Design of a Compact 4x4 MIMO Antenna System with High-Diversity Gain Performance

A project report submitted in partial fulfillment of the requirements for the award of the degree of

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BONAFIDE CERTIFICATE

This is to certify that the project titled **“Design of a Compact 4x4 MIMO Antenna System with High-Diversity Gain Performance”** is a bonafide record of the work done by

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ABSTRACT

To achieve high isolation and minimal channel capacity loss, a compact four-element dual-band multiple-input multiple-output (MIMO) antenna system is presented. The first frequency band is a large band, and the MIMO antenna was constructed and tuned to span the dual-frequency bands.

It spans the 1550–2650 MHz frequency range, whilst the other frequency band spans the 3350–3650 MHz range. It achieved greater than 10 dB and 19 dB isolation in the lower and upper frequency bands, respectively. Four innovative antenna components and a plus-sign-shaped ground structure on a FR4 substrate make up the suggested construction.

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NOMENCLATURE

PEC:	PERFECT ELECTRIC CONDUCTOR
PTFE:	POLY TETRA FLUORO ETHYLENE
FR-4:	FLAME RETARDANT WOVEN GLASS REINFORCED EPOXY RESIN
MIMO:	MULTIPLE IN MULTIPLE OUT
SPARAMETER:	SCATTERING PARAMETER
BER:	BIT ERROR RATE
SNR:	SIGNAL TO NOISE RATIO
CST:	COMPUTER SIMULATION TECHNOLOGY

1 Introduction

1.1 Introduction to 4*4 MIMO

A MIMO antenna, which stands for Multiple-Input Multiple-Output, is a technology used to improve wireless communication by using multiple antennas on both the transmitting and receiving devices.

The increasing demand for high data rates and reliable communication has led to the wide spread adoption of MIMO (Multiple Input Multiple Output) antenna enabling the development of more robust, efficient and high-performance wireless communication technologies.

1.2 Problem Statement

Existing antenna technology faces various limitations, including restricted bandwidth, which hampers data transmission rates, and size and weight constraints that hinder integration into compact devices. Moreover, susceptibility to interference compromises signal quality, while efficiency losses reduce overall performance. Limited directionality restricts coverage areas, and vulnerability to environmental factors impairs reliability. Additionally, high cost and complexity pose barriers to widespread adoption and scalability. Overcoming these challenges is crucial for advancing communication systems and enabling seamless connectivity across diverse applications and environments.

1.3 Objective

Achieving good isolation and low channel capacity loss across both frequency bands requires careful optimization when designing a small 4-element dual-band MIMO antenna. The goal is to achieve optimal performance in the widely utilized 2.4GHz and 5GHz bands. To measure how successful the design is, key performance parameters including bit error rate (BER), channel capacity, and signal-to-noise ratio (SNR) are carefully defined and assessed. To determine the antenna's capacity to sustain reliable communication links even in difficult situations with noise and interference, extensive testing and analysis are required. The ultimate objective is to create a MIMO antenna system that is dependable and effective enough to satisfy the rigorous demands of contemporary wireless communication applications.

2 Review Of Literature

2.1 Study on existing Design

Examining existing MIMO antenna designs entails investigating a variety of factors in order to improve performance and efficiency. There is continuous research to enhance their powers. Engineers work on fine-tuning patch size and substrate qualities to influence resonant frequency and bandwidth, which are critical for maximizing antenna performance. Additionally, improving feeding systems to reduce signal loss is an important concern. Slots or non-rectangular patch shapes are solutions for expanding frequency range or enabling operation over various Wi-Fi bands. To make these advances efficiently, engineers frequently use software simulations to optimize designs before to actual execution. This iterative technique enables the study of various parameters and configurations in order to obtain optimal MIMO antenna performance.

2.1.1 Reference 1

As mentioned in the article by Deng, C., Liu, D., & Lv, X, for 5G mobile terminals, a small multiple-input multiple-output (MIMO) antenna is provided. The antenna is made up of four closely spaced components and three combined parts. There is hardly 1 mm separating neighboring parts edge to edge. It is discovered that the mutual coupling between two elements may be greatly reduced by adding an inductor at the current lowest site or a capacitor at the current maximum place. Experimental analysis is conducted on a four-element MIMO antenna operating in the 3400–3600 MHz range, based on high-isolated dual-element constructions.

2.1.2 Reference 2

This article by Chen, S. C., Chiang, C. W., & Hsu, C. I. G demonstrated a small dual-band four-element multiple-input multiple-output (MIMO) antenna system for fifth-generation (5G) laptops with a large display-to-body ratio They are divided into two dual-antenna components. To accomplish short-circuit decoupling, the two IFAs in each unit are skew-symmetric to the display ground plane and their short-circuit sites are brought near together. The two units are mirror imaged with a short gap and coupled by two decoupling chip inductors, resulting in a high-isolation four-element MIMO antenna system. 5G operating bands (3300-3600 and 4800-5000 MHz) demand high isolation and antenna efficiency (more than 35%).

