Project Report on

MIMO ANTENNA IN 5G COMMUNICATION

Submitted in partial fulfillment of the requirements for the B. Tech degree in **Electronics and Communication Engineering**

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From,

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This is to certify that **Nabanita Saha** (Registration No.- D01-1212-0077-18, Roll No.- T91/ECE/184047) and **Tamojit Das** (Registration No.- D01-1112-0082-18, Roll No.- T91/ECE/184052) 8th semester student of B. Tech in Radio Physics and Electronics at the University of Calcutta has submitted their B. Tech Project report entitled "**MIMO antenna in 5G Communication**". They have carried out their B. Tech project work, under my supervision during the academic year 2021 to 2022.

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ABSTRACT

This project work proposes a four-port MIMO antenna for the sub-6 GHz 5G applications. The four identical elements of the proposed MIMO antenna are placed strategically on both sides of a square-shaped FR4 substrate to realize both space and pattern diversities along with better isolation between the ports. One pair of oppositely placed antennas is orthogonal to another pair of antennas that are placed on the opposite side of the dielectric substrate. Further, four partial cuts are included along the diagonals of the substrate to ensure reduced mutual coupling among the antenna elements. Each antenna element is a rectangular monopole patch of length 27.92 mm, and width of 21.48 mm, with its corners truncated to make the proposed design resonate at the desired frequency band. The proposed antenna element operates across 1.45 GHz to 4.50 GHz, dedicated for Sub-6 GHz 5G communication applications. It offers more than 15 dB isolation throughout the operating band and also exhibits a better envelope correlation coefficient (ECC < 0.02) and diversity gain (> 9.5 dB). Significant design parameters are finalized through some parametric studies. The proposed structure is fabricated and measured. The measured S-parameters are in good agreement with their simulated counterparts.

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CHAPTER 1 – INTRODUCTION

1.1. Basic of Micro-strip Patch Antenna

1.1.1. What is MSA?

An MSA in its simplest form consists of a metallic patch and metallic ground plane that are printed on two opposite sides of the dielectric substrate. The geometry of a micro-strip antenna consists of a dielectric substrate of certain thickness d, having a complete metallization on one of its surfaces and of a metal "patch" on the other side. The substrate is usually thin ($d \ll \lambda$). The micro-strip antenna produces maximum radiation in the broadside (perpendicular to the substrate) direction and ideally no radiation in the end-fire (along the surface of the substrate) direction. The size of the antenna is usually designed such that the antenna resonates at the operating frequency, producing a real input impedance. For a rectangular micro-strip antenna, this requires the length of the antenna, L, to be about half a wavelength in the dielectric medium. The width of the antenna, W, on the other hand, determines the level of the input impedance. The micro-strip antenna can be thought of as a rectangular cavity with open sidewalls. The fringing fields through the open sidewalls are responsible for the radiation. However, the structure is principally a resonant cavity, with only limited fringing radiation.

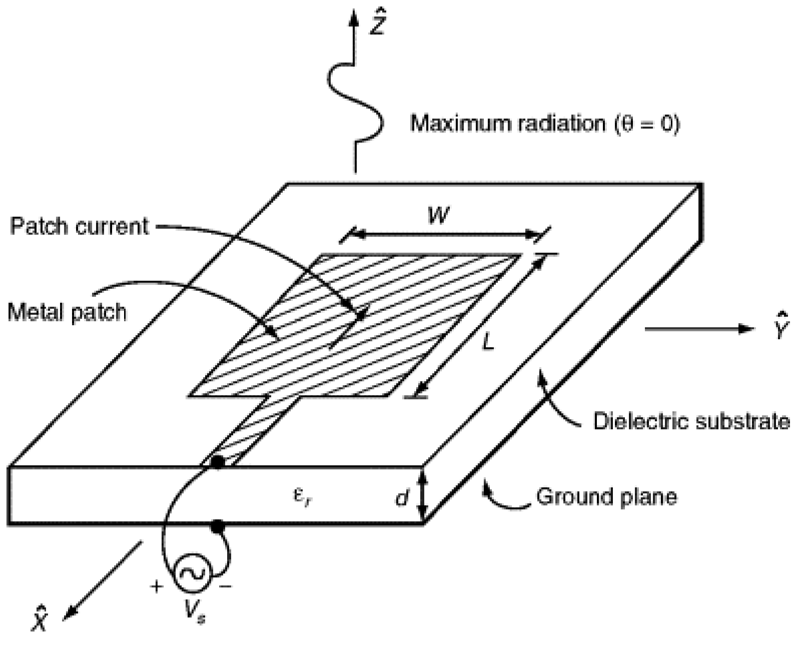


Fig.1.1: Rectangular Micro-strip Patch Antenna

1.1.2.1. Advantages of MSA?

- ★ Light weight, small size and low-profile conformable to planar & non-planar surfaces.
- ★ Low fabrication cost and ease of mass production.
- ★ Easier to integrate with MICs on the same substrate.
- ★ Allow both linear and circular polarization.
- ★ Allow multi-frequency operations.
- ★ Feed lines and matching networks can be easily integrated with antenna structure.

1.1.2.2 Disadvantages of MSA?

- ★ Narrow bandwidth (≈ 5%)
- ★ Low power handling capacity (Using very thin PCB, how can we use for high power?)
- ★ Lower gain
- ★ Poor isolation between the feed and the radiating elements (Due to feed structure there will be coupling)
- ★ Possibility of excitation of surface waves (Broad side radiation from the patch is desirable but radiation along surface due to fringing field generates surface waves).
- ★ Polarization purity is difficult to achieve.

1.1.3. Application of MSA:

- ★ Mobile phones
- ★ Doppler and other radars
- ★ Satellite communication
- ★ Command guidance and telemetry in missiles
- ★ Feed elements in complex antennas
- ★ Satellite navigation receiver
- ★ Biomedical radiator

1.1.4. Common antenna parameters:

1. S-parameter: Describe the input-output relationship between ports or terminals in an electrical system.
2. VSWR: Numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.
3. Radiation pattern: The energy radiated by an antenna is represented by the *radiation pattern.* Radiation Patterns are diagrammatic representations of the distribution of radiated energy into space, as a function of direction.
4. Polarization: It is defined as the direction of the electromagnetic fields produced by the antenna as energy radiates away from it.
5. Gain: Key performance number which combines the antenna's directivity and electrical efficiency.

1.1.5. Antenna Design and Placement Constraints

1. Size: comparable to sub 6GHz radiowave's wavelength
2. Isolation: 15 dB isolation required between the antennas.
3. Interference: No high speed signal nearby
4. Industrial Design: Slim Narrow Bezel
5. Carrier OTA requirements

1.2. 5G Communication

1.2.1. What is 5G Communication?

5G is the fifth generation technology standard for broadband cellular networks, which cellular phone companies began deploying worldwide in 2019, and is the planned successor to the 4G networks.
5G is based on OFDM (Orthogonal frequency-division multiplexing), a method of modulating a digital signal across several different channels to reduce interference. 5G uses 5G NR air interface alongside OFDM principles. 5G also uses wider bandwidth technologies such as sub-6 GHz and mmWave.

1.2.2. Advantages of 5G

- ➢ Data rates: 10 - 20 gbps
- ➢ Low Latency: < 1 ms
- ➢ Higher Bandwidth
- ➢ Dynamic Beamforming to overcome path-loss at higher frequency
- ➢ 10x decreased latency, 10x throughput, 10x connection density, 100x traffic capacity, 100x network efficiency, 3x spectrum efficiency

1.2.3. 5G Frequency Bands

The 5G spectrum is a range of radio frequencies in the sub-6 GHz range and the millimeter-wave (mmWave) frequency range that is 24.25 GHz and above. The 5G spectrum refers to the radio frequencies that carry data from user equipment (UE) to cellular base stations to the data's endpoint.

- ➔ Low bands below 1GHz: Mobile broadband and Massive IoT
- ➔ Mid bands 1GHz to 6GHz: eMBB and mission critical
- ➔ High band above 24GHz: extreme bandwidth

Sub 6GHz Band : Mid Band (1GHz to 6GHz)

1.2.4. 5G usage scenario

➢ eMBB: The initial phase of 5G Non-Standalone
deployments focuses on eMBB, which provides greater data-bandwidth complemented by moderate latency improvements on both 5G NR and 4G LTE. This will help to develop today’s mobile broadband use cases such as emerging AR/VR media and applications, Ultra HD or 360-degree streaming video and many more.

➢ mMTC: mMTC has been already developed as part
of 3GPP Release 13/14 low power wide area (LPWA) technologies, which includes NB-IoT. These are expected to meet most 5G mMTC requirements.

➢ URLLC: Technologies that require more
bandwidth with ultra-reliable low latency (full URLLC) will require the 5G Core deployment for full end-2-end latency reduction. Mission critical applications that are especially latency-sensitive will also require wide coverage.

All applications are shown in Fig. 1.2.

