Elmore Family School of Electrical and Computer Engineering

ARES GROUP

Automated Radio Evaluation Suite

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Team Member	Role
José Abraham Bolaños Vargas (bolanosv@purdue.edu)	Undergraduate Researcher
Alex David Santiago Vargas (adsv@purdue.edu)	Mentor
Dimitrios Peroulis (dperouli@purdue.edu)	Principal Investigator

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1. Abstract

The telecommunications industry faces surging energy demands driven by the deployment of next-generation communication systems like 5G, which demand stringent performance specifications for power amplifiers (PAs) and antennas. Current testing methods for these components are often labor-intensive, time-consuming, and reliant on expensive commercial software. This project presents the Automated Radio Evaluation Suite (ARES), an open-source MATLAB-based application designed to simplify and automate the testing process. ARES interfaces seamlessly with existing laboratory equipment using standard communication protocols, offering a comprehensive and user-friendly interface. ARES provides comprehensive testing capabilities for both PAs and antennas. It measures essential PA parameters, including gain, output power, and efficiency, while also facilitating antenna parameters such as gain, return loss, and radiation pattern characterization. The toolbox supports a variety of measurement techniques, ensuring robust characterization of RF components. Furthermore, its integration with standard communication interfaces enables efficient data acquisition and visualization, producing detailed and quick performance insights for PA and antenna systems. Preliminary testing with two PhD researchers, specializing in antenna and power amplifier characterization respectively, utilized the tool to gather comprehensive datasets within minutes—a process that traditionally demands several hours of meticulous manual adjustments. By offering a cost-effective and customizable alternative to commercial software, ARES promotes collaboration and reproducibility within the research community. Future developments will focus on expanding functionality, enhancing measurement efficiency, and delivering detailed user tutorials to further support the adoption of this tool.

2. Introduction

With the advent of 5G communication systems, the need to shift away from the current paradigm is increasing. This shift is driven by the new era of wireless communication standards and the telecommunications industry demands. Power amplifiers (PAs) and antennas are critical components of these modern communication systems, playing vital roles in signal transmission and reception. With these emerging technologies, highly efficient and linear PAs as well as high-performance antennas, must meet these new industry standards. Our project aims to address these evolving needs by developing an automated toolbox for parametric testing of power amplifiers and antenna gain measurements, providing more efficient and accurate characterization methods.

Characterizing PAs involves measuring various key parameters such as saturation power, compression points, gain, drain efficiency (DE), power-added efficiency (PAE), adjacent channel power ratio (ACPR) and error vector magnitude (EVM). These metrics quantify the performance of the PA, and its contribution to the transmitter system. Similarly, antenna characterization includes measuring gain, efficiency, and radiation patterns. These parameters quantify how well the antenna can transmit and receive electromagnetic waves and how much of the input power is turned into output power. Traditional testing methods for both PAs and antennas are time-consuming and prone to human error.

Recognizing these challenges, Cai et al. developed an automated testing system using LabVIEW to enhance the efficiency of power amplifier data collection [1]. We used their work as an initial model for the automated testing toolbox presented in this report. Building on these principles, our project integrates both power amplifier and antenna measurements into a single automated platform. By leveraging MATLAB instead of LabVIEW, this toolbox provides a more versatile programming environment, which improves user interaction and functionality.

Packaged as a MATLAB App with a user-friendly graphical interface, the toolbox allows for intuitive control of testing parameters and visualization of measurement results, offering a more accessible and enhanced user experience compared to the command-line interface typical of LabVIEW applications.

Recent advancements in PA and antenna design have increasingly focused on optimizing efficiency, linearity, and gain across wide bandwidths, fitting into the newer telecommunication standards. Advanced PA architectures such as the Class B Doherty power amplifier (DPA), show an improvement in backoff efficiency, and gain expansion when using a two-tone modulation mechanism [2]. At the 2021 High-Efficiency Power Amplifier (HEPA) student design competition, Lyu, Cao, and Chen's worked on a highly efficient and linear Quasi-Balanced DPA. They developed a novel design methodology using a quadrature coupler-based output network that would consider the AM-AM expansion and AM-PM improvement[3]. Their design achieved a gain of 13 dB at 3.485 GHz, and a PAE of 57.2%. Modulated signals such as LTE and 5G were also assessed and their results were superior, earning them first place in the competition.

Similarly, Chen and Peroulis presented an adaptive GaN PA for octave-bandwidth applications, incorporating a tunable matching network (OMN) using varactors with high breakdown voltages [4]. The PA demonstrated a DE of 64-79% and a PAE of 55-72% at maximum power, with dynamic load modulation providing over a 15% efficiency improvement at 10 dB back-off. Their paper is thorough in its analysis of varactor diodes and the PA's performance, making it a valuable reference for those looking to implement similar technology. The well-documented experimental results and consideration of device parasitics offer a solid foundation for future research and development in this area.

The need for high-performance antennas capable of delivering significant gain at elevated frequency ranges has intensified in recent times. Designing compact antenna solutions with substantial gain is crucial for realizing compact, efficient communication systems. Abdelaziem et al. made notable progress in this area by proposing an innovative antenna architecture that leverages Mu-near-zero (MNZ) meta surface (MS) structures to achieve high gain [5].

MNZ-MS are a class of engineered materials designed to exhibit unique electromagnetic properties. Unlike traditional materials, which are characterized by their inherent physical properties, metamaterials derive their behavior from their structure rather than their composition. This allows them to manipulate electromagnetic waves in ways that natural materials cannot, such as achieving negative permittivity and permeability, which can enhance the performance of devices like antennas. Research is still being done to document how these materials can be used for antenna miniaturization, gain enhancement, and improved isolation in wireless communication systems [6].

Their design, which places an MNZ-MS layer above a patch antenna source, demonstrated a peak gain of 13.13 dBi at 26.3 GHz, representing an impressive gain enhancement of more than 5 dB compared to the patch antenna alone. This significant improvement in gain, combined with the compact form factor, positions the MNZ-MS antenna as a promising solution for realizing high-data-rate 5G communication systems.

In conjunction with these advancements in power amplifier and antenna designs, the development of an automated testing toolbox has become increasingly vital. By building upon the concepts from [1] and incorporating additional functionality, this project aims to provide a comprehensive solution for efficient characterization of power amplifiers and antennas in the context of evolving 5G technologies. Packaged as a MATLAB application, the toolbox streamlines the testing process by automating parametric sweeps and data acquisition, thereby improving efficiency and accuracy compared to traditional manual methods.