3 Proposed work and methodology

3.1 Design considerations

3.1.1 Antenna Design

To begin, construct a substrate utilizing FR-4 material with a permittivity of 4.3, known for its dielectric properties. Employ PEC material to fashion a single feed or element; PEC's reflective properties minimize backward radiation, enhancing antenna performance. Next, design a patch using the same PEC material, implementing chamfering techniques on both the patch and feed for refined performance.

Precisely align the feed and patch to achieve impedance matching, a critical factor for optimal signal transmission. On the substrate's reverse side, engineer a ground plane using PEC material to establish a stable reference point for the antenna system. Incorporate strips or pads around the ground plane, arranged in a plus symbol configuration, to augment radiation characteristics and enhance antenna efficiency.

Introduce a feed comprising inner and outer components, extending beyond the patch. Surround the feed with PTFE material to capitalize on its low dielectric loss and high thermal stability, ensuring signal integrity. By removing the inner feed, craft a partial ground structure, further optimizing the antenna's radiation pattern and impedance matching capabilities. Through this meticulous design process, aim to achieve a high-performance MIMO antenna system with superior radiation efficiency and minimized backward radiation.

All Dimensions Are in mm	
Wg = 5	L5 = 9.89
Wt = 2.82	L6 = 12.02
W1 = 2	L7 = 11.58
W2 = W3 = 1.41	L8 = 7.77
W4 = 2	L9 = 5.5
L1 = 17	L10 = 7.07
L2 = 12	L11 = 4.5
L3 = 11	L12 = 1
L4 = 10.59	L13 = 2

Table 3.1 Parameters of the dual-band multiple-input and multiple-output (MIMO)

