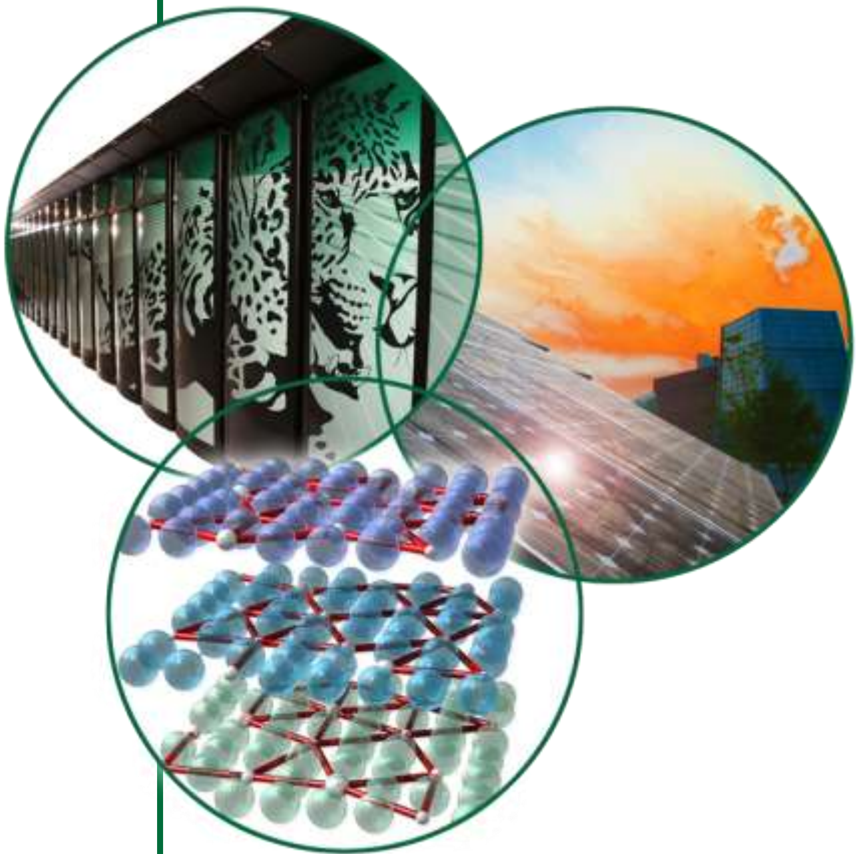
RF Systems



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

RF Systems – Presentation Outline

- Equipment Status
  - Ion Source RF
  - RFQ
  - MEBT Rebuncher System
  - Warm Linac RF
  - Ring RF
  - Low Level RF
- Reliability Issues
- Klystron Lifetime and Spares
- RF Test Stand
- Superconducting RF Support
- Summary

