Interface Box for Dual Power Amplifier Modulators in Main Injector

Diana Ayala, Elgin Community College
Supervisor: Susanna M. Stevenson

August 6, 2024

1 Introduction

The Proton Improvement Plan II (PIP-II) aims to enhance the current Fermilab particle accelerator complex to intensify and accelerate more beam. The project will power the beam as it heads from Illinois to the Deep Underground Neutrino Experiment (DUNE) in South Dakota by providing them with neutrinos.

To intensify the beam, one of the PIP-II upgrades is to add a second power amplifier (PA) to the existing Main Injector cavities. In turn, this boosts the maximum output power to 400kW per station even though the PIP-II requirement is only 240kW. With more output power, more protons can be accelerated through the particle accelerator and in the case of the DUNE project, this is ideal given that the chance of a neutrino interacting with a proton or a neutron is one in ten billion.

The power amplifier is added to the cavity and driven by the modulator. Within the modulator, the control unit receives input signals from the power supplies, moderates they are working properly, and controls the timing of the power up sequence. However, a challenge imposed by an additional PA was that the control unit could only read signals coming from the previous power supplies but not the additional second set. For this reason, the interface box was designed to facilitate the issue.

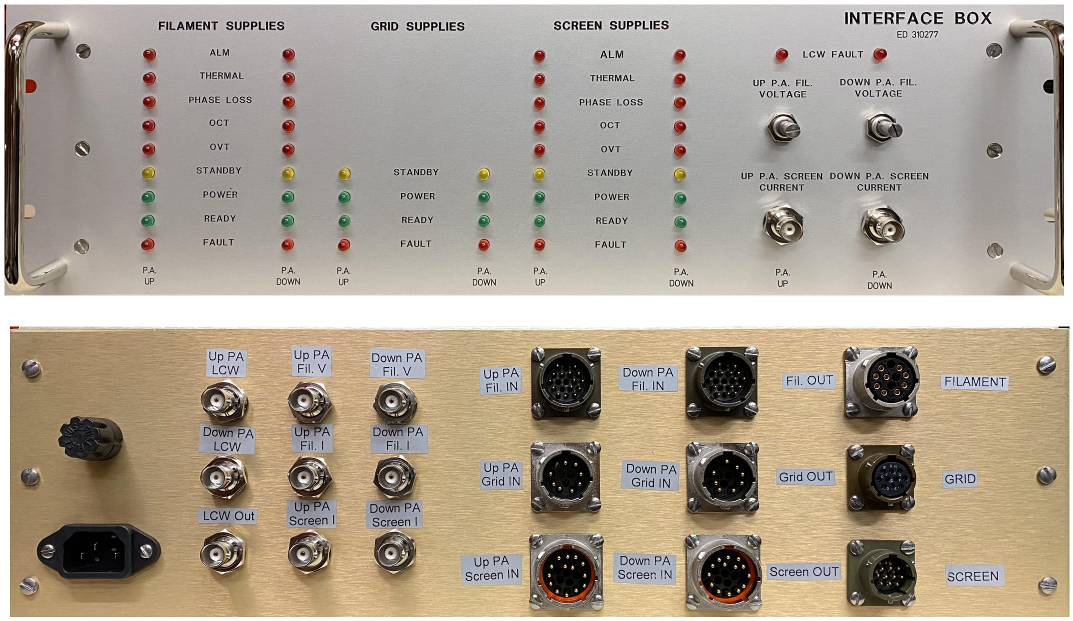

Figure 1: Front and back panel

2 Purpose

The main purpose of the interface box is to sum two signals from the power supplies into one signal and send them over to the control unit as a signal that it can read. Other functions include latching the LCW and Grid Supply error circuits and generating a filament current ramp circuit.

In the past, when the latch circuits in the LCW and Grid Supply were not present, there were instances that a station would be taken down if they flickered into a fault, but when it came back up, there would not be a clue as to why the station went down in the first place. With the latch circuits, if a station comes down, it will require a reset signal to clear the error and thus prevent past incidents from occurring.

The filament current ramp circuit is there to slowly build up the voltage in the Filament, otherwise a large amount of voltage in a short period of time may damage it.

3 Procedure

The three main aspects of building the interface box are soldering, assembling, and testing. Soldering connects the electronic components to the circuit boards, assembling ensures everything is secured, and testing confirms the electronic parts are connected properly and work as expected.