The primary goals of this project are to (a) integrate both power amplifier and antenna measurements into a single automated platform, (b) increase the efficiency and accuracy of data collection by automating multiple testing runs, and (c) create a versatile toolbox that can accommodate various PA designs, antenna types, and testing environments. By leveraging MATLAB instead of LabVIEW, this toolbox offers a more versatile programming environment that enhances user interaction and functionality while offering a cost-effective alternative to expensive commercial solutions.

3. Methodology

3.1. VISA Interface

What makes the automation process possible is that each instrument can be connected to the testing computer, enabling data transfer between each device. The main idea behind instrument automation is to connect effectively via a communication protocol to an instrument, then using the Virtual Instrument Standard Architecture (VISA), standard commands for programmable instruments (SCPI) can be sent to control the instrument. VISA is a software protocol created by Keysight and National Instruments for communicating with instruments regardless of their communication protocol (LAN, USB, GPIB, RS-232) [7]. SCPI are built on the foundation of IEEE-488.2 and provide a common language between devices and instruments, making it easier to interface with them. Since SCPI is hardware independent, SCPI strings can be sent over any instrument interface that supports it [8].

To utilize VISA and connect to the instruments four software prerequisites must be installed first. This includes:

1) Keysight IO Libraries
2) Keysight Connection Expert
3) Keysight Command Expert
4) MATLAB with Instrument Control Toolbox

The first software installs the drivers needed by VISA to establish connection to the instruments. The second software is a connection manager for all your instruments, this tool allows you to scan and add instruments once you connect them to your computer. Connection Expert gives you information about the device such as manufacturer, model, and VISA address. The process of building the initial code was to first program each instrument to do their job, e.g., signal generation. This was first done in Command Expert which provides each connected instrument's SCPI sets, which come with documentation making it easier to decide what commands to use and how to use them. The program also features an option to export the SCPI sequence into different programming languages, including MATLAB, Python, and C. After establishing the sequence of strings for each instrument, the resulting code was exported into MATLAB which allowed us to use the sequence dynamically.

One early problem we faced when exporting code was that MATLAB would warn us that the code was not up to date and in the future, it would not be supported. The cause of the problem was that Command Expert was referencing the original VISA interface, meanwhile MATLAB had updated its Instrument Control Toolbox, introducing the new VISAdev interface. This did not set us back, as MathWorks provides documentation to transition code from VISA to VISAdev [9]. The following table includes the major changes that we had to implement for our code to successfully run in MATLAB.

Table 1: Transitioning Code from VISA Interface to VISAdev Interface

VISA Interface	VISAdev Interface	Purpose
visa()	visadev()	Connect the instrument
fprintf()	writeline()	Write to the instrument
fscanf()	readline()	Read from the instrument
query()	writeread()	Write and read at the same time
binblockread()	readbinblock()	Read binblock data
clrdevice()	flush()	Flush data from memory
fclose()	delete() & clear()	Disconnect the instrument

Soon after getting accustomed to the SCPI strings, the process got significantly easier, allowing us to combine each instruments commands together to form complex code capable of setting parameters, running the measurements, extracting, processing, and visualizing the data, and handling each instrument gracefully.

3.2. SCPI Strings

As previously mentioned SCPI strings allow an instrument to be controlled programmatically mirroring the utilities that come with the physical inputs to the instrument (touch screen, buttons). There are two types of SCPI strings,

:KEY and :KEY?

The former is called a command string and is reserved for when we want to write to the instrument and not receive anything back. The latter is called a query string and is reserved for when we want to read data back from the instrument. In this case :KEY represents the name of an instrument's feature such as measuring something, setting parameters, and more. SCPI strings can also take in parameters,

:KEY <parameter>

Complex SCPI strings can be made by combining several features and parameters into one string,

:KEY1:KEY2:KEY3? <parameter1> <parameter2>

All instruments which adhere to the VISA standards share a small set of SCPI strings. These strings can be found in all instruments. These were useful and were employed in the application for distinct reasons discussed in the table below. They have a different form to previous SCPI strings,

*KEY and *KEY?

Table 2: Common SCPI Strings Across Instruments

Command / Query	SCPI String	Purpose	When To Use
Identification Query	*IDN?	Returns a string that uniquely identifies the instrument. Including brand, model, and serial numbers.	After connecting the instrument, one can use the command to verify the instrument.
Reset Command	*RST	Resets most instrument functions to factory-defined conditions.	After connecting the instrument unless working with a preconfigured environment.
Clear Status Command	*CLS	Clears the registers from the status byte.	When measuring sweeps, such that the next set of data is not compromised.
Operation Complete Query	*OPC?	The query returns the ASCII character one when all pending operations have finished.	Especially helpful when debugging the QUERY Interrupted error from the instruments.

Wait Command	*WAI	Prohibits the instrument from executing any new commands until all pending overlapped commands have been completed.	Like *OPC? but this approach is less dynamic.
Data Format Commands	:FORM:BORD: SWAP :FORM:DATA <type>,<bits>	Defines the type and format of data that is returned after a trace measurement. These commands are required to query the data.	Swapped endianness is preferred on most modern computers.

There are three types of data to be chosen. REAL,32 is best for transferring substantial amounts of data. REAL,64 is slower but has more significant digits than REAL,32. For these types use readbinblock(), because they transfer data in block format. The last one is ASCii,0 easiest to implement, but slow, used when you have small amounts of data to transfer.

Table 3: Specific SCPI Strings Across PA Instruments

Instrument	Command / Query	SCPI String
Power Supply	Set voltage, current limit, and supply mode	:APPLY <mode> <voltage> <current>
	Measure voltage	:MEAS:VOLT:DC? <mode>
	Measure current	:MEAS:CURR:DC? <mode>
Signal Generator	Set frequency	:SOUR:FREQ:CW <frequency>
	Set RF power	:SOUR:POW:LEV:IMM:AMPL <power>
Spectrum Analyzer	Set center frequency	:SENS:FREQ:CENT <frequency>

	Set span	:SENS:FREQ:SPAN <span>
	Set sweep points	:SENS:SWE:POIN <points>
	Set reference level	:DISP:WIND:TRAC:Y:SCAL:RLEV <reference>
	Initializes the type of sweep entered by the user. Available types are single, continuous or hold.	:INIT:CONT <type>
	Starts the sweep	:INIT:IMM
	Fetch trace data	:TRAC:DATA? <trace>