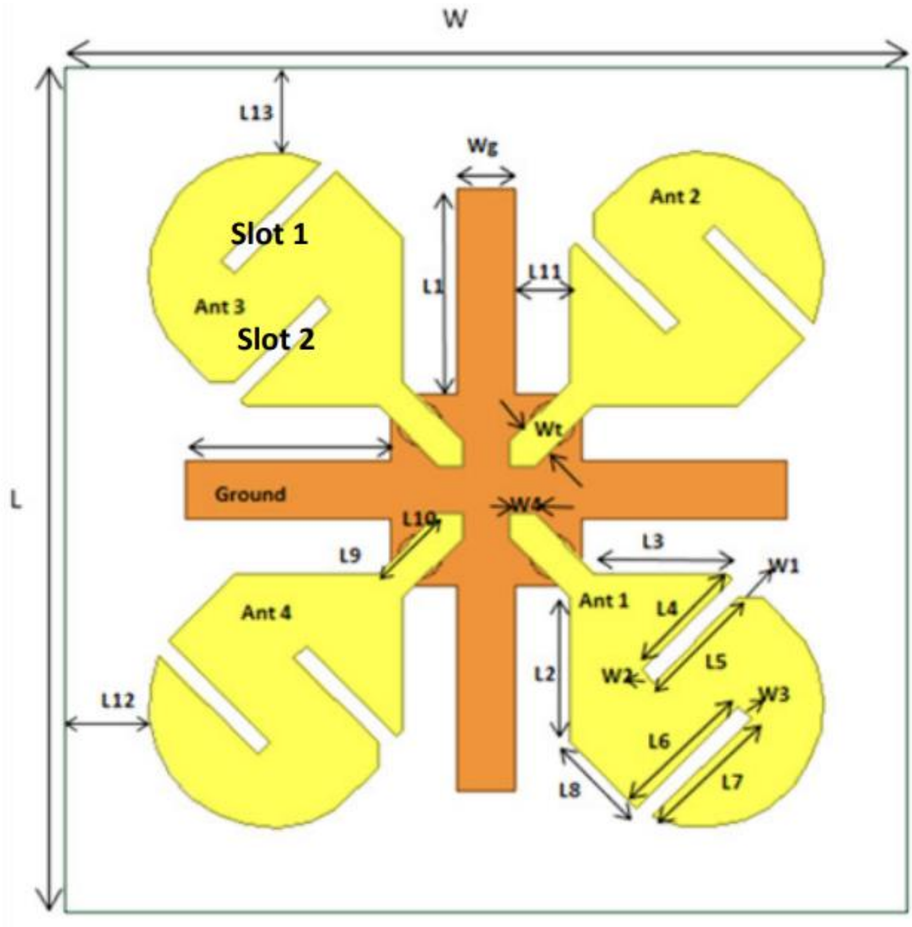

Fig: 3.1 Geometry of the four-element MIMO antenna system

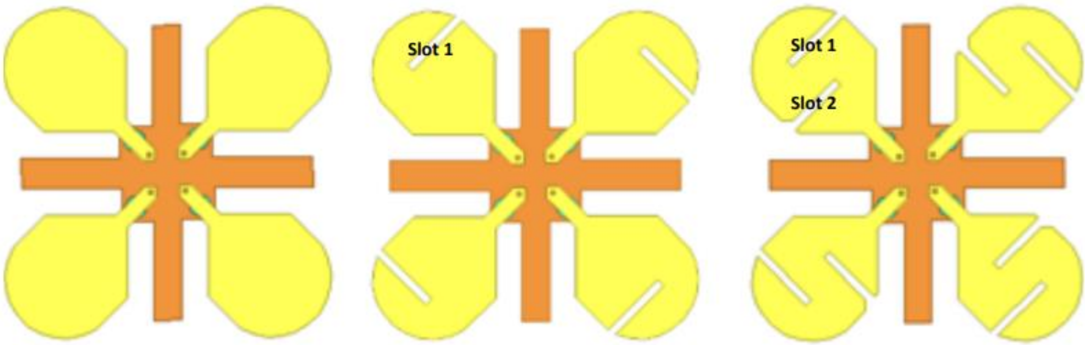

Fig: 3.2 Development steps to achieve dual-band MIMO antenna (a) basic elements without slot, (b) elements with slot 1, (c) elements with slots 1 and 2.

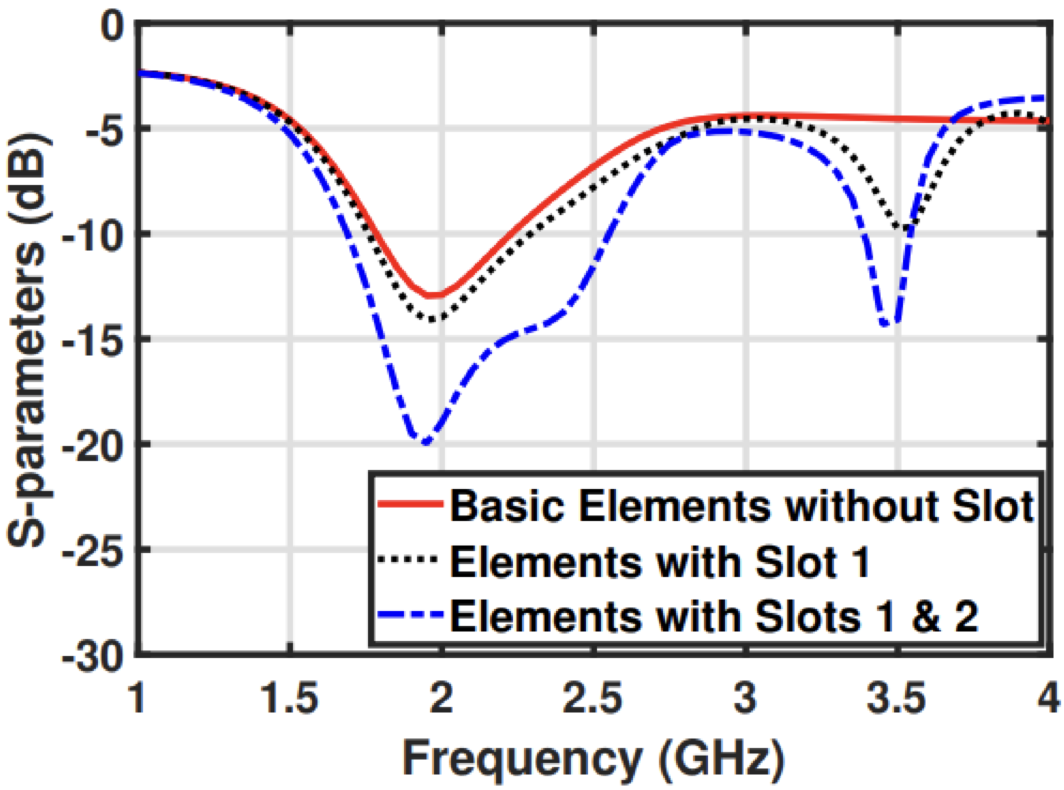

Fig: 3.3 S-parameters for each development step for the dual-band MIMO antenna

3.1.2 Simulation Software

Use of the electromagnetic simulation approach is necessary to provide an exact analysis and design of intricate circuits, antennas, and microwaves. In the CST STUDIO SUITE electromagnetic simulator (CST MICROWAVE STUDIO2010). When using the antenna's dimensions in the electromagnetic simulation tool for this application's characteristics, it is necessary to identify them beforehand. The CAD and EDA design processes are made simple with its help. It is common for CAD software to use CAD designs. Due to the fact that it has damaged and frequently intricate components, it is not appropriate for simulation. The two-dimensional structures of EDA systems are frequently used as data in CAD software. The data is three-dimensional and this is a CST. Utilizing simulation findings to complete and compute data, CST is a post-processing processing system that is template-based. Remote field sources or S-PARAMETERS are used in the design of the antenna, which is CST STUDIO SUITE. The findings are derived from a calculation of the simulation, which may be done automatically.

