Master of Science in Electrical and Electronic Engineering



Circularly Polarized Microstrip Patch Array Antenna for Satellite Applications: An Approach Using Simple Feed Network

by

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List of Publications

The following publication is a direct consequence of the research carried out during the elaboration of the thesis and gives an idea of the progression that has been achieved.

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Abstract

Microstrip antennas, among various types of antennas, offer considerable advantages over traditional microwave antennas and are consequently utilized in numerous practical applications. Circularly polarized (CP) microstrip patch array antennas offer numerous benefits, such as reduced sensitivity to polarization orientation, the capability to counteract the ionosphere's Faraday rotation effect, enhanced resistance to interference, and improved long-distance transmission. Consequently, they play a crucial role in radar systems, satellite communications, GPS, and various other applications. Furthermore, a reconfigurable antenna functions as a multifunctional apparatus, yielding a more compact and efficient design while also reducing expenses. Polarization reconfigurable antennas can switch between various polarization modes, including LP, LHCP, and RHCP. This thesis presents the construction of a 2×2 dual-sense circularly polarized octagonal-shaped microstrip array antenna, followed by the integration of pin diodes to achieve reconfigurable circular polarization for the Ku-band frequency suitable for satellite communication. Both antennas have a single input feed and utilize dual-sided microwave integrated circuit (MIC) technology to enhance design flexibility and simplify the bias control circuit, resulting in a straightforward feeding circuit for the antenna. Each segment of the array is stimulated orthogonally. The switching mechanism is regulated by a single-pole double-throw (SPDT) switch composed of two PIN diodes integrated within a $\lambda/2$ delay line. The simulated outcomes indicate that the antenna may alternate between RHCP and LHCP, showcasing proficient circular polarization performance. The simulated findings demonstrate excellent circular polarization (CP) performance, with a relative power level difference of 30 dB and an ARBW of 400 MHz. The array demonstrates effective impedance matching, featuring an impedance bandwidth of 1600 MHz. The gain, directivity, and efficiency findings indicate that the antenna effectively transmits a highly focused beam in the broadside direction.

Keywords: Array antenna, LP, LHCP, RHCP, Reconfigurability

বিমূর্ত

মাইক্রোস্ট্রিপ অ্যান্টেনা, অন্যান্য বিভিন্ন ধরনের অ্যান্টেনার মধ্যে, প্রচলিত মাইক্রোওয়েভ অ্যান্টেনার তুলনায় উল্লেখযোগ্য কিছু সুবিধা প্রদান করে এবং ফলস্বরূপ, এগুলো বহু বাস্তব জীবনের ক্ষেত্রে ব্যবহার করা হয়ে থাকে। বৃত্তাকার মেরুকরণযুক্ত মাইক্রোস্ট্রিপ প্যাচ অ্যারে অ্যান্টেনাগুলো অনেকগুলো সুবিধা প্রদান করে, যেমন: মেরুকরণের অভিমুখের প্রতি সংবেদনশীলতা কম, আয়নমণ্ডলের ফ্যারাডে ঘূর্ণন প্রভাব মোকাবিলা করার সক্ষমতা, হস্তক্ষেপ প্রতিরোধে অধিক দক্ষতা এবং দীর্ঘ দূরত্বে উন্নত ট্রান্সমিশন সক্ষমতা। ফলে, এসব অ্যান্টেনা রাডার সিস্টেম, স্যাটেলাইট যোগাযোগ, জিপিএস এবং অন্যান্য বহু ক্ষেত্রে গুরুত্বপূর্ণ ভূমিকা পালন করে। পুনঃসংবেদনযোগ্য অ্যান্টেনা একটি বহুমুখী ডিভাইস হিসেবে কাজ করে, যার ফলে এটি একটি আরও কমপ্যাক্ট ও কার্যকর ডিজাইন নিশ্চিত করে এবং খরচও হ্রাস করে। মেরুকরণ পুনঃসংবেদনযোগ্য অ্যান্টেনা বিভিন্ন মেরুকরণ মোডে পরিবর্তিত হতে পারে। এই থিসিসে একটি 2×2 ডুয়াল-সেন্স বৃত্তাকার মেরুকরণযুক্ত অক্টাগোনাল-আকৃতির মাইক্রোস্ট্রিপ অ্যারে অ্যান্টেনার নির্মাণ উপস্থাপন করা হয়েছে, যার মাধ্যমে কু-ব্যান্ড ফ্রিকোয়েন্সিতে উপযুক্ত স্যাটেলাইট যোগাযোগের জন্য পুনঃসংবেদনযোগ্য বৃত্তাকার মেরুকরণ অর্জনে পিন ডায়োড সংযুক্ত করা হয়েছে। উভয় অ্যান্টেনা একটি একক ইনপুট ফিড ব্যবহার করে এবং ডিজাইনে নমনীয়তা আনতে ও বায়াস কন্ট্রোল সার্কিট সহজ করতে দ্বিপার্শ্বিক মাইক্রোওয়েভ ইন্টিগ্রেটেড সার্কিট প্রযুক্তি ব্যবহার করা হয়েছে, যার ফলে ফিডিং সার্কিটটি সহজ হয়। অ্যারেটির প্রতিটি অংশকে পরস্পরের সাথে অরথোগোনালি উদ্দীপ্ত করা হয়েছে। সুইচিং ব্যবস্থা নিয়ন্ত্রণের জন্য একটি একক-পোল ডাবল-থ্রো সুইচ ব্যবহার করা হয়েছে, যা দুটি পিন ডায়োডসহ একটি $\lambda/2$ ডিলে লাইন দ্বারা গঠিত। সিমুলেশন ফলাফল দেখিয়েছে যে অ্যান্টেনাটি ডানহাতি ও বামহাতি বৃত্তাকার সমাবর্তনের এর মধ্যে পরিবর্তন করতে সক্ষম এবং দক্ষ বৃত্তাকার মেরুকরণ কর্মক্ষমতা প্রদান করে। সিমুলেশন অনুযায়ী, অ্যান্টেনাটি চমৎকার বৃত্তাকার মেরুকরণ পারফরম্যান্স প্রদর্শন করে, যেখানে শক্তির আপেক্ষিক পার্থক্য ৩০ ডিবি এবং অ্যাক্সিয়াল রেশিও ব্যান্ডউইডথ ৪০০ মেগাহার্টজ। অ্যারেটি কার্যকর ইনপিড্যান্স ম্যাচিং নিশ্চিত করে, যার ইনপিড্যান্স ব্যান্ডউইডথ ১৬০০ মেগাহার্টজ। গেইন, ডিরেক্টিভিটি এবং দক্ষতা নির্দেশ করে যে অ্যান্টেনাটি ব্রডসাইড দিকে অত্যন্ত ফোকাসড বিম প্রেরণ করতে সক্ষম।

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List of Abbreviations

AR	Axial ratio
ARBW	Axial Ratio Bandwidth
BW	Bandwidth
CO-POL	Co Polarization
CP	Circular Polarization
EMW	Electromagnetic Wave
GPS	Global Positioning System
LHCP	Left-Hand Circular Polarization
LP	Linear Polarization
MIC	Microwave Integrated Circuit
RFID	Radio Frequency Identification
RHCP	Right-Hand Circular Polarization
Wi-Fi	Wireless Fidelity
WLAN	Wireless Local Area Network
X-POL	Cross Polarization

Chapter 1

Introduction

1.1 Overview

Several sorts of antenna designs exist, including wire antennas, aperture antennas, and microstrip antennas. Microstrip antennas, in particular, have significant benefits over conventional microwave antennas and are thus frequently employed in various practical applications. Microstrip antennas provide several benefits, such as lightweight construction, small dimensions, simplicity of fabrication, compatibility with microwave integrated circuits (MIC), and the capacity to adapt to the host surface [1]. Again, circularly polarized (CP) antennas provide various advantages, including lower sensitivity to polarization orientation, the ability to offset the ionosphere's Faraday rotation effect, and increased interference resistance. Consequently, they have a significant role in radar systems, satellite communications, and GPS, among other applications.

A reconfigurable antenna functions as a multifunctional antenna, facilitating a decrease in the quantity of antennas necessary in a system. This results in a more compact and efficient design while also minimizing costs. Among antennas that are reconfigurable in terms of pattern, polarization, and frequency, polarization reconfigurable antennas can alternate their polarization modes, including LP, LHCP, and RHCP. Unlike LP antennas, the circularly polarized reconfigurable antenna effectively mitigates multipath fading and misalignment. Additionally, it offers advantages for applications in satellite communication and 5G mm-wave communications [2, 3, 4]. As a result, the need for reconfigurable circularly polarized microstrip antenna is growing faster day by day.

1.2 Background

The antenna is the main component in wireless communication. An antenna serves as a directed device, significantly augmenting the sent or received electromagnetic radiation in one direction while attenuating it in others [5]. Wire antennas were introduced by Joseph Henry, the creator of wire telegraphy, in 1842 [6]. Afterwards, wireless communication system was invented by Marconi in 1901 [7]. Research advancement continued and Harold A. Wheeler designed compact antennas in 1940 [8]. After few years, zero generation Wireless analog mobile communication started by mounting radio telephones in automobiles, trucks, and other vehicles [9]. In 1979, the 1^{st} generation (1G) wireless analog mobile communication technology was introduced in Tokyo [10]. In this wireless communication system, analog Frequency modulation technique was incorporated. The quality, reliability and security of the voice were far below the expectations. However, advancement in wireless communication was fast in the past years and now most of the countries are ready to introduce fifth generation (5G) wireless telecommunications systems.

Microstrip antennas, in particular, have significant benefits over conventional microwave antennas and are thus frequently employed in various practical applications. Octagonal patches outperform other forms in bandwidth. Wireless communications and radar applications using ultra-wideband (UWB) and multiband antennas benefit from the design's larger frequency spectrum [11]. Octagonal patches outperform other forms in bandwidth. Wireless communications and radar applications using ultra-wideband (UWB) and multiband antennas benefit from the design's larger frequency spectrum. Octagonal patches improve radiation patterns and gain. The patch's extra edges and symmetrical structure help conduct current more consistently, improving radiation efficiency and sometimes generating more focused or omnidirectional patterns [12]. To meet application needs, octagonal configuration changes allow fine gain and directivity variations. Multiband antennas are possible because the antenna's architecture permits many resonant modes. Devices that need to change configuration and use a single antenna for many communication standards benefit from such designs. The octagonal patch can save area by 30% compared to a rectangular patch in portable and embedded systems while still supporting dual-band or multiband capabilities. Compact gadgets like cellphones and sensor systems can use it. For advanced applications, the octagonal form lets designers include slots, notches, or parasitic features in numerous ways to adjust impedance, polarization, and bandwidth [13, 14].

Researchers worldwide are working hard to build high quality CP microstrip antennas [15]. Two orthogonal excitations with a quarter-wavelength phase difference are required to achieve CP. In a dual-feed single element microstrip patch antenna, achieving a phase shift of 90 degrees can be accomplished by using an external phase shifter or a delay line. The orientation of the delay line on the feed line determines whether the antenna produces RHCP or LHCP [16]. A multilayer CP structure has an approximate gain of 2 dB more than a single-layer design, attributable to side lobe suppression. A unique compact 2×1 Microstrip array antenna utilizing a multilayer method for orthogonal CP may give wideband characteristics [17]. However, the design and construction of a multilayer structure is somewhat complicated. A feed network using microstrip and slot lines exhibits a more straightforward design and facilitates quicker impedance matching compared to conventional feed networks [18]. A unique slot-embedded microstrip antenna using a single-layer configuration with a square-shaped radiator may be suitable for dual-band, dual-polarization functionality [19]. Many studies have been conducted to construct a wideband antenna for the Ku band and to increase the gain of an X band antenna [20, 21, 22]. A novel approach to creating antennas with polarization reconfigurability that uses two different kinds of perturbations is presented in [23]. An L-shaped microstrip segment and ground plane with a square slot simultaneously allow polarization reconfigurability. For applications involving Ku-band satellite television reception, a novel low-profile, very light, and highly efficient CP microstrip antenna array has been shown [24]. A 16×6 CP patch array of 96 elements was constructed and examined to verify the design idea.

A reconfigurable antenna can be achieved by implementing a switching mechanism [25].Popular switching mechanisms comprise PIN diodes, varactor diodes, and MEMS switches. The switching mechanism for an array antenna can be implemented on the radiators or integrated into the feeding network [26]. Several investigations have been conducted in recent years regarding polarization reconfigurable array antennas. A 1×4 patch array has been designed in [27], and the feed network of the single input is configured with a switching mechanism to modify its polarization states in the bottom layer. Only two diodes are required for each patch to enable the switching mechanism. To facilitate switching among LP, LHCP, and RHCP, each feed line end is equipped with three probes penetrating the patch, ultimately compensating for antenna performance. In [28], a 1×4 array antenna features a cross aperture in the ground layer, incorporating four RF switches positioned between the aperture lines directly beneath the center of each patch. The feed network is located in the bottom layer. The total number

of switches for a four-element array is sixteen. The incorporation of multilayer structures increases antenna volume. Incorporating a switching mechanism into the feed network leads to the feed network design in the bottom layer of the array antenna. This makes the antenna multilayer, leading to an overall volume increase. To integrate the feed network into the top layer, a proposed array for polarization reconfigurability has been detailed in [29]. This design ultimately results in 20 diodes for a 2×2 array. Additionally, it incorporates a multilayer design to enhance antenna performance. A straightforward microstrip line feed single layer microstrip patch array antenna has been detailed in [30] for polarization reconfigurability. However, for an extensible array, the design of the feed network becomes significantly more complex. To simplify the feed network design on the top layer of a substrate, a simple feed single layer 2×2 element array antenna is designed in [31], using double-sided microwave integrated circuit (MIC) technology.

1.3 Motivations

CP antennas are more preferable to LP antennas due to their various advantages like weather penetrating, ability to offset the ionosphere's Faraday rotation effect, flexible polarization orientations, and offset the multi-path reflections and other interferences [32].In the construction of a circularly polarized antenna, it is essential to attain a favorable axial ratio ($\leq$3 dB) and return loss ($\leq$10 dB) at specified operational frequencies. The losses in the feeding network and undesired radiation at the feed are significant concerns in the design of microstrip antennas. They significantly affect impedance bandwidth and gain, particularly at elevated frequencies, which are essential for 5G wireless communication [33, 34]. By increasing the element number in the array this problem may be addressed [35]. Another method may be designing efficient feed network [36, 37, 38, 39, 40]. For example, about 50% reduction in conductor trace may be achieved by employing a corporate-series feed [36]. This will result in a decrease in conduction loss, enhanced radiation efficiency, and increased array gain bandwidth performance. To enhance antenna performance, a feed network with the sequentially rotated approach has been reported in [38, 37]. A reconfigurable antenna enhances functions by altering its mode of operation in response to an interfering signal or a fading channel [41]. Different types of reconfigurable antennas have been proposed in the literature [42, 43, 44]. PIN diodes, MEMS, varactor diodes etc. switches are regularly used to design the reconfigurable microstrip antennas [45, 46, 47].

Mechanical, electrical, or liquid metal are common methods for obtaining reconfigurable circular polarization using a microstrip antenna. A rotational corner truncated patch with a fixed L probe feed allows for mechanical circular polarization reconfiguration [48]. It may switch from LHCP to RHCP simply rotating the patch 90 degrees. The drawback with this technology is that it requires an external motor to rotate the patch. Additionally, converting the antenna into an array increases the design complexity. One method for reconfigurability with liquid metal is to create two semicircular slots diagonally in a patch and fill one of them with metal liquid while leaving the other slot empty or filled with non-metal liquid so that the other slot remains detached from the patch, resulting in two orthogonal degenerative modes that produce CP in one sense [49]. Filling the other slot with liquid metal results in the CP of another sense. However, to accomplish this, an extra motor to pump the liquid is necessary, which limits switching speed. As a result, electrical switching is the most preferred switching technology due to its fast switching capability. The most common components used for this function are p-i-n diodes, RF MEMS, and varactor diodes [50]. Many studies have been conducted on reconfigurable CP patch array antennas over the years. In [51], a 2×2 patch array is built for circular polarization and reconfigurability is achieved by dual port. Switching between polarizations requires individual excitation of the input ports or can be accomplished using an external switching circuit, which increases the total size of the array antenna. In addition, the antenna is multilayered. To accomplish CP reconfigurability by single input port stimulation in a multilayer antenna, a cross-shaped slot in the middle layer can be used, along with two p-i-n diodes between one of the slot's arms to regulate the switching between polarization states [52]. The issue with this setup is that for an array antenna, each slot beneath the patch requires two diodes. So, a 2×2 array antenna requires eight diodes; for large-scale arrays, the antenna will require a huge number of diodes, and the diode biasing will become complex. Making an antenna single layer with switching capabilities complicates the design for both the feed and bias circuits. To address this issue, using double-sided microwave integrated circuit (MIC) technology simplifies the feed circuit [16, 53, 54].

The primary issues with microstrip patch arrays are power loss in the feeding network and the emission of unintended radiation at the feed point. Conversely, the majority of arrays developed to date lack compactness and feature feed lines that experience power loss. Further research is required to develop a Circular Polarization Reconfigurable Array Antenna using a simplified feed network.

1.4 Objectives With Specific Aims and Outcomes of the Thesis Work

The main objective of the proposed research is to design a circular polarization reconfigurable array antenna with a simple feed network. The specific aims and outcomes to achieve the objectives are described below:

1. To design an octagonal-shaped patch array antenna for dual-sense CP in the Ku band frequency range using a simple feed network.
2. To integrate electrical switching into the simple feed octagonal-shaped patch array antenna to acquire reconfigurable CP.
3. To verify the design and performance of the proposed antennas through electromagnetic software simulation.

Thus, the outcomes of the proposed circular polarization reconfigurable array antenna are listed below:

1. The proposed antenna can achieve circular polarization with good axial ratio bandwidth and impedance bandwidth, which is required for satellite communication.
2. The proposed antenna can achieve polarization reconfigurability, which is the demand of satellite communication. For example, Bangabandhu satellite (BB-1) uses dual polarization (LHCP and RHCP).
3. The proposed circular polarization reconfigurable array antenna uses a simple feed network, which ensures effective power distribution at the junctions.

1.5 Research Methodology

This section elucidates the process of fabricating an octagonal patch array antenna capable of alternating between two forms of circular polarization and being reconfigured by electrical switching. The process is divided into several structured phases, encompassing requirement definition and simulation validation. This ensures that Ku-band performance is systematically optimized over time. Figure 1.1 shows the process that would be followed during the completion of this thesis work.

