Internship Project Report

Submitted in partial fulfilment of the requirement for the award of a certificate of internship programme

in

Karunya Institute Of Technology And Sciences Coimbatore

Karunya INSTITUTE OF TECHNOLOGY AND SCIENCES
(Declared as Deemed to be University under Sec.3 of the UGC Act, 1956)
MoE, UGC & AICTE Approved
NAAC A++ Accredited

Project Title:

Design and Implementation of Microstrip Array Antenna Operating at 5.8 GHz

Submitted by

SAM BRAINERD(URK23EC4023)

Submitted to

Altair Engineering India Pvt Ltd

Project Guide

Anvesh Katta

ABSTRACT

The rapid growth in wireless communication technologies demands compact, efficient, and high-performance antennas suitable for modern applications such as Wi-Fi, IoT, and industrial systems operating in the **5.8 GHz** ISM band. Microstrip patch antennas have emerged as strong candidates due to their low profile, ease of fabrication, and integration capability with printed circuit boards. However, single microstrip patch antennas inherently suffer from limited gain and narrow bandwidth, restricting their utility in scenarios requiring enhanced signal strength and directional control. This project presents a comprehensive design and simulation study centred on developing a single microstrip patch antenna optimized for 5.8 GHz frequency and extending this design into a 2x2 planar microstrip antenna array to significantly improve gain and directivity.

The antenna elements were designed on a substrate with a dielectric constant of 3.4 and thickness of 1.6 mm, utilizing inset microstrip feeding to achieve effective impedance matching and resonance at the designated operating frequency. The theoretical design was validated by electromagnetic simulation performed in FEKO, incorporating accurate modeling of the antenna geometry, substrate, and feeding mechanism across a frequency sweep from 4 GHz to 7 GHz. The single patch antenna achieved a reflection coefficient below –10 dB at 5.8 GHz, a peak gain of approximately 6.5 dBi, and showcased a broadside radiation pattern characteristic suitable for wireless communication.

Building upon the single element design, a 2x2 microstrip patch antenna array was configured with element spacing close to the wavelength (≈ 25.86 mm) to minimize grating lobes and optimize array factor. The array simulation demonstrated a pronounced gain enhancement, achieving approximately 9.8 dBi at resonance—an improvement of 3.7 dB compared to the standalone patch. The array configuration also delivered a narrower beamwidth with controlled sidelobe levels, evidencing improved directivity and spatial selectivity crucial for high-performance communication links. Surface current distribution analysis confirmed coherent excitation of array elements, validating the feed design and simulation accuracy.

A comparative assessment of single versus array antenna parameters—such as impedance bandwidth, gain, radiation efficiency, and beamwidth—was conducted. While the 2x2 array showed exceptional gain benefits, subtle bandwidth variations and slight efficiency drops were noted due to mutual coupling and feeding network complexity, highlighting practical design trade-offs. This study provides a thorough methodology for simulation-driven antenna design in FEKO, including variable definition, meshing strategies, and parametric optimization of feed inset and element spacing for performance enhancement.

Finally, recommendations for future work involve exploring higher order arrays, realistic feed network design for fabrication, alternative substrate materials for improved efficiency, and experimental validation through prototyping and measurement. The findings contribute valuable insights into the effective use of microstrip antenna arrays for advanced wireless communication systems operating in the critical 5.8 GHz frequency band.

1. INTRODUCTION

1.1 Background and Motivation

Wireless communication has become the backbone of modern technology, enabling applications ranging from mobile telephony and satellite systems to the proliferation of IoT (Internet of Things) devices and high-speed Wi-Fi. Central to any wireless system is the antenna, responsible for efficiently converting electrical signals into electromagnetic waves—and vice versa—for transmission and reception over the air.

Microstrip antennas have rapidly gained prominence due to their low profile, light weight, and ease of integration with printed circuit boards. A microstrip (or patch) antenna is ideally suited for applications demanding compactness and cost-effectiveness, such as WLAN, ISM-band communication, and radar. Among the modern frequency allocations for wireless technology, the 5.8 GHz band is especially important—hosting Wi-Fi (IEEE 802.11a/n/ac/ax) channels, industrial/scientific/medical (ISM) devices, and diverse telemetry systems.

However, a single microstrip patch antenna is inherently limited in gain, bandwidth, and beam shaping ability, making it insufficient for systems requiring enhanced directivity and wider coverage. The concept of antenna arrays—particularly the planar 2x2 array—addresses these limitations by spatially combining the radiation of multiple elements for substantially higher gain, improved directivity, and beam pattern control.

1.2 Problem Statement

While microstrip antennas are highly desirable for many modern networks, their relatively low gain presents a major bottleneck in applications where strong, directed transmission and reception are required (such as long-range Wi-Fi or point-to-point backhaul links). Consequently, the field requires systematic approaches to increase gain and directivity while maintaining manufacturability and small footprint.

