Planar CP Array Antenna for Small Satellite Systems to enable IoMT Devices

Report submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

Electronics & Tele-Communication Engineering

by

Varigala Sai Charan Gupta

ID: B221065

Under the guidance of

Prof. Dr. Sanjeev Kumar Mishra

Electronics & Tele-Communication

International Institute of Information Technology

Bhubaneswar, Odisha – 751003, India

Dec 2024

With the blessings of almighty. To
my beloved parents, family
members, and my mother

Electronics & Tele-Communication Engineering
International Institute of Information Technology
Bhubaneswar – 751003, Odisha, India

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This is to certify that the work in this report entitled **"Planar CP Array Antenna for Small Satellite Systems to enable IoMT Devices"** by **Varigala Sai Charan Gupta**, bearing ID: **B221065**, is a record of an original research work carried out by him under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology in Electronics & Tele-Communication Engineering**. Neither this thesis/report nor any part of it has been submitted for any degree or academic award elsewhere.

Date: Dec 2024
Place: IIIT Bhubaneswar

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Department of ETC,
IIIT Bhubaneswar, Odisha, India

Electronics & Tele-Communication Engineering
International Institute of Information Technology
Bhubaneswar – 751003, Odisha, India

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Title of Report: Planar CP Array Antenna for Small Satellite Systems to enable IoMT Devices

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Supervisor

Co-Supervisor

Project Co-Ordinator

ETC HoD, ETC

Electronics & Tele-Communication Engineering
International Institute of Information Technology
Bhubaneswar – 751003, Odisha, India

Declaration of Originality

I, Varigala Sai Charan Gupta bearing roll number B221065 hereby declare that this thesis/report entitled **“Planar CP Array Antenna for Small Satellite Systems to enable IoMT Devices”**, presents my original work carried out as a bachelor student of International Institute of Information Technology, Bhubaneswar, and to the best of my knowledge, contains no material previously published or written by another person, nor any material presented by me for the award of any degree or diploma of International Institute of Information Technology, Bhubaneswar or any other institution. Any contribution made to this work by others, with whom I have worked at International Institute of Information Technology Bhubaneswar o elsewhere, is explicitly acknowledged in this thesis/report. Works of other authors cited in this dissertation have been duly acknowledged under the sections “Reference”. I have also submitted my original research records to the scrutiny committee for the evaluation of my report.

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Place: IIIT Bhubaneswar

Name: Varigala Sai Charan Gupta
Roll: b221065
Electronics & Tele-Communication Engineering,
International Institute of Information Technology,
Bhubaneswar, Odisha, India

Acknowledgement

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Name: Varigala Sai Charan Gupta
Roll: B221065
Electronics & Tele-Communication Engineering,
International Institute of Information Technology,
Bhubaneswar, Odisha, India

Abstract

This paper presents the design and optimization of a 4×4 planar microstrip patch antenna array to achieve high gain, circular polarization (CP), and improved bandwidth performance. The antenna operates at a target frequency of 8.25 GHz with a bandwidth of 372.55 MHz, a gain of 18.29 dBi, and an axial ratio below 3 dB (almost equal to 1.1387 dB). Circular polarization is achieved using techniques such as corner truncation and slot insertion in the patch elements. The design progression includes single-element, 1×2, and 2×2 arrays, leading to the final 4×4 array configuration.

A corporate feeding network is employed to ensure phase coherence and broadside radiation. Challenges such as grating lobes due to unequal spacing and feed network complexity were addressed by redesigning the corporate feed and maintaining uniform element spacing. Using RT/Duroid 5880 as the substrate, the 4×4 array achieves a gain of 18.29 dBi with an impedance-matched network.

Future work focuses on incorporating a Butler matrix for beam steering, optimizing the feed network for improved performance, and fabricating the design for validation. This study demonstrates a robust methodology for designing high-performance planar antenna arrays suitable for wideband and high-gain applications.

Contents

List of Acronyms

CP: Circularly Polarized

SWR: Standing Wave Ratio

AR: Axial Ratio

Chapter 1

Introduction

- Introduction to Microstrip Patch Antennas
- Circular Polarization in Microstrip Antennas
- Design innovations for improved performance
- Improving antenna bandwidth and gain
- Microstrip antenna array types and design

Chapter 1

Introduction

1.1 Introduction to Microstrip Patch Antennas

The microstrip patch antenna is a widely preferred candidate for multiple functionality systems. However, major limitations of microstrip antennas are low gain and narrow bandwidth. Several techniques are used to increase the impedance bandwidth of patch antennas, such as aperture-coupled feed [1], L-shaped probe feed [2], U-slotted patch [3].

1.2 Circular Polarization in Microstrip Antennas

Generating circular polarized radiation using single-feed configuration requires slight perturbation of the antenna structure and optimizing the position of the perturbation with respect to the feed to excite orthogonal modes. Perturbation approaches for single-feed CP configuration involve the insertion of cross- or Y-shaped slots, slits [2], truncating corners [3], spur lines, stub loading [4] in the boundary of the patch. The single-feed circularly polarized antennas are fed at 45° with respect to the perturbation. Different types of feeding techniques may be used for the circular polarized microstrip patch antenna. Coaxial probe feed [3] – [7] though simple, provides only narrow bandwidth. The authors have demonstrated a directional, wideband antenna having SWR bandwidth of 54.2 % fed using a nonplanar Γ-shaped feeding structure and two meandering strips [2]. The antenna shows a high gain of 9 dBi and good cross-polarization characteristics, polarization less than −27 dB over the entire operating frequency range. In [3], truncated corner square patch is used to generate circular polarization characteristics. The antenna incorporates the use of U-slot to increase bandwidth, offers low gain (4.5 dBi), and AR bandwidth is 3.2 % at L band frequencies. By introducing asymmetrical triangular shaped slits in diagonal direction of square microstrip patches [5], the single coaxial feed microstrip patch antenna is realized for CP radiation with compact antenna size. The impedance and axial ratio bandwidths are small around 2.5 and 0.5 %. Antenna arrays used to improve the antenna gain [8].

1.3 Design Innovations for Improved Performance

For achieving improvement in antenna bandwidth various techniques like use of ground structure with circular patch, partial and modified ground plane, use of inset feed, use of open stubs are used [9]-[12].

1.4 Improving Antenna Bandwidth and Gain

Now there are two kinds of microstrip antenna arrays according to the feeding network, namely series-fed array and corporate-fed array [13]. The series-fed array [14], formed by interconnecting the radiating elements with high-impedance microstrip line sections, is simple and has compact feeding network, but is subject to beam squint with frequency. As to the corporate-fed array [15]-[18], the elements are fed by a power divider with identical path lengths from the feed point to each element, which insures phase coherence and a broadside array beam. But it experiences efficiency limitations especially in large arrays, where the feeding network is long and complicated.