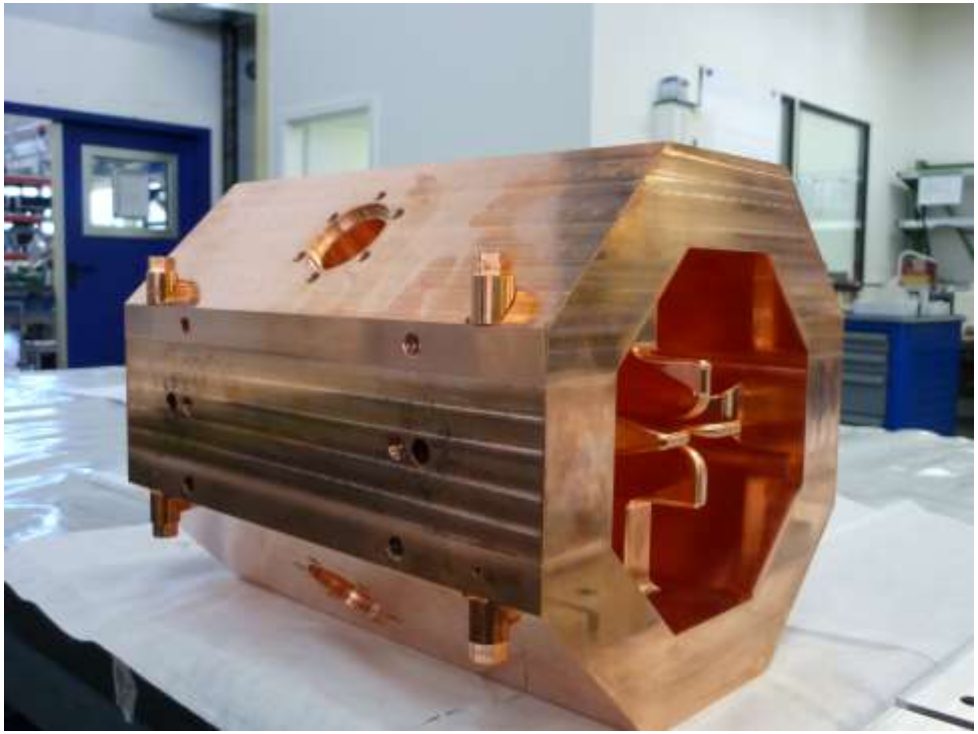
Ion Source RF

- Goal is to develop a Low Level RF control system and operate with a Solid-State power amplifier at ground potential
  – Installed High-Voltage insulated RF transformer
    - Production 2 MHz High Voltage Isolation Transformer has been in operation since July 2010
    - Plan to provide a 13 MHz transformer to allow operation of the 13 MHz amplifier system at ground potential
  – Installed ground-referenced QEI hard-tube amplifier and controls
  – Preparing to install Solid State Amplifiers in Front End
  – Plan to concentrate on developing a closed-loop Low Level RF system for Ion Source (Not presently funded)

Transmission Line High Voltage Isolation Transformer

RFQ Status

- Retuned RFQ after a major shift in frequency (January 2009)
  - 2nd time we have done this
- Concerned another shift could take place
- May have field errors we do not observe
- Working on obtaining a spare
  - Have contract with RI (Germany)
  - Design Complete
  - Fabricated two short prototype segments to verify mechanical design issues and brazing operation
- Anticipate delivery Fall 2012



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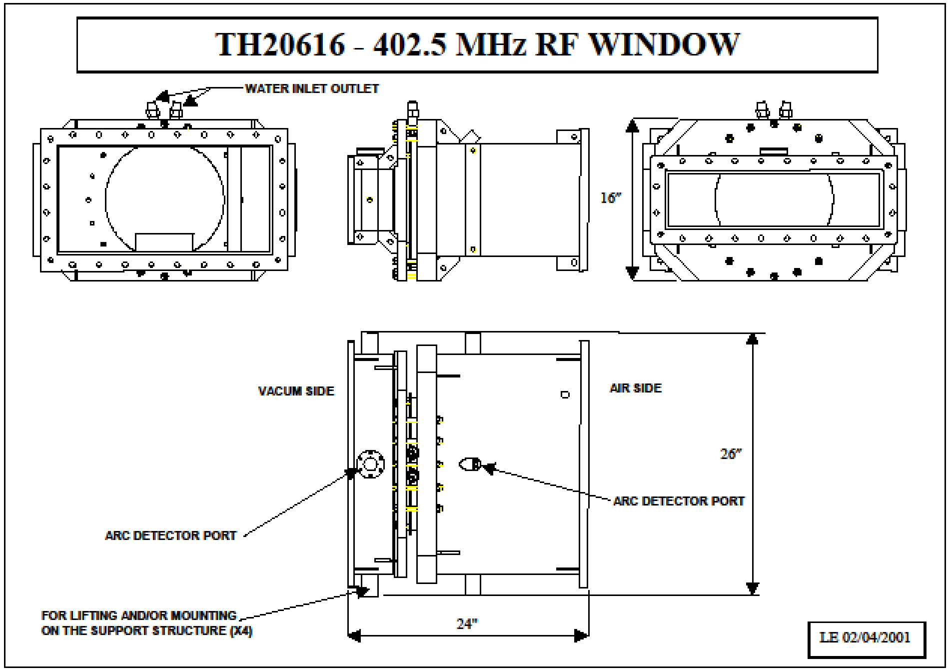
Warm Linac Issues

