MULTIPORT RECONFIGURABLE ANTENNA SYSTEM

An Undergraduate Research Scholars Thesis

by

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CHAPTER

ABSTRACT

Multiport Reconfigurable Antenna System

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The objective of this research project was to design, fabricate and test a multiport reconfigurable antenna for use in a beamforming system. This antenna is designed to be fed by a Butler matrix control circuit which will allow for phase shifting and switching of the antenna. The Butler matrix is a beamforming network that will be able to transmit and receive signals through the 2-patch 2-port antenna. The goal of this system is to be able to change the multiport antenna radiation pattern according to the radiofrequency (RF) environment. This allows for optimized signal strength and directivity.

The functionality of reconfigurable antennas can be useful in automated systems. Control of the antenna can be done by adjusting the excitations of a Butler matrix, which in turn adjusts the phase shifts at each of the input ports of the antenna and the directivity of the antenna.

The project sets out to create and prove the benefits of a dual patch, dual port antenna system. The output will optimize the strength of an antenna. This is tested by applying phase shifts to the input ports to the antenna. The phasing corresponded to that of a Butler matrix circuit. The antenna showed increased directionality in simulation and in testing.

CHAPTER I

INTRODUCTION

Reconfigurable antennas are being researched as an option for greater strength and reliability in communication networks. The purpose of this project is to design a multiport antenna that expands the capability of a standard reconfigurable antenna system and allows for automation. Reconfigurable antenna systems provide the functionality of a multi-antenna system in the space of a single antenna. They are able to cover a wide frequency range in changing surroundings and have the ability to change the direction, frequency and radiation pattern of a single antenna system [1]. The use of a Butler matrix control circuit with a multiport antenna will increase functionality of the reconfigurable antenna. This system can be programmed to implement an automated, self-learning antenna for optimized directivity.

Reconfigurable antenna systems can also be useful in controlling autonomous vehicles. As an example, a vehicle can generate radio waves with its antenna that it uses to map its surroundings. The information about its surroundings can then be used to reconfigure itself in response to these surroundings. For example, a very wide, plain, grassy area would require a different signal than a hilly, wooded area. The multiport system aims to increase signal strength across a wide bandwidth in changing environments. The goal is for the signal connection to grow stronger with repeated trials. The integration of a reconfigurable antenna with an autonomous vehicle in changing topographies will help determine the advantages of its potential use in vehicles, GPS and many other systems related to transportation.

In addition to optimized performance in moving vehicles, commercial applications of reconfigurable antennas include increased signal strength for Wi-Fi signals. The antenna can change geometries to direct more of its beam to devices that require increased bandwidth. For example, a device that is streaming videos would receive a stronger signal than one checking email. This functionality can be achieved with a Butler matrix reconfigurable antenna system feeding a dual patch, dual port antenna.

Dr. Youssef Tawk of the University of New Mexico, Albuquerque has contributed research in the field of reconfigurable antenna design. Dr. Tawk's work has focused on optimizing connectivity for Multiple Input Multiple Output (MIMO) devices for space applications. Reconfigurable antenna systems have proven beneficial for these applications where a wide-band of high frequency signals is necessary [1].

Reconfigurable antenna systems have also been designed and implemented at the Vellore Institute of Technology. Microwave technologies were explored as a safe option for medical imaging. Variable radiation geometries allowed the body to be imaged with electromagnetic waves. The signal was reconfigured depending on the location and the characteristics of the part of the body being imaged [2].

The research in this paper expands on components of the research conducted in other applications. This system will include the addition of a Butler matrix for further configurability of the antenna. The goal of this project is to successfully create an antenna that will increase signal directivity when fed by a 4x4 Butler matrix. In order to achieve this, a dual patch, dual port antenna will be designed and optimized in simulation before being fabricated and tested. The circuit will be modified after fabrication if necessary to enhance performance.

CHAPTER II

BACKGROUND

Patch antennas are often used due to their cost effectiveness and simple fabrication process. The size of a rectangular patch antenna is determined by the resonant frequency (f_r) of the circuit and dielectric constant (ε_r) of the antenna.