Table 4: Specific SCPI Strings Across Antenna Instruments

Instrument	**Command / Query**	**SCPI String**
Vector Network Analyzer	Set start frequency	:SENS<cnum>:FREQ:STAR <frequency>
	Set end frequency	:SENS<cnum>:FREQ:STOP <frequency>
	Set sweep points	:SENS<cnum>:SWE:POIN <points>
	Create a measurement	:CALC<cnum>:PAR:DEF:EXT <mnum>,<mname>
	Display the created measurement	:DISP:WIND<cnum>:TRAC<mnum>:FEED <mnum>
	Start a sweep	:SENS<cnum>:SWE:MODE <mode>
	Select measurement to populate with data	:CALC<cnum>:PAR:SEL <mname>

	Fetch trace data	:CALC<cnum>:DATA? SDATA
	Fetch the frequency data from trace	:SENS:X:VAL?
	Delete all existing measurements	:CALC:PAR:DEL:ALL
EM Center	Get current position	1<slot-letter>:CP?
	Set speed	1<slot-letter>:SPEED <speed>
	Seek angle	1<slot-letter>:SK <angle>
	Stop movement	1<slot-letter>:ST

For the VNA, cnum is the channel number which defaults to one if not specified, mnum is the measurement number, and mname is the name of the measurement. For the EM Center which controls the anechoic chamber, the tower and table are in slot one, however the table is in letter A, and the tower is in letter B.

3.3. Application Structure

The application began as a collection of separate MATLAB files and functions, each responsible for specific tasks such as controlling the instrument, acquiring data, and processing data. Leveraging MATLAB's App Designer framework for creating a graphical user interface (GUI), the initial code was integrated into the framework for a more user-friendly experience. Since the application functions as a class, it is organized in two main structures.

1) Properties: There are two property blocks. The first block oversees all properties that correspond to app components. MATLAB manages this block automatically, and stores all components (buttons, tables, panels). The second block oversees all properties that correspond to global variables. In this block, the instrument objects are initialized, as well as the data parameters. Any variable that is initialized in this block is made global and can be accessed at all moments within the application.
2) Methods: There are four method blocks. The first block includes all helper functions used throughout the application. The second block includes all callbacks that manage component events, these callbacks execute dynamically when the user presses a button in the application. The last two blocks include all methods that relate to app components, MATLAB manages these blocks automatically.

Key functions that manage the data collection and processing include:

1) measureRFOutput.m: Measures RF output power and DC power.
2) measureRFParameters.m: Calculates gain, DE, and PAE.

3) measureSParameters.m: Measures S-parameters, and frequency values.
4) measureAntennaGain.m: Measures antenna gain using the two-antenna method and the antenna comparison method.

These functions are located within the application's workspace, allowing the application to call them even if they are not in the main code. This allows users to interact with a cohesive interface rather than running multiple scripts, but at the same time have access to these files to modify them, as necessary.

3.4. Application Algorithm

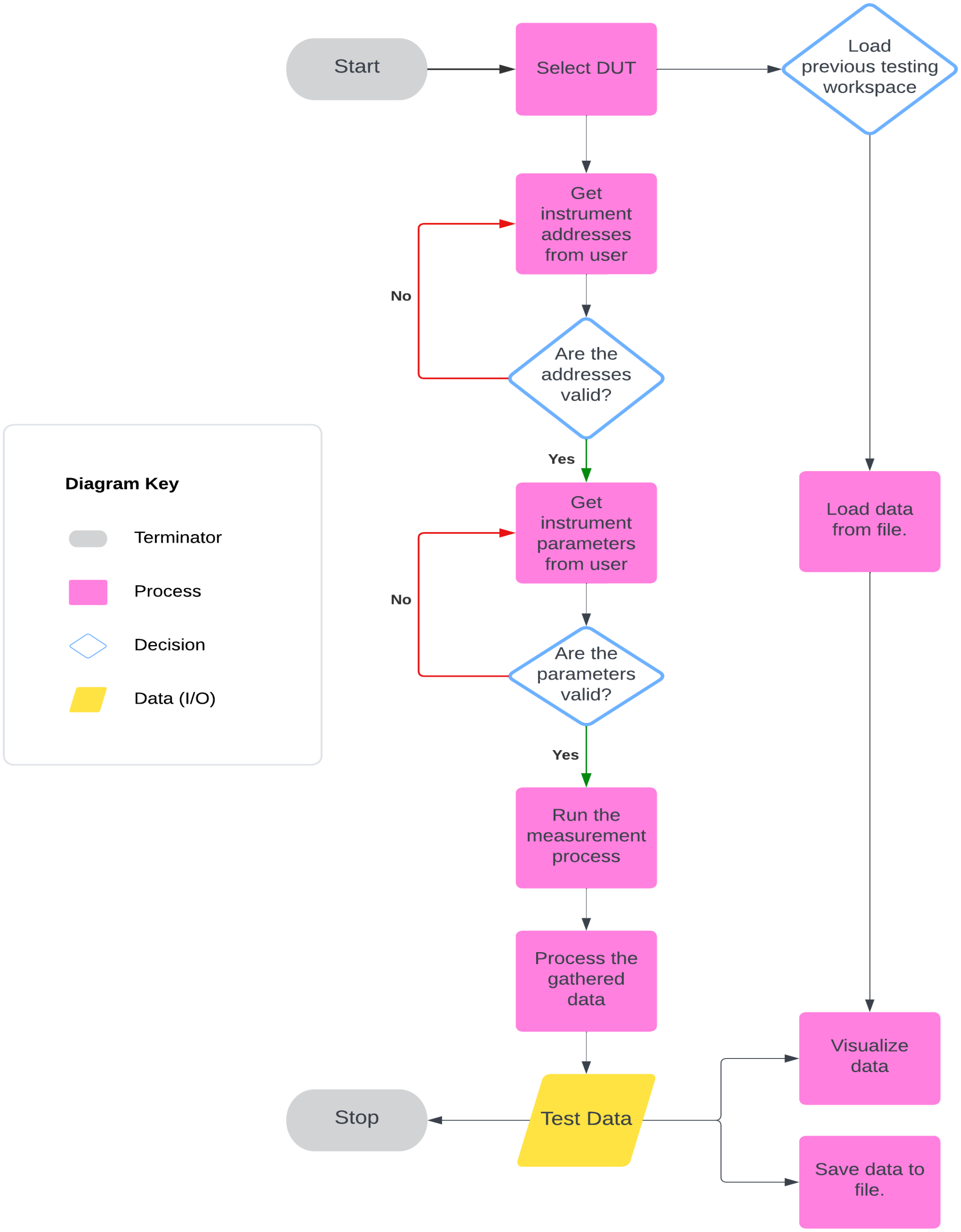

Figure 1: Application Logic Flowchart

3.5. Measurement Setup

The initial phase of this project focused on characterizing power amplifiers using a standardized measurement setup. The goal was to automate the testing process while ensuring accurate and repeatable results for key PA performance metrics including gain, output power, and efficiency.