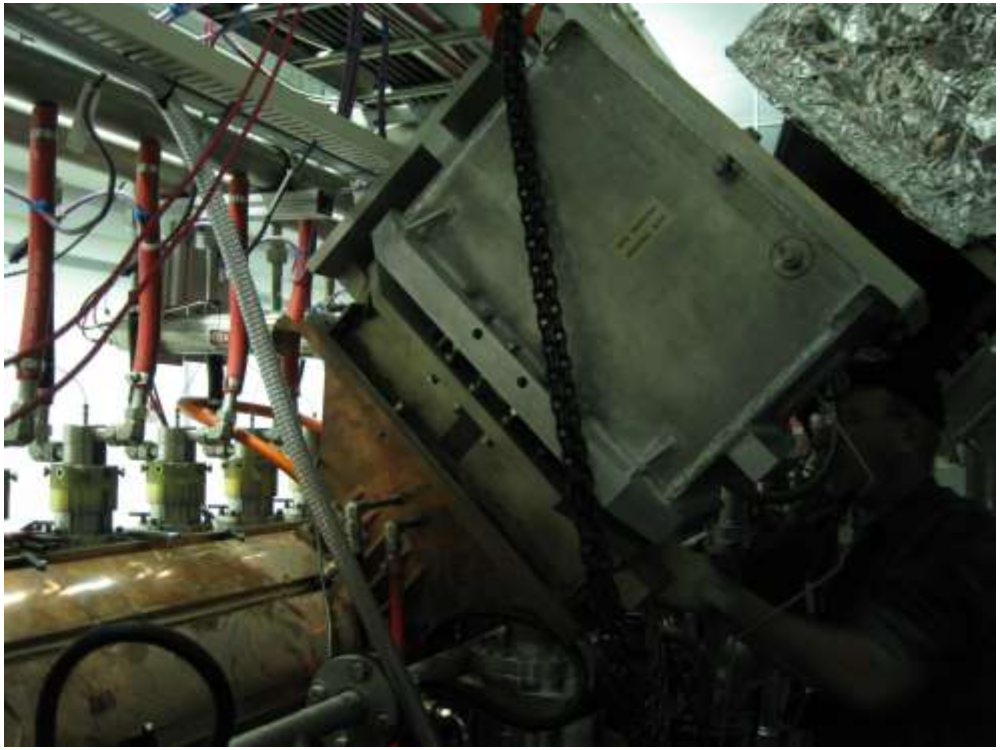
- Have recently developed a vacuum to water channel leak in DTL-4 Tank
  - We traced the leak to an RF vacuum window and believe it is a braze joint failure.
- Replaced 2 DTL windows due to vacuum leaks at waveguide flange braze joint
- Have arcing in the Iris/Window regions of several DTL tanks
- During the July 2010 shutdown we inspected DTL-3 and DTL-4 coupling Irises
  - Did not see signs of arcing on DTL-4
  - Found DTL-3 missing an RF Shield on the vacuum pumping port
  - Installed Shield during January 2011 shutdown
  - Irises have some high field regions we can improve
  - Intend to redesign irises and fabricate replacement for DTL 3 and a couple of spares (Redesign and prototype is funded. Manufacture of replacement units is not currently funded.)
- During February 2011 startup we broke a CCL window
  - Believe this is a thermal failure from Thales past experience
  - Not satisfied with original water cooling path design
  - Will improve design and manufacture new spares locally (Design is funded. Manufacture of windows is not presently funded.)
- Will want to redesign both DTL and CCL Couplers for operation at 1.4 MW
  - Increased beam loading will require higher power through already troublesome couplers