The width and length of the patch are calculated using the following equations.

$$W = \frac{1}{2f_r\sqrt{\mu_o\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L \tag{2}$$

Antennas can be polarized to emit a wave that radiates in specific time-varying direction and magnitude [3]. Linearly polarized antennas transmit waves in one direction. Circularly polarized antennas radiate in two planes, rotating in a corkscrew shape. While linearly polarized signals can be easily misaligned, circular polarized waves are rotationally invariant. Consequently, circular polarization is useful for increased reliability in changing RF environment conditions compared to linearly polarized antennas.

Circular polarization of the patch antenna can be obtained by feeding a patch at two specific points. The feed lines to the ports should have equal magnitude and a phase offset between them of $\boldsymbol{\frac{\pi}{2}n}$, where n is an odd integer. The equations for the phase offsets of the two components for circular polarization are shown below.

$$phase\ offset = \begin{cases} +\left(\frac{1}{2}+2n\right)\pi, n = 0,1,2, \ldots \text{for CW} \\ -\left(\frac{1}{2}+2n\right)\pi, n = 0,1,2, \ldots \text{for CCW} \end{cases} \tag{3}$$

Multiple antenna elements used together is called an antenna array. Antenna arrays are used to create directed radiation patterns. These radiation patterns exhibit higher gains in a certain direction. This is accomplished through the constructive and destructive interference of the radiation from the array elements [3].

The total electric field radiating from an antenna array can be found by multiplying the field of a single element of the array by the array factor. The equation for the total electric field and two-element array factor are shown below.

$$E(total) = E(single\ element) \times \text{ [Array Factor]} \tag{4}$$

$$Array\ Factor = 2\cos\left(\left[\frac{1}{2}(kd\cos(\theta)+\beta\right]\right. \tag{5}$$

$\beta =$ Phase offset between elements, $d =$ array element separation, $k =$ wave number

Increasing the distance between elements in the array creates more lobes in the radiation pattern. Adjusting the phasing, β, of the elements of the antenna array affects the direction of the main lobe of the array radiation pattern. This is described by the equation below.

$$Phase\ between\ elements = kd\cos(\theta) + \beta \tag{6}$$

$\theta =$ angle of main lobe

Determining the separation, size, phasing and port placement of the patches are all important steps in the design of a multiport antenna for a specific function.

Butler matrices are beamforming networks that are made using hybrid couplers, phase shifters and crossover elements. The Butler matrix determines the phase shifts at its output depending on which input is excited in increments of 45°. The inputs and outputs of a Butler matrix are isolated, meaning there is no leakage in the power between the ports [4]. It can be used as a beamforming network to steer the radiation when used as a feedline to a multiport antenna.

Antennas need to be tested in an anechoic chamber to ensure accuracy of the measurements. The walls of the anechoic chamber are foam pyramids clad with radiation absorbent material that are designed to absorb radiofrequency waves. This prevents reflections which could cause large measurement errors.

CHAPTER III

METHODS

The antenna was designed using ANSYS HFSS (High Frequency Structure Simulator) software. The antenna model was simulated using 62 mil Rogers RT/duroid substrate. Two ports were placed on each patch to create two circularly polarized patches. In order to accurately phase shift the four ports of the antenna array, a 4x4 hybrid Butler matrix can be used as a feedline. Test sweeps with varying 45° Butler matrix phase shifts and patch spacing were performed. Figure 1 below shows the antenna simulation model and radiation pattern in HFSS.