3.2 Parametric Sweep

Perform a parametric sweep on two key design parameters:

3.2.1 Substrate height

From a baseline value to a specified upper limit, simulate the antenna with varying substrate thicknesses. Lower resonance frequencies, or the frequencies at which antennas function best, are typically associated with thicker substrates. Because the antenna can function well over a larger range of frequencies, this may help to create a wider bandwidth.

3.2.2 Patch Length

Simulate the antenna with different patch lengths, progressively decreasing the length from a baseline value while staying within practical limitations. Reducing the patch length usually results in a higher resonant frequency. While this might seem counterintuitive for bandwidth, it can be strategically used. By carefully choosing the new resonant frequency and potentially implementing additional design techniques (like slots or notches in the patch), we can achieve a wider bandwidth while maintaining or even improving the gain.

3.3 System Model

Vary the patch length of the antenna in the simulation while adhering to realistic constraints and gradually reducing the length from a baseline value. The resonance frequency often rises when the patch length is lowered. This may be utilized deliberately even if it may appear paradoxical for bandwidth. A wider bandwidth can be achieved while preserving or even increasing the gain by carefully selecting the new resonant frequency and possibly using extra design approaches (such slots or notches in the patch).

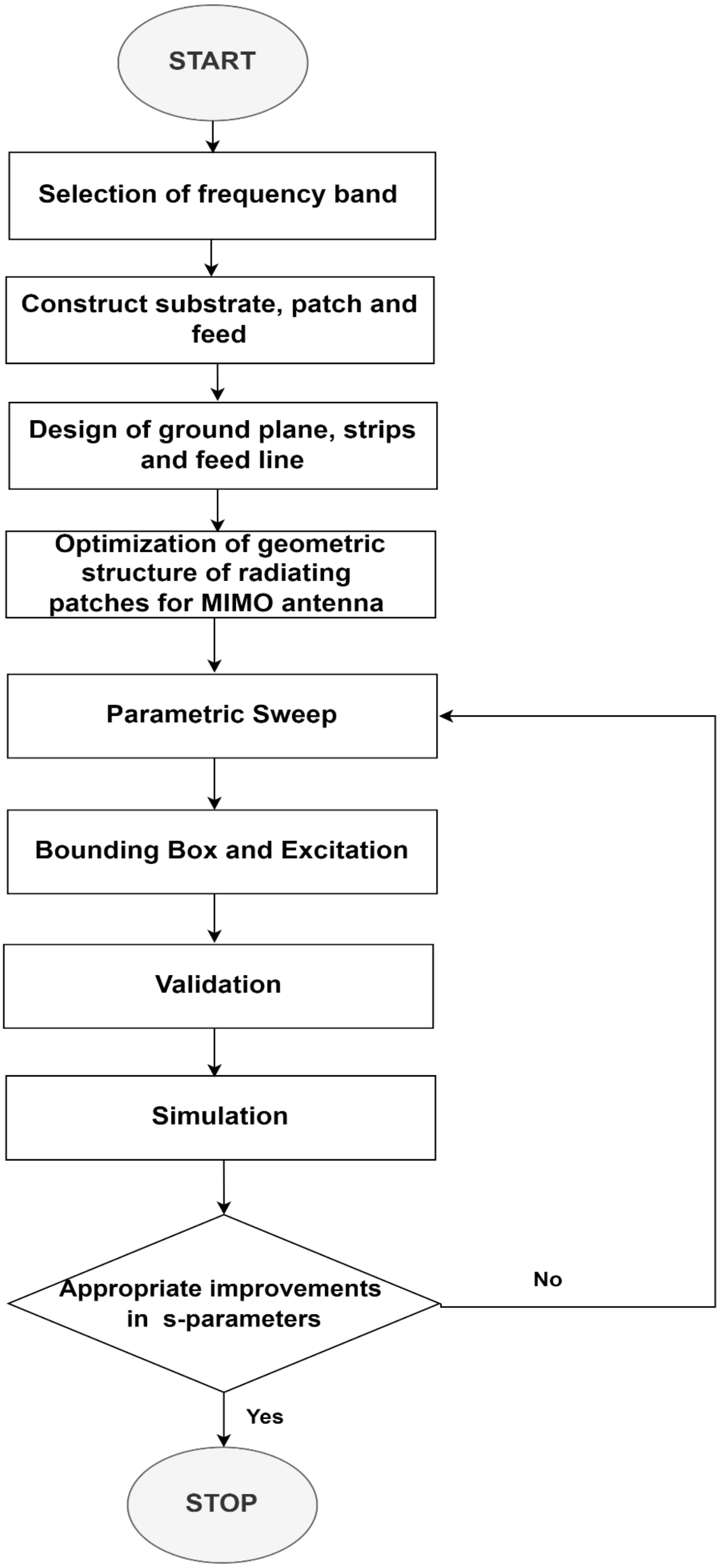

Fig: 3.4 system model flow chart

3.4 Design Equations

Envelope Correlation Coefficient:

$$\rho_{ij} = \frac{\left|S_{ii}{}^{*}S_{ij} + S_{ji}{}^{*}S_{jj}\right|^2}{(1 - |S_{ii}|^2 - |S_{ji}|^2)(1 - |S_{jj}|^2 - |S_{ij}|^2)},$$