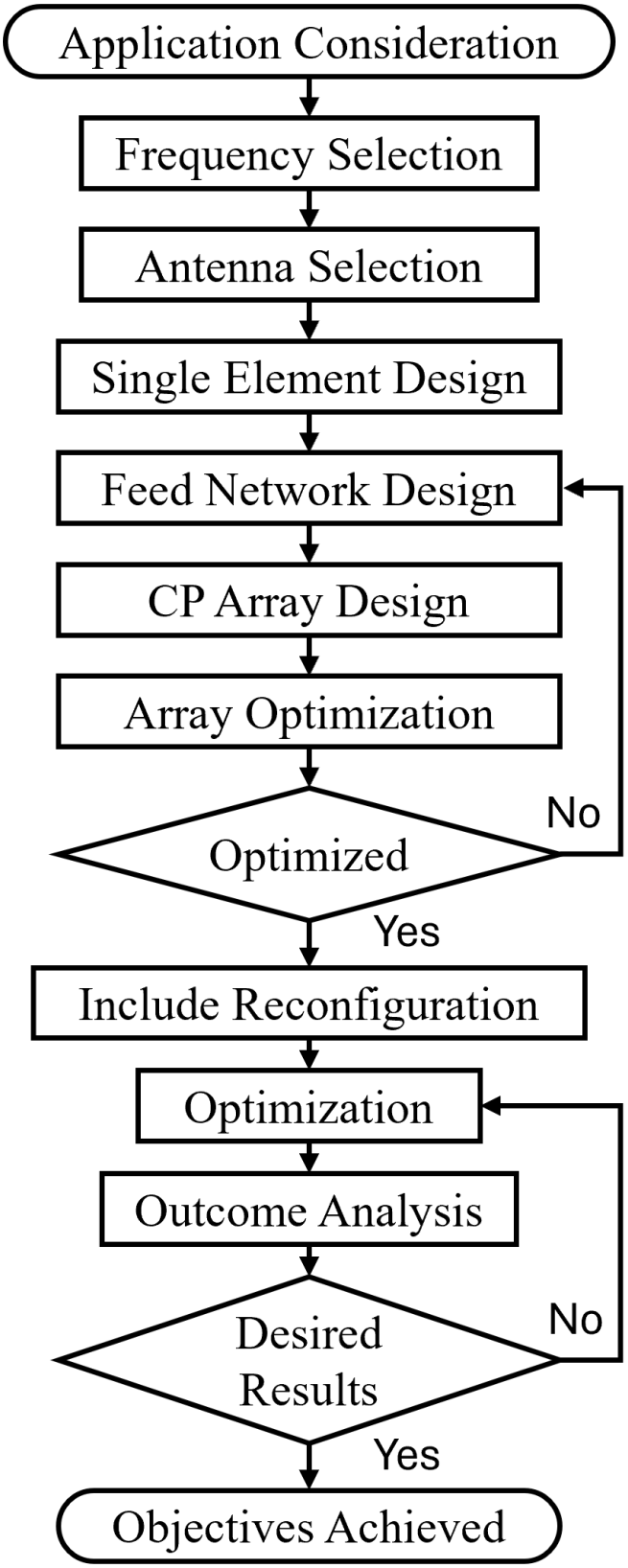


Figure 1.1: Flowchart for the research methodology of this thesis work.

1.5.1 Identifying Requirements

The initial phase involves determining the primary design requirements of the proposed antenna. These are the following:

- Operational frequency within the Ku-band
- Capability to utilize both RHCP and LHCP
- Assembling a compact and straightforward feed network
- Incorporating electrical switching to provide polarization reconfigurability
- Compact array configuration featuring a low profile and symmetrical beam distribution

These criteria enable you to make additional design decisions, such as the type of form to utilize, the substrate to select, and the method of animal feeding.

1.5.2 Selecting the Initial Geometry and Structure

The octagonal patch structure was selected due to its symmetrical configuration, which inherently facilitates circular polarization and is compatible with arrays. The array configuration is arranged in a planar format to facilitate construction and testing. Theoretical equations are employed to estimate the dimensions of the patch, the spacing between the elements, and the locations of the feed points.

1.5.3 Selecting the Appropriate Substrate and Material

We select appropriate dielectric substrate materials to achieve a balance among bandwidth, loss, and mechanical stability. The primary factors considered includes dielectric constant (ϵ_r), substrate thickness (h), loss tangent (tan δ). Materials such as Rogers RT/Duroid, FR-4 or Teflon can be evaluated based on their performance in the Ku-band and their availability.

1.5.4 Parametric Evaluation and Enhancement

A parametric sweep is conducted to evaluate the influence of critical elements such as patch size, feed offset, slot size, and ground structure on performance. This phase encompasses:

- Establishing the resonance frequency

- Minimizing return loss (S11)
- Determining the optimal axial ratio (AR) for circular polarization
- Ensuring sufficient gain and radiation efficiency

Optimization is conducted in stages utilizing full-wave simulation technology, Advanced Design System (ADS), in this case.

1.5.5 Designing and Streamlining the Feed Network

A fundamental feed mechanism is designed to operate with dual-sense circular polarization. This encompasses both-sided MIC (Microwave Integrated Circuit) configuration for compact and uniform feeding. Also, ensure that the impedance is calibrated to 50 Ω for optimal power transfer streamlining, and reducing the size of the feed network

1.5.6 Integration of Electrical Switching

Switching devices, like as PIN diodes, are included in the feed or ground plane to facilitate antenna reconfiguration. The switch is designed to alternate between RHCP and LHCP. The switching circuitry is designed to ensure that the radiation properties and mode isolation do not deteriorate excessively.

1.5.7 Comprehensive Wave Simulation and Evaluation

3D electromagnetic tools are utilized to replicate the entire antenna assembly, encompassing the switching components. The performance metrics examined include S11, also known as the reflection coefficient, axial ratio (AR) during various stages of polarization, and Radiation pattern (co-polarized and cross-polarized). Simulations will be conducted for both switching states to ensure that the system can be altered and that the polarization remains pure.

1.5.8 Performance Analysis and Finalization

Subsequent to the simulation, the results are juxtaposed with the design objectives. According to the research:

- We implement requisite modifications to the dimensions or biasing circuits.
- A record of performance exists at various frequencies and switching states.
- The definitive design is established for potential testing and construction.

1.6 Contribution

- The proposed antenna employs a more straightforward feed network to achieve circular polarization and the capability to alter its configuration.
- It significantly enhances satellite communication by improving system performance and increasing flexibility.
- The architecture facilitates dynamic polarization control, yielding several significant advantages:
- Minimizes polarization mismatch losses between the transmitter and receiver.
- Facilitates multiple services through the utilization of polarization diversity.
- Ensures the reliable transmission of signals despite variations in weather conditions or antenna orientation.
- The antenna's characteristics render it particularly advantageous for satellite systems requiring robustness and adaptability.
- This work serves as a valuable resource for future research on the design of reconfigurable antennas with variable polarization.

1.7 Thesis Outline

The focus of this thesis is to design circular polarized microstrip antenna using simple feed technique for various wireless applications including satellite communications. The content of the existing chapters in this thesis is briefly explained as follows:

In this chapter, a brief overview and introduction to the background of circular polarized antenna including literature review, a description of motivations, and the focus of the thesis work are presented. Also, the introduction section illustrates the necessity and advantages of reconfigurable circular polarized microstrip antennas.

In chapter 2, the basic geometry of the microstrip antenna and different antenna parameters are discussed. Moreover, design techniques of circular polarized microstrip antenna and different feed techniques are also illustrated.

In chapter 3, study on constructing a dual-sense CP microstrip antenna array using octagonal-shaped patches for Ku-band satellite applications is focused. The

study also intends to test the antenna's performance characteristics using electromagnetic (EM) simulation software. The antenna design, functioning mechanisms, and findings are also explained here in detail.

In chapter 4, the design and simulation of a 2×2 microstrip Circular Polarization Reconfigurable Array Antenna utilizing both-sided MIC technology is presented. This approach aims to simplify the feed network and the diode biasing network, enabling circular polarization reconfigurability. The antenna design, functioning mechanism, and results, accompanied by a discussion of each aspect are also discussed here.

In chapter 5, the overall discussion of the findings including contributions of the thesis work are discussed. Moreover, the scope of future work regarding this proposed antenna is also discussed here briefly.

Chapter 2

Antenna Theory

In order to provide context for the work done in this dissertation and to set the stage for the contributions that will be discussed in later chapters, This chapter offers a concise summary of the antenna basics emphasizing on circular polarization antennas. Planar microstrip antennas and a brief review of circular polarization techniques, feed network and configurability techniques will be discussed. This chapter also covers the parameters and the fundamental properties of the antenna and a summary of other aspects.

2.1 What is Antenna

An antenna is a device that transforms electrical impulses into electromagnetic waves and vice versa. This is just like a transducer. This is the most important component in wireless communication. If we consider a simple wire, by itself, it is not an antenna, even if electromagnetic waves from nearby transmitters induce currents in it [55]. But when this wire is connected to a VHF radio and improves signal reception, it then functions as an antenna. Hence, an antenna is not merely a physical object, but a component of the system that effectively facilitates the transmission or reception of electromagnetic wave.

There are several types of antenna exist tailored for specific applications and operating environments. Wire antennas are the most familiar and widespread due to their simplicity and visibility [55]. If this wire antenna forms a loop can be considered a loop antenna. Other simple form of antenna is aperture antenna is a class of antenna that radiates or receives electromagnetic energy through a physical opening (aperture), typically located at the end of a waveguide or cavity [56].

In scenarios where the desired radiation pattern cannot be achieved by a single element, an array of multiple radiating elements can be employed. By configuring

these elements with precise electrical and geometric arrangements, the resulting radiation can be steered or enhanced in specific directions. Arrays offer high gain and directivity and are widely used in radar and satellite systems. Other forms of antenna can be possible, like a lens antenna [57], a reflector antenna [58]. Each type has its specific advantages.

2.2 Microstrip Patch Antenna (MPA)

MPA gained popularity during the 1970s, particularly in space-based systems. A metal patch is attached to a grounded dielectric base to make them.

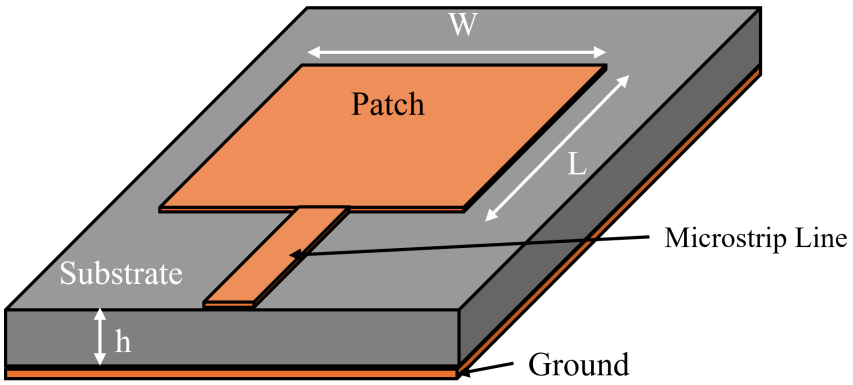


Figure 2.1: An MPA

Despite having limited bandwidth, low radiation efficiency, and high Q-factor, these antennas are known for several advantages over other antennas, such as,

- Low profile and conformability
- Compatibility with Monolithic Microwave Integrated Circuits (MMICs)
- Simple, cost-effective fabrication via printed-circuit techniques
- Versatility in polarization, frequency, and radiation patterns
- Easy to manufacture with PCB techniques

The simplest type of microstrip antenna consists of two conducting layers in parallel, separated by a dielectric medium, also known as the dielectric substrate as shown in Figure 2.1. The upper conducting layer, also known as the patch, and the bottom conducting layer on the opposite side of the dielectric substrate make up the reflecting plane. The radiation comes from fringe fields that pass through the exposed sidewalls. Rectangular, square, and circular geometries are

the most often utilized among countless shapes owing to their ease of fabrication, analysis, and performance forecasting. The patch's shape and excitation mode are chosen to control parameters such as frequency, polarization, and radiation pattern.

Microstrip patch antenna can be fed in different ways. An indirect or direct feedline contact stimulates the patch to radiate. Feeds carry electromagnetic radiation from the source to the patched region. By fringing effect, energy radiates into space from the patch. Microstrip patch antennas feed signals in various ways. Two feeding methods exist: contacting and non-contacting [33].

The non-contacting approach utilizes electromagnetic field coupling to deliver power from the microstrip line to the radiating patch. In the contacting approach, a connector transmits radio frequency power directly to the patch.

The four most common feeding methods are coaxial, microstrip line [59], aperture-coupled, and proximity-coupled [60]. Different feeding methods affect antenna bandwidth, radiation pattern, polarization, gain, and impedance.

2.3 Reconfigurable Antenna

A reconfigurable antenna is one that can dynamically alter its frequency and radiation pattern in a controlled and reversible manner. Reconfigurable antennas contain an internal mechanism (such as varactors, RF switches, mechanical actuators, tunable materials, etc.) that enables the intentional redistribution of RF currents across the antenna surface, leading to reversible alterations in its characteristics to facilitate a dynamic response. The ability of reconfigurable antennas to reconfigure is utilized to optimize antenna performance in dynamic situations or to meet evolving operational needs. The three main categories of reconfigurable antennas are polarization, radiation pattern, and frequency.

2.3.1 Categories of Reconfigurable Antennas

2.3.1.1 Frequency Reconfigurable

Frequency reconfigurable antennas are capable of dynamically modifying their operational frequency. In Figure 2.2, frequency reconfiguration is shown. Generally, frequency reconfigurability can be achieved by electrically or physically altering the antenna size through the use of tuneable materials, RF switches, or impedance loading [61]. A frequency reconfigurable antenna is depicted in Figure 2.2. When the diode is in the ON state, the antenna electrical length increases and the resonance occurs at lower frequency. Again, when the diode is in the

off state, the antenna electrical length is reduced and the resonance frequency is higher.

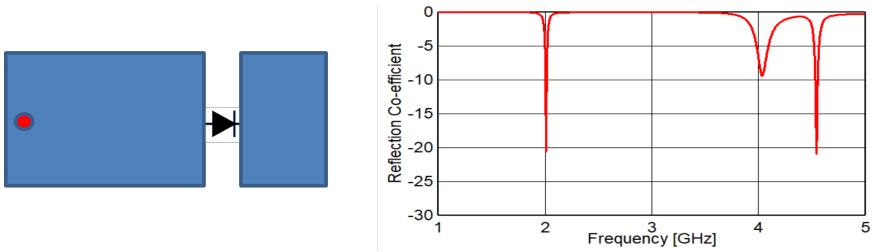


Figure 2.2: Frequency reconfigurable antenna structure and reflection coefficient [61].

2.3.1.2 Pattern Reconfigurable

The radiation pattern of the reconfigurable antenna is based on changes in the spherical radiation distribution. A radiation pattern reconfigurable antenna is shown in Figure 2.3. By rearranging parasitic strip lines that are positioned around a radiating dipole and using PIN diodes to reflect metal pieces beneath the dipole, the antenna's main beam can be switched between four different elevation plane directions, roughly between 90° (right end-fire) and 270° (left end-fire). In order to boost antenna gain, beam steering—the most complex application—involves guiding the direction of maximum radiation.

2.3.1.3 Polarization Reconfigurable

The corner truncation method allows polarization reconfigurable antennas to switch between several polarization modes. Figure 2.4 displays HP, VP, LHCP, and +45° LP, contingent on the diode ON or OFF condition and activation ports. A portable device's ability to switch between horizontal, vertical, and CP can help lower polarization mismatch losses.

2.3.2 Switching Techniques for Reconfigurable Antennas

The design of reconfigurable antennas presents important challenges for antenna designers compared to conventional antennas [64]. This is a laborious procedure that considers several factors, including as achieving a good impedance match, stable radiation, and a good gain in all of the antenna's operating modes [65]. When constructing a reconfigurable antenna, it is necessary to decide on the reconfiguration attribute and reconfiguration technique at the beginning of the design process [66]. Several successful implementation strategies have been put

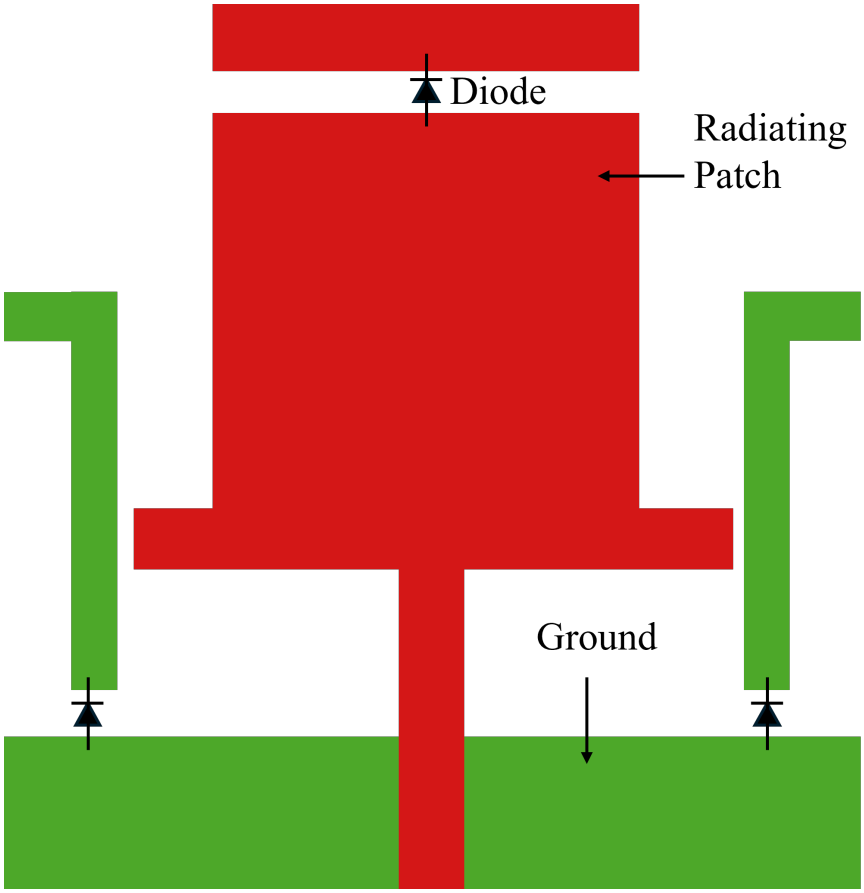


Figure 2.3: A pattern reconfigurable antenna [62].