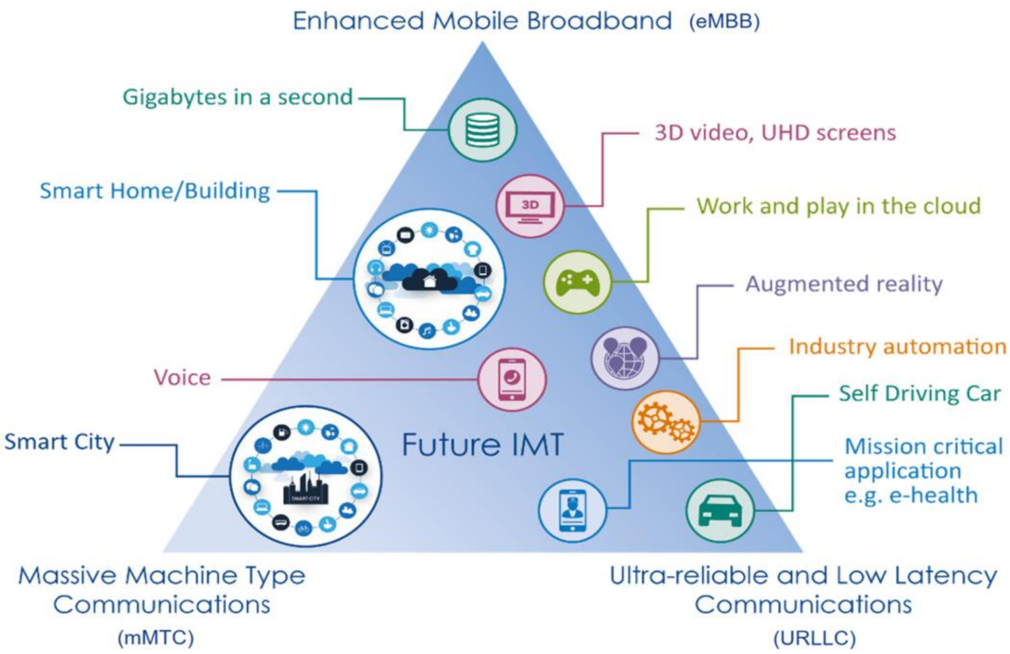


Fig.1.2: 5G Usage Scenario

1.3 MIMO Technology

1.3.1. What is MIMO Technology?

MIMO (multiple input, multiple output) is an antenna technology for wireless communications in which multiple antennas are used at both the source (transmitter) and the destination (receiver). The antennas at each end of the communications circuit are combined to minimize errors, optimize data speed and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. Shown in Fig. 1.3

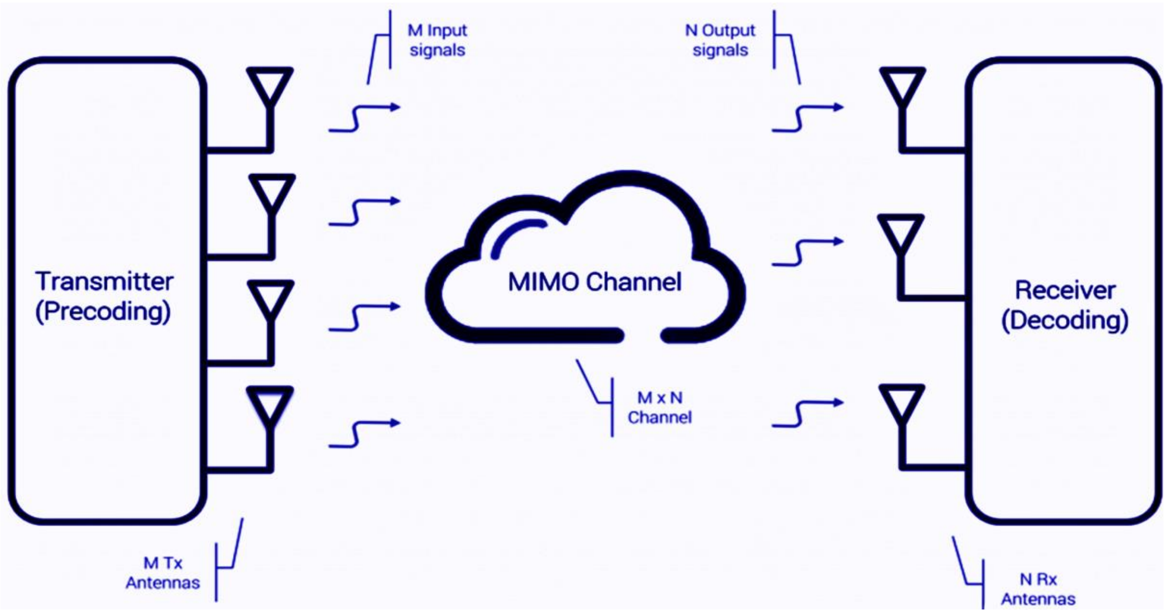


Fig 1.3: MIMO Technique Representation

1.3.2. MIMO Design Techniques

Implementation using,

1. Diversity Technique :

Same information sent across independent channels to combat fading. More diversity paths can be created by adding multiple antennas at either or both Tx and Rx).

Provides *Diversity Gain*, Improves reliability, Combats Fading.

2. Spatial Multiplexing Technique :

Each spatial channel carries independent information, thereby increasing the data rate of the system. Provides *Multiplexing Gain*, Maximize data rate/Transmission rate, use rich scattering for advantage.

1.3.3. MIMO antenna parameters

★ Envelope correlation coefficient (ECC): Envelope Correlation Coefficient tells us how independent two antennas' radiation patterns are. It takes into account the antennas' radiation pattern shape, polarization, and even the relative phase of the fields between the two antennas. If the radiation pattern is: $\overline{F_1(\theta,\phi)} = F_{1\theta}(\theta,\phi)\cdot\overline{a_\theta} + F_{1\phi}(\theta,\phi)\cdot\overline{a_\phi}$

The envelope correlation coefficient is mathematically given by:

$$\rho_e = \frac{|\int\int \overline{F_1}\cdot\overline{F_2^\star}\,d\Omega|^2}{\int\int |\overline{F_1}|^2 d\Omega \cdot \int\int |\overline{F_2}|^2 d\Omega}$$

The formula for ECC in terms of isolation (s12) is given by:

$$\rho_e = \frac{|S_{11}^\star S_{12} + S_{21}^\star S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)}$$

★ Diversity gain (DG): Diversity gain is the increase in signal-to-interference ratio due to some diversity scheme, or how much the transmission power can be reduced when a diversity scheme is introduced, without a performance loss.

★ Channel Capacity Loss (CCL): The maximum error-free data rate that a channel can support is called the channel capacity. It depends on the number of antennas, the signal-to-noise ratio, the channel state, and the autocorrelation or covariance matrix of the transmitted signal vector. Channel Capacity Loss (CCL) helps in defining the loss of transmission bits/s/Hz in a high data rate transmission.

★ <u>Total active reflection coefficient (TARC)</u>: TARC relates the total incident power to the

total outgoing power (unwanted reflected power) in a MIMO antenna. With this definition we can characterize the multiport antenna's frequency bandwidth and radiation performance. TARC can be computed directly from the scattering matrix by:

$$\Gamma_a^t = \frac{\sqrt{\sum_{i=1}^{N} |b_i|^2}}{\sqrt{\sum_{i=1}^{N} |a_i|^2}}$$

1.4. Design Procedure of Rectangular Micro-strip Patch Antenna (RMSA)

Based on the simplified formulation, a design procedure is out- lined which leads to practical designs of rectangular micro-strip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate (ϙr), the resonant frequency (fr), and the height of the substrate h. The procedure is as follows:

Specify: ϙr , fr (in Hz), and h

Determine:

Width (W) and Length (L):

1. For an efficient radiator, a practical width that leads to good radiation efficiencies is,

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}};$$

2. Determine the effective dielectric constant of the micro-strip antenna using

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

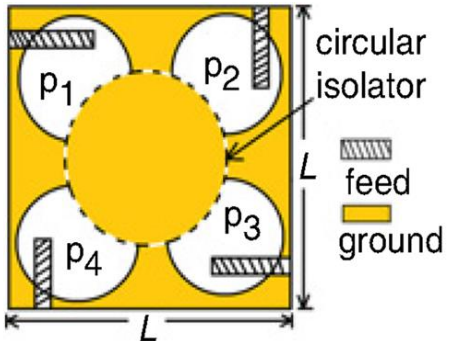
3. The actual length of the patch can now be determined for L can be formulated by the expression below.

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$

1.5. Literature Review

A. MIMO antenna with built-in circular shaped isolator for sub-6 GHz 5G applications [1]

- Bandwidth: 400 MHz
- Operating Band: 3.4–3.8 GHz
- Isolation Improvement: This disc acts as a pool of current with 180° phase difference leading to isolation between various ports.
- Isolation improvement technique: A circular-shaped metallic disc in the ground plane



B. Isolation and frequency reconfigurable compact MIMO antenna for wireless local area network applications [2]

- Dual Band wireless LAN
- Good Isolation (less than -15dB achieved)
- Both antenna element and decoupling network are designed using meander line concept.
- Isolation between the antenna elements also made as reconfigurable by placing PIN diodes in the decoupling network.