Channel Capacity Loss:

$$CCL = -\log_2 \det(\boldsymbol{\alpha}),$$

$$\boldsymbol{\alpha} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} \end{bmatrix}$$

$$\alpha_{ii} = 1 - \left(\sum_{j=1}^{M} |S_{ij}|^2\right), \alpha_{ij} = -\left|S_{ii}{}^{*}S_{ij} + S_{ji}{}^{*}S_{jj}\right|.$$

We consider, Optimized decreased patch length = 3.8 cm

And Increased substrate height = 0.36cm

3 Simulation and Evaluation Parameters

4.1 Schematic

The rectangular microstrip patch antenna design would be visually represented by the CST schematic model, which would also capture the material parameters, feeding mechanism, and geometric features for electromagnetic simulations.

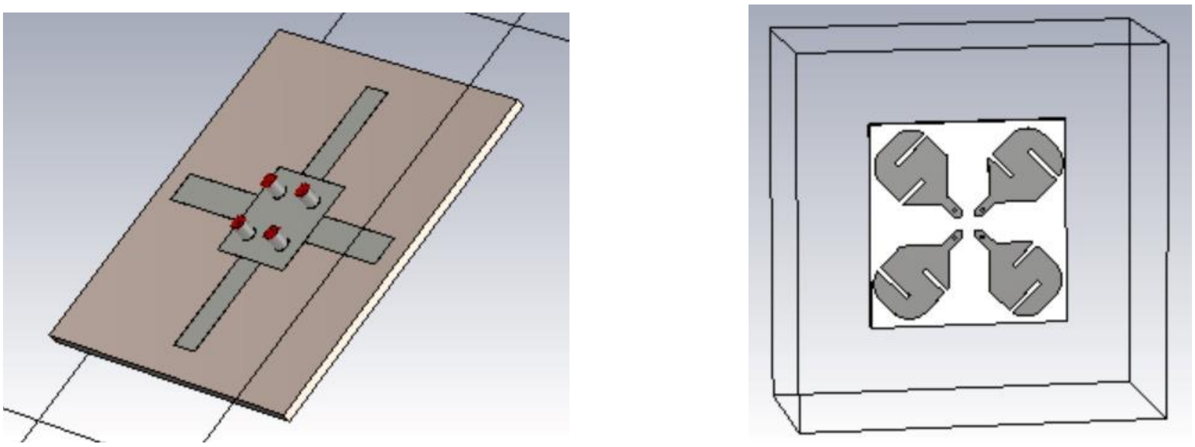

Fig: 4.1 Schematic of 4x4 MIMO front-view and back-view

4.2 Parameters

4.2.1 S parameters

A collection of electrical measures called S-parameters, or scattering parameters, are used to assess the functionality of electrical networks, especially those operating at radio frequencies. The input reflection coefficient is denoted by S11. It is a measurement of the amount of signal that, instead of being emitted outward, is reflected back towards the source from an antenna. Good impedance matching between the antenna and the transmission line is indicated by a low S11 value, which translates to less signal reflection and more effective power transfer.