Warm Linac Issues

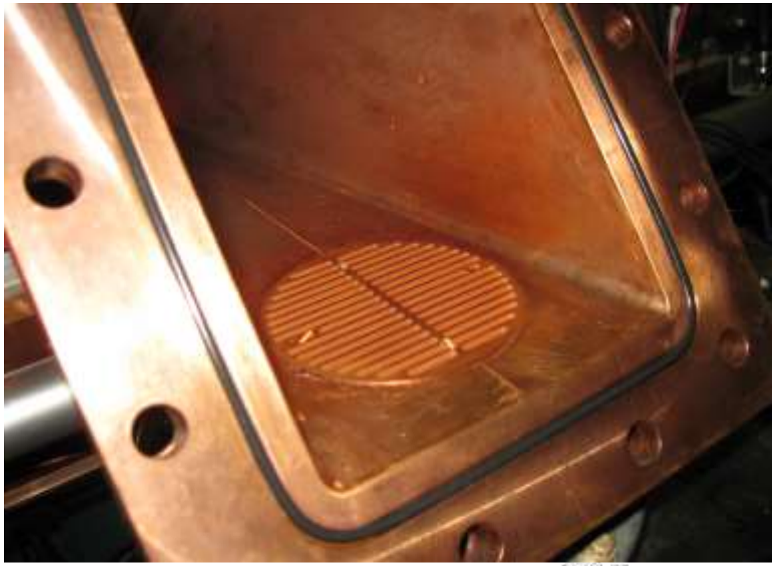


- Vacuum Leak on DTL-6 RF window (May 2009)
  - Traced to a braze joint in the vacuum side waveguide section
  - May have had similar problem on DTL-4
  - RF conditioned 4 spare windows
    - Two with improved welded waveguide joint
  - Replaced DTL-4 window July 2010
  - Planning to build 3 more spare windows in-house