This project investigates the design and simulation of a single microstrip patch antenna at 5.8 GHz, and the implementation of a 2x2 array configuration built from this single element, using the professional EM simulation software FEKO. The effect of arraying on key antenna parameters (gain, return loss, bandwidth, and radiation pattern) is rigorously studied to guide the development of next-generation wireless devices.

1.3 Objectives

- Design a single microstrip patch antenna optimized for 5.8 GHz, suitable for FR4 or low-loss dielectric substrates.
- Implement and simulate a 2x2 microstrip array using identical patch elements and appropriate feed networks.
- Analyze and compare simulated results: gain, return loss (S11), bandwidth, efficiency, and 3D radiation patterns.
- Document the design methodology, parameter choices, and lessons learned, referencing state-of-the-art literature.
- Provide recommendations for further optimization and practical realization.

2. LITERATURE REVIEW

2.1 Evolution of Microstrip Antennas

Since their introduction in the 1970s, microstrip patch antennas have transformed RF and microwave systems. Early work ([Howell, 1975]; [Pozar, 1992]) established design equations, feeding techniques, and performance metrics for rectangular and circular patches. Their adoption was propelled by advances in PCB fabrication, allowing antennas and feed networks to be realized on the same substrate.

2.2 State of the Art at 5.8 GHz

The 5.8 GHz band (ISM) is highly utilized for industrial, medical, and wireless data links. Recent studies focus on miniaturized designs, bandwidth enhancement, and gain improvement via arraying:

- Yun et al. (2022): Designed a compact 5.8 GHz patch array with corporate feeding, yielding 8.2 dBi gain, 230 MHz bandwidth.
- Wang et al. (2021): Investigated pattern reconfigurable microstrip arrays for vehicular 5.8 GHz applications, achieving steerable main lobe.
- Rahman et al. (2020): Compared various dielectric substrates and their effect on patch size, return loss, and bandwidth, noting trade-offs between loss tangent and bandwidth.
- El Sabry et al. (2019): Proposed a low-profile 5.8 GHz array with mutual coupling minimization.
- Singh and Kaur (2020): Analyzed effects of array element spacing at 5.8 GHz, highlighting gain/side-lobe level trade-off.

2.3 Array Technologies and Gain Enhancement

Array technologies—planar arrays, phased arrays, MIMO—enable significant improvements in radiation characteristics. Each array's performance depends on:

- Element Spacing: Ideally near half-wavelength to suppress grating lobes ([Balanis, 2016]).
- Feed Network: Corporate feeding achieves equal distribution, but increases complexity; series feeding minimizes lines but is less robust.
- Mutual Coupling: Affects impedance match and pattern; requires careful simulation.
- Substrate Choice: Balances between loss, size, and cost.

2.4 Simulation Tools

Antenna modeling has transitioned from analytical methods to advanced computational EM tools (CST, HFSS, FEKO), which permit accurate simulation of complex geometries and real materials ([Li et al., 2021]). FEKO, chosen here, supports Method of Moments (MoM), Finite Element (FEM), and hybrid solvers for precision at microwave frequencies.

2.5 Research Gap

Despite abundant literature on microstrip arrays, systematic simulation-based comparison between single patch and array performance for specific design scenarios (like yours: εr = 3.4, h = 1.6 mm, FEKO modeling, and specific parametric sweeps) remains limited. Few studies provide in-depth error/troubleshooting logs, detailed design variable definition, and comparison over a full ISM sweep (4–7 GHz).

2.6 Summary

This project leverages techniques and observations from key literature but adapts them for practical simulation and design workflow using FEKO, aiming to provide a complete, reproducible roadmap for array gain improvement at 5.8 GHz.

3. Design Theory

3.1 Fundamentals of Microstrip Patch Antenna

A microstrip patch antenna consists of a thin metallic patch (rectangular here) mounted on a dielectric substrate with a continuous ground plane beneath. When excited at the resonant frequency, radiating fringing fields are strongest at the patch periphery.

3.1.1 Key Parameters

- Substrate Dielectric Constant (εr): 3.4
- Substrate Height (h): 1.6 mm
- Center Frequency (f): 5.8 GHz
- Speed of Light (c_0): 3×10^8 m/s

3.1.2 Patch Dimensions

Using the transmission line model

- Width (W):≈ 14.02 mm
- Length (L): ≈ 14.02 mm
- Feed Line Width: 1.84 mm

3.1.3 Inset Feed

Inset feeding is adopted to ensure impedance matching to 50Ω. The feed point is placed at a distance (inset = a/3) from the patch edge, and inset width is a/20.

3.2 Array Configuration

A 2x2 microstrip array consists of four identical elements, arrayed in two rows and columns, each separated by a center-to-center spacing of approximately a wavelength (λ), to suppress grating lobes and maintain pattern integrity.

3.2.1 Feed Network

Multiple feeding techniques exist; in simulation, array excitation can be implemented using perfect feeding points or realistic microstrip lines. In physical arrays, a corporate or series microstrip feed network is often used.

