The SNS MEBT RF Power Amplifier Solid State Upgrade

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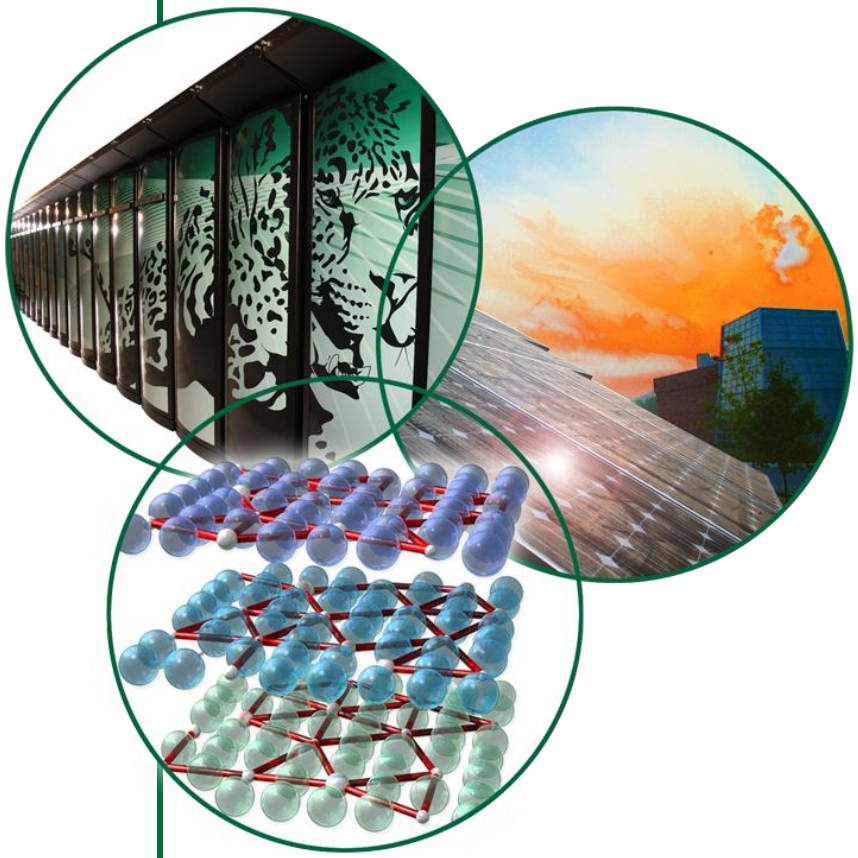

U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY

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Introduction

- Acknowledgements
- SNS Accelerator
- Medium Energy Beam Transport (MEBT) Structure
- Original MEBT RF Power Amplifiers
- MEBT Solid State RF Power Upgrade
- Summary

Acknowledgements

- Mike Clemmer, RF Team, Electrical Group, SNS
- Tom Hardek, RF Team Leader, Electrical Group, SNS
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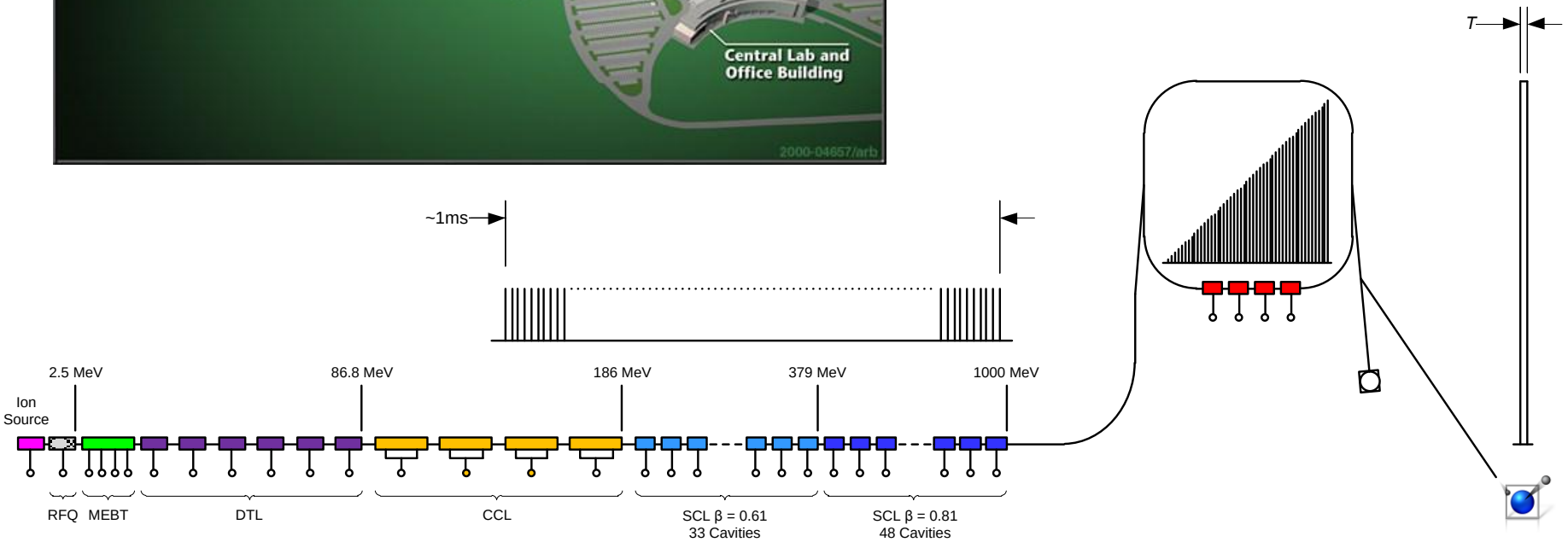
- Mark Cardinal, RF Team, Electrical Group, SNS
- Dale Heidenreich, RF Team, Electrical Group, SNS
- Tim Miner, RF Team, Electrical Group, SNS
- Bill DeVan, Controls Group, SNS
- Teresa Arthur, Electrical Group, SNS
- John Moss, Electrical Group, SNS
- James Schubert, Water Group, SNS
- Shane Dillon, Tomco Technologies
- Paul Smith, Micro Communications, Inc.

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



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$$\text{Total\_charge\_per\_pulse} := \text{Number\_of\_protons} \times q \qquad \text{Total\_charge\_per\_pulse} = 2.403 \times 10^{-5}\,\text{C}$$

$$\text{Total\_current\_per\_pulse} := \frac{\text{Total\_charge\_per\_pulse}}{\tau} \qquad \text{Total\_current\_per\_pulse} = 34.579\,\text{A}$$

$$\text{Power\_per\_pulse} := \frac{\text{Total\_current\_per\_pulse} \times \text{Energy}}{q} \qquad \text{Power\_per\_pulse} = 3.458 \times 10^{10}\,\text{W}$$

$$\text{Average\_power} = \text{Power\_per\_pulse} \times \text{duty\_factor} \qquad \text{Average\_power} = 1.442 \times 10^{6}\,\text{W}$$

$$\text{Energy\_per\_pulse} := \text{Power\_per\_pulse} \times \tau \qquad \text{Energy\_per\_pulse} = 2.403 \times 10^{4}\,\text{J}$$

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$$Moonshine\_Equivalent := \frac{Energy\_per\_pulse}{Moonshine}$$

$$Moonshine\_Equivalent = 1.135 \times 10^{-3} \cdot L$$

$$Fifty\_Cal\_Equivalent := \frac{Energy\_per\_pulse}{Fifty\_Cal}$$

$$Fifty\_Cal\_Equivalent = 1.335$$

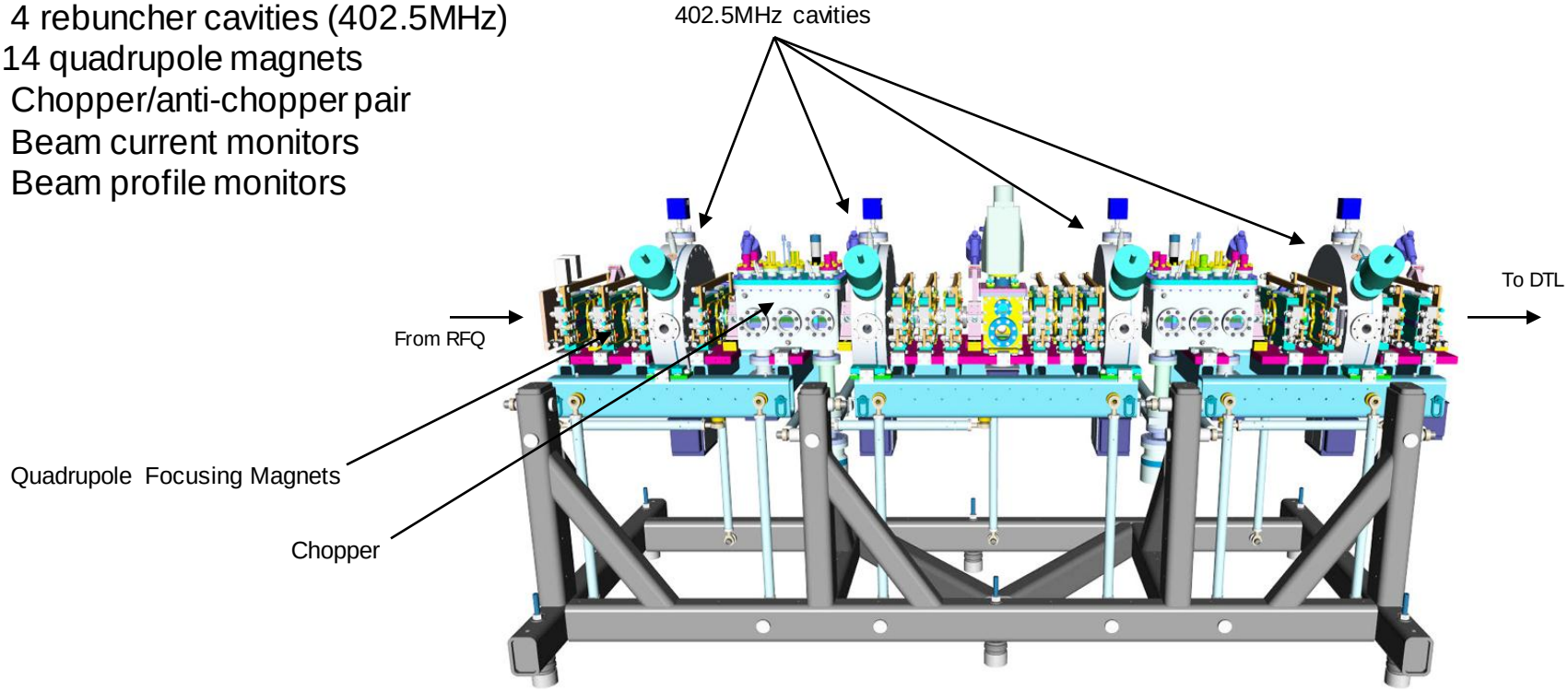
$$TNT\_Equivalent := \frac{Energy\_per\_pulse}{TNT}$$

