RF Systems

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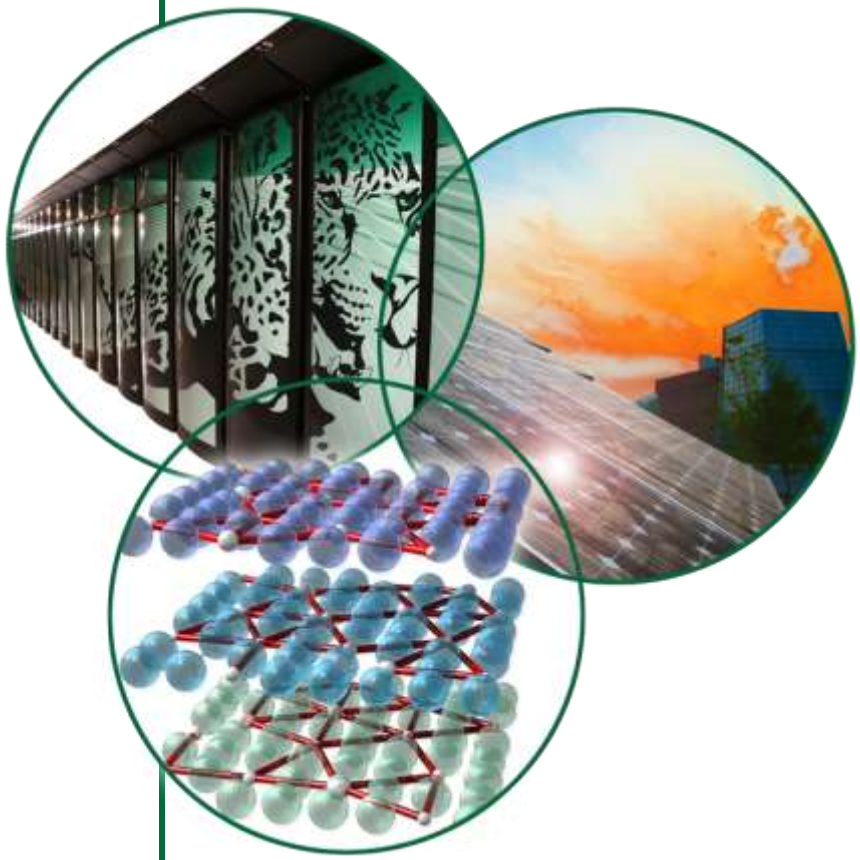
February 2 – 4, 2010



U.S. DEPARTMENT OF ENERGY

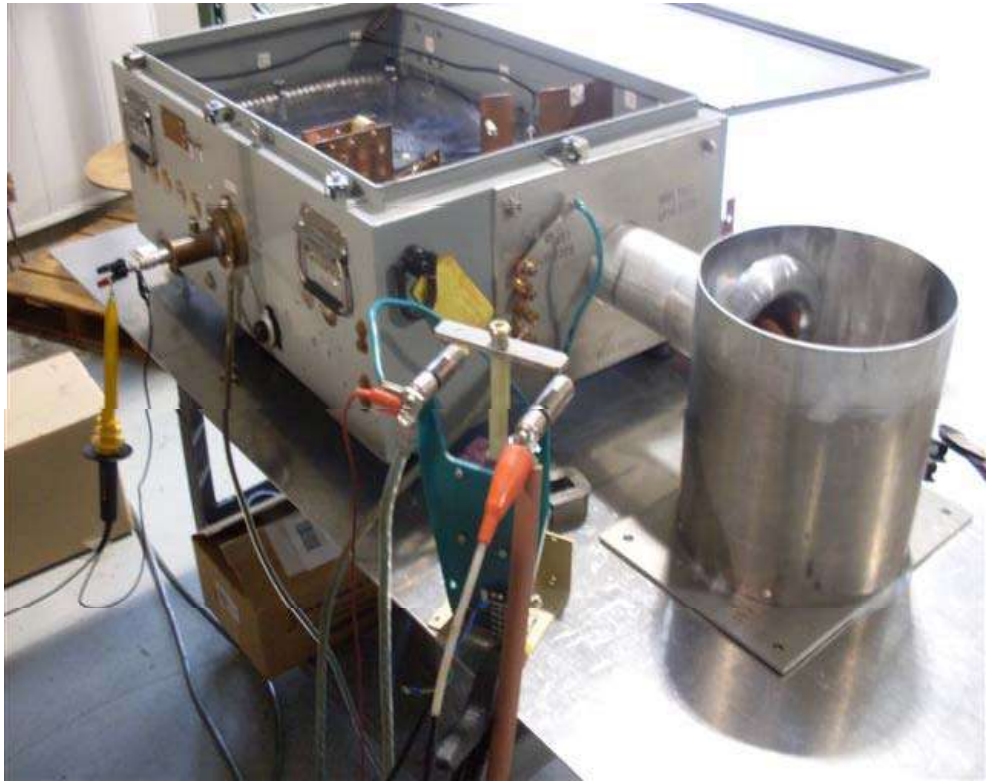
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

