DESIGN AND PERFORMANCE EVALUATION OF A CIRCULARLY POLARISED PATCH ARRAY ANTENNA

A MINI-PROJECT REPORT

submitted by

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to
the partial fulfillment of the academic requirements for the award of the degree
of
Bachelor of Technology
in
Electronics & Communication Engineering

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DECLARATION

We, the undersigned, declare that the project report **”DESIGN AND PERFORMANCE EVALUATION OF A CIRCULARLY POLARISED PATCH ARRAY ANTENNA”** submitted for partial fulfillment of the requirements for the award of the degree of Bachelor of Technology of Vasavi College of Engineering (Autonomous),Ibrahimbagh , Hyderabad is a bonafide work done by me under supervision of *Dr.P.Sathish and B.Uma Mahesh Babu* This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the sources. We also declare we have adhered to the ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. We understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources that have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma, or similar title of any other University.

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CERTIFICATE

This is to certify that the report entitled **Design and Performance Evaluation of a Circularly polarized Patch Array Antenna** submitted by

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students of Electronics and Communication Engineering Department, Vasavi College of Engineering in partial fulfilment of the requirement for the award of the degree of Bachelor of Engineering in Electronics & Communication Engineering is a record of the bonafide work carried out by them during the academic year 2025-2026. The results embodied in this project report has not been submitted to any other university or institute for the award of any degree.

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ABSTRACT

This mini-project details the design and performance assessment of a circularly polarized (CP) patch array antenna for modern wireless and satellite communication use. The proposed array uses microstrip patch radiators arranged with a suitable feed network to create circular polarization. This setup improves signal reliability, reduces multipath fading, and allows for better tolerance to polarization mismatch.

A systematic design method is utilized, which includes optimizing the unit element, configuring the array, and matching impedance. Simulation tools like HFSS are used for this process. Key performance factors such as return loss, axial ratio, radiation pattern, and gain are examined to confirm the antenna's effectiveness.

Simulation results show stable circular polarization, a wide impedance bandwidth, and better gain. These findings support that the designed CP patch array antenna is ideal for compact, high-performance communication systems.

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Chapter 1

INTRODUCTION

Circularly polarized (CP) antennas are crucial in modern wireless and satellite communication systems. They reduce signal loss from multipath effects and polarization mismatch. Among different CP antenna types, microstrip patch arrays are popular due to their low profile, light weight, easy fabrication, and compatibility with planar RF circuits. By arranging several patch elements in an array and using the right feeding technique, we can significantly improve gain, bandwidth, and radiation stability. This project focuses on designing and evaluating the performance of a CP patch array antenna. It looks at important features like impedance matching, axial ratio, and radiation patterns to ensure consistent circular polarization within the target frequency band.

1.1 BASIC CONCEPT

The basic idea of a circularly polarized patch array antenna is to use several microstrip patch elements arranged in a specific pattern. These elements are fed with particular phase differences to create circular polarization. A single patch usually produces linear polarization. However, circular polarization can be obtained by exciting two orthogonal modes with equal strength and a 90° phase difference. By combining multiple patches into an array, the antenna achieves higher gain, better directivity, and improved radiation performance. The feed network is essential for distributing power evenly and maintaining the necessary phase shift across the elements. This setup helps the antenna deal with polarization mismatch, reduce multipath fading, and ensure stable communication, particularly in satellite, GPS, and wireless applications where signal orientation changes constantly.

1.2 MOTIVATION

The goal of this work is to create an antenna that provides reliable communication even when the device orientation changes or when multipath effects happen. Circularly polarized antennas offer better signal stability and reduced polarization losses than linearly polarized antennas. Designing a CP patch array helps achieve higher gain, wider coverage, and better performance for modern wireless and satellite applications. This project also provides hands-on experience in practical antenna design and simulation.

1.3 PROBLEM STATEMENT

Modern wireless and satellite communication systems need antennas that can provide reliable signal transmission despite issues like polarization mismatch, multipath fading, and device orientation changes. Conventional linearly polarized patch antennas often lose performance in these situations. Thus, there is a need to design a compact, efficient, and high-gain antenna that can maintain stable circular polarization within the desired frequency range. This project tackles the task of designing and simulating a circularly polarized microstrip patch array antenna that meets the necessary axial ratio, impedance matching, and radiation performance. The goal is to create an optimized array structure and feeding mechanism, assess its performance using electromagnetic simulation tools, and confirm if the antenna fulfills the requirements for practical communication applications.