The application offers two testing methodologies for PAs: single frequency testing and frequency sweep testing. In the former method, the PA is tested at a specific frequency while varying the input power levels. This method generates two key plots: one showing the relationship between RF input power and RF output power (both measured in dBm), which provides insight into the PA's performance and efficiency; and another plot illustrating Gain, Drain Efficiency (DE), and Power Added Efficiency (PAE) as functions of RF output power, allowing users to understand the trade-offs involved in amplifier performance.

In the latter method, the PA is tested across a range of frequencies while varying input power levels. This method produces four primary plots: Gain vs. RF Output Power, which shows how the gain changes with varying output power at each frequency; Peak Gain vs. Frequency, highlighting the peak gain achieved across the tested frequency range; Peak Drain Efficiency and Power Added Efficiency vs. Frequency, detailing how DE and PAE vary with frequency to help identify optimal operating conditions; and Compression Points and Saturation Power vs. Frequency, displaying the -1dB and -3dB compression points and the saturation power at each frequency, indicating the amplifier's linearity and maximum output capabilities.

The initial test setup to measure the Mini Circuits ZVE-3W-83+ PA, used an Agilent E3634A DC supply, a Keysight N9000B CXA signal analyzer, and an Agilent signal generator as test instruments. Between the PA and the analyzer, a 30 dB attenuator was connected to ensure proper handling and safety. Figure 2. shows the testing workbench used during the summer to both build the application and test the PA.

The application provides a comprehensive method for antenna testing using 360° turntable rotation. This method generates four key plots to analyze the antenna's performance. The first plot illustrates the gain versus frequency at a specific angle chosen by the user. The second plot shows the gain versus angle at a particular frequency selected by the user. This allows the user to analyze how gain varies with the angle of radiation, helping to understand the antenna's directivity and radiation efficiency. The third plot depicts the return loss of the antenna, which indicates how much of the waves are reflected, a particularly important metric for evaluating impedance matching networks. Finally, the 2D radiation pattern plot presents the antenna's radiation characteristics in polar coordinates, emphasizing how the antenna radiates energy across different angles and providing a visual representation of the gain distribution.