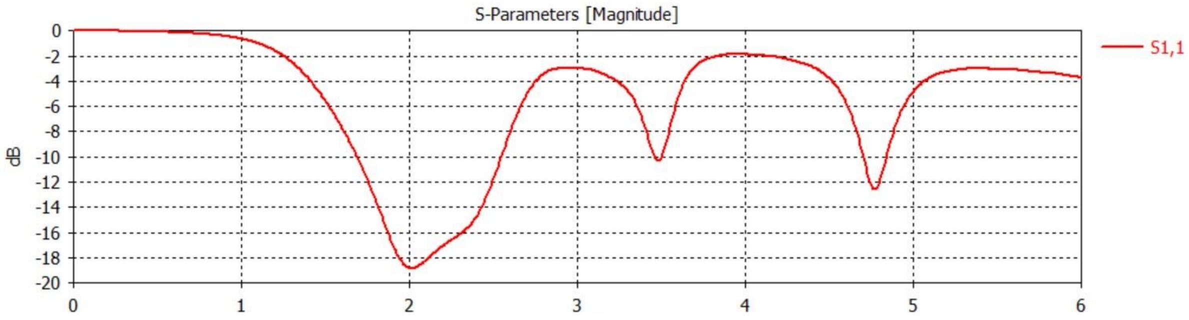

Fig.: 4.2 S11 paramter

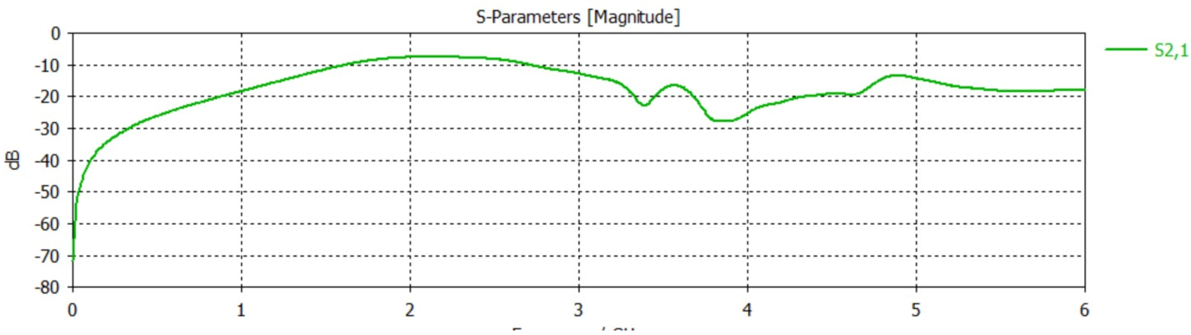

Fig: 4.3 S21 parameter

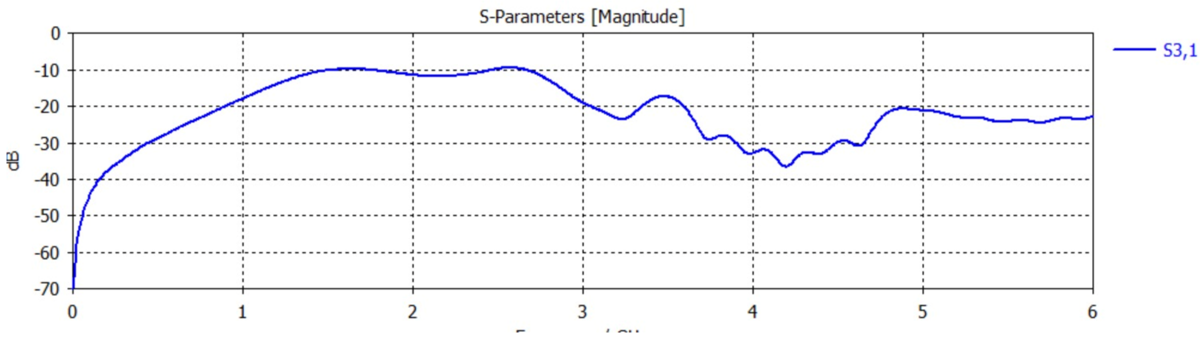

Fig: 4.4 S31 parameter

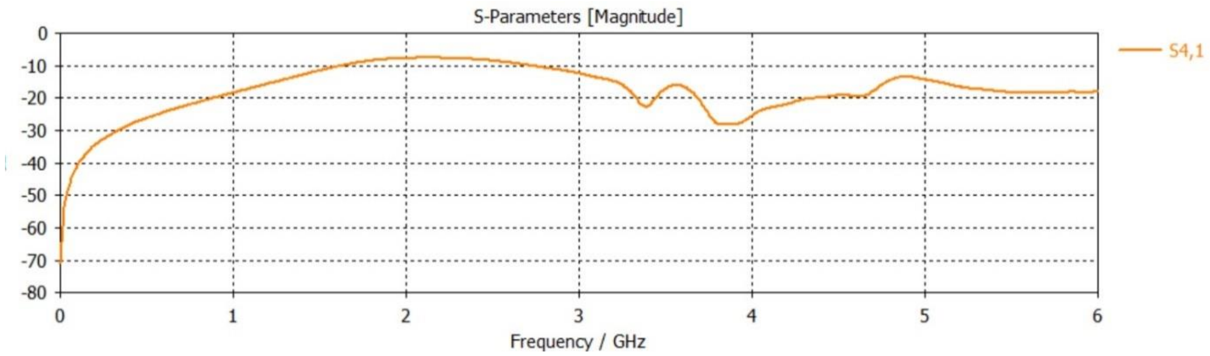

Fig: 4.5 S41 parameter

4.2.2 Correlation Co-efficient

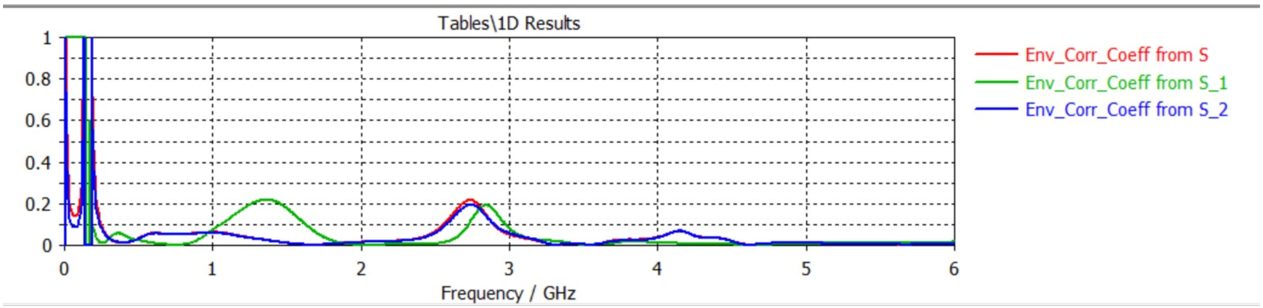

Fig: 4.6 Corealtion Coefficient

4.2.3 Gain

The directional intensity of an antenna's radio waves, either radiated or received, is denoted by its antenna gain in relation to an isotropic antenna, which radiates uniformly in all directions. It indicates, to put it more simply, how efficiently the antenna focuses radio waves in a specific direction.