$$TNT\_Equivalent = 5.744 \times 10^{-3} \cdot kg$$

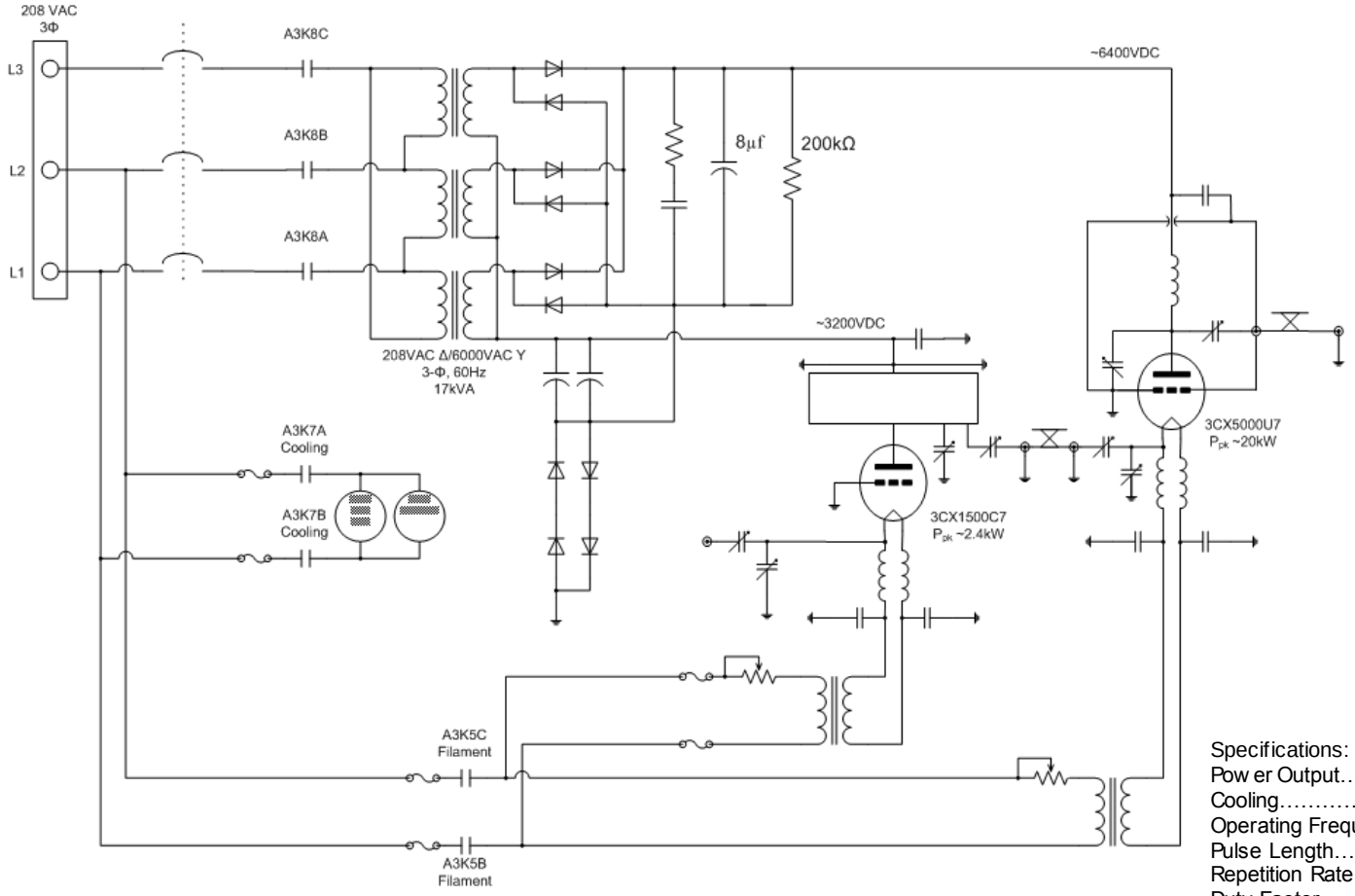
Medium Energy Beam Transport (MEBT) Structure

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

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

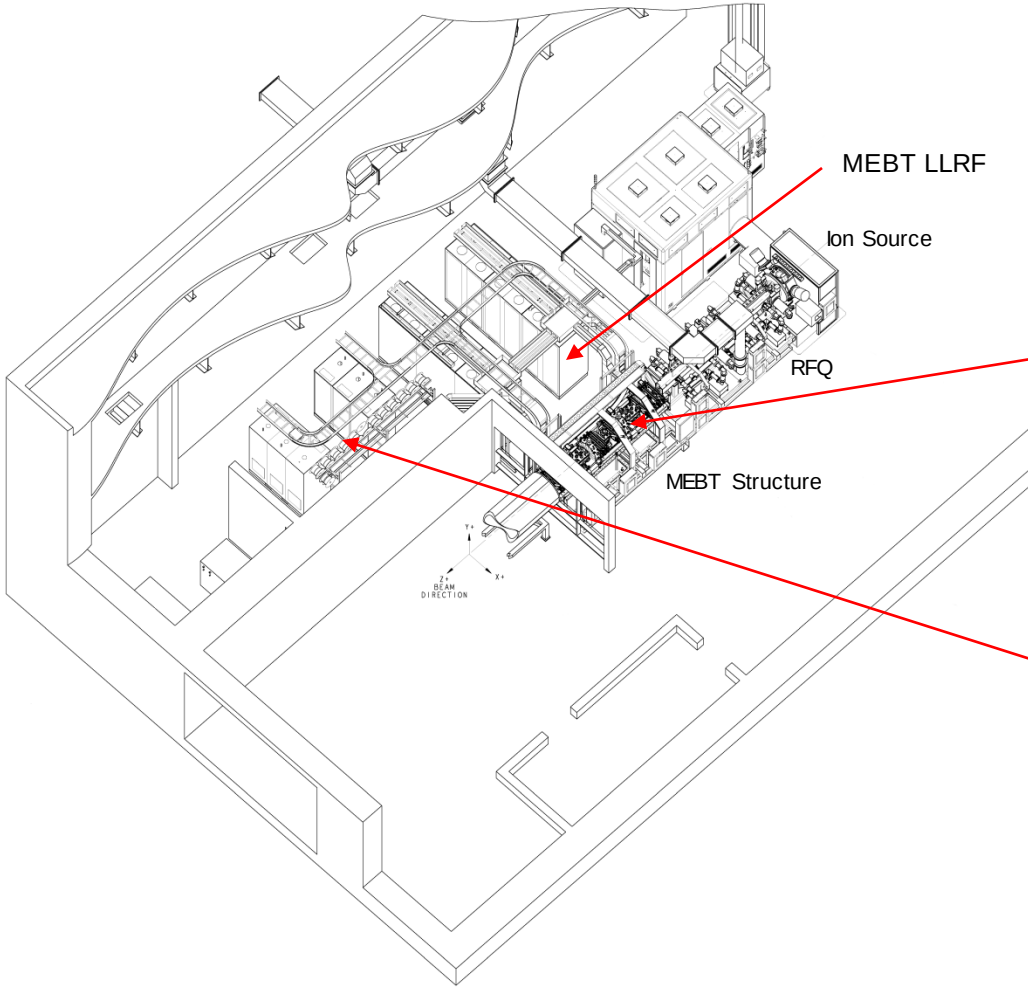


MEBT RF Power Amplifiers - Baseline Installation



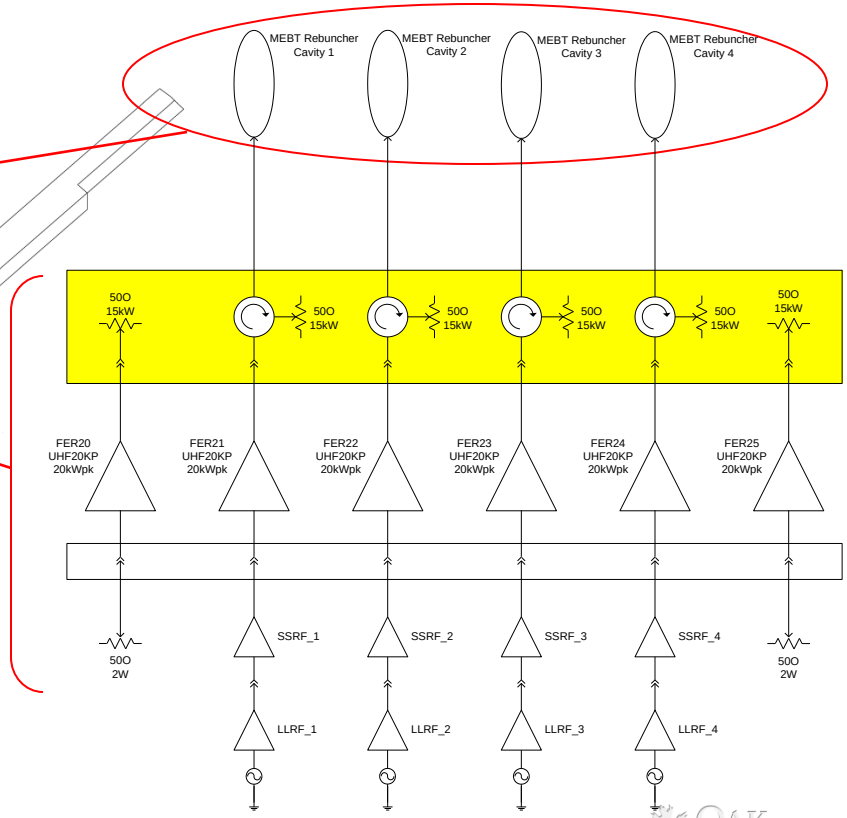
Specifications:
Power Output……0-20kW peak pulse
Cooling……Forced Air
Operating Frequency……402.5MHz
Pulse Length……..1 ms
Repetition Rate……..60Hz
Duty Factor……6%
Pulse Flatness……..better than 10%
RF Load Impedance……50 ohms
VSWR……..1.6:1 max @ full power
Input Power for 20kWpk Pulse…0dBm

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



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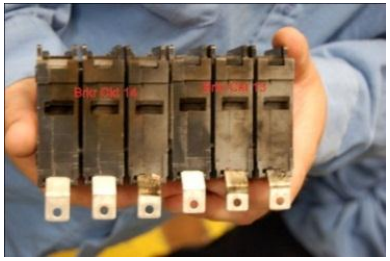
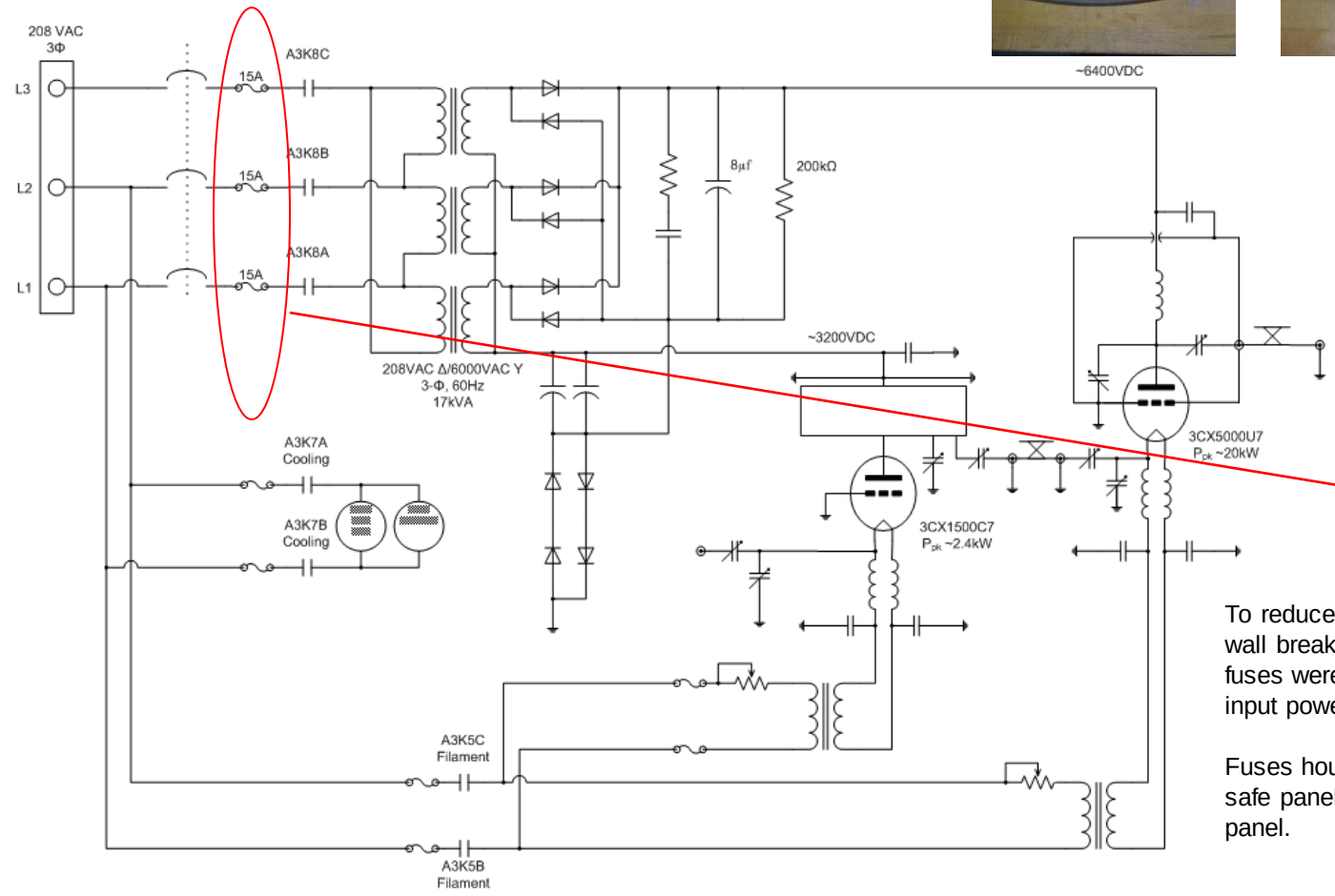


- Problems with the MEBT PAs started showing up soon after installation:
  - Amplifiers would fault and trip AC wall breakers.
    - Soft start was added by manufacturer after installation in attempt to address wall breaker trips.
    - Helped on startup, but did not solve fault issues.
  - Unable to 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.