1.5 Microstrip Antenna Array Types and Design

After study the above literature and utilizing [8] referred for 4x4 antenna array design. Here in this design a unique corporate feeding network is designed for the 4x4 array design. For getting a minimized CP across the band we use a truncated patch.

Chapter 2

Planar CP Array antenna

- Initial Single-Element Design
- Circular Polarization Achievement:
- Progressive Array Design
- 4x4 Array with Corporate Feed Network
- Issue with Grating Lobes 4x4 Array
- Feed Network Redesign and Equal Spacing Implementation

Chapter 2

Planar CP Array Antenna

2.1 Initial Single-Element Design

A single-element, microstrip-fed square patch antenna was designed and optimized to achieve an S11 parameter at a resonant frequency of 8.25 GHz.

2.1.1 Patch Antenna

Patch antennas are popular in array configurations due to their unique advantages, especially in applications where high gain, compact size.so we have chosen a patch antenna for this configuration.

The **length (L)** and **width (W)** of a rectangular microstrip patch antenna are crucial for determining its resonant frequency (f0) and radiation performance. These dimensions depend on the desired operating frequency and the substrate properties.

1. Width (W)

The width (W) of the patch controls the input impedance and radiation efficiency. It can be calculated as:

$$W = \frac{c}{2f_0\sqrt{\varepsilon_r + 1}}$$

Where:

- c is the speed of light (3×10^8 m/s),
- f_0: Desired resonant frequency (Hz),
- ε_r : Relative permittivity (dielectric constant) of the substrate.

2. Effective Dielectric Constant (ε_{eff}): CST determines the effective dielectric constant of the microstrip line, which depends on:

- Substrate height (h),
- Width of the microstrip line (w),
- Permittivity of the substrate (ε_r).

The effective dielectric constant is calculated approximately as:

- $\varepsilon_{\text{eff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right)$hhh: Height (thickness) of the substrate (m),
- W: Width of the patch (calculated above).

3. Length (L)

The length (L) of the patch determines the resonant frequency and is slightly less than half the wavelength in the substrate due to fringing effects. It is calculated as:

$$L = \frac{c}{2f_0\sqrt{\varepsilon_{\text{eff}}+1}} - 2\Delta L$$

Fringing Length Correction (ΔL):

$$\Delta L = \frac{0.412h\left((\varepsilon eff\ + 0.3)\left(\frac{W}{h} + 0.264\right)\right)}{\left((\ \varepsilon eff\ - 0.258)\left(\frac{W}{h} + 0.8\right)\right)}$$

Where:

- ΔL: Extension of the length due to fringing fields (m).

To calculate the size of your antenna in terms of the wavelength (λ) at the operating frequency of 8.25 GHz, follow these steps:

Step 1: Wavelength Calculation

The wavelength (λ) is given by:

$$\lambda = \frac{c}{f}$$

where:

- c is the speed of light (3×10^8 m/s),
- f is the frequency (8.25 GHz = 8.25×10^9).

$$\lambda = \frac{3\times10^8}{8.25\times10^9} = 0.03636 \text{ m} = 36.36 \text{ mm}$$

Step 2: Antenna Size in Terms of Wavelength

The antenna size is 11.7 mm×11.7. To express it in terms of λ:

$$\text{Antenna size in } \lambda = \frac{Antenna\ dimension}{\lambda}$$

For both dimensions:

$$\text{Size in } \lambda = \frac{11.7\,mm}{36.36\,mm} \approx 0.32\lambda$$

Final Result:

The antenna size is approximately **0.32λ×0.32λ** at 8.25 GHz.

If the feed line has a characteristic impedance of Z_f = 50 Ω, and the antenna has an impedance of Z_a = 100 Ω, you can use a λ/4 line with a characteristic impedance Z_0:

$$Z_0 = \sqrt{Zf \times Za} = \sqrt{50 \times 100} = 70.7\ \Omega$$

This λ/4 line will transform the impedance such that the antenna is matched to the feed line.

Wavelength in Free Space*:* The wavelength in free space (λ0\lambda_0λ0) is calculated using:

$$\lambda_0 = \frac{c}{f}$$

where f is the operating frequency.

Effective Dielectric Constant (ε_{eff})*:* CST determines the effective dielectric constant of the microstrip line, which depends on:

- Substrate height (h),
- Width of the microstrip line (w),
- Permittivity of the substrate ($\boldsymbol{\varepsilon}_{\mathbf{r}}$).

The effective dielectric constant is calculated approximately as:

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h}{w}}}\right)$$

Wavelength in the Medium (λ_g)*:* The guided wavelength ($\boldsymbol{\lambda}_{\mathbf{g}}$) is the wavelength in the substrate medium and is given by:

$$\lambda_g = \frac{\lambda_0}{\sqrt{\varepsilon_{eff}}}$$

Quarter-Wavelength Line Length*:* The physical length of the λ/4 line is:

$$L_{\lambda/4} = \frac{\lambda_g}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{eff}}}$$

2.1.2 Initial Single-Element Design:

A single-element, microstrip-fed square patch antenna was designed and optimized to achieve an S11 parameter at a resonant frequency of 8.25 GHz.

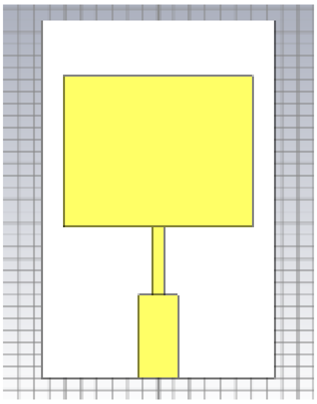


Fig.1 microstrip patch antenna at 8.25 GHz

2.2 Circular Polarization Achievement

Square patches are easily modified to produce circular polarization (CP) by adding features like corner truncation or asymmetrical slots. There are many methods are available for generating CP in microstrip patch antenna. We have designed some of the structure using these techniques-

2.2.1 Corner Truncation:

Truncating the corners of a square or rectangular patch can create the orthogonal modes required for CP, often used in microstrip patch designs.

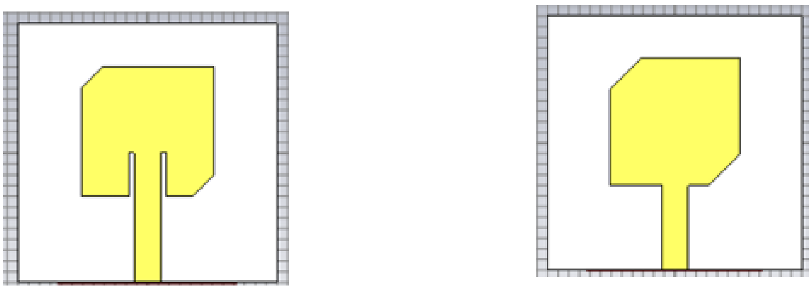


Fig.2 Truncated corner microstrip patch antenna for CP

2.2.2 Slits or Notches and stub:

Adding slits or notches in the patch at strategic locations can induce CP.

