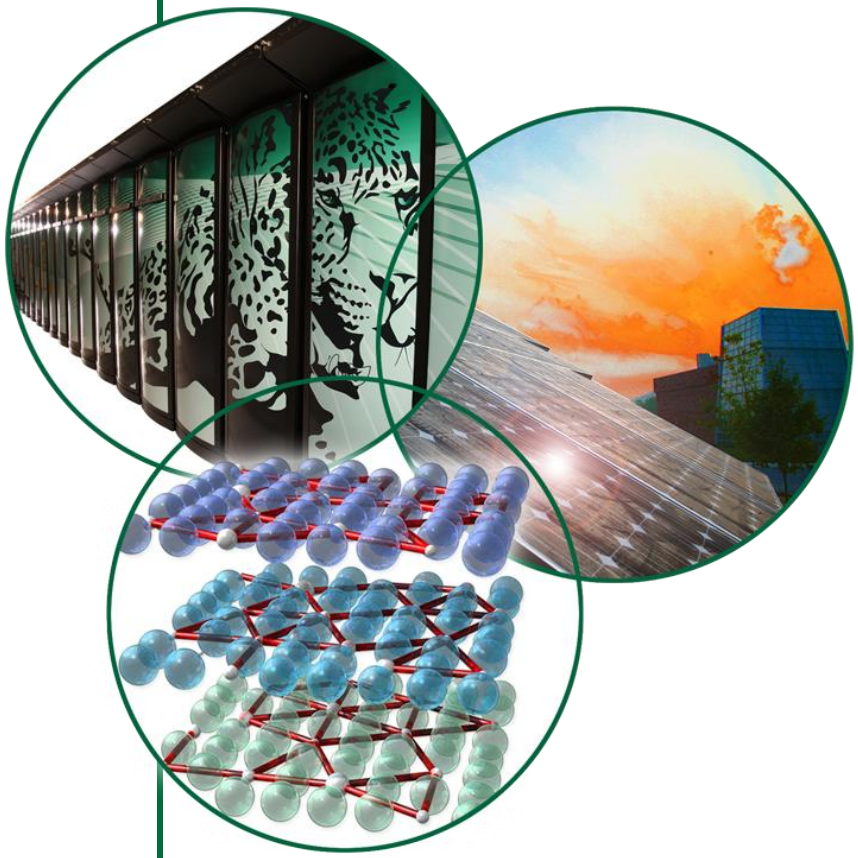
Upgrades to the SNS MEBT RF Power Amplifiers



Mark E. Middendorf

Sixth CW and High Average Power RF Workshop
ALBA
Barcelona, Spain
May 4 – May 7, 2010

U.S. DEPARTMENT OF ENERGY

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

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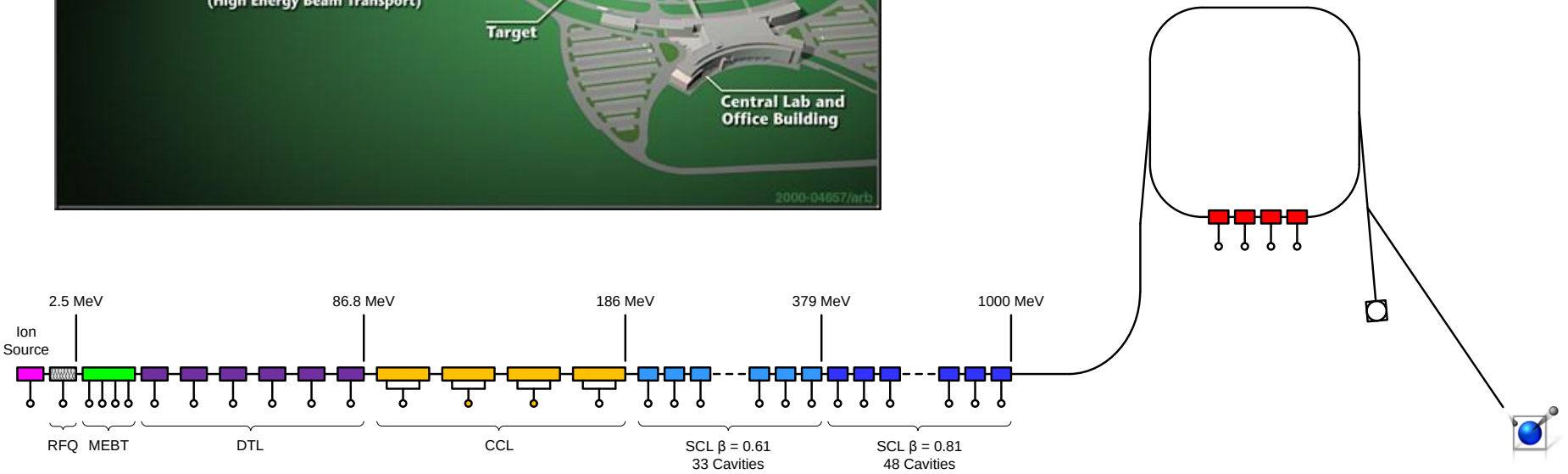
Introduction

- SNS Accelerator
- Medium Energy Beam Transport (MEBT) Structure
- MEBT RF Power Amplifiers - Baseline Installation
- Modifications to the Original MEBT RF Power Amplifiers
- MEBT Amplifiers Accelerator Improvement Project (AIP)
- Summary

SNS Accelerator

Baseline Technical Parameters:

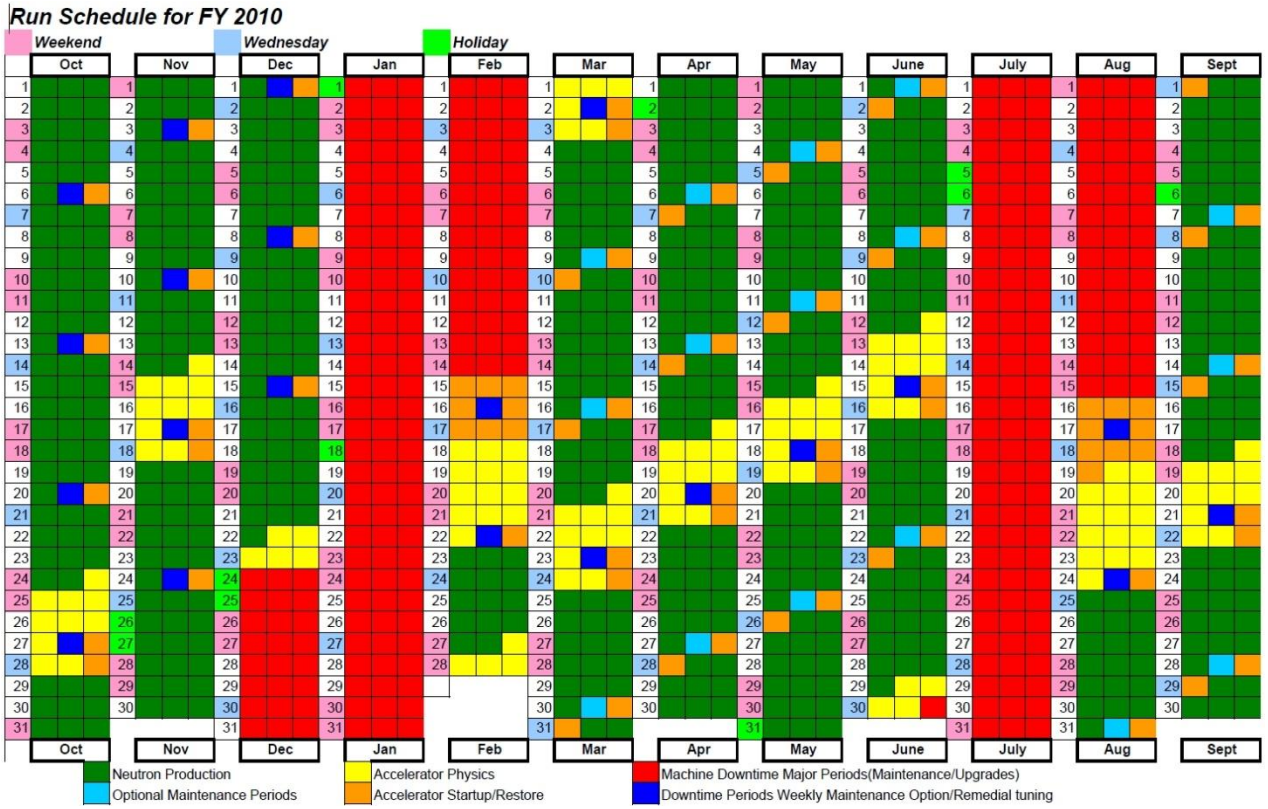
Beam Energy:	1 GeV
Average Beam Current on Target:	1.4mA
Beam Power on Target:	1.4MW
Pulse Repetition Rate:	60Hz
Protons/Pulse:	1.5×10^{14}
Pulse Length on Target:	695ns



