FERMILAB-PUB-24-0400-STUDENT

Remote Power Distribution Prototyping For Bergoz ACCT

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Abstract

The objective of this project focuses on the design and construction of remote power distribution to the Bergoz ACCT amplifier module. Responsibilities included designing a prototype amplifier placeholder using SketchUp, 3D printing it using PrusaSlicer, and mounting the placeholder inside a junction box with 35 mm DIN rail. Wiring was run through a penetration in a wall inside the accelerator building to the Tevatron to keep all electronics outside the radioactive enclosure. A Power over Ethernet switch was set up for remote power distribution to the amplifier. This project ensures that the amplifier module can be effectively integrated and managed within Fermilab's infrastructure once it is procured.

1 Introduction

Particle physics research at Fermilab often involves working with sensitive electronic modules. Fermilab's Proton Improvement Plan-II is no exception, as it aims to upgrade the existing accelerator infrastructure to support future experiments. An essential part of this upgrade is the Bergoz ACCT electronics module, also referred to as an amplifier, which is used at Fermilab for the PIP-II BCM systems to provide accurate, real-time measurements of the AC components of the beam current.

However, there are scheduled power outages on site, which can temporarily result in a power surge and force electronics such as the amplifier to operate outside their range, damaging them. For PIP-II, the BCM system architecture needs the capability to remotely monitor and control power to the ACCT amplifiers.

Fermilab has not yet procured the amplifier, so prototype development involving designing and constructing a placeholder as well as simulating its fitment inside its enclosure is necessary. A placeholder can be designed using CAD software, and a junction box can be modified to function as an enclosure for the amplifier. Both the power source and the amplifier should be placed outside the tunnel. Instead of locally plugging into a socket, it is possible to use power over ethernet and shut off power to the amplifier remotely. This is easier to maintain and reduces risk of anything breaking. The ethernet cable will run from a switch into a PoE splitter, into a DC/DC converter inside the amplifier's enclosure, which will supply power. The overarching goal of this project is to ensure that when the time comes, the electronics module can be effectively integrated and managed within Fermilab's infrastructure.

2 Progress

2.1 Amplifier Placeholder

2.1.1 Placeholder Dimensioning

Because Fermilab had not yet procured the amplifier, it was imperative that a placeholder be designed in preparation for the arrival of the real module. An ideal place to start was to measure the dimensions of the amplifier using the schematic provided by Bergoz online. Since Fermilab already had procured the junction box, which was going to be functioning as the enclosure for the amplifier, accurately measuring the dimensions of the module made it possible to determine whether or not it fit inside the enclosure, as well as a setup for ideal fitment.

First, the schematic had to be printed out in a 1:1 ratio. A printer with this capability was necessary. Then, to measure the dimensions of the module, it was ideal to use a tape measure or a ruler, since the schematic is two dimensional. BNC connectors were attached to the placeholder, so it was also necessary to determine the dimensions of the connectors so that holes of the correct size could be hollowed out into the sides of the placeholder. Once these measurements were taken, it was then possible to start designing a placeholder in CAD.