1.4 OBJECTIVES OF THE WORK

- To design the basic geometry of a circularly polarised patch element suitable for the target frequency band using standard antenna design formulas.
- To create the 2×2 or 4×4 patch array structure and define appropriate element spacing for improved gain and radiation performance.
- To design a feed network that provides equal power distribution and the required 90° phase shift for circular polarization.
- To model the complete antenna (unit cell + feed network + array) in an electromagnetic simulation tool such as HFSS .
- To run simulations to analyze S-parameters, return loss, and radiation patterns of the antenna.
- To optimize key design parameters (patch dimensions, slot sizes, feed lengths, substrate properties) to achieve the required gain, bandwidth, and CP performance.
- To validate the final antenna design through simulation results before moving toward fabrication.

Chapter 2

LITERATURE SURVEY

Circularly polarised (CP) antennas have been studied a lot because they can reduce multipath fading and polarization mismatch in wireless and satellite communication systems. Early research focused on single patch designs that used perturbation techniques to create CP. However, these designs often had limited bandwidth and low gain. Later studies looked at crossed-dipole antennas, slot-coupled patches, and metasurface-based radiators to improve axial-ratio bandwidth and radiation performance. Array configurations, especially 2×2 and 4×4 layouts, were developed to achieve higher gain. Sequential rotation feeding became a useful method to enhance CP purity and impedance bandwidth. Recent research, including the uploaded reference paper, shows how multilayer substrates, cross-shaped coupling slots, and serial feed networks can achieve wide AR bandwidths and gains exceeding 15 dB. These developments demonstrate the ongoing progress of CP patch array antennas and influence the design and simulation approach for the current project.

Table 2.1: Tabulated overview of few reviewed circularly polarized slot antennas.

Year & Author	Title of the paper and design	Remark
2024 T.-H. Lee et al. [1]	Circularly Polarized 4×4 Array Antenna with a Wide Axial Ratio Bandwidth.	Presents a 4×4 CP patch array with cross-slot coupling and sequential feed achieving wide AR bandwidth and less than 16 dB gain.
2023 H. Wang et al.[2]	Circularly Polarized Wideband Unipolar Crossed-Dipole Antenna with Folded Striplines.	Introduces a wideband CP crossed-dipole structure with improved AR and stable gain performance.
2022 R. Xu et al. [3]	Compact Ultra-Wideband Circularly Polarized Antenna with Stable Radiation Pattern.	Achieves UWB CP performance with compact size and consistent beam characteristics across wide frequency span.
2020 Z. Yang et al.[4]	Broadband Circularly Polarized Antenna with Non-Planar Reflector.	Uses a non-planar reflector to significantly enhance CP bandwidth and peak gain.
2008 J.-W. Baik et al. [5]	Broadband Circularly Polarised Printed Crossed Dipole Antennas.	Early work using crossed-dipole structure to obtain broadband axial ratio and improved CP purity.

Chapter 3

DESIGN AND METHODOLOGY

The design process for the antenna begins with optimizing a circularly polarized patch element. This element is then organized into an array with a phase-controlled feed network. Performance is evaluated through EM simulations to reach the target gain, bandwidth, and axial-ratio characteristics.

3.1 DESIGN PROCESS

The design of the circularly polarized patch array antenna starts with defining the target operating frequency, bandwidth, and performance needs like axial ratio (AR), gain, and return loss. First, a single microstrip patch element is designed and optimized to excite two orthogonal modes with a 90° phase shift. This allows for circular polarization. Techniques like geometry changes or slot-coupling, based on the chosen substrate, achieve this. After the unit element meets the desired CP characteristics, a 2×2 or 4×4 array is developed to improve gain and radiation performance. A feeding network that rotates sequentially or phase-shifted microstrip feed lines are used to ensure equal power division and the necessary phase differences between elements. The full antenna is modeled in an EM simulation tool like HFSS or CST. Parametric sweeps are performed to refine dimensions, element spacing, and feed-line lengths. The simulated results, including S-parameters, axial ratio, gain, and radiation patterns, are analyzed to check performance and make adjustments to the design. This structured approach helps create a well-optimized CP patch array for modern wireless and satellite communication applications.