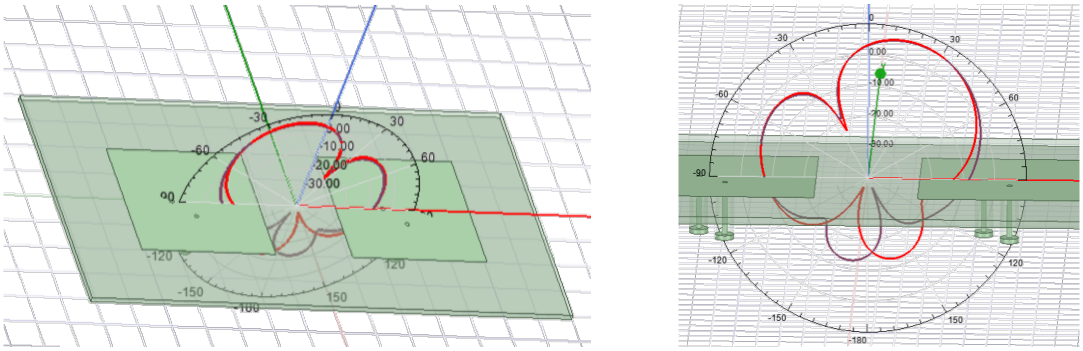

Fig. 1 Multiport Antenna with Radiation Pattern

The antenna was then fabricated on RT/duroid 5880, also with a thickness of 62 mil. The substrate is cladded with copper which is stripped away to the desired patch shapes using a milling machine. The antenna was fabricated with a two-wavelength separation between the patches.

The reconfigurable antenna's S-parameters were tested after fabrication was completed. Before beginning testing, the network analyzer was calibrated to ensure accuracy. The S-parameters showed an impedance match at 2.54GHz. The antenna was then tested in an anechoic chamber at this frequency to obtain the radiation patterns for the desired phase states. Figure 2 below shows the multiport antenna set up for testing in the chamber. An RF phase shifting matrix served as the network feed that provided phasing to the four input signals of the antenna. The phasing corresponds to the phase offsets in a 4x4 Butler matrix. The phase shifters were programmed with an Arduino. The 4 phases were set to 0°, 45°, 90° and 135° to replicate progressive phase shifting from a Butler matrix feed. The test was also completed with reversed progressive phase inputs. The phase shifters used in testing are not capable of obtaining a full 360° phase shift, so not all states of the Butler matrix could be tested.

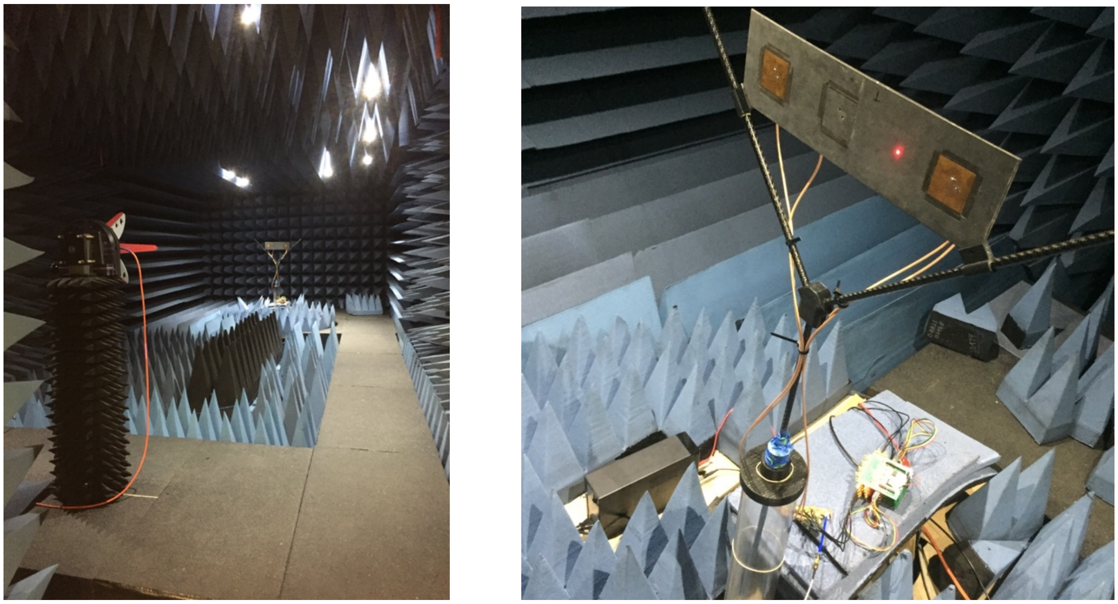

Fig. 2 Antenna in Anechoic Test Chamber

CHAPTER IV

RESULTS

Simulation

The S-Parameter data was collected and plotted in HFSS for varying phase shifts and excitations of the Butler matrix's ports. Radiation patterns at different lengths of separation between the two patch antennas were also analyzed. Figures 3 and 4 show the simulated radiation pattern at varying phase shifts and at half and full wavelength separations, respectively.

