EM Characterization of Radar Absorbing Materials

RCS and NRL Arch Project Report

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Executive Summary / Concept of Operations

Radar Cross Section is a measure of the effective area of an object under the view of a radar system. It is dependent on a variety of factors, including the geometry of the object under test and the material the object is composed of. Tangitek has developed a material that can be placed on the exterior of various objects that would decrease their effective RCS and reflectivity without making alterations to their surface area and geometry, thereby reducing their visibility on radar systems.

Our project is the development of an automated measurement system for determining the monostatic (receiver and transmitter at the same location) RCS and reflectivity of various microwave absorbing materials provided to us by TangiTek. The measurements would have been performed within the confines of Portland State University's RF chamber and would have been composed of an RCS measurement system, a motor-driven turntable, and an NRL Arch setup for reflectivity measurements. *Unfortunately, due to complications from the Covid pandemic, hardware was abandoned in lieu of simulations and documentation.*

To assist future measurements and testing, we shifted some of our team's focus into development of testing automation. We utilized two main methods of automating the process: Keysight's VEE software and a Software Development Kit developed by the motor manufacturer Robotis. VEE is an object-oriented programming kit that easily interfaces with instrumentation - in particular for this project, Agilent's Vector Network Analyzer - and allows the user to create a test plan. The Robotis SDK is a C++ suite containing interfacing language with the Dynamixel motor used by the turntable. Automated rotation plans were written for the motor to simplify the RCS testing process, which requires measurements for a full 360° rotation of the Material Under Test (MUT). These two processes were combined in the final product to allow the VEE software to control both instrumentation measurements and motor rotation.

The RCS measurements are performed a VNA and a transmitting horn antenna mounted on a stand that transmits continuous signals in the 2-40 GHz range, a turntable to rotate the object under test on the opposite side of the room from the antenna, a receiving horn antenna to catch the backscattered signals and feed back into the VNA, and a computer connected both to the VNA and turntable to automate the measurement process. *Since access to the anechoic chamber was prohibited due to the pandemic, initial tests of the measurement system were performed in Kent Thomson's(Tangitek) living room.*

The NRL Arch setup is composed of a portable arch, a pair of opposing horn antennas, a mechanism by which the horn antennas can move about the arch, a turntable to rotate the object under test, and a VNA operating in the 2-40 GHz range. *Due to the pandemic, testing of the NRL Arch setup was not performed, but a test plan was developed.*

Requirements

In the initial project proposal, the project was divided into two major sections: RCS measurements and NRL Arch measurements. The focus was on the performance of the measurements themselves, with software and a detailed automation procedure as a stretch goal; however, with the advent of the covid-19 pandemic, we were inhibited from doing any laboratory work and could work only on those tasks that could be completed remotely.

The goal of the project was no longer to perform the NRL Arch and RCS measurements as originally prescribed, but instead to explicate the theory behind the measurements, begin the process of automating the measurements with the turntable, provide a means of processing experimental data into RCS measurements, and comparing ad hoc RCS measurement results with simulation.

The deliverables, after the big changes, are as follows:

- RCS HFSS simulation results of 0.125 and 0.25 m diameter copper spheres in 2-40 GHz range
- Clear instructions on how to perform RCS simulations of spheres and other objects in HFSS
- Produce VEE code that will collect RCS measurements of a sphere or any object
- Clear instructions on how to use VEE and change frequencies and s parameters collected
- Protocol for collecting RCS measurements in anechoic chamber with VNA
- MATLAB Script to compare simulated and measured RCS values
- Fully operating turntable with instructions for use
- NRL arch that:
    - Is physically sturdy and reliable
    - Has antennas that can be easily repositioned to knowable desired angle of transmission/reflection
    - Can be transported into and out of PSU's RF chamber with relative simplicity
    - Is physically sturdy/strong and reliable
    - Is composed of materials offering minimal interference with measurements
    - Thorough documentation on the NRL Arch set up
- Reflection Loss simulations
    - Adopt EMPro for waveguide simulations, or
    - Begin HFSS experiments for waveguide simulations
- Documentation describing how to set up and use RCS measurement system
- Program to automate measurement system integrating turntable rotation and VNA frequency sweeps(or suggestions on how to move forward)
- Professional and thorough GitHub database

- A comprehensive instruction manual detailing how to perform RCS simulations and measurements, and how to operate the turntable.