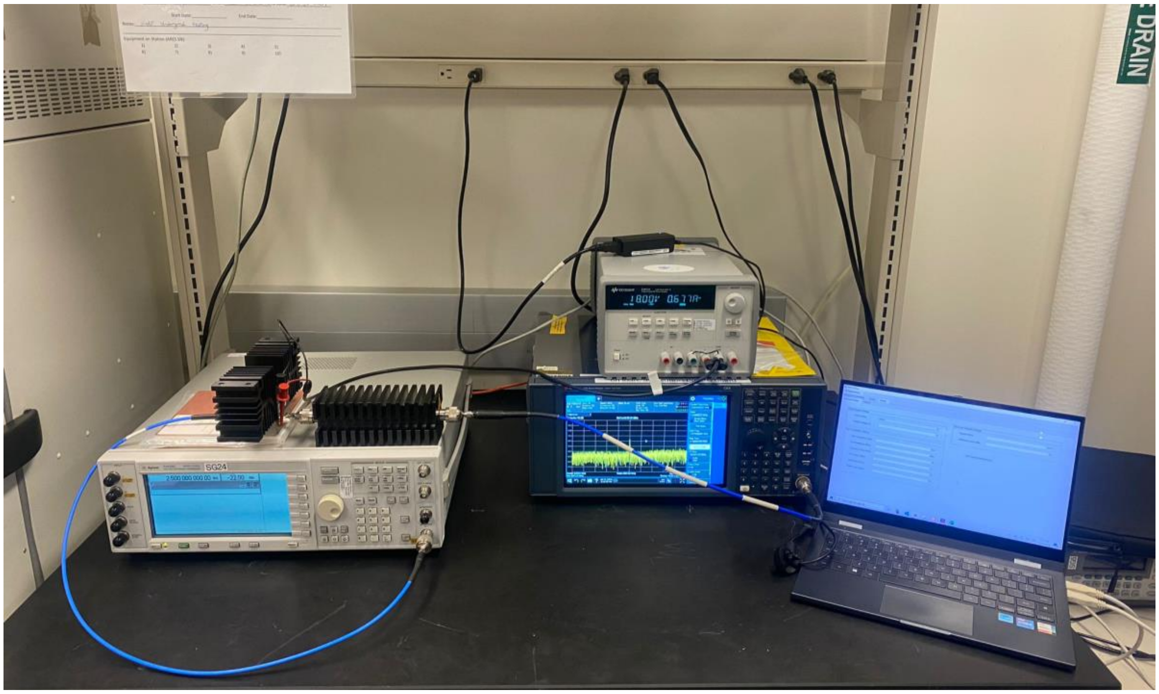

Figure 2: Power Amplifier Test Workbench

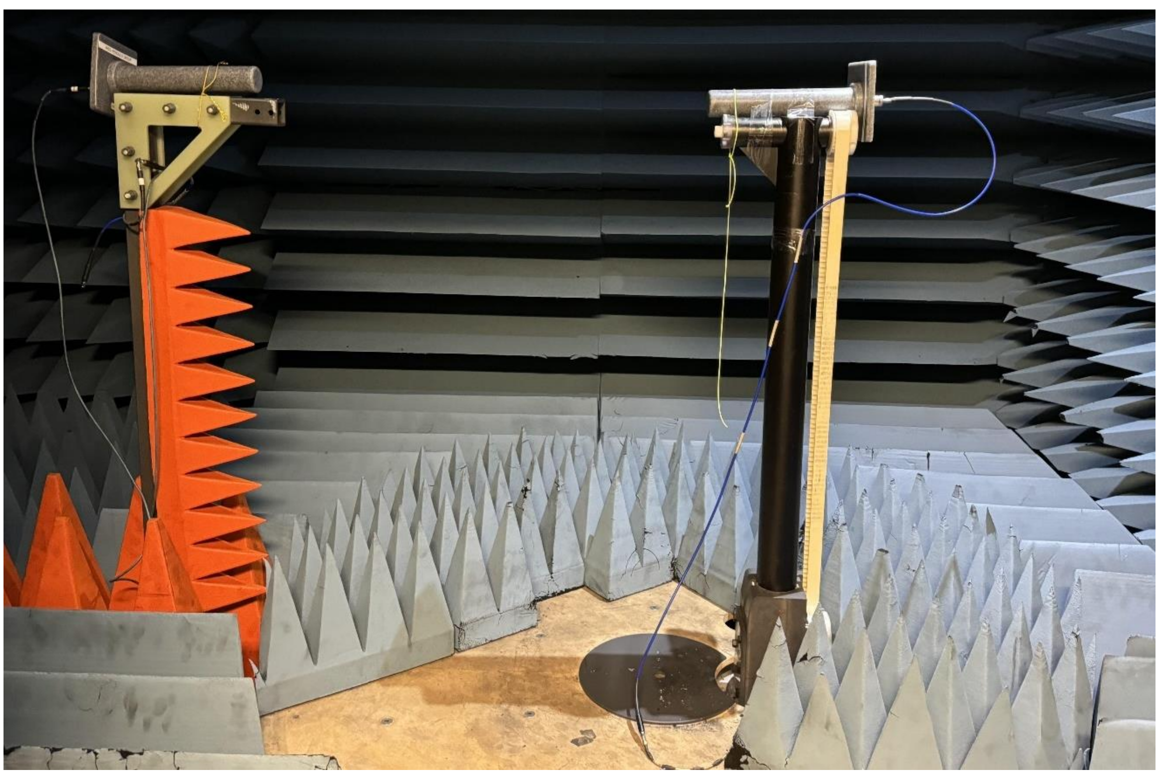

Figure 3: Antenna Test Workbench

During the summer testing process, several observations and challenges arose that affected the quality and reliability of the measurements. On the power amplifier (PA) side, the DC power supply could not provide the necessary input power levels to properly bias the PA at higher RF input powers. As a result, while it was still possible to collect measurements, key metrics such as gain, and efficiency were significantly impacted. Much of the data collected under these conditions was corrupted, rendering it unsuitable for accurate analysis. This issue highlighted the importance of using a power supply capable of supporting the full operational range of the PA.

For the antenna testing, a few limitations also became apparent. One major issue was the inability to control the linear slider, as it operates independently of the EMCenter and the team was unable to establish a connection to it. This meant that the antenna spacing had to remain fixed, preventing the ability to perform measurements at varying distances. Additionally, the antennas had to be manually secured to the positioners using ties or tape, as shown in Figure 3. This method proved unreliable, as the antennas frequently shifted during testing or failed to align properly. Such misalignments negatively impacted measurement accuracy and repeatability, making the results less than ideal. These challenges underscored the need for improved equipment integration and mounting solutions to ensure consistent and reliable testing.

In the fall, several improvements were made to enhance the antenna testing process. Alex designed, and 3D printed custom mounts, ensuring that antennas could be securely positioned for more effective testing. The antenna measurement setup transitioned to the comparison antenna method, which enabled more accurate gain measurements by comparing the test antenna to a known reference antenna. The reference antenna, chosen for its known gain values and suitable operating frequency range, was the lab's horn antenna, as shown in Figure 4. The test antennas, including the primary one designed by fellow researcher Duhan Eroğlu for his PhD research, varied in design but were crucial to further improve the application, especially when it came to user experience. Additionally, this semester we successfully established how to connect to and control the linear slider programmatically. This advancement allowed us to fully utilize the slider's range and control the spacing between antennas, which is essential for precise antenna gain calculations. By integrating the spacing of the turntable, the physical dimensions of the antennas, and the movement of the slider, we ensured that the most accurate spacing values were used. This setup enabled us to perform both far-field and near-field antenna measurements, depending on the user's needs.

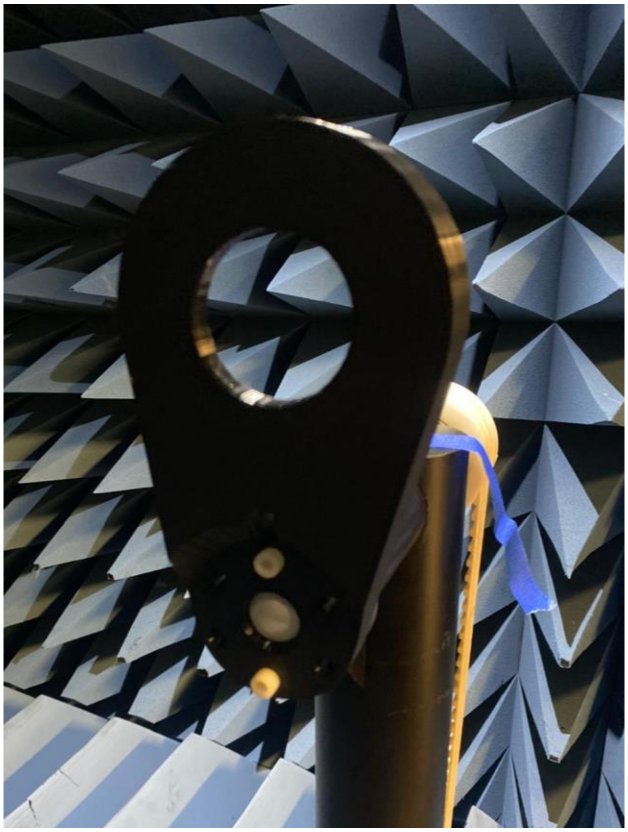
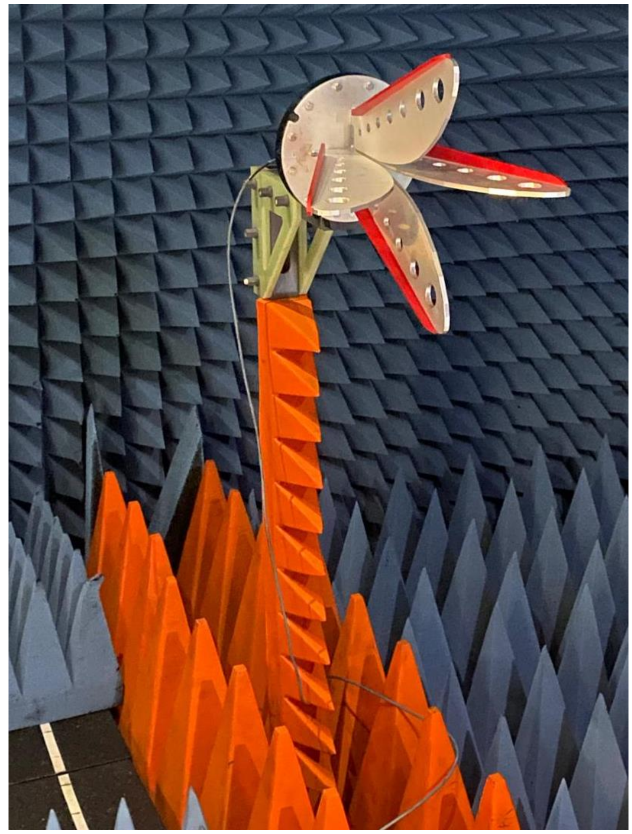

