*

Thales TH2089A s/n 089041

- Presently in service at **RF2**
- **43,976 hours** as of March 13, 2008
- Ongoing unresolved problems with excessive x-ray emissions and high body power
- Sideband instabilities suppressed by careful adjustment of circulator bias; *very sensitive to output match*
- *Reduced efficiency by ~ 2% to achieve stability!*
- *Suspected input cavity electron instability which causes erratic rf output between 300-400kW*

APS 350-MHz Operating Klystrons

EEV K3513A s/n 01

- Presently in service at **RF3**
- **42,478 hours** as of March 13, 2008
- No operational problems noted; *absolutely trouble free!*

Thales TH2089A s/n 089030

- Presently in service at **RF4**
- Refurbished and factory acceptance tested on 10/31/2000
- Installed at RF4 on 11/15/05
- **15,774 hours** as of March 13, 2008
- No serious problems, *but can become unstable*.

Thales TH2089A s/n 089026

- Presently in service at **RF5** (Booster-Synchrotron)
- **33,881 hours** as of March 13, 2008
- No operational problems noted

APS 350-MHz Spare Klystrons

Thales TH2089A s/n 089043

- Last NEW klystron purchased, delivered to APS on 12/5/01
- Presently in spares storage

Thales TH2089A s/n 089036

- Refurbished; *factory acceptance tested on 12/13/02*
- Presently in spares storage

Thales TH2089A s/n 089029

- Refurbished; *factory acceptance tested on 12/8/03*
- Presently in spares storage

APS 350-MHz Klystron Inventory

Thales TH2089A s/n 089024

- Refurbished; *factory acceptance tested on 8/30/04*
- Presently in spares storage

Thales TH2089A s/n 089033

- Removed from service at RF4 on 11/15/05 at 52,720 hours
- Shipped to Thales on 3/30/06
- Thales factory refurbishment and factory acceptance test completed on 2/6/07
- Delivered to APS on 3/20/08, and passed gas test on 3/21/08
- Presently in spares storage

Klystron Operational Record 2006-2008

- ***No klystron-related downtime during this period!***

→ **Klystron issues (arcing, instabilities) were originally suspected in some beam losses, but further investigation proved otherwise!**

→ **350-Mhz klystron performance contributed to the outstanding overall reliability from the APS rf systems:**

	% DOWNTIME	MEAN TIME TO FAULT
• FY 2006	0.84%	195.0hr
• FY 2007	0.39%	339.3hr

But there were some klystron problems……

Klystron Problems 2006-2008

- **Pantak Socket Problems**

→ *cracked sockets*

-- over-tightening?

→ *broken or distorted contact springs*

-- caused several cases of intermittent heater current

→ *oil seepage into socket*

-- causes swelling of cable plug, loss of cable (~ $6K!!)

WHITE PANTAK SOCKETS CAN BREAK!

More attention to proper maintenance has reduced these failures

Klystron Problems 2006-2008

- **Excessive x-ray emissions from RF2 klystron garage** – ***Thales s/n 089041***

  → ***Routine Health Physics monitoring indicated ~ 7-25mr at mid-point of garage (same region of klystron where drift tube melted in 1999)***

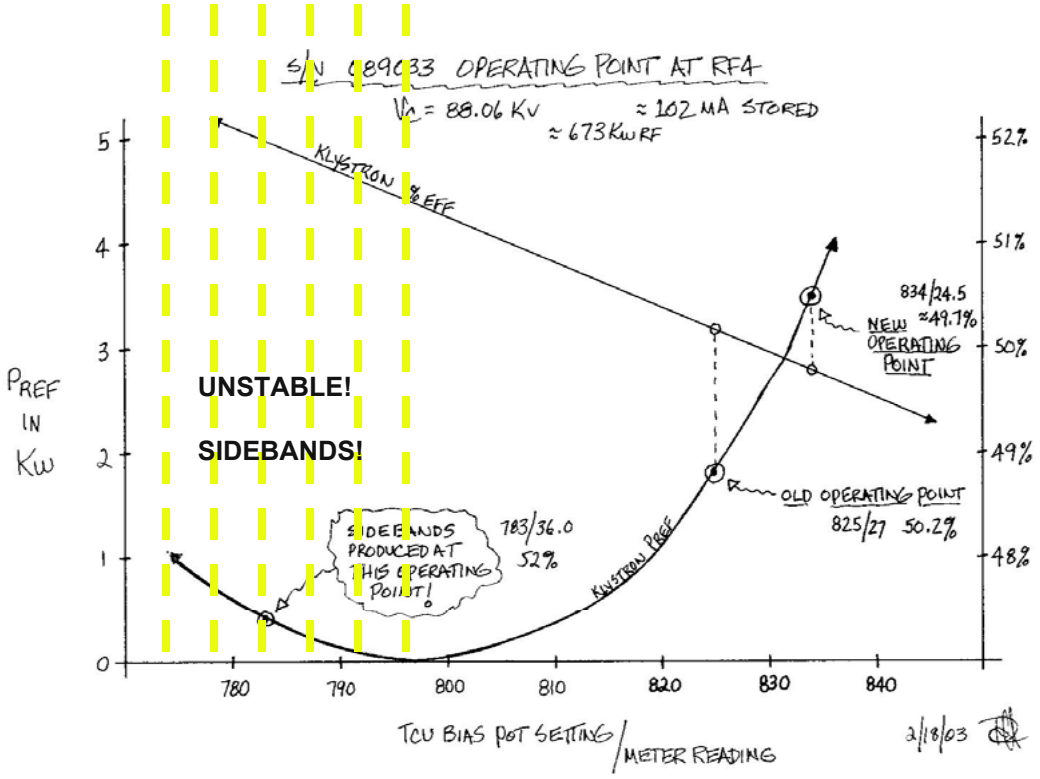
  → ***Excessive Body1 power dissipation (~9-15kW!)***