By following strict documentation guidelines and presenting a cohesive project database, the goal of this project is to leave following research/capstones with a solid foundation from which to continue. Next year's capstone must be able to pick up our ending point and be able to quickly set-up and take measurements in order to provide the deliverables as outlined previously in this document.

Project Planning

From the project's onset, we decided to use SCRUM methodology in conjunction with Trello to stay organized. We met in person every Friday to discuss our progress in detail and go over technical issues. Every other Friday we had a Sprint Retrospective, Review, and Planning meeting. We also had standups on Tuesdays in person and on Sundays via Google Hangouts. We communicated constantly on our Slack channel and we used Github for version control for all code and project documentation. Kirk performed as SCRUM master, but all team decisions were made democratically.

After the covid interruptions, all in-person meetings were cancelled and our team stayed organized and managed ourselves with bi-weekly meetings with both Dr. Brano and Tangitek team members. Much of the work shifted towards being individually oriented rather than a collaborative effort as well. This shift was difficult at first and created some difficulties in determining who was responsible for what tasks, but these difficulties got sorted out quickly and we were all able to be productive again, though no formal organization was rearticulated. Our use of Trello waned as well, and in the end we just stopped using it altogether.

Technical Summary

Our overall system can be easily delineated into four main groups: RCS Measurement/Simulation, VNA Automation, Turntable Automation, and NRL Arch. The VNA and Turntable automation architecture can be adapted for either the NRL Arch or RCS measurement system.