DTL 3 Iris Pumping Port RF Screen

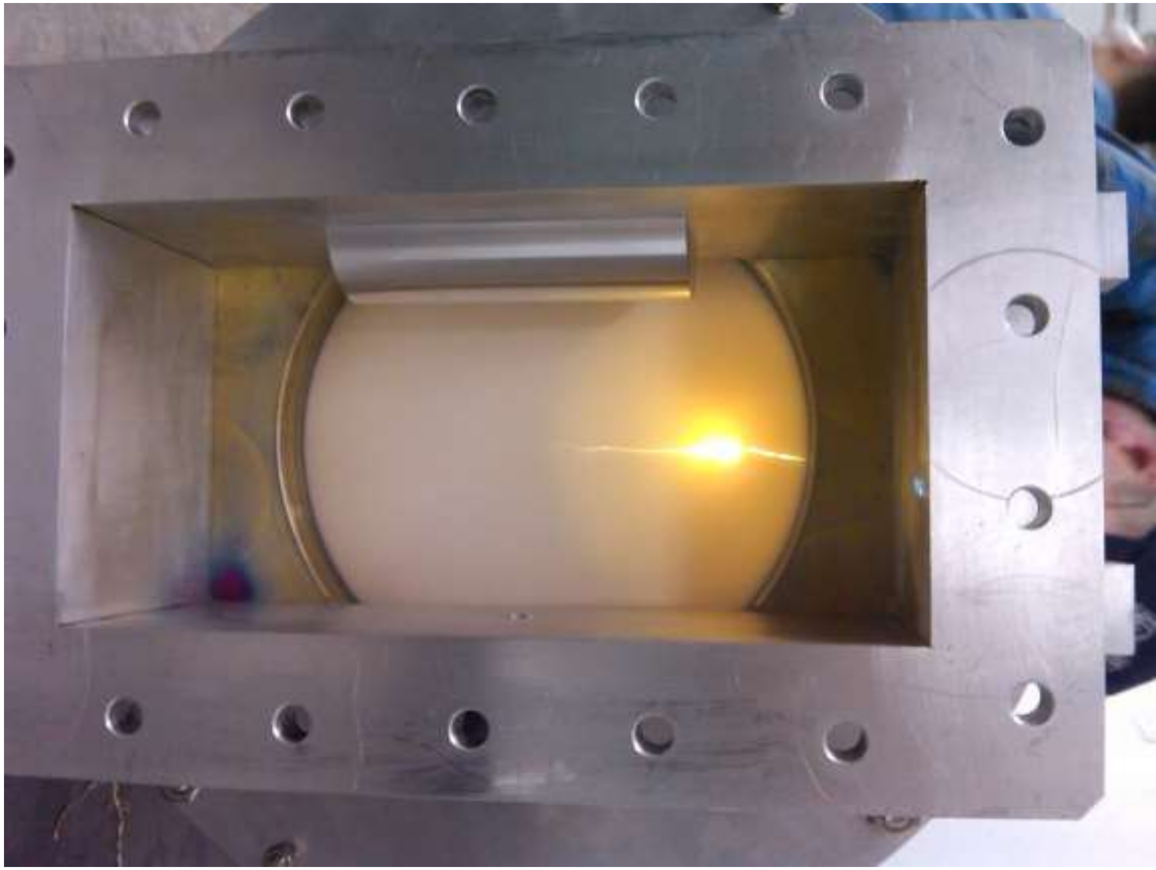


Screen installed during shutdown period - Jan. 2011



CCL 3b Window Failure

- Replaced with a spare – Feb. 2011



Ring RF

- Replaced QEI driver amplifiers
  - We have had several QEI amplifiers fail
  - Can no longer acquire replacement components
  - Have replaced QEI drivers with Tomco amplifiers identical to the sub-system amplifiers used in the new Ion Source amplifier.
- Had several failed Lambda ALE anode supplies
  - Had a variety of failure causes
  - Working with Lambda to develop in-house repair capability
- Working on improved Low Level RF system
  - Present system lacks some desirable features that may be important for 1.4 MW operation.

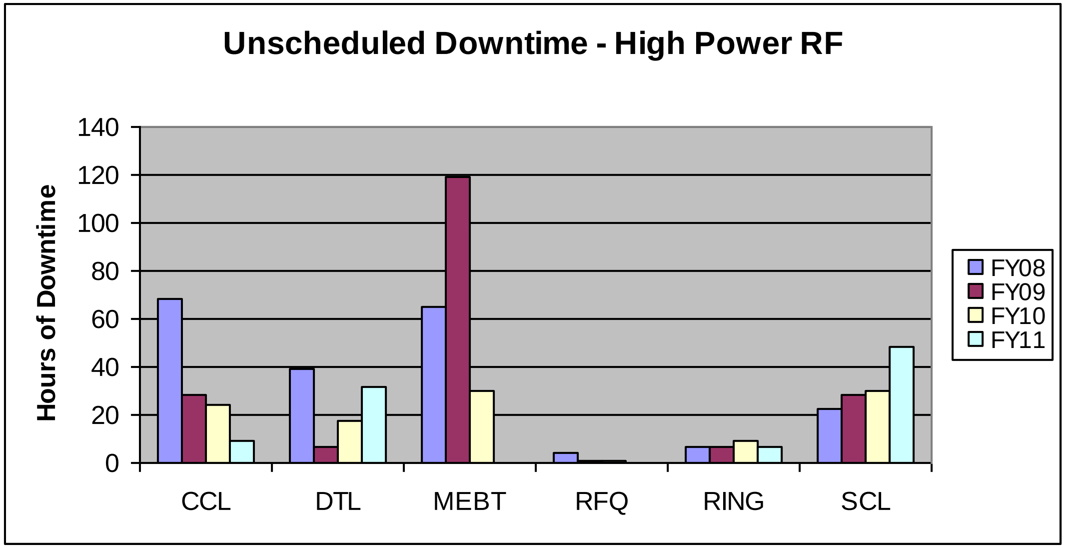
Linac Low Level RF Improvements

- Overall the LLRF systems have been very dependable
- Minor temperature dependence found on LLRF systems
- Developed prototype system to limit temperature dependence
  - Laboratory testing completed
  - Plan to install for Accelerator testing January 2012
- Redesign of Analog Front End & RF Output module complete – cost of new units is significantly lower than original unit cost.
- Developed an inexpensive 8 channel pulse power meter for monitoring RF channels and measuring klystron perveance
  - Several units in use but production of remaining units is not yet funded.