  → ***Ongoing problem……..many attempts by Thales to resolve problem***

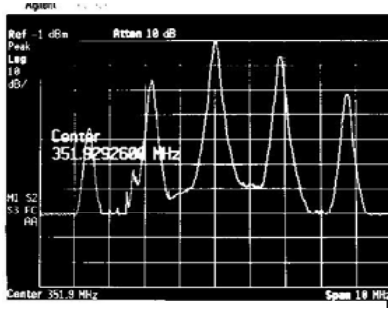
Supplemental lead shielding added to garage!

Klystron Problems 2006-2008

- **Sideband instabilities**
  - → *Can cause sudden beam losses and are hard to diagnose*
  - → *Only seen on Thales klystrons*
    - ***s/n 089041 particularly bad***
  - → *Best remedy is to adjust circulator bias for additional reflected power on the low-efficiency side of the curve*
    - ***sacrifice ~ 1-2% efficiency***



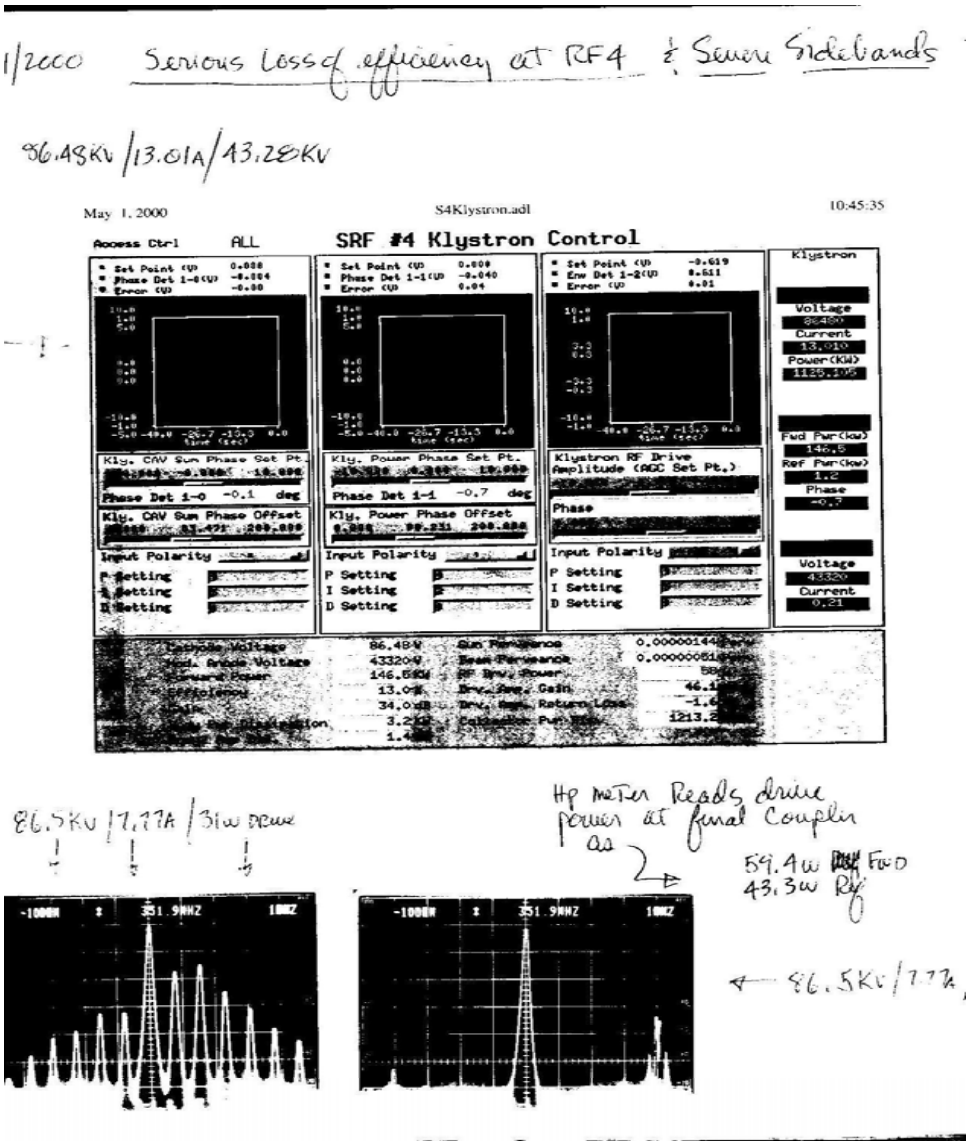
Typical klystron sidebands ± ~ 1.8MHz from carrier