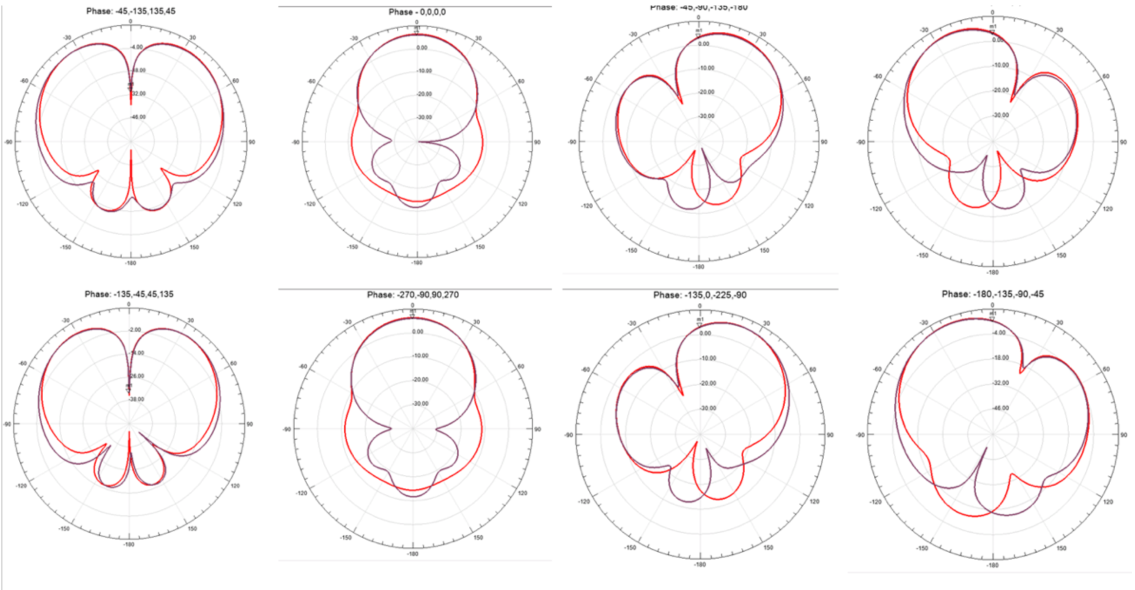

Fig. 3 Half Wavelength Patch Separation Simulation Results

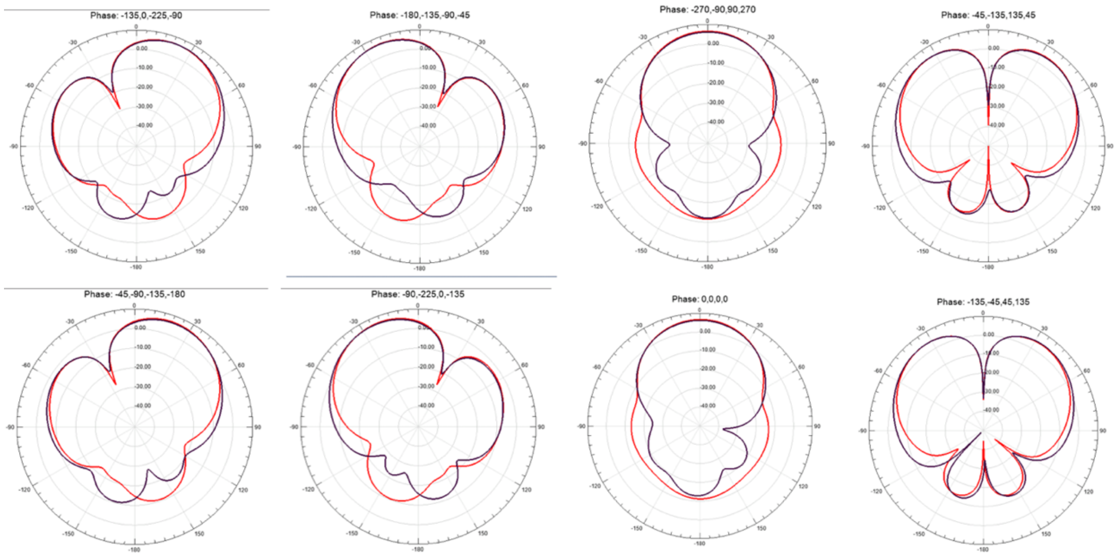

Fig. 4 Full Wavelength Patch Separation Simulation Results

The direction of the main beam of the radiation pattern shows that there is increased signal strength in that direction when the patches are separated at half wavelength and full wavelength increments. Varying the phase at the input ports changes the direction of the radiation pattern. The radiation pattern shows directivity while also maintaining a decently strong signal strength across all forward-facing directions. As seen in Figures 3 and 4 above, similarly directed radiation patterns can be formed with different phase shifts. For example, in Figure 4, the phasing of -135°, 0° ,-225° ,-90° results in a radiation pattern of the same shape as the -45°,-90°,-135°, -180° phasing thus showing symmetry in the antenna array system's radiation patterns.

The patch was then simulated at a distance of two wavelengths. The 2-wavelength separation is equal to 244 mm for the 2.45 GHz resonant frequency of the antenna. The figures below show the antenna design and radiation data for the two-wavelength separation.