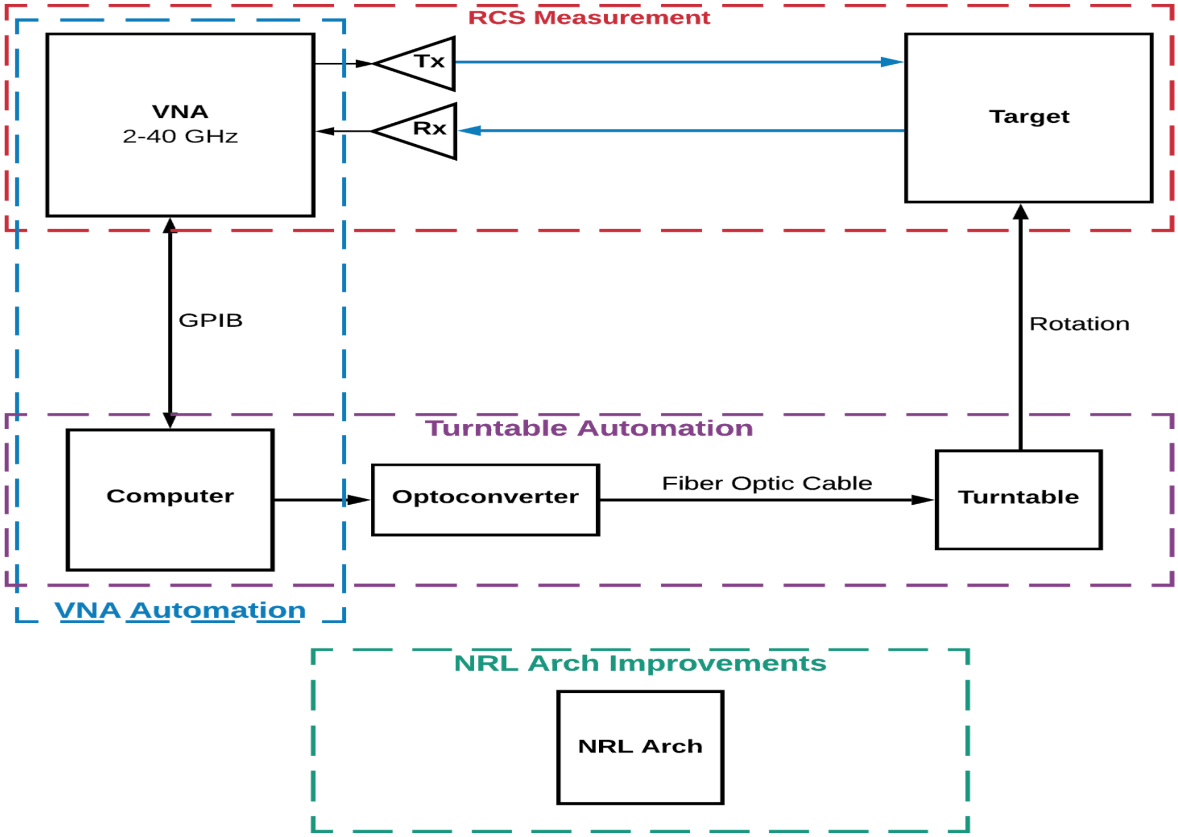

Figure 1: Overall System Architecture

Figure 1 shows how the individual systems work together when performing RCS measurements. The following subsections describe how each component within this greater system operates.

RCS Measurement System

The RCS measurement system will have a VNA capable of 2-40 GHz frequency transmission injecting signals into a transmission horn antenna corresponding to the frequency band being tested. The signal will then propagate towards the target, which will be a recorded distance away from the transmission antenna. The reflected signal will then travel to an identical receiving horn antenna, which will feed back into the VNA as S21 measurements.

These S21 measurements will be processed by a MATLAB script and converted into RCS results. Another MATLAB script will then compare these experimental RCS results to the results of HFSS simulations and theoretical predictions.

Since the anechoic chamber was unavailable, the initial RCS measurements were performed in Kent Thompson’s living room, as shown in Figure 2.

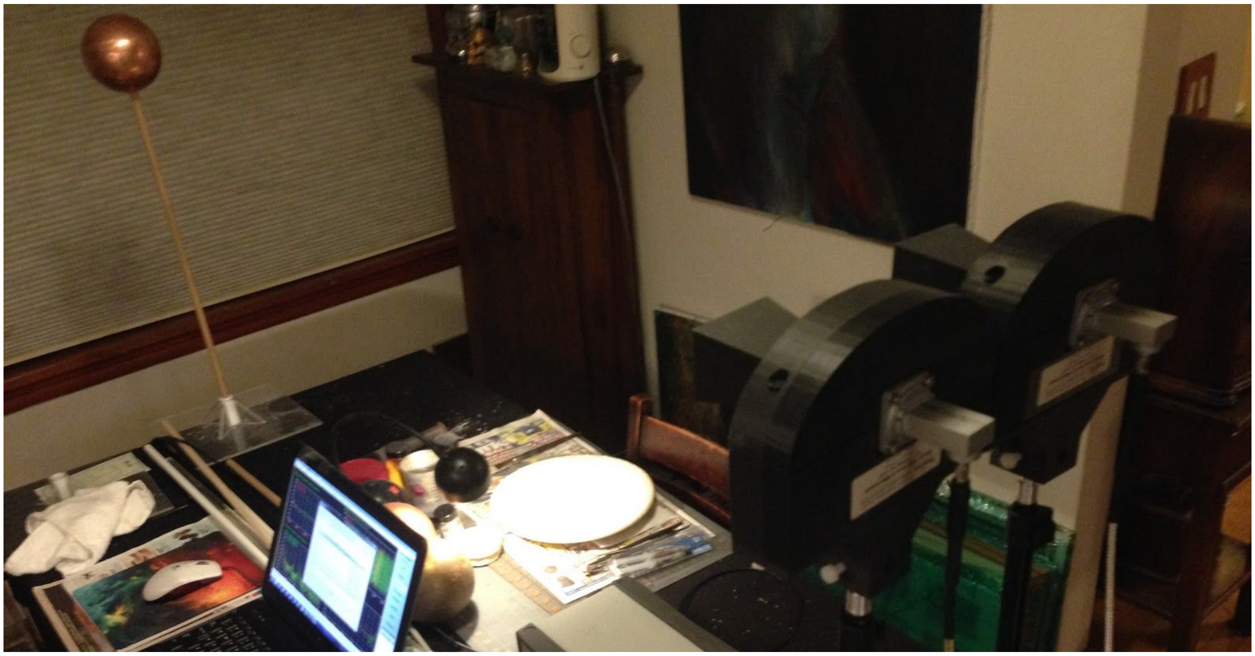

Figure 2: RCS Measurements

After processing in MATLAB, the initial results of this experiment in the 8-12 GHz range yielded a normalized RCS of around 50, while both theory and simulation predicted a normalized RCS of around 1. This was likely due to the reflections, near field effects, and other artifacts introduced by this nonideal environment.