SNS Accelerator

For FY2010

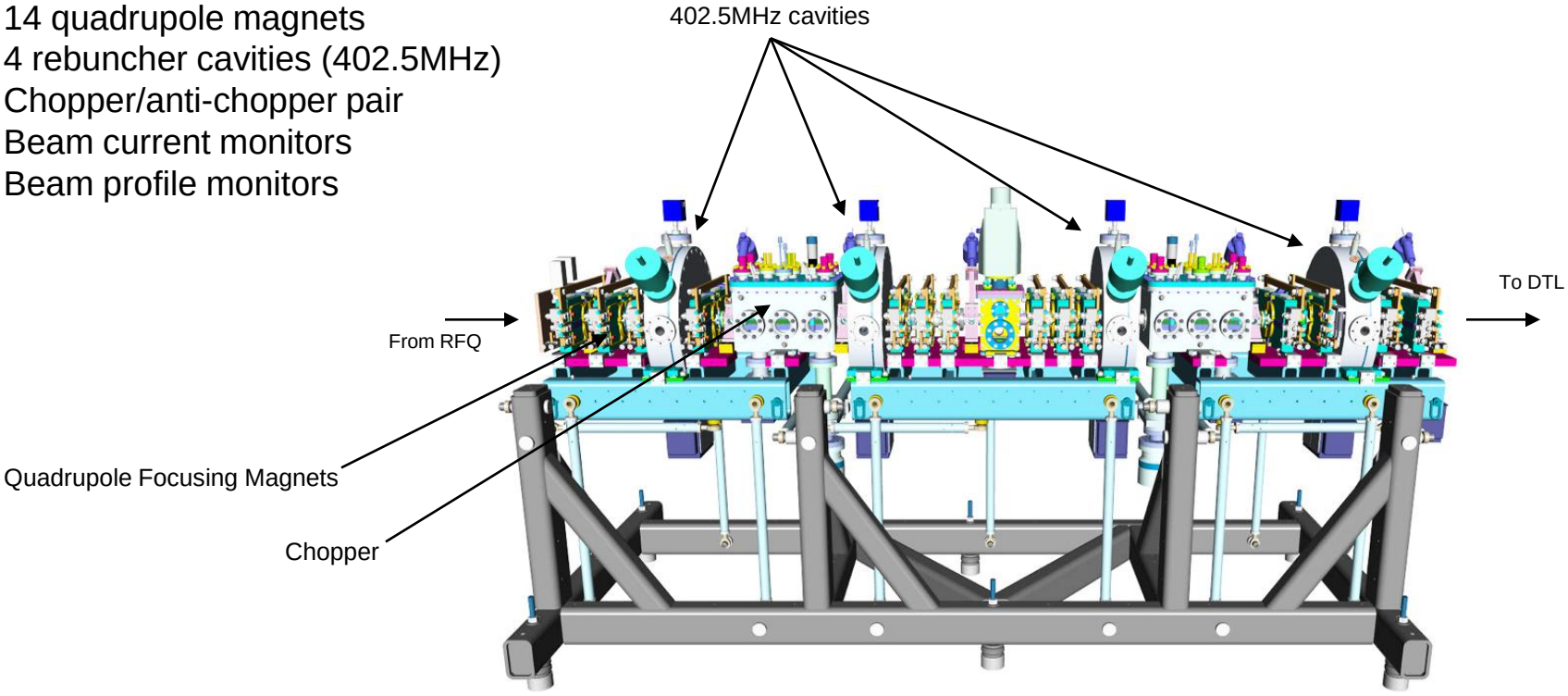
- Total of ~38 weeks of operation
- Two major maintenance periods of ~7 weeks each



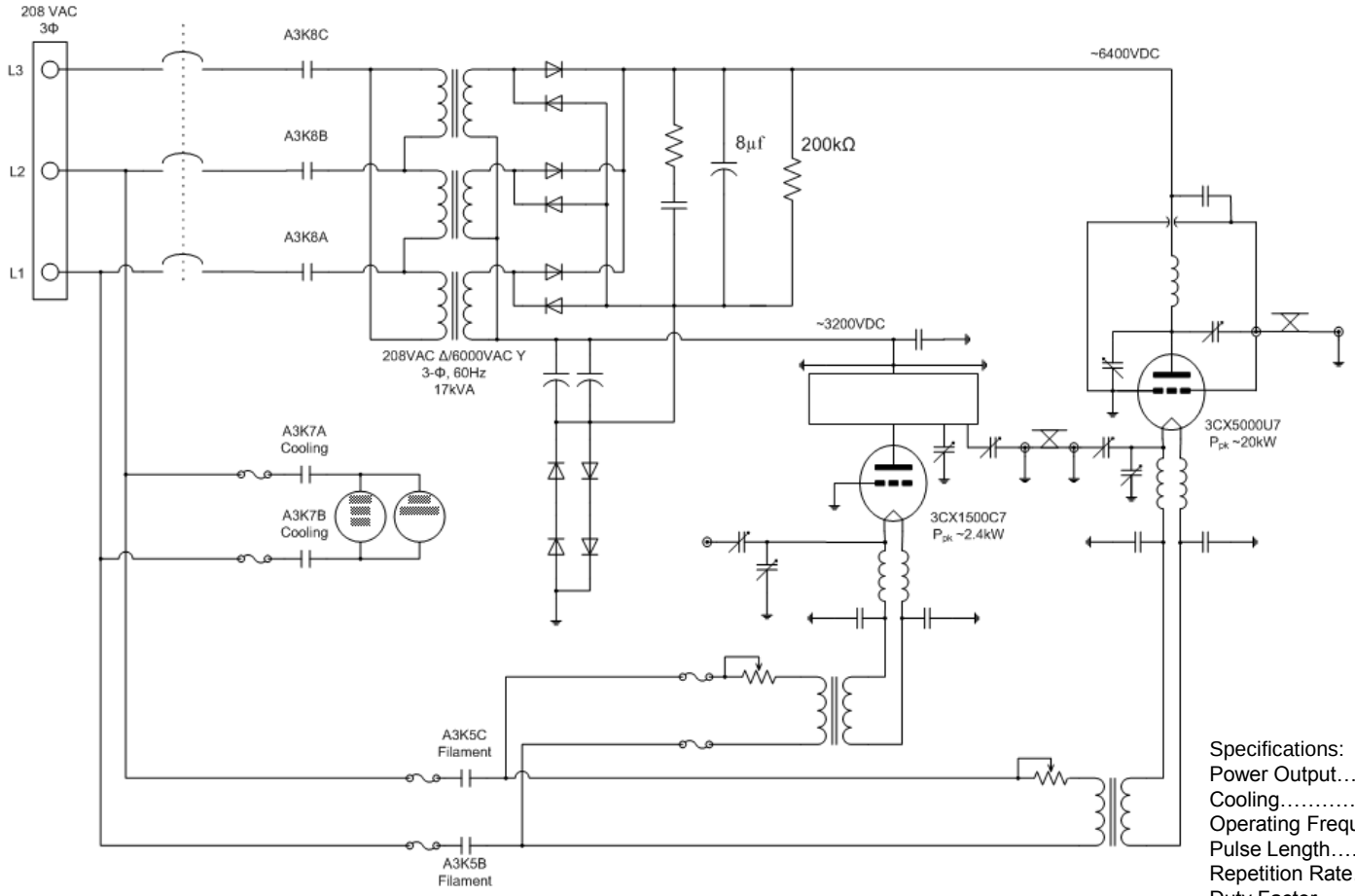
Medium Energy Beam Transport (MEBT) Structure

Function
- Match 2.5MeV from RFQ to DTL
- Accommodate chopper (provides gap for ring extraction kicker rise-time).
- Accommodate beam diagnostic elements

Structure consists of
- 14 quadrupole magnets
- 4 rebuncher cavities (402.5MHz)
- Chopper/anti-chopper pair
- Beam current monitors
- Beam profile monitors

