NOvA Recycler Upgrade for Multi-Batch Slip Stacking

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ABSTRACT

As part of the ANU, an effort to upgrade the accelerator and neutrino beamlines, Fermilab is installing three RF cavities into the recycler ring. These cavities will convert the recycler from a storage ring into a pre-injector that will be utilized to slip stack the beam, effectively doubling the beam power the Main Injector deliveres. The cavities are operated via an array of Modulators, Control units, Bias Supplies, Driver racks, Power Amplifiers, and an Anode Power Supply. During this upgrade, I worked on the Anode supply, as well as various other components of the RF station, such as the Modulator B+ Bypasses and Control racks. These components allow for the rest of the RF system to be installed, and will eventually be used to generate a twice as powerful beam.

BACKGROUND

NOvA is attempting to observe the oscillation of muon neutrinos into electron neutrinos, the ordering of neutrino masses, and the symmetry between neutrinos and antineutrinos. To support these high intensity experiments, Fermilab requires a 700kW beam [1].

The Recycler Ring (RR) is a kinetic energy storage ring located directly above the Main Injector (MI) beamline. It is a fixed 8GeV ring that acted as a post-Accumulator and receptacle for recycled antiprotons [2]. Since the shutdown of the Tevatron, there is no longer a need for an antiproton recycler, so the RR will be repurposed to increase the beam power via slip stacking.

Table 1: The 2013 upgrade will almost double the power of the beam. [3].

	Particles per Pulse	Cycle Duration	Proton Beam
Current	40E12 ppp	2.06 sec	370 kW
Upgrade	49E12 ppp	1.33 sec	700 kW

The RR will accept 12 Booster batches, and it will inject six slipped batches into the MI. MI will accelerate 49E12 ppp at 1.33 sec to provide the 700kW beam [4]. To slip beam in the RR, three new RF stations need to be built. My responsibility was to help construct the Anode supply and B+ filters for these stations, as well as to execute various smaller aspects of different upgrades, such as replacing the old RF driver racks with the new solid state models, creating (and testing) delay lines, disassembling control units, tin-plating various connections, and testing power supplies.

TECHNICAL APPROACH

ANODE POWER SUPPLY

The Anode Power Supply (APS) is a 30KV DC supply for the Power Amplifier (PA). The supply mounts to a Vacuum Circuit Breaker (VCB), switchgear, and transformer by which it receives 13.8 KV AC and supplies power for the PA. A simplified view of the station is illustrated by Figure 3 in the appendix.

The first part of the process was to prepare for and oversee the transportation of these modules to the APS. We began by calculating the move and disconnecting the modules that we transported from other areas. Once prepared, we contracted a crane to move the parts and laid out the modules, ensuring that the gasket on the 2500 lb transformer would cleanly connect to the flange on the outer wall of the APS and that the transformer was in-line with the VCB. This required 1/16" accuracy, and took an afternoon to complete. Once aligned, the flange was welded to the outer wall of the APS; the entire structure was shielded from the weather.

When that was complete, we were able to start the construction of the Anode Supply. The APS begins by transferring voltage from the transformer to diode sticks, large assemblies with resistors and capacitors equalizing the voltage across multiple diodes. The diode sticks, along with an inter-phase transformer they connect to, turn three-phase delta and wye input (a total of 6 phases) into DC power. That power runs through a capacitor bank that smoothes the DC signal, and a series of other hardware senses the current and enables various shut-offs before passing current to the Modulators and the RF Cavities' Power Amplifiers. At the time of writing, this is all we've completed on the Anode Supply.

MODULATOR B+ BYPASS

With ≈23kV of DC going to the Power Amplifier, it's important to filter out any high frequency RF noise that may enter the PA. The bypass filter ideally reduces the amplitude of the higher frequency signals as shown in Figure 1, protecting the Power Amplifier from RF