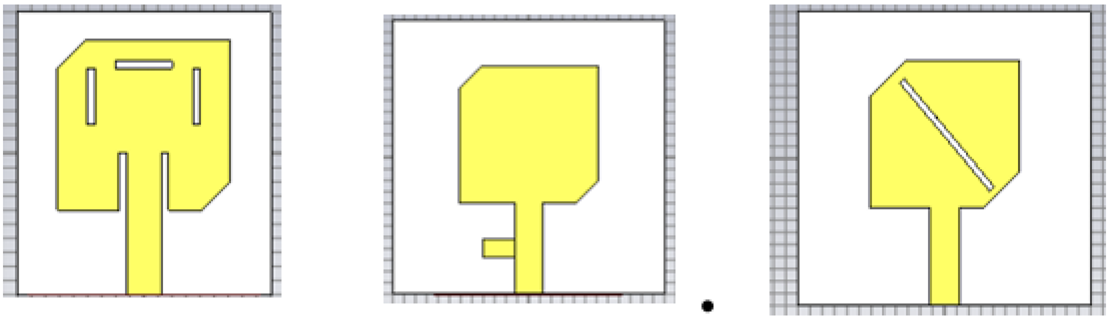


Fig.3 Slot and stub microstrip patch antenna for CP

2.2.3 Cross-Slot in Patch:

A cross-slot in the patch with specific dimensions and orientations can help generate circular polarization, especially in microstrip patch antennas.

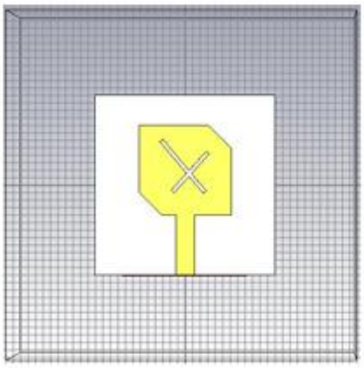


Fig.4 Cross slot microstrip patch antenna for CP

2.2.4 Circular Polarization Achievement:

Circular polarization (CP) was obtained for the above antenna by employing a truncated corner technique, achieving the desired CP at 8.25 GHz.

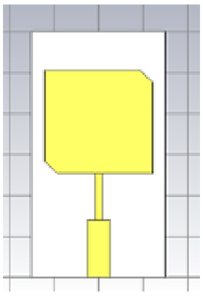


Fig.5 Single element microstrip patch CP antenna at 8.25 GHz

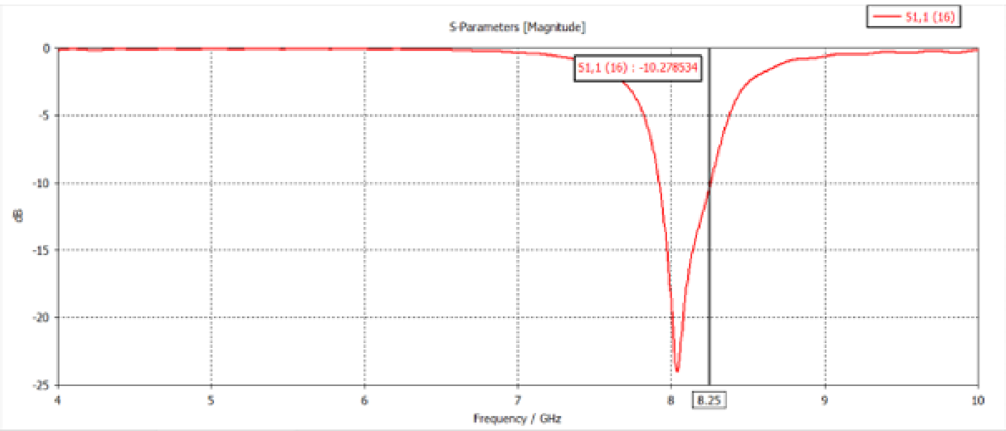


Fig.6 S11 of Single element microstrip patch CP antenna at 8.25 GHz

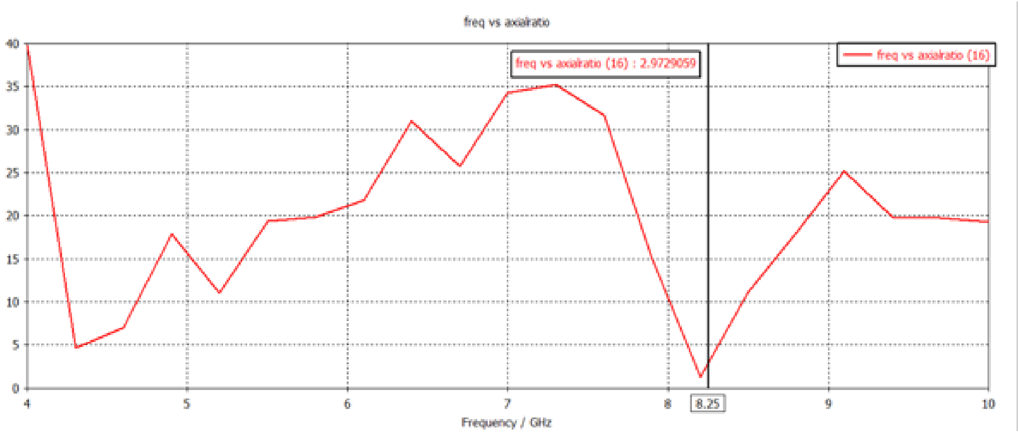


Fig.7 Axial Ratio of Single element microstrip patch CP antenna at 8.25 GHz

2.3 Progressive Array Design

Prior to designing the final 4x4 array, intermediate arrays of 1x2 and 2x2 configurations were developed and validated to ensure reliable performance and to progressively scale up to the larger array.