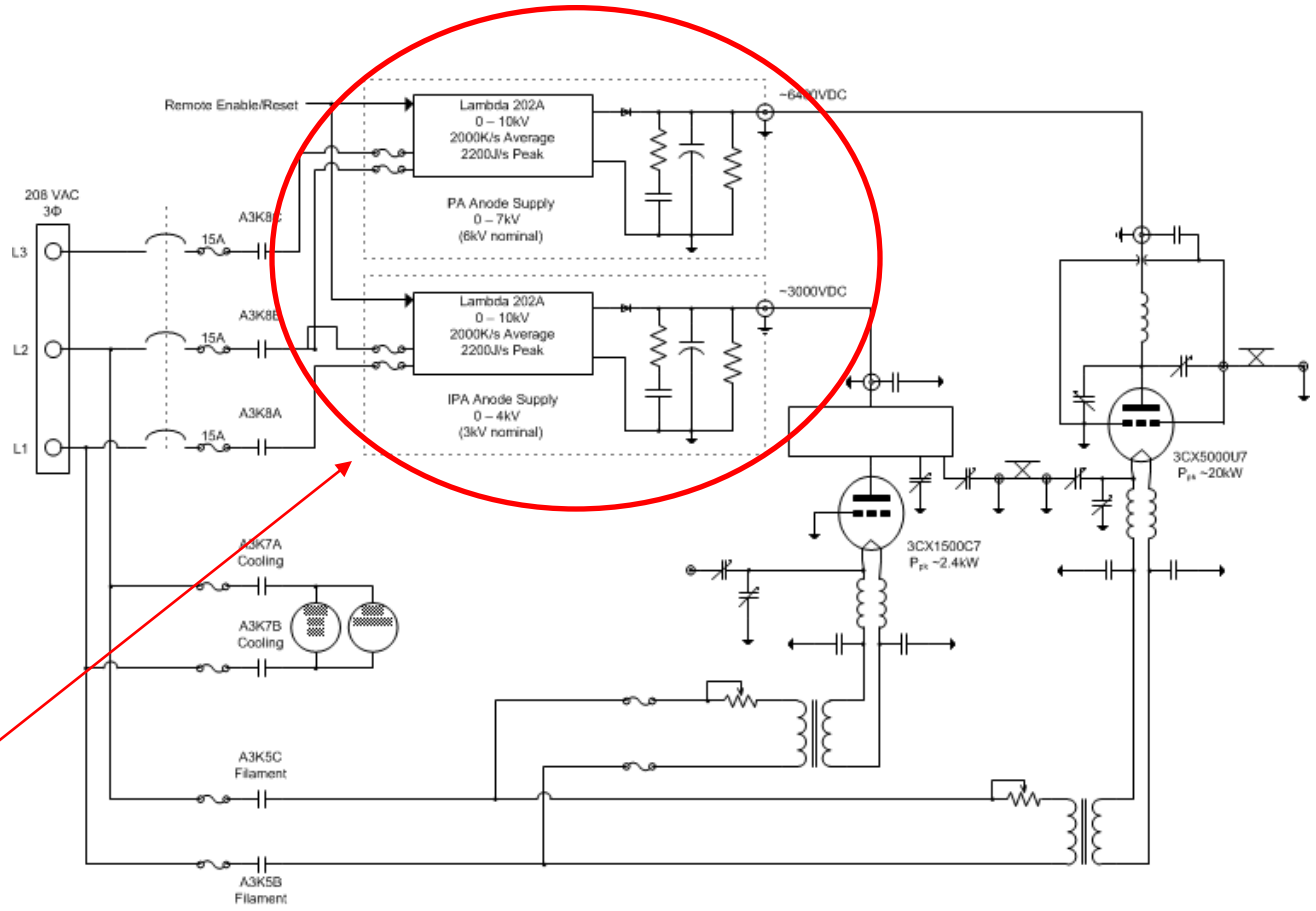
Modifications to the Original MEBT RF Power Amplifiers



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

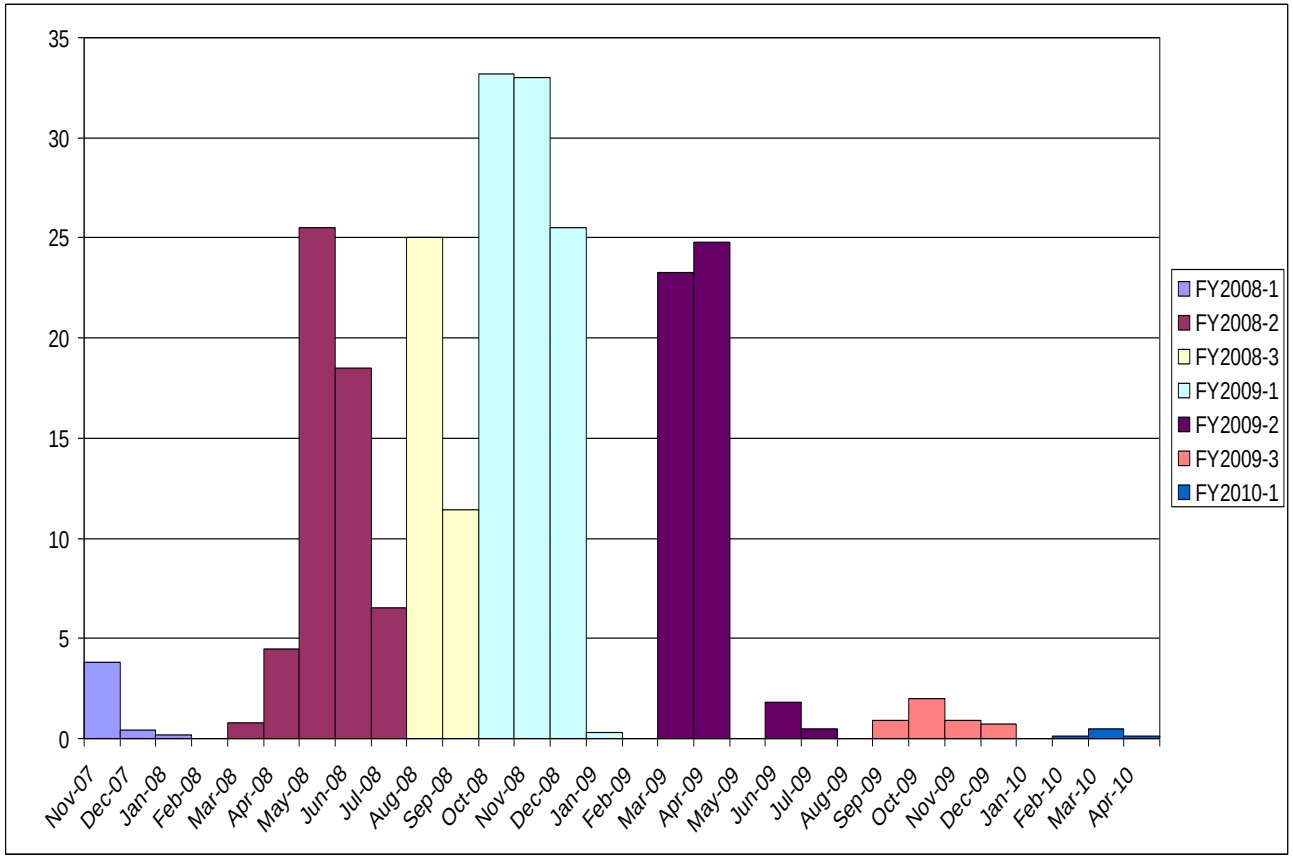
Fuses housed in finger-safe panel on front panel.

Modifications to the Original MEBT RF Power Amplifiers



Modifications to the Original MEBT RF Power Amplifiers

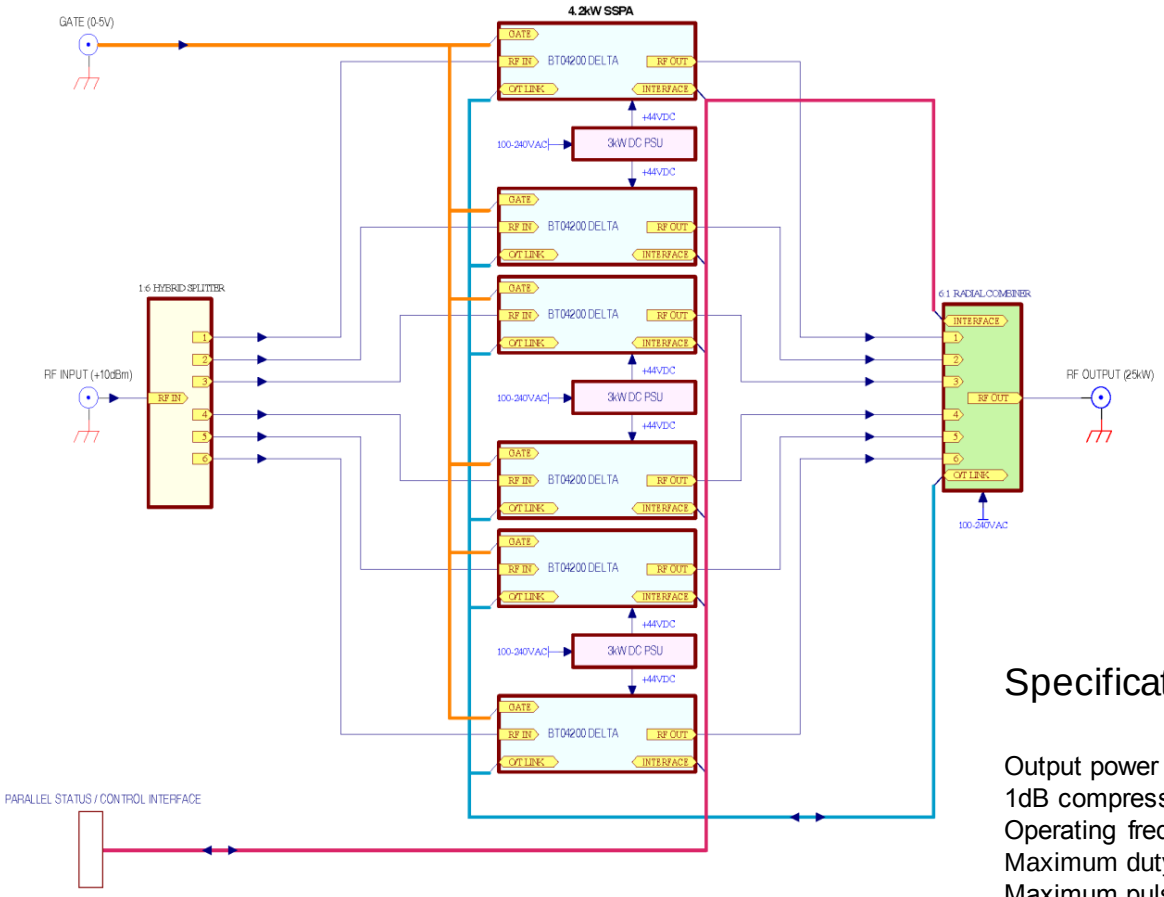
• We saw a significant decrease in down time due to the MEBT RF power amplifiers as we converted units to new anode supplies.