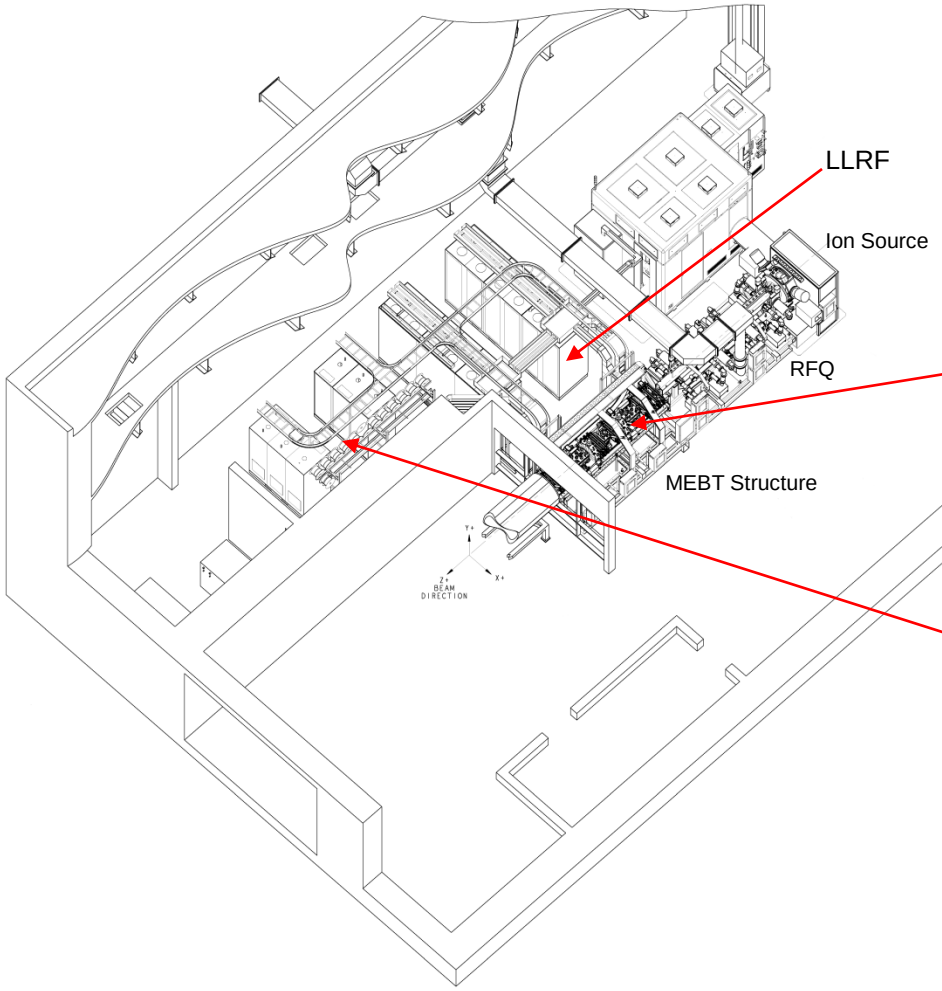


MEBT RF Power Amplifiers - Baseline Installation



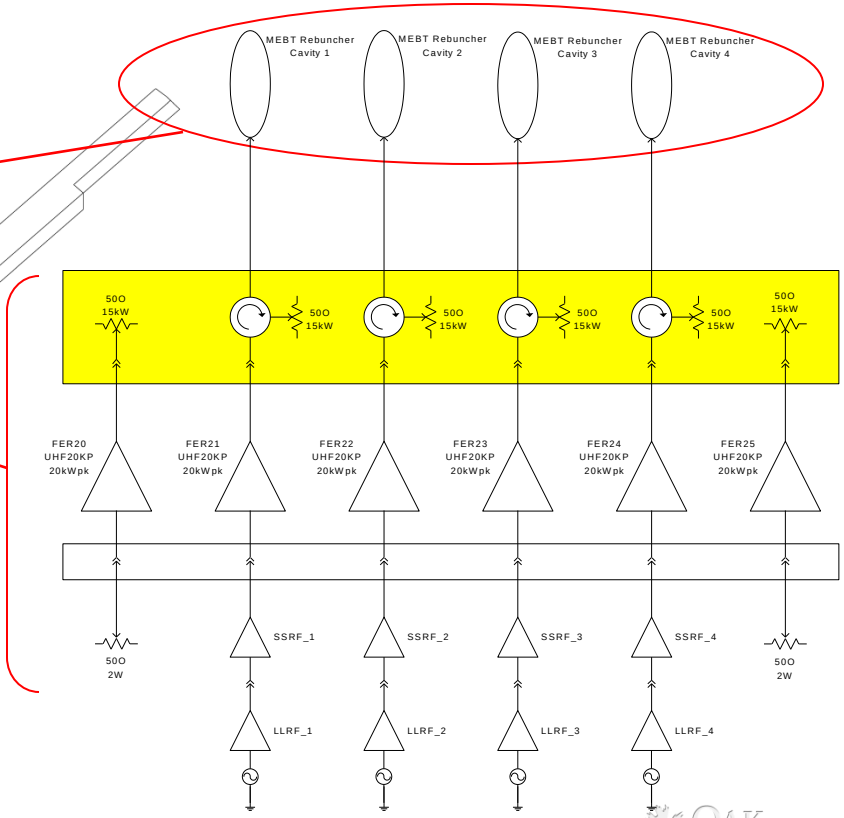
Specifications:
Power Output……0-20kW peak pulse
Cooling……Forced Air
Operating Frequency……402.5MHz
Pulse Length……1 ms
Repetition Rate……60Hz
Duty Factor……6%
Pulse Flatness……better than 10%
RF Load Impedance……50 ohms
VSWR……1.6:1 max @ full power
Input Power for 20kWpk Pulse…0dBm

MEBT RF Power Amplifiers - Baseline Installation



Power Requirements:

	MEBT1 Ppk (kW)	MEBT2 Ppk (kW)	MEBT3 Ppk (kW)	MEBT4 Ppk (kW)
Est.(FDR)	11	6.8	8.1	28.2
Actual	9.3	5.2	7.3	20.2

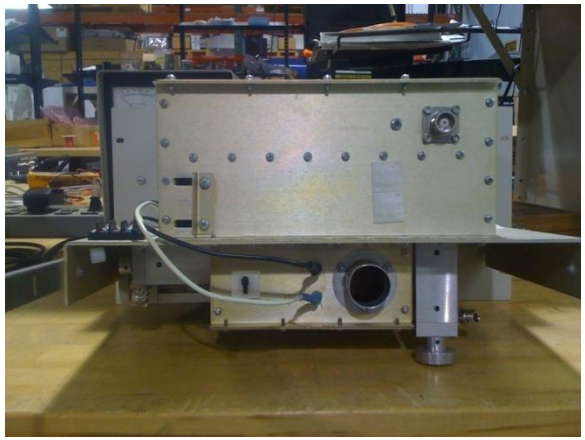


MEBT RF Power Amplifiers - Baseline Installation

- Problems with the MEBT PAs started showing up soon after installation:
  - Amplifiers would fault and trip AC wall breakers.
  - Soft start was added by manufacturer after installation in attempt to address wall breaker trips. Helped on startup, but did not solve fault issues.
  - Unable to make full rated power.
- Design and quality control issues.
  - Slide tuners fixed with hose clamps – made tuning and repeatability difficult.
  - Inadequate air flow through cabinet.
  - Inadequate diagnostics.
  - Inaccurate metering resulting in low filament voltage and current.
  - Each unit was slightly different.