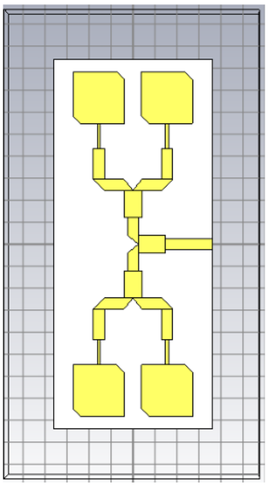


Fig.8 2x2 microstrip patch CP antenna at 8.25 GHz

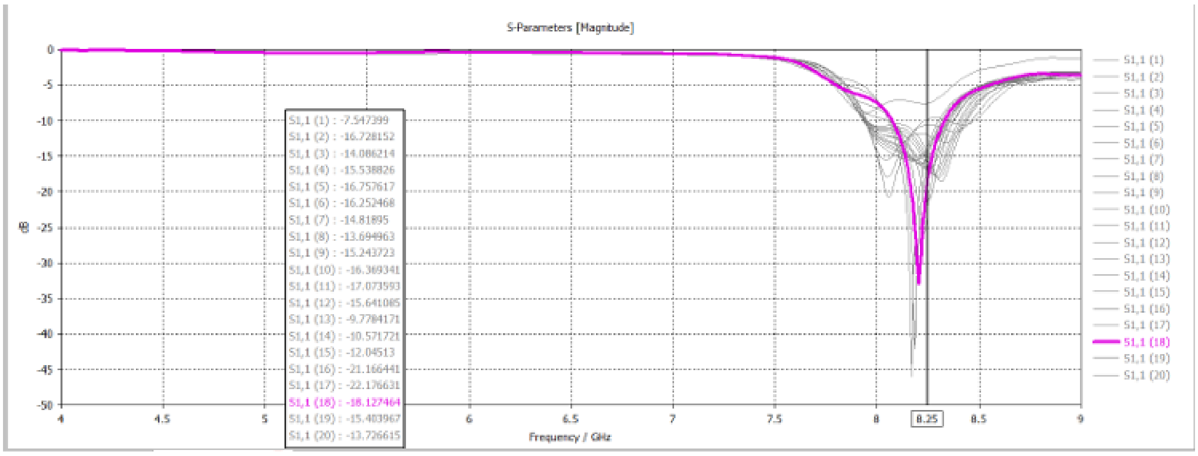


Fig.9 S11 of 2x2 microstrip patch CP antenna at 8.25 GHz

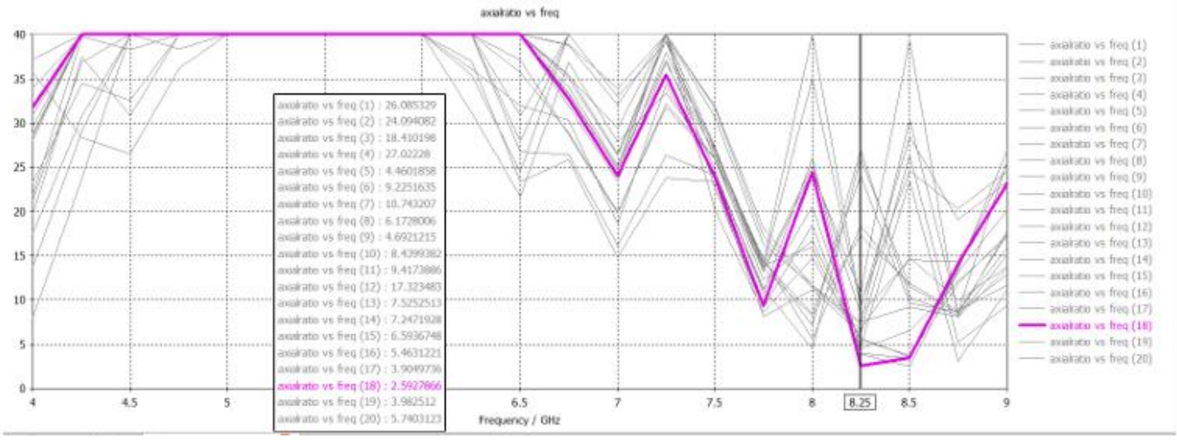


Fig.10 Axial Ratio of 2x2 microstrip patch CP antenna at 8.25 GHz

2.4 4x4 Array with Corporate Feed Network

A 4x4 array configuration was implemented, incorporating a corporate feed network to achieve circular polarization. This design scaled up the gain while maintaining the CP characteristics observed in the single-element design.