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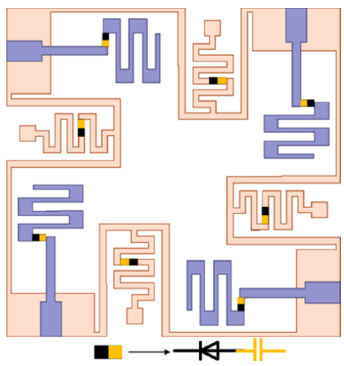
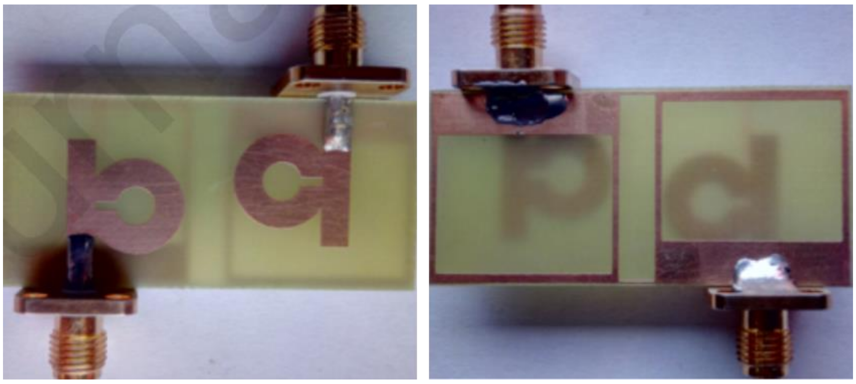


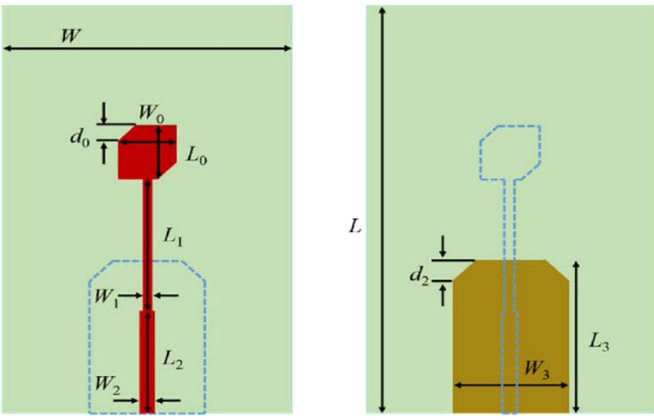
C. Single Split-Ring Resonator Loaded Self-Decoupled Dual-Polarized MIMO Antenna for Mid-band 5G and C-band Applications [3]

- Operating Bands: Mid Band (3.4 – 3.6 GHz), C Band (4-8 GHz)
- Minimum isolation of 15 dB for the two frequency bands with a smaller edge-to-edge spacing of 4 mm (0.04λ) between the two antenna elements.
- Dual-band response: First band linear polarization, Second band circular polarization.



D. Ultra-Wideband Patch Antenna for Sub-6 GHz 5G Communications [4]

- To increase Bandwidth: Optimized Ground Plane Structure and changing the step-impedance resonator (SIR)
- Operating Band: 2.32 to 5.34 GHz
- cover WiFi, Bluetooth and WLAN applications



1.6. Motivation and Objective

Motivation

- ➢ Increased demand of 5G usage
- ➢ MIMO antenna is the obvious choice for the 5G applications
- ➢ Mutual coupling among the antenna elements is the key factor for a MIMO antenna
- ➢ Enough scope is there to work with the placement of antenna elements for better isolation

Objective

- ✓ Design and analysis of MIMO antenna for 5G applications
- ✓ Sub 6 GHz band is the target operating range of the antenna
- ✓ Improvement of isolation between the antenna elements
- ✓ Design that can provide both space and pattern diversity

1.7. Software Used to Design Micro-strip Patch Antenna

1.7.1. CST Studio Suite

CST Studio Suite is a high-performance 3D EM analysis software package for designing, analyzing and optimizing electromagnetic (EM) components and systems.

Electromagnetic field solvers for applications across the EM spectrum are contained within a single user interface in CST Studio Suite. The solvers can be coupled to perform hybrid simulations, giving engineers the flexibility to analyze whole systems made up of multiple components in an efficient and straightforward way. Co-design with other SIMULIA products allows EM simulation to be integrated into the design flow and drives the development process from the earliest stages.

1.7.2. Adobe Illustrator

Adobe Illustrator is a popular software application used by artists and graphic designers to create vector graphics. It offers sophisticated digital drawing tools for creating vector-based illustrations, icons, typography, logos, and other artwork. Used as part of a larger design workflow, It allows for the creation of everything from single design elements to entire compositions.

Adobe Illustrator is one of the software applications included in Adobe Creative Cloud.

We used this software during fabrication of the proposed antenna for printing the antenna design with accurate dimensions.

CHAPTER-II: DESIGN OF A MIMO ANTENNA FOR 5G COMMUNICATION

2.1 Introduction

The 5G spectrum refers to the radio frequencies that carry data from user equipment (UE) to cellular base stations to the data's endpoint.

In 5G technology, two kinds of frequency bands are classified. First are Sub-6 GHz bands where the frequency transmitted from cell phone towers are less than 6GHz frequency. This is very similar to 4G, where the frequencies transmitted from cell phone towers are below 6GHz.

On the other hand, the higher speeds that really set 5G apart from any of the 4G LTE flavors require mmWave (millimeter wave, above 24GHz) high-frequency bands.

So in 5G, these two types of frequency ranges have been defined as:

Frequency Range-1 (Sub-6 GHz, less than 6GHz) also known as **Mid-band**.

Frequency Range-2 (mmWave, above 24GHz) known as **C band**.

Shown in Fig. 2.1.

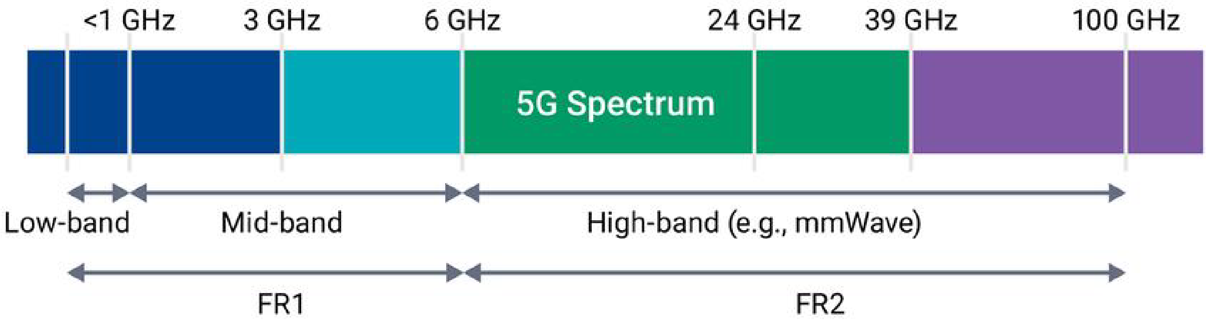


Fig 2.1: 5G Frequency Spectrum

- **We are interested in designing a MIMO antenna that works in sub 6GHz band or Mid-band (1-6 GHz).**

2.2. Design Approach

In this foundation of the project we have placed two micro-strip monopole antennas at different arrangements and observed the S parameters. Lesser the value of S_{21} and S_{12}, better the isolation between the antennas. Here we have displayed six different arrangements of the antennas.

Design Parameters:

Each antenna patch has the following dimensions.

	Antenna Patch	Feed line dimensions are:
Length	21.484023919693 mm	14.5 mm
Width	27.922505310634 mm	5.5845010621268 mm
Height	0.035 mm	0.035 mm

Materials Details:

Dielectric Material – FR4

Patch and Ground – Copper

*** (Design Parameters and Materials Details are same for all 4 designs)**

We have put the antennas in six arrangements:

1. Single Monopole
2. Orthogonal placement of Two Monopoles
3. Two Monopoles orthogonally opposite side of the substrate
4. Two Monopoles opposite along X axis

2.2.1. Antenna-1: Single Monopole

The following design in Fig. 2.2 is for the structure of a single micro-strip patch monopole with a micro-strip line feed and a ground plane. This is the initial design where we will add design modifications to achieve the desired results for requirements.