RF Systems – Presentation Outline

- Equipment Status
  - Ion Source RF
  - RFQ
  - MEBT Rebuncher System
  - Warm Linac RF
  - Superconducting Linac RF
  - Ring RF
  - Low Level RF
  - RF Test Stand
- Reliability Issues
- Klystron Spares
- Operation at 95 % Beam Availability
- Summary

Ion Source RF

- Goal is to operate with a Solid State amplifier at ground
- Prototype 2 MHz High Voltage Isolation Transformer



- 1:1 Transmission Line Transformer
- Hi Pot tested to 80 kV
- Operated with 60 kW of RF for extended period
- Preparing a fully operational test producing Ion Beam
- Will ultimately combine the matching network and isolation transformer

Ion Source RF

Tomco Solid State 2 MHz Amplifier

- 120 kW in 2 racks
- First unit in our lab
  - Setting up for Site Acceptance Test
- Second unit on order
  - Anticipate April delivery
- Each amplifier rack can operate independently
- Each rack produces 60 kW

RFQ Status

- Retuned RFQ after a major shift in frequency and field flatness last year (January 2009)
  - Seems to be the result of a vane shifting due to a water pressure surge during maintenance
  - Similar to shift that occurred several years ago
  - Concerned another shift could take place
  - May have field errors we do not observe
- Working on obtaining a spare
  - Prepared specification
  - Received bids from several possible vendors
  - Working on clarifying some items with vendors
- Had issues with loss of resonance control at high duty after several hours of operation
  - Limiting Ion Source gas flow
  - Upgraded water manifold to improve cooling
  - Added feedback loops to LLRF control page to regulate pulse width and chiller temperature
  - Added pressure relief valves
  - Changed pumps in chiller

MEBT Rebuncher Amplifier System

- Now operating the system at design power levels (20 kW)

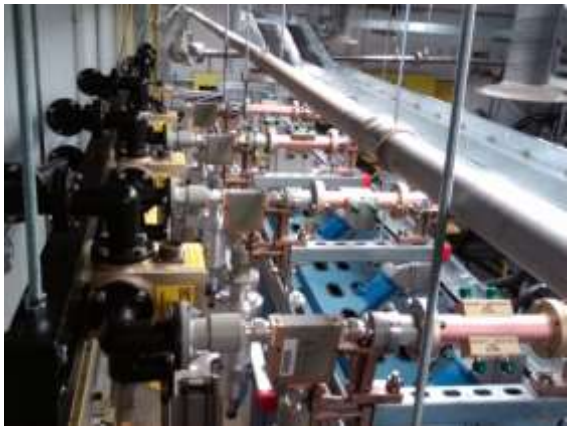
Capacitor Charging Supply

- Installed Capacitor Charging supplies in existing amplifiers
  - The amplifiers still trip off but can be reset from the Control Room
  - Down time now near zero
- We are now running Cavity 4 from a Tomco Solid State amplifier
- Have remaining Solid State amplifiers on order
  - Delivery in April
  - Will install a total of 5 amplifiers with the 5th amplifier able to be remotely switched to power any cavity
  - We are presently installing racks, switch networks, LLRF, and all cabling
  - Will install the amplifiers during summer maintenance period
  - Existing system will remain in place and can be connected if necessary