3.2 PROCEDURE ADOPTED

1. Requirement Definition

- Identify the target frequency and bandwidth.
- Set performance goals.

2. Unit Patch Element Design

- Choose substrate material based on dielectric constant and thickness.
- Design a basic microstrip patch for the resonant frequency.
- Introduce slots or changes to create circular polarization.
- Perform parametric sweeps to optimize patch dimensions.

3. CP Technique Implementation

- Generate two orthogonal modes with a 90° phase difference.
- Verify circular polarization through axial ratio simulation.

4. Array Formation

- Arrange patches in a 2×2 or 4×4 configuration.
- Maintain proper spacing to avoid mutual coupling issues.
- Improve gain by enhancing the array factor.

5. Feed Network Design

- Develop a feed network that is sequentially rotated or phase-shifted.
- Ensure equal power distribution to all elements.

- Maintain the required 90° phase difference between adjacent patches.

6. Full Antenna Simulation

- Model the entire structure in HFSS, CST, or MATLAB EM toolbox.
- Simulate S11, return loss, and impedance matching.
- Evaluate radiation patterns, gain, beamwidth, and axial ratio.

7. Optimization

- Adjust patch dimensions, slot parameters, and feed lengths.
- Minimize side-lobe levels and improve polarization purity.
- Re-run simulations to confirm improvements.

8. Final Evaluation

- Confirm that the antenna meets circular polarization performance criteria.
- Prepare final plots: S11, gain graph, and radiation patterns.

Chapter 4

IMPLEMENTATION

The process of creating the circularly polarized patch array antenna starts with designing the radiating patch on a suitable substrate. This includes adding a cross-slot coupling structure to invoke two orthogonal modes necessary for circular polarization. The patch element is modeled using electromagnetic simulation software. Here, factors like patch radius, slot lengths, and microstrip line dimensions are optimized.

Next, a feed network is set up that rotates sequentially and uses a 1:2, 1:4 power divider to feed a 2×2 array, 4×4 array respectively.This setup ensures that power is evenly distributed and provides a 90° phase shift between neighboring elements. The feed lines are created using quarter-wavelength sections with specific impedance values to keep phase accuracy.

Once the antenna is built, which includes the radiating layer, ground plane with slots, and feed network, it is simulated to check S-parameters, axial ratio, gain, and radiation patterns. Parametric sweeps are carried out to refine the design. The final array structure is confirmed through full-wave simulations to ensure it operates effectively in wideband circular polarization, has a low voltage standing wave ratio, and achieves high gain necessary for efficient communication.

Chapter 5

RESULTS & DISCUSSION

1. Results of a single patch element

The team first designed and simulated the single patch element to confirm resonance at the target frequency. They also ensured that the cross-slot coupling produced circular polarization. The optimized unit displayed good impedance matching and acceptable axial-ratio behavior around the operating band.

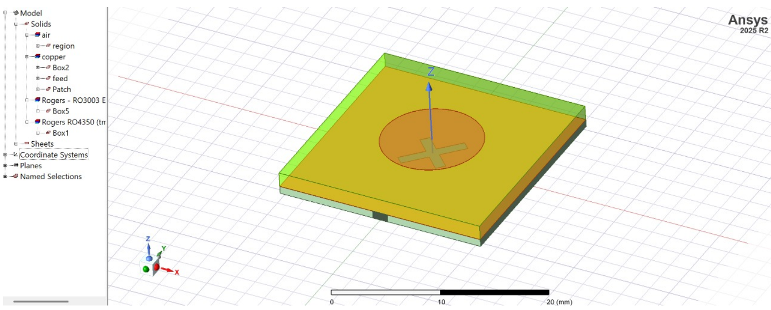

Figure 5.1: Single Element(isometric)

The S-parameter results show that the element resonates near the design frequency with S11 below -49 dBm. This indicates a good impedance matching.

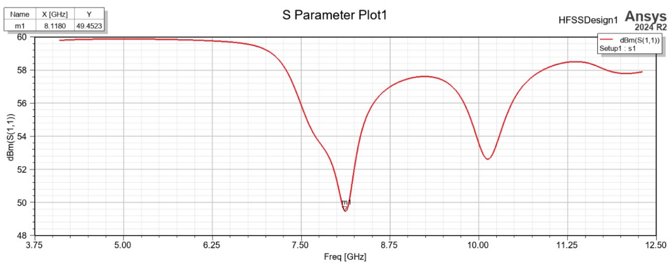

Figure 5.2: S11 / S-parameter plot for single element

The VSWR plot also confirms proper matching, maintaining values below 2 across the intended bandwidth.