A second experiment was performed with time-domain gating used on the VNA to isolate the reflections coming from the target, which yielded a normalized RCS of around 1. These results, along with a comparison to simulation and a calculation of error, are shown in Figure 3.

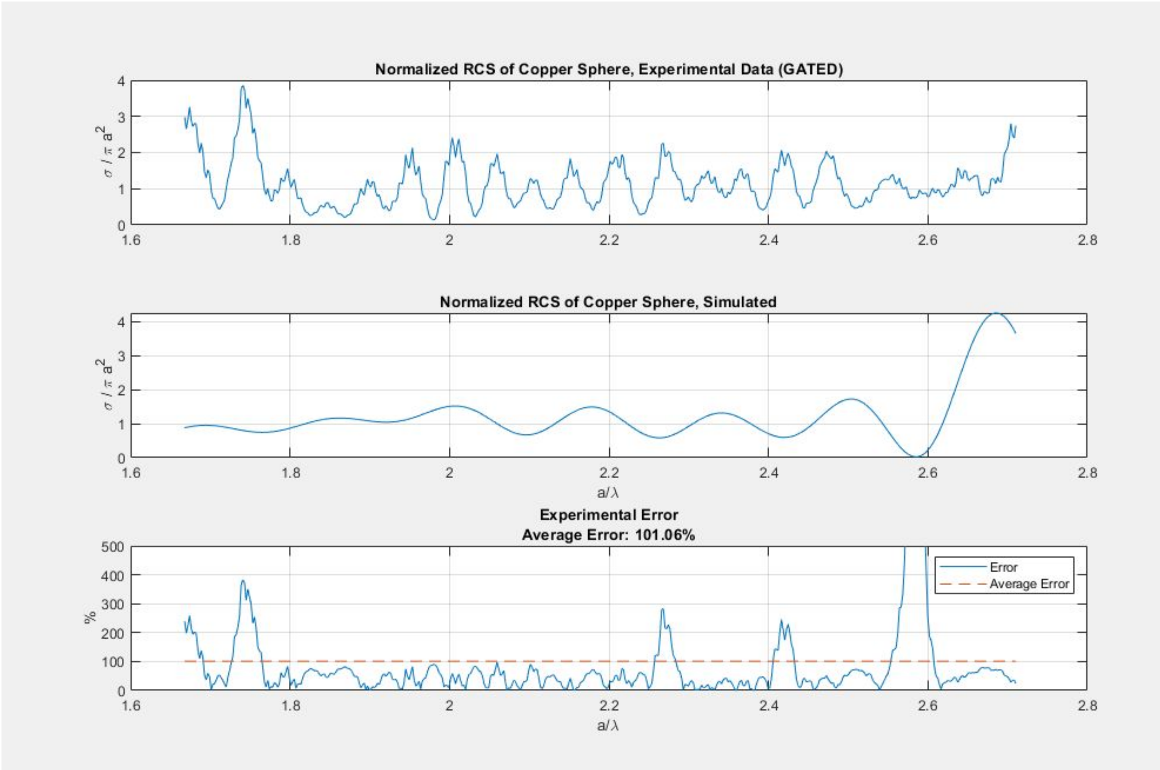

Figure 3: Experimental and simulated RCS results

The significant improvements in accuracy of the results as a result of gating seem to indicate that the method of measurement and data processing is valid, but that measurements must be performed in a more ideal environment for accurate results.

Details of the theory behind RCS measurement, all associated MATLAB scripts, and simulation procedures are available in the team Github repository.

Reflectivity Measurement System

The Naval Research Laboratory (NRL) Arch from last year's project was wobbling and not in good alignment. This instability and misalignment was due to excessive slack in the wood and in the joints. The Arch was improved upon by embracing the joints with aluminum plates and screws at the weak joints. After these small modifications, the antenna alignment on the Arch is much more accurate than before, and the whole arch is now stable and easy to transport. The Arch is in good shape for future material iterations by Tangitek to retest reflection measurements.