out to illustrate reconfigurable antennas in a variety of wireless systems, including satellite, multiple-input multiple-output (MIMO), and cognitive radio communications. These strategies fall into the following categories [67]:

- Electrical reconfiguration
- Optical reconfiguration
- Physical reconfiguration
- Reconfigurable antennas with smart materials

2.3.2.1 Electrical Reconfiguration

Electronic switching components such as varactors, MEMS, or PIN diodes alter the antenna's characteristics using this type of reconfiguration technique. These switches enable the modification of the antenna structure, which modifies the distribution of surface current as well as the basic characteristics of the antenna, including frequency, radiation pattern, and polarization. A basic reconfigurable

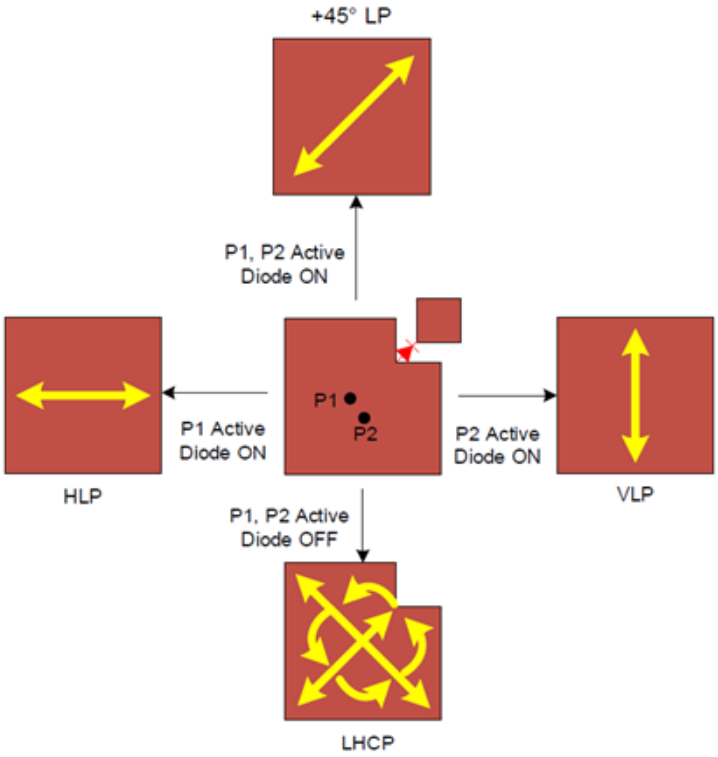


Figure 2.4: Polarization reconfigurable antenna with four different polarization states [63].

antenna with switching parts like this has attracted a lot of scientific attention [68, 69]]. A number of methods—each having pros and cons—are described for obtaining the pertinent reconfigurability function for electrically reconfigurable antennas utilizing PIN diodes, varactors, or MEMS switches.

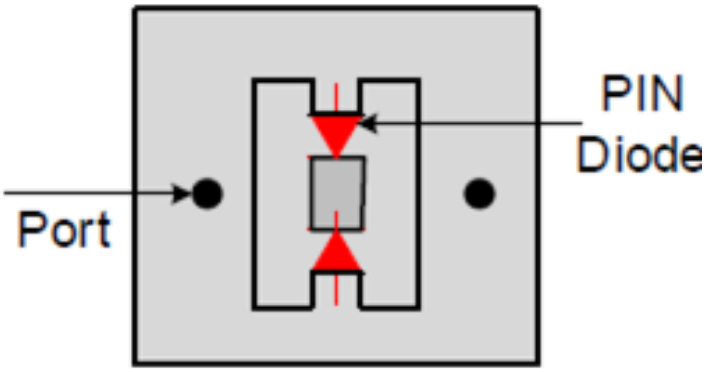


Figure 2.5: Reconfigurable antenna utilizing PIN diodes [70].

PIN Diodes PIN diodes are commonly employed as switching components in various wireless systems. Reconfigurable antennas necessitate an additional

dimension for the direct current (DC) and radio frequency (RF) components, which must be considered during the antenna design process [70], as illustrated in Figure 2.5. PIN diode switching is prevalent in RF and microwave systems; nonetheless, it presents various challenges. It requires substantial forward bias current, resulting in increased power consumption, and its performance fluctuates with temperature. At low frequencies, it exhibits increased insertion loss and reduced switching rates due to the charge storage in the intrinsic layer. Furthermore, it possesses intricate biasing circuitry and may exhibit non-linear behavior under specific conditions, potentially distorting signals. It cannot accommodate as much power as mechanical switches; hence, it is less suitable for high-power applications.

Tuneable Varactors Varactors can be incorporated into the reconfigurable antenna's feeding line or radiating patch where a direct DC voltage supply is necessary. Adjusting the varactor's voltage levels alters its capacitance, which in turn adjusts the antenna's performance. One popular method for achieving the frequency tuning function is to incorporate varactors into reconfigurable designs. In [71], a varactor-loaded reconfigurable filter is shown, as seen in Figure 2.6. The varactor has a small dynamic range and is nonlinear. A sophisticated bias circuitry is also needed. It does, however, have continuous tuning properties and a tiny current flow when compared to other active elements like a PIN diode or MEMS.

MEMS Research interest in reconfigurable antennas with MEMS switches has grown significantly. MEMS switches are gadgets that create an open or short circuit in radio frequency circuits by means of mechanical motion. MEMS switches can be manufactured in several configurations based on the signal path (series or shunt), actuation mechanism (electrostatic, thermal, or magnetostatic), type of contact (ohmic or capacitive), and structure (cantilever or bridge). Several actuation systems, including electrostatic and magnetostatic ones, can produce the force needed for mechanical movement. Radar systems, network analyzers, satellite communication systems, and base stations have all used RF MEMS switches with a 20 W maximum capacity and a 1012 cycle [72]. Figure 2.7 shows an antenna using a MEMS switch for reconfiguration.

2.3.3 Optical Reconfiguration

Photoconductive switches, constructed from semiconductor materials such as silicon or gallium arsenide, underpin this type of reconfiguration technology [73, 74].

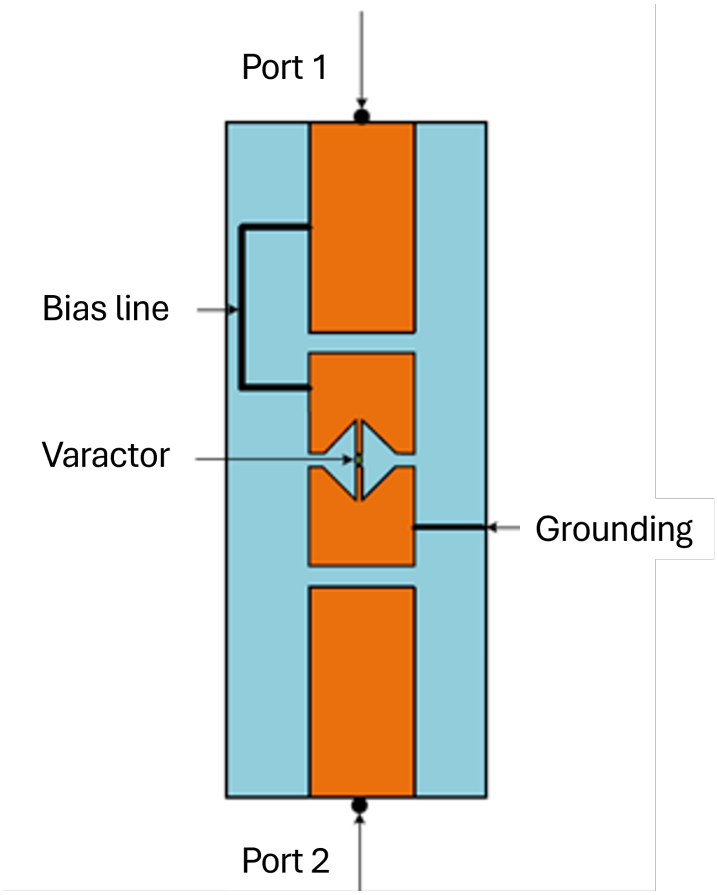


Figure 2.6: Reconfigurable filtena utilizing varactor [71].

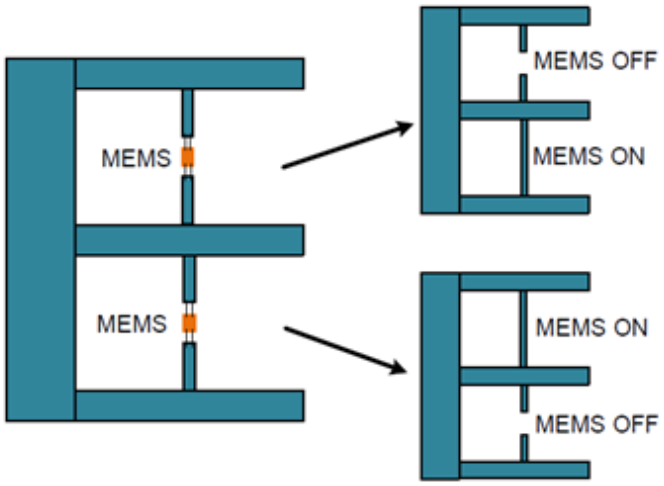


Figure 2.7: Reconfigurable antenna utilizing RFMEMS for two CP states [72].

In contrast to electrical switches, bias lines offer higher isolation and fewer interference, while photoconductive switches eliminate the need for metallic wires in optical reconfiguration. They also have incredibly quick switching speeds—

nanoseconds to be exact. The operational bandwidths and radiation pattern of an antenna can be optically controlled by using photoconductive switches.

2.3.4 Mechanical Reconfiguration

In mechanical reconfiguration, the antenna's principal radiator can be mechanically altered to provide diverse functionalities [75]. This type of reconfigurable antenna necessitates the incorporation of active elements, biasing systems, or swathing processes, unlike other reconfiguration methods that utilize switches. Nonetheless, this type of antenna has restricted performance adaptability, making it difficult to incorporate multifunctional reconfigurable features [76]. Figure 2.8 shows a waveguide-fed mechanical reconfiguration antenna with metallic grooves and flaps.

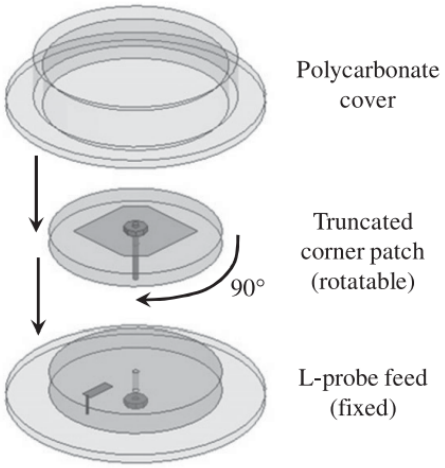


Figure 2.8: Illustration of the mechanically reconfigurable patch antenna exhibiting polarization variety [76].

2.3.5 Reconfigurable Antennas With Smart Materials

Smart material-based reconfigurable antennas are a very new field of study, and there are still a number of issues that need to be looked into, including efficiency and dependability. But recently, various designs with noteworthy accomplishments have been published [77].This reconfiguration technology enables modification of antenna properties by injecting fluid into a hollow space behind the antenna, hence altering the substrate's relative electric or magnetic permittivity [78].

2.4 Circular Polarization Techniques

It is possible to design microstrip antennas for circular polarization by employing dual feeds, truncating corners, or adding perturbations. In order to achieve circular polarization, these methods seek to induce two orthogonal modes with identical amplitudes and a 90-degree phase shift.

2.4.1 Truncating Corners

Truncating a rectangular patch antenna's corners is a popular technique. For instance, truncating the corners at a 45-degree angle to the feed can aid in the creation of circular polarization. Figure 2.9 shows a corner-truncated patch with dual feed antenna.

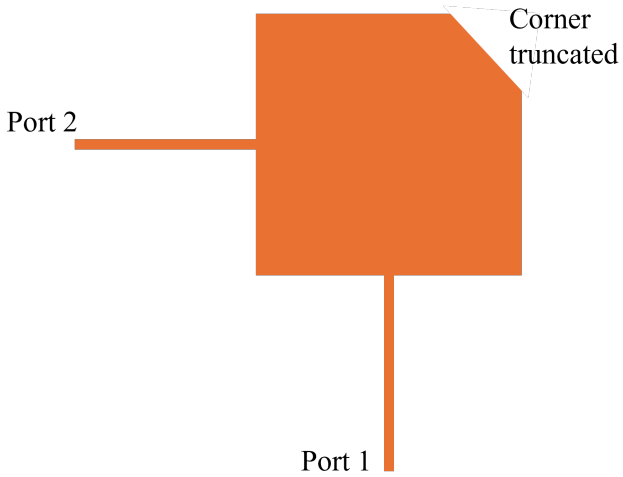


Figure 2.9: A corner-trimmed, dual CP, patch antenna. [79]

2.4.2 Introducing Perturbations

To alter the current distribution and produce the required phase difference between the orthogonal modes, perturbation segments, such slots or cuts, can be used into the patch design. Figure 2.10 shows the antenna coniguration for circular polarization with corner perturbations.

2.4.3 Dual Feeds

Circular polarization can be achieved by supplying the antenna with two signals of equal magnitude that are 90 degrees out of phase. Hybrid couplers can be

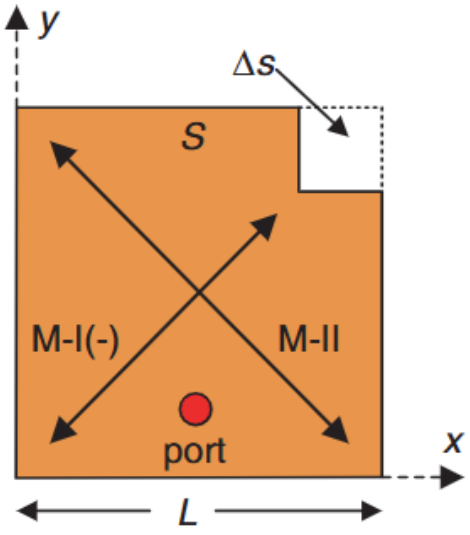


Figure 2.10: Configuration of a negatively perturbed circularly polarized antenna [23].

employed to achieve this. Figure 2.9 shows the dual feed technique to acquire CP. If not corner truncated, then an external phase shifter is required.

2.4.4 Adjusting Patch Dimensions

The polarization characteristics can be modified by varying the microstrip patch's physical dimensions, including its length and breadth.

2.4.5 Feeding With Probes

Circular polarization can also be produced by inserting a probe into the patch using the probe feeding technique. Figure 2.11 shows an antenna achieving CP with four probe feeds. Prob feeding requires an external phase shifter.

2.5 Circular Polarized Array Antenna

When each element in an antenna array emits circular polarization and their excitations are appropriately phased, the array achieves circular polarization. Arrays enhance gain and reconfigurability, both of which are crucial for satellite applications where polarization purity and directionality are essential [81]. Typically, there are two primary methods to achieve the appropriate polarization properties in a CP antenna array. In the initial process, each segment of the array

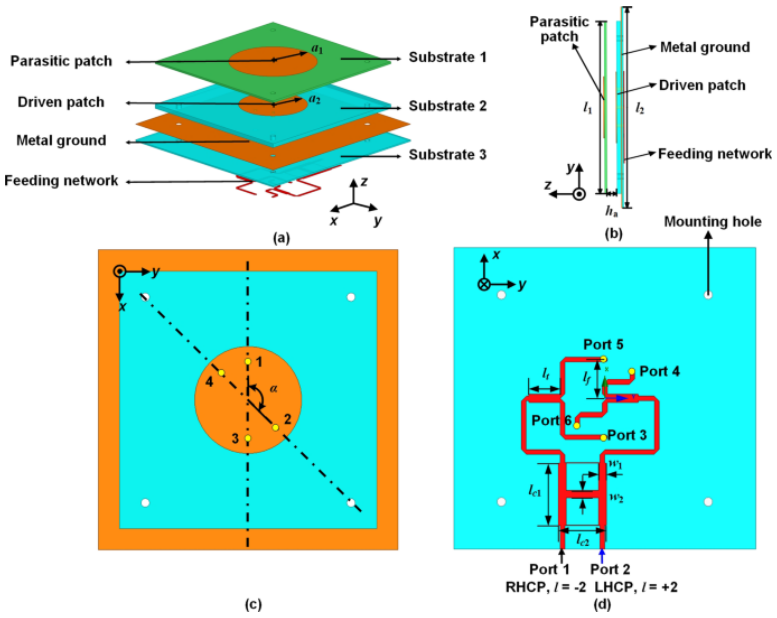


Figure 2.11: Configuration of the quad-feed patch antenna. (a) Exploded view. (b) Side perspective. (c) Superior perspective devoid of the parasitic patch. (d) Bottom perspective [80].

is independently constructed to produce circular polarization. This is typically accomplished using techniques such as corner truncation, perturbation slots, or dual-feed configurations with a 90° phase difference. This method ensures that each component maintains an optimal axial ratio, hence enhancing the array's overall circular polarization performance [82].

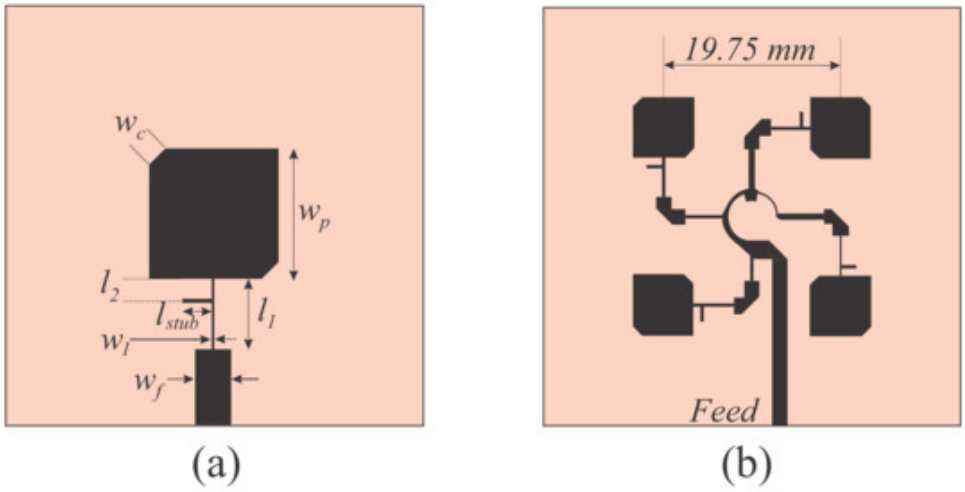


Figure 2.12: Configuration of (a) Single element. (b) 2×2 sequential rotation CP array [83]

In the second way, the antenna elements exhibit natural linear polarization. A well designed feed network subsequently generates circular polarization at the

array level. In this configuration, the feed network modifies the phase and amplitude of the excitation signals to ensure that the array's resultant radiation pattern produces circular polarization. Common techniques include sequential rotation, wherein elements are physically rotated and excited with progressively larger phase shifts (e.g., 0°, 90°, 180°, and 270°); delay lines, which introduce phase disparities; and orthogonal feeding, utilizing two perpendicular feed points with a quadrature phase difference [84]. Figure 2.12 shows a sample corner truncated CP antenna and a sequential feed CP array antenna.