Figure 4: 3D Printed Antenna Mount and Reference Horn Antenna

The two-antenna method used in the summer provided an efficient starting point for building the application. However, as the app approached its readiness for actual use in the fall, the comparison antenna method was adopted. This new method allowed for measuring the gain of a test antenna without needing an identical antenna, as it relied on comparing the test antenna to a known reference. This transition marked the project's shift toward more flexible and practical measurement techniques, better accommodating the diverse requirements of power amplifier and antenna testing.

During the fall, the lab received a new batch of DC power supplies, capable of handling much higher power levels than those used in the summer. On the PA side, the application underwent two key changes. First, there was a major overhaul of the user interface, which introduced new features to accommodate the use of these upgraded power supplies in a more versatile way. Although the focus shifted primarily to the antenna side, meaning no new code was developed for the PA side due to time constraints on my part, the code from the summer remained useful. Alex was able to use it with some on-the-spot modifications, allowing him to test one of his PAs effectively.

The future new PA testing methods will offer several options for DC power supply configurations: no supply, a single supply, or a dual supply. This flexibility will allow users to control the DC power from an external source without needing the app to manage it, or to use the app for direct control. Additionally, this setup allows users to apply different DC voltages to bias the gate, drain, and source of their amplifiers, with the option to use up to four distinct voltages simultaneously, as each supply is dual-channel.

4. Results

The following two figures showcase how the power amplifier and antenna menus appeared toward the end of their development during the summer.