Klystron Problems 2006-2008

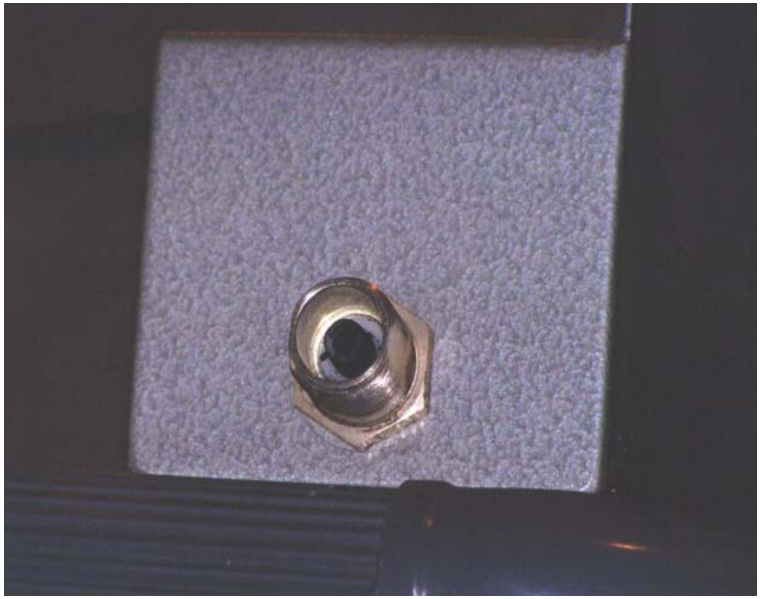
- **Unstable rf output due to suspected electron instabilities**
  - → *multipactor in 1st or 2nd cavity suspected*
  - → *severe ~ 800kHz sidebands*
  - → *kept under control by determining a stable range for rf drive power*

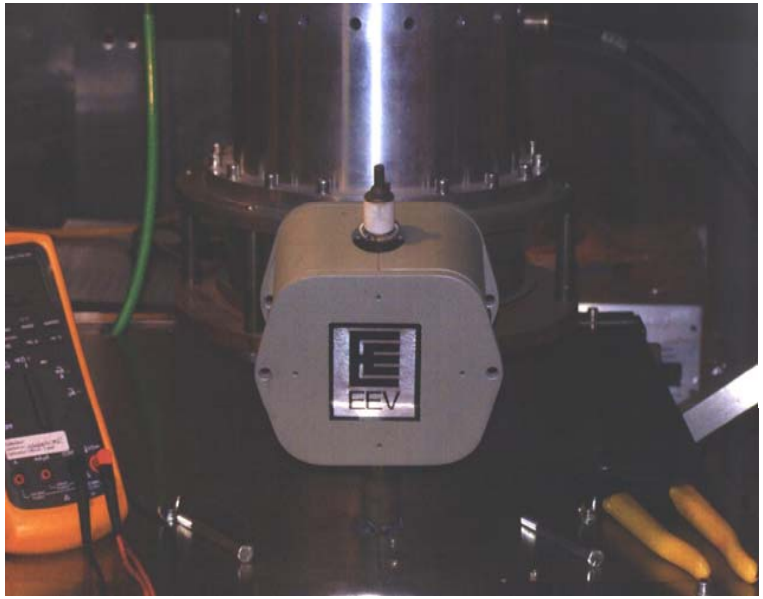
- ***Thales s/n 089041 particularly bad……..only stable between 42-46 watts of rf drive power!***