This form of array-level synthesis facilitates the simplification of each element's design, enhances manufacturability, and enables polarization reconfigurability. Both methods aim to create a uniform circularly polarized wavefront, which is crucial for satellite communication systems as it mitigates polarization mismatch resulting from satellite rotation or atmospheric variations [85].

2.6 Both-sided MIC Technology

A creative technique that is applied in the process of creating antennas is known as microwave integrated circuit (MIC) technology. This technology is also sometimes referred to as both-sided MIC technology.

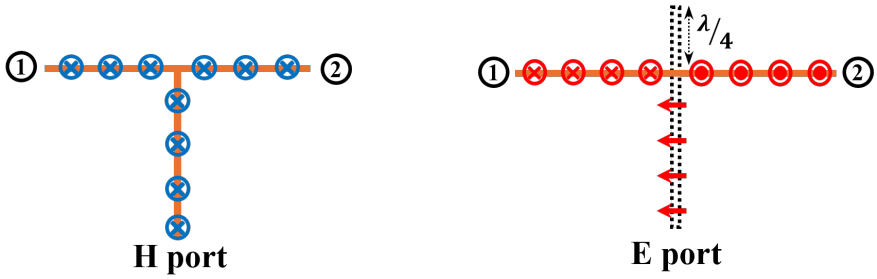
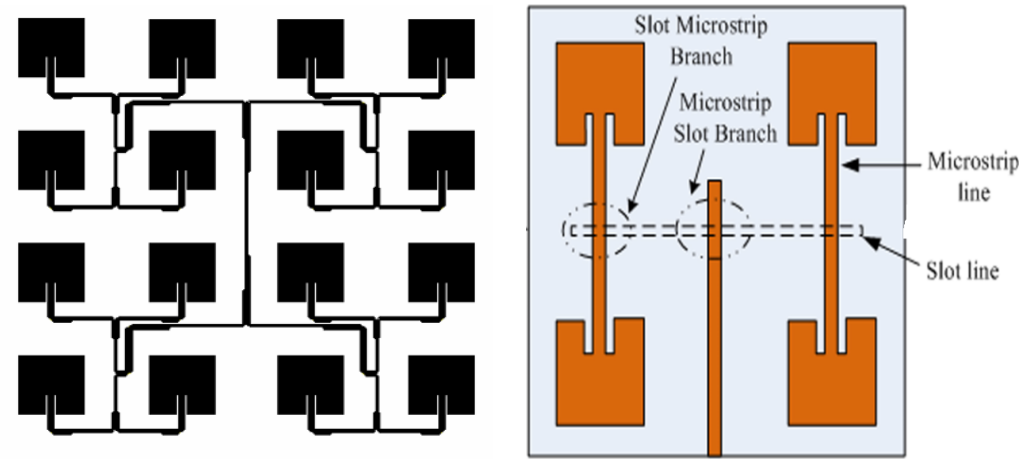


Figure 2.13: Applications of double-sided MIC technology: E-plane divider and H-plane divider.

It is utilized in the process of integrating a microwave circuit into an antenna by utilizing both sides of the substrate. Additionally, it possesses a significant amount of design freedom [86], in addition to having improved antenna performance. In-phase dividers (H port) and out-of-phase dividers (E port) are both capabilities that can be achieved by the utilization of the technology known as both-sided MIC as seen in Figure 2.13.

2.7 Array Antenna: Simple Feed Approach

The utilization of double-sided microwave integrated circuit (MIC) technology in a microstrip patch array antenna provides a more simple and efficient feeding structure than the traditional microstrip line-fed method. In conventional designs, the feed network occupies the same plane as the radiating patches, resulting in routing complexity, heightened cross-coupling, and challenges in impedance matching due to physical limitations and restricted layout flexibility. Conversely, dual-sided MIC technology positions the feed network on the substrate's opposite side, employing vertical vias to energize the patches. This separation facilitates a more compact arrangement, diminishes extraneous radiation from the feed lines, and streamlines impedance matching by permitting more adaptable feed network designs free from interference by the radiating devices. Moreover,



(a) Conventional Microstrip line Feed Array Antenna

(b) Array Antenna using both-sided MIC technology

Figure 2.14: Geometry of (a) an array antenna with a conventional feed approach [87], (b) using both-sided MIC technology [88].

it provides volumetric benefits through multilayer integration, minimizing the total footprint and profile of the antenna system—rendering it suitable for small and low-profile applications where space is limited. Figure 2.14 shows an array antenna structure with a conventional microstrip line feed and an array antenna using double-sided MIC technology. It is clear from the figure that using double-sided MIC technology enables the design to make the feed network simpler. Also, the imepdance matching of the feed network gets simpler by this technique by forming microstrip-slot and slot-microstrip junctions.

2.8 Importance of CP in Satellite Communication

Satellite communication relies on CP due to its technological and practical benefits over linear polarization. Circularly polarized antennas reduce losses from satellite and ground station antenna polarization discrepancies. Satellites and ground stations don't always align perfectly, and their relative locations can alter as satellites move or rotate. CP makes antenna orientation for signal transmission or reception less important. This increases satellite and ground station design flexibility. CubeSats and mobile terminals with poor attitude control benefit from it [89]. Figure 2.15 shows the network topology for satellite communication. The figure also shows the Faraday rotation effect on polarization due to charges in the ionosphere and Earth's magnetic field.

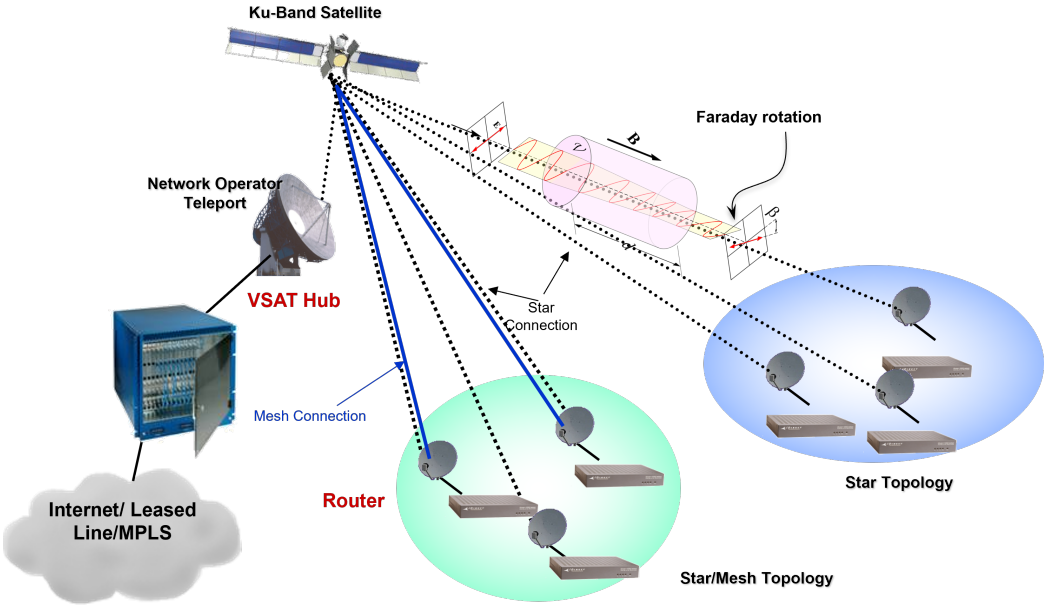


Figure 2.15: Network topology and Faraday rotation effect in satellite communication system.

CP signals are less susceptible to multipath interference and reflections. A circularly polarized wave reverses its polarization sense when it hits a surface. This shows that the receiving antenna mostly ignores the reflected signal, decreasing interference and improving signal integrity [90]. RHCP and LHCP allow satellites to transmit two data streams on the same frequency, increasing data throughput. Essentially doubling the data rate. Earth observation, research missions, and real-time telemetry require large data sets [91].

For circularly polarized transmissions, the antenna does not need to be aligned

with the satellite's polarization angle while boresighting. This helps ground stations and mobile terminals locate and monitor signals. CP is used in X-band and Ka-band. This simplifies new system integration and satellite infrastructure compatibility. They also preserve signal quality and performance even when satellite or ground station mobility, weather, or impediments impair the connectivity [92].

2.9 Antenna Parameters

2.9.1 Radiation Pattern

The radiation pattern of an antenna is defined as a mathematical function or graphical representation of the antenna's radiation characteristics in relation to spatial coordinates. The characteristics of radiation include power flux density, radiation intensity, field strength, directivity, phase, and polarization. The radiation pattern is typically evaluated in the far-field region and expressed as a function of angular coordinates. Figure 2.16 shows the radiation pattern of an antenna.

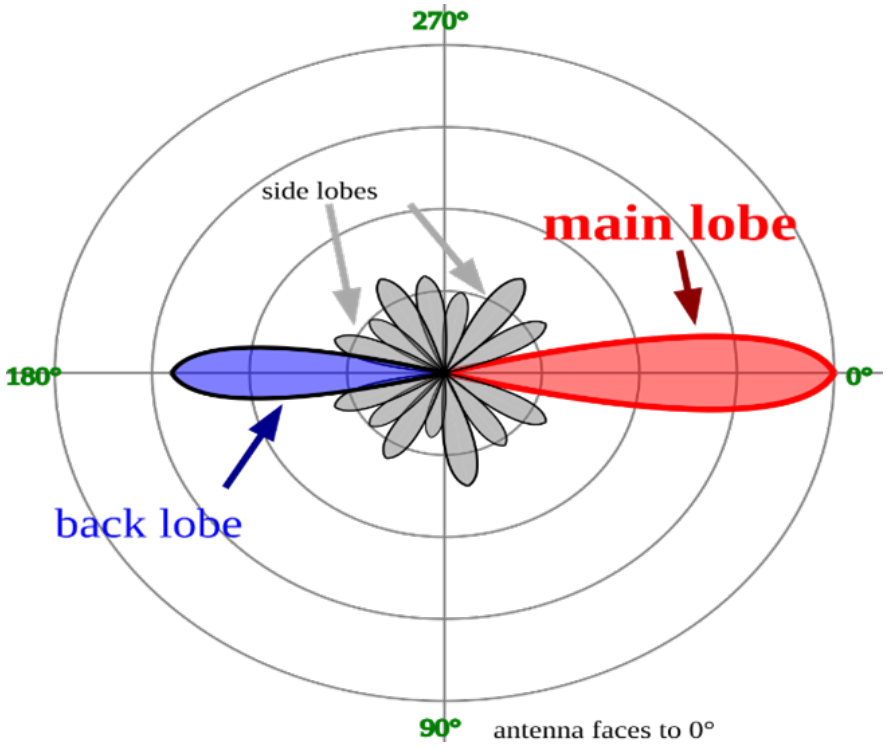


Figure 2.16: Radiation pattern of a dipole antenna [93]

The paramount characteristic of radiation is the spatial distribution of emitted energy relative to an observer's location on a constant-radius sphere. A record of the electric or magnetic field intensity at a certain radius is referred to as the

field pattern, whereas a graph depicting the spatial fluctuation of power density at the same radius is termed the power pattern.

- The field pattern (linear scale) represents the magnitude of the electric/-magnetic field versus angle.
- The power pattern (linear scale) represents the square of the field magnitude versus angle.
- The power pattern (in dB) represents the logarithmic (in decibels) value of power as a function of angle.

2.9.2 Directivity

Directivity quantifies the concentration of radiated power in a specific direction compared to an isotropic radiator. Defined by IEEE (1983) as:

> "The ratio of radiation intensity in a given direction to the average radiation intensity over all directions."

Figure 2.16 shows that the antenna is directed in the right side as the main lobe is in the right direction. The directivity can be expressed as,

$$\text{Directivity} = \frac{U_{max}}{P_{rad}/4\pi} \tag{2.1}$$

Where, U_{max} = Maximum radiation intensity (W/sr), P_{rad} = Total radiated power (W)

2.9.3 Antenna Efficiency

Antenna efficiency quantifies the effectiveness of an antenna in transforming input power into radiated power. It can be quantified by the ratio of emitted power to the total input power. An ideal antenna would exhibit 100% efficiency, however a competent antenna generally transmits 50–60% of the power provided to it.

2.9.4 Gain

Gain represents an antenna's ability to radiate power in a given direction, considering both directivity and efficiency:

$$\text{Gain } = 4\pi\frac{U(\theta,\varphi)}{P_{\text{in}}} \tag{2.2}$$

Where, $U(\theta, \varphi)$ is radiation intensity and P_{in} is the total input power of antenna.

However, this gain does not take into account the reflection or mismatch losses. When reflection losses are included, it is defined as absolute gain.

2.9.5 Bandwidth

Bandwidth refers to the frequency range within which the antenna sustains satisfactory performance according to specific requirements, such as:

- Input impedance
- Gain
- Radiation pattern
- Polarization
- Beamwidth

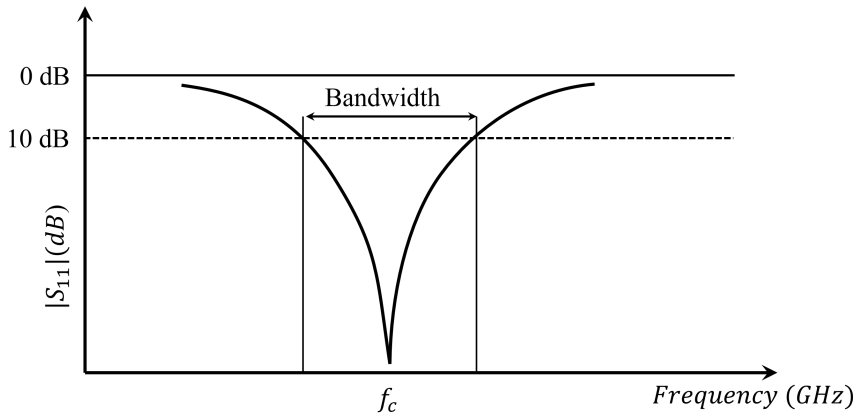


Figure 2.17: Bandwidth of an antenna [94]

Bandwidth is a measure over which an antenna can perfectly operate. It is the difference between the upper cut-off frequency (f_h) and the lower cut-off frequency (f_l) to the center frequency ($f_\circ$). It can be expressed as follows [95]:

$$Bandwidth, BW = \frac{f_h - f_l}{f_\circ} \tag{2.3}$$

where, $f_\circ = \frac{f_h + f_l}{2}$

- **Impedance bandwidth**: Relates to VSWR or return loss.
- **Pattern bandwidth**: Relates to gain, beamwidth, polarization, etc.

2.9.6 Polarization

Polarization is a significant consideration in antenna design and its use. The polarization of an antenna in a specific direction is defined as the polarization of the wave emitted (or transmitted) by the antenna in that direction, as seen in the Figure 2.18. In the absence of defined direction, polarization is conventionally assumed to align with the direction of maximum gain. The polarization of the emitted field might differ by direction, resulting in various segments of the radiation pattern displaying distinct polarization characteristics [96].

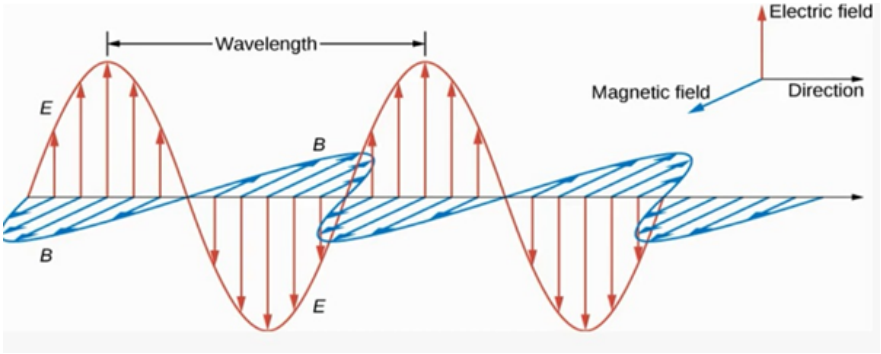


Figure 2.18: Electromagnetic wave propagation [97]

The polarization of an electromagnetic wave refers to the temporal variation in the orientation and relative amplitude of the electric field vector. It specifically denotes the path delineated over time by the apex of the electric field vector at a stationary point in space, as perceived in the direction of wave propagation. This curve illustrates the characteristics of polarization—linear, circular, or elliptical.

In the far field, the emitted wave from an antenna can be represented as a locally planar wave. The polarization at a specific position is considered the polarization of this comparable plane wave. As the radial distance grows, the curvature of the wavefront decreases, resulting in the wave becoming locally planar [96].

The polarization of a received wave by an antenna is defined as the polarization of an incident plane wave from a specified direction that results in maximum power transfer to the antenna terminals. Thus, polarization alignment between the transmitting and receiving antennas is critical for optimal communication. Polarization types include,

- Linear Polarization: The electric field vector maintains a constant direction (e.g., vertical or horizontal).
- Circular Polarization: The electric field vector rotates with constant magnitude, forming a circle.