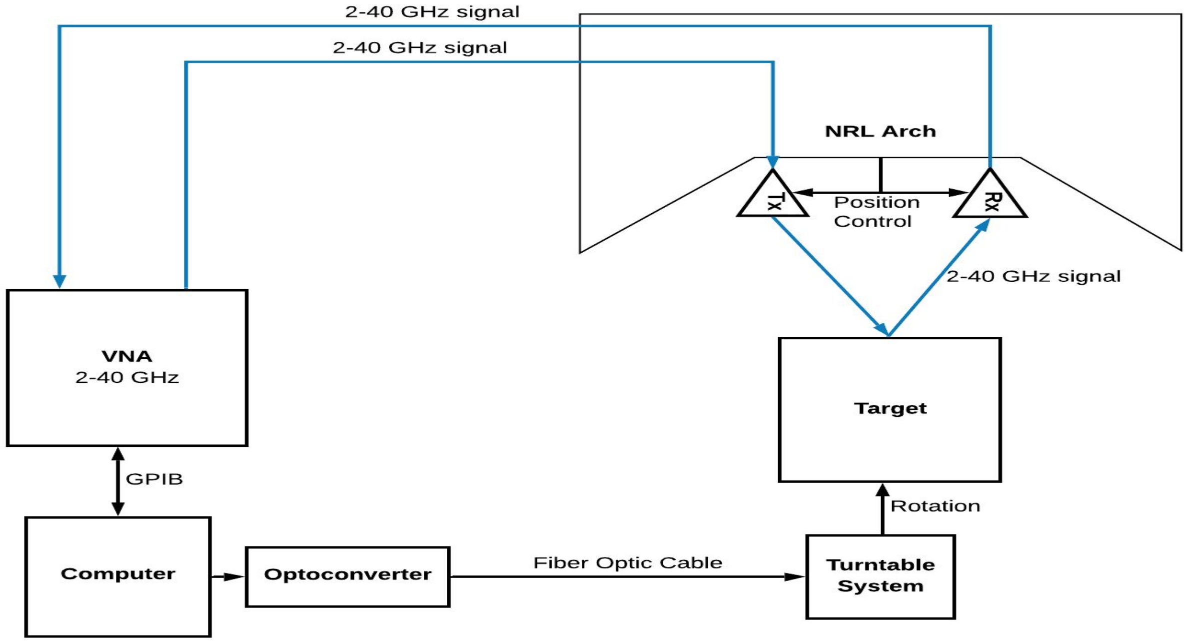

Figure 4: NRL Arch Measurement System Block Diagram

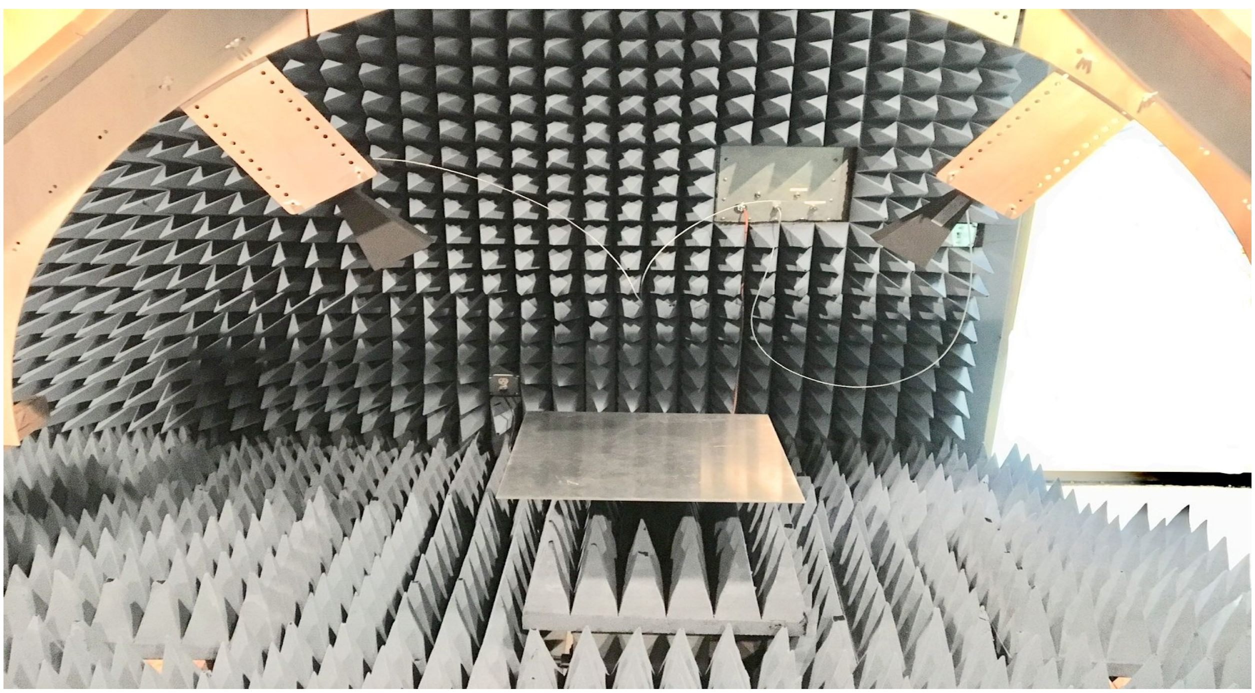

Figure 5: Similar Experimental Setup for NRL Arch System

VNA Automation

In order to make the VNA system more automated when collecting data we have decided to use VEE which is an object based software similar to simulink. When creating the program we began by identifying the steps needed when setting up the VNA manually, so we wrote down the steps necessary in sequential order. Before we could insert any type of block we had to ensure that the VNA was connected properly to be used in VEE. In order to be able to do this a small program was designed to be able to retrieve the VNA identification number. Figure 6 shows an example of what the program would look like.

Once the VNA was talking with VEE it was time to create the direct IO blocks that would control the VNA. In order to make the program easy to read and modify, the direct IO blocks were separated into different categories such as channel/trace setup, frequency setup, calibration setup, and data read/saving. In the first block, we defined Channel 1 to be used and have turned on Trace 1. We also defined the S parameter to be measured and in the case of RCS measurements we are interested in S21. The next block controlled the frequency in which it specifies when to start/stop and for the frequency sweep to be linear. The third block defined the calibration kit to be used and the types of calibration measurements to be taken. In the final direct IO block we are able to read/write the S parameter data as well as the frequency. We also added a mini VNA screen so that we can see what is displayed on the VNA in the VEE program. Another feature that we added was two alpha-numeric displays that show the data of S21 with its corresponding frequency. We defined it to have 201 measuring points, but we can add more if finer data is required.

The ultimate results of our efforts are displayed in Figure 7, where we can see the completed program ready to take measurements once the “Measure Data” button is selected. The measurement system works and matches up nicely with the actual VNA readings, except that the data is not able to be saved in a SNP file. Due to license and remote connection issues a picture was not saved of the system in action showing the mini VNA screen and alpha-numeric displays with data. Once the connection issues are resolved, the save feature could be implemented.