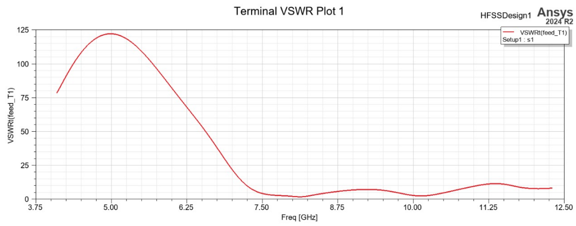

Figure 5.3: VSWR plot for single element

The axial ratio plot demonstrated that the single patch element achieves circular polarization near the resonance frequency, maintaining AR ¡ 3 dB in the required band.

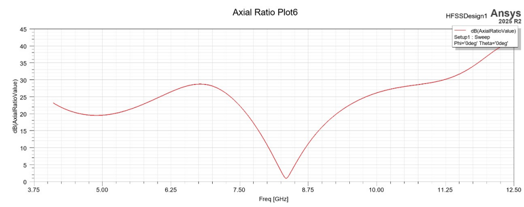

Figure 5.4: VSWR plot for single element

The gain of a single element was analyzed. It showed stable radiation with moderate gain that is suitable for array integration.

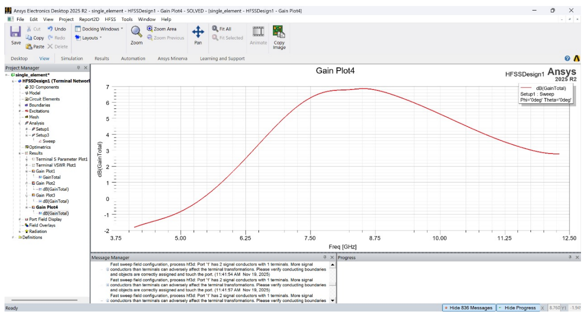

Figure 5.5: gain 2d plot for single element

The 3D radiation pattern illustrates the circularly polarized radiation behavior and the directional nature of the patch.

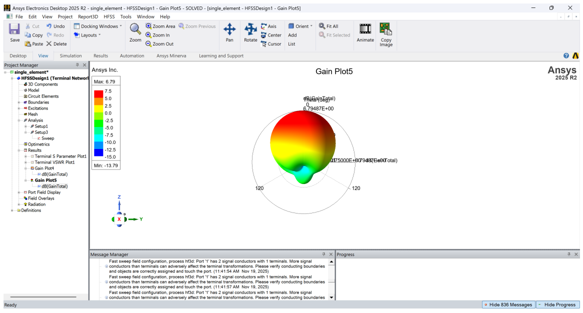

Figure 5.6: X view

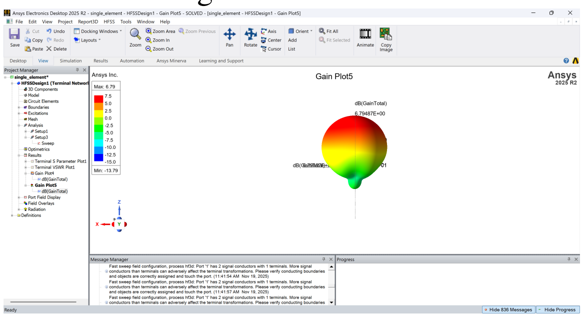

Figure 5.7: Y view

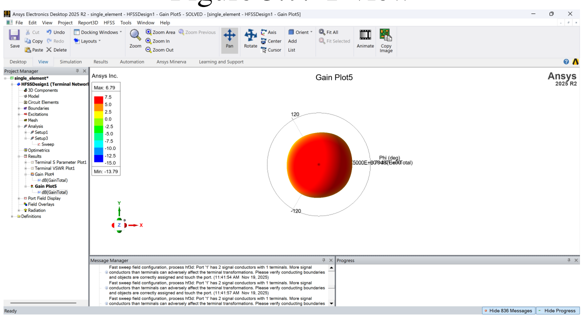

Figure 5.8: Z view

Figure 5.9: 3D gain/radiation pattern of single element (X,Y,Z views)

2. 2×2 Patch Array Results

The team simulated the 2×2 circularly polarized array to improve gain, bandwidth, and axial ratio using sequential rotation feeding. The array offered better circular polarization performance and increased radiation efficiency compared to the single unit.

