Robotically Controlled Measurement System for mm-band Antennas

Abstract—**After an antenna's behavior is simulated, it must be physically measured in order to determine its characteristics such as gain, directivity, and radiation pattern. For extremely high frequency mm-band antennas specifically, measurement is more limited as even slight movements can disrupt the collection of accurate data. Typically, the antenna under test (AUT) is rotated and data is collected at discrete positions. However, in order to avoid errors, if the AUT remains stationary while its data is being recorded, accurate results may be easier to be obtain. Previous studies find that using a robotic system aids in reducing errors in measurement. This paper presents a robotically controlled system used for measuring the characteristics in extremely high frequency mm-band antennas. Instead of rotating the AUT, the harmonic mixer and the horn of the system are rotated around the AUT while attached to a robotic arm. The system pauses at discrete intervals to ensure accurate collection of data. This setup will enable characterizing the behavior of antennas by a significant positive margin, and facilitates further research involving the measurement of mm-band antenna properties. The demonstrated setup allows for measuring the radiation pattern of mm-band antennas, especially when the AUT is being probed. This is increasingly needed as higher frequency antennas are more easily accessible.**

Keywords - AUT, mm-band, harmonic mixer, horn

I. Introduction

In order to characterize an antenna, typically another antenna is used either as a transmitter or receiver to be able to measure the AUT (which itself can either transmit or receive). After a simulation stage of testing, mm-band antennas are put through extensive trials to gauge their behavior. Extremely high frequency mm-band antennas are sensitive to sources of error, (movement, reflection, etc) as they can potentially produce incorrect results that may improperly describe the properties of the mm-band antenna. Currently, while testing the characteristics of the antenna, the AUT is rotated as the horn and harmonic mixer remain stationary [1]. However, recent studies have found that the use of robotic systems paired with a different approach in measuring the data from the antenna has increased the accuracy of results [2], [3]. In this study, a custom robotic system was built with the goal of measuring D-band (110-170 GHz) antennas. This way of characterizing the antenna entails having the horn antenna of the test system rotated around the AUT, while the AUT is probed externally to provide a signal rather than using a coaxial cable connection. Similar antenna measurement setups are likely to have the AUT rotate, but by utilizing this approach, errors may be reduced. This method also allows us to utilize the Friis transmission equation, featured in (1), to calculate the received power, keeping all else constant.

$$\frac{P_n}{P_t} = (\frac{\lambda}{4\pi R})^2 G_{0t} G_{0r} \tag{1}$$

This setup allows for measuring the radiation pattern of mm-band antennas, especially when the AUT is being probed. With technology advancing, and even higher frequency antennas being more easily fabricated in labs, the ability to measure these patterns is a necessity to understand the antennas' physical properties. Future applications of this system will permit measurement of three-dimensional radiation patterns of extremely high frequency antennas with unknown characteristics.

II. Measurement System Design

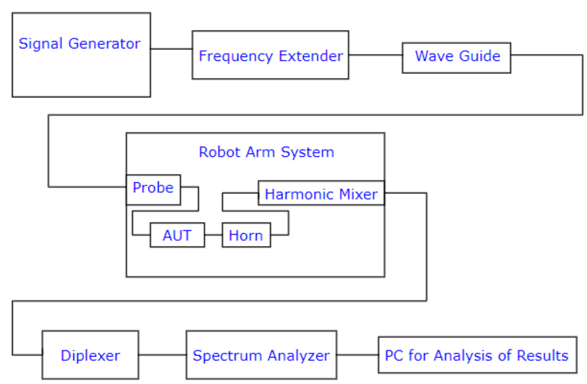

Fig. 1. High level system overview of test setup.

A high level block diagram of the ideal testing setup is shown in Figure 1. It represents the entire layout and how all the components will work together in order to properly record and process the data from the AUT.

The arm model of the robotically controlled system used for collecting data from the AUT is shown in Figure 2. The system is comprised of multiple arm designs (ASTM A513 steel and ABS printable filament), ATmega328P microcontroller on an Arduino NANO, A4988 PWM H-Bridge stepper motor driver, NEMA 17 stepper motor, CL5611AH 7 segment displays, HD74LS48P Binary-7 segment decoder, and status lights. The schematic of this system is shown in Figure 3.

The arm's structure rises 12" radially and extends 5" outwards. On the end of the extension, a bulkhead is attached in order to provide a connection for SMA coaxial cable and a

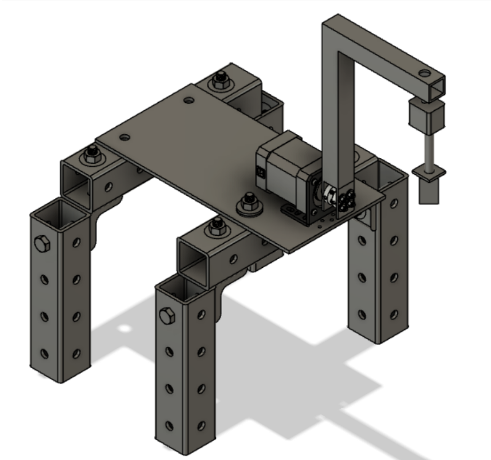

Fig. 2. Robotic arm test setup in CAD.