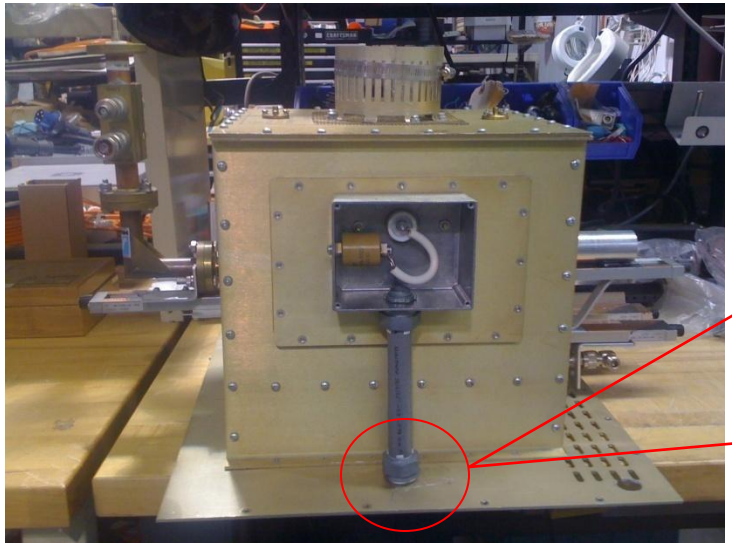
Modifications to the Original MEBT RF Power Amplifiers

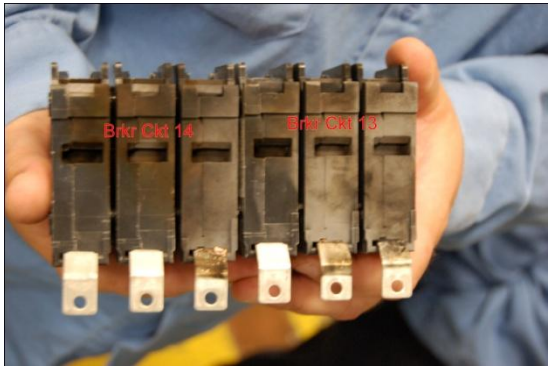
- Technicians proposed modifications and implemented a number of them as time allowed:
  - Modified slide tuners to include verniers.
  - Rebuilt amplifier chassis (input and output cavities) with attention to connections, flanges and rf grounding.
  - Improved cooling air flow through cabinets.
  - Suggested replacing anode supplies with constant-current charging supplies.
- Facilities was asked to provide better cooling to the amplifier racks.
- An Accelerator Improvement Project (AIP) was funded to replace the original MEBT amplifiers with something that worked.



IPA and PA chassis with input and output slide tuners modified to include verniers.

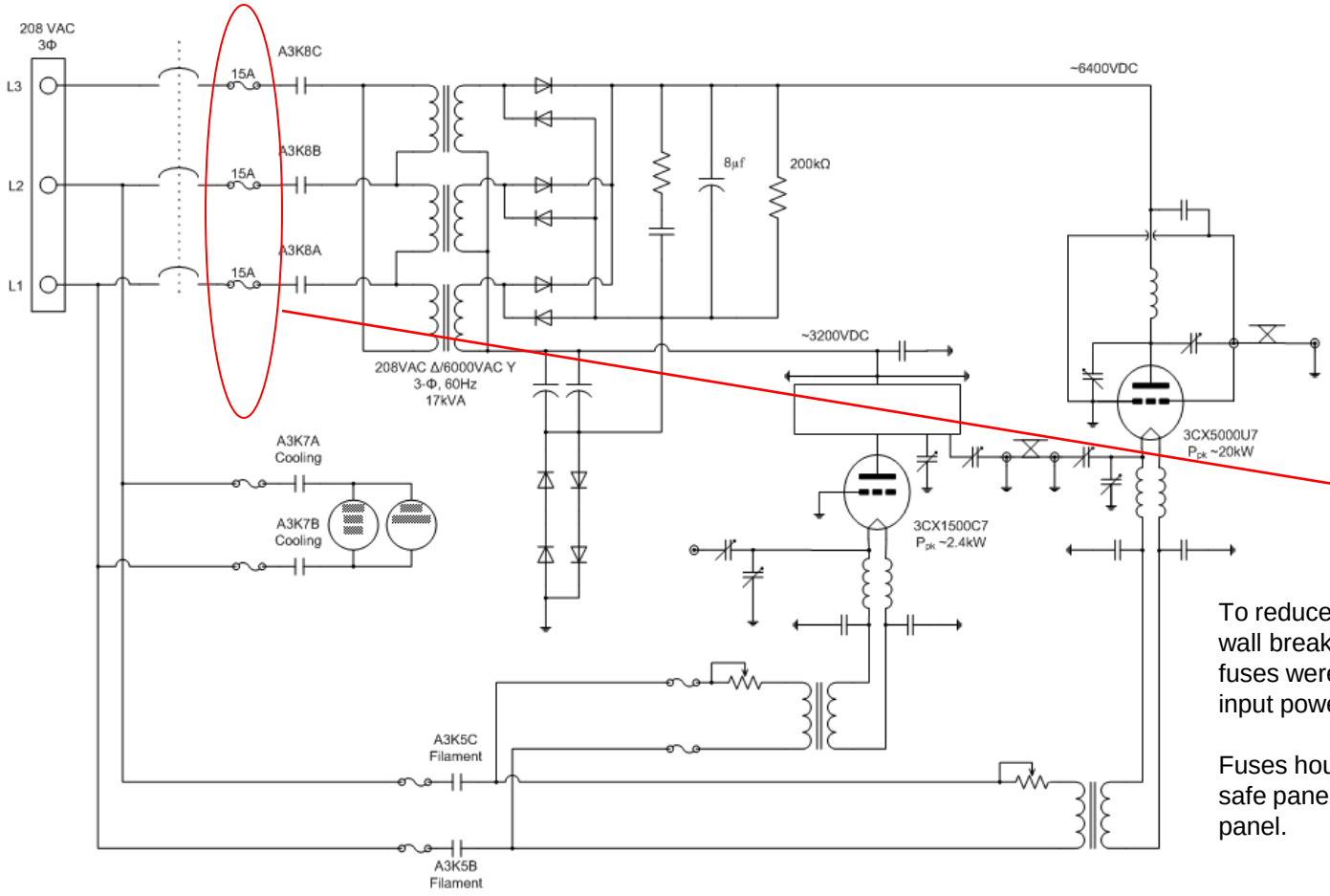
Modifications to the Original MEBT RF Power Amplifiers





Wall-breaker trips continued to be a problem….

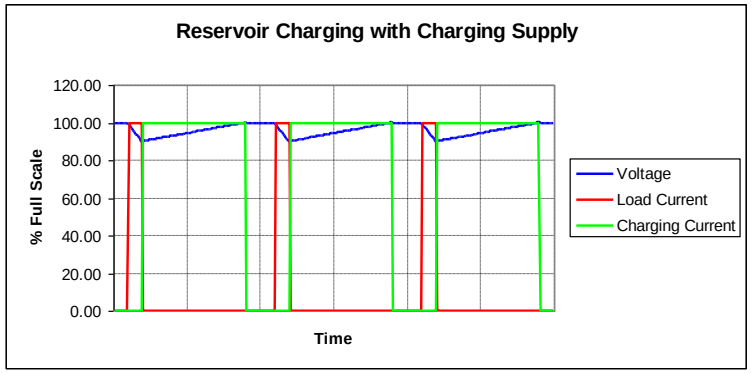
Modifications to the Original MEBT RF Power Amplifiers



To reduce damage to wall breakers, fast-acting fuses were installed on input power.

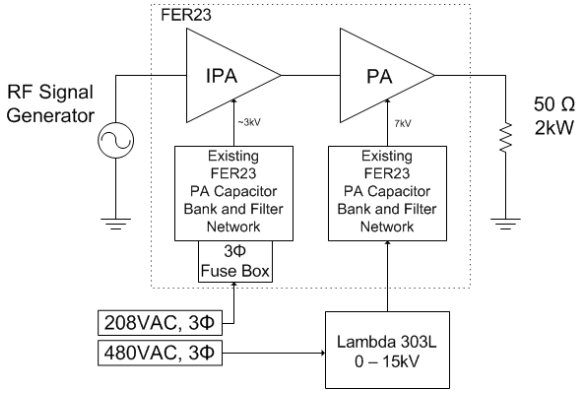
Fuses housed in finger-safe panel on front panel.

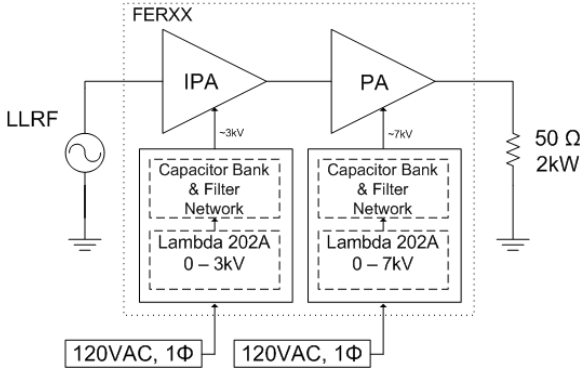
Modifications to the Original MEBT RF Power Amplifiers



Lambda 303L:
0 – 15kV
30000J/s Average
37500J/s Peak

Used in SNS Ring RF systems.