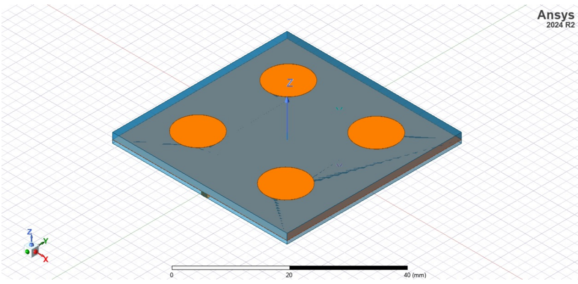

Figure 5.10: isometric

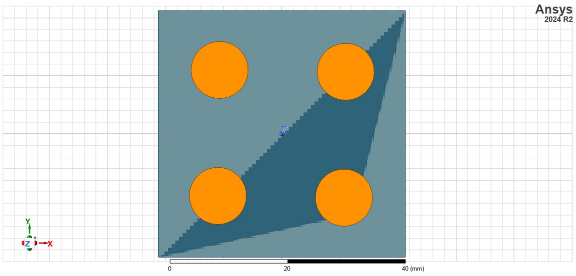

Figure 5.11: top view

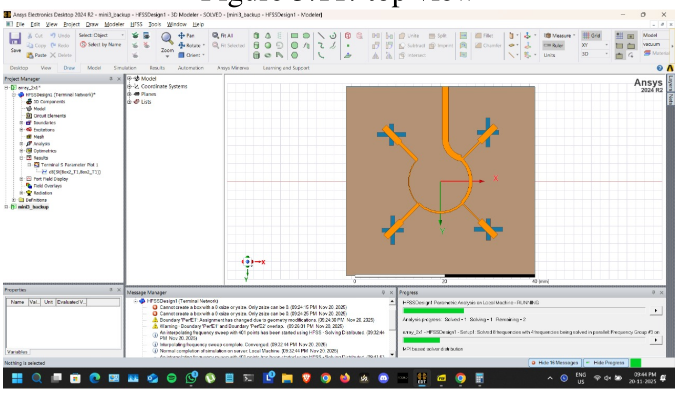

Figure 5.12: bottom view

Figure 5.13: 2×2 array antenna design

The S-parameter response of the array shows improved matching, with deeper S11 values and a wider operating bandwidth.

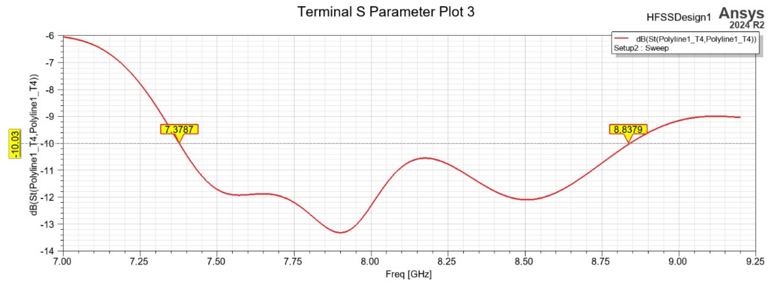

Figure 5.14: S11 / S-parameter plot for 2×2 array

The VSWR plot remains below 2 across the expanded bandwidth. This proves effective feed-network behavior and reduced reflection.

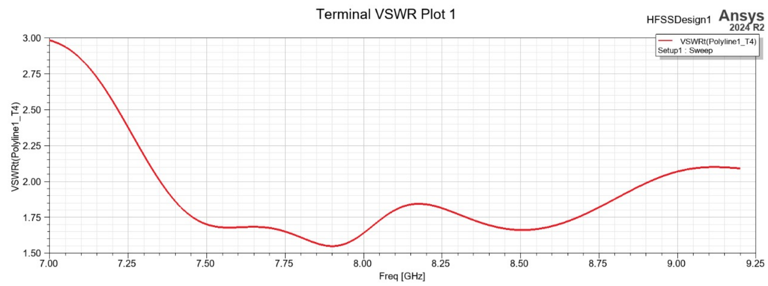

Figure 5.15: VSWR plot for 2×2 array

The axial ratio plot demonstrated that the array achieves circular polarization near the resonance frequency, maintaining AR ¡ 3 dB in the required band.