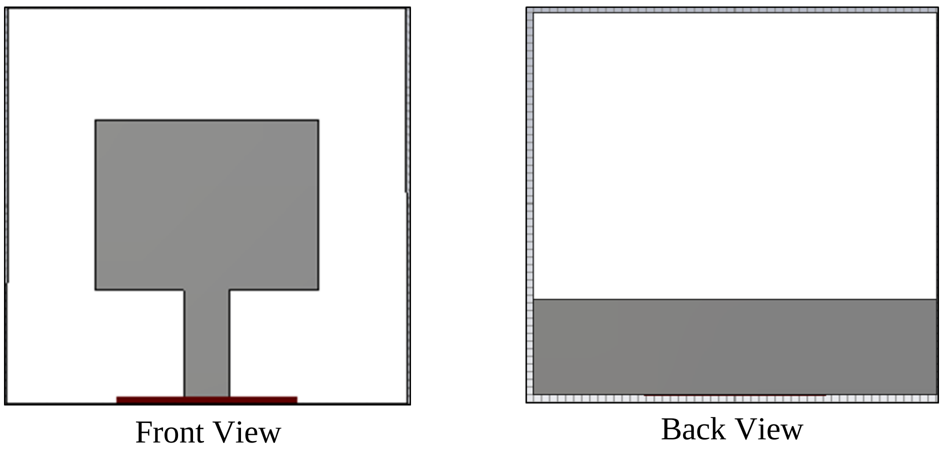


Fig. 2.2: Single Monopole Design

As we can observe from the graphical plot in fig. 2.3 we have s-parameter curve for reflection (S_{11}) in the frequency range 0-6 GHz. For desired results for performance of antenna, the S_{11} parameter curve should dip below -10 dB. Hence, the operating band is 2.1087 – 4.4534 GHz here. So, we get a bandwidth of 2.3447 GHz.

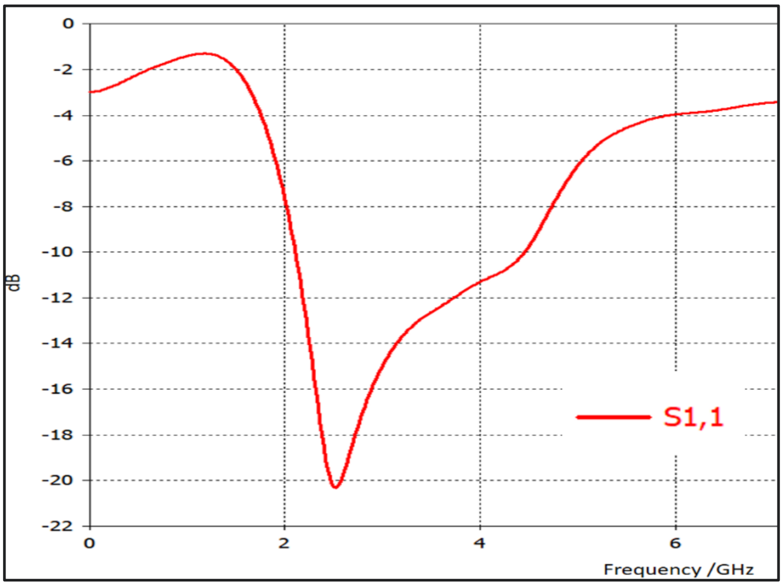
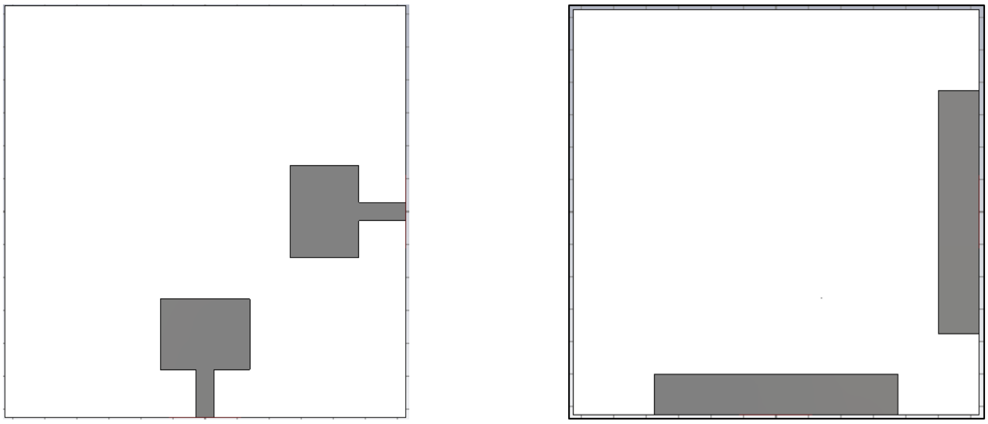


Fig.2.3: S Parameters (S_{11})

2.2.2. Antenna-2: Orthogonal Placement of Two Monopoles

To achieve fast communication and data transfer we use the MIMO technology. In this design modification as shown in Fig. 2.4, we have placed two identical monopoles orthogonally, i.e. 90°. It must be noted that both the antennas are at the same side of the dielectric. We aim to get better parametric results via further modification.



Front View Back View

Fig. 2.4 Orthogonal Placement of Two Monopoles

The S – parametric plots for design depicted in Fig.2.4 is shown in Fig.2.5 Here we have four curves for S_{11}(Red), S_{21}(Blue), S_{22}(Orange) and S_{12}(Green), which gives us the simulated results of the MIMO antenna performance. We can conclude from the results that the Operating band of this design is 3.2505GHz – 4.6002GHz and a bandwidth of 1.397GHz. The maximum isolation between the radiation of the antennas according to the plot is -13dB.

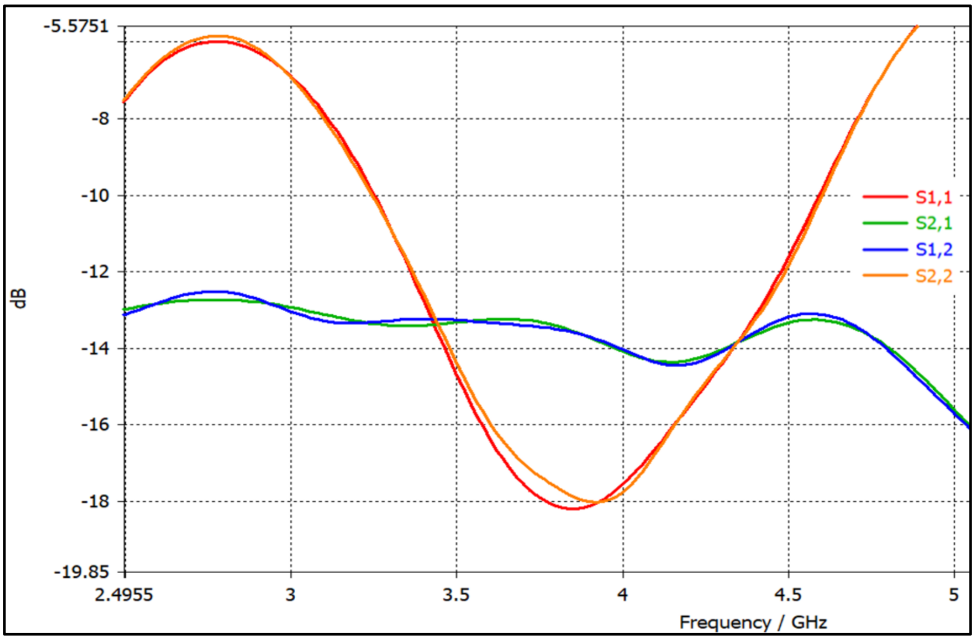
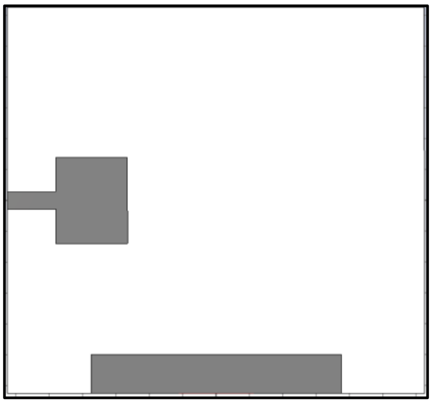


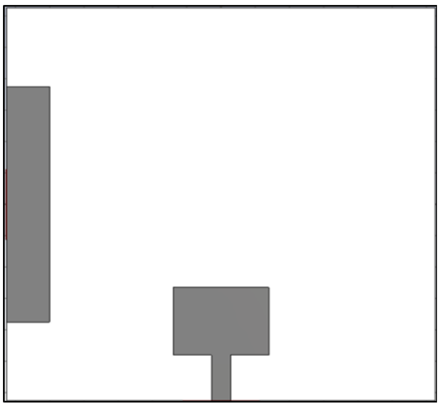
Fig.2.5: S Parameters

2.2.3. Antenna-3: Two Monopoles orthogonally opposite side of the Substrate

In this section, we have modified design shown in Fig.2.4, by flipping the antenna to the other side of this dielectric such that each antenna in orthogonal to the ground of the other. Fig. 2.6 depicts the modified structure of the antenna. The purpose of this modification was to get improved isolation and pattern diversity.