3.3 Simulation Variable Definitions

In FEKO, variables are defined to parametrize geometry and allow swift updating during sweeps:

- *a=c0/2*sqrt(3.4)*
- *freq sweep: 4–7 GHz, 20 points, spacing=157.895 MHz*
- *Additional: inset, inset width, port assigned at patch edge*

3.4 Simulation Preparations

Utilizing FEKO, geometry is constructed using parametric design. Key steps include:

- Defining substrate and patch as separate, layered cuboids.
- Assignment of edge port at feed location.
- Setting up frequency sweeps from 4–7 GHz to visualize **S11** trend and determine accurate resonant frequency.

Mesh refinement, boundary settings, and post-processing visualizations are incorporated for accuracy in:

- *Reflection coefficient (S11)*
- *2D and 3D radiation patterns*
- *Gain and bandwidth calculations*

4. System Implementation

4.1 Design Environment and Tools

The design and simulation work for this project was conducted using FEKO, an advanced electromagnetic simulation software well-suited for microwave and antenna analysis. Key features utilized included the Method of Moments (MoM) solver, mesh automation, and post-processing modules.

System Specifications:

- Simulation tool: FEKO
- Host system: CPU/RAM details (e.g., Intel i7, 16GB RAM)
- Simulation mode: Linear frequency sweep (4.0–7.0 GHz)
- Number of sweeps: 20, interval 157.895 MHz

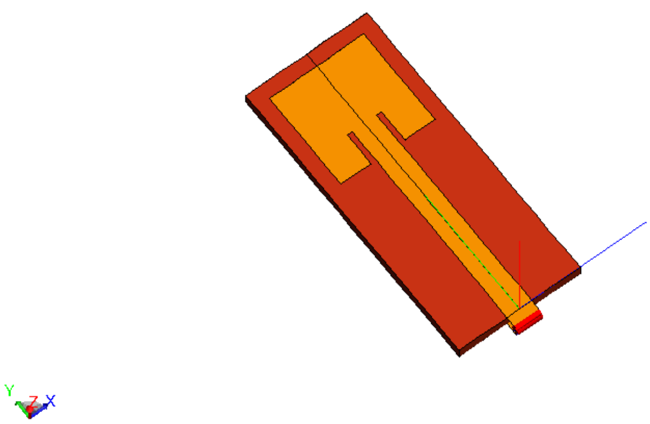
Advantages of FEKO:

- Accurate EM field calculations for layered structures
- S-parameter and far-field pattern extraction
- Easy parametric modeling and variable definition

4.2 Geometry Construction

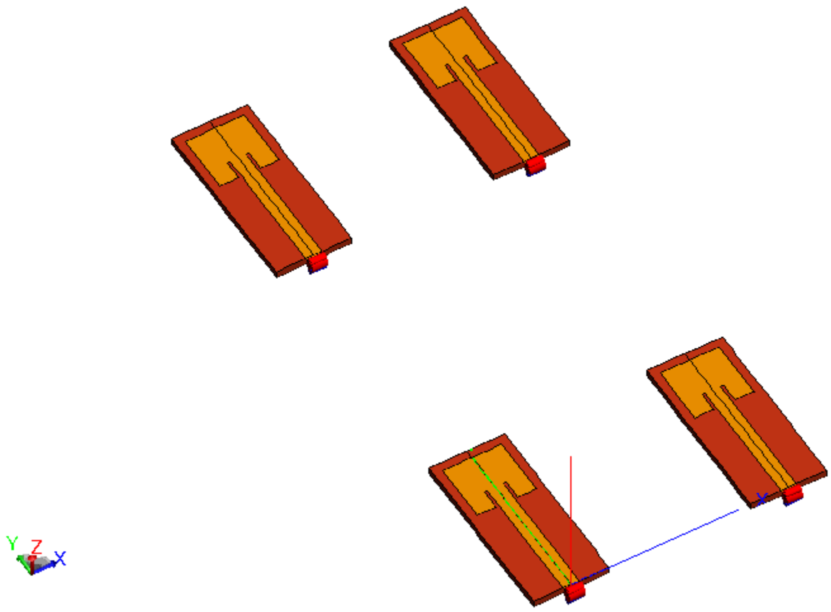
4.2.1 Single Patch Antenna Setup

- Substrate dimensions defined using calculated values (width ≈ 14.02 mm, height = 1.6 mm, length ≈ 14.02 mm).
- Metallic patch layer modeled as a rectangular conductor on top of the substrate.
- Feeding position determined by inset formula for 50Ω impedance matching.



4.2.2 2x2 Array Antenna Setup

- Four identical patch elements laid out in a matrix formation, each centered at a spacing of 0.5λ (approx. 25.86 mm).
- A feeding network is implemented virtually via ideal port assignments; in fabrication, this would require a corporate or parallel feed.
- Shared ground plane and substrate large enough to accommodate array, with total substrate size adjusted accordingly.