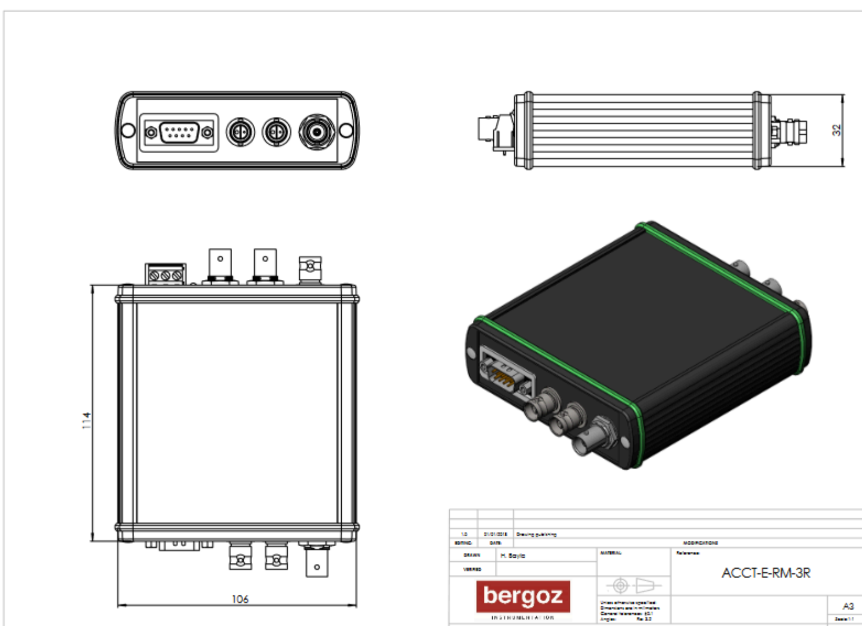


Figure 1. Schematic showing the dimensions of the ACCT-E-RM-3R courtesy of Bergoz

2.1.2 CAD Design

Utilizing the Sketchup application, the measurements of the amplifier's dimensions were used to design the first iteration of a placeholder. This placeholder was designed to determine the maximum amount of space that the amplifier itself would occupy inside its enclosure. Hence, the connectors were left in a rectangular form, so that only the width and length of the connectors were accounted for. This allows for some leeway once the actual amplifier is fitted inside the enclosure, should more room be necessary.

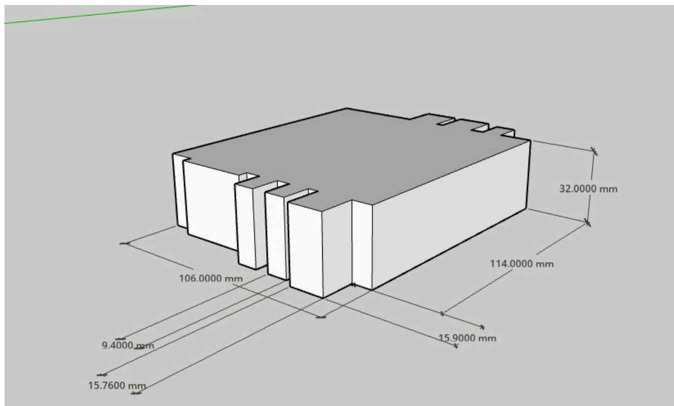


Figure 2. First iteration of amplifier placeholder in Sketchup

The second iteration of the amplifier was designed to attach BNC connectors to the placeholder. This time, the diameter of the connectors (6.35mm) was used and hollow holes were punched into the design. The top was left open so that the connectors could be attached and secured using nuts. The thickness of the walls all around was increased to 3.125mm, which added stability.

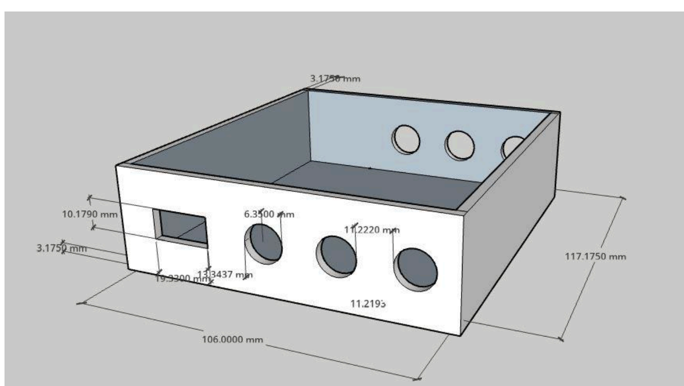


Figure 3. Second iteration of amplifier placeholder in Sketchup

2.1.3 3D Printing

The PrusaSlicer software was used to make the two Sketchup designs compatible with the 3D printer onsite. Jessie PLA was the filament used to print, and supports were used to aid with printing the cutouts for the BNC connectors, since the printer would effectively be printing onto empty space otherwise. Afterwards, the files were uploaded into PrusaConnect, and a Prusa i3 MK3S+ 3D printer was used to print both iterations of the placeholder. Before printing each design, the printing bed was cleaned with ethanol. The printer was supervised for the first 15 minutes in both instances to ensure that the first layer printed without issues. The total duration of printing each placeholder was roughly six hours.