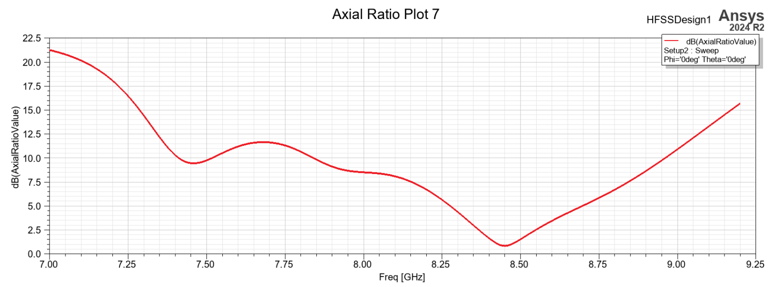

Figure 5.16: 2x2 array axial ratio plot

The gain performance of the array shows a significant increase compared to the single element. This confirms successful array formation.

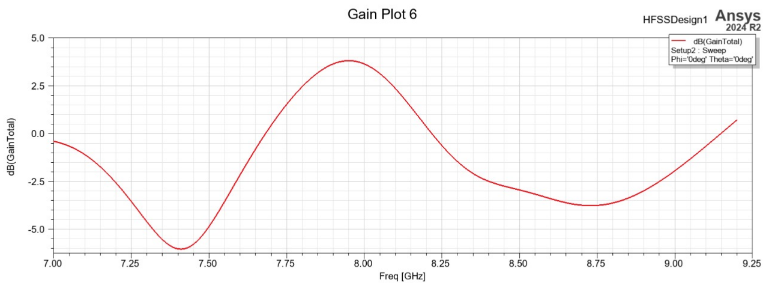

Figure 5.17: gain plot for 2×2 array

The 3D gain patterns in X, Y, and Z planes illustrate stronger directivity, improved polarization purity, and higher boresight gain.

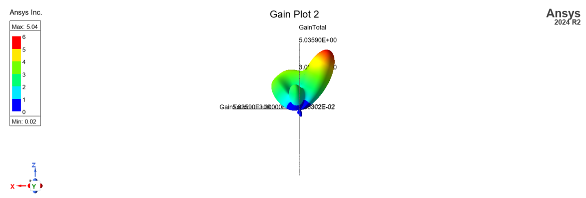

Figure 5.18: Y view

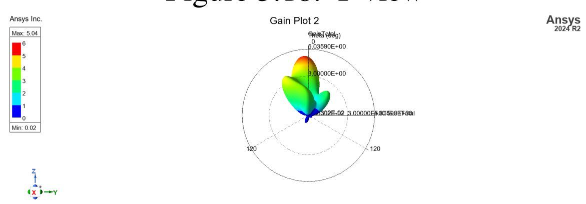

Figure 5.19: X view

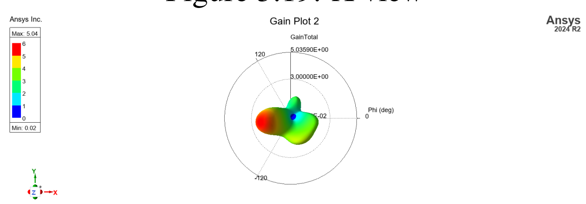

Figure 5.20: Z view

Figure 5.21: 3D gain/radiation pattern of single element (X,Y,Z views)

5.1 RESULTS SECTION

This section of the project shows the performance results of the designed circularly polarized patch antenna and its array configurations. It gives a clear summary of the main simulation findings, including VSWR, S-parameters, axial ratio, gain, and radiation patterns, without offering any analysis or interpretation. These findings are directly related to the research goal of assessing the antenna's impedance matching, circular polarization behavior, and radiation performance. By presenting the relevant plots and antenna models, this part documents how the design acts during simulation and how well it meets the expected performance criteria. The aim is to present the technical data clearly and objectively, so readers can understand the antenna's performance before moving on to interpretation or conclusions.