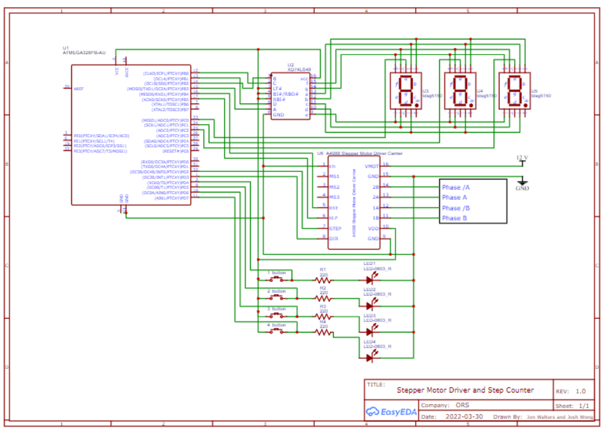

Fig. 3. Schematic of stepper motor driver and step counter.

harmonic mixer. The frequency of the signal received by the horn antenna is stepped down by the harmonic mixer to 2.8 GHz, which allows the bulkhead to transfer the signal to the rest of the system, while serving as a means of attaching the horn antenna and harmonic mixer to the structure.

The NEMA 17 motor is connected to the arm's structure by its axle, where two mounting hubs constrain it. When the AUT is placed along the motor's axle, the trajectory of the horn antenna around the AUT is circular, resulting in a horn with a constant distance from the AUT.

The arm's motor and structure are elevated by a table with a steel top and aluminum legs. This table provides a platform for the arm, AUT and electronics board.

III. Results

The designed antenna measuring system's main goal is to provide a way of measuring power received from the horn at various discrete points while minimizing error in measurements. The stepper motor itself is programmed by push buttons, two of which make it step clockwise or counter clockwise, one which resets the motor to its initial location, and one that sets the current location to the new location. The Arduino interfaces with the 7 segment displays in order to indicate how many steps have been taken from the current location. The stepper motor and arm are shown in Figure 4, and the actual protoboard containing the circuit is shown in Figure 5.

Fig. 4. Robotic arm test setup with modular mounting table, stepper motor, and rotating arm for horn maneuverability.

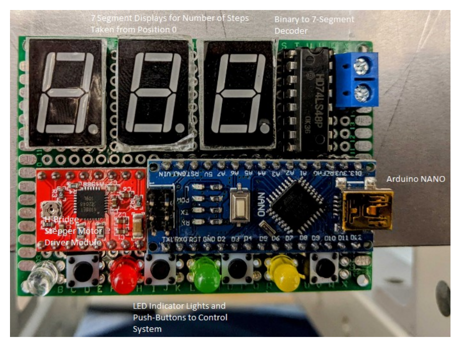

Fig. 5. Protoboard implementation of stepper motor driver and step counter.

Due to the modular nature of the design, each part can be removed and replaced with ease. Once an arm that meets desired criteria (length, weight, extension radius, material) is attached to the NEMA 17, the microcontroller is enabled. The zero location of the arm can be manually set. Additionally, the spectrum analyzer and the frequency generator will be enabled. The arm can then move 100 times to make a full 180° rotation, as each step on the motor is 1.8°. At each point received power can be recorded and then processed to calculate the received gain, which corresponds to the radiation pattern of the antenna. The AUT's received power and gain are known and will be set to desired specifications. A spectrum analyzer can then measure the transmitted power, and transmitted gain will be calculated by Friis' Transmission equation, as featured in (1).

IV. Conclusion

Results from the research have lead to the fabrication of a test setup to measure the radiation pattern from an extremely high frequency AUT, by stationary AUT probing methods with a radially moving horn antenna. The specific setup design allows for complete modularity to swap out parts for future tests; to test different arm weights, materials, radii, table height, motor type, and step size. With the main research focus being the future potential this device has when finding various radiation patterns, the working test setup provides an easy way to measure physical antenna characteristics of any D-band antenna under test.

V. Future Work

Tests will be executed with sample AUTs with known properties to determine the effectiveness of the system. This entails running trials with the system and AUTs in an appropriate testing location, and processing the results in order to verify the behavior of the AUT. When tests are conducted, RF absorbing material will be placed on the arm to absorb any radiation that might reflect off surfaces and enter into the horn. Materials used will be carefully chosen to have qualities that would be rigid and have less surface area to reduce the region of reflection. The test location will be chosen based on it having an open area so that environmental impacts will have little to no negative effect on the data. The arm system allows for extended delays between discrete steps to properly record the magnitude of the received power before moving to the next position. Ideally, a diagram of the radiation pattern will be constructed using the test results [3].

The design would also benefit from other capabilities such as added degrees of freedom, which will allow the system to measure the antenna on another axis without having to reposition the AUT or the system itself. This would lead to even more accurate representations of the antenna.

Other work includes designing a stand for the AUT and experimenting with different extension length for the arm.

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