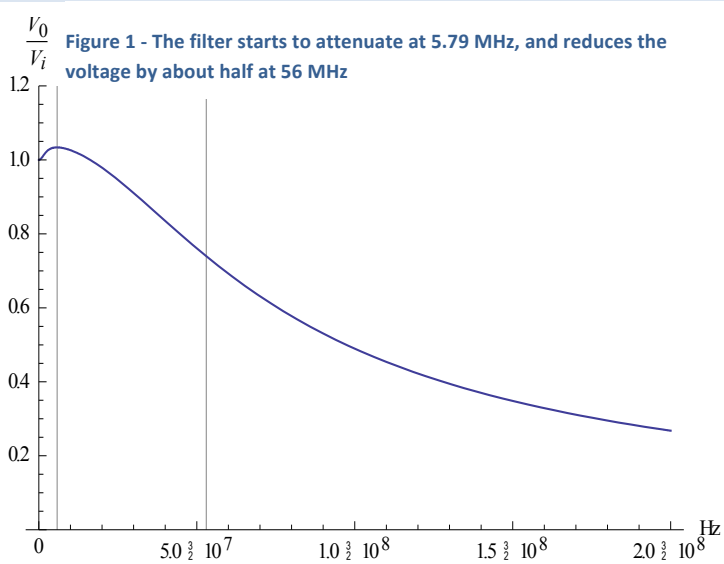

Figure 1 - The filter starts to attenuate at 5.79 MHz, and reduces the voltage by about half at 56 MHz

noise.

When building the filters, we started by having the high and low-voltage terminals machined, as well as ordering the boxes that housed the assembly. We then tested the capacitors and cut the hardware we required. We also cut mounting holes in the steel boxes that housed the assembly and installed connectors for the 50Ω load, grounding connection, and RG-218 and RG-220 cables. Figure 4 in the appendix outlines the specifics of the B+ Bypass.

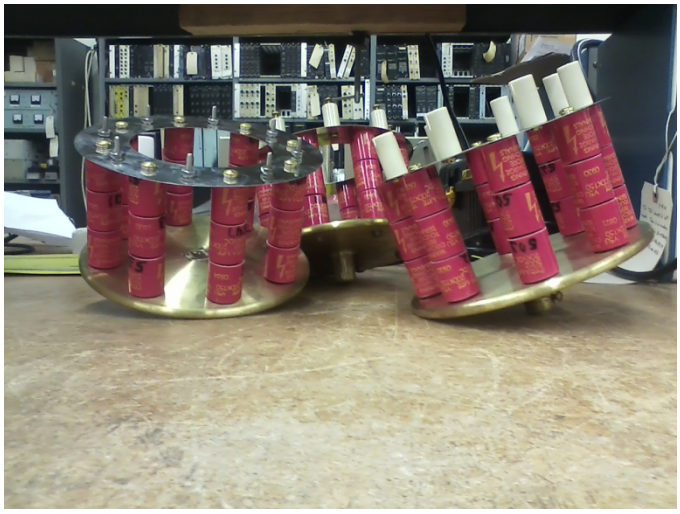

Figure 2 - The capacitor assembly for the filter

We built the capacitor assemblies separately and then mounted them in the box. They consisted of 8 parallel arrangements of three capacitors in series. We tested each capacitor for its 0.5nF capacitance rating, and tested the entire assembly for a total capacitance of 1.3nF. This, along with an 1.436×10^{-7}H inductance from the wire we coiled between the assemblies, gave us the optimal attenuation for the filter. Once everything was set up and performance tested, it was just a matter of mounting the filter and connecting everything to the station.

FUTURE WORK

There is still quite a bit of progress left to be made in the APS. While most of it is complete, there are still many cables to run and interlocks to finish. We have yet to finish the control rack for the APS, so we haven't been able to wire it. We also have yet to finish the Ross interlocks, wiring, nor the Kirk Key system to prevent unsafe entry. The RF cavities are also still being designed and installed, along with the modulators.

IMPACT ON LABORATORY AND NATIONAL MISSIONS

The experiments enabled by the increased beam energy will allow Fermilab to further basic research and will enhance our understanding of matter and energy. This will enable us to peer more closely at rare interactions of particles, which builds the foundation for more capably addressing our countries energy and environmental challenges.

CONCLUSIONS

Building these new RF stations allows us to pull slip stacking from the MI and therefore increase the intensity of the beam. The recycler will solely be responsible for slip stacking in the 53 MHz cavities, and the focus of the MI will be accelerating the beam. This decreases the cycle duration from 2.06 to 1.33 seconds, which means that the MI can provide more energy per second. This, with the increased number of bunches per cycle, will push the beam energy to 700kW, and eventually perhaps up to 1MW.