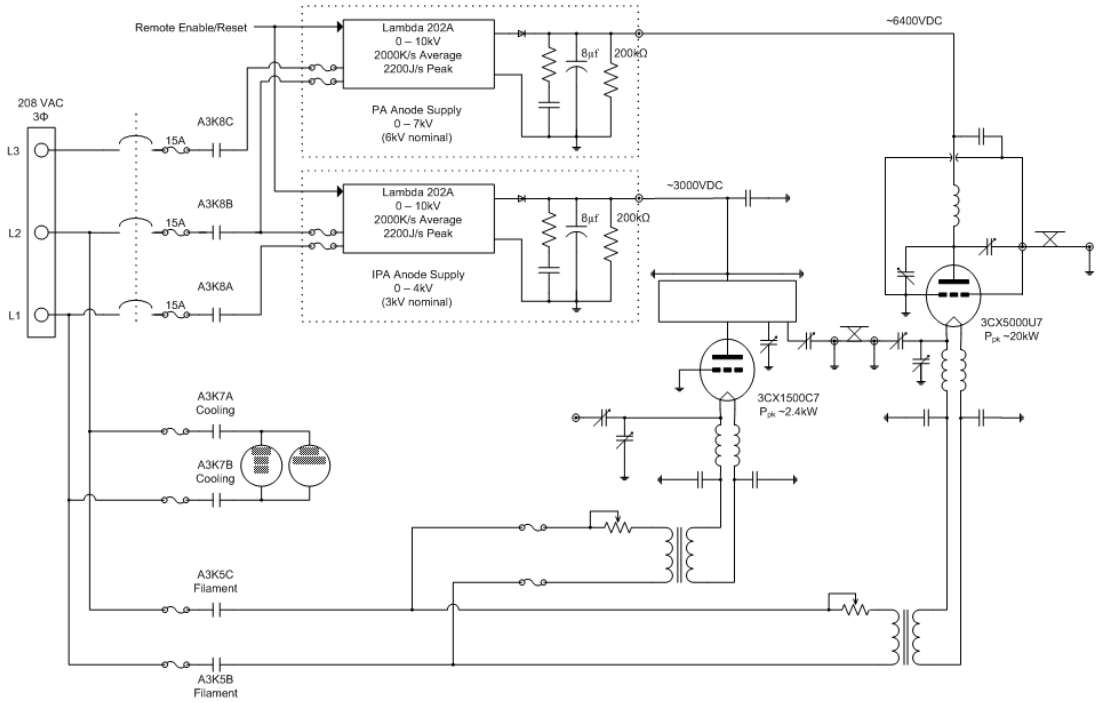


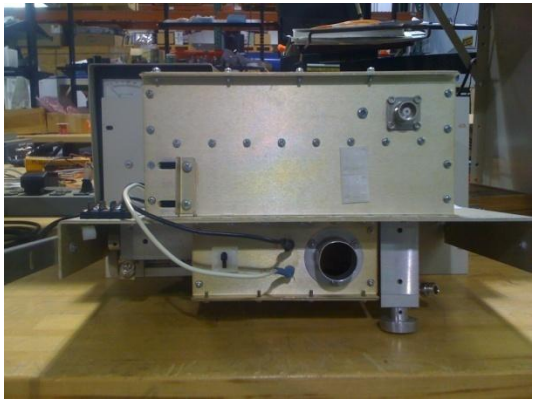
Lambda 202A:
0 – 10kV
2000J/s Average charging rate
2200J/s Peak charging rate
→ Charging Current = 0.44A

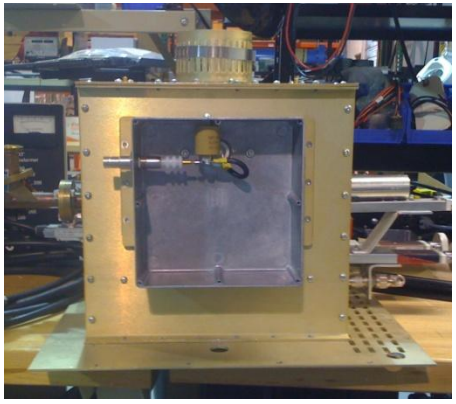
For C = 8 μF and V = 6.4kV with 10% pulse droop
E ~ 31 J → P = 31kW for 1ms pulse (efficiency of amplifiers?)
T_{EOC} ~ 12ms

(..and will recharge to full voltage in ~ 120ms after a full discharge.)

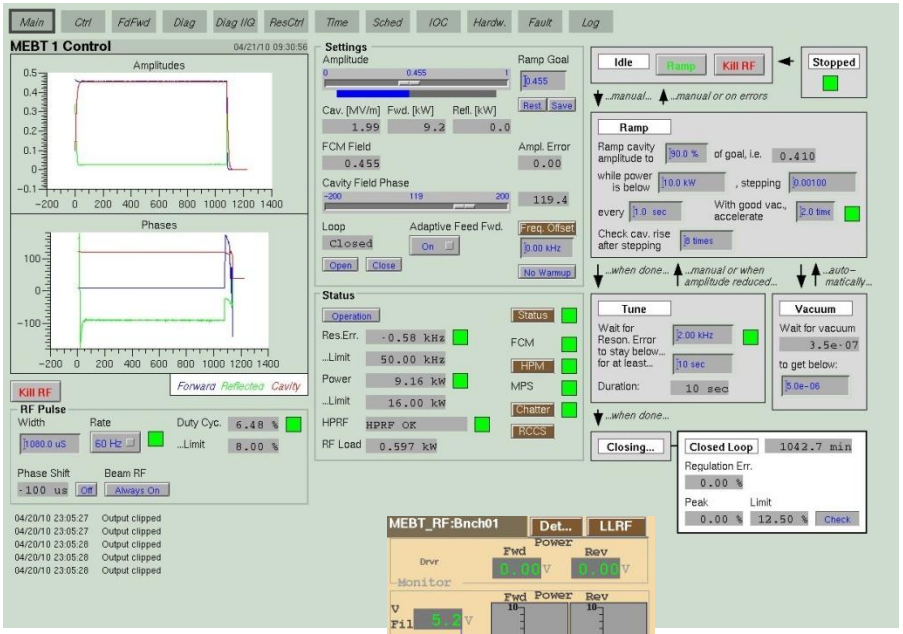
Modifications to the Original MEBT RF Power Amplifiers

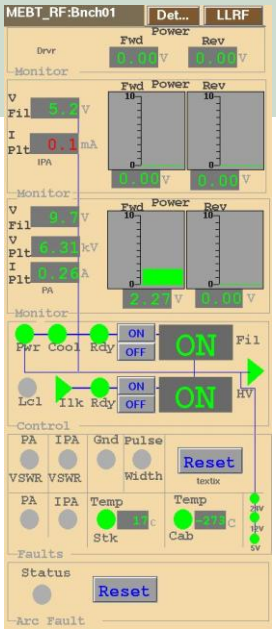


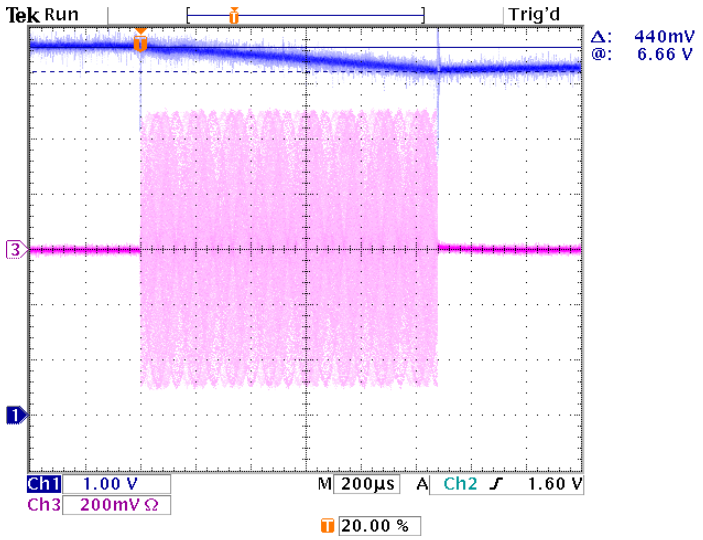




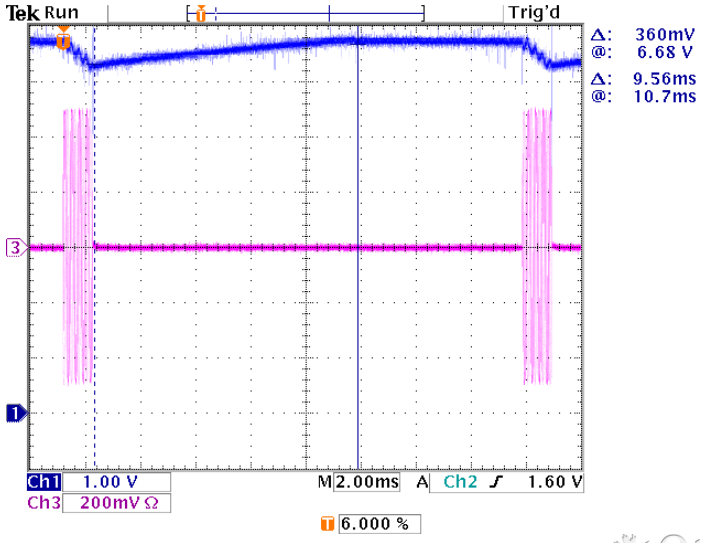
Modifications to the Original MEBT RF Power Amplifiers