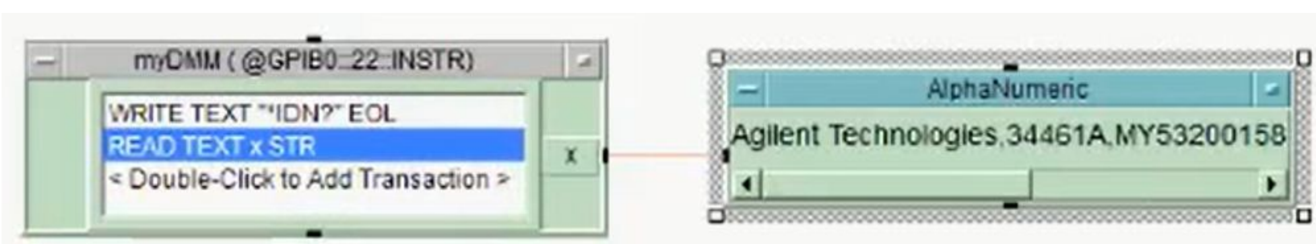

Figure 6: Program to retrieve instrument identification number

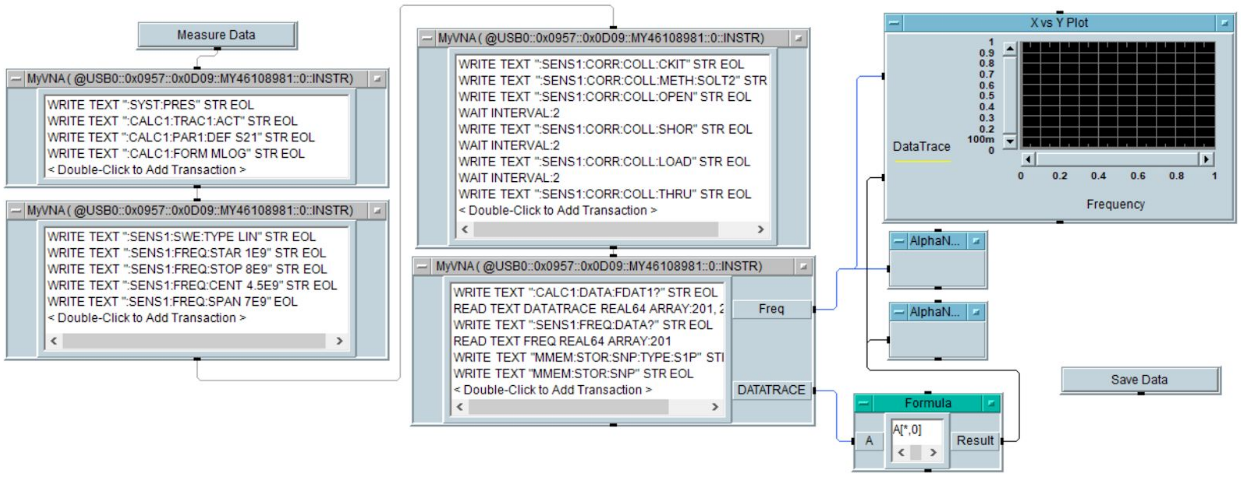

Figure 7: Completed VNA program for data collection

Raspberry Pi/SDK/Motor

Due to the nature of EMag parameter measurements, great care must be taken to suppress any electrical noise in the anechoic chamber. Thusly, the turntable and motor must be controlled separately from the main user PC. The motor is placed in a non-conductive box inside the chamber with a Raspberry Pi, which will control the motor. The Pi is fed commands from the user by SSH through a fiber optic cable (to reduce electrical noise). The Pi is connected to the Dynamixel motor using U2D2, a proprietary converter from Robotis that converts USB to serial communication. Previous installments of this capstone have utilized a Pi to Arduino setup and constructed a manual serial communication through the GPIO pins. The U2D2 takes out problems associated with manual hardware serial communication, allowing fluid two-way communication between computer and motor.

The motor can be controlled through several methods. A software called Dynamixel Wizard allows for GUI-based interfacing with the motor, and is indeed very user-friendly and easy to use for manual control. The scope of this project is a bit more ambitious, however, and as such we utilized Robotis' SDK to communicate with the motor. The SDK is an open-sourced repo that utilizes its own API for motor control and comes complete with several example programs which were more than enough to modify for our testing purposes.

The motor used is the Dynamixel MX-64T, a step up from the prior AX-12A model used in last year's capstone. The motor was upgraded to ensure no issues with loading from the heavier turntable, and because the MX-64T has better overall resolution at 0.088°. The motor is powered by a PSU within the non-conductive container and a 12V adapter provided by Tangitek. Currently the adapter-to-motor connection is just some jumper wire and a splitter; this could easily be improved in future iterations.

Finally the VEE and motor were conjoined into one large automation apparatus. The Raspberry Pi opens a listening port through which the VEE software can use its sockets protocol to send integer commands informing the Pi to run the command code to rotate the motor at the desired speed and to a specified position goal. Figure 8 shows a block diagram of the final system architecture.