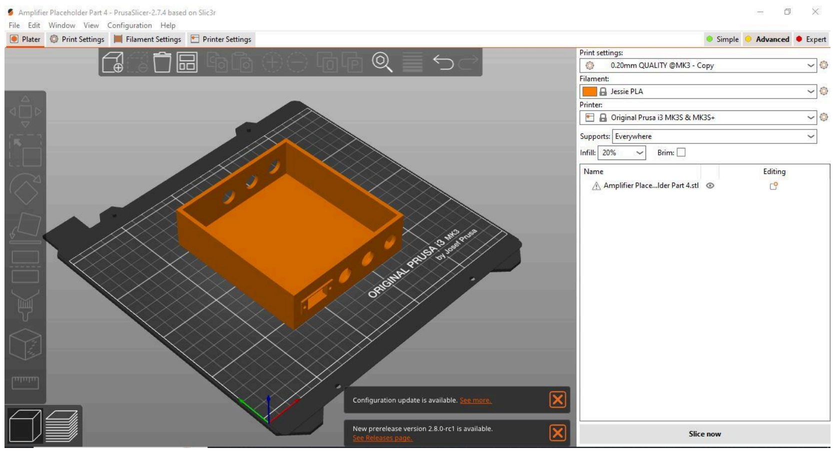


Figure 4. Second iteration of amplifier placeholder in PrusaSlicer

Once the second iteration of the placeholder was done printing, the printer bed was detached and flexed by hand to remove the placeholder. The supports were then removed by hand so that BNC connectors could be attached and secured with nuts. BNC connectors were attached so that the wires could be accounted for in regards to overall fitment inside the enclosure.

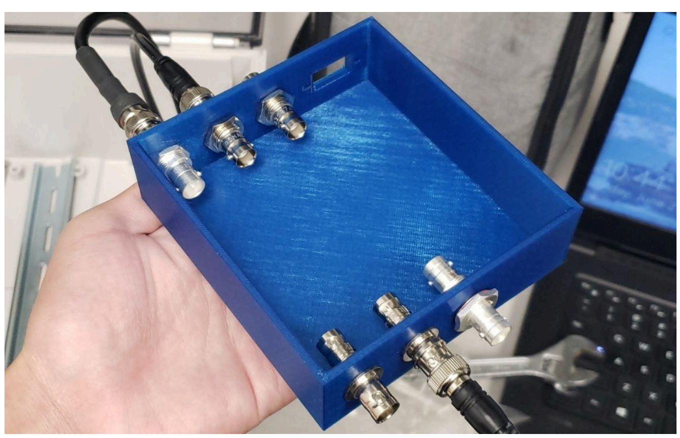


Figure 5. 3D printed amplifier placeholder, second iteration

2.2 Enclosure Layout

The enclosure used to house the amplifier had dimensions of 308.36 x 299.97 x 160.02 mm. Seven punch outs were made into the bottom panel of the enclosure; six for the BNC connectors, and one for the RJ45 connector that was necessary for power over ethernet. Dimensioning and measurements were done using a 1:1 paper printed copy of the bottom panel of the enclosure produced in Sketchup. This paper copy served as an overlay for the bottom panel during the punch out process. All seven connections were going to be running out of the bottom panel of the enclosure. The electronics inside the enclosure consist of a DC/DC converter, a power over ethernet splitter, the amplifier placeholder, and two terminal blocks, should they be needed. All electronics were mounted onto and secured in place by two 35 mm DIN rails. According to the manual, the amplifier module is compatible with 35 mm DIN rail out of the box. However, it was necessary to modify the placeholder so that a DIN rail mount could be fastened to the bottom of it.

Figure 6. Electronics mounted inside the enclosure (Note: Not all wires attached, hole punch outs not yet made at this point.)