5.2 DISCUSSION SECTION

This part of the report explains the meaning and importance of the antenna's simulation results. It interprets how well the circularly polarized patch array meets its performance goals, such as achieving low VSWR, keeping a stable axial ratio for circular polarization, and improving gain through its configuration. It also connects the observed behavior to antenna theory and earlier designs, providing reasons for strong performance or any variations. Additionally, this section highlights the benefits of the chosen feeding technique and structural design while noting any limitations seen during the simulation. Overall, it offers insight into what the findings indicate about the effectiveness, reliability, and potential applications of the antenna.

Chapter 6

CONCLUSION

The design and simulation of the circularly polarized patch antenna showed clear improvements in performance as the structure evolved from a single radiating element to a 2×2 array configuration. The single patch element achieved good impedance matching with a VSWR below acceptable limits, a distinct resonance in the S-parameter response, and an axial ratio close to 3 dB around the target frequency, confirming basic circular polarization behavior. However, the gain of the single element stayed modest due to its limited aperture size.

With the 2×2 array, significant improvements were seen in all key performance areas. The array had a broader impedance bandwidth and better return loss characteristics, indicating stronger and more stable matching. The axial ratio performance further improved, showing consistent circular polarization across a wider frequency range thanks to the sequential phase-fed arrangement. The most significant enhancement was in the gain parameter, where the array exhibited a substantial increase compared to the single element. This was due to constructive array factor contributions and a larger effective aperture. The radiation patterns also became more directional and symmetrical, highlighting the benefits of integrating the array.

In summary, the design approach effectively created a compact, high-gain, and circularly polarized antenna system. The comparison between the individual element and the array shows that expanding the array greatly improves performance. This makes the antenna suitable for communication applications that require reliable circular polarization and better directivity.

Parameter	Single Element	2×2 Array Element
Gain	6.8dB	9.7dB
VSWR	2.8dB	1.55dB
Axial Ratio	0.95dB	1.1dB
S Parameter	-15dB	-13.4dB
Operating Frequency	7.88Ghz	7.9Ghz
Antenna Type	Circularly Polarised Microstrip Patch Antenna (slot-coupled patch element)	Circularly Polarised Microstrip Patch Array Antenna (2×2 sequentially phase-fed array)
Feed Type	Microstrip line feed with cross-slot coupling for CP generation	Sequentially rotated feed network providing equal power and 90° phase shift between adjacent elements
Radiation Pattern	Moderately directional with a single main lobe; lower gain; wider beamwidth; basic circular polarisation achieved around the resonant frequency	Highly directional with increased gain; narrower beamwidth; improved circular polarisation stability; more symmetrical and focused radiation pattern
Bandwidth	1.45Ghz	550Mhz

Table 6.1: Parameters Comparasion.

6.1 SCOPE OF FURTHER WORK

The results of this project open several exciting opportunities for future development and research. One of the key next steps is to build and test both the single patch element and the array configuration. Creating a physical prototype will allow us to compare simulated and measured parameters like S11, VSWR, axial ratio, gain, and radiation patterns. This comparison will help us identify practical losses, manufacturing tolerances, and limits of real-world performance.

A major future direction is to design and implement a 4×4 circularly polarized patch array, similar to the one in the referenced research paper. Scaling the array from 2×2 to 4×4 can significantly improve gain, directivity, and axial ratio bandwidth. Using a sequential rotation feeding network for the 4×4 structure would further improve the purity of circular polarization and enhance radiation symmetry.

Additional improvements may involve exploring substrates like Rogers RO4003C or RT/Duroid to reduce dielectric loss at higher frequencies and boost overall antenna efficiency. We can apply optimization methods like genetic algorithms, Particle Swarm Optimization (PSO), or machine learning-based tuning to refine patch dimensions, slot shapes, and feed line layouts for wider bandwidth and better axial ratio performance.

We can also expand the antenna for reconfigurable or dual-band circular polarization using PIN diodes, varactors, or metasurface-based loading. Another area of exploration is to integrate the antenna with RF front-end modules, which will enable its use in practical applications such as satellite communication, UAV telemetry, 5G mmWave front ends, radar sensing, or IoT communication systems.

In summary, this project establishes a foundation for fabrication, higher-order array development, and numerous technical enhancements that can greatly improve the antenna's performance and broaden its use in modern communication systems.

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