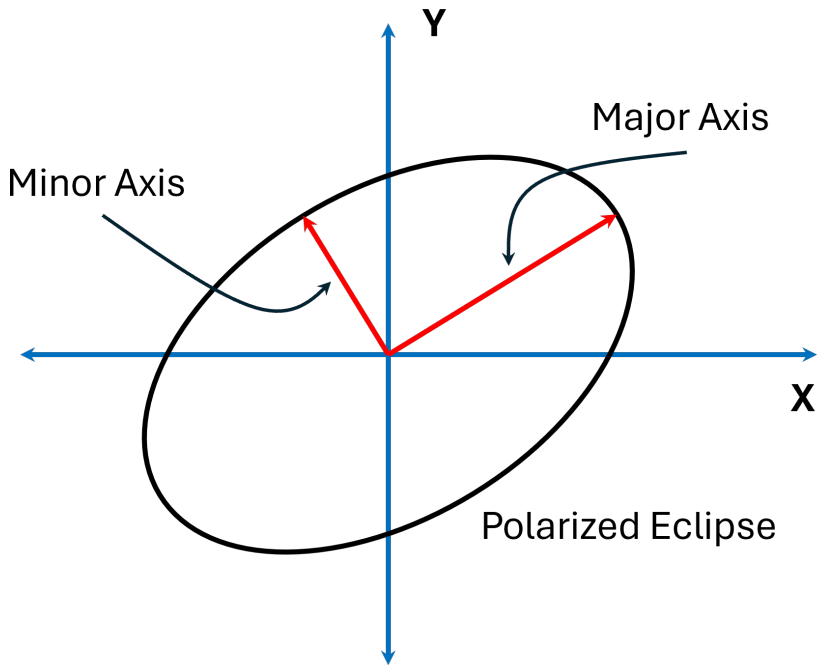


Figure 2.19: Axial Ratio. [98]

- Elliptical Polarization: The general case where the electric field vector traces an ellipse.

Circular and linear polarizations are special cases of elliptical polarization. The sense of rotation (clockwise or counterclockwise) determines whether the polarization is right-hand or left-hand, respectively. At each point on the radiation sphere, the field is decomposed into:

- Co-polarization: The intended or desired polarization component.
- Cross-polarization: The orthogonal (undesired) component.

In the case of linearly polarized antennas, co-polarization is often defined by fixing the orientation of the electric field vector at a reference point (usually a pole), and ensuring it maintains a consistent angle relative to great circle paths on the sphere.

2.9.7 Axial Ratio (AR)

Figure 2.19 illustrates the definition of the axial ratio (AR), which is the ratio of the polarization ellipse's major to minor tones. An ellipse's orientation is established by the angle formed between its major axis and a reference axis, usually the vertical or horizontal axis. Electromagnetic (EM) waves emitted

by antennas generally display elliptical polarization, which includes, as special examples, linear and circular polarization.

An indicator of the wave's resemblance to pure circular or linear polarization is the AR's magnitude. Depending on whether the polarization is with the major or minor axis, the AR for linearly polarized (LP) waves tends toward infinity or zero, while for circularly polarized (CP) waves, the major and minor axes are equal in length, resulting in an AR of 1 (or 0 dB on a logarithmic scale).

In reality, though, perfect circular polarization is not possible. Consequently, it is generally agreed that the highest limit for circular polarization is an AR threshold of 3 dB. In other words, if an antenna's AR is less than or equal to 3 dB, it is said to be circularly polarized.

Chapter 3

Simple Feed Dual Circular Polarized Array Antenna

This chapter describes a 2 × 2 circularly polarized octagonal microstrip patch array antenna for Ku-band frequencies. A simple feed network architecture was selected to improve the compactness and efficacy of the design. This design does not employ complicated multilayer or hybrid feeding methods. It employs a single-feed, single-layer microstrip line feed antenna design in the Ku band frequency, which can help in simplifying the antenna design in satellite communication. The antenna is designed on a Teflon substrate. Slot line on antenna ground plane allows both-sided MIC arrangement with parallel and series power dividers. Orthogonal excitation of each patch is possible when the series divider microstrip line splits into two. Quarter-wavelength phase shift between orthogonal excitations is caused by the length difference of the microstrip lines supplying the patches. A meander line is integrated into the microstrip line along the diagonal patch to align all array components' horizontal field lines. Position of the meander line on the microstrip line arm determines dual polarization senses. Detailed explanations of antenna design, functioning mechanisms, outcome explanations, and conclusions are provided in the subsequent sections of this chapter.

3.1 Design and Functioning Mechanism

This section examines the intricacies of the feed network design for the proposed microstrip patch array antenna, as well as a comprehensive analysis of the antenna itself. Subsequently, the explanation of the circular polarization mechanisms is presented.

3.1.1 Antenna Geometry

A Teflon substrate with a relative dielectric constant, ε_r of 2.15 and a thickness of 0.8 millimeters is used to construct a feed network for a four-element octagonal patch array. This is the first step in the initial construction process. Initial optimisation of the feed network is performed, with the frequency of operation within the Ku-band spectrum being taken into consideration. After that, the patch is included in the design within the frequency band that was defined. The dimensions of the octagonal-shaped patch were evaluated using the formula for square patch dimensions. The length (l_p) of the octagonal patch is equivalent to the length of a square patch at the same frequency. There is an octagonal patch that is incorporated into the design, and its diagonal length is 8.7 mm. The patch and the feed network are both currently located on the surface of the substrate. Within the ground plane, a slot line with a measurement of 0.2 millimeters is formed in order to assist the functionality of parallel and series dividers. Table 3.1 contains the ideal measurements for the parameter dimensions seen in the figure.

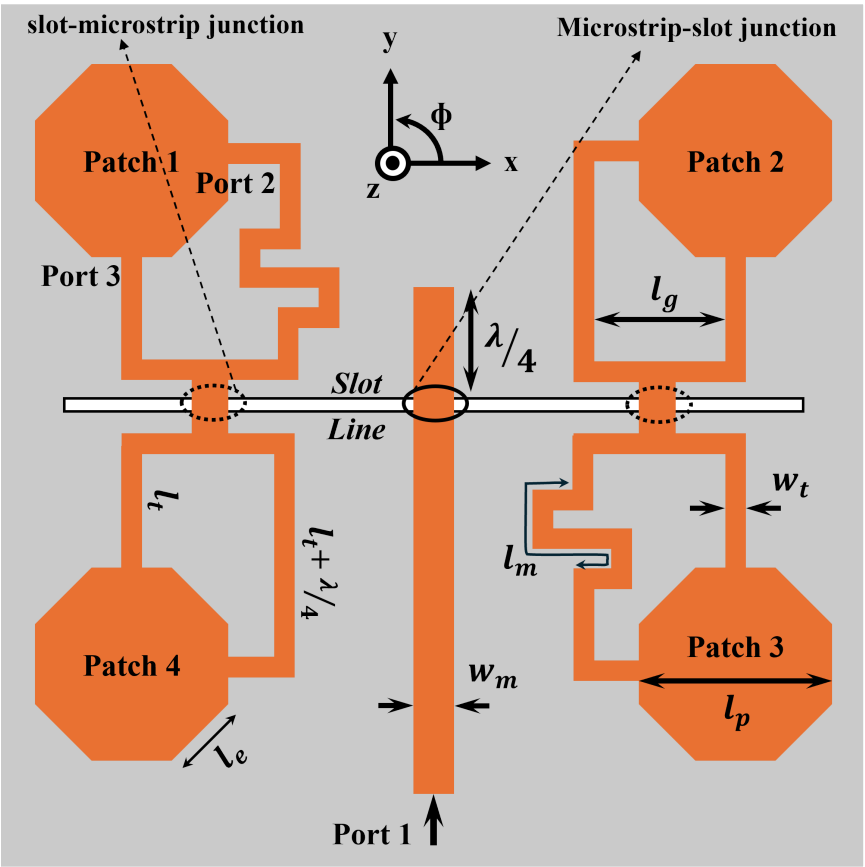


Figure 3.1: Structure of the proposed circular polarized 2×2 microstrip patch array antenna.

The process takes place as a result of the formation of the microstrip-slot and slot-microstrip junctions, respectively. As depicted in Figure 3.1, the microstrip line divides into two parallel microstrip lines, forming a parallel divider. This occurs from the slot-microstrip junction. In order to achieve orthogonal excitation of each patch that is attached to the ends of the microstrip lines, the two microstrip lines create the necessary conditions. Using a microstrip line on the upper surface and a slot line within the ground plane, the figure displays the power divider configured in parallel and series arrangements. The microstrip line is represented by a solid line circle, and the slot line is represented by a dashed line circle. In order to provide efficient power distribution at the junctions, the microstrip-slot and slot-microstrip junctions make use of the possibilities offered by double-sided microwave integrated circuit technology.

Table 3.1: Dimension and design parameter of the proposed microstrip antenna array.

Parameter	**Value (mm)**
Patch length, l_p	8.7
Microstrip line width, w_t	0.8
Ground plane slot line width	0.2
$\lambda/4$ Microstrip line length	4.9
Meander line length, l_m	12
Parallel Microstrip line gap length, l_g	6
Microstrip patch edge length, l_e	3.6
Microstrip line length, l_t	10.25
Microstrip line width, w_m	2.4
Microstrip line width, w_t	0.6

3.1.2 Functioning Mechanism

The layout of the field lines is depicted in Figure 3.2-3.4, which also provides a discussion of the key principles that are involved in achieving CP through the utilization of this array design. It is important to have two orthogonal excitations with a quarter-wavelength phase difference in order to accomplish the goal of achieving CP. It is demonstrated in the illustration that the orthogonal excitation that is applied to each patch is sufficient to supply the orthogonal excitation that is required for each patch. An illustration of the field lines that correlate to each patch may be found in Figure 3.2.

Following its division into two signals of identical amplitude and in phase at the microstrip-slot junction, the signal then makes its way from the port to

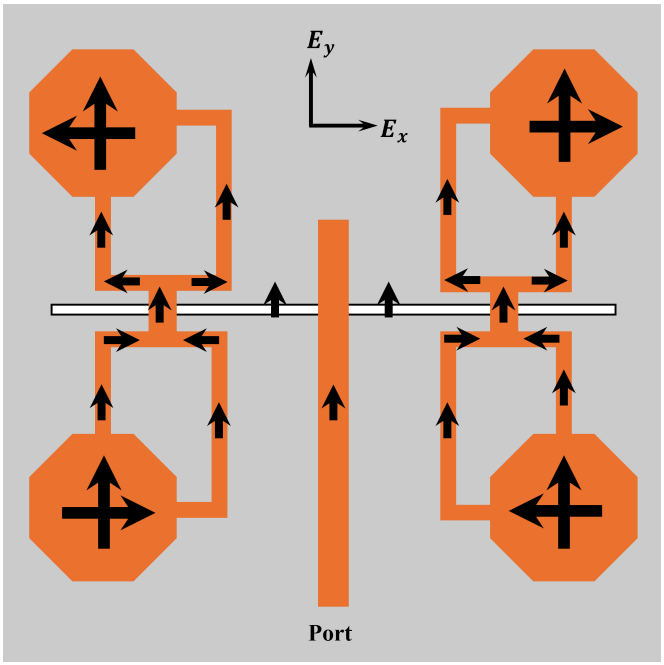


Figure 3.2: Working principle of the proposed circularly polarized patch array antenna without meander line in the design.

the slot lines. After that, it continues to the series divider at the slot-microstrip junction in order to accomplish a further separation into two out-of-phase signals with equal amplitudes. After that, the signal is further divided into two signals of identical amplitude and in phase, which then excite the individual patches in an orthogonal fashion. The out-of-phase signal that is produced by the series divider, on the other hand, generates field lines in such a way that, when the array is arranged, the vertical excitation of each patch remains constant. On the other hand, the horizontal excitation is in the opposite direction for the diagonal patches (Patch 1 and Patch 3, as well as Patch 2 and Patch 4). In order to achieve the required phase difference between the orthogonal excitation, the gap that exists between the lines that supply each patch, denoted by l_g, generates a length difference of a quarter-wavelength between the two microstrip lines that supply the separate patches. However, these opposite directions of horizontal excitation cancel each other out, making the whole array radiate in a linear polarization sense.

As seen in Figure 3.3 and 3.4, a meander line of length, denoted by the symbol l_m, is introduced in order to overcome this troublesome issue. As illustrated in Figure 3.3, the RHCP is obtained by the meander line that is present in the microstrip line arms that are feeding to Patch 2 and Patch 4. In the case of LHCP, the meander line is incorporated along the microstrip lines that supply patch 1 and patch 3, as depicted in Figure 3.4.

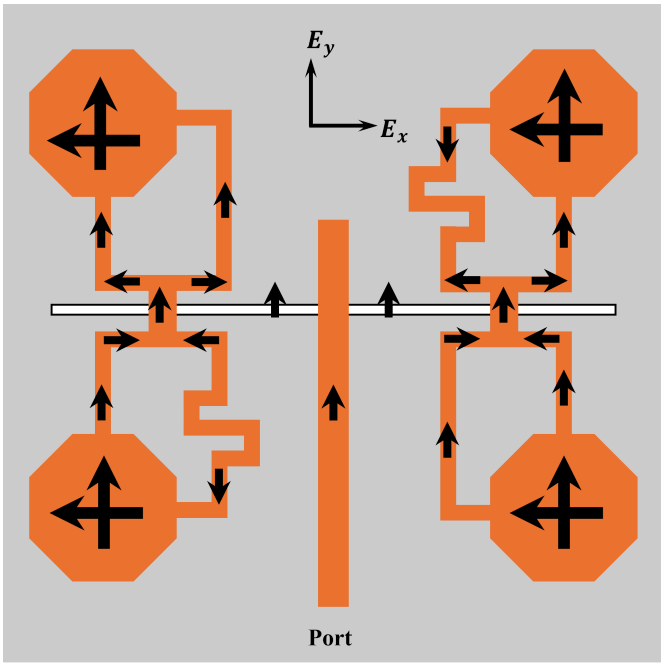


Figure 3.3: Working principle of the proposed circularly polarized patch array antenna with meander line in the design for RHCP operation.

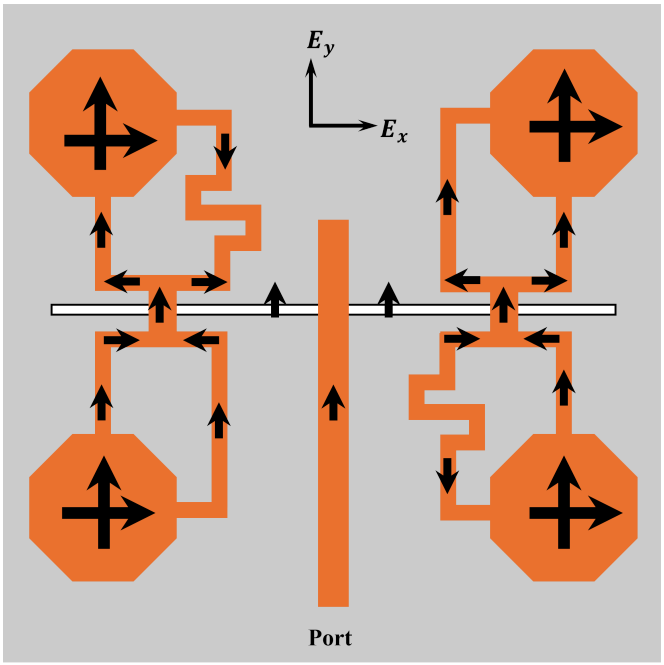


Figure 3.4: Working principle of the proposed circularly polarized patch array antenna with meander line in the design for LHCP operation.

By introducing a half-wavelength change to the horizontal excitation of the patches (Patch 1 and Patch 3 or Patch 2 and Patch 4), the meander line (l_m) brings the field lines into alignment with the patches that are still there. Because of this, the CP is now within reach due to this. The array is able to align field

lines in a manner that can be seen in Figure 3.5 because the design incorporates a meander line. Following the insertion of a meander line into the design, two ports, namely Port 2 and Port 3, were added at the terminal of the feed network in order to analyze the phase relationship that existed between them. It is demonstrated in the figure that the incorporation of the meander line leads to the alignment of the field lines with the horizontal field lines that were already there.

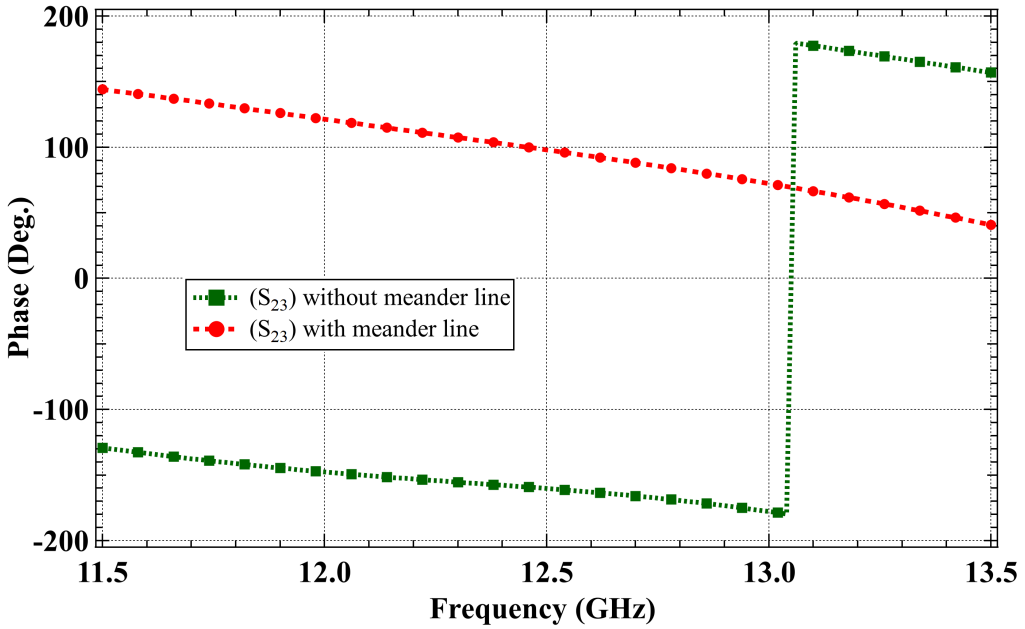


Figure 3.5: Phase difference between Port 2 and Port 3 before and after adding meander line into the arms of the microstrip line of the proposed design.

Consequently, the configuration illustrated in those figures display a CP that is left-handed when the meander line is connected to patches 1 and patch 3 microstrip line arms. And the microstrip lines that connect Patch 2 and Patch 4 include a meander line that generates the right-hand CP.

3.2 Simulation Outcomes and Discussions

The findings of the accompanying simulations are presented in this part, together with a discussion of the implications of those results. In the first part of this section, a parametric analysis is used to investigate the reflection coefficient (RC) and its associated axial ratio (AR). This is then followed by a discussion on the relative power. Lastly, the section concludes with a discussion of current distribution, gain, and antenna efficiency.