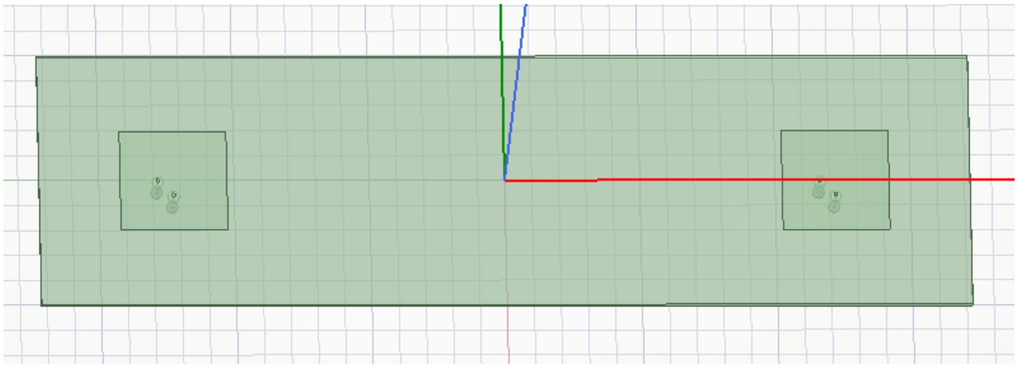

Fig. 5 Two-Wavelength Patch Separation Model

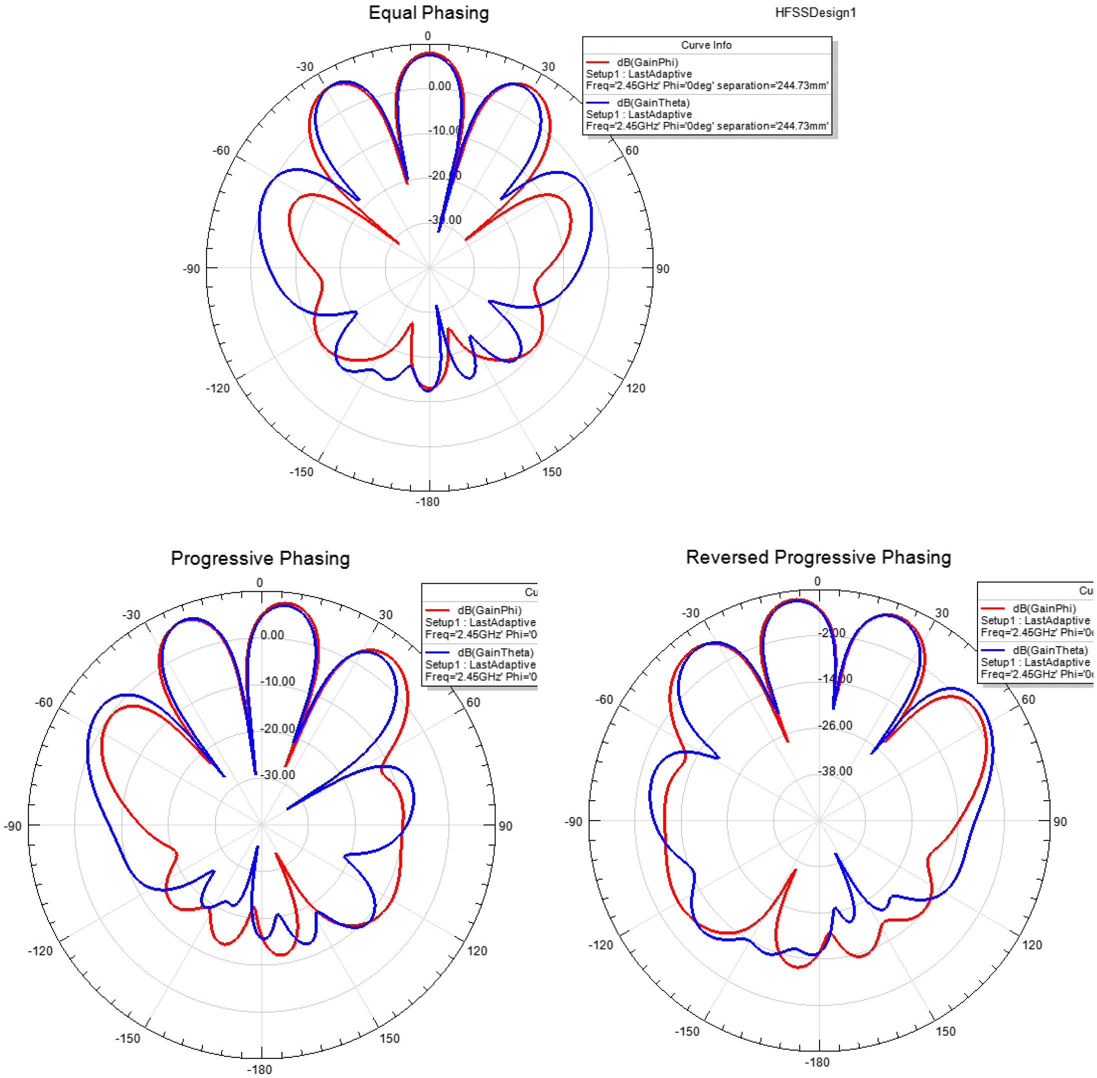

Fig. 6 Simulated Two-Wavelength Patch Separation Radiation Patterns

Fabrication

As seen in Figure 6, the directivity of the pattern changes depending on the phase inputs to the antenna. The phase inputs to the antenna ports correspond to the 45° phase shifts from a Butler matrix. The figures above show progressive and reversed progressive 45° phase shifts at the ports, which result in shifted directivity of the radiation pattern. This same effect was seen in testing of the fabricated circuit. Radiation patterns for the horizontal and vertical polarizations of the fabricated antenna are shown in Figure 7 below.