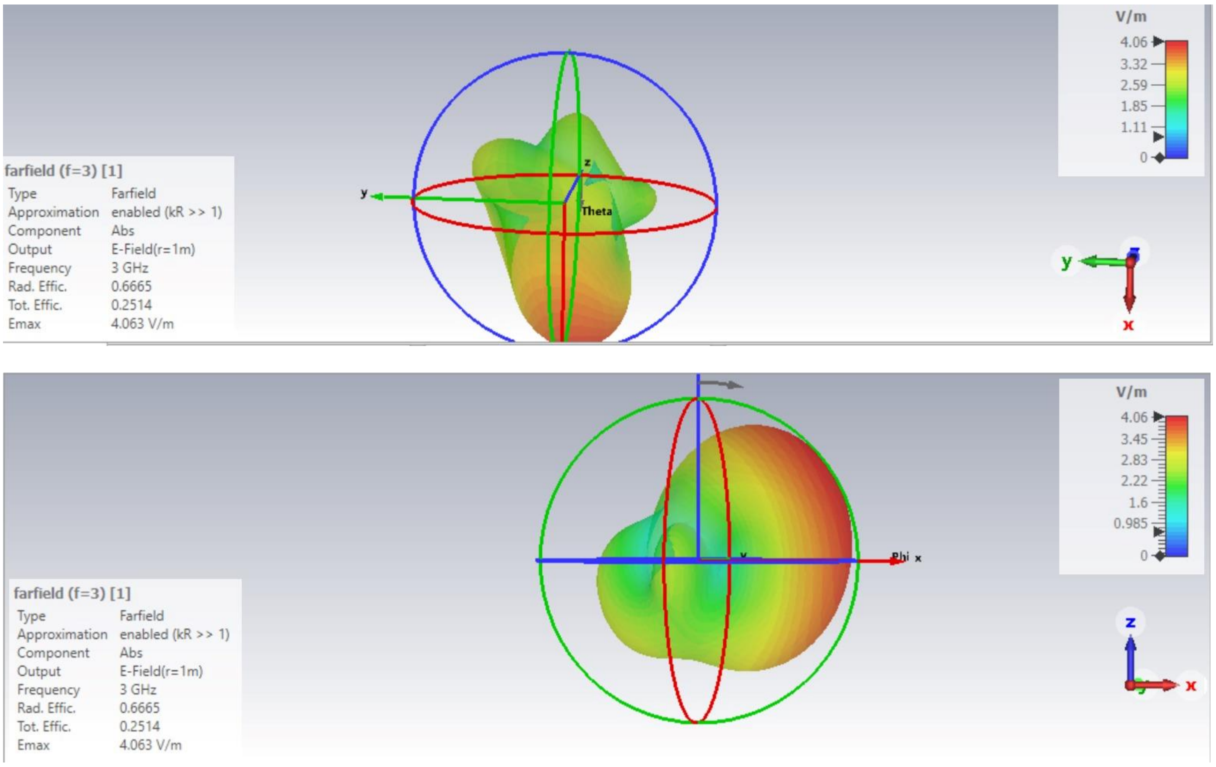

Fig: 4.7 Gain and 3D radiation pattern

4.2.4 Smith Chart

A Smith chart is a graphical tool used in antenna engineering to visualize and analyze complex impedance. It helps to understand how impedance changes along a transmission line and aids in impedance matching, ensuring optimal signal transfer between the antenna and transmission line. Essentially, it provides a roadmap for adjusting antenna parameters to achieve the desired impedance matching and maximize signal efficiency.