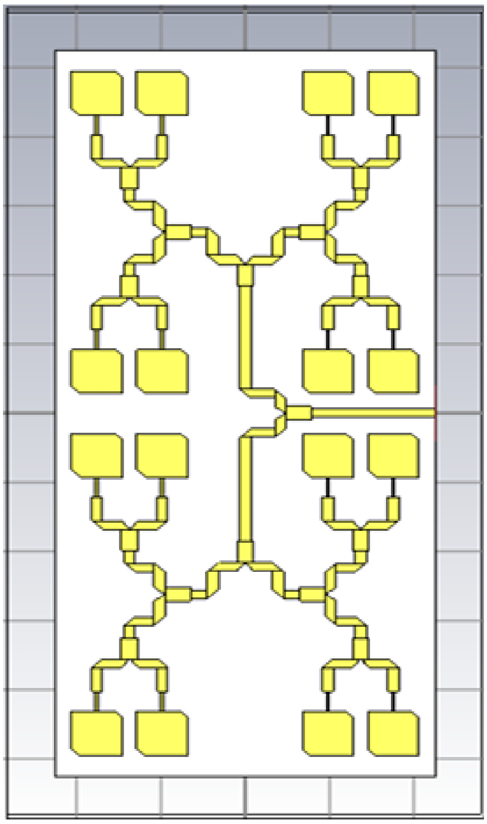


Fig.11 4x4 microstrip patch CP antenna at 8.25 GHz

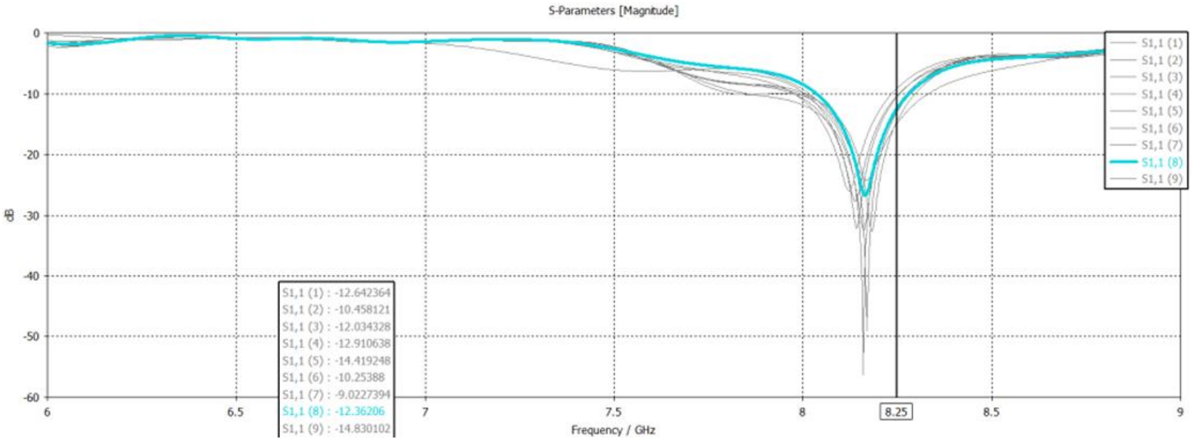


Fig.12 S11 of 4x4 microstrip patch CP antenna at 8.25 GHz

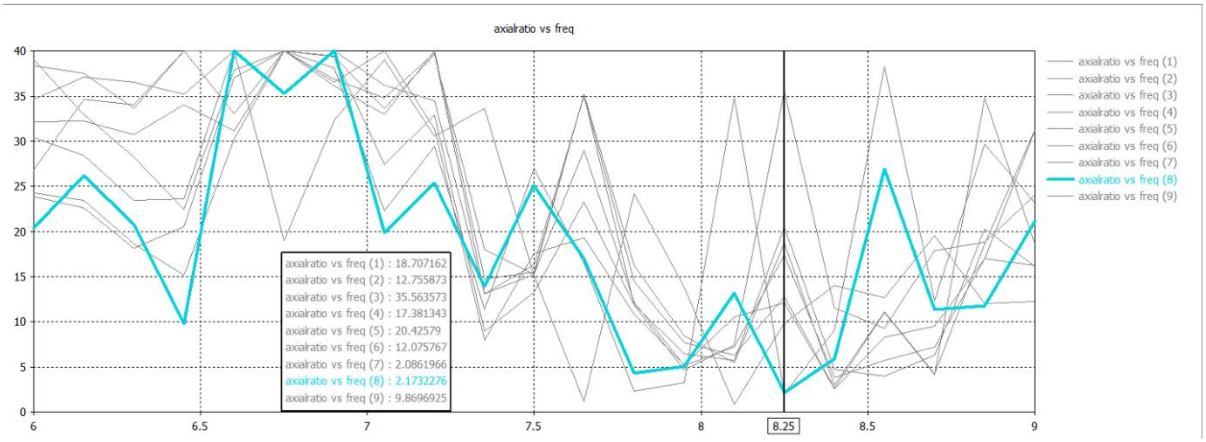


Fig.13 Axial Ratio of 4x4 microstrip patch CP antenna at 8.25 GHz

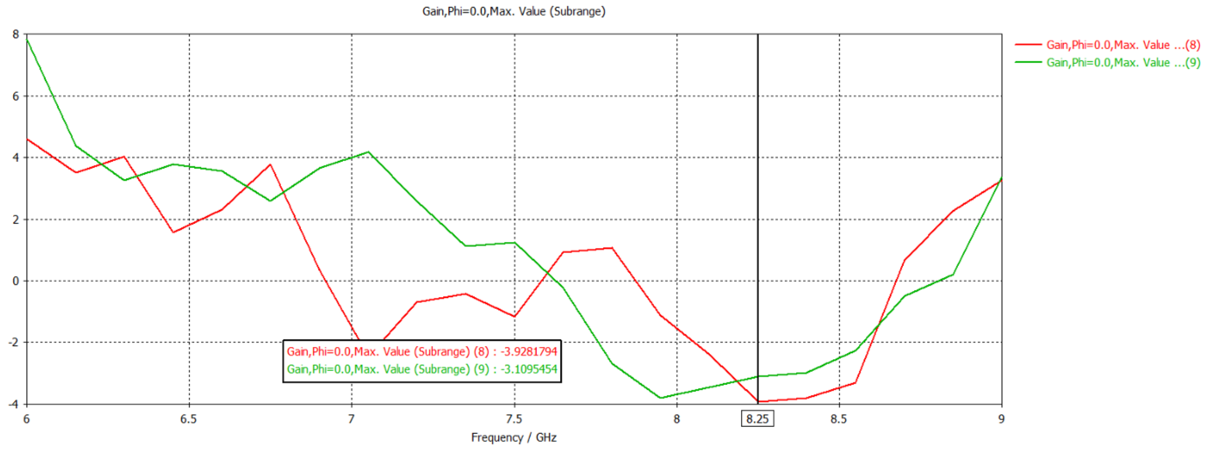


Fig.14 Gain of 4x4 microstrip patch CP antenna at 8.25 GHz

2.5 Issue with Grating Lobes 4x4 Array

The initial 4x4 array design experienced significant grating lobes due to unequal spacing between antenna elements and the complexity of the corporate feed network, which led to non-uniform element placement.