MEBT Rebuncher Amplifier System

First MEBT RF Amplifier – Now Operating Cavity 4

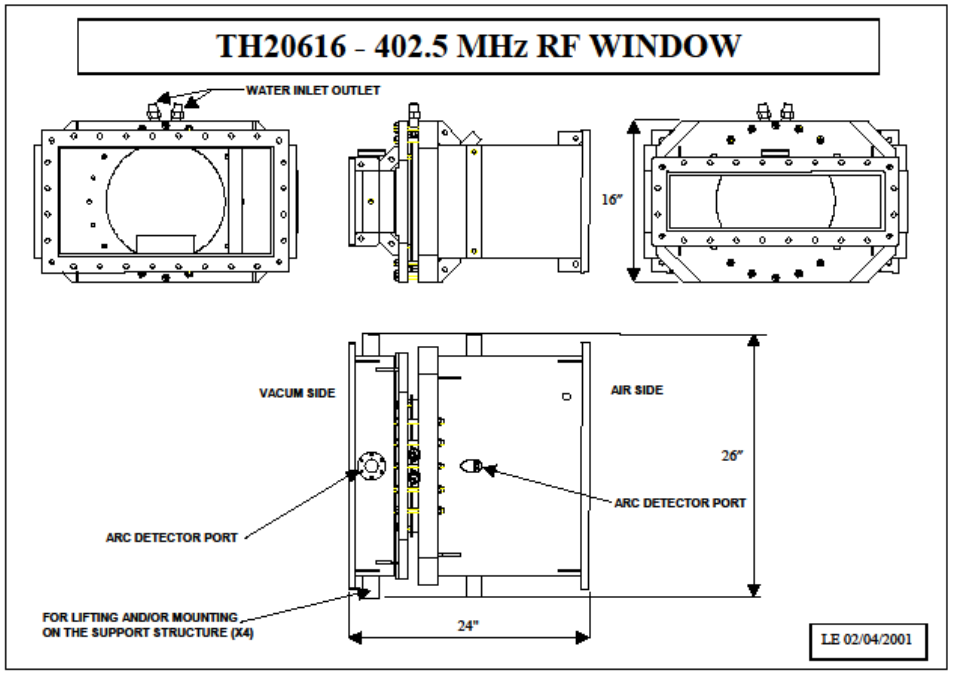
Tomco Solid State Amplifier



Switching Assembly, Circulators, Directional Couplers

Racks waiting for Amplifiers

Warm Linac Issues



- Vacuum Leak on DTL-6 RF window
  - Traced to a braze joint in the vacuum side waveguide section
  - May have a similar problem on several windows
  - RF conditioned 2 spare windows
  - Replaced DTL-6 window this maintenance period
  - Have 3 spare windows on order
    - These will have the waveguide joint welded
  - Planning to build 3 more spare windows in-house

Klystron Anticipated Lifetime

/ade/epics/iocTop/R3.14.8.2/snsMachine/rfApp/srcOpi/NC_HPRF_perveance.edl

18:33:56 **NC HPRF Perveance Values** RF Screens EXIT

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 have added a screen to display perveance 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