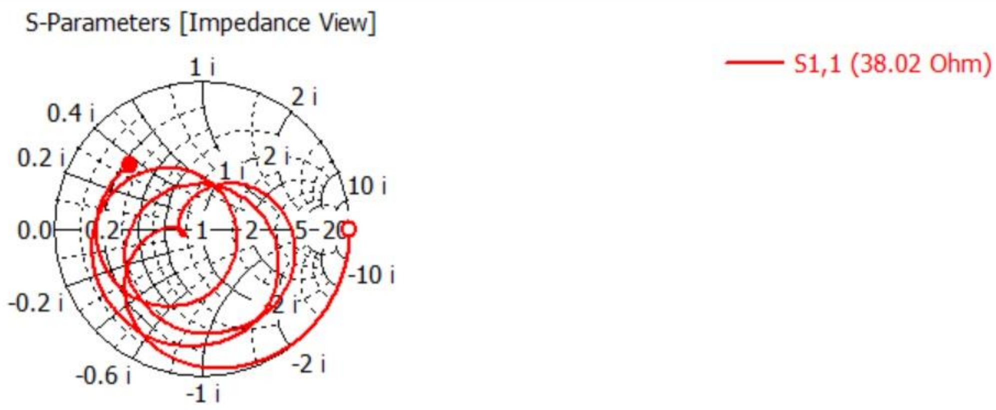

Fig: 4.8 Impedance and admittance chart

4.2.5 Far Field Realized Gain

Far-field realized gain combines the two most important aspects of an antenna: its ability to transmit power effectively (accounting for losses) and concentrate radio waves in a certain direction (like a spotlight beam). A larger far-field realized gain, expressed in decibels relative to an isotropic antenna, indicates a stronger signal in a particular direction, making it perfect for long-distance transmission or focused reception. Engineers can select the ideal antenna for applications that need to transmit concentrated signals by using this value.

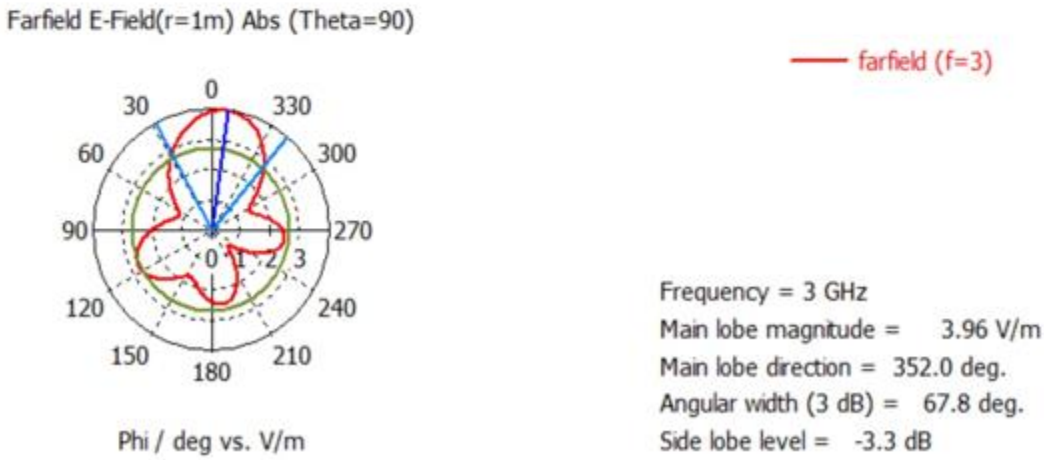

Fig: 4.9 Far field realized gain

5 Results and Discussion with Future Scope

5.2 Result

A compact and high-performance MIMO antenna system with significant gain has been developed for LTE and 5G applications. This four-element antenna system is designed with overall dimensions of 58 x 60 x 1.6 mm^3. It covers dual frequency bands: a wide band spanning 1550-2650 MHz, suitable for 2G, 3G, 4G, and various 5G bands, and an upper frequency band covering the common 3.5 GHz frequency band for 5G applications. The computed channel capacity loss is less than 0.4 bits/s/Hz in both frequency bands. Additionally, the envelope correlation coefficient is kept below 0.08 and 0.02 in the lower and upper frequency bands, respectively. These characteristics indicate that the proposed MIMO antenna meets the requirements for both 4G and 5G wireless communication systems.

5.3 Future scope

Extend the frequency bandwidth of the antenna system to support multi-band operation, catering to a wider range of wireless communication standards and applications such as 5G, Wi-Fi 6E, and beyond and to investigate the feasibility of scaling up the MIMO antenna system to support massive MIMO configurations with a larger number of antenna elements. Integration of millimeter-wave (mm Wave) technology can further enhance data throughput and network capacity. Conduct extensive field trials and real-world deployments of the compact 4x4 MIMO antenna system to validate its performance in various scenarios and environment

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