ACKNOWLEDGEMENTS

This project was completed at Fermi National Accelerator Laboratory, under the supervision of Joe Dey and Mitch Adamus in the RF department of the Accelerator Division. Not only did Mitch and Joe provide an amazing amount of knowledge, guidance, and instruction, but everyone in the RF department was extremely helpful throughout my entire 10-week term. Fermilab itself provided a great atmosphere of support and knowledge that made the internship very enjoyable, and the lecture series and tours provided a unique first-hand look at the work that many physicists and engineers do. With that said, I hope that FNAL and the DoE continue to support this opportunity so more students can be a part of the scientific community here at Fermilab. It was a great experience and I hope many more students will be able to enjoy it.

Bibliography

[1] “The NOvA Experiment,” November 17 2009, http://www-nova.fnal.gov/nova_experiment_print.html

[2] “Fermilab Recycler Ring Technical Design Report”, 1.2, November 5, 1996, pp. 3-6

[3] Sam Childress, “Present and Future Neutrino Beams at Fermilab.”

[4] B. Chase, J. Dey, P. Joireman, I. Kourbanis, J. Reid, K. Seiya, “Progress in Multi-Batch Slip Stacking in the Fermilab Main Injector and Future Plans.”

APPENDIX

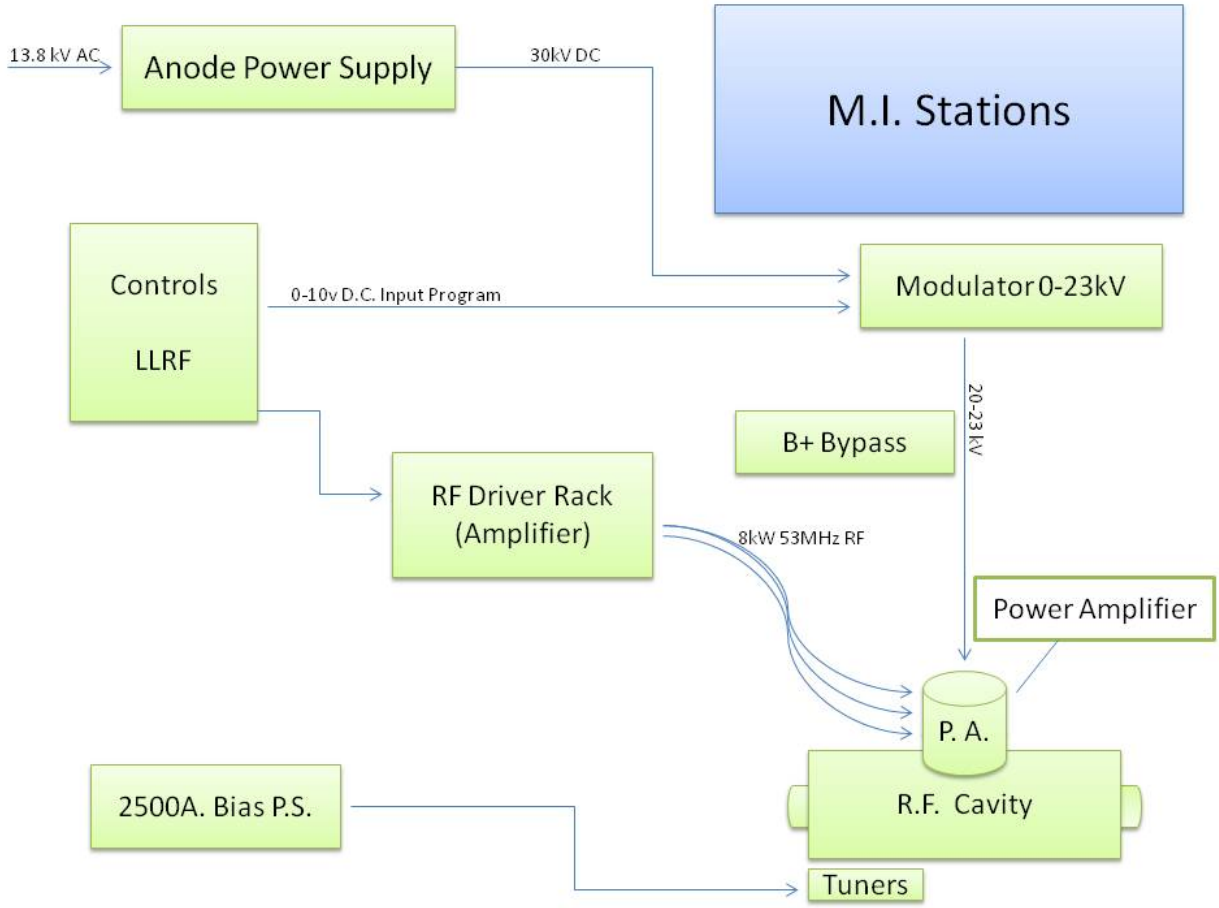

Figure 3 - An Overview of a M.I. Station

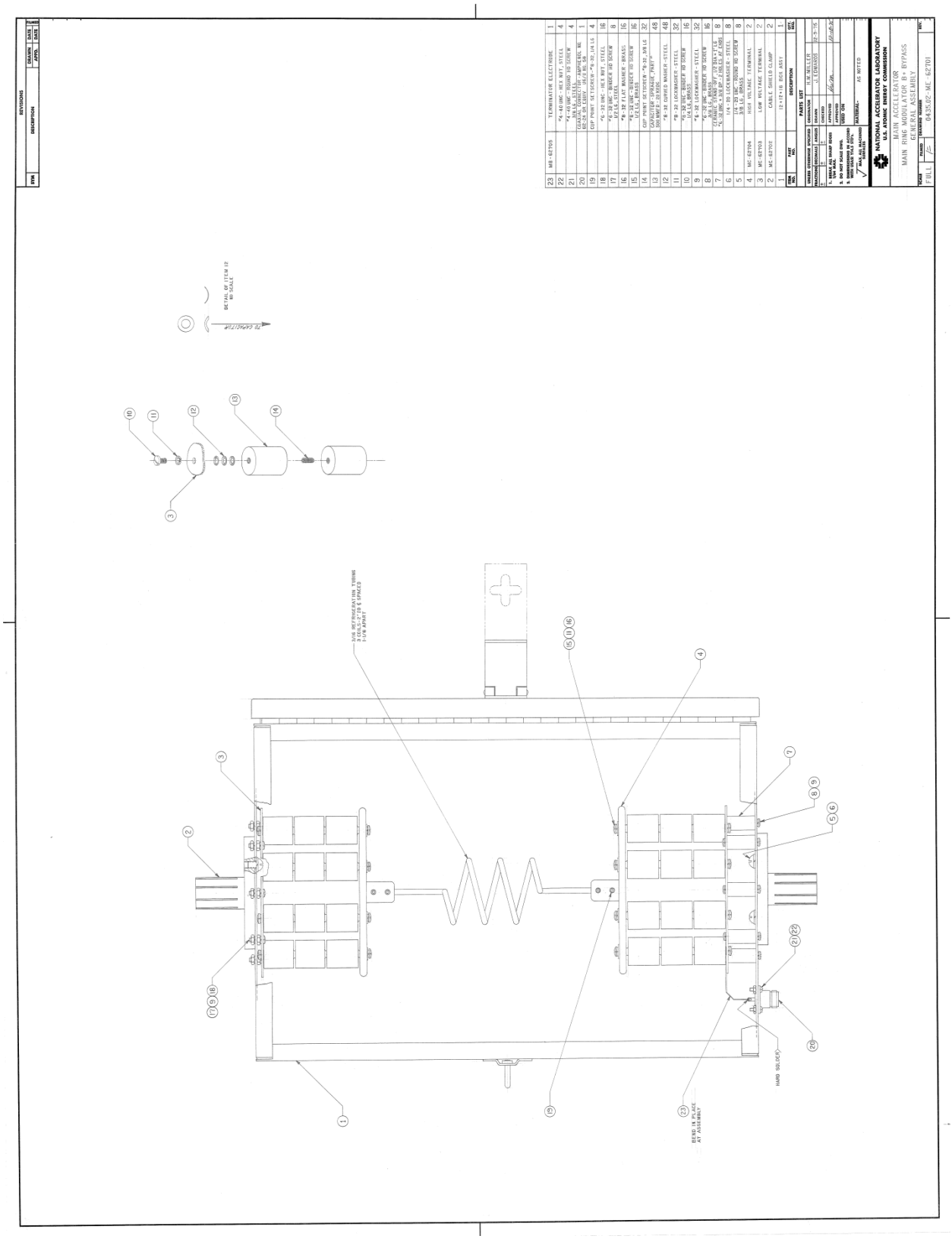

Figure 4 - The draft for the Modulator B+ Bypass