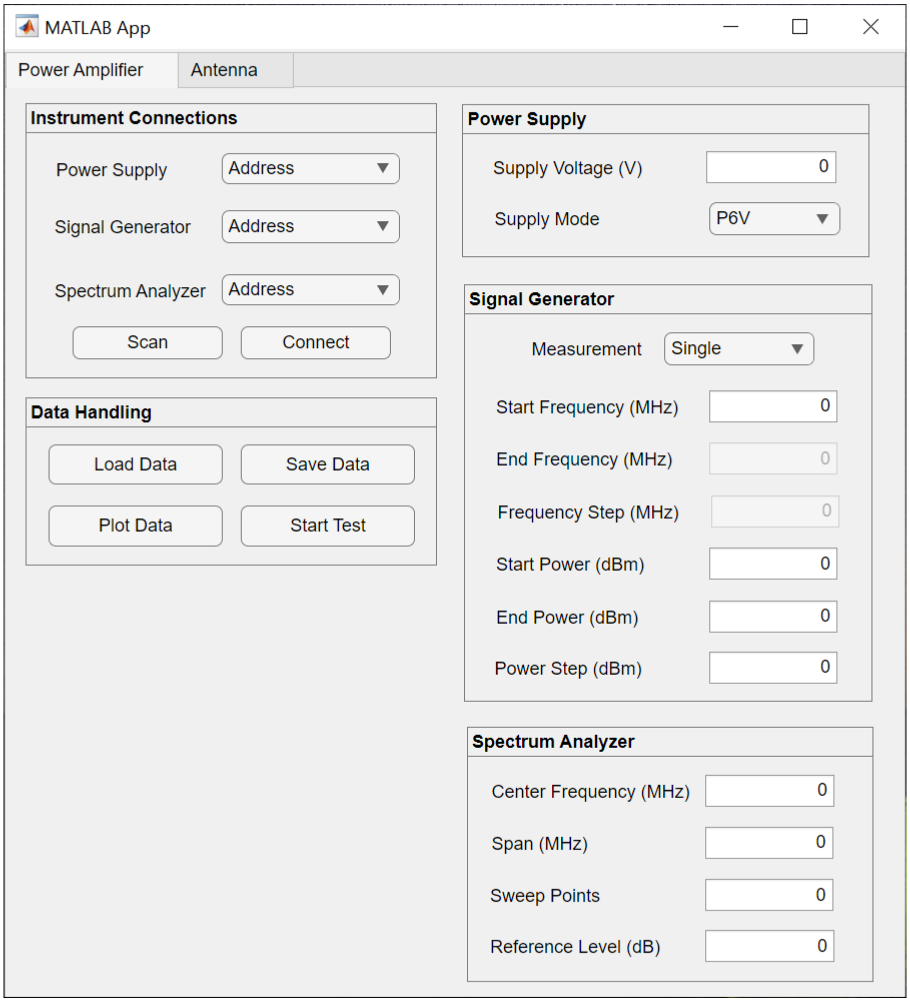

Figure 5: State of the Power Amplifier Tab – Summer 2024

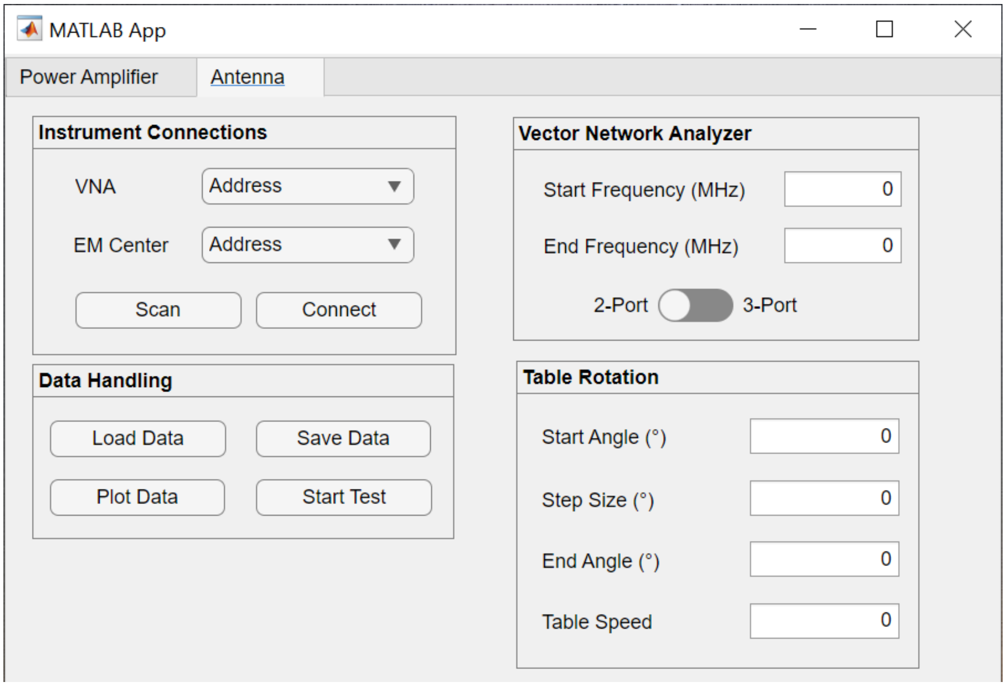

Figure 6: State of the Antenna Tab – Summer 2024

During the fall, we tested the ZVE-3W-83 power amplifier to validate the application's functionality. With an expected gain of 35 dB and a bandwidth of 2-8 GHz, testing was limited to 4.6 GHz due to signal generator constraints. Using a 20 MHz step size, we gathered a comprehensive dataset, shown in Figure 7. Significant compression effects in gain and peak values were observed, primarily due to power supply limitations.

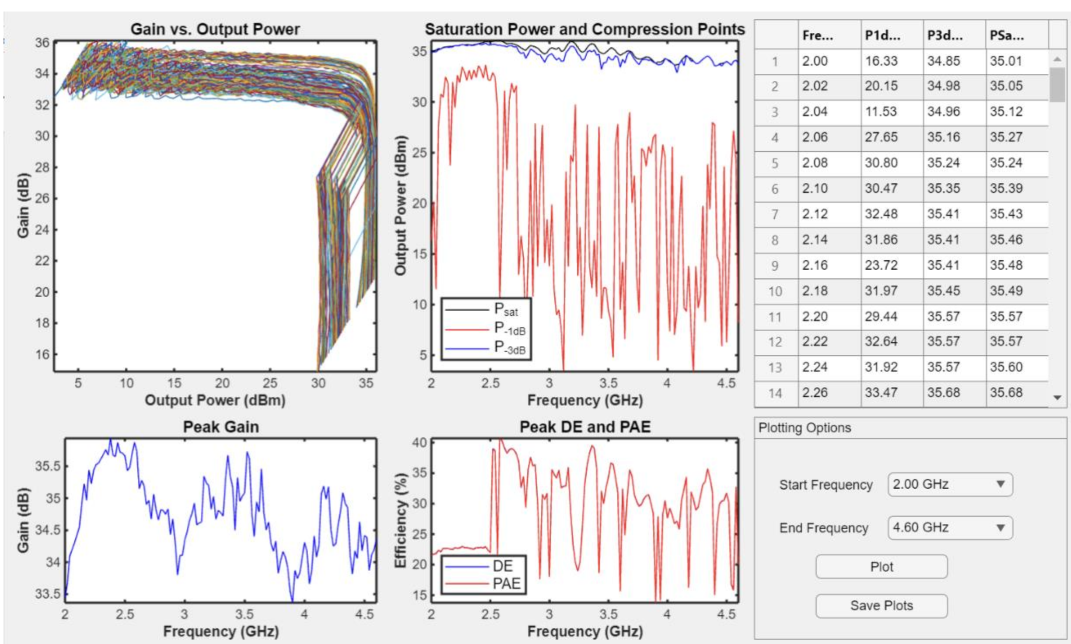

Figure 7: PA Frequency Sweep Measurement Test

With most of the functional code developed during the summer, the focus in the fall shifted to completing the antenna side and preparing the app for deployment in the ARES lab, making it accessible to users. The application is designed with user experience in mind, starting with an introductory page that outlines its features, acknowledges the team responsible, and provides links to the GitHub repository. From there, users can easily navigate between the major sections, with distinct tabs for power amplifier testing and antenna characterization.