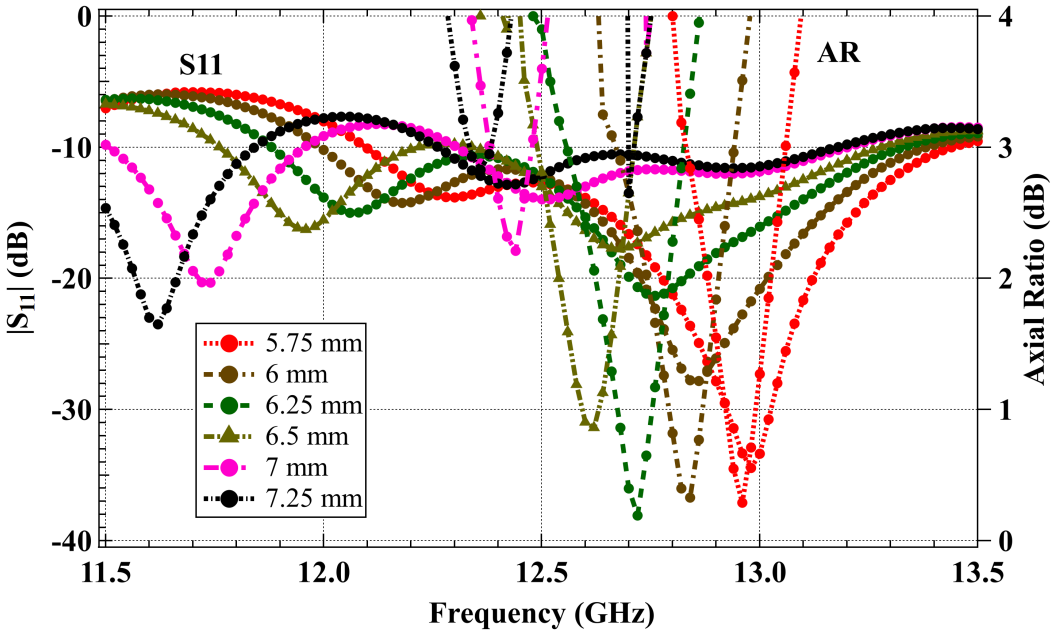


Figure 3.6: Simulated reflection coefficient and the AR of the proposed microstrip patch array antenna for l_g variation.

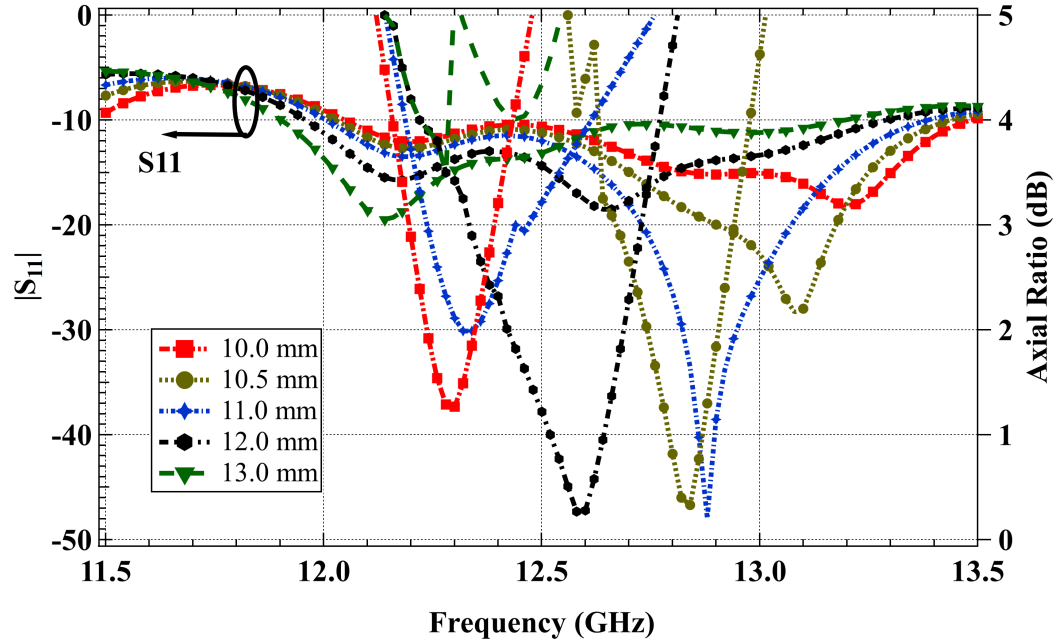


Figure 3.7: Simulated reflection coefficient and the AR of the proposed microstrip patch array antenna for l_m variation.

3.2.1 Parametric Study of RC and AR

While the microstrip lines that supply the patch horizontally create the necessary quarter-wavelength phase difference between orthogonal excitation for the

antennas, the approach stipulates that the meander line in the design is responsible for ensuring that the entire array is aligned horizontally with the field. It is anticipated that the performance of the antenna in terms of circular polarization will be impacted by both the length of the meander line and the distance that separates the two microstrip lines. Figure 3.6 illustrates the reflection coefficient of the antennas in conjunction with the related axial ratio (AR) values. This is done in response to the change in the gap length, denoted by l_g. When compared to the vertical feeding microstrip lines, the length of the horizontal feeding microstrip line is altered as a result of the adjustment of the gap length, regardless of whether the gap length is increased or decreased. The reflection coefficient is shown in conjunction with the relevant AR in Figure 3.7, which illustrates how the length of the meander line varies.

As shown in Figure 3.6, a reduction in the length of l_g has an impact on the performance of the antennas' circular polarization and impedance when the gap is smaller than 5.75 mm. This is due to the fact that it is unable to maintain a quarter-wavelength phase difference along the microstrip line. A meander line length, denoted by l_m, that is greater than 13 mm and falls below 10 mm has a significant impact on the circular polarization and impedance features of antennas, as shown in Figure 3.7. A measurement of 12 mm reveals that the antenna exhibits the best possible performance in terms of circular polarization, and it has an axial ratio bandwidth of 400 megahertz.

3.2.2 Radiation Pattern

It is possible for the proposed microstrip patch array antenna to generate both left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP), depending on the configuration of the meander lines on the arms of the microstrip line that correspond to each other. The configuration that is shown in Figure 3.1 is capable of demonstrating LHCP. A representation of the antenna's relative strength is shown in Figure 3.8. The figure makes it abundantly clear that the antenna exhibits left-hand circular polarization. Furthermore, the power level disparity is greater than 30 dB, which indicates that the antenna possesses remarkable circular polarization performance overall.

Figure 3.9 provides a visual representation of the characteristics that make up the antenna's performance. Gain, directivity, and efficiency are some of the characteristics that are associated with the antenna. A directivity that is greater than 10 dBic is exhibited by the antenna within the operational frequency range. This shows that the antenna possesses a radiation pattern that is very directional

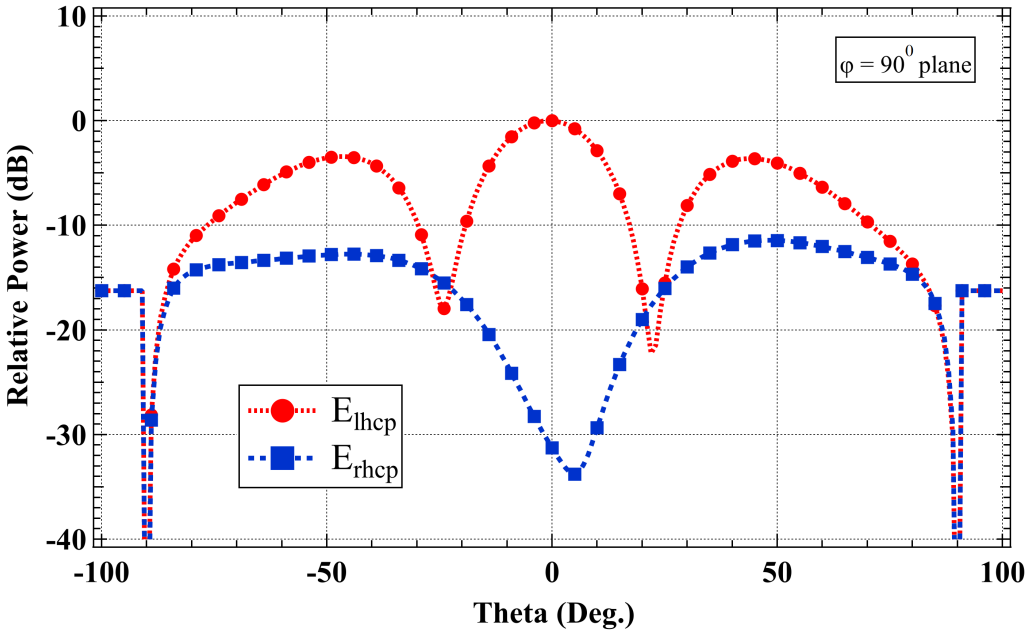


Figure 3.8: Simulated relative power of the proposed array antenna for LHCP operation.

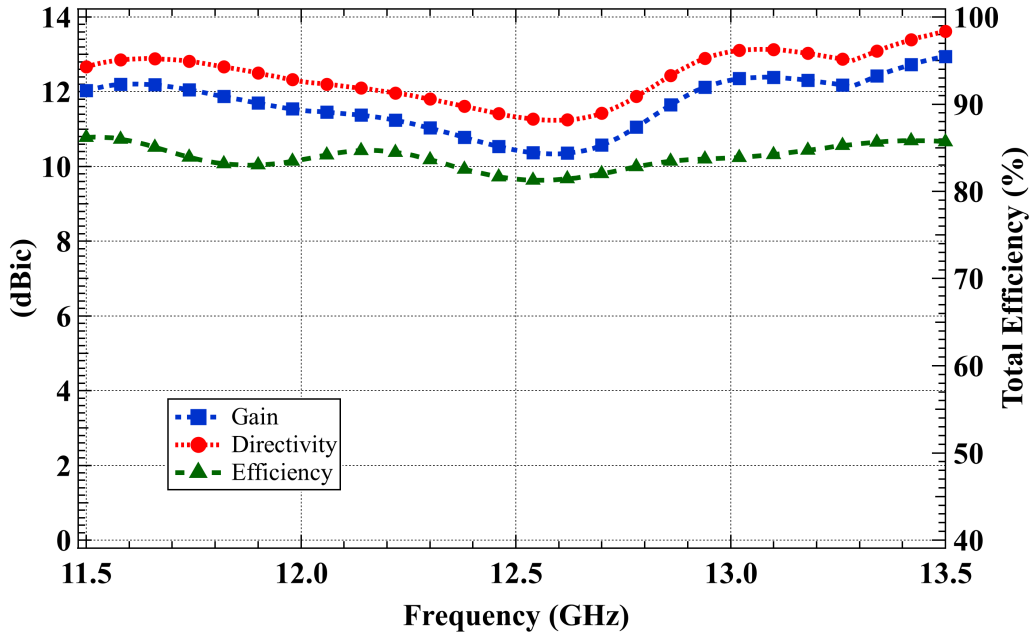
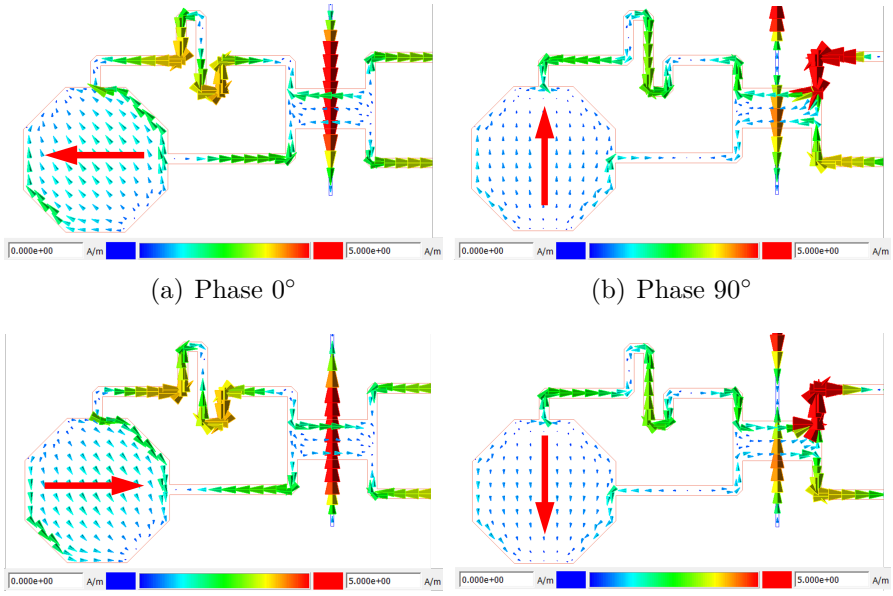


Figure 3.9: Simulated gain directivity and efficiency of the proposed circular polarized patch array antenna.

and an overall efficiency that is 80% over the frequency spectrum.

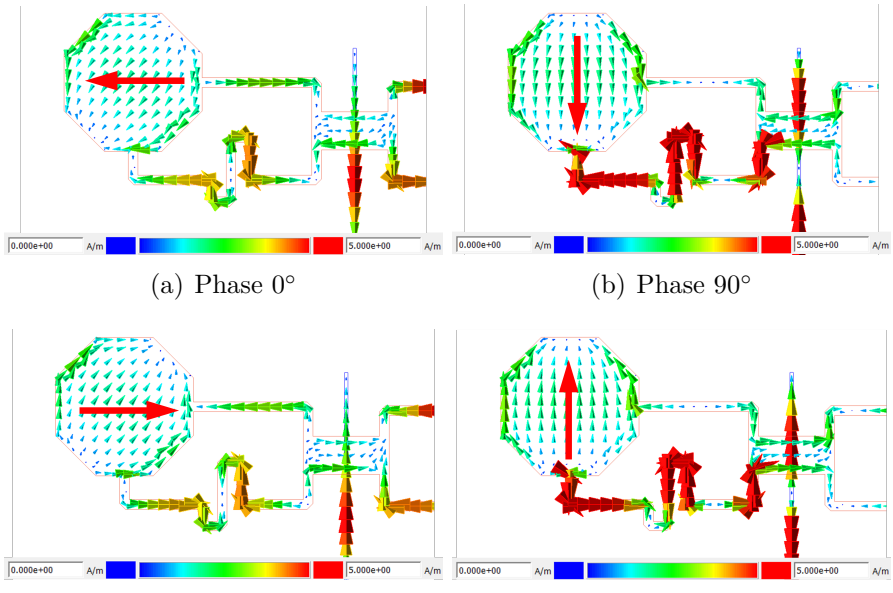
Figure 3.10 provides a visual representation of the current distribution that occurs throughout the majority of the antenna. The graphic only represents the current dispersion of the antenna's Patch 1, and it is included here for the sake



(a) Phase 0° (b) Phase 90°

(c) Phase 180° (d) Phase 270°

Figure 3.10: Current distribution of Patch 1 of the proposed 2×2 patch array antenna for LHCP. (For a better understanding of the patches' current distribution, only patch 1 is shown.)



(a) Phase 0° (b) Phase 90°

(c) Phase 180° (d) Phase 270°

Figure 3.11: Current distribution of Patch 2 of the proposed 2×2 patch array antenna for RHCP. (For a better understanding of the patches' current distribution, only patch 1 is shown.)

of clarity. A representation of the field distribution of the selected patch can be

found in Figure 3.10(a) through Figure 3.10(d), which correspond to the different phase values. This issue is explained in a manner that is both clear and succinct through the use of an example. The fact that the electric field of the antennas spins in a clockwise direction is an indication of left-hand circular polarization, also known as LHCP.

Figure 3.11 illustrates the current distribution prevalent across the majority of the antenna during right-hand circular polarization (RHCP) operation. This graphic exclusively depicts the current dispersion of the antenna's Patch 2. The field distribution of the selected patch at various phases is presented in Figure 3.11(a) through Figure 3.11(d). It is evident from these figures that the electric field of the antennas rotates in an anticlockwise direction, indicating RHCP.

3.3 Comparison

The antenna demonstrates exceptional performance compared to prior studies on dual-polarized patch array antennas, as detailed in Table 3.2. The comparison fo-

Table 3.2: A comparative analysis of the performance of the proposed array antennas against various circularly polarized array configurations.

[Ref.]	CP Pattern	Imp. BW (MHz,%)	ARBW (MHz,%)	Gain (dBic)
[18]	LHCP	370, 3.68	150, 1.41	6.36
[21]	LHCP & RHCP	600, 7.52	170, 2	6.4
[22]	LHCP & RHCP	300, 5.45	120, 2.18	6
[23]	LHCP & RHCP	530, 5.32	140, 1.41	6.33
[31]	LHCP& RHCP	500, 4.87	132, 1.26	14.25
[This work]	LHCP & RHCP	1600, 12.69	400, 3.19	11.85

cuses on three key performance metrics: impedance bandwidth (Imp. BW), axial ratio bandwidth (ABBW), and gain. The proposed design demonstrates significant improvements, particularly in bandwidth performance. With an impedance bandwidth of 1600 MHz (12.69%) and an axial ratio bandwidth of 400 MHz (3.19%), the array outperforms existing works, such as [18], [21], and [31], which exhibit narrower bandwidths. Additionally, the proposed antenna achieves a competitive gain of 11.85 dBic, surpassing most referenced designs except [31], which reports a higher gain at the expense of reduced bandwidth. The dual-CP capability (LHCP & RHCP) of the proposed array further enhances its versatility for modern wireless communication systems. This comparison underscores the design's balanced trade-off between bandwidth, polarization purity, and gain, making it a suitable candidate for applications requiring CP performance.

3.4 Summary

This chapter presents a four-element circularly polarized octagonal patch array antenna designed for Ku-band applications. The modeling results indicate that the antenna may produce circular polarization in both left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) configurations, contingent upon the direction of the meander line. The antenna exhibits an axial ratio bandwidth of 400 MHz and an impedance bandwidth of 1600 MHz, indicating effective circular polarization within the applicable frequency range. The antenna exhibits a gain of 11.85 dBic at working frequencies.

Chapter 4

Simple Feed Reconfigurable Circular Polarized Antenna

This chapter explores the design and simulation outcomes of a reconfigurable 2×2 circularly polarized patch array antenna, building upon the antenna construction presented in the previous chapter, intended for Ku-band frequencies. This design also offers a simple feed network to the design as well as a simple switching mechanism. The reconfigurability is facilitated via a single-pole double-throw (SPDT) switch. The switch utilizes two PIN diodes to manage the delay line switching for each patch. This approach can be applied in satellite communication systems, where circular polarization and dynamic polarization management are essential to mitigate polarization mismatch, facilitate multiple services, and provide reliable signal transmission across diverse environments and orientations.