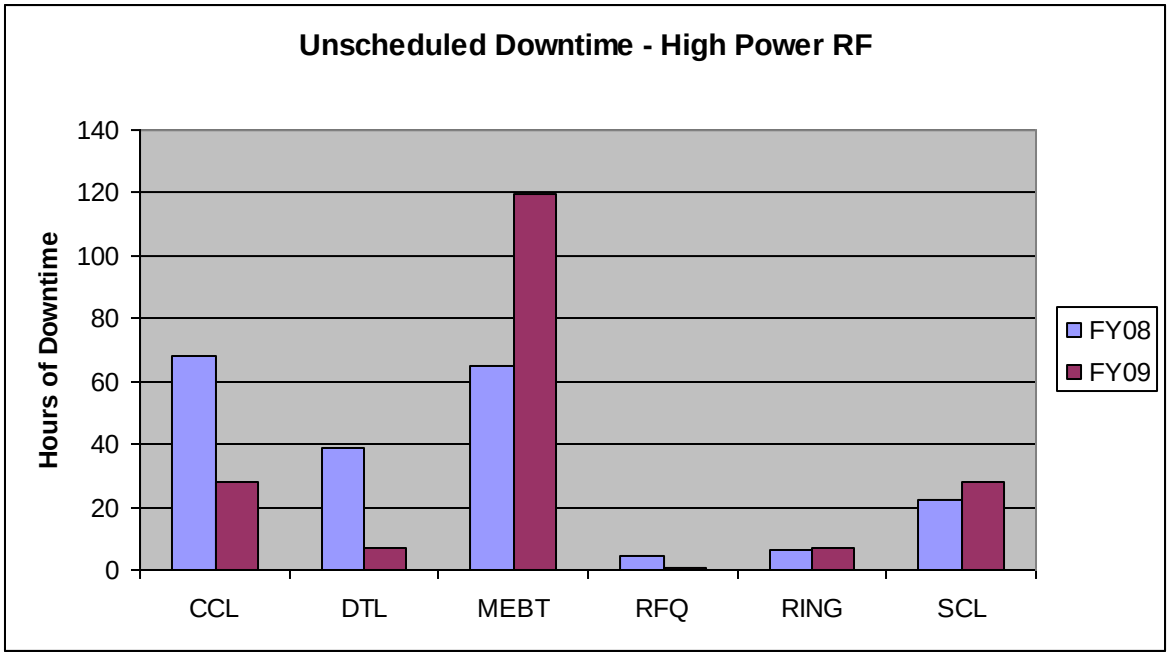
SCL RF

- Now operating klystrons at design cathode voltage of 75 kV
- Replaced 9 Thales klystrons
  - 3 klystrons showed instability issues
  - All Thales klystrons have high gain
  - Plan to replace the remaining 2 next maintenance period
- Suffered arcing condition in SCL-5A coupler
  - We were able to recover this cavity
- Beam loss injured cavities SCL-5A and SCL 6C
  - Made some progress recovering SCL-5A
  - Hope to recover both cavities by careful conditioning

Ring RF

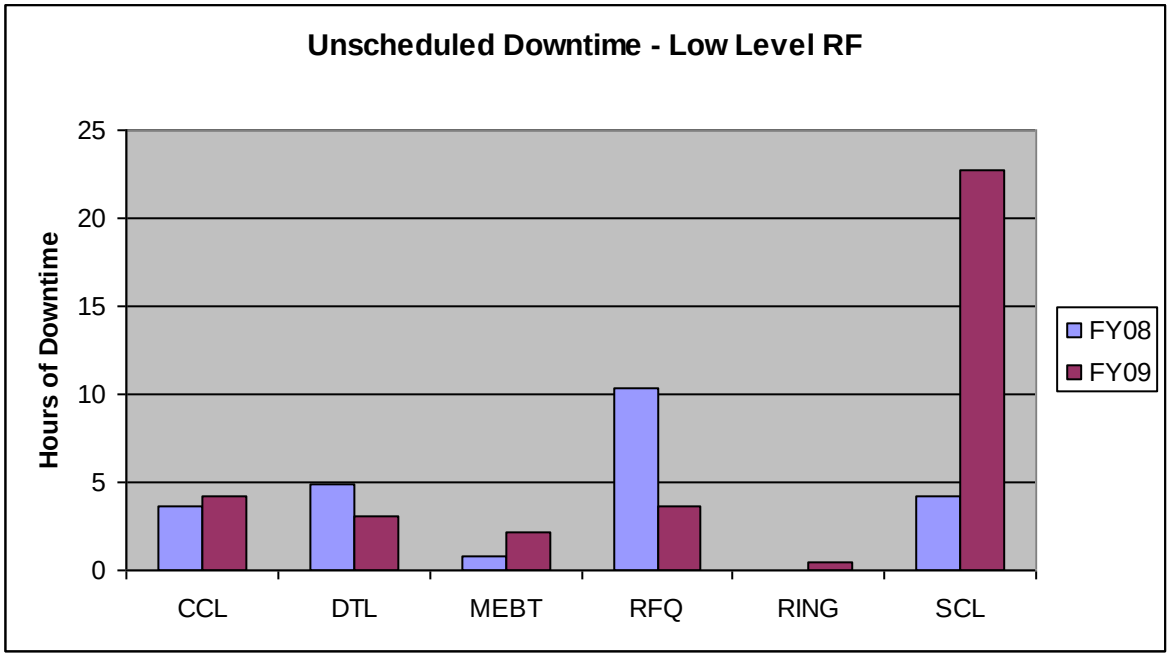
- Replacing QEI driver amplifiers
  - We have had several QEI amplifiers fail
    - We have one amplifier we have not been able to repair
  - Can no longer acquire replacement components
  - Have purchased Tomco amplifiers identical to the sub-system amplifiers used in the new Ion Source amplifier.
- Had several failed Lambda ALE anode supplies
  - Had a variety of failure causes
  - Working with Lambda to develop in-house repair capability

Unscheduled Downtime – High Power RF



- MEBT Rebuncher amplifiers are the major contributing item
  - In FY 08 we allowed the operations staff to reset tripped circuit breakers
  - After inspecting the circuit breakers and finding significant damage we installed fast acting fuses requiring a technician to travel to the site to replace blown fuses
  - We have replaced the power supplies with Capacitor Charging supplies designed to recharge the filter capacitors in a current regulated mode
  - Even though the faults still occur we no longer open fuses or circuit breakers
  - The LLRF system shuts down the drive but can be quickly reset by operations staff
  - MEBT RF Downtime practically eliminated