Front View



Back View

2.6: Orthogonally Opposite Monopoles

The Fig.2.7 shows the S-parametric curves for the design modification in Fig.2.6. we have four curves for S_{11}(Red), S_{21}(Blue), S_{22}(Orange) and S_{12}(Green), which gives us the simulated results of the MIMO antenna performance. We can conclude from the results that the Operating band of this design is 3.2396GHz – 4.5971GHz and a bandwidth of 1.3575GHz. The maximum isolation between the radiation of the antennas according to the plot is -13.5dB.

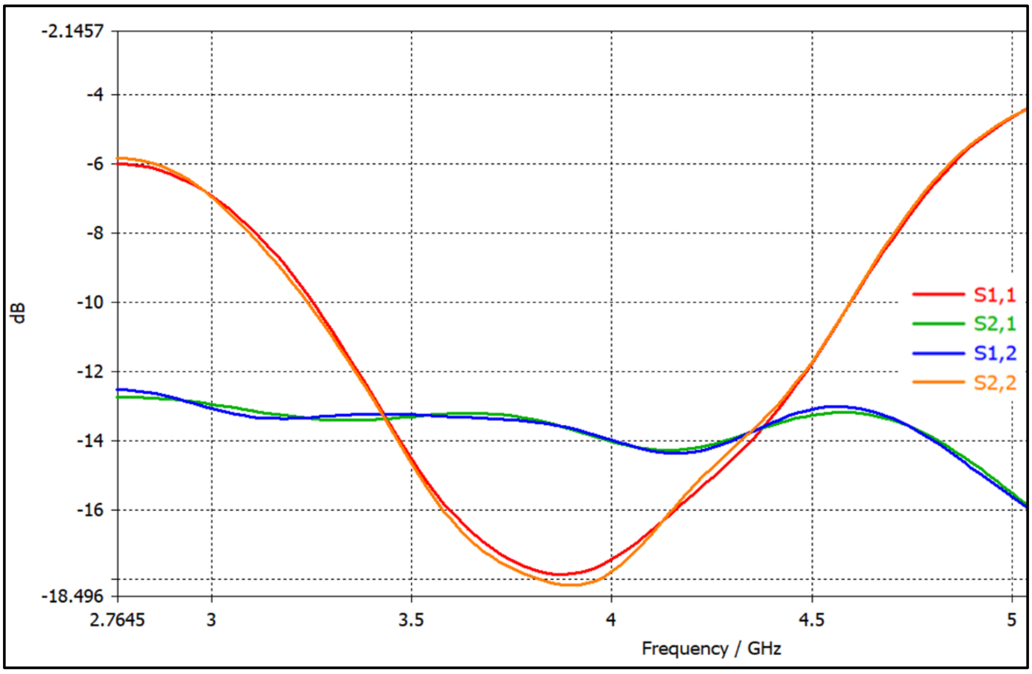
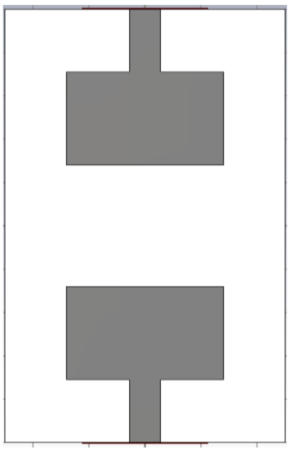


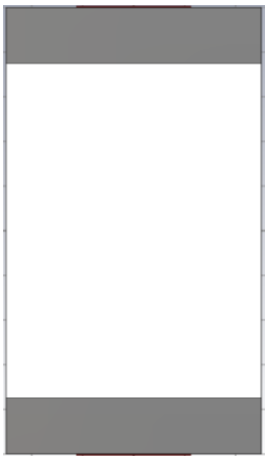
Fig. 2.7: S Parameters

2.2.4. Antenna-4: Two Monopoles opposite along X axis

In this section, we have placed an identical monopole in the dielectric opposite along X-axis. Fig. 2.8 shown the modified design where both the monopoles are on the same side of the dielectric.



Front View



Back View

Fig. 2.8: Two Monopoles Opposite Along X axis

The Fig.2.9 shows the S-parametric curves for the design modification in Fig.2.8. we have four curves for S_{11}(Red), S_{21}(Blue), S_{22}(Orange) and S_{12}(Green). We can conclude from the results that the Operating band of this design is 2.0838GHz – 4.1218GHz and a bandwidth of 2.038GHz. The maximum isolation between the radiation of the antennas according to the plot is -16dB.

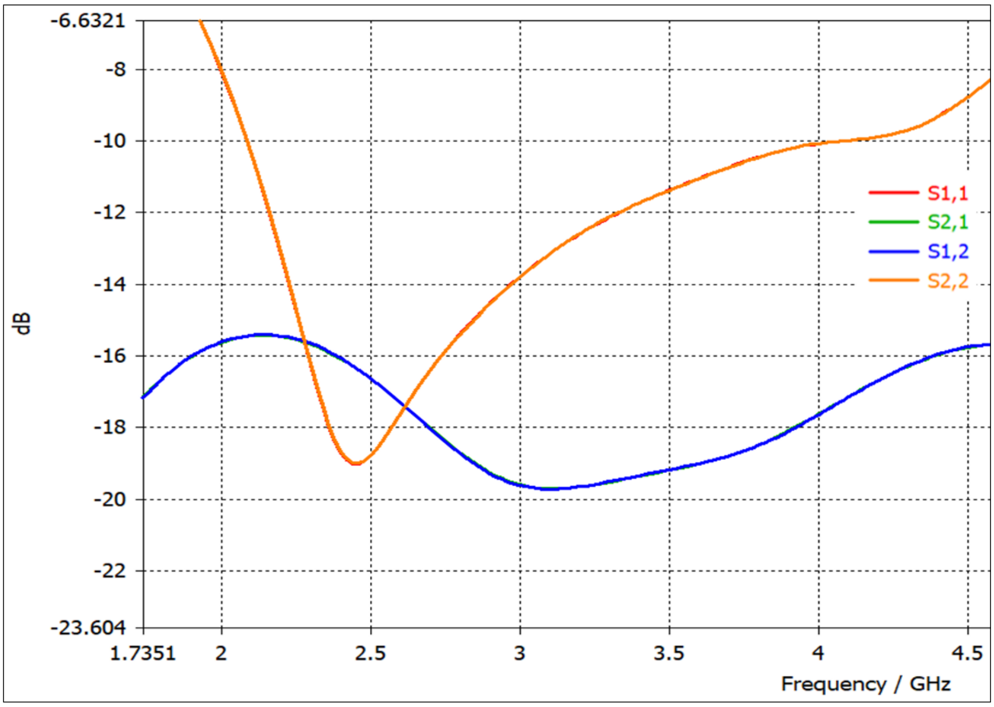


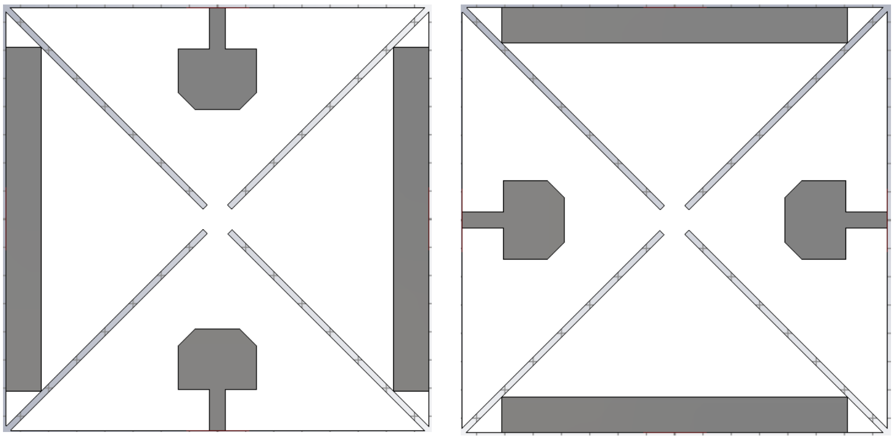
Fig. 2.9: S Parameters

2.2.5. Proposed MIMO Antenna

MIMO Configuration of the four element design is achieved utilizing the corporate feed technique is extended to the MIMO configuration of four ports as shown in Figure.2.10. Position of the antennas are as such, two antenna along an axis and such two pairs are orthogonal to each other and on the opposite side of the dielectric in order to achieve pattern diversity and good isolation among antennas, lack of which can cause issues when extending arrays to MIMO. We further truncated the corners of each antenna elements and cut through the diagonals of the substrate to improve the isolation.

Antenna Parameters

	Antenna Patch	**Feed line**	**Dielectric**
Length	21.484023919693 mm	14.5 mm	150 mm
Width	27.922505310634 mm	5.5845010621268 mm	150 mm
Height	0.035 mm	0.035 mm	1.6 mm



Front View Back View

Fig 2.10: Final Design

2.3 Scattering Parameters: Reflection and Isolation

The results obtained through simulation and measurements for the proposed MIMO antenna is depicted in graphs below are analyzed in this section. In Figures below, the s-parameters are shown for the proposed MIMO antenna results analysis and parametric studies.