MEBT Solid State Amplifier Upgrade (AIP)

- AIP was funded in early FY2008 to replace MEBT power amplifiers.
- Decision in the fall of 2008 to consider a solid-state amplifier.
- Specifications written and a request for bid was provided to selected vendors.
- Vendor proposal was selected in late 2008 and a single amplifier was purchased with the option to purchase four more.
- Removed the original amplifier in FER20 in February, 2009 and installed a new rack, PPS chassis, AC distribution chassis and PLC controls.
- The solid state amplifier was received in the end of March 2009.

MEBT Solid State Amplifier Upgrade (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 @ $P_{full\ rated\ output}$

MEBT Solid State Amplifier Upgrade (AIP)

Parallel Status/Control Interface

- Addressing
- Status
  - DC Power
  - RF Power
  - Over temperature
  - Over duty
  - Shutdown status
  - Amplifier module (4) status
  - Mismatch
- Control
  - Enable
  - Shutdown

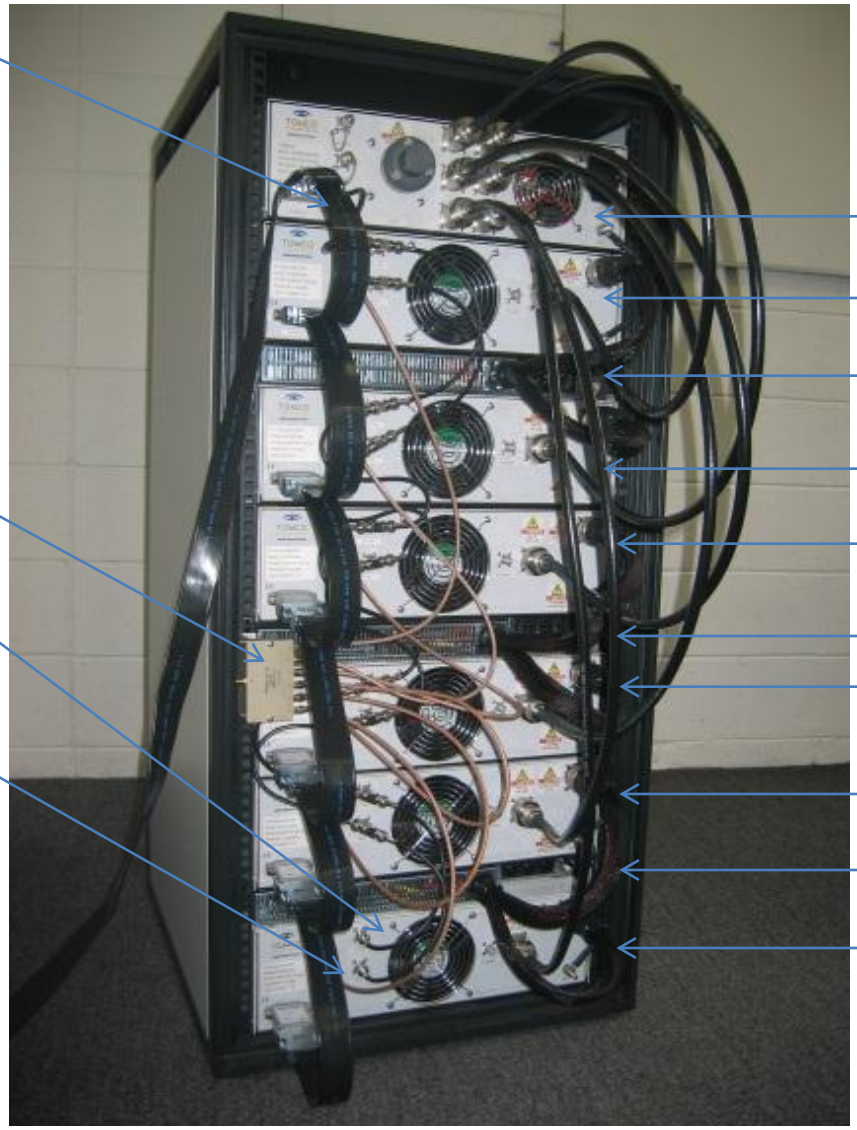
Input Splitter

Gate In

- Activates amplifier's rf input gate, bias circuitry and output noise gate.

O/T Link

- Carries shutdown from final combiner
- Carries over temp signal between all units
- Carries ref voltage check that a min of 5 units connected and operating
- Connects to the final combiner ensuring system cannot operate without mismatch shutdown connected and final combiner powered up



Output Combiner

PA1

Power Supply (3kW switch mode)

PA2

PA3

Power Supply

PA4

PA4

Power Supply

PA6

MEBT Solid State Amplifier Upgrade (AIP)

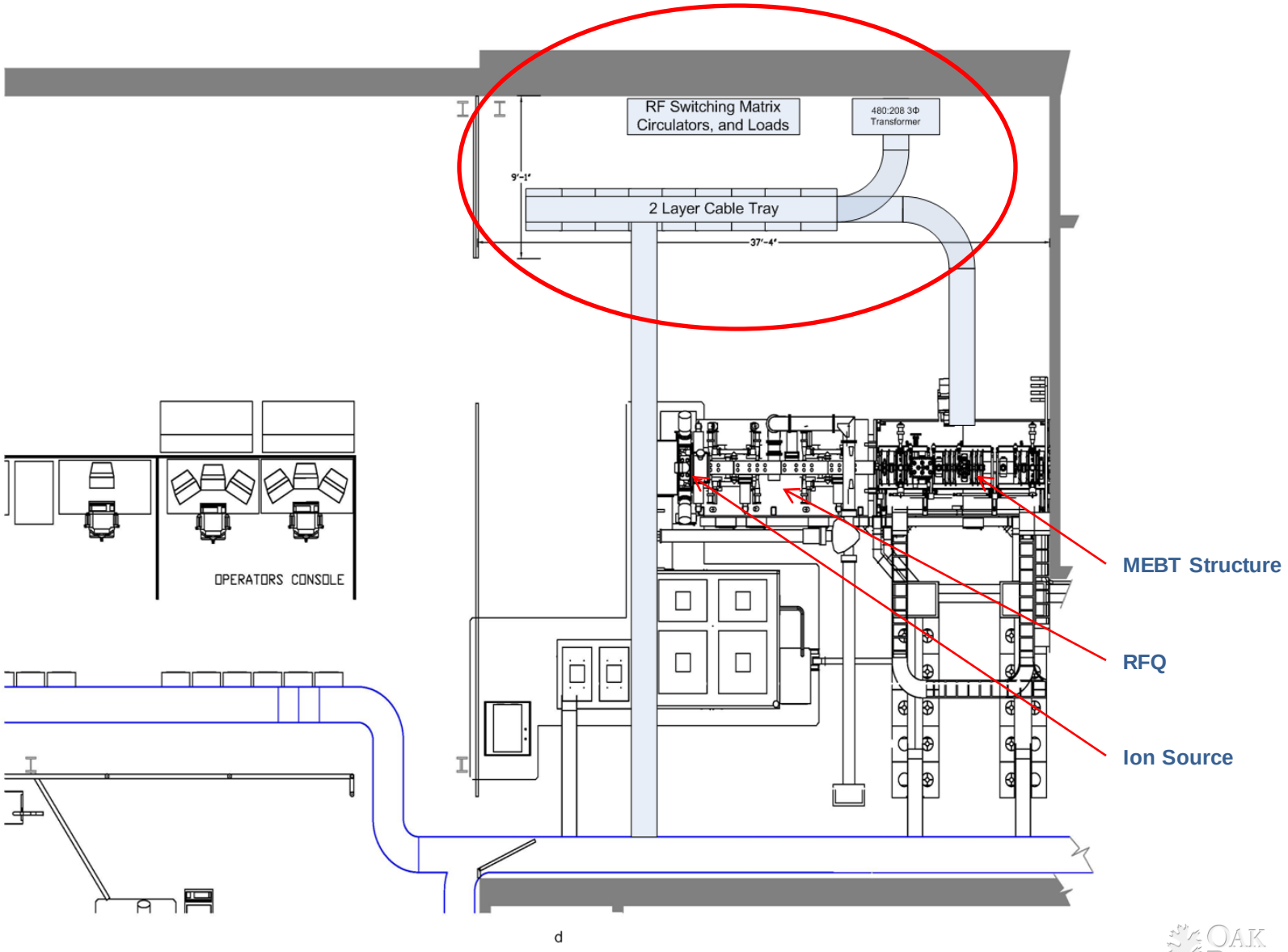
- Installed in FER20 in April 2009 and connected to MEBT cavity 4.
  - MEBT cavity 4 had historically been operating at ~14kW (increased to ~18kW and then to 20kW with new amplifier).
- Operated continuously until 8/2010 with few problems
  - Lost two separate amplifier chassis due to failure in driver 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.

* The Spallation Neutron Source Eight-Channel Pulsed Power Meter, M.Crofford, T. Davidson, X.Geng, T.Hardek Proceedings of 2011 Partical Accelerator Conference, New York, NY, USA

MEBT Solid State Amplifier Upgrade (AIP)

- After successful testing of first amp, design to replace all original MEBT amplifiers started in April, 2009
- A 4 + 1 switching scheme was decided on and four additional (slightly modified) amplifiers were purchased in June, 2009.
- High power switch matrix received September, 2009.
- Infrastructure installation (power, cable trays, racks, switch matrix, interconnections) began fall, 2009.
- Reported on progress-to-date at CWRF2010.