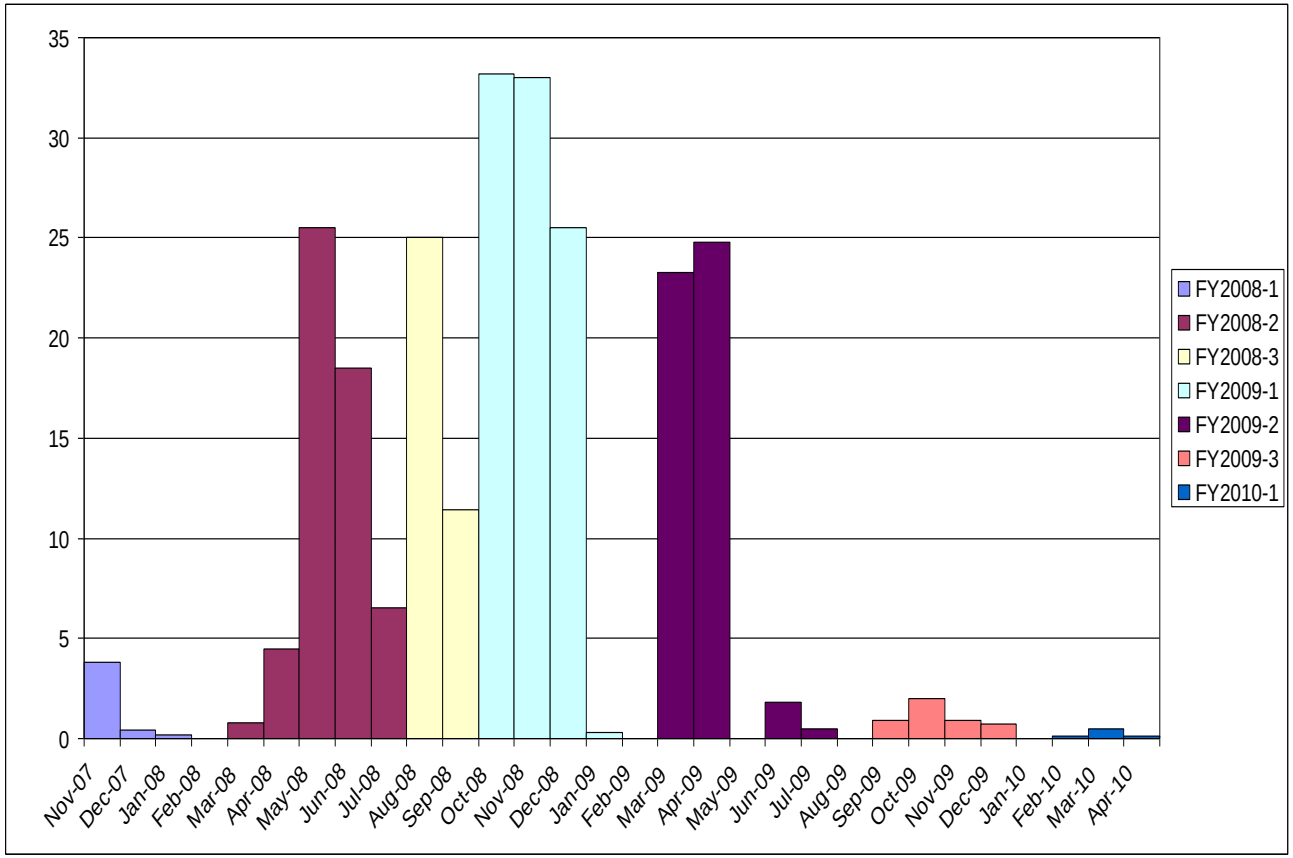
Channel 1: MEBT1 (FER23) PA Anode Voltage (1kV/V)
Pulse droop ~ 7%



Modifications to the Original MEBT RF Power Amplifiers

Modifications to the Original MEBT RF Power Amplifiers

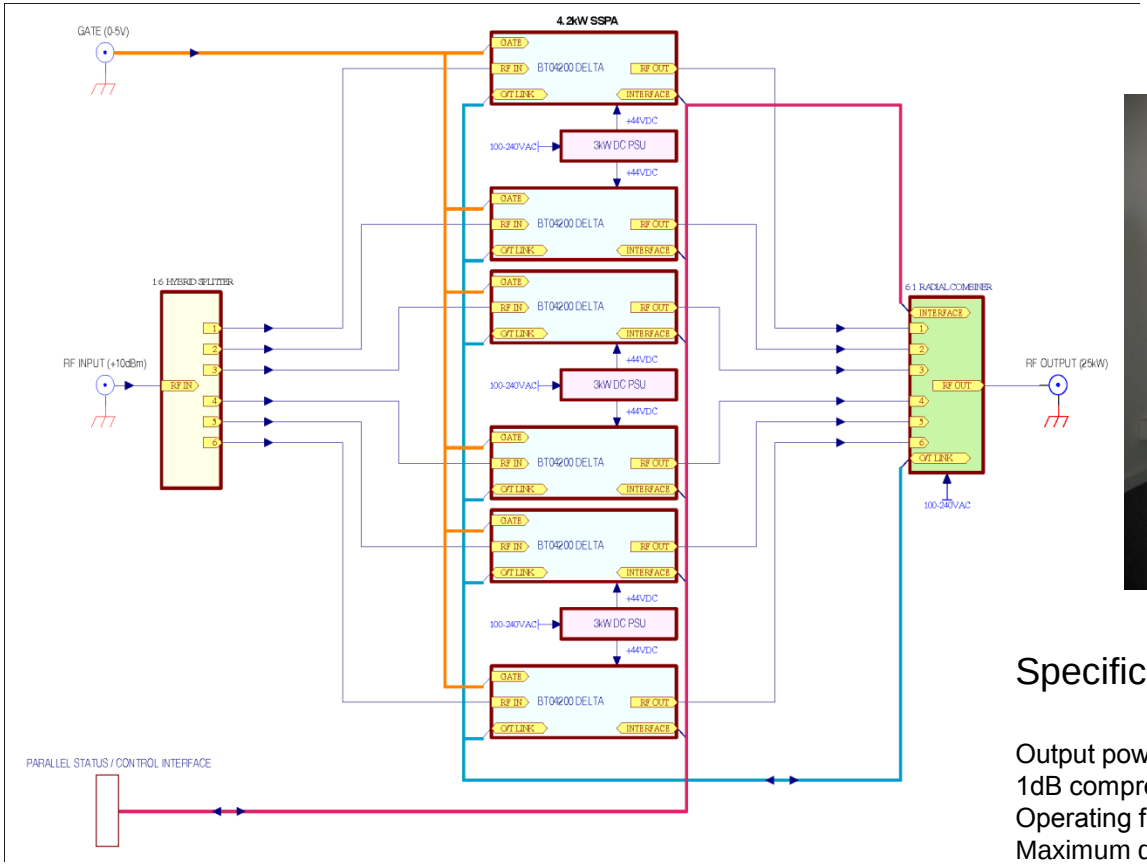
• We saw a significant decrease in down time due to the MEBT RF power amplifiers as we converted units to new anode supplies.

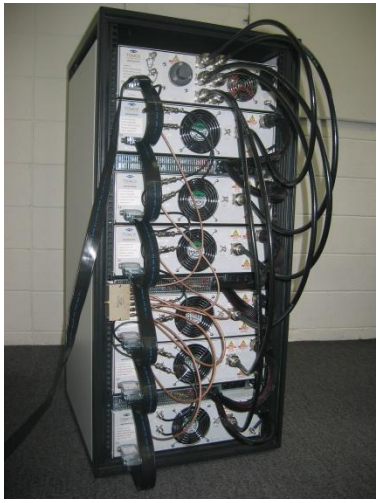


MEBT Amplifiers Accelerator Improvement Project (AIP)

- AIP was funded in early FY2008 to replace MEBT power amplifiers.
- A decision was made in the fall of 2008 to consider a solid-state amplifier.
- Specifications were written and a request for bid was sent to selected vendors.
- A vendor proposal was selected in late 2008 and a single amplifier was purchased with the option to purchase four more.
- The amplifier was received in the end of March 2009, and installed in FER20 and connected to MEBT cavity 4 in early April, 2009.