2.3 Power Over Ethernet

2.3.1 Hardware Installation

The power over ethernet switch that was going to be used to distribute power had to be mounted inside a test rack. To accomplish this, some hardware was required. This consisted of a shelf, a spirit level, measuring tape, and screws. First, the measuring tape was used to determine a height that the shelf would sit at inside the rack. The specific height chosen did not matter too much, as long as some room was left beneath the shelf for installation of future equipment. Next, the left side of the shelf was held in place with two screws partially threaded into square brackets with rails underneath them. These brackets allowed for height adjustment of the shelf inside the test rack. This process was repeated for the right side of the shelf, and a flat platform was wedged in between the two sides. A spirit level was placed on top of the platform, in order to make sure that the two sides of the shelf were sitting at even levels. To ensure that the shelf was leveled correctly, the bubble in the center tank of the spirit level had to be between the two black lines. After the shelf was leveled, the screws were fully tightened with a screwdriver.

Figure 7. Hardware and equipment used inside the test rack

Figure 8. Spirit level used to ensure correct leveling of shelf

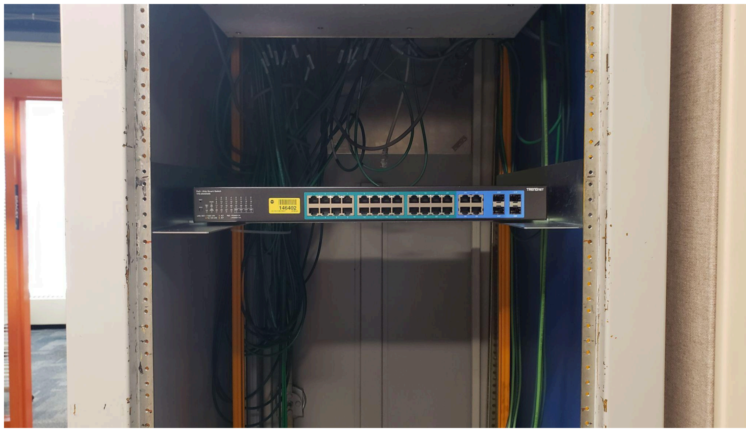
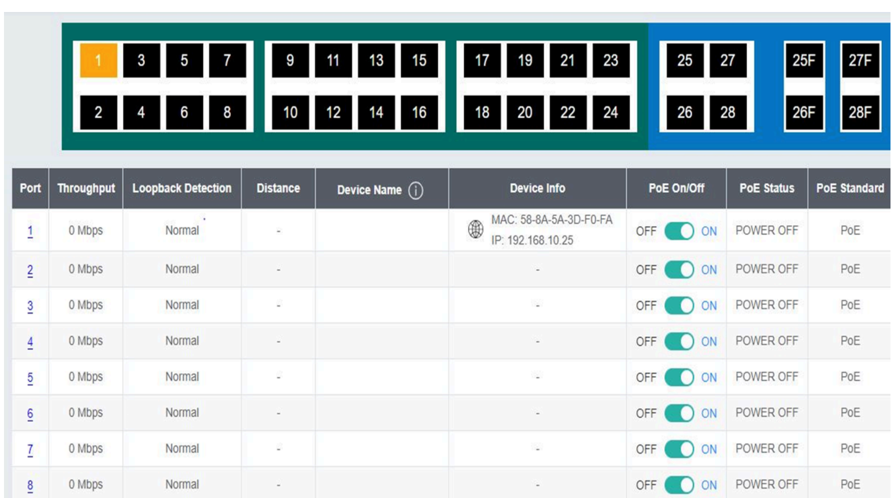


Figure 9. TRENDnet TPE-2840WS Power Over Ethernet Switch sitting on shelf in test rack

2.3.2 PoE Switch Setup

To set up the TRENDnet TPE-2840WS Power Over Ethernet Switch using its built-in web interface, both the device used and the switch itself had to be on the same network. To do this, an ethernet cable was hooked up to both the switch and a laptop. From there, the switch's interface was accessible by inputting its IP address into a web browser. The page would then prompt the user for a username and password, both of which were "admin" as default. The set up interface loaded, and the user would be prompted to input information pertaining to the switch, such as an IP address, subnet mask, and login information to access the switch's main interface going forward. Logging into the switch again then provided access to the switch's main interface, which allowed for configuration and management of the switch. The interface allows the user to enable, disable, and monitor power over ethernet connections as well as query the status of all ports being used. Additionally, the switch can be configured through the interface so that it can be accessed and controlled through other secure methods, such as through SSH.