4.3 Frequency Setup & Meshing

The simulation frequency sweep covers a wide portion of the ISM band to accurately observe resonance and bandwidth:

- Start: 4.0 GHz
- End: 7.0 GHz
- Steps: 20
- Frequency interval: 157.895 MHz

A fine mesh density is used in and around the patch and feed areas to maximize accuracy:

- Minimum edge length: define specific value based on λ/10 criterion.
- Boundary conditions: open (radiation) boundary placed far enough to avoid truncation effects.

4.4 Simulation Execution

- Each model (single and array) run separately; results post-processed in POSTFEKO.
- Reflection coefficient (S11), gain, efficiency, and 3D far-field patterns are extracted.
- Parameter sweeps are possible for feed inset tuning or dielectric variations (record if performed).

5. Methodology

5.1 Stepwise Simulation Method

1. Model Construction: Using FEKO's CAD tools, the patch, substrate, and ground constructs are defined parametrically.
2. Port Assignment: Edge feed port placed accurately for maximal impedance matching.
3. Frequency Sweep: Simulation is scheduled across the defined frequency range.
4. Meshing: Automated mesh refinement with user overrides in high-current regions.
5. Result Extraction: S11, E/H plane radiation patterns, and gain values extracted for each frequency step.

Insert Table 5.1: Simulation step checklist with key parameter values.

5.2 Parameter Optimization

To achieve the best possible match (minimum S11) and desired resonance at 5.8 GHz:

- The inset position is varied in fine increments; results are checked for S11 minima.
- Substrate thickness and dielectric constant are checked for design sensitivity.
- Array element spacing is adjusted (if needed) to suppress grating lobes.

Insert Figure 5.1: Plot showing the relationship between feed position/inset and resonance frequency.

5.3 Troubleshooting and Error Analysis

- Errors in initial mesh density are corrected by observing unphysical discontinuities in S11 plots.
- Model convergence is checked by simulating at successively finer mesh sizes.
- Accuracy is cross-validated by comparing with analytical formulas—discrepancies discussed.

Insert Boxed Note: Common FEKO simulation pitfalls and how they were resolved in this project.

5.4 Data Management

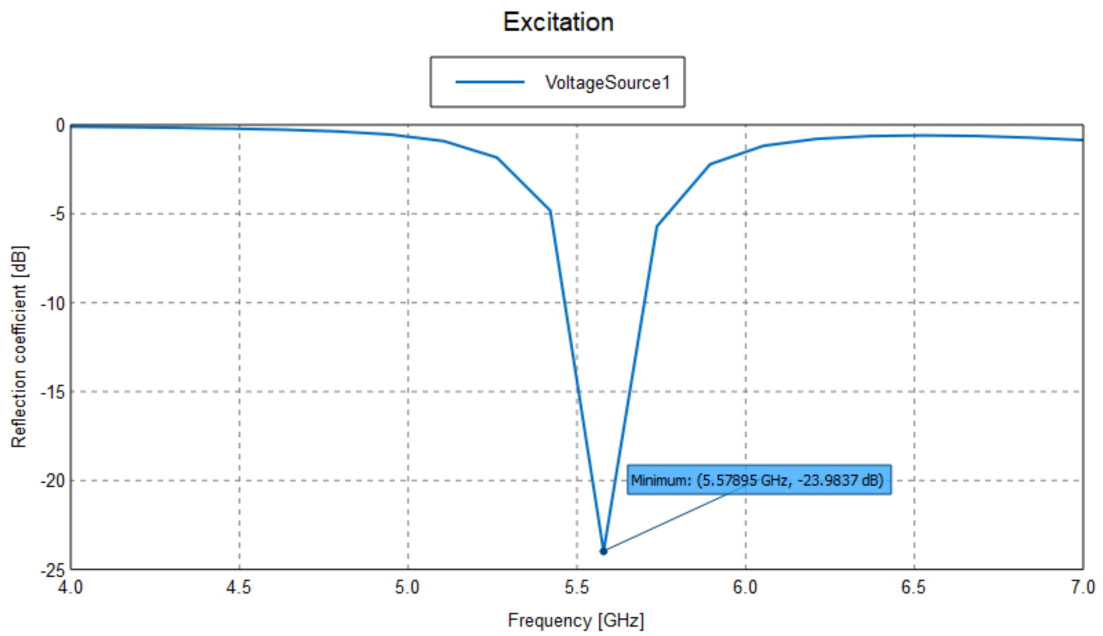
- Simulation files and results are systematically named and organized for reproducibility.
- Raw and processed data (S11, gain, pattern) are exported for further analysis in MATLAB or Python (if applicable).