MEBT Solid State Amplifier Upgrade (AIP)



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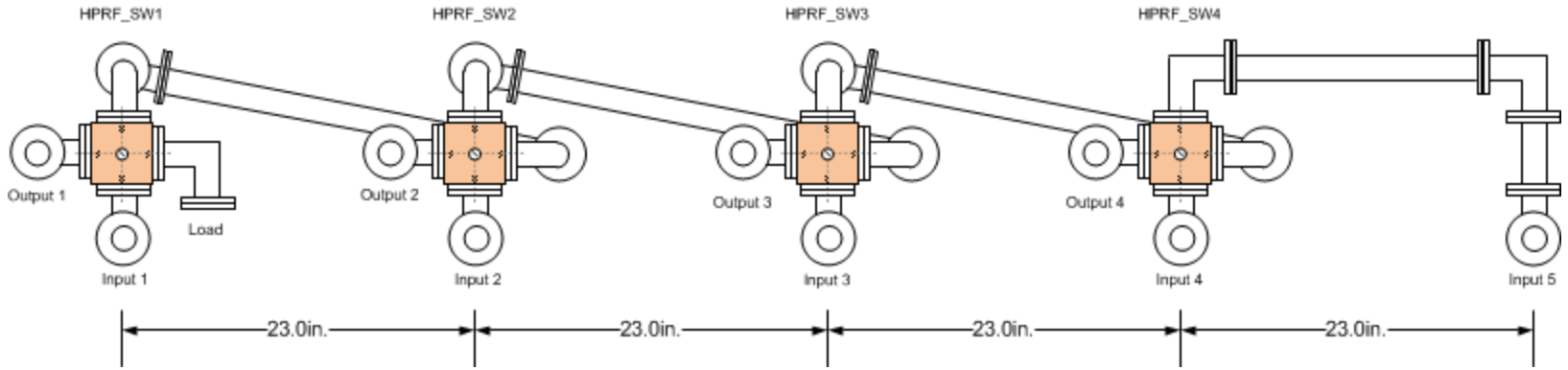
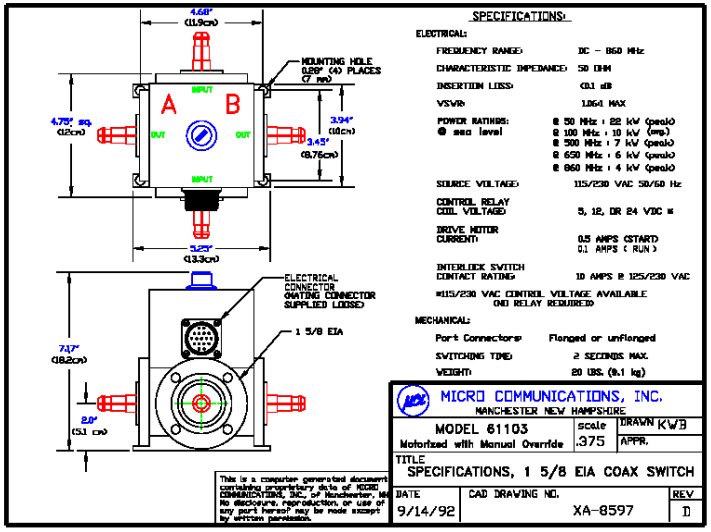
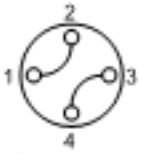
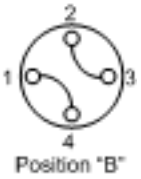
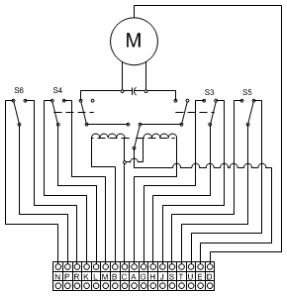






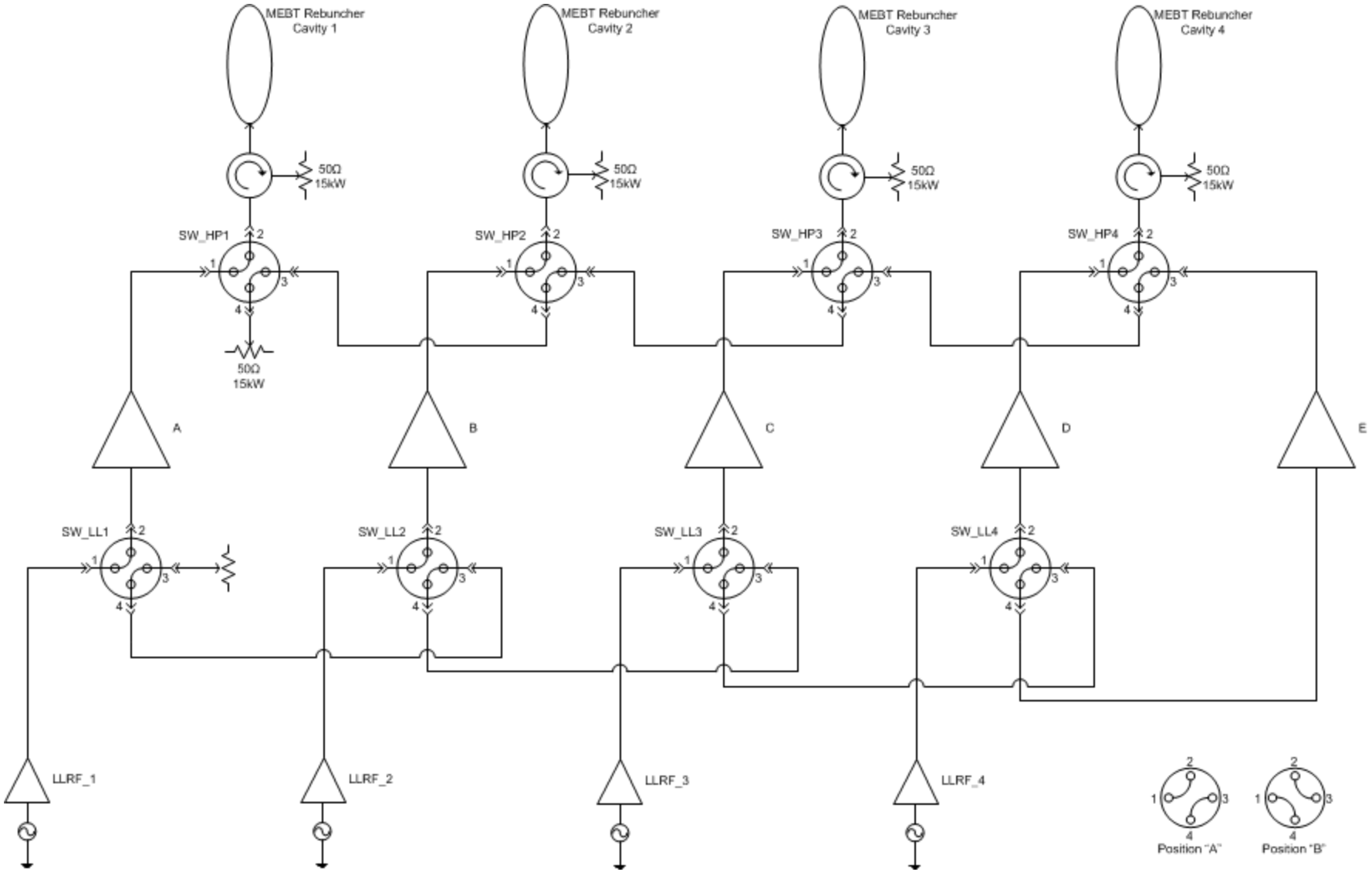




Specifications:

- Frequency Range: DC – 860 MHZ
- Z_0: 50Ω
- Insertion Loss: <0.1 dB
- VSWR: 1.06:1 max
- Source Voltage: 120VAC
- Control Relay Voltage: 24VDC
- Switching Time: 2 seconds max
- Flange: 1 5/8” EIA
- Interconnections: 1 5/8” hard line

MEBT Solid State Amplifier Upgrade (AIP)



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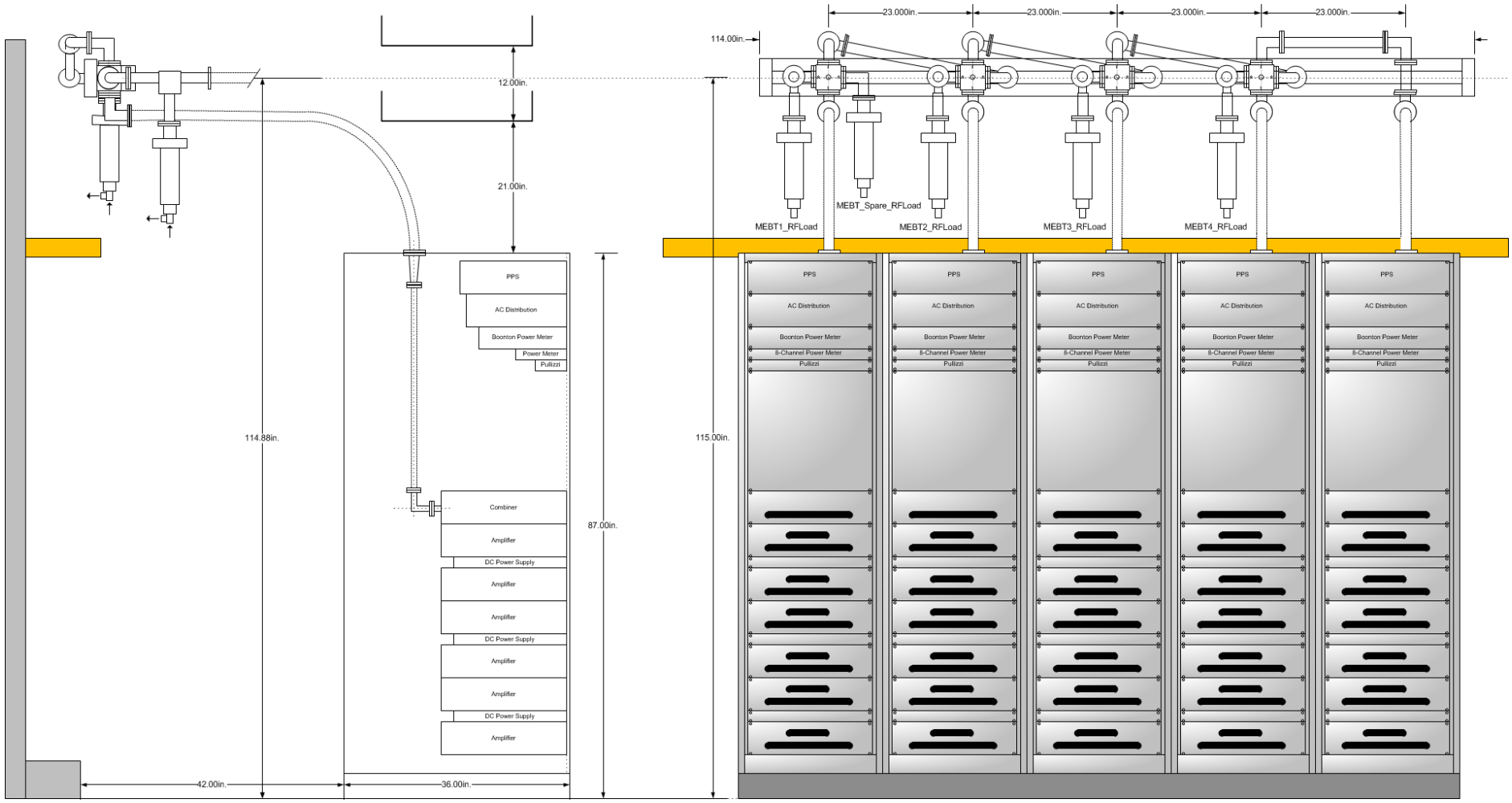

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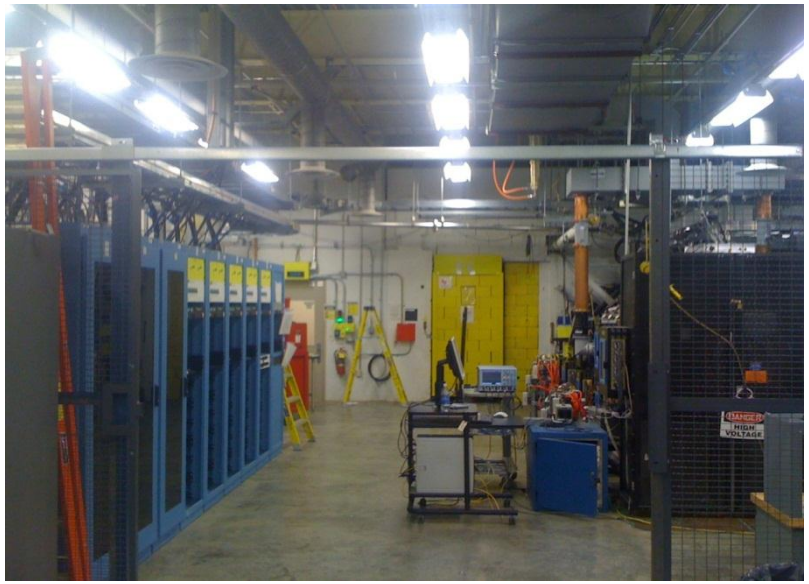
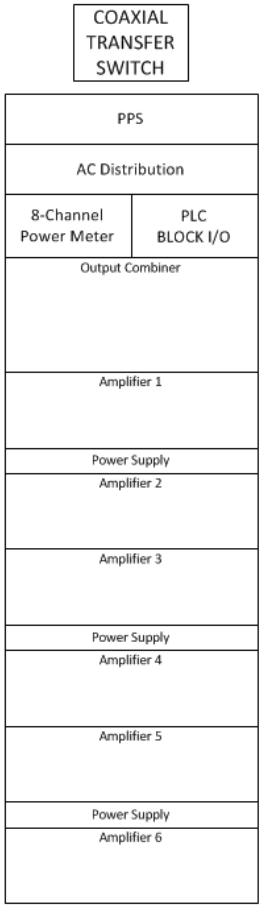