Unscheduled Downtime – Low Level RF



- **SCL is the major contributing item**
  - **The majority of downtime is from the LLRF protecting real cavity fault conditions**
  - **05a and 06c events were responsible for most of SCL downtime during recent run – See SH Kim talk (includes time to retune)**
  - **We are considering adding a category to better address this downtime**

LLRF Issues and Improvements

- Input/output Controller (IOC) is heavily loaded resulting in performance limitations
  - Current IOC >85% utilized
  - Some data reduction was required to support adaptive feed-forward for 825 μs beam time
  - Pulse data is still occasionally missed
- Replacement IOC's have been purchased
  - Improved data throughput to lower IOC loading
  - Awaiting testing & implementation

LLRF Temperature Stabilization

- Development of 50 MHz Baseband Analog Front End (AFE) and RF Output (RFO)
  - Removes temperature sensitive components from Field Control Module (FCM)
  - Solves end-of-life issues with some components
  - Creates a "universal" controller
    - Can use controller with modified frequency converter for Ring, Ion Source, FNAL RF, etc.
- Temperature stabilized frequency converter chassis to replace down-converter
  - Moves all frequency dependant components from FCM
  - Solves temperature drift issue on FCM

RF Test Stand

- Primary test stand for RF components
  - 402.5 & 805 MHz klystrons routinely tested
  - Window conditioning
  - Support for SCL cavity testing
  - HVCM testing to support development efforts

Klystron Spares Inventory

- Klystrons
  - DTL: 2.5 MW, 402.5 MHz (7 in service)
    - E2V ------- 4 each
    - Thales ---- 3 each
  - CCL: 5 MW, 805 MHz (4 in service)
    - Thales ---- 3 usable -1 fully conditioned
      ---- 1 Failed with an internal high voltage connection issue (Working with Thales)
      ---- 1 Failed with loss of vacuum
      ---- Procurement of 4 additional klystrons in process
  - SCL: 550 kW, 805 MHz (81 in service)
    - CPI --------- 11 original
      --------- 29 each 700 kW version (replaced 9 Thales)
    - Thales ----- 3 each (9 Thales with 6 usable)
- Gridded Tubes
  - Ring RF Tetrode: 500 kW Tetrode TH558/4CM500,000G (4 in service)
    - Thales ----- 3 each
    - CPI ---------- 1 each
  - Ion Source Tetrode: 20 kW Tetrode (4CX20000)
    - CPI --------- 2 each (Readily available from several sources)
  - MEBT Triode: 5 kW Triode (3CX5000)
    - CPI --------- 2 each

Operation at 95 Percent Beam Availability

- For operation with 95% beam availability the RF system goal is 38 hours per 5000 yearly operating hours (99.24% availability)
- Monitor Perveance of all klystrons
  - We have initiated a program to obtain this data
- MEBT Rebunchers
  - Replace the Hard-Tube amplifiers with Solid-State units
  - Understand the X-ray emission from existing cavities
  - Build spare cavities
- RFQ
  - Prepare a spare structure
- Linac
  - Remove voltage limitations on converter-modulator
  - Remove converter-modulator droop
  - Condition spare klystrons to full duty factor

Operation at 95 Percent Beam Availability

- SCL Linac
  - Resolve the issue of tripping 20 cavities when a single klystron has a cathode arc
    - Inhibit HV pulsing instead of shutting down the modulator
  - Add redundant power supplies where possible
  - Improve cavity protection schemes
- Ring RF
  - Replace driver amplifiers
  - Produce spare cavity and final amplifier
    - Install in Ring as a dedicated spare switchable to either 1 or 2 MHz
  - Provide complete spare transmitter and LLRF system
  - Improve Lock/Tag/Verification process
- Low Level RF
  - Improve SCL protection software to reduce chatter fault trips
  - Replace existing Analog Front End and Output Amplifier with a temperature controlled version
  - Provide Master Oscillator with Amplitude regulation
  - Re-design LLRF modules replacing obsolete components

Summary

- There remains significant Ion Source RF System work
- MEBT RF has a clear path to completion
- Warm LINAC still has some problems
- SCL RF Power limitation is being resolved
- We are beginning to acquire Klystron Perveance Data
  - Analyzing archive data
- Working on identifying reliability issues and formulating a plan for high beam availability