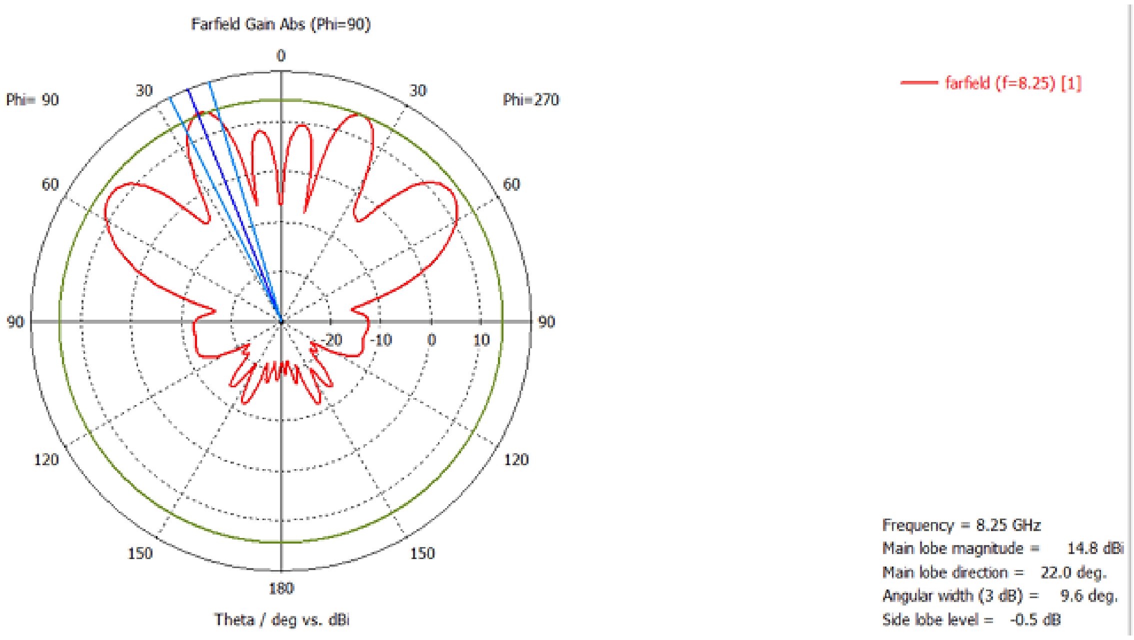


Fig.15 1D Radiation Pattern of 4x4 microstrip patch CP antenna at 8.25 GHz

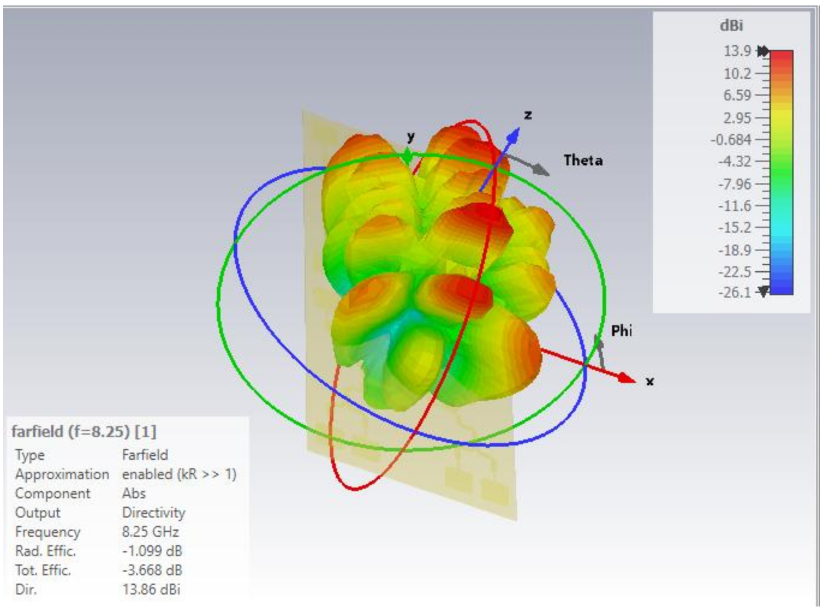


Fig.15 3D Radiation Pattern of 4x4 microstrip patch CP antenna at 8.25 GHz

2.6 Feed Network Redesign and Equal Spacing Implementation:

To reduce grating lobes, the corporate feed network was redesigned, and the antenna elements were repositioned with equal spacing, ensuring uniformity across the array and minimizing unwanted lobes.

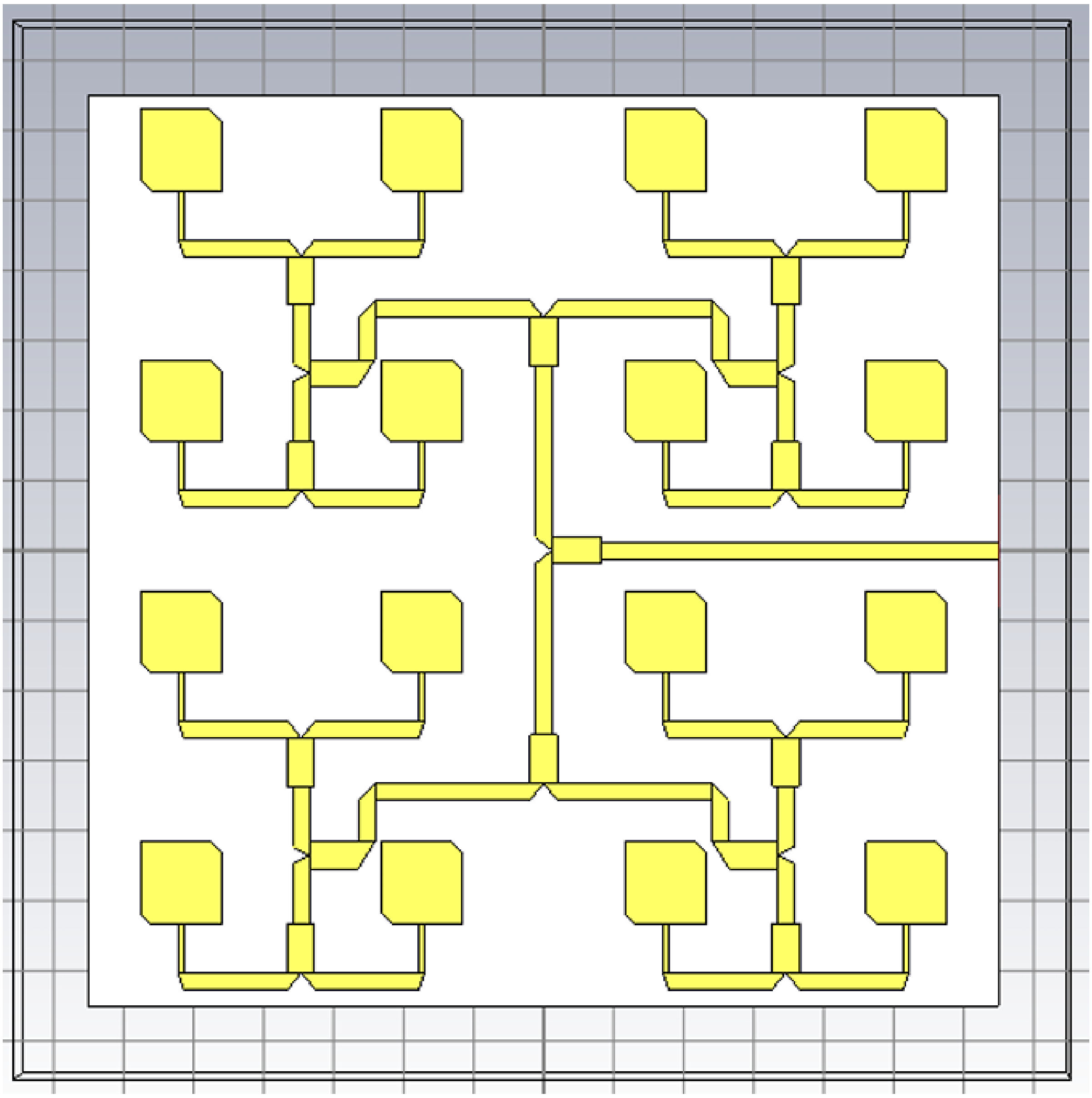


Fig.16 Revised 4x4 microstrip patch CP antenna at 8.25 GHz

Chapter 3

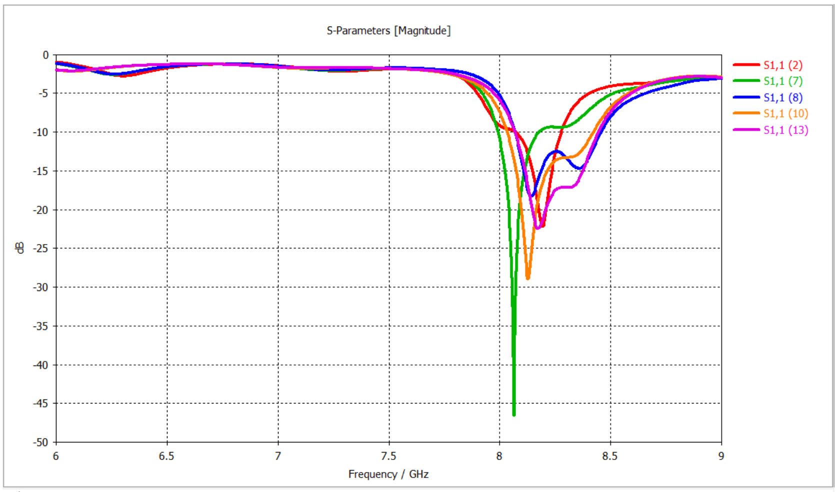
Results & Discussion

- Final Design Phase and Improvement in the process while Comparison results based on the various Parameter Sweep
- FINAL RESULTS