2.3.1. Parametric Studies on micro-strip line feed:

A conducting strip is connected directly to the edge of antenna for its feed. Few points we need to have in mind while determining the width of the strip. If the width is too large then it will interfere with the radiation of the antenna and if the width is too small we face high impedance in the conducting strip.

In order to determine the optimum value of the micro-strip line feed we took different width value (W/4, W/5, W/7.5 and W/10) and compared the s-parameters for each. Here W refers to the width of the antenna.

In Fig 2.11 on comparison of the s-parameters for the proposed design with different measurements of micro-strip line feed width, we can conclude that, **we get optimum results for feed width equal to W/5**. Maximum value of isolation between opposite antennas i.e. S_{21}, S_{43} are -16.7 dB. Similarly, maximum value of isolation between orthogonal antennas i.e. S_{31}, S_{41} are -17.7 dB.

Which is below -15 dB.

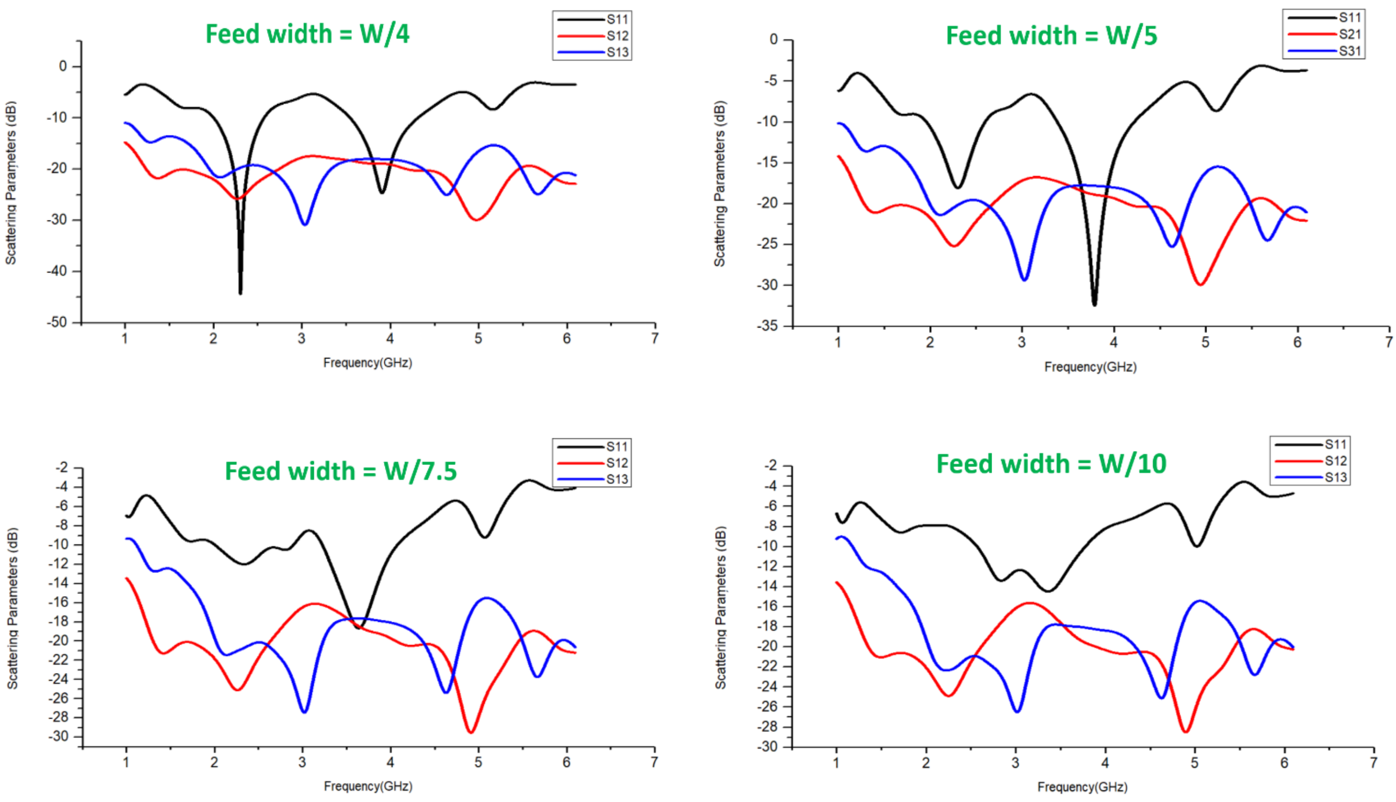


Fig 2.11: Variation of Micro-strip Line Feed Width

2.3.2 Parametric Studies on ground length:

A ground plane is a flat or nearly flat horizontal conducting surface that serves as part of an antenna, to reflect the wave from the other antenna elements. Ground plane shape and size play major roles in determining its radiation characteristics including gain.

We have compared s-parameters for the MIMO antenna with different measurements of the ground metallic patch in terms of L (length of the dielectric) which is 150 mm.

In order to determine the optimum value of the ground length we took different values in terms of L (L, L/2, L/1.5 and L-28) and compared the s-parameters for each. Here L refers to the length of the antenna.

In Fig. 2.12 on comparison of the s-parameters for the proposed design with different measurements of ground length in terms of L, we can conclude that we get optimum results for ground length equal to L-28 mm. Maximum value of isolation between opposite antennas i.e. s_{21}, S_{43} are -20 dB. Similarly, maximum value of isolation between orthogonal antennas i.e. S_{31}, S_{41} are -15.5 dB. Which is below -15 dB.

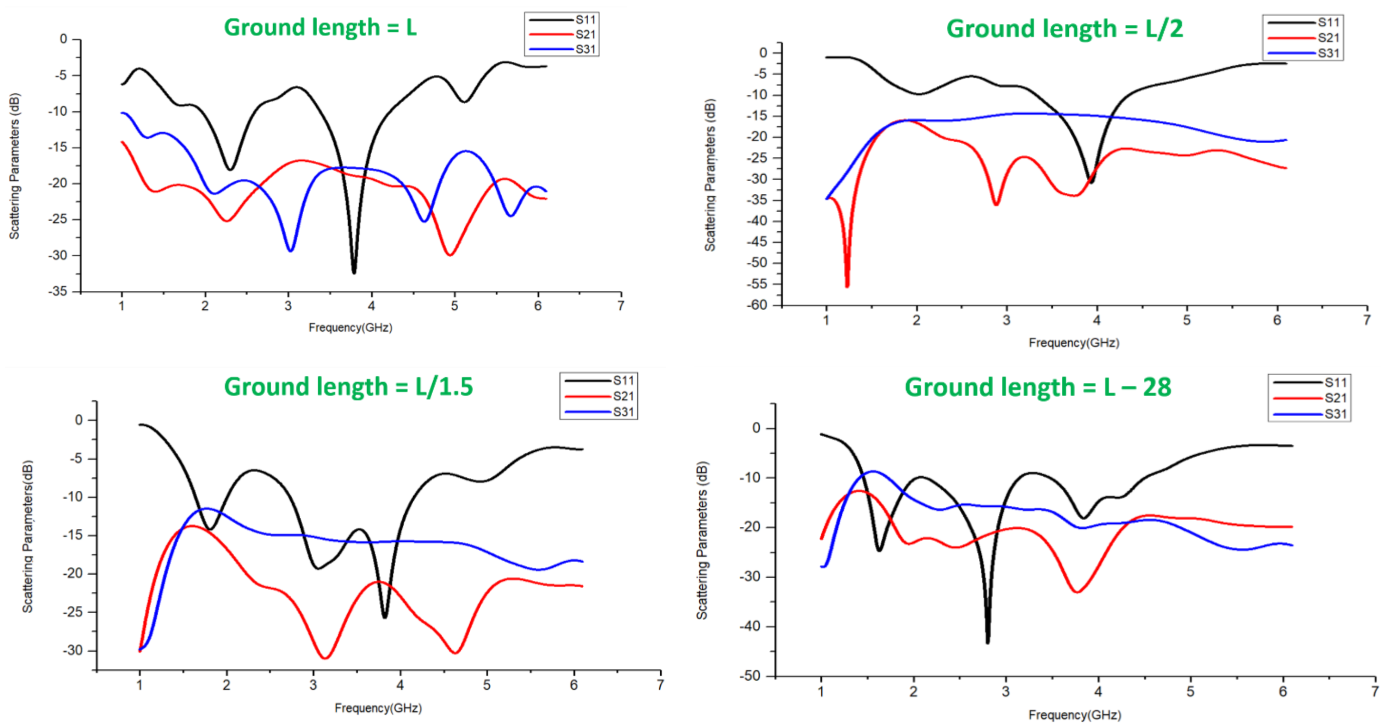


Fig 2.12: Variation of ground length.