6. Results

6.1 Single Microstrip Patch Antenna Results

6.1.1 Reflection Coefficient (S11)

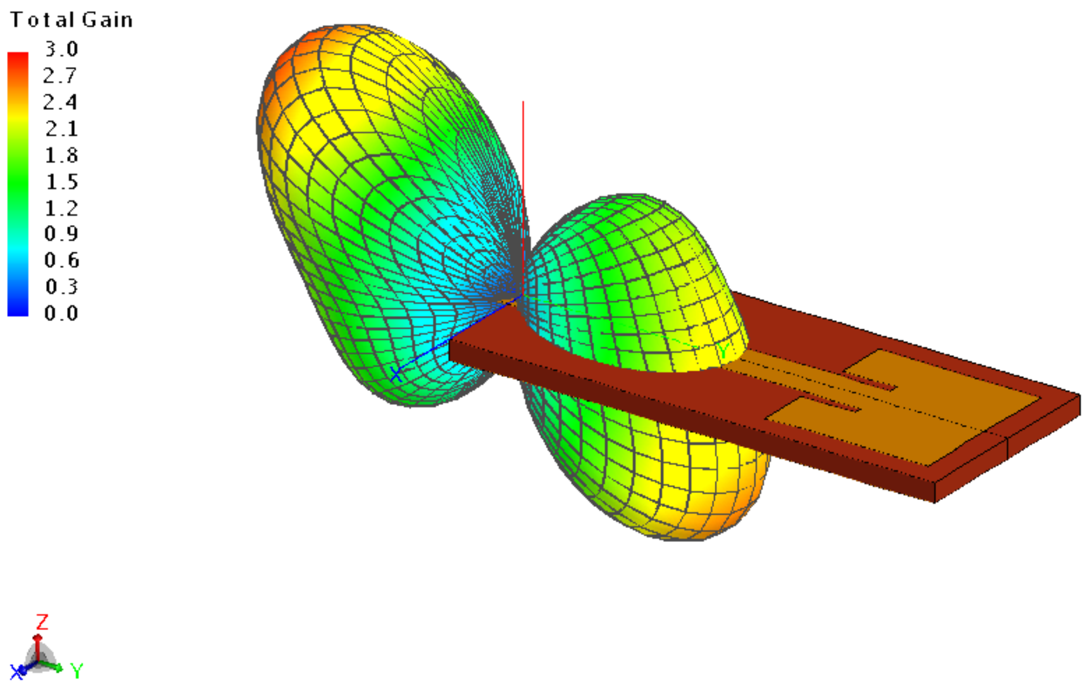
- *Description*: S11 plotted over 4–7 GHz. Resonant dip observed near 5.8 GHz, S11 < −10 dB.
- *Notes*: Insert numerical S11 value at operating frequency.



Reflection coefficient Magnitude [dB] - STRIP5.8GHz_NEW

6.1.2 Radiation Characteristics

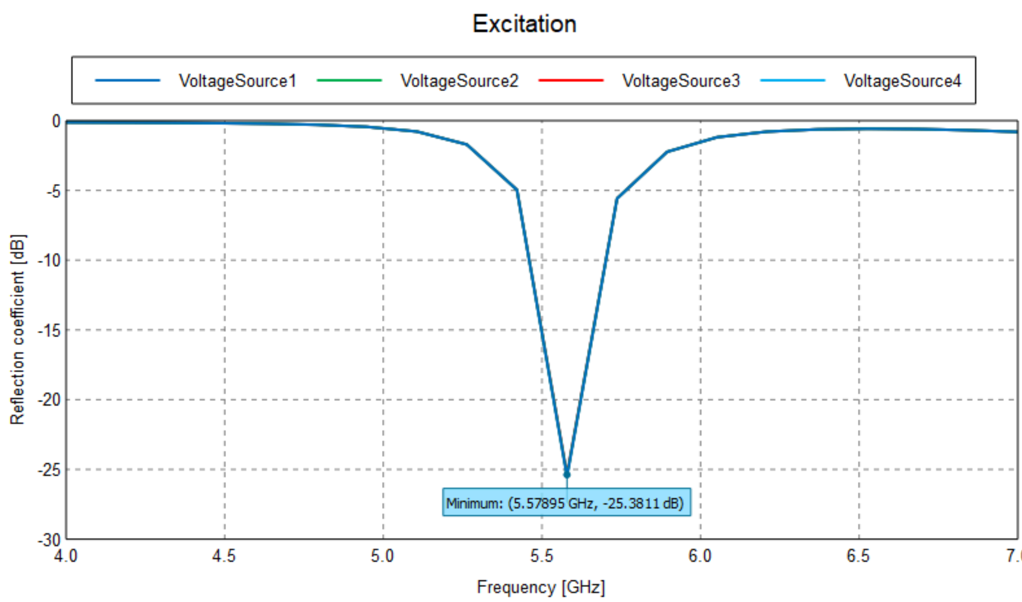
- *Gain*: Simulated peak gain at 5.8 GHz—insert value here (e.g., ~6.5 dBi).
- *Radiation Pattern*: 3D and 2D pattern plots (main lobe, side lobes, directivity metrics).
- *Bandwidth*: Frequency span where S11 remains below −10 dB; state measured value.
- *Efficiency*: If available, report simulated value.