Klystron Problems 2006-2008

- **Arcing in ion pump connector -- *EEV s/n 01***
  - → *Dirty connector ????*
  - → *Did not result in downtime (auxiliary non-interlocked ion pump)*





Klystron Problems 2006-2008

- **Output window arc detector trip on RF1**
  -- *EEV s/n 02*

  → *Only one arc event (appeared to be a real arc)*

  → *Ran klystron into load at ~ 700-800kW for four hours with no problems*

  → *Placed back into SR service with no further problems for over a year*

APS 350-MHz Klystron Maintenance

- Adjust the rf system for best possible stability and performance ……..*then leave the klystron alone if it is happy!*

- Weekly analysis of operating parameters

  → *Watch for changes in efficiency, body losses, mod-anode current, perveance*

- Monitor and alarm on klystron sideband instabilities

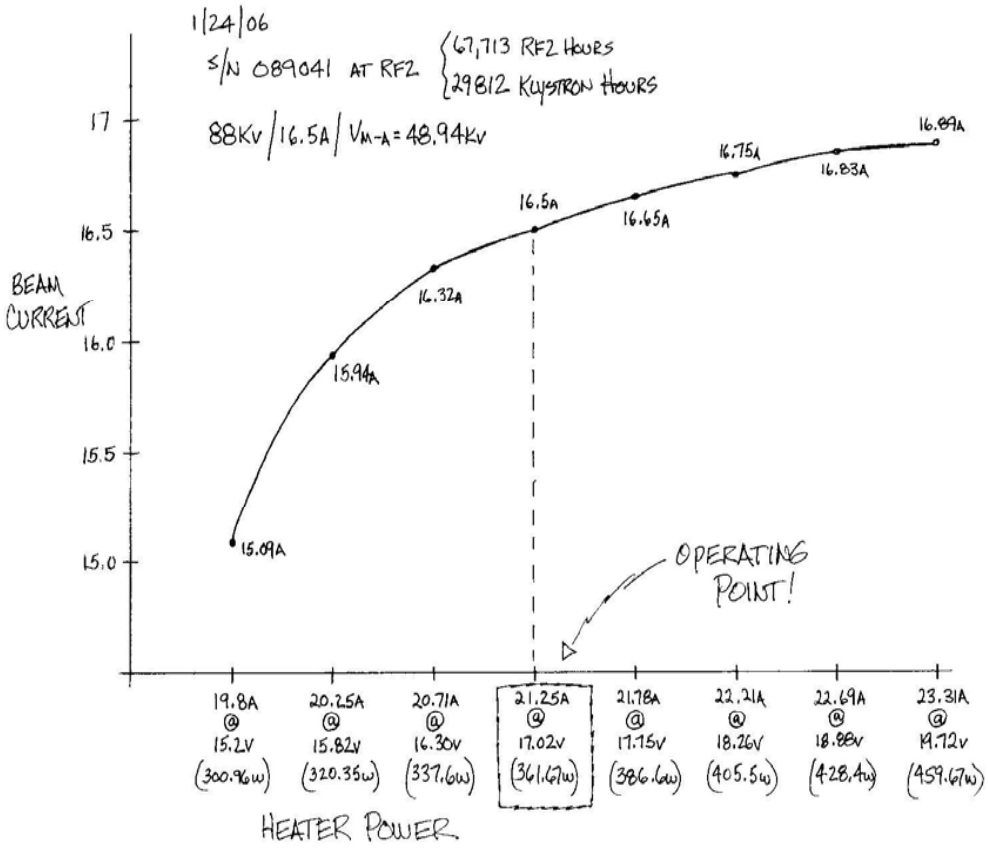
- Thorough visual inspection of klystron every shutdown, including Pantak plugs and sockets

- Check oil quality every shutdown (30kV or greater breakdown)

APS 350-MHz Klystron Maintenance

- Perform emission checks every 7000 hours at nominal operating point.

  → *Running the cathode hotter than necessary can cause many types of chronic problems!*



APS 350-MHz Klystron Maintenance

- "Spotknock" the klystron gun at least once every two years…….*and whenever your crowbar fires excessively!*

  → A very valuable test!

  → Helps find the real cause of crowbar events…….
  it may not be the klystron!