Future Low Level RF Work

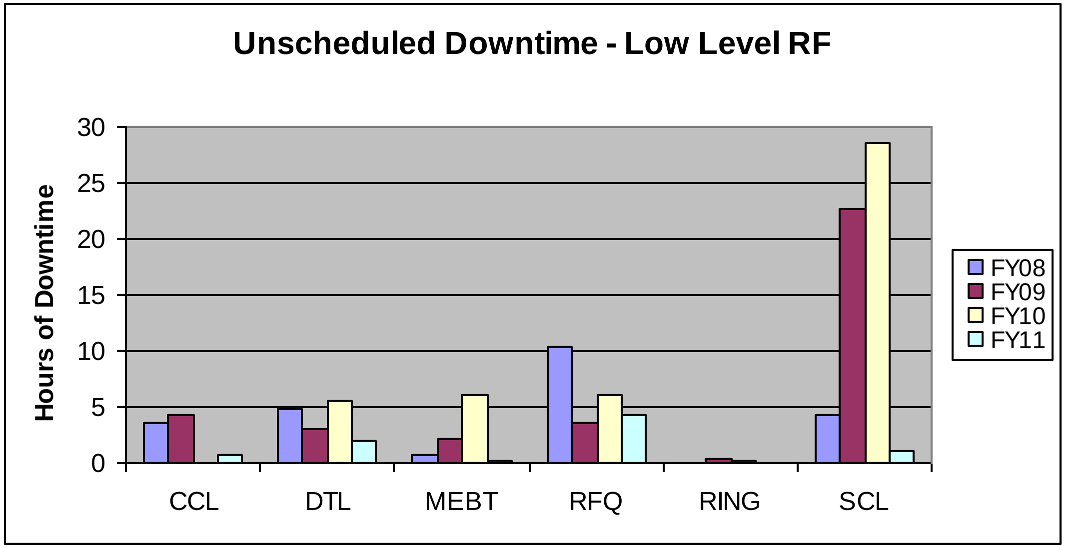
- Obsolescence is the major issue for the current LLRF systems
- Redesign of High Power Protection Module underway to mitigate FPGA obsolescence and improve resolution
- Field Control Module (FCM) will need to be addressed in the near future due to FPGA obsolescence
- Ring LLRF systems lack some features that may be required to support 1.4 MW operation
- Need for an Ion Source LLRF system to optimize control
  - Currently operated open loop
  - Not currently funded

Unscheduled Downtime – High Power RF



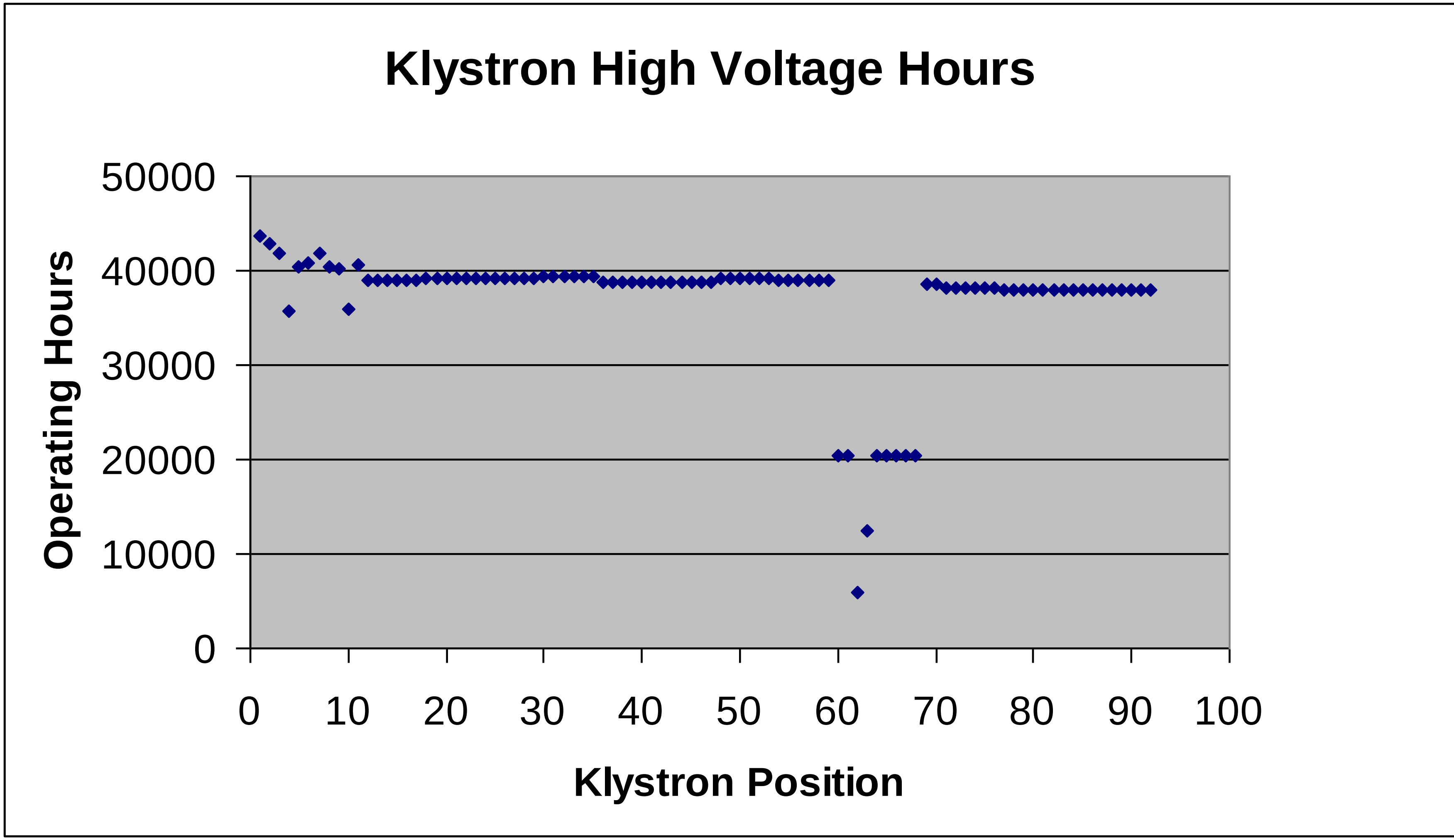
- **MEBT Rebuncher amplifiers were the major cause of downtime but fell off sharply when we replaced the brute force high voltage supplies with capacitor charging supplies.**
  - **We have now fully implemented Solid State MEBT amplifiers and downtime is essentially zero.**
- **DTL downtime is increasing Due to window/Iris arcing and vacuum issues**
- **The jump in SCL downtime in FY11 is the result of transmitter faults. Two transmitters had problems during FY 2011.**