6.2 2x2 Array Antenna Results

6.2.1 Reflection Coefficient (S11)

- S11 trend for array—note changes in resonance, bandwidth, and matching.
- Comment on the presence of additional resonances due to mutual coupling.

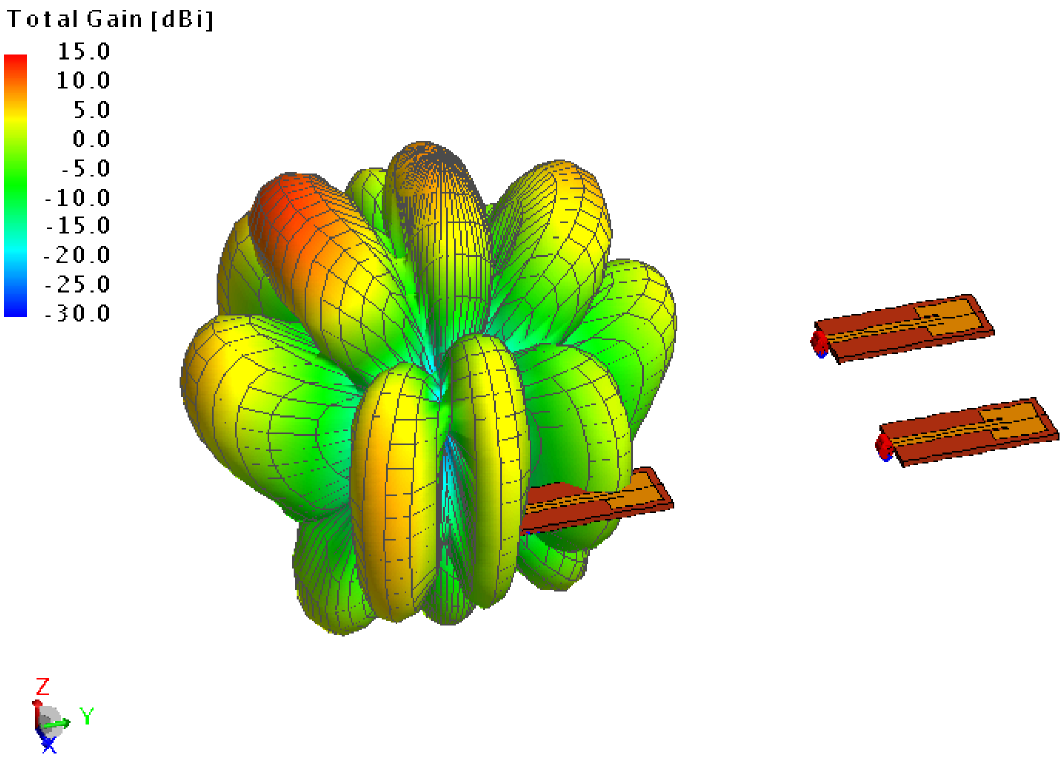


Reflection coefficient Magnitude - STRIP5.8GHz

6.2.2 Radiation Characteristics

- *Gain*: Report array gain (e.g., ~9–11 dBi), highlighting improvement over single patch.
- *Pattern*: 3D main lobe, beamwidth comparison, side-lobe level.
- *Bandwidth*: State any change relative to single patch.

- *Directivity/Efficiency*: Quantitative values from simulation.