MEBT Solid State Amplifier Upgrade (AIP)

- Received remaining four solid state amplifiers and installed during summer, 2010
- Began operation with four amplifiers in September, 2010
  - After reasonable "break-in" period, sent the original amplifier back to factory for modifications

MEBT Solid State Amplifier Upgrade (AIP)



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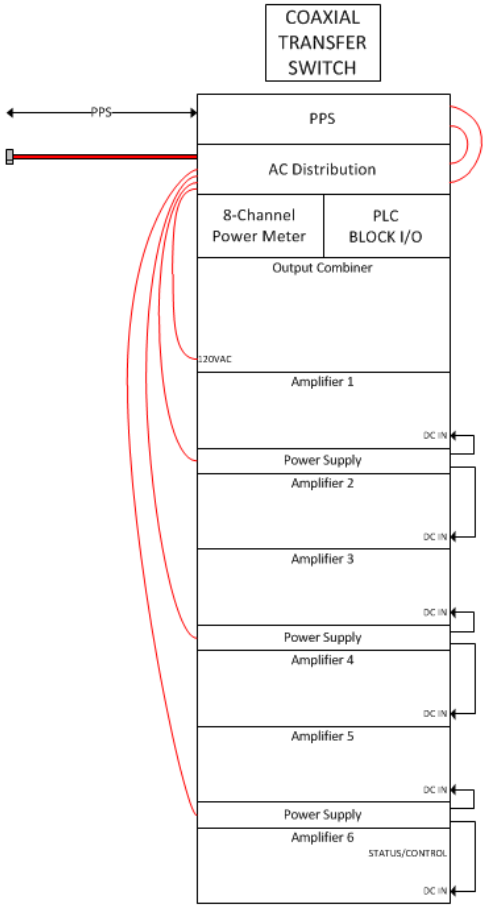

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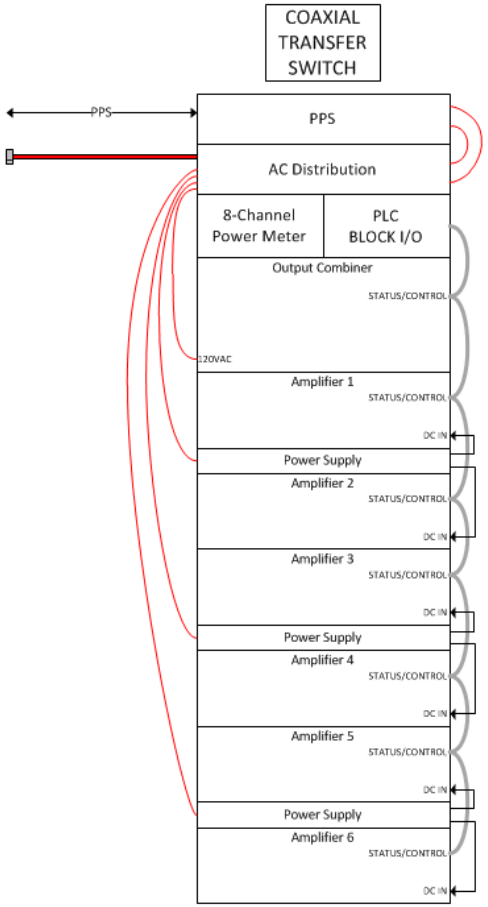

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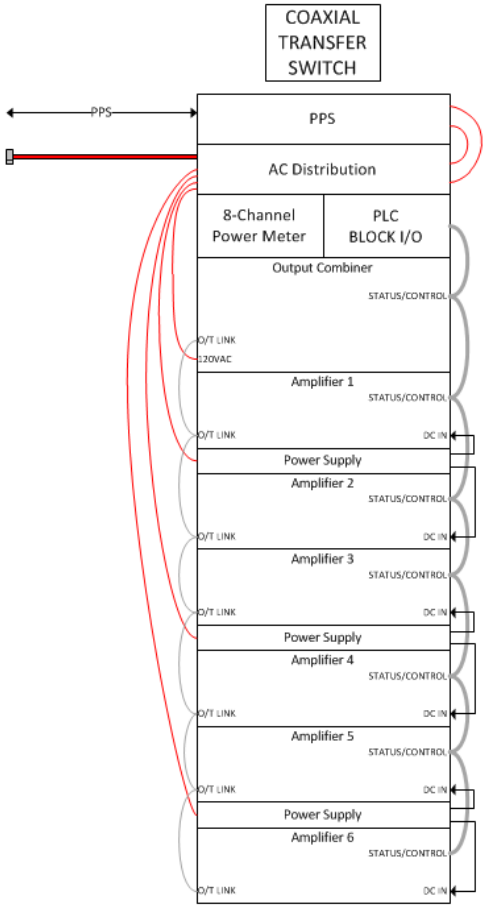

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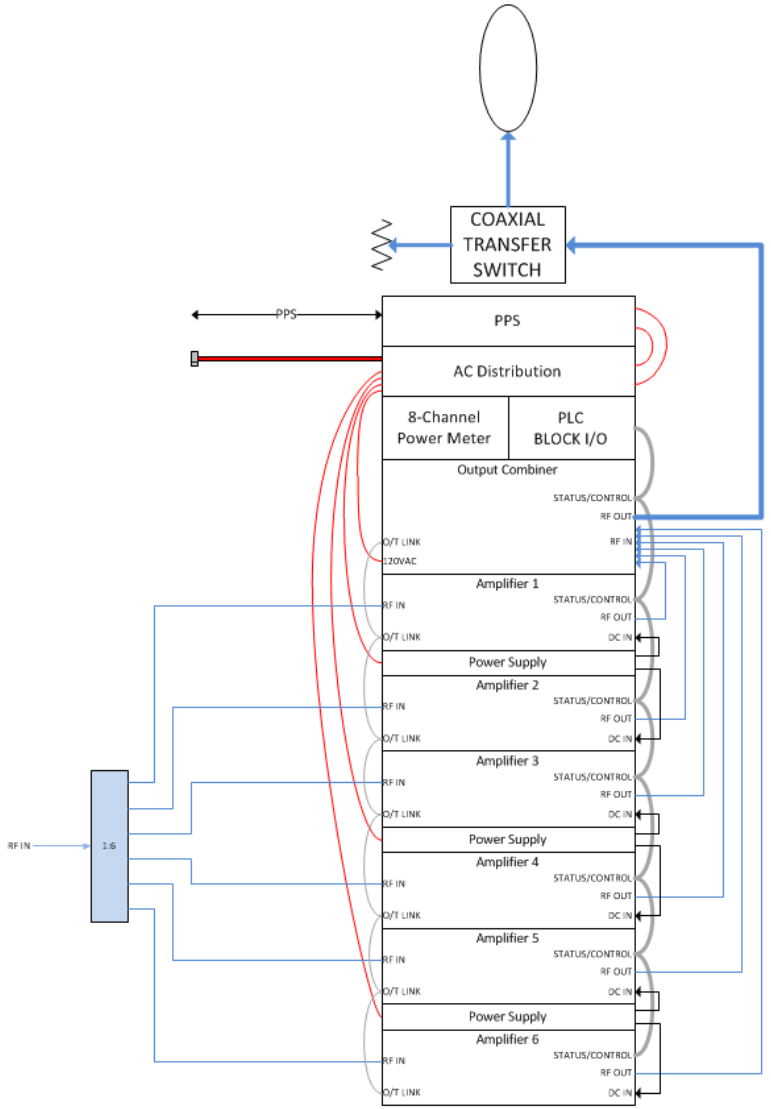

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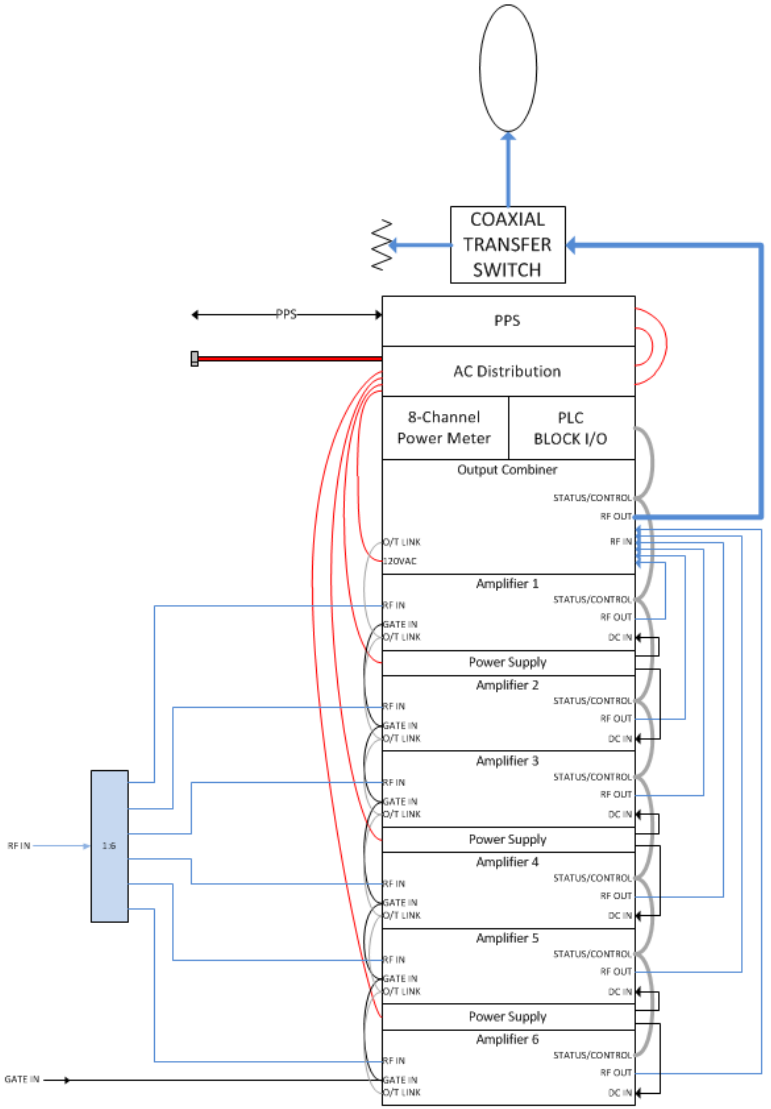