MEBT Amplifiers Accelerator Improvement Project (AIP)





Specifications:

Output power for +10dBm input…25kW minimum
1dB compression point……...25kW minimum
Operating frequency……402.5MHz 2MHz
Maximum duty-cycle……8%
Maximum pulse width……..1.3ms
Load SWR……Tolerates at least 2:1 @ $P_{\text{full rated output}}$

MEBT Amplifiers Accelerator Improvement Project (AIP)

- Removed the original FER20 completely February, 2009 and installed a new rack, PPS chassis, AC distribution chassis and PLC controls.

- Installed solid-state amplifier in FER20 in April 2009.

- FER20 connected to MEBT cavity 4.

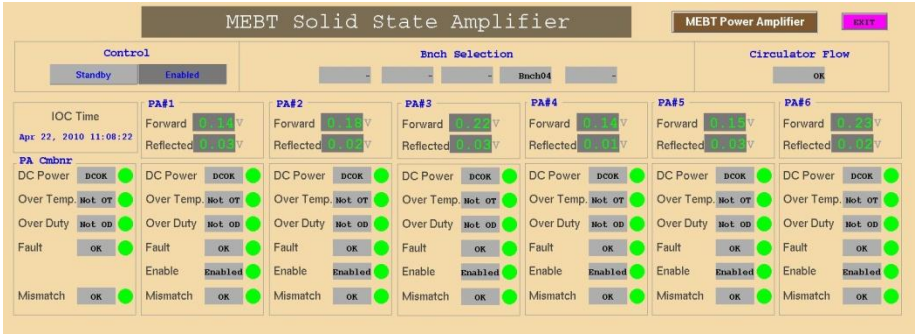
- MEBT cavity 4 had historically been operating at ~14kW (increased to ~18kW and then to 20kW with new amplifier).

- Has operated continuously since installation with few problems –
    - Lost two separate amplifier chassis due to failure in driver bias resistor. We were able to remove the amplifier chassis from the rack, recover operations on the reduced number of amplifier chassis, and return failed units to vendor for repair.

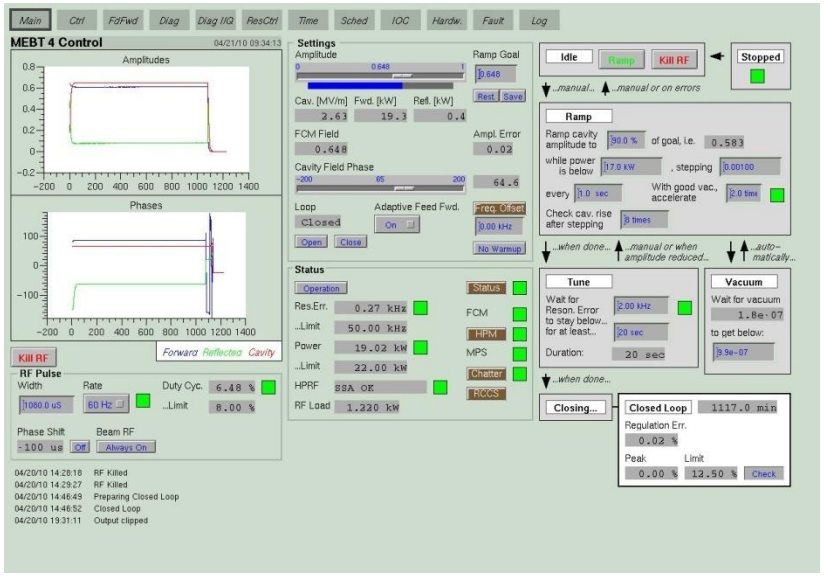
- Currently operating MEBTcavity 4 at ~20kW.

MEBT Amplifiers Accelerator Improvement Project (AIP)

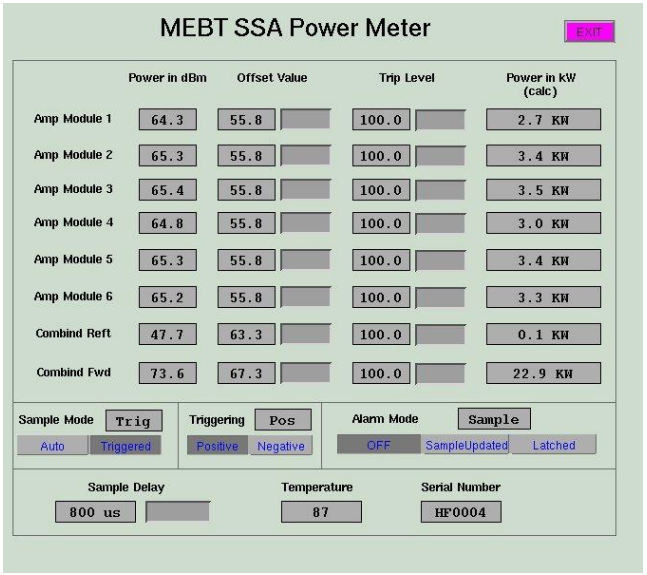
EDM screens for 25kW$_{pk}$ solid state amplifier, connected to MEBT rebuncher cavity 4.



Solid-state amplifier status indicators.

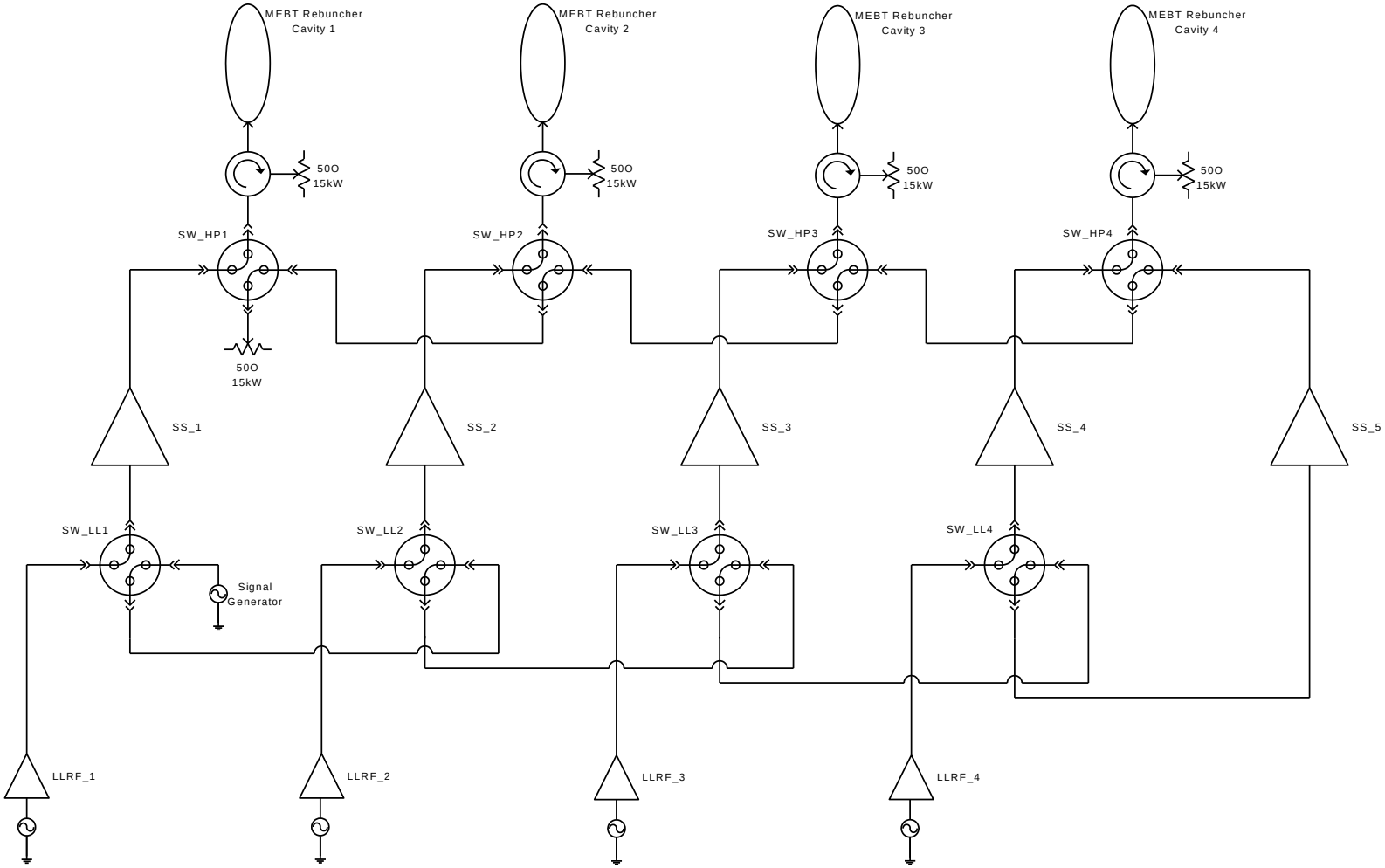


MEBT 4 LLRF control screen.