2.3.3. Design Modification

- Combining the designs depicted in Antenna 3 and 4 we get Antenna 5 in table below.
- In antenna 6 we truncated the corners of each monopole antenna.
- In antenna 7, we modified antenna 5 by cutting through the diagonals of the dielectric.
- In proposed antenna we combined the modifications of antenna 6 and 7 to get our final design.

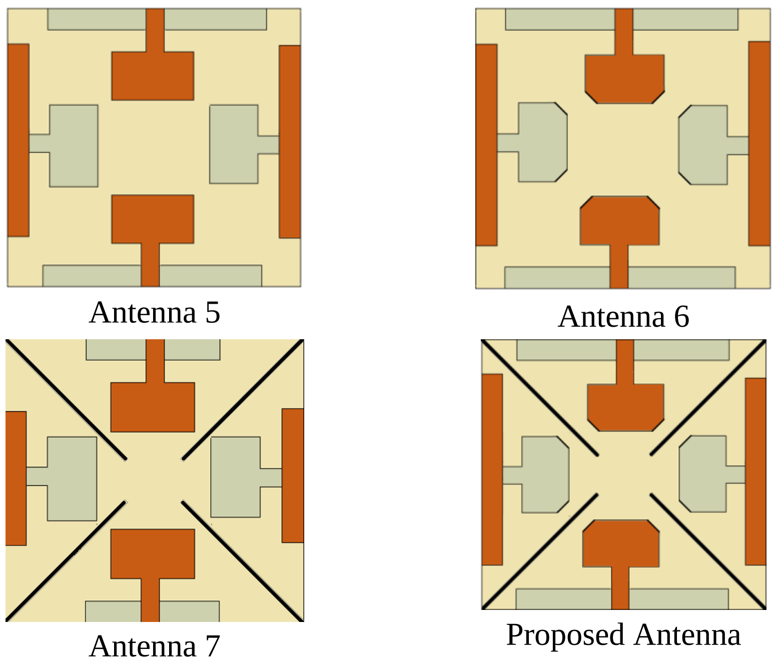


Fig 2.13: Design Modifications

2.3.4. S-Parameter for corresponding designs

In this section we compare the s-parameter results of the four designs with modifications. Starting from design 1 to 4 we observe the improvement in reflection and isolation between each antenna. As we can clearly see we get the best result in design 4, where reflection is below -10dB and isolation is well below -15dB in the operating band (1.4556 – 4.5015) GHz.

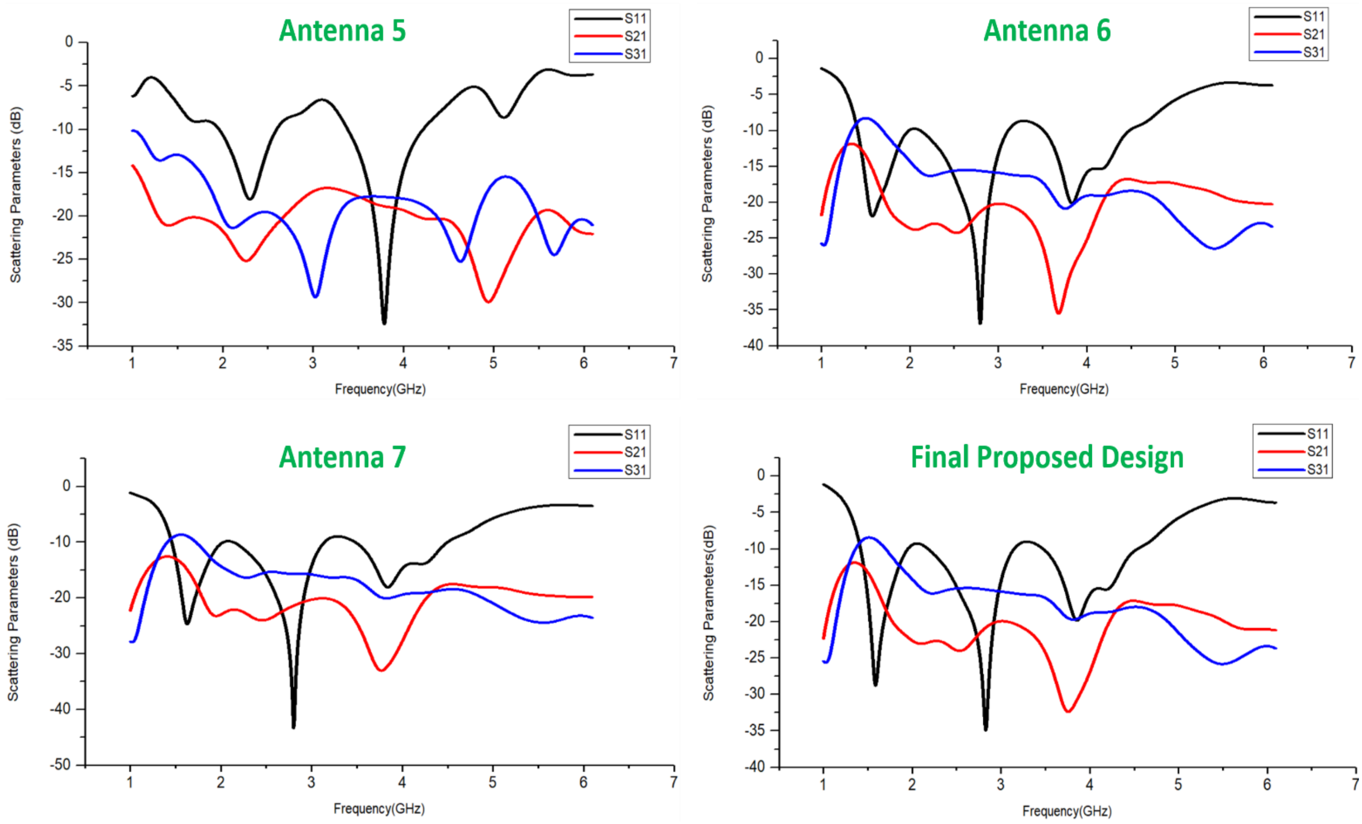


Fig. 2.14: S-Parameters for modified design

2.4. Radiation Pattern – Directional dependence of Power

The antenna far-field measurements are done at each port by exciting that port while connecting the other three ports terminated with 50Ω matched load. At port 1 and 2 the antenna shows a gain of 5.22 dBi and at port 3 and 4 it shows 4.78 dBi gain.

In Fig. 2.15 radiation pattern at each port has been depicted. Each antenna shows omnidirectional radiation pattern as they all are monopoles.

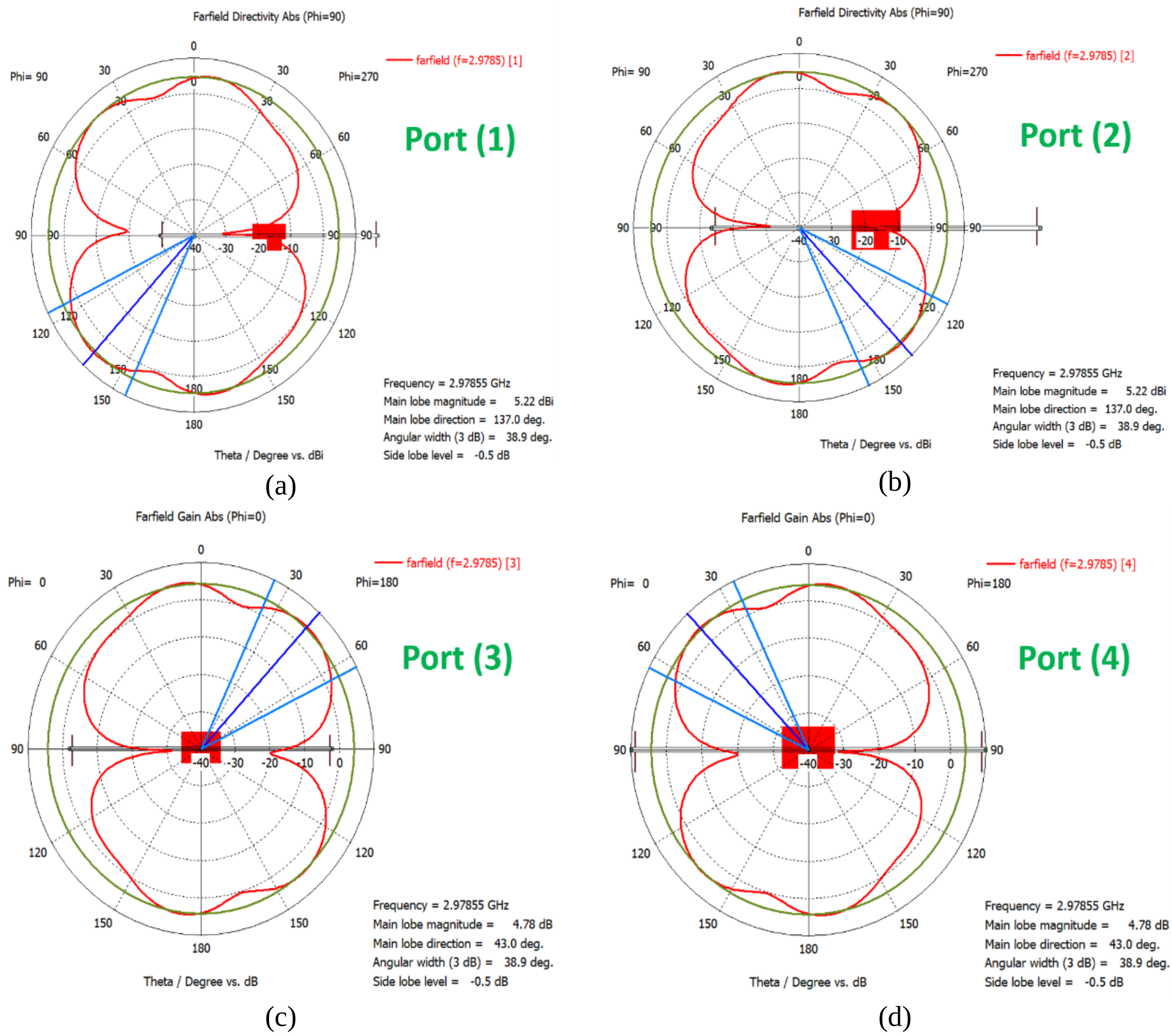
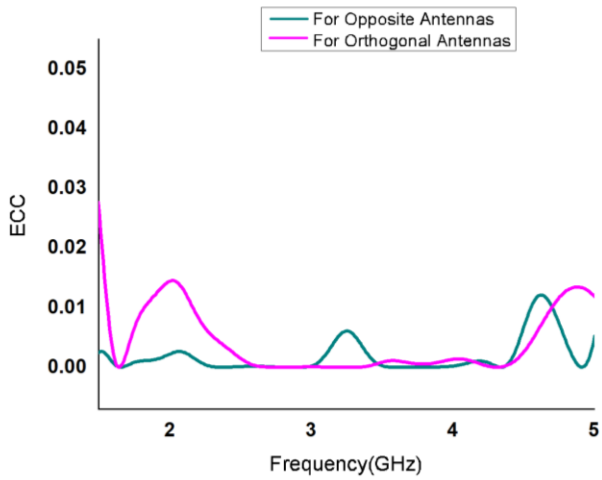