4.1 CP Reconfiguration and Design Method

This section provides a comprehensive performance assessment of the antenna. It elaborates on the fundamental concepts and techniques employed to attain circular polarization.

4.1.1 CP Array Mechanism

The utilization of PIN diode switching allows for the creation of a straightforward microstrip line feed four-element octagonal-shaped microstrip patch antenna that is capable of achieving circular polarization (CP) reconfigurability. The proposed CP reconfigurable antenna is depicted below in the form of a block schematic, as seen in Figure 4.1. The array antenna is made up of four different elements, eight PIN diodes that allow for the operation of four single-pole double-throw

(SPDT) switches, and a feed network. A microstrip-slot junction and two slot-microstrip junctions are included in the feed network, which makes use of both-sided microstrip integration technology. A method that is orthogonal is used to feed each individual element of the array. A phase difference of either 90° or 270° can be presented by the switching mechanism, which enables the elements to accept input from the delay lines. The antenna is able to emit in either the right-hand CP (RHCP) sense or the left-hand CP (LHCP) sense due to the precise method in which it switches along the diagonal. If the patch that is located along one diagonal is the one that receives the phase-shifted signal of 270°, then the other patch that is located along this diagonal ought to be the one that receives the phase-shifted signal of 90°, which is controlled by it.

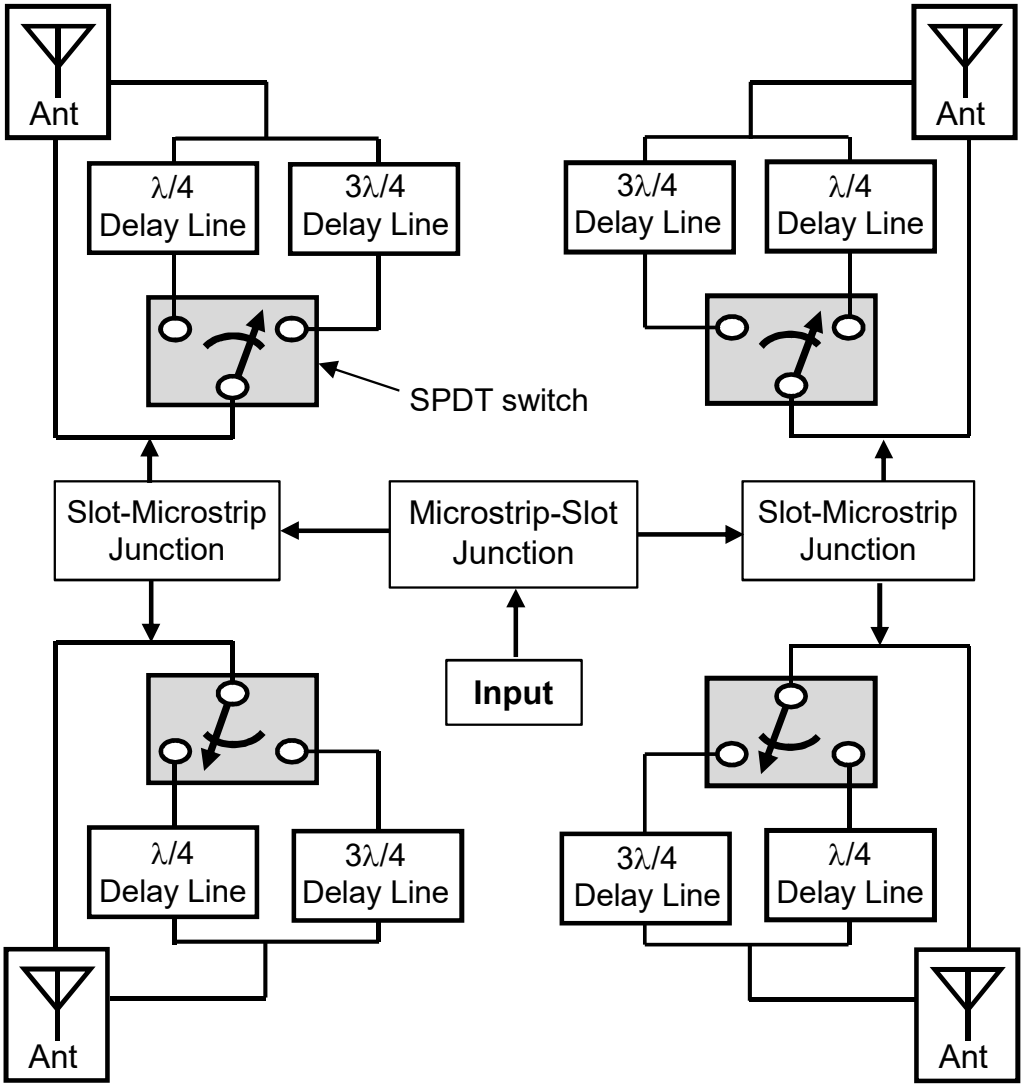


Figure 4.1: Block diagram of the working mechanism of the proposed circular polarization reconfigurable patch array antenna. λ is the guided wavelength at the design frequency.

At the microstrip-slot parallel divider, the input signal from the port is divided into two in-phase signals of equal amplitude. These signals then divide further into two out-of-phase signals of equal amplitude at the slot-microstrip series junctions. In the end, this signal from the series junction is sent to the patch in an orthogonal way after being further separated into two signals of similar amplitude and in phase with each other. The quarter-wavelength phase difference that is required can be obtained by identifying the difference in line length between those orthogonal microstrip feed lines. Because of the series divider, each of the antennas receives the identical vertical excitation. On the other hand, the delay line is utilized for the horizontal excitations that occur along the diagonal configuration. To ensure that the horizontal field lines of all antenna elements are aligned in the same direction, it is necessary to have a difference of $\lambda/2$ between the feed lines that correspond to diagonal configurations. The CP perceptions that are produced by various diagonal configurations are distinct. Consequently, in order to transition between LHCP and RHCP, there are four switching components that are required.

Table 4.1: Optimized dimension values of design parameters for the suggested circularly polarized microstrip array antenna.

Parameter	**Value (mm)**
Patch length, l_p	8.7
Microstrip line width, w_t	0.8
Ground plane slot line width	0.2
$\lambda/4$ Microstrip line length	4.9
Delay line extension length, l_d	4
Parallel Microstrip line gap length, l_g	6.2
Microstrip patch edge length, l_e	3.6
Microstrip line length, l_t	10.25
Microstrip line width, w_m	2.4
Microstrip line width, w_t	0.6
$\lambda/2$ line length	10.4
Substrate height/thickness	0.8

Table 4.1 details the parameter and their respective optimum values for the proposed reconfigurable patch array antenna. All the values are in mm units.

4.1.2 Antenna Geometry

In Figure 4.2, the design arrangement of the suggested antenna that incorporates a DC biasing network is presented in detail. An electromagnetic (EM) simulation software is used to simulate the antenna after it has been fabricated on a Teflon

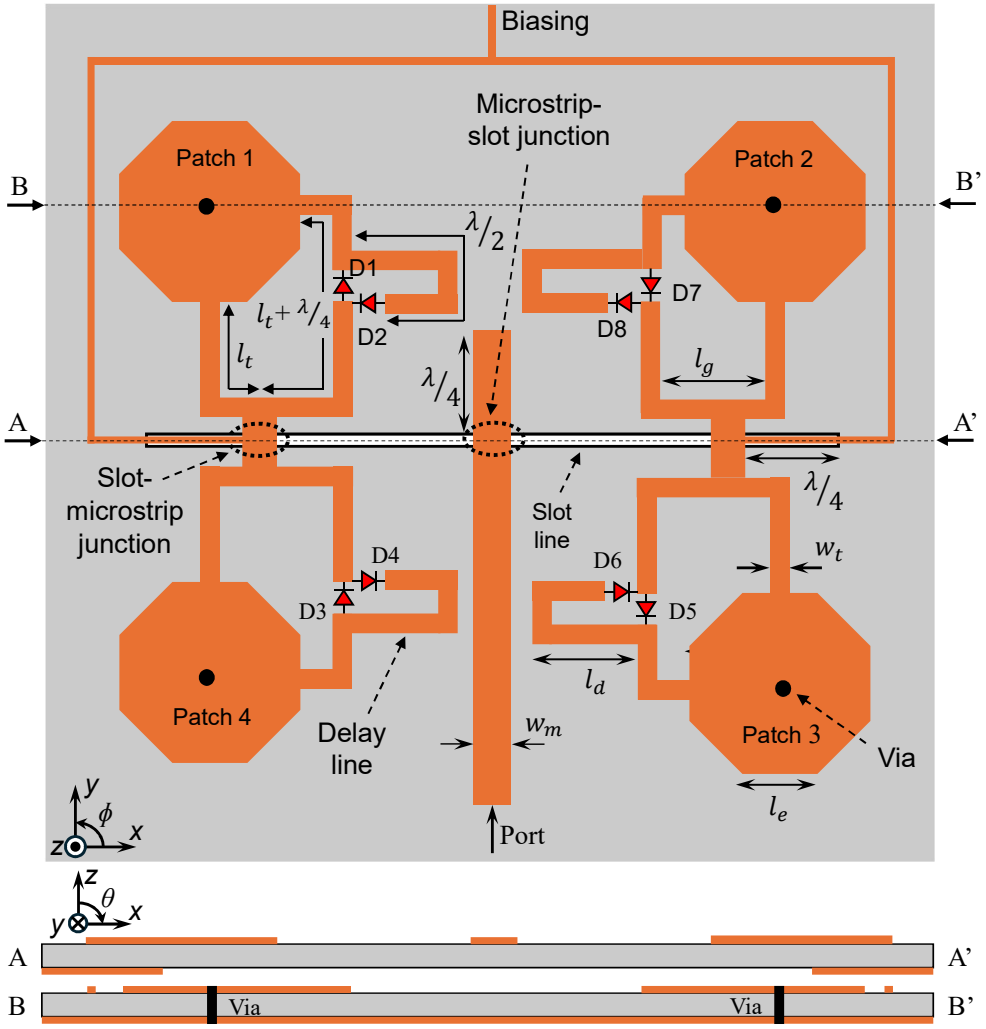


Figure 4.2: Design layout and a cross-sectional view along AA' of the proposed antenna.

substrate that has a relative dielectric constant of 2.15. In the ground plane, the design incorporates a slot line that measures 0.2 mm in width. In addition to the patch, all of the other components are located above the substrate. Every pair of PIN diodes, which are positioned at four junctions, is positioned along the microstrip line in order to offer switching between 90° and 270°.

The diodes with odd numbers are connected in series along the delay lines with a delay of $l_t + \lambda/4$, while the diodes with even numbers are connected along the delay lines with a delay of $3\lambda/4$. The delay lines supply the patch with the required 270° phase difference when the even-numbered diodes are in the ON position. The delay line with a length of $\lambda/2$ has the advantage of being ended when the diodes on the delay lines are in an OFF state. This results in an efficient flow of signal to the patch along the delay microstrip lines with a length of $\lambda/4$.

An impedance of 50 Ω is present in the input feed line. The impedance of

Table 4.2: Polarization sense at various diode conditions for changing the bias voltage.

Bias Voltage	D1, D4, D5, D8	D2, D3, D6, D7	Pol. Sense
Positive	ON	OFF	RHCP
Negative	OFF	ON	LHCP

the slot line is 100 Ω, and it serves as a parallel divider at the junction of the microstrip and the slot. The width of the T-divider microstrip line that originates from the series junction is 0.6 mm, and it has an impedance of 110 Ω. Table 4.2 presents an description of the diode circumstances that correlate to various bias voltages, as well as the output polarization states that emerge from these bias voltages. When the odd-numbered diodes of the $\lambda/4$ delay lines on one diagonal and the even-numbered diodes along the $\lambda/2$ delay lines on the other diagonal of the array are in the ON state, the antenna displays a certain type of CP. This occurs when the array is subjected to a particular biasing scenario. When subjected to varying biasing conditions, the ON and OFF states of the diodes undergo internal transformations, which end up producing a distinct type of CP configuration. Using positive bias, diodes D1, D4, D5 and D8 are activated or turned ON, resulting in the production of RHCP by the antenna. Conversely, when the diodes are deactivated or turned OFF, the antenna generates LHCP through the application of negative bias. In the figure, it is shown that the bias voltage is applied to the biasing network that was designed by high-impedance microstrip lines. A width of 0.2 mm is used for the microstrip lines that originate from the biasing port and are linked to the series junction. This width ensures that there is no impedance mismatch at the series junction. For the purpose of establishing a complete biassing circuit, a via is positioned in the middle of the four patches.

4.2 Simulated Outcomes and Discussions

A parametric research is conducted to determine the best outcome for the circular polarization of the proposed antenna. This section addresses the parametric outcome initially and thereafter examines the antenna's radiation pattern.

4.2.1 Parametric Study of RC and AR

The requisite quarter-wavelength phase difference between two orthogonal feeds is provided by the gap length, denoted by the symbol l_g, that has been established

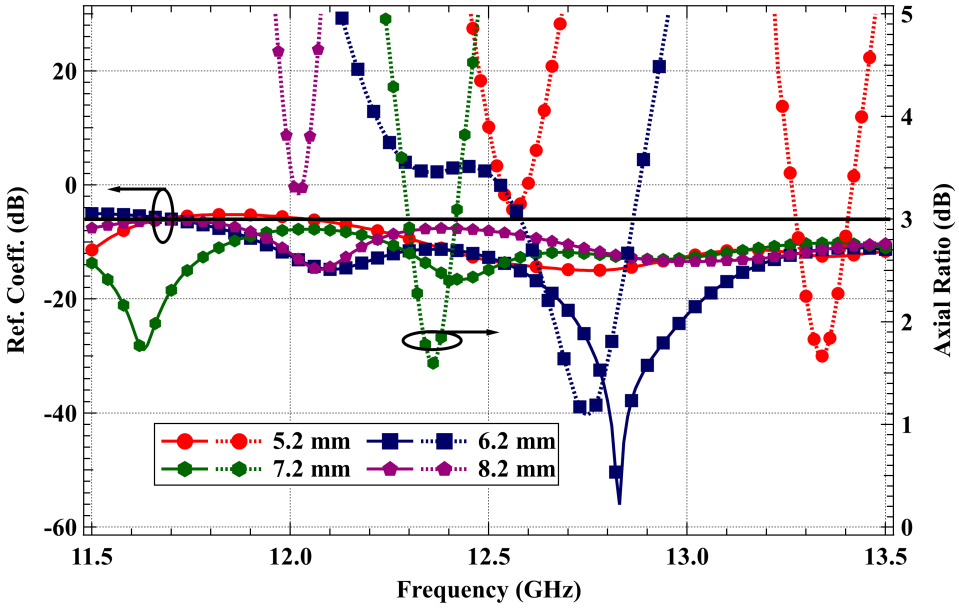


Figure 4.3: Simulated reflection coefficient and the AR of the proposed microstrip patch array antenna for l_g variation.

between the T-shaped dividers of the microstrip lines. The circular polarization (CP) performance of the antenna will be affected by the fluctuation in the value of l_g throughout the experiment. Figure 4.3 presents a visual representation of the reflection coefficient and the axial ratio (AR) for a range of different values of l_g. The microstrip line length is unable to achieve the requisite phase shift between the orthogonal feed lines when the value of l_g is more than 8 mm. Whenever the value is less than 6 mm, the AR decreases in conjunction with the impedance matching from the optimal result.

One of the parameters of the antenna, which is symbolized by the symbol l_d, ensures that the array is polarized in a circular fashion across its entirety. It is possible to adjust the horizontal field lines of the patches with the assistance of the delay lines. All of the CP performances are determined by the fluctuation in the values of l_d. A representation of the reflection coefficient and AR for a range of different l_d values can be found in Figure 4.4. As soon as the l_d values go below 3.5 mm, the CP performance of the antenna begins to gradually decline. Due to the fact that l_d values that are more than 4 mm result in a delay line length that is greater than $\lambda/2$, the antenna completely loses its capability to perform CP when the values exceed 4 mm. With regard to the dimensions of l_g and l_d, the optimal measurements are 6.2 mm and 4 mm, respectively. In addition, it is clear from the data that the antenna possesses an impedance bandwidth that is greater than 1500 MHz and an AR bandwidth that is 270 MHz.

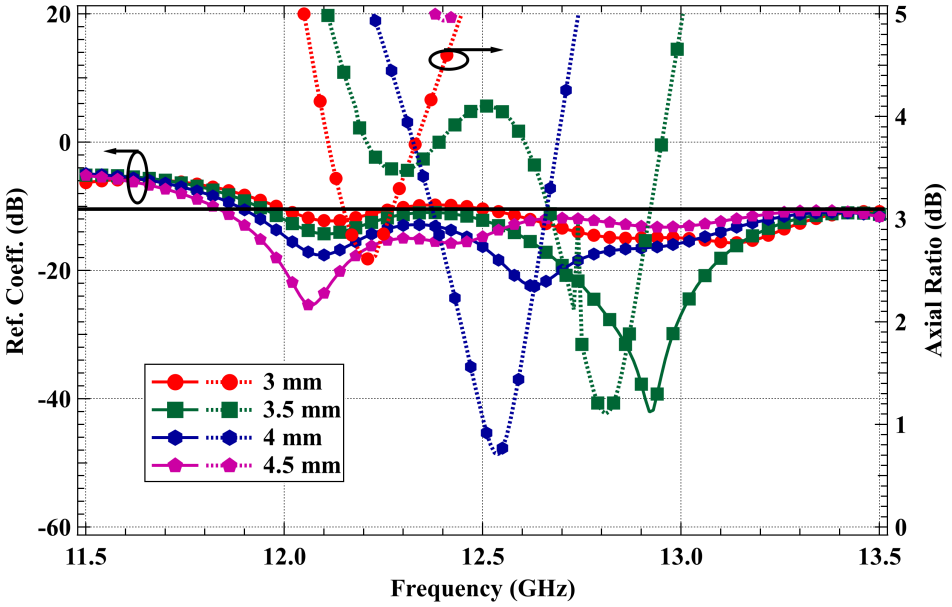


Figure 4.4: Simulated reflection coefficient and the AR of the proposed microstrip patch array antenna for l_d variation.

4.2.2 Radiation Pattern

For the LHCP and RHCP modes, respectively, the simulated relative power level difference in the $\phi = 90°$ plane is depicted in Figure 4.5 and Figure 4.6, respectively. According to the findings, the antenna possesses outstanding CP performance in both senses at a frequency of 12.54 GHz. This is demonstrated by relative power level discrepancies that are greater than 25 dB in the broadside direction.