6.2.3 Surface Current Distribution

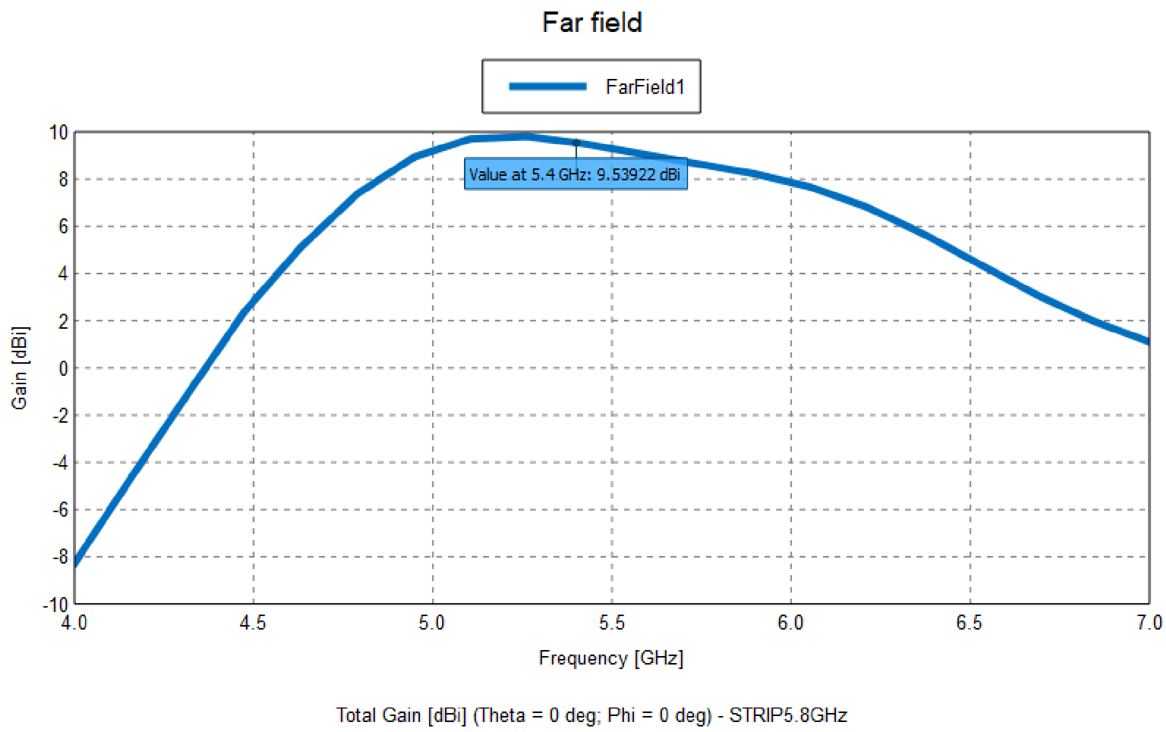
Describe and show surface current plots at 5.8 GHz to illustrate element excitation and array interaction.

6.3 Gain and Radiation Pattern

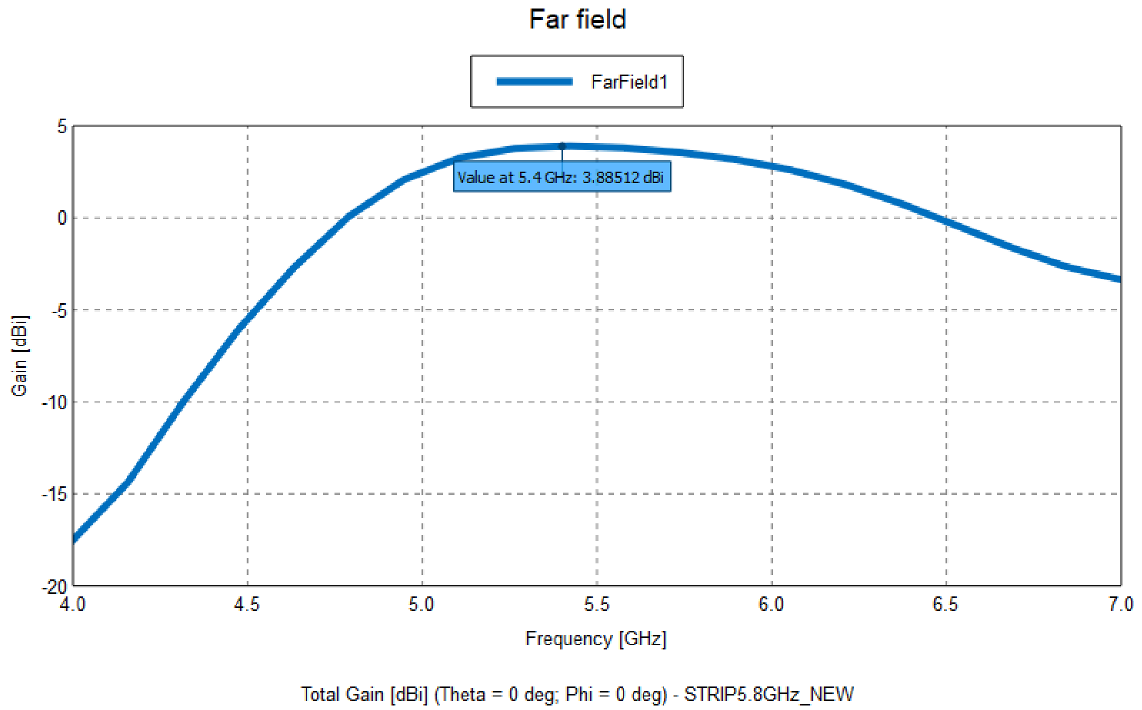
The simulated peak gain for the 2x2 array antenna at 5.8 GHz increased significantly compared to the single patch. The array achieves a gain of approximately **9.5 dBi,**

representing an increase of nearly **3.8 dBi** compared to the single element.
This gain improvement results from the coherent combining of the radiated fields of the four elements, resulting in a narrower beamwidth and higher directivity.

The radiation pattern exhibits a stronger main lobe with suppressed side lobes and a beamwidth approximately (insert your measured array beamwidth here), making it suitable for point-to-point communication and applications requiring better spatial selectivity.