Unscheduled Downtime – Low Level RF

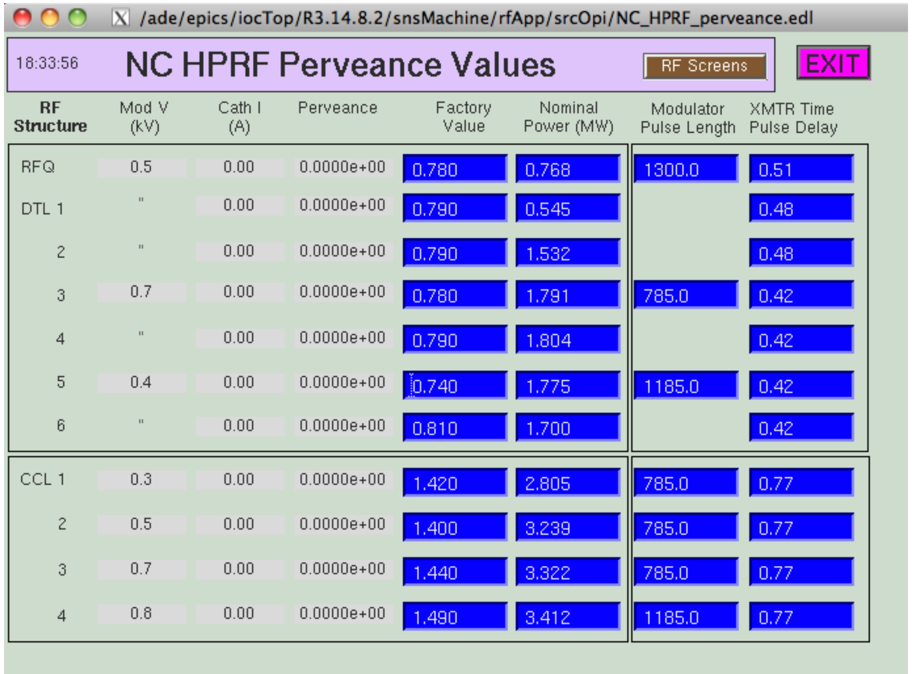


- **SCL had been the major contributing item**
  - **In FY-2011 we shifted these faults to High Power RF**
    - **We believe they are structure related which fits into High Power RF**
    - **The majority of downtime is from the LLRF protecting real cavity fault conditions**