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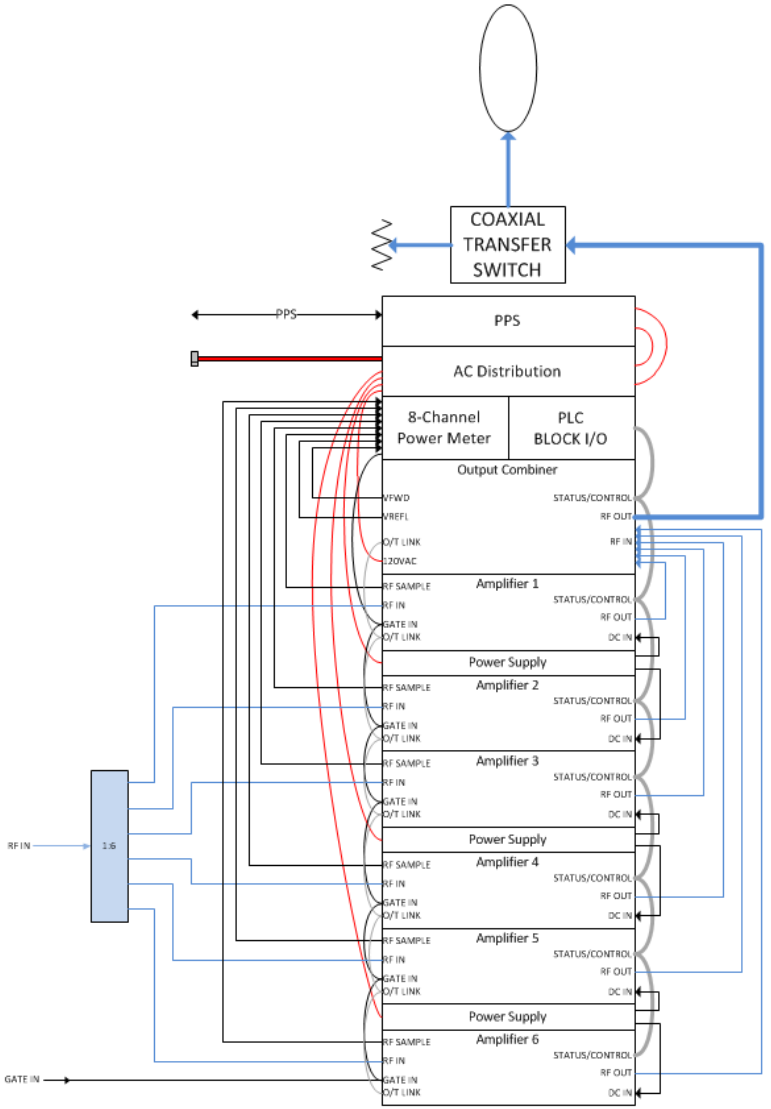

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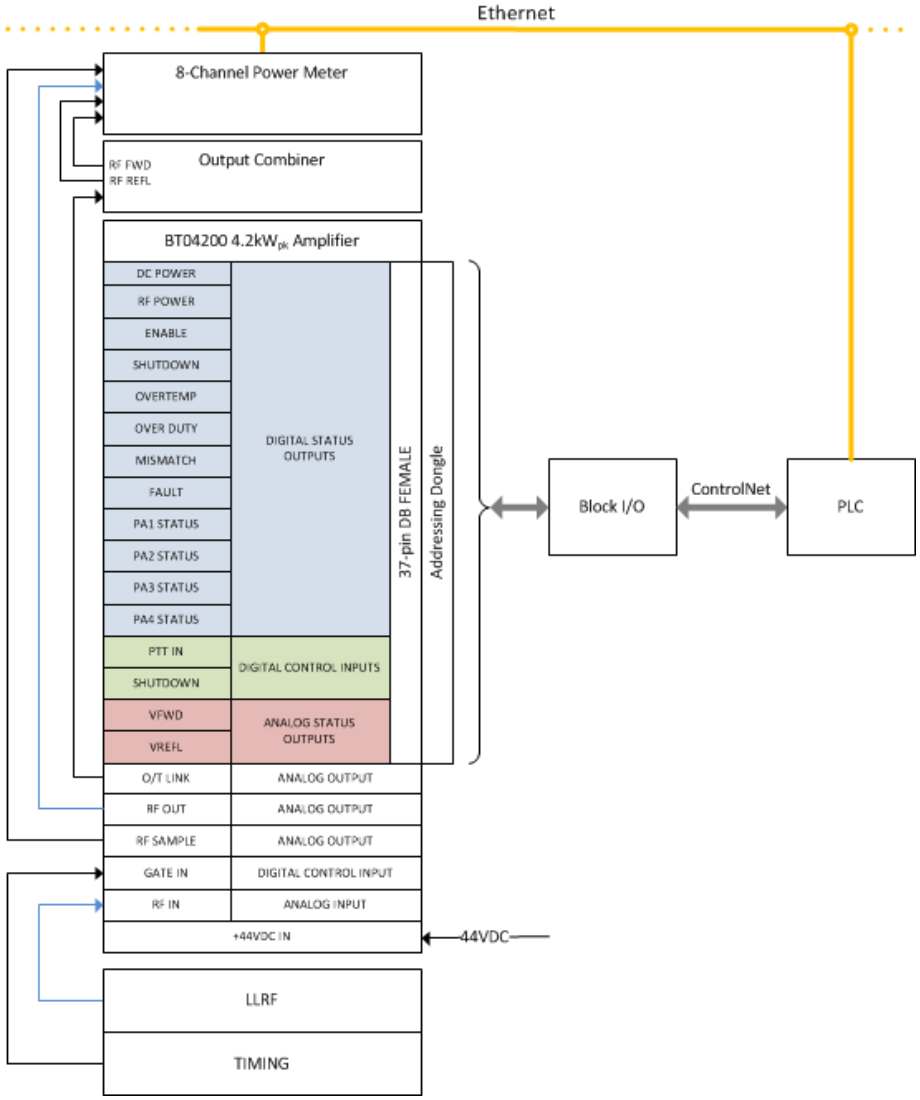