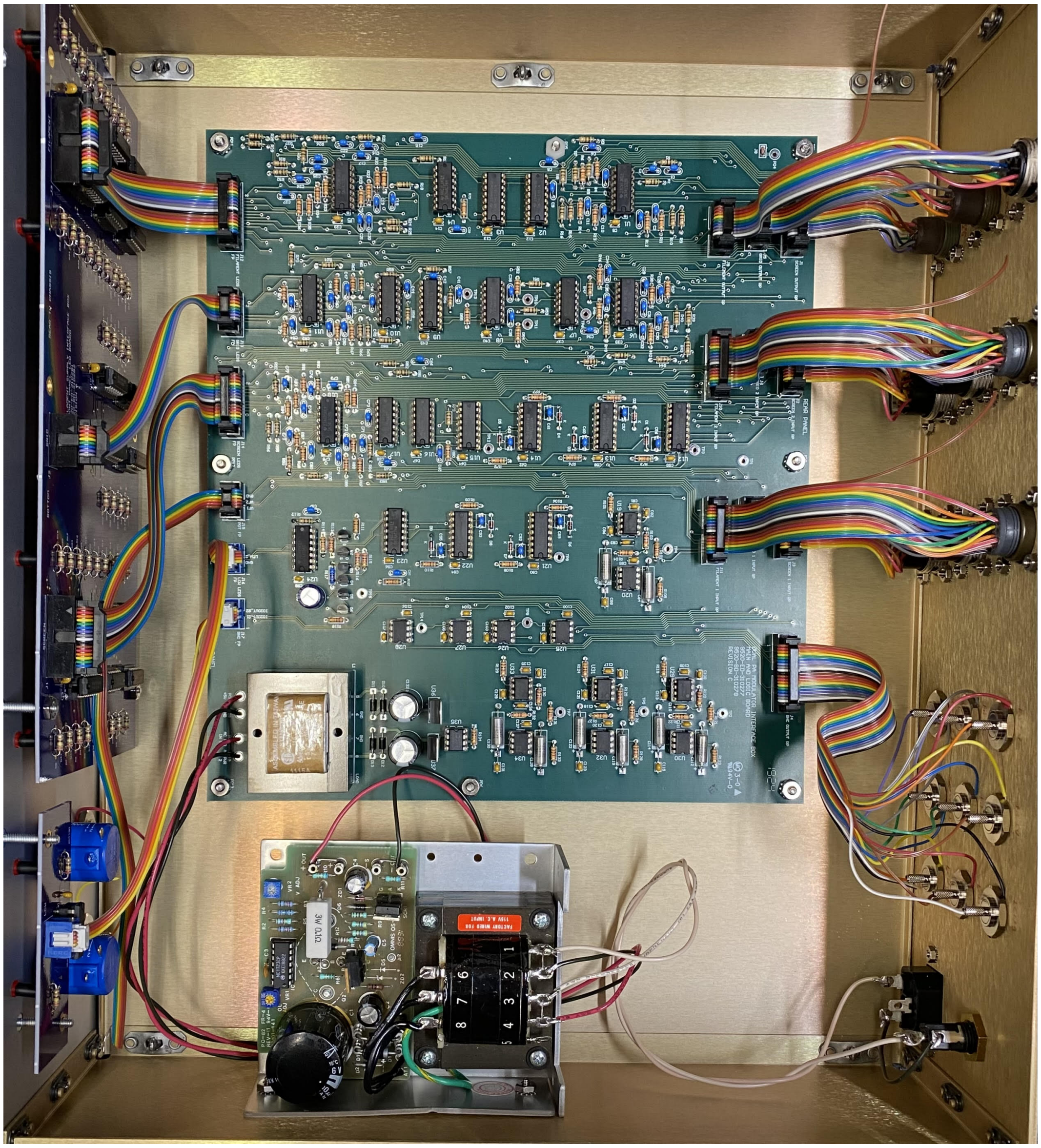

Figure 2: Interior of interface box

3.1 Soldering

The soldering aspects of the project include the LED board, the LCW board, the main circuit board and the wires that connect the main board to various other parts.

Both the LED board and the LCW board are made up of chips, resistors, capacitors, connectors, and LEDs. Given that they have the same components, soldering the LCW board is similar to the LED board but in a significantly smaller scale of quantities soldered. Aside from making sure that chip holders and chips are mounted in the correct orientation, another important aspect that needs to be carefully done is soldering the LED lights, especially in the LED board which has forty-four LEDs. The front panel that contains these LEDs has specific measurements for where they will be placed and if some of the LEDs are slightly bent, it makes the process of securing the LED board to the front panel exceedingly difficult.