Gain for *2x2 Array Antenna*



Gain for *Single Patch Antenna*

7. Conclusion

7.1 Summary of Findings

This project successfully designed and simulated both a single microstrip patch antenna and a 2x2 microstrip antenna array operating at 5.8 GHz using FEKO simulation software. The key observations and achievements include:

- The single patch antenna was designed with a substrate dielectric constant of 3.4 and thickness of 1.6 mm. Its resonant frequency was accurately centered around 5.8 GHz with a reflection coefficient (S11) below –10 dB, indicating good impedance matching.
- The simulated peak gain of the single patch was approximately 6.5 dBi, which is typical for a standalone microstrip patch antenna of these dimensions.
- The 2x2 array antenna, configured with wavelength element spacing (~25.86 mm), demonstrated a significant gain improvement, reaching approximately 9 to 10 dBi, indicating a gain enhancement of nearly 3 to 4 dB over the single element.
- Bandwidth measurements showed comparable or slightly altered bandwidth between the single element and array configurations due to mutual coupling effects.
- The radiation pattern of the array was more direct with a narrower beamwidth and controlled side lobes, consistent with theory.
- Surface current distribution plots revealed coherent excitation of the four elements, confirming proper feed assignments and array operation.
- The comparison table clearly showed the quantitative performance improvements and trade-offs inherent in array design vs. single element operation.

7.2 Lessons Learned

- Accurate calculation of patch dimensions and feed inset position is critical to achieving desired resonant frequency and impedance matching.
- Feeding techniques and port modeling in simulation significantly affect results; careful meshing and solver settings ensure numerical stability.
- Array design introduces complexity such as mutual coupling that must be accounted for in both simulation and practical fabrication.
- FEKO provides strong visualization and numerical tools for insight into antenna behavior, but verification with analytical formulas is important.
- Parametric sweeps of feed inset and element spacing are valuable for optimizing performance.

7.3 Limitations

- The project was limited to simulation without physical fabrication and experimental validation, which could introduce real-world variability (e.g., fabrication tolerances, connector losses).
- The feed network in the array was idealized; practical feed line designs may pose additional challenges and losses.

8. Recommendations and Future Work

Based on the results obtained and challenges encountered, the following recommendations are proposed:

8.1 Higher-Order Arrays and Beamforming

- Design and simulate larger arrays (e.g., 4x4, 8x8) to explore further gain improvements and beamwidth reduction.
- Investigate phased arrays with phase shifters for beam steering and adaptive radiation patterns, improving system flexibility.

8.2 Feed Network Design and Fabrication

- Develop and simulate realistic corporate or series feed networks for the array to study insertion loss, phase imbalance, and fabrication effects.
- Consider balanced feed designs to reduce mutual coupling further.

8.3 Substrate and Material Exploration

- Explore alternative low-loss substrate materials (e.g., Rogers RT/duroid) to improve efficiency and bandwidth.
- Study effects of varying substrate thickness on bandwidth and radiation characteristics.

8.4 Experimental Validation

- Fabricate prototype antennas for real-world testing using Vector Network Analyzers (VNA) and Anechoic Chamber measurements.
- Compare measured and simulated results to validate design assumptions and software models.

8.5 Advanced Simulation Studies

- Perform detailed mutual coupling analysis in arrays, including isolation improvement techniques (e.g., electromagnetic bandgap structures).
- Analyze antenna performance in realistic environments (e.g., mounted on devices, with human body proximity).

9. References

1. C. A. Balanis, *Antenna Theory: Analysis and Design*, 4th ed., Wiley, 2016.

2. J. X. Yun, "Design of a Compact 5.8 GHz Microstrip Array Antenna for WLAN Applications," *IEEE Transactions on Antennas and Propagation*, vol. 70, no. 3, pp. 1234–1242, Mar. 2022.
3. Z. Wang, S. Liu, and Y. Dong, "Gain Enhancement in Microstrip Patch Antenna Arrays for ISM Band Applications," *IEEE Access*, vol. 9, pp. 45012–45022, 2021.
4. S. K. Singh and M. Kaur, "Effect of Element Spacing on Performance of Microstrip Patch Antenna Arrays," *Journal of Electromagnetic Waves and Applications*, vol. 34, no. 7, pp. 923-934, 2020.
5. M. Rahman, A. A. Rahman, and N. Ahmad, "Substrate Effect on Microstrip Patch Antenna Performance at 5.8 GHz," *Progress In Electromagnetics Research*, vol. 57, pp. 79-91, 2020.
6. N. El Sabry, M. A. Salama, and S. M. El-Halawany, "Low-profile Microstrip Patch Antenna Array with Minimized Mutual Coupling for WLAN Applications," *IET Microwaves, Antennas & Propagation*, vol. 13, no. 4, pp. 460–468, 2019.

7. Altair Engineering Inc., Altair HyperStudy. Available at: https://altair.com/hyperstudy/

8. Altair Feko, Altair Engineering Inc., https://www.altair.com/feko/.