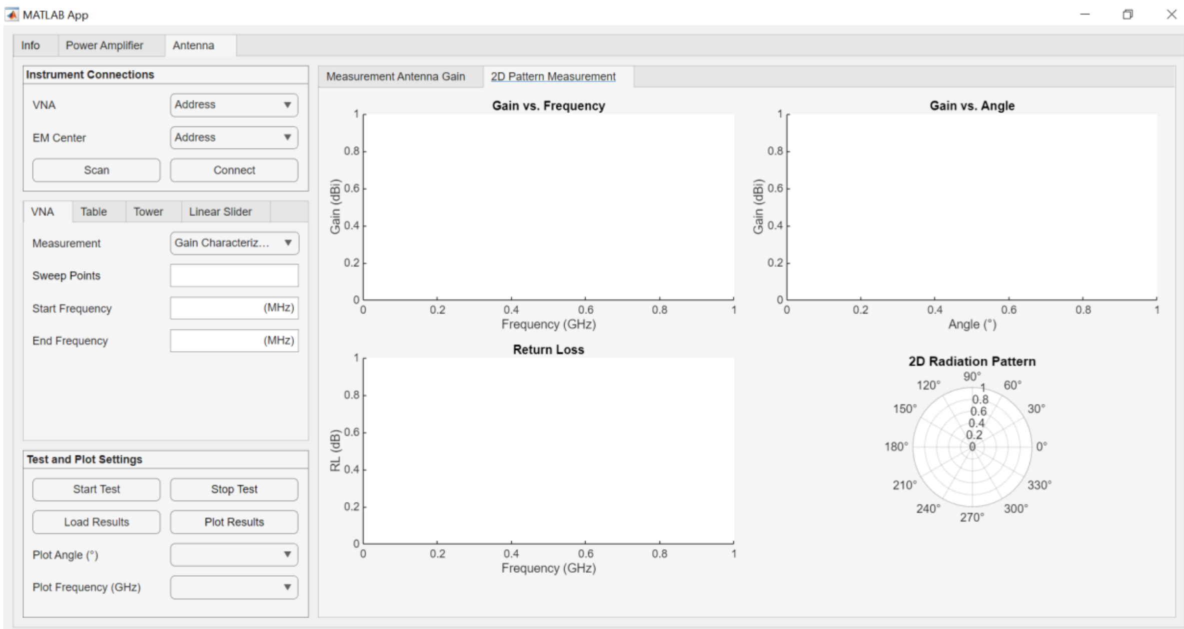

Figure 8: State of the Antenna Tab – Fall 2024

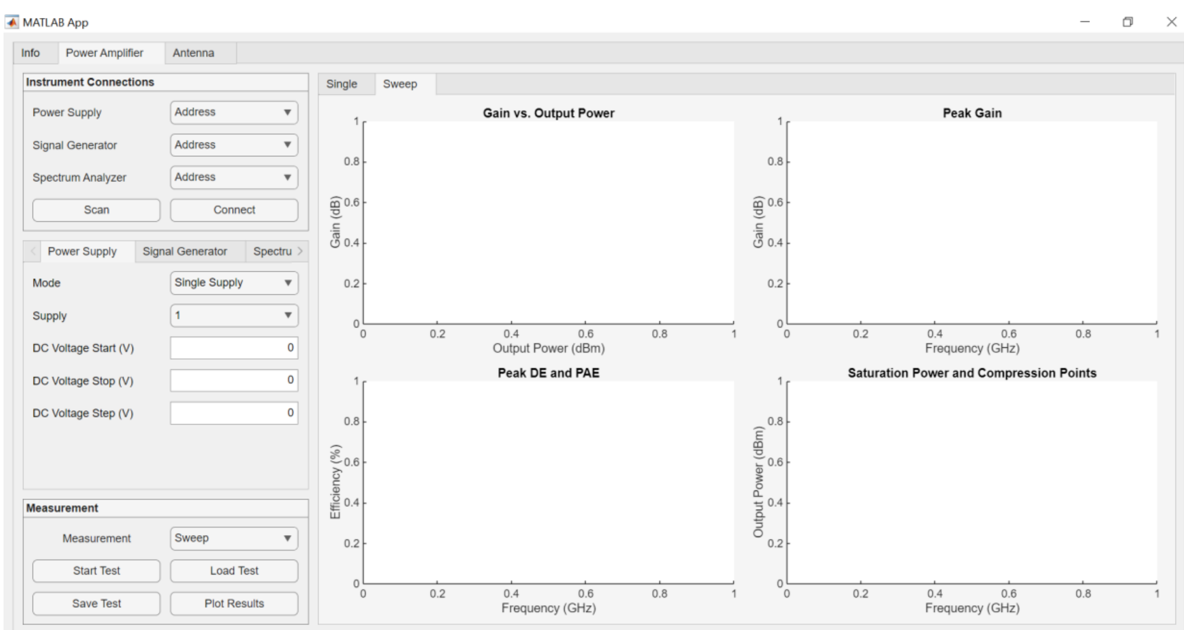

Figure 9: State of the Power Amplifier Tab – Fall 2024

The first beta user of the application was Duhan Eroğlu, a fellow researcher at Purdue. Duhan's work focused on designing a novel, compact antenna, using a unique substrate material. To validate the theoretical results from his simulations and assess whether his antenna met the desired specifications, he needed to conduct physical tests. Using the ARES application, Duhan tested his antenna by first manually securing it into the mounts. He adjusted the positioning until he identified the resonance frequency and confirmed that the antennas were properly matched. Once this was achieved, he utilized the application by inputting his target parameters, allowing the code to automate and manage the testing process.

Over several weeks of testing, Duhan used the data collected from the application to refine his antenna design before returning for additional tests. While this was a lengthy and iterative process, the impact of the ARES application was clear—it significantly reduced overall testing times. Additionally, his extensive use of the application provided valuable feedback, allowing us to identify and correct errors that had not surfaced during earlier, limited testing. This collaboration was mutually beneficial, as it helped advance both Duhan's research and the development of ARES.

On the antenna side, test time is influenced by the rotational step size and table movement patterns. The system allows users to configure step sizes to balance measurement resolution and testing duration. The approximate times for a full 0–360° rotation at the default speed (50/100) with different step sizes are as follows:

- **1-degree step size:** ~16 minutes
- **3-degree step size:** ~8 minutes
- **5-degree step size:** ~6 minutes
- **10-degree step size:** ~4 minutes

Additionally, during testing of the full 0–360° rotation, the turntable introduces movement delays when repositioning to specific angles during the test including:

- **Initial rotation:** Starting at -180° and moving to 0 → 180°, takes ~45 seconds
- **Transition rotation:** Moving from 360° back to 0°, takes ~55 seconds
- **Final rotation:** Ending at +180° and returning to 180 → 0°, takes ~30 seconds

These delays contribute to the total test duration. Moving forward, efforts will focus on optimizing the table's movement logic to minimize these delays, potentially reducing the total testing time by up to 2 minutes.

5. Conclusion

The development of the Automated Radio Evaluation Suite (ARES) represents a significant step forward in streamlining RF testing workflows. By automating measurements for power amplifiers and antennas, the application has substantially reduced testing times.

Overall, the application's continuous development promises to significantly reduce testing times while increasing customization options. These advancements will make the tool more adaptable to various testing scenarios, improving the efficiency and accuracy of both power amplifier and antenna evaluations.

Early beta testing, such as with Duhan’s antenna research, has not only validated the application’s functionality but also provided valuable insights for further refinement. Through this iterative feedback process, the application has proven its reliability and adaptability, meeting a range of testing needs while also allowing for seamless integration with existing hardware.

The application has already been deployed in the ARES lab at Purdue University, ensuring its accessibility to current and future researchers. Additionally, comprehensive documentation has been made available on GitHub, allowing for easier sharing, collaboration, and future enhancements. This open-source approach not only facilitates the adoption of ARES within the lab but also positions it as a scalable tool that can be adapted by other researchers and institutions.

Beyond technical contributions, this project has also served as an opportunity for personal growth. Working on ARES strengthened my RF engineering skills, deepened my understanding of automated testing systems, and offered invaluable experience in collaborating with researchers to address real-world challenges.

Looking ahead, there are several areas for potential expansion. Enhancing the graphical interface to further improve usability, extending compatibility to additional testing equipment, and integrating new features such as multi-frequency support are just a few of the future developments under consideration. These advancements will ensure that ARES continues to meet the evolving needs of researchers and remains a cornerstone tool for RF testing.

In summary, ARES has demonstrated its value as a practical, user-friendly application that addresses critical bottlenecks in RF testing. Its deployment marks a meaningful contribution to the ARES lab, while also laying a foundation for continued innovation and impact within the field.

6. References

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7. Appendix

Source Code and Documentation

The app and its base code are hosted on GitHub and can be accessed here: https://github.com/bolanosv/RF-Testing-App.

This repository contains detailed documentation, source code, and instructions for setup and use, making it a valuable resource for researchers looking to adopt or extend the application.