Chapter 3

Results & Discussion

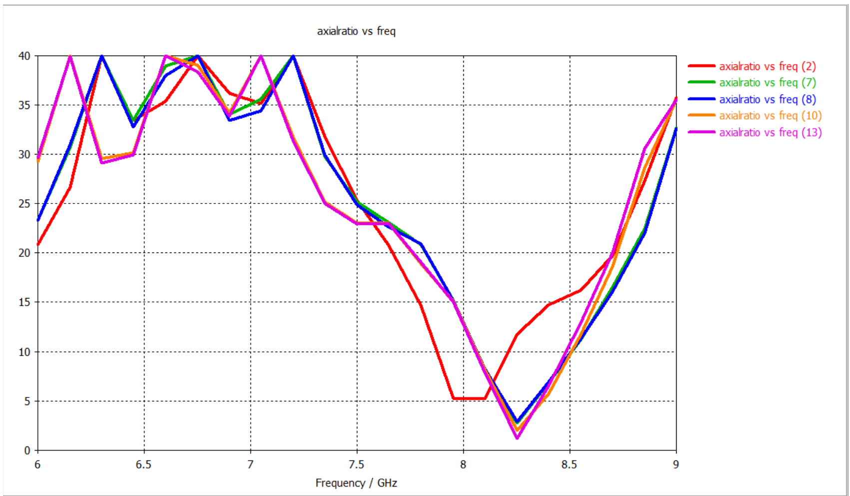
3.1 Final Design Phase & Improvement in the process while Comparing results based on the various Parameter Sweep



Result Navigator

3D Run ID	a	b	l	lp	lwf1	lwf10	lwf2	lwf5	lwf6	lwf9	w	wp	x
2	1.5	1.4	130	11.9	26.3	26.3	6.1	8.5	7	6.1	130	11.8	-2.5
7	1.6	1.5	130	11.9	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
8	1.6	1.5	130	11.7	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
10	1.6	1.5	130	11.7	26.3	26.3	6.9	9.3	7	6.9	130	11.5	-2.8
13	1.5	1.4	130	11.6	26.3	26.3	7	9.3	7	7	130	11.5	-2.8

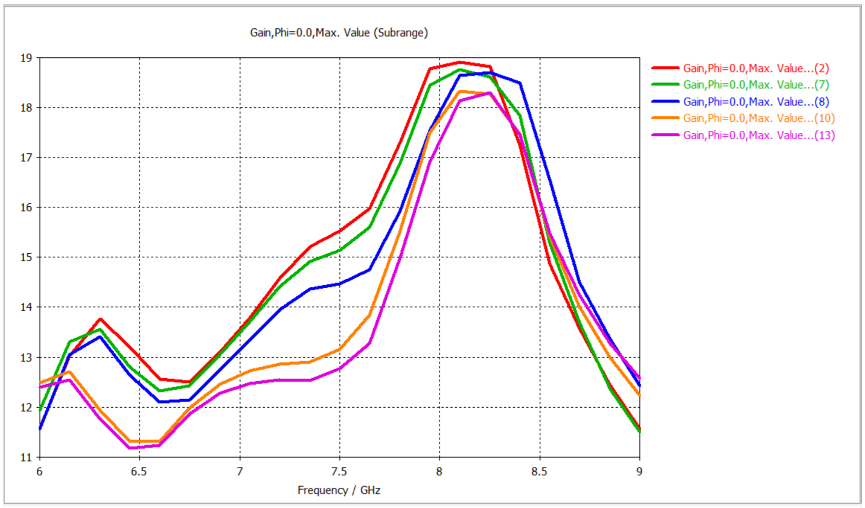
Fig.17 Parameter sweep (S11) of Revised 4x4 microstrip patch CP antenna at 8.25 GHz



Result Navigator

3D Run ID	a	b	l	lp	lwf1	lwf10	lwf2	lwf5	lwf6	lwf9	w	wp	x
2	1.5	1.4	130	11.9	26.3	26.3	6.1	8.5	7	6.1	130	11.8	-2.5
7	1.6	1.5	130	11.9	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
8	1.6	1.5	130	11.7	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
10	1.6	1.5	130	11.7	26.3	26.3	6.9	9.3	7	6.9	130	11.5	-2.8
13	1.5	1.4	130	11.6	26.3	26.3	7	9.3	7	7	130	11.5	-2.8

Fig.18 Parameter sweep (Axial Ratio) of Revised 4x4 microstrip patch CP antenna at 8.25 GHz



Result Navigator

3D Run ID	a	b	l	lp	lwf1	lwf10	lwf2	lwf5	lwf6	lwf9	w	wp	x
2	1.5	1.4	130	11.9	26.3	26.3	6.1	8.5	7	6.1	130	11.8	-2.5
7	1.6	1.5	130	11.9	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
8	1.6	1.5	130	11.7	26.3	26.3	6.3	8.7	7	6.3	130	11.5	-2.5
10	1.6	1.5	130	11.7	26.3	26.3	6.9	9.3	7	6.9	130	11.5	-2.8
13	1.5	1.4	130	11.6	26.3	26.3	7	9.3	7	7	130	11.5	-2.8

Fig.19 Parameter sweep (Gain) of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

3.2 FINAL RESULTS

The redesigned 4x4 array with improved feed network and equidistant element placement is now in the final stage of completion.