Klystron Operating Hours



Klystron Anticipated Lifetime



RF Structure	Mod V (kV)	Cath I (A)	Perveance	Factory Value	Nominal Power (MW)	Modulator Pulse Length	XMTR Time Pulse Delay
RFQ	0.5	0.00	0.0000e+00	0.780	0.768	1300.0	0.51
DTL 1	"	0.00	0.0000e+00	0.790	0.545		0.48
2	"	0.00	0.0000e+00	0.790	1.532		0.48
3	0.7	0.00	0.0000e+00	0.780	1.791	785.0	0.42
4	"	0.00	0.0000e+00	0.790	1.804		0.42
5	0.4	0.00	0.0000e+00	0.740	1.775	1185.0	0.42
6	"	0.00	0.0000e+00	0.810	1.700		0.42
CCL 1	0.3	0.00	0.0000e+00	1.420	2.805	785.0	0.77
2	0.5	0.00	0.0000e+00	1.400	3.239	785.0	0.77
3	0.7	0.00	0.0000e+00	1.440	3.322	785.0	0.77
4	0.8	0.00	0.0000e+00	1.490	3.412	1185.0	0.77

- Previously recorded perveance data is hard to interpret due to changing modulator pulse length
  - Voltage is recorded as an average value and droops throughout the pulse
  - Current is recorded at selected time into cycle
  - Analyzing existing data
- We have recently recorded waveform data for each klystron
- We are adding a screen to display perveance data and are data-logging the parameters
- Developed multichannel power meter with extra channels to record klystron voltage and current waveforms and calculate perveance
  - Several installed in the klystron gallery
  - Production of more units is not currently funded

Klystron Spares Inventory

- Klystrons
  - DTL uses 2.5 MW, 402.5 MHz klystrons (7 in service, 7 spares)
    - We have 4 spare E2V versions (E2V has stopped building these)
    - Thales has completed the design of a replacement and delivered 3 acceptable klystrons
  - CCL uses Thales 5 MW, 805 MHz klystrons (4 in service, 5 spares)
    - We have 5 spare Thales klystrons with 4 klystrons fully conditioned
    - We have 2 more klystrons on order
    - 1 klystron failed when we got the cathode and filament connections reversed.
    - 1 klystron failed with loss of vacuum while in storage
  - SCL uses 550 kW, 805 MHz (81 in service, 43 spares)
    - We have 11 spare original design CPI klystrons
    - We have 20 spare CPI klystrons capable of 700 kW version (replaced 9 Thales)
    - We have 12 spare Thales klystrons (three have stability issues we can correct)
- Gridded Tubes
  - Ring RF uses 500 kW Tetrodes, TH558/4CM500,000G (4 in service, 4 spares)
  - Ion Source RF uses 20 kW Tetrodes, 4CX20000 (3 in service including test stands, 2 spares)
    - Will replace with solid state amplifiers

RF Test Stand

- Primary test stand for RF components
  - 402.5 & 805 MHz klystrons routinely tested and conditioned
  - Window/coupler conditioning
  - Support for SCL cavity testing
  - High Voltage Converter Modulator (HVCM) testing to support development efforts

Superconducting RF Support

- Developing 4 output mechanical Vector-Modulator
  - Independent phase/amplitude control of each output
  - Will be used to power all 4 cavities within a High B Superconducting Cryo-module simultaneously
  - Developing LLRF controls for vector-modulator
- Providing RF and controls for Vertical Test Stand

Single output Vector Modulator

Wide Range Mechanical Phase Shifters

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Summary

- There remains significant Ion Source RF System work
- MEBT RF upgrade complete
- Warm LINAC still has some problems
- SCL RF Power limitation resolved
- We are beginning to acquire Klystron Perveance Data
  - Analyzing archive data
- Continue to identify and resolve reliability issues