Figure 4.7 provides a visual representation of the performance parameters of the antenna, which may be found in the referenced figure. The gain, directivity, and efficiency of the device are included in these measures. A directivity that is greater than 12 dBic is demonstrated by the antenna within the operational frequency range. This implies that the antenna has a radiation pattern that is highly directional. Furthermore, the antenna was able to attain an overall efficiency that was greater than 80 percent across the whole frequency spectrum during its operation.

As depicted in Figure 4.8, the surface current distribution of the proposed reconfigurable 2×2 microstrip patch array antenna is displayed in four distinct phase states, namely 0°, 90°, 180°, and 270°. A demonstration of the formation of left-hand circular polarization (LHCP) is presented here. The figures demonstrate that the surface current rotates in a clockwise direction throughout the course of time, which is a clear indication that LHCP radiation is present. A significant

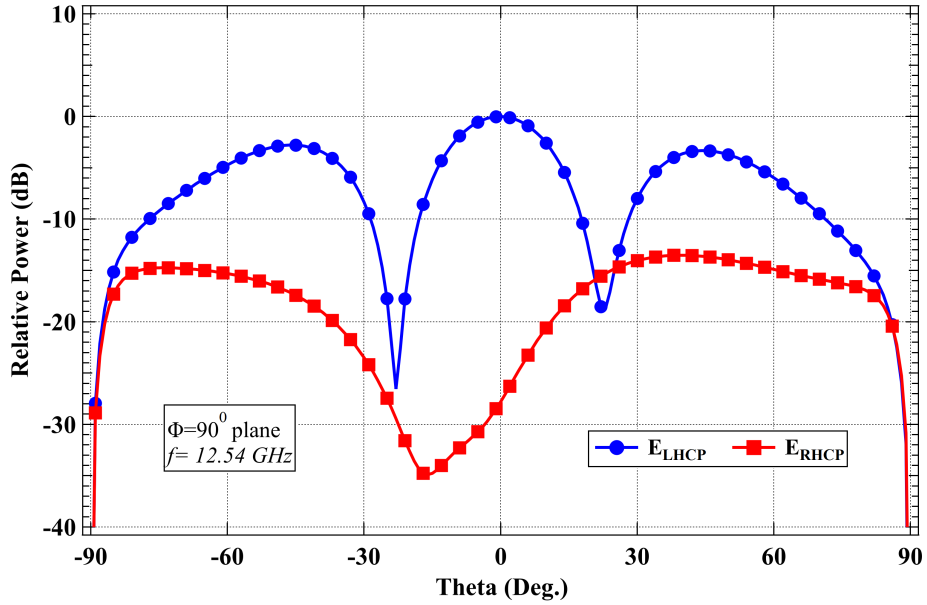


Figure 4.5: Simulated relative power of the proposed array antenna for LHCP mode.

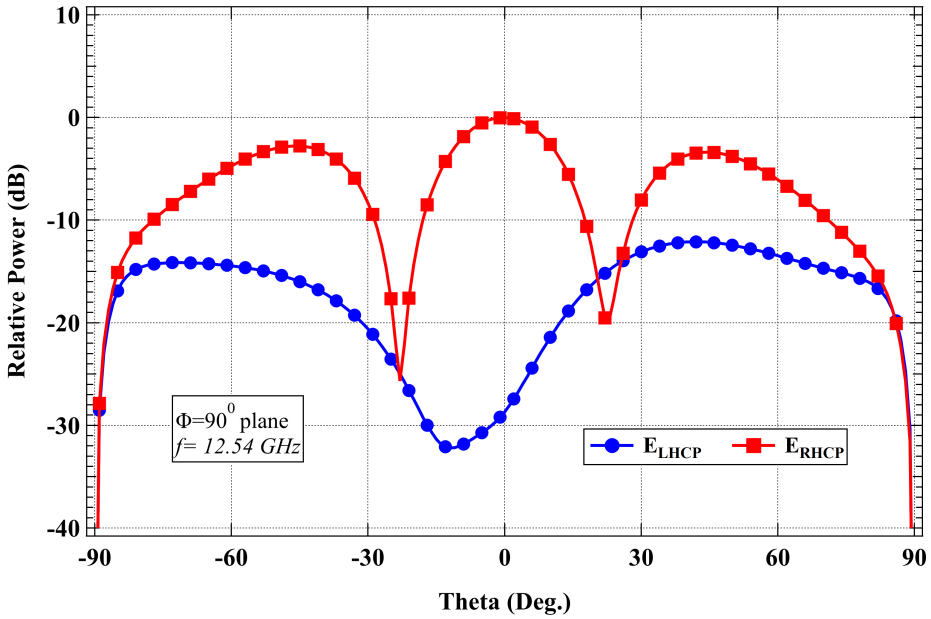


Figure 4.6: Simulated relative power of the proposed array antenna for RHCP mode.

portion of the current is flowing in a single direction along a particular axis on each patch element when the phase is 0° (a). With this, the current travels to the orthogonal axis when the phase moves to 90° (b), which indicates that a quarter-wave progression is taking place. This rotation goes all the way through 180° (c) and 270° (d), completing a full cycle.

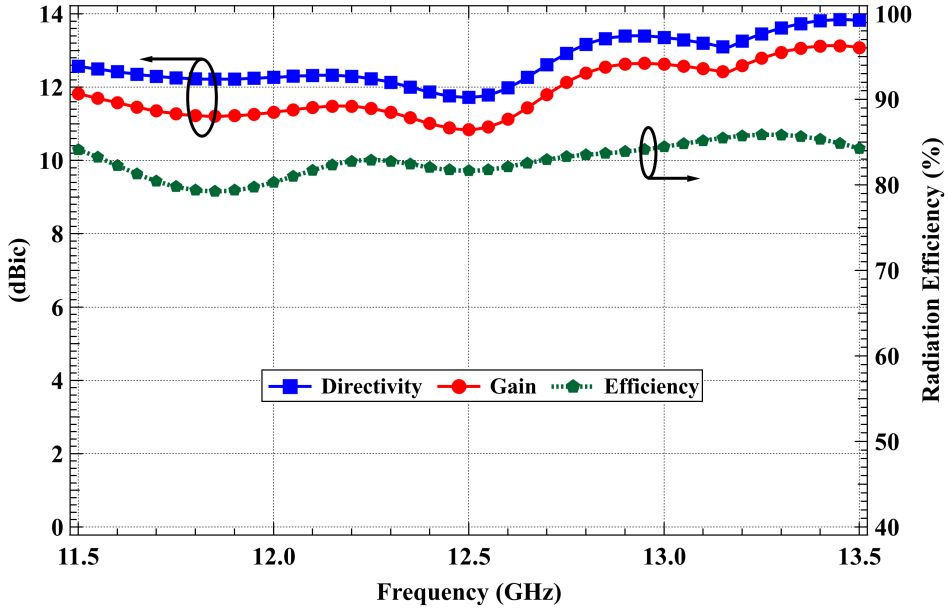
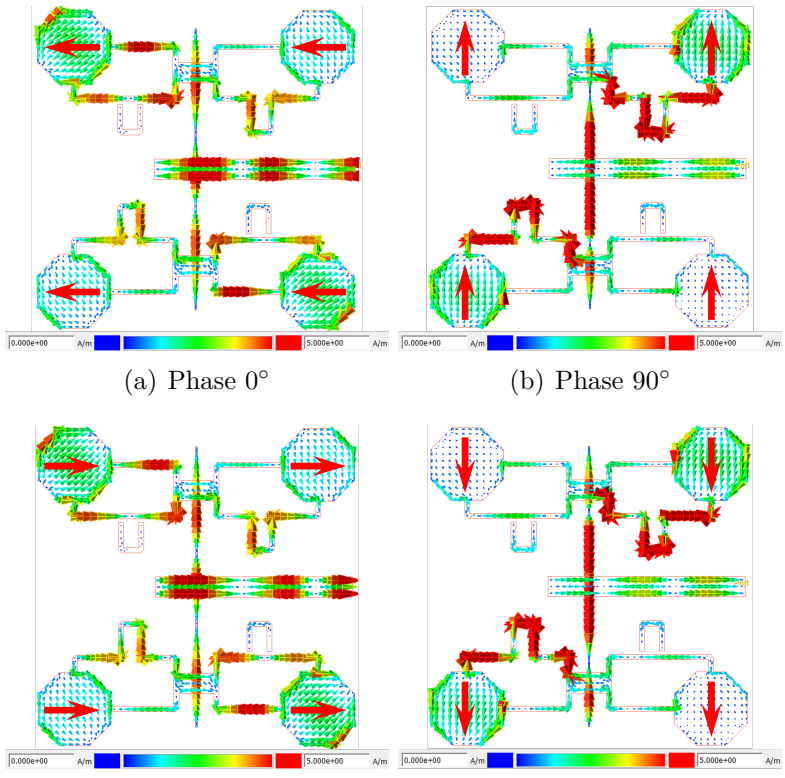


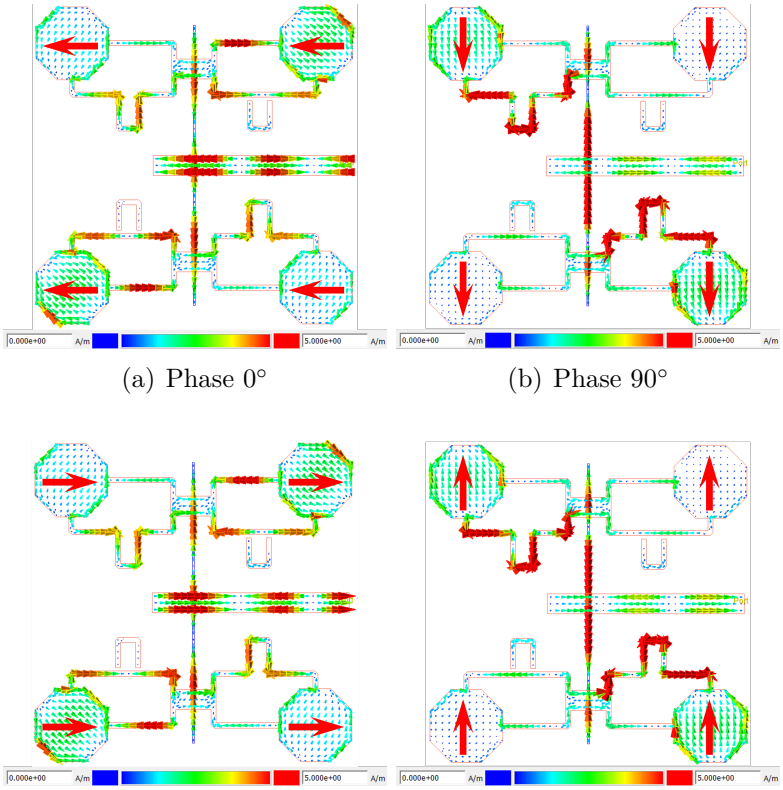
Figure 4.7: Simulated relative power of the proposed array antenna for RHCP mode.



(a) Phase 0° (b) Phase 90°

(c) Phase 180° (d) Phase 270°

Figure 4.8: Current distribution of the proposed reconfigurable 2×2 patch array antenna for LHCP.



(a) Phase 0° (b) Phase 90°

(c) Phase 180° (d) Phase 270°

Figure 4.9: Current distribution of the proposed reconfigurable 2×2 patch array antenna for RHCP.

This quadrature phase progression ensures that the vector sum of the surface currents rotates smoothly and continuously, which is evidence that the antenna is capable of transmitting LHCP waves. In order to achieve the desired polarization state, the feed network and switching mechanism must perform very well, as evidenced by the fact that the current rotates in the same manner across all four phases.

Likewise, Figure 4.9 illustrates the proposed 2×2 patch array antenna designed for right-hand circular polarization, along with its surface current distribution. The present motion proceeds counterclockwise through the 0°, 90°, 180°, and 270° phase states, thus demonstrating right-hand circular polarization by successive quadrature phase excitation.

4.3 Comparison

The antenna has enhanced performance relative to other current reconfigurable antennas, as illustrated in Table 4.3. The proposed 2×2 array achieves an excep-

tional impedance bandwidth of 1600 MHz (12.69%), significantly outperforming referenced works like [27] (300 MHz) and [30] (400 MHz), while maintaining a compact switching system with only 8 switches. Notably, the design also delivers a wide ARBW of 270 MHz (2.15%), surpassing [30]'s narrow ARBW of 50 MHz, which is critical for robust CP operation. With a gain of 11.96 dBic, the array exceeds most counterparts (e.g., [27]: 9.8 dBic; [30]: 10.15 dBic) while supporting dual-CP states (LHCP/RHCP) without compromising bandwidth. In contrast, other works either require more switches (e.g., [28]: 16 switches) or lack ARBW data ([28], [29]), highlighting the proposed design's efficiency in balancing performance, reconfigurability, and hardware simplicity. This advancement positions the array as a promising solution for adaptive wireless systems requiring wideband CP operation with minimal switching complexity.

Table 4.3: A comparison of performances of the proposed array antenna with other reconfigurable CP array works of different configurations.

[Ref.]	Array Config.	No. of Switch	Imp. BW (MHz,%)	ARBW (MHz,%)	Gain (dBic)	Pol. States
[27]	1×4	8	300, 12.5	300, 12.5	9.8	LP/RHCP/LHCP
[28]	1×4	16	200, 9.3	–	13	±45°
[29]	2×2	20	290, 12	–	–	HP/VP
[30]	2×2	8	400, 10	50, 1.41	10.15	+45° LP/CP
[This work]	2×2	8	1600, 12.69	270, 2.15	11.95	LHCP/RHCP

4.4 Summary

This chapter examines the design and simulation results of a 2×2 reconfigurable circularly polarized patch array antenna functioning in the Ku-band. The feed network utilizes two PINs to control the switching of the delay line for each patch. The SPDT switch can choose between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). The antenna functions across all frequencies with a total efficiency of 80%. This signifies that the antenna's radiation pattern is exceedingly directed.

Chapter 5

Conclusion

While acting as directional device, an antenna plays a vital role in enhancing the transmitted or received electromagnetic energy in one direction while suppressing in other directions. Microstrip antennas, in particular, have significant benefits over conventional microwave antennas and are thus frequently employed in various practical applications. Researchers worldwide are working hard to build high quality CP microstrip antennas. Two orthogonal excitations with a quarter-wavelength phase difference are required to achieve CP. CP antennas are more preferable to LP antennas due to their various advantages like weather penetrating, ability to offset the ionosphere's Faraday rotation effect, flexible polarization orientations, and offset the multi-path reflections and other interferences.In the construction of a circularly polarized antenna, it is essential to attain a favorable axial ratio ($\leq$3 dB) and return loss ($\leq$10 dB) at specific operational frequencies. The losses in the feeding network and extraneous radiation at the feed are significant concerns in the design of microstrip antennas.

A reconfigurable antenna operates as a multifunctional device, enabling a reduction in the number of antennas required in a system. This reduces expenses and produces a more efficient and small design. Among antennas that may be adjusted in terms of frequency, pattern, and polarization, polarization reconfigurable antennas have the ability to switch between three different polarization modes: linear polarization (LP), left-hand circular polarization (LHCP), and right-hand circular polarization (RHCP). The circularly polarized reconfigurable antenna efficiently reduces misalignment and multipath fading in contrast to LP antennas. Consequently, the need for circularly polarized microstrip antennas that are reconfigurable is increasing daily. The main concern of this thesis is to design, analyze and optimize a CP Reconfigurable Array Antenna using a simple feed network.

The design objectives of creating an octagonal patch array antenna for dual-

sense circular polarization in the Ku-band using a straightforward feed network had been achieved. The proposed antenna configuration effectively generated both right-hand and left-hand circular polarizations through a compact, symmetrical feeding mechanism. The feed network incorporated electrical switching, enabling the alteration of the polarization state without compromising the antenna's performance or dimensions. Comprehensive full-wave electromagnetic simulation methodologies were employed to rigorously evaluate the complete antenna design. This validated its capability for dual-sense circular polarization, elevated radiation efficiency, and consistent performance throughout the designated Ku-band frequencies. The results indicated that the antenna is applicable in practical satellite communication and radar systems requiring compact, adaptable, and polarization-diverse solutions. Initially, a feed network for a four-element octagonal patch array was constructed using a Teflon substrate with a relative dielectric constant of 2.15 and a thickness of 0.8 mm. The feed network underwent initial optimization tailored to the operating frequency within the Ku-band spectrum. Subsequently, the patch was integrated into the design within the specified frequency band. The design incorporated an octagonal patch with a diagonal length of 8.7 mm. The modeling results indicated that the antenna can produce circular polarization in both left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) configurations, contingent upon the direction of the meander line. The antenna exhibits an axial ratio bandwidth of 400 MHz and an impedance bandwidth of 1600 MHz, indicating effective circular polarization within the applicable frequency range. The antenna exhibits a gain of 11.85 dBic at working frequencies.

Based on the concepts, another novel technique was proposed to design a reconfigurable 2×2 circularly polarized patch array antenna intended for Ku-band frequencies. The reconfigurability was facilitated via a single-pole double-throw (SPDT) switch. The switch utilized two PIN diodes to manage the delay line switching for each patch. The feed network utilizes two PINs to control the switching of the delay line for each patch. The SPDT switch can choose between left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP). The antenna functions across all frequencies with a total efficiency of 80%. This signifies that the antenna's radiation pattern is exceedingly directed.

The proposed antenna was designed with a simplified feed network having circular polarization with reconfigurability. This research work has made a tremendous contribution to the satellite communication environment. It will also be beneficial for researchers. The requirement for circular polarization and dynamic polarization control, which allows for the mitigation of polarization mismatch, the

accommodation of multiple services, and the guarantee of reliable signal transmission across a wide range of environmental and orientation conditions, makes this design particularly advantageous for satellite communication systems.

5.1 Limitations of This Work

Though the proposed antenna will be suitable for satellite communication it has some limitations. The polarization sensing for both antennas may be obtained only by altering the feed configuration. There were no inherent mechanisms capable of concurrently modifying the polarization states to meet the specific needs of real-world applications.

5.2 Future Work

The antennas for circular polarization presented in this study are capable of configuring both left-hand circular polarization, and right-hand circular polarization. A potential future recommendation for this thesis work is to adapt the suggested antenna design to acquire cross polarization i.e. different CP (LHCP and RHCP) for Tx and Rx.

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