Although the main circuit board does not have LED lights, the numerous components that it does contain makes completing the main board the most time-consuming process of building the interface box. It contains resistors, capacitors, diodes, chips, ribbon cables, regulators, transistors, and a power supply. A key component to building the main circuit board is orientation as it is vital for many of the circuit aspects. It is also particularly important to keep track of the steps that have been completed within the main board because it is easy to miss adding a small part but tough to catch the missing part once you think you have finished.

Wires are soldered once the bottom, front and back, and side panels are assembled, and their respective components have been added. The soldered wires connect the main board to the 5V power supply and the power supply to the 120V input plug. Since the wires are enclosed by the surrounding panels and their components, the soldering iron and solder must be carefully moved to not solder any of the other items. The smoke from the solder is also very prevalent at this stage because the panels get in the way of the fan that usually blows the smoke away.

3.2 Assembly

The front panel features the LED board, LCW board, POT's, and BNC shells, which only requires screws and k-nuts, or washers to be installed. As for the back panel, it is made up of multipin connectors, BNC shells, a 120V plug and fuse. The bottom and one of the side panels contain the main board and the 5V power supply, which are drilled prior to securing the components.

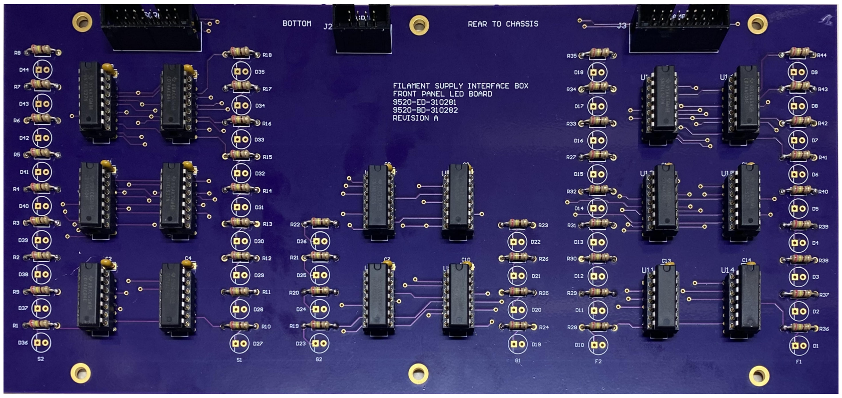

Figure 3: LED board

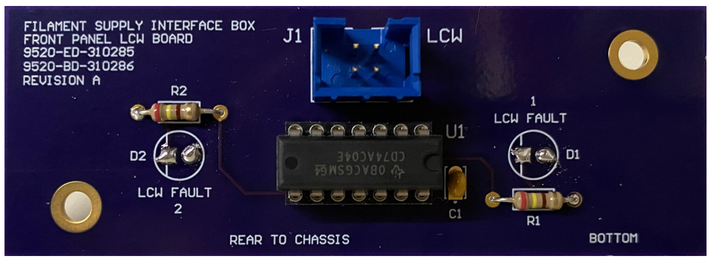

Figure 4: LCW board

The multipin connectors themselves are only secured with screws and k-nuts, but the pins have their own process before they are fully assembled to the back panel. Ribbon cables are cut to their appropriate sizes and the ends are stripped to reveal the wiring inside. Initially, one problem when wire-stripping the ribbon cables was that some of the actual wire could get cut off along with the insulating jacket. This was resolved by being more careful with how the wire strippers pulled the wire jackets off. Pins are then crimped to the wire and inserted into the multipin connector's respective socket. While inserting them, there must be a barrier between your hand and the tool used to push the pins to avoid hand injury.

The positions are traced with a marker within the inside of the bottom and side panel before drilling the mounting holes for the main board and power supply. A center punch is used to make a dent in the middle, then drilled with a smaller bit before drilling with a bit of the appropriate size.

One of the biggest challenges came down to securing the top and bottom panels with the two side panels. This is because the top and bottom panels came with pre-assembled screws that would only need to be turned once before they are secured by the side panels. However, a recurring issue was that the screw would not turn at all, no matter with how much force you tried turning them. We later found that the part in the side panels that was supposed to secure the screws were slightly lifted, so pressure was applied in the middle using a screwdriver and hammer without damaging the surrounding areas where the screws get locked in.

3.3 Testing

Once the boxes are fully assembled, they require thorough testing to ensure that all the components are working properly before installing them into the Main Injector modulators.

Boolean Logic is checked to make sure we receive the expected output whenever two signals are sent to the interface box. A signal generator and an oscilloscope are used to ensure the ON/OFF circuit in the Filament and Screen supply and the Reset circuit in the Filament supply work properly.