Eight channel power meter.

MEBT Amplifiers Accelerator Improvement Project (AIP)



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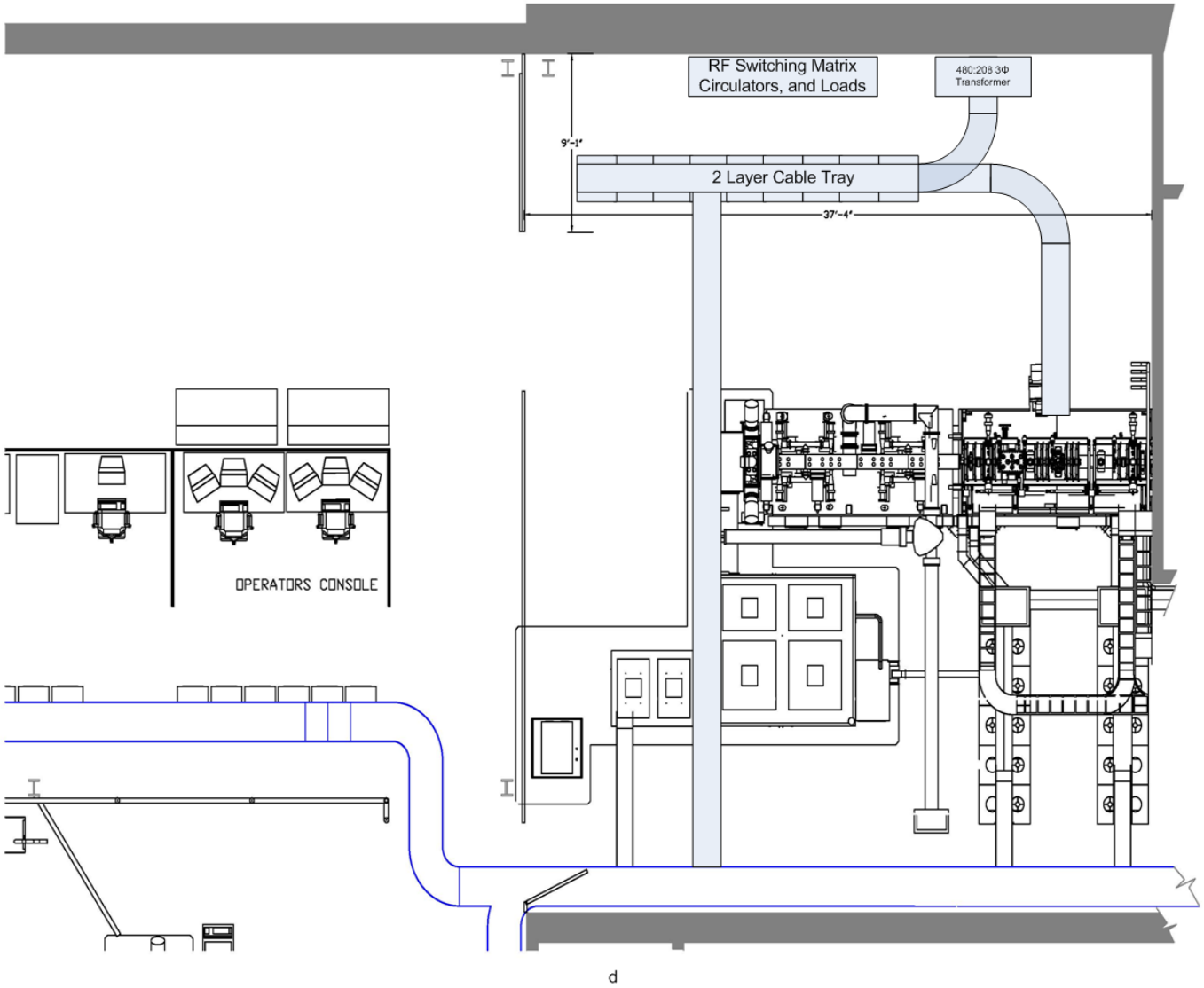

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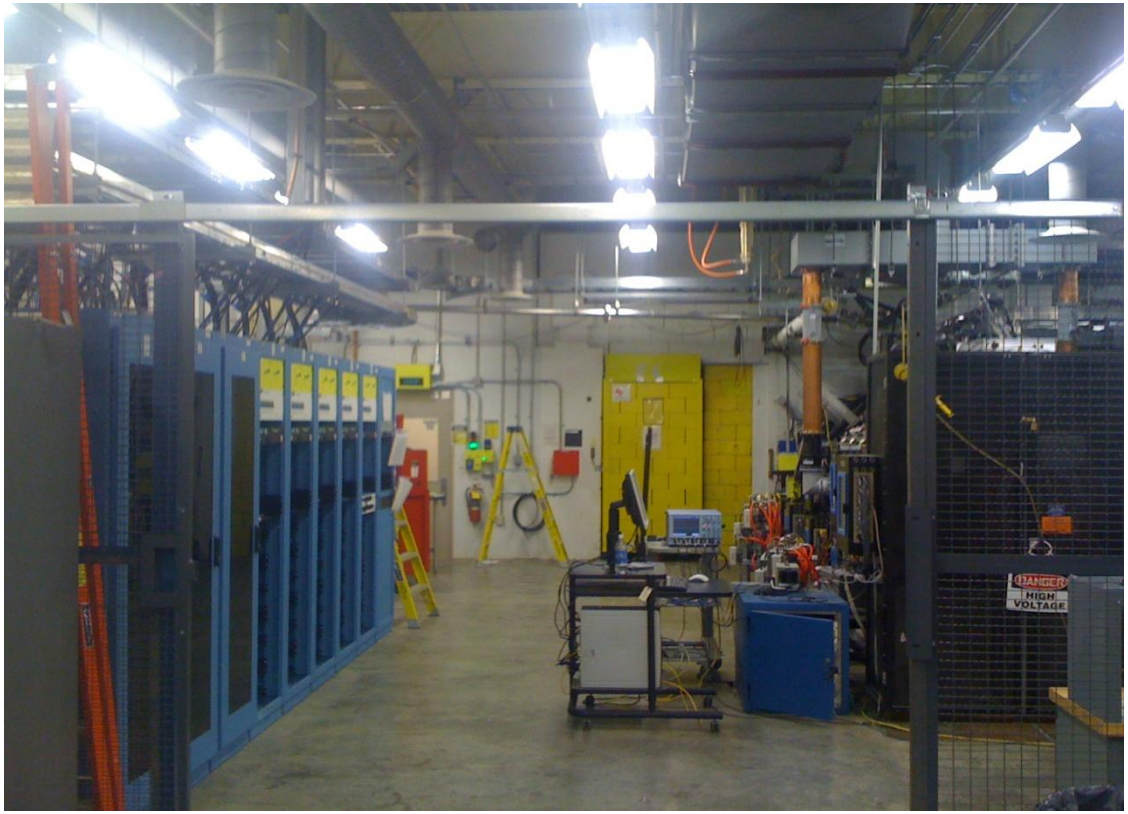

Summary

- Modifications to baseline MEBT RF power amplifiers have led to significant decrease in associated down time.
- Not a fix, but a reliable band-aid.
- Tomco Model BT25k-Delta 25kWpk solid-state amplifier, installed in April of 2009, has proven to be a reliable solution.
- Infrastructure in place to install five solid-state amplifiers in new location with PLC control and EPICS interface.
- Awaiting delivery of three amplifiers.
- Anticipating ordering fifth amplifier this FY.
- When the installation is complete, the MEBT power amplifiers are expected to provide reliable operation, and remotely-enabled redundancy.