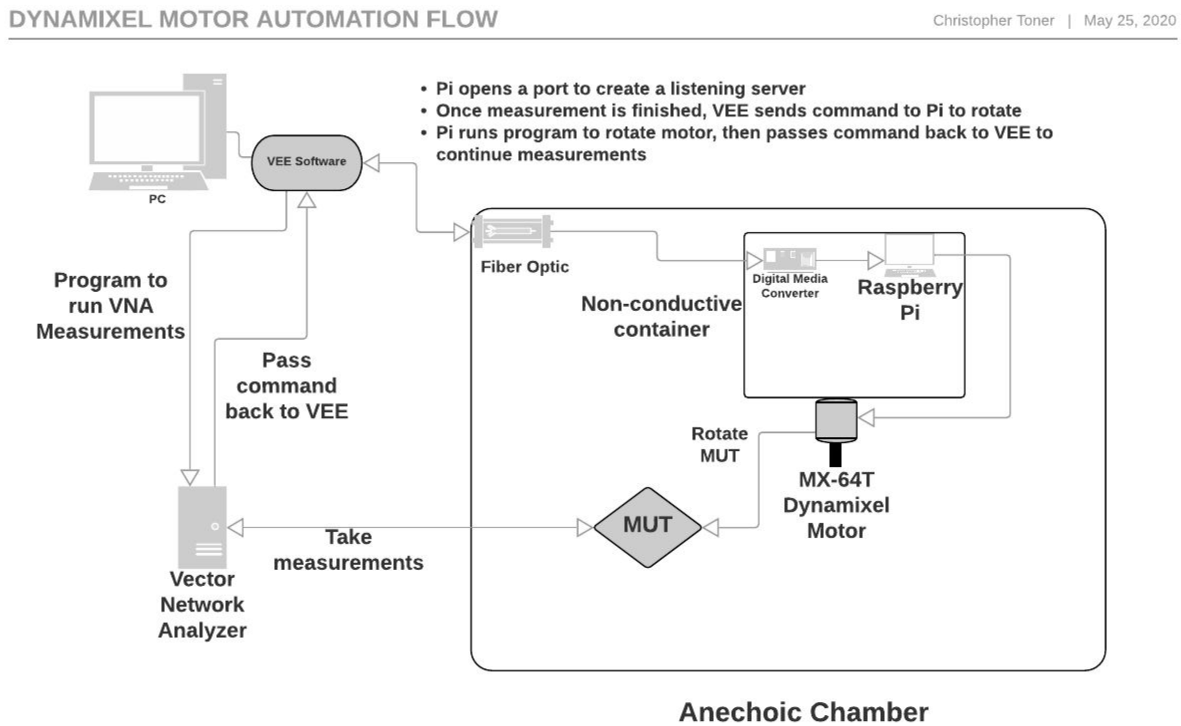

Figure 8:

System Integration

Unfortunately, due to both physical and temporal constraints, we were not able to integrate the separate RCS Measurement, VNA Automation, and Turntable Automation into a single, automated measurement system as we had initially planned. Accordingly, testing of the entire integrated system was also not possible. Future teams may wish to build upon our work by integrating all of these disparate parts into one comprehensive system.

Conclusion

This project initially had a set of requirements that were primarily focused on the delivery of RCS measurements performed in the anechoic chamber of PSU with a comparison to simulations. When the pandemic hit, the requirements were changed to prioritize automation of the RCS measurement system with an emphasis on documenting our work in each portion of the project. Project management style changed as well, going from a structured SCRUM style of management to an ad hoc style of management with regular online meetings.
RCS measurements were performed in a nonideal environment, processed with written MATLAB scripts, and the results agreed reasonably well with theory and simulation. VNA automation and automation of the Dynamixel motor used to drive the turntable was also successfully implemented in VEE. The NRL Arch also had improvements made to its structure to provide greater stability and precision for measurements.

These systems were not tested together, but theoretically, since we have successfully automated both the VNA and the turntable, we would need only to use this automated process while performing either RCS or NRL Arch measurements, and we will then have a complete, automated measurement system.

Detailed instructions on the VNA, turntable, RCS measurement procedure, RCS simulation in HFSS, and NRL Arch structural improvements have been compiled into a single instruction manual, along with all related code, and is available on the team Github repository at https://github.com/KirkJungles/TangitekCapstone2020.

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