For example, one common test is checking to see if there is an alarm, registered as a high output, if either of the inputs are in a fault condition, which is also registered as a high output. This condition should be apparent by looking at the front panel LED's as well as checking the output voltage level from that part of the circuit. Other tests maybe be different depending on which circuit we are focusing on. For instance, a test for the Grid power supply checks the PSReady and LCW latch circuits. If both inputs are high, the output will also be registered as high, and if one input is low, the outputs will be low, and it will remain low unless a pulse is sent from the GridReset.

The signal generator with a squared function is used to send a precise 5V signal to the interface box. For both the Filament and Screen power supplies, a Low-High signal sends a pulse to the OFF outputs. In the Filament power supply, a High-Low signal sends a pulse to the Reset outputs and then to the ON inputs. On the other hand, a High-Low signal sends a pulse straight to the ON inputs for the Screen power supply. There is no reset signal in the Screen power supply because if they are tripped off, the modulator may need to go back through the filament and grid timing in sequence, and a person needs to be present at the station to turn the high voltage back on before the screens can be turned back on as well.

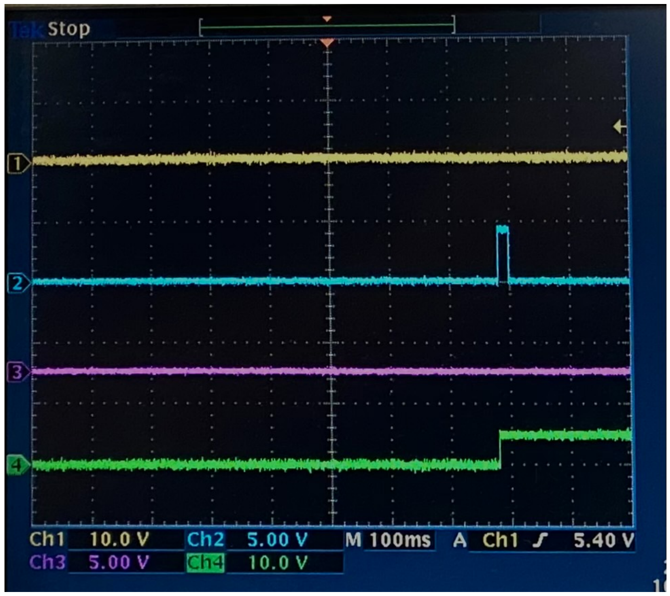

Figure 5: Oscilloscope reading for Screen's OFF circuit

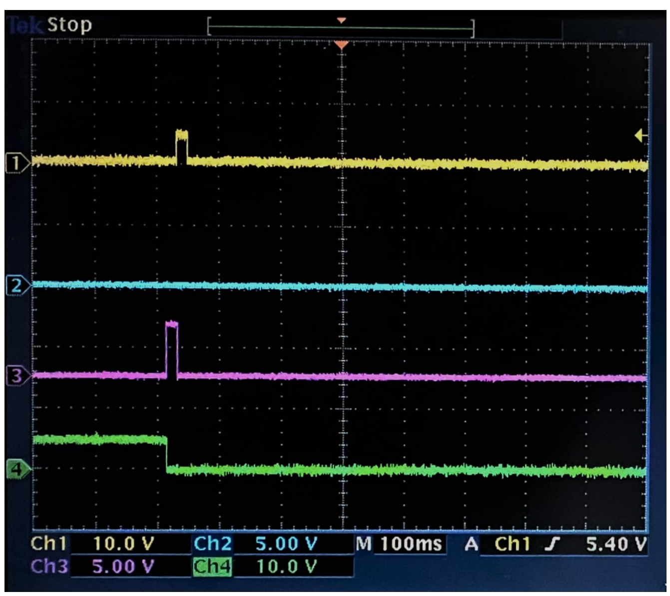

Figure 6: Oscilloscope reading for Filament's ON and RESET circuit

4 Conclusion

The interface box will allow stations in the Main Injector to be upgraded to dual PA seamlessly. Previous designs were modified to counteract recurring problems along the way, but upon the completion of an interface box without any errors in May of 2024, the design was set to be mass-produced. Seven have been successfully made this summer enabling the next few years' worth of station upgrades to be completed. While the main focus of PIP-II is to power the beam to South Dakota for DUNE, the project will also enable Fermilab's research program to reach breakthroughs in scientific discoveries.

This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists (WDTS) under the Community College Internship (CCI)

References

PIP-II. Proton Improvement Plan-II (n.d). *https://pip2.fnal.gov*

RF Systems for Accelerators. RF Cavities and Components for Accelerators (2010). *https://uspas.fnal.gov/materials/10MIT/Lecture17.pdf*