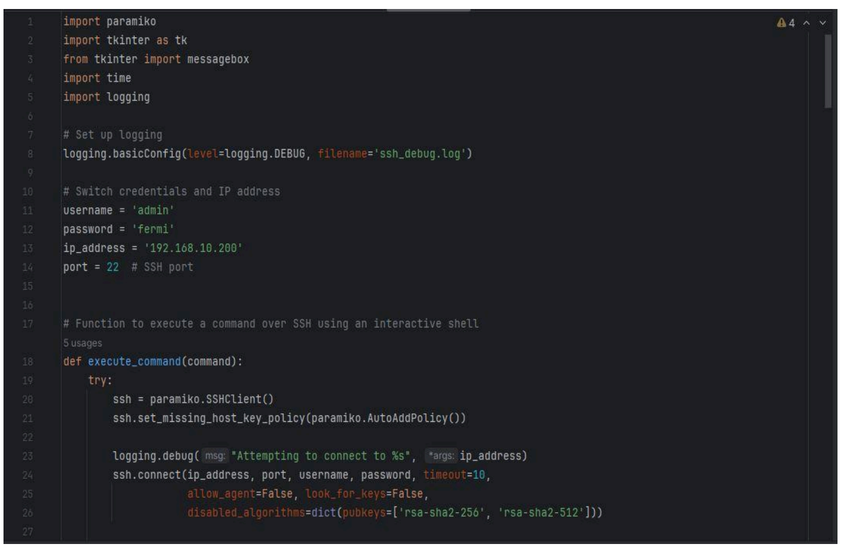
Port	Throughput	Loopback Detection	Distance	Device Name	Device Info	PoE On/Off	PoE Status	PoE Standard
1	0 Mbps	Normal	-		MAC: 58-8A-5A-3D-F0-FA IP: 192.168.10.25	OFF ON	POWER OFF	PoE
2	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
3	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
4	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
5	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
6	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
7	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE
8	0 Mbps	Normal	-		-	OFF ON	POWER OFF	PoE

Figure 10. Power over ethernet management page accessible through built-in interface

2.3.3 Python Program

An attempt was made to write a python-based script and design a gui to remotely communicate with the switch via SSH instead of relying on the switch's web interface. The paramiko library was used for SSH, and the tkinter library was used for the gui. The switch's login information was implemented into the program so that the user would not have to manually enter it in. To execute the program, Ubuntu was downloaded onto a Windows-based laptop. Then, Python 3 was installed on Ubuntu by running a few command lines. The directory was changed so that Ubuntu could open and execute the program.

Once the program was executed, the user was supposed to be able to input a port number and click a button if they desired to enable or disable power over ethernet for that specific port. Additionally, it was supposed to be possible to query the status of the port by clicking on a third button. It was assumed that the switch supported the same functions through SSH that are available through its web-based interface. So, placeholders were initially implemented into the script for the SSH commands, and emphasis was placed on ensuring that SSH and the gui functioned properly. However, once both were properly working, it was discovered that no such commands existed to enable or disable power over ethernet, nor to query the status of any ports through SSH. This information was later confirmed by the switch's vendor through customer support. As a result, the switch's built in web-based interface was used instead.



```python
import paramiko
import tkinter as tk
from tkinter import messagebox
import time
import logging

# Set up logging
logging.basicConfig(level=logging.DEBUG, filename='ssh_debug.log')

# Switch credentials and IP address
username = 'admin'
password = 'fermi'
ip_address = '192.168.10.200'
port = 22  # SSH port


# Function to execute a command over SSH using an interactive shell
5 usages
def execute_command(command):
    try:
        ssh = paramiko.SSHClient()
        ssh.set_missing_host_key_policy(paramiko.AutoAddPolicy())

        logging.debug( msg: "Attempting to connect to %s",  *args: ip_address)
        ssh.connect(ip_address, port, username, password, timeout=10,
                    allow_agent=False, look_for_keys=False,
                    disabled_algorithms=dict(pubkeys=['rsa-sha2-256', 'rsa-sha2-512']))