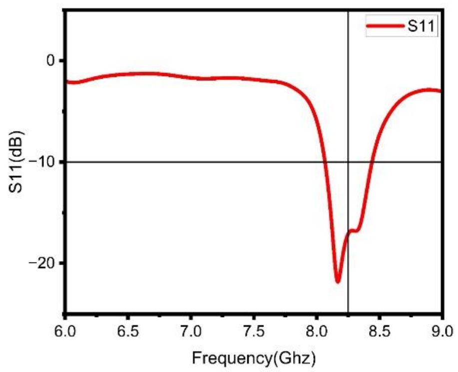


Fig.20 S11 of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

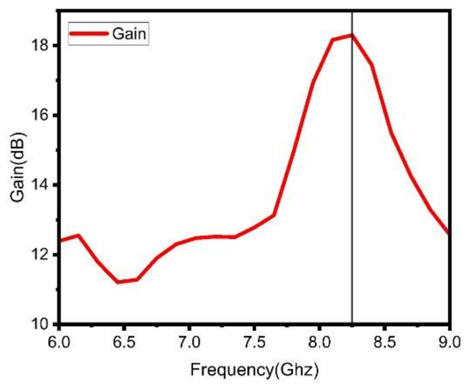


Fig.21 Gain of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

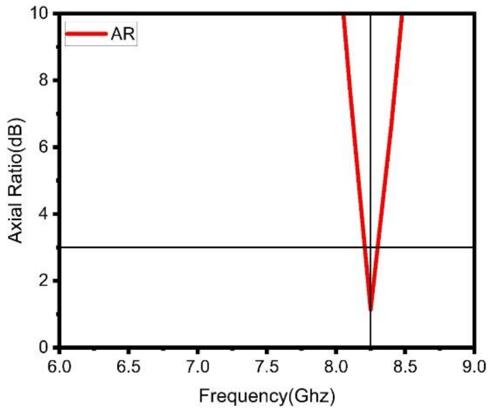


Fig.22 Axial Ratio of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

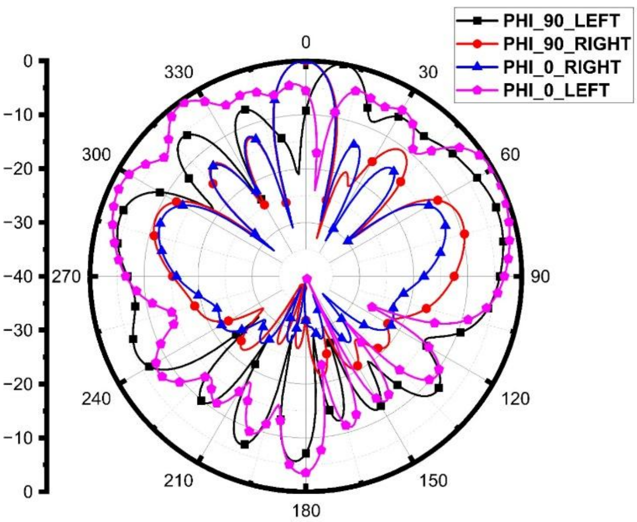


Fig.23 1-D Farfield showing RHCP of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

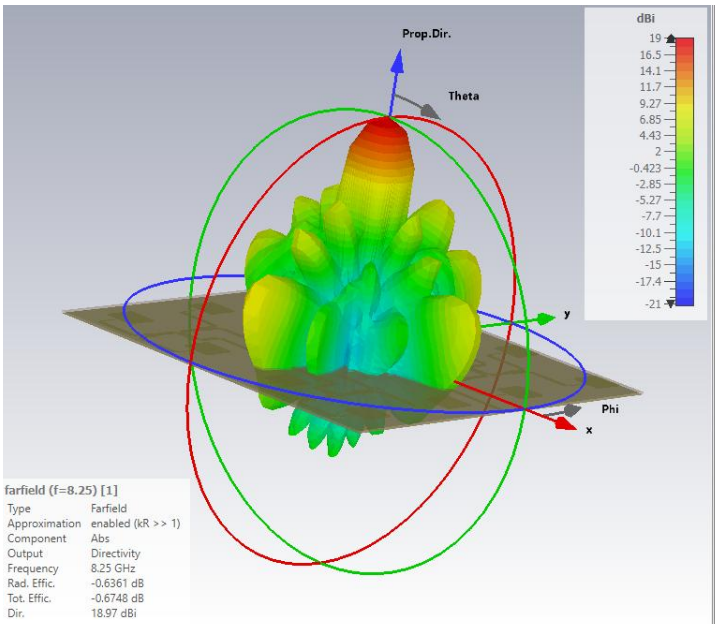


Fig.24 3-D Farfield of Revised 4x4 microstrip patch CP antenna at 8.25 GHz

Chapter 4

Conclusion & Future Work

- Conclusion
- Future Work

Chapter 4

Conclusion & Improvement

4.1 Conclusion

- In this Design, a 4×4 planar antenna array is designed using 0.787 mm thick RT/Duroid 5880™ substrate with permittivity of 2.2, a loss tangent of 0.0002.
- The design considerations ensured efficient impedance matching and contributed to the overall performance of the antenna.
- The impedance bandwidth achieved from 8.066 GHz to 8.442 GHz of 375.5 MHz
- The gain achieved for the 4×4 planar antenna array is 18.2 dBi.
- AR < 3dB for the band of 91.78MHz demonstrating the effectiveness of the design in achieving high performance.

4.2 Future Work

4.2.1 Gain Improvement

The gain of the antenna will be further increased by modifying the antenna array configuration and optimizing the element spacing. Additionally, using techniques like phased-array configurations and employing higher-directivity antenna elements, the overall antenna gain will be boosted beyond the current 18.2 dBi, leading to better performance in applications requiring high directional gain.

4.2.2 Coaxial Feeding Technique

One of the key techniques for enhancing performance will be the implementation of the coaxial feeding technique. This method will improve the impedance matching and minimize the losses typically encountered in other feeding techniques. The coaxial feed will offer a more stable and reliable connection, ensuring better power transfer and contributing to the overall enhancement in both bandwidth and gain.

4.2.3 Integration of Wilkinson Power Divider

Helps in Increasing the bandwidth due to better impedance matching than the present design.

4.2.4 λ/4 Line Optimization

Further reduces axial ratio and S11, enhancing overall performance.

4.2.5 Fabrication & Testing

Validates the simulated design and identifies areas for practical improvements.

Chapter 5

Antenna used for small satellite system to enable IoMT devices

- Low Latency Data Transmission via LEO Satellites
- Real-Time Monitoring and Analysis
- Remote Healthcare Access

Chapter 5

Antenna used for small satellite system to enable IoMT devices

The use of the 8.25 GHz frequency in healthcare through small satellites is transforming medical accessibility, efficiency, and innovation. Here's a detailed explanation of how this technology can be effectively utilized:

5.1 Low Latency Data Transmission via LEO Satellites

5.1.1 Technology

- Low-Earth Orbit (LEO) satellites at 8.25GHz provide low-latency connectivity due to their proximity to earth.
- This Ensures faster response times for healthcare professionals to address anomalies.

5.1.2 Use Case

During Cardiac Arrest event detected by an ECG, the low latency enables a hospital to receive the alert instantly and prepare for patient treatment.

5.2 Real-Time Monitoring and Analysis

5.2.1 Functionality

- The 8.25 GHz frequency supports **high-speed data transmission**, enabling real-time communication between patients and medical facilities.
- Devices like **ECG monitors** can detect irregularities in heart activity and send alerts for immediate medical attention.
- **Glucose meters** can track blood sugar levels, helping diabetic patients and doctors adjust medications quickly.

5.2.2 Impact

- Continuous monitoring reduces the risk of medical emergencies.
- Doctors can provide remote consultations or recommend timely interventions based on live data.

5.3 Remote Healthcare Access

5.2.1 Challenge

Remote, rural, and disaster-prone areas often lack robust healthcare infrastructure, making timely diagnosis and treatment challenging.

5.2.2 Impact

- Small satellites provide connectivity for **Internet of Medical Things (IoMT)** devices, such as ECG monitors, glucose meters, and wearable health trackers.
- Patients in remote areas can use these devices to monitor vital health parameters, which are transmitted to healthcare providers via satellite links.

Chapter 6

References

Chapter 6

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