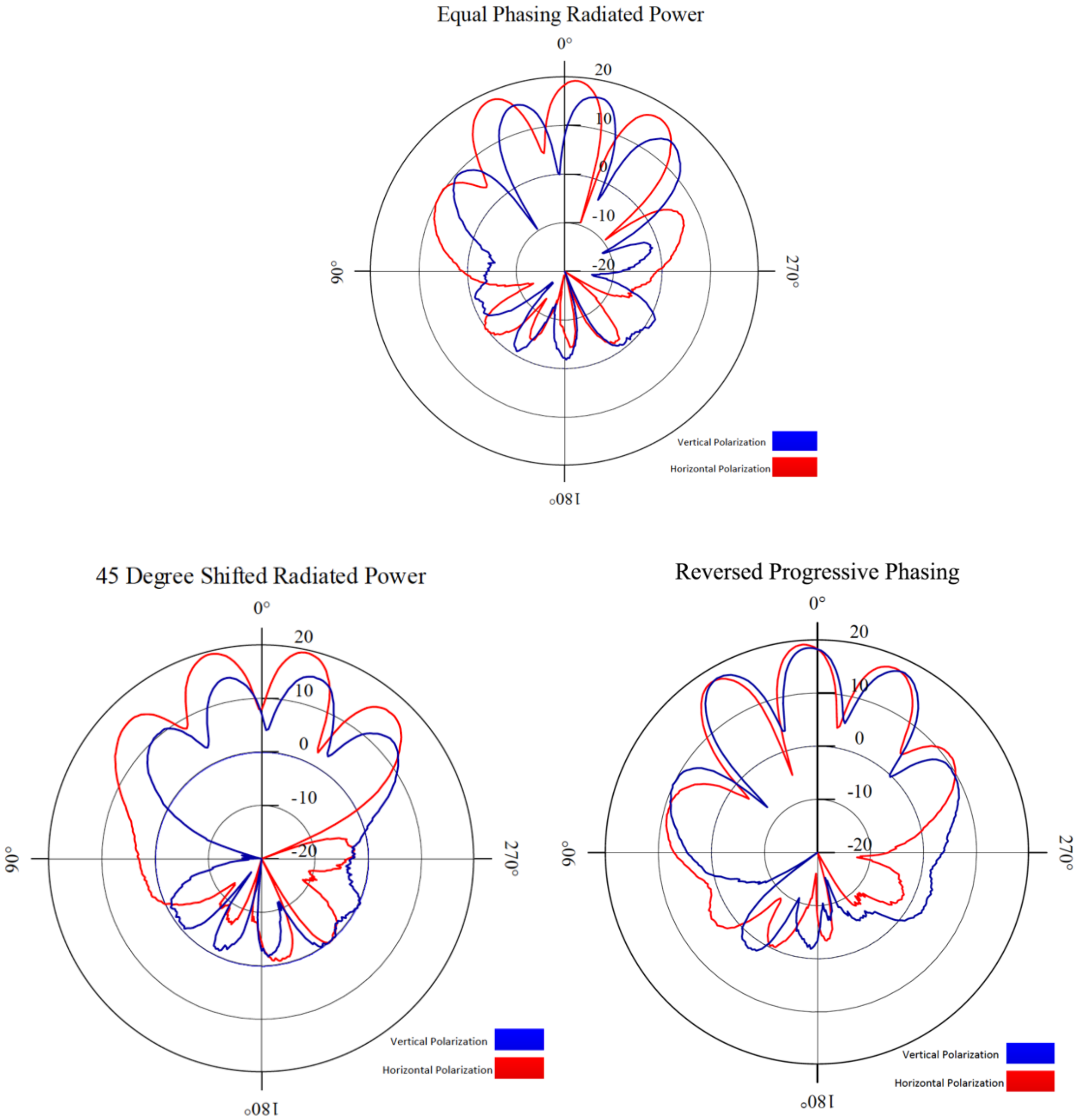

Fig. 7 Measured Two-Wavelength Patch Separation Radiation Patterns

While the radiation pattern for the antenna with equal phasing applied at all the ports looks symmetrical, an increase in directivity in opposite directions can be seen when unequal phasing is applied to the antenna. All of the tested phase shifts had a maximum gain of approximately 20dB.

CHAPTER V

CONCLUSION

The multiport antenna system exhibited strong gain and directionality when fed through a phase shifted four-port system. Radiation from the four ports of the antenna combine in predictable ways, meaning a Butler matrix could be used to produce steerable beams based on the excitations on the control circuit.

The directionality of the antenna was stronger in simulation than in testing, however, the antenna still showed directionality and strong gains in testing, proving that with further optimization this antenna can be useful in a Butler matrix control circuit reconfigurable antenna system. The dual patch, dual port antenna can be used to increase signal strength in certain directions, while still providing a base signal in all forward directions. The implementation of this multiport, reconfigurable antenna system can, therefore, benefit many applications, particularly in automation of antenna systems in changing RF environments.

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