```

Figure 11. First portion of code written in PyCharm

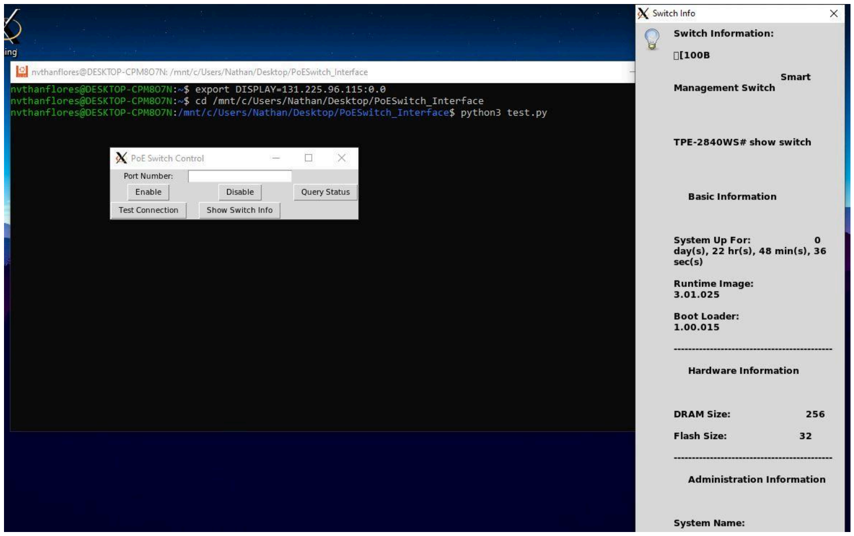


Figure 12. Execution of program in Ubuntu (Note: “show switch info” is a working SSH function, used to test program functionality)

2.3.4 Load Test

Because the amplifier had not yet been procured, it was necessary to verify that the PoE switch could distribute power by using a 5 ohm resistor as a load. Prior to this, the pin numbers had to be identified in order to determine which actually supplied power and which were dedicated to ethernet data. According to the datasheet for the switch, pins 1 and 2 were for PoE+, and pins 3 and 6 were for PoE-. Once this was determined, a 5 ohm resistor was connected to the power output of a PoE splitter, which was connected to the switch with an ethernet cable. The voltage was measured across the resistor terminals using the multimeter, and the current was measured by placing the multimeter in series with the 5 ohm resistor. Additionally, the voltage output was able to be monitored through the switch’s web interface from a lab computer. This set up proved that power distribution was fully functional.

Figure 13. 5 ohm aluminum clad resistor used in performing load test

Figure 14. Digital multimeter used to measure voltage and current during load test

3 Conclusion and Future Work

The enclosure is now fully prepared to securely house the real amplifier module. Fermilab will be able to provide as well as cut off power to the amplifier once it is procured. The PoE switch is able to be remotely accessed with a ControlsVPN account through the Fermi Controls network using the switch's built in interface. With the amplifier powered and remotely managed through PoE, the amplifier can be more easily maintained and the risk of any catastrophic component failure is reduced. In the future, the real amplifier module will replace the placeholder inside the enclosure and the project will be integrated into PIP-II.

4 Acknowledgements

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5 References

(2019a) *3-range AC current Transformer*. Available at: https://gmw.com/wp-content/uploads/2019/05/ACCT-E-RM-3R-manual.pdf (Accessed: 23 July 2024).

(2019b) *ACCT datasheet_v7.0*. Available at: https://www.bergoz.com/wp-content/uploads/ACCT-datasheet_v7.0.pdf (Accessed: 23 July 2024).

(2019c) *ACCT-E-RM-3R Dimensions*. Available at: https://gmw.com/wp-content/uploads/2019/05/ACCT-E-RM-3R-dimensions.pdf (Accessed: 23 July 2024).

(2024) *PTR-28490-C bud industries | boxes, enclosures, racks*. Available at: https://www.digikey.com/en/products/detail/bud-industries/PTR-28490-C/17765878 (Accessed: 23 July 2024).

28-port gigabit web smart poe+ switch (2024) *TRENDnet*. Available at: https://www.trendnet.com/support/support-detail.asp?prod=275_TPE-2840WS (Accessed: 23 July 2024).