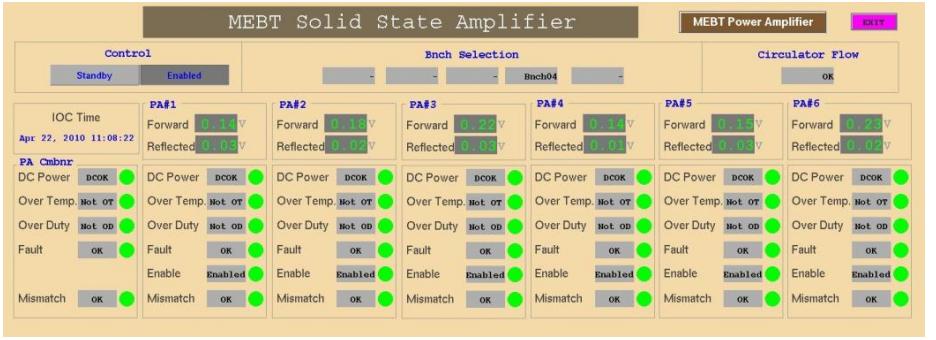

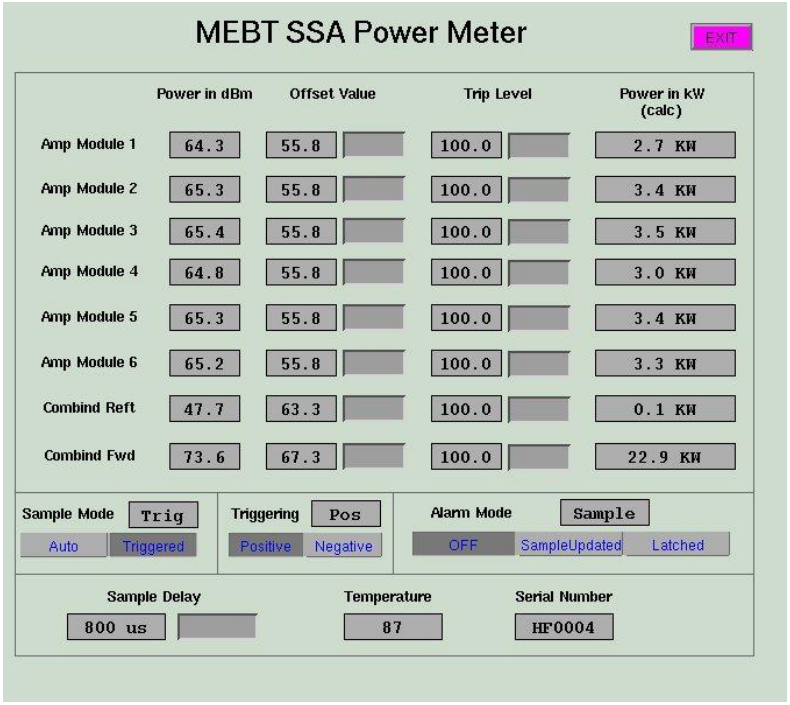

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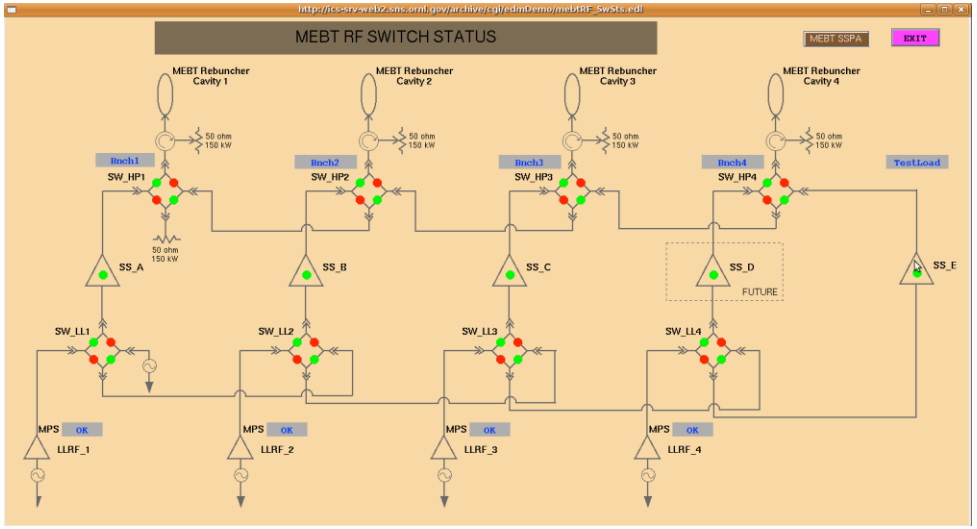
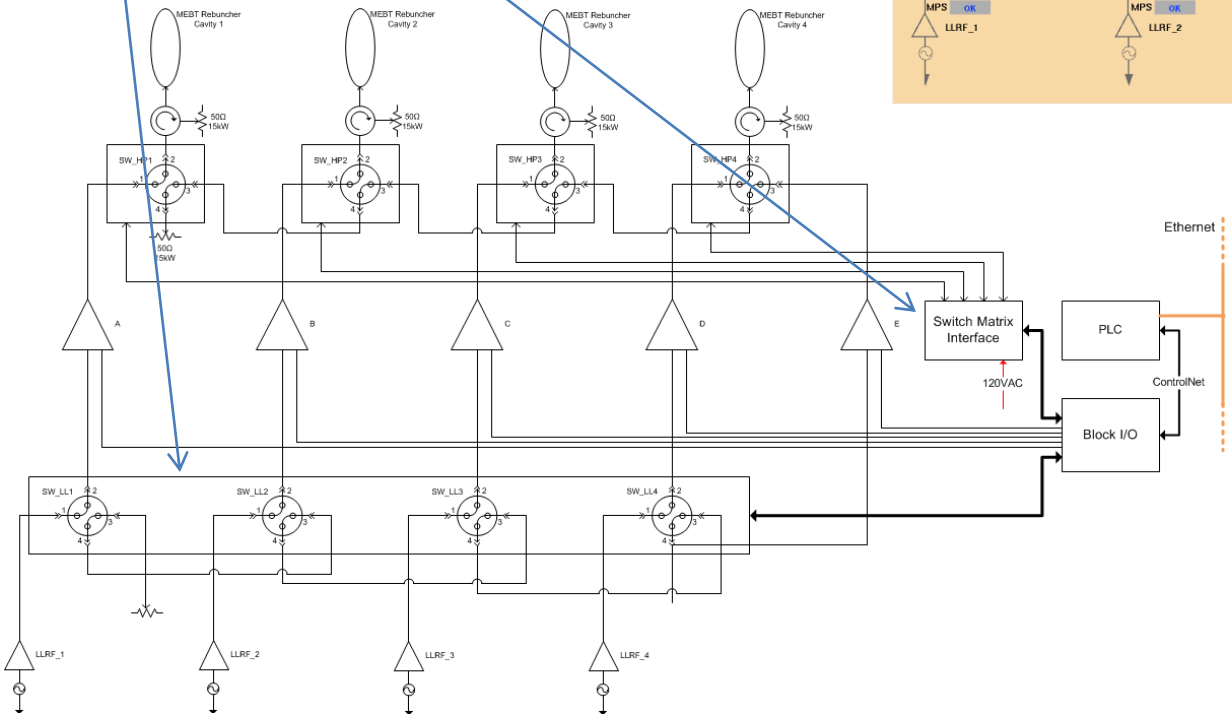
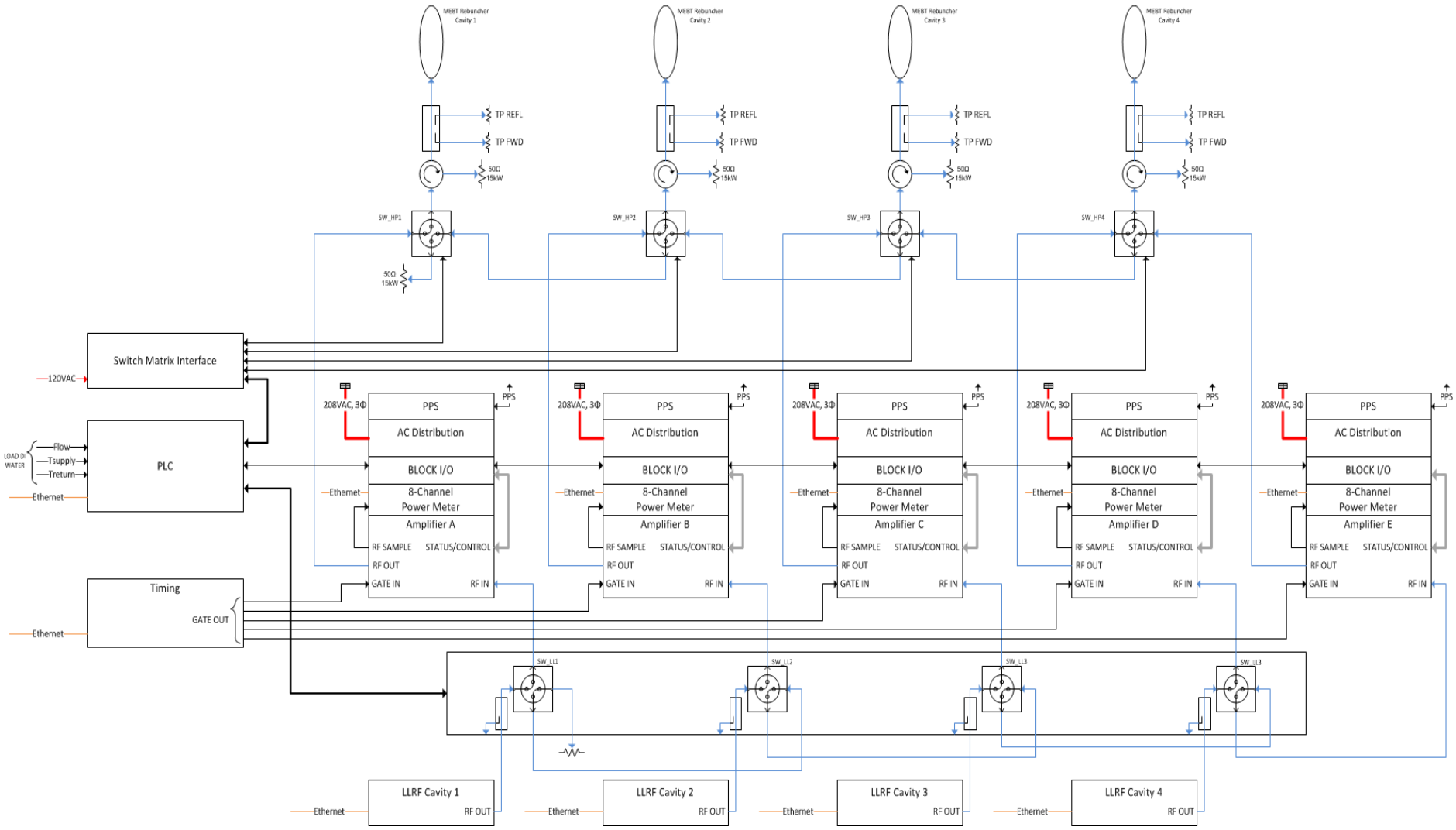




COMMAND	STATUS				
	MEBT				TEST STAND
	1	2	3	4	
NORMAL	A	B	C	D	E
REPLACE P.A.A	X	X	X	X	X
REPLACE P.A.B	X	X	X	X	X
REPLACE P.A.C	X	X	X	X	X
REPLACE P.A.D	X	X	X	X	X

MEBT Switch Status

MEBT Solid State Amplifier Upgrade (AIP)



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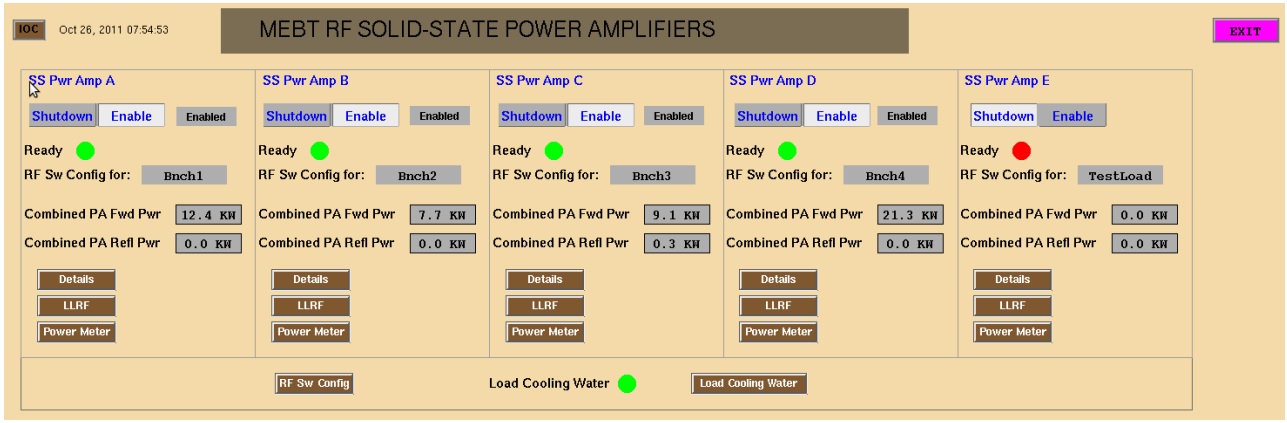
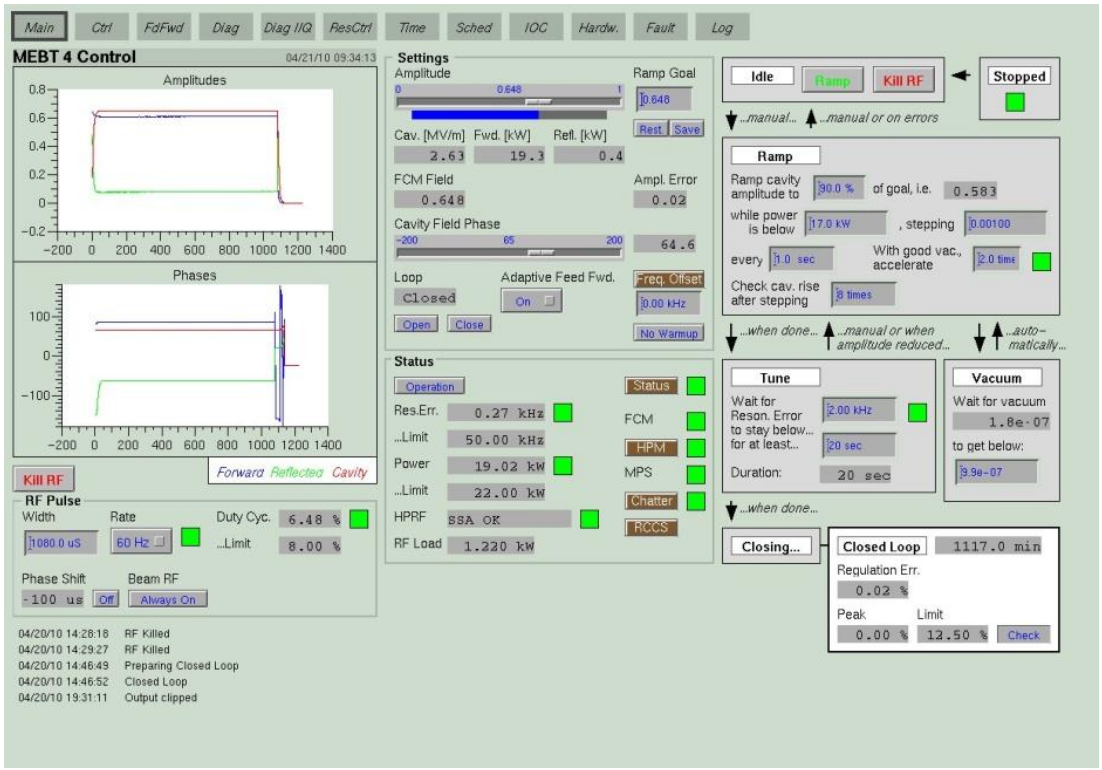
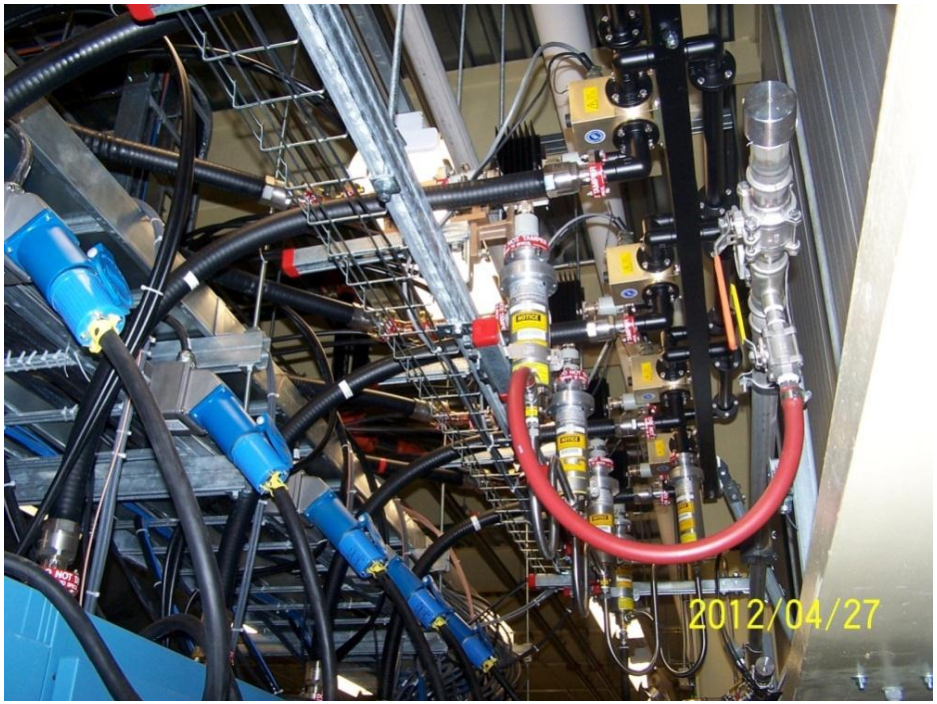




MEBT Solid State Amplifier Upgrade (AIP)

- **Fifth amplifier was installed in September of 2011.**



Summary

- The MEBT RF power amplifier solid state upgrade is complete.
- Simple and straightforward system.
- Works reliably.
- Provides a couple of layers of redundancy.
- Switch matrix provides remote switching of the spare amplifier into any of the four cavities.
- When a system operates with little or no downtime, one tends to forget about it.
  - Importance of complete and organized documentation – it will fail at some point!

- Vote for me! (throw a "redneck" to the sharks!)