Fig. 2.15: Diagrams at (a), (b), (c), (d) represents radiation pattern at ports 1, 2, 3, 4 respectively

2.5. Diversity parameters analysis

2.5.1. Envelope Correlation Coefficient

The Envelope Correlation Coefficient (ECC) is a parameter that describes the level of correlation among multiple antennas which come into close proximity of each other. For the proposed MIMO configuration of four port four port MIMO antenna, the ECC value is below 0.015 for the entire operating bandwidth, as shown in Fig. 2.16. It satisfies the standard criteria of a value of ECC<0.5, and depicts that isolation among the elements in MIMO antenna is quite high.



2.16. Envelope Correlation Coefficient

2.5.2. Diversity Gain

Another performance metric of MIMO is Diversity Gain (DG)—meeting or coming close to the standard value of 10 dB shows that reduction in the transmitted power will have no major effect on the quality of transmission or MIMO performance. As shown in Fig. 2.17, the DG value is very close to 10 dB for the entire operating bandwidth, which satisfies the standard criteria. All the results discussed above show that MIMO antenna is very suitable for future 5G Sub-6 GHz communication.

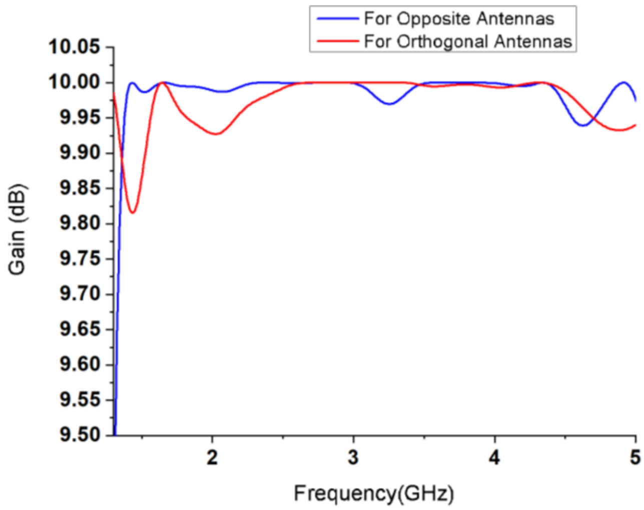


Fig. 2.17: Diversity Gain

2.6 Fabrication of the proposed design

2.6.1. Steps for fabrication

1] Conversion of .cst file into .dxf file in cst studio software.

2] Import the .dxf file into Adobe illustrator. Separating individual parts of design in adobe illustrator by ungrouping elements and coloring them.

3] Printed out the .ai file on a photo paper.

4] Cut the substrate with exact dimension of design.

5] Aligned our design on both side of the copper layer of the PCB board.

6] Apply heat to paper pasted substrate and let it cool.

7] Remove the photo paper and we can find that all the printed colors has been transferred on copper layer of the substrate.

8] Use marker pen or nail-polish to fill up portions where ink was not transferred properly.

9] Mix $FeCl_3$ with hot water and dip the printed prototype into the solution to carry out etching. 10] Use alcoholic solution to remove all printed ink and nail-polish from copper layer.

11] Solder the SMA connector with feedline.

12] And finally we fabricate the antenna, as shown in Fig. 2.18.

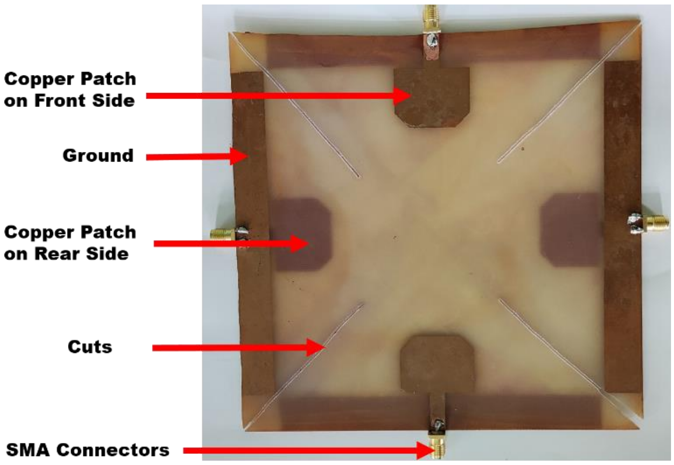


Fig. 2.18: Image of Fabricated Prototype

2.6.2. Measured Results

In the Fig. 2.19, the curves for measured S – parameters plots for the fabricated MIMO antenna are plotted against frequency with the curves for simulated S – parameters coinciding in the plane for better comparisons. As we can conclude from the graphs, we have proper isolation and reflection in the operational frequency and hence, the fabricated antenna is ready for commercial use.

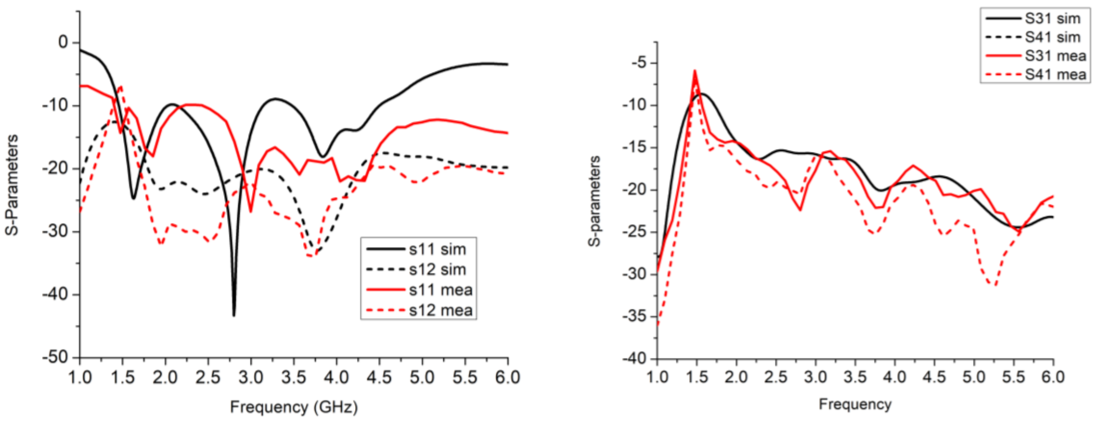


Fig. 2.19: Measured S-parameters of the fabricated MIMO antenna

2.7. Conclusion

In this project, a Multi Input Multi Output (MIMO) technology based antenna is designed and fabricated with diagonal line cuts, consisting of four patch antennas placed in such a fashion where two pairs of oppositely placed (along an axis) antenna are orthogonal to each other on two opposite side of the dielectric substrate edged off to make the prototype with operating band at **1.47 – 4.51 GHz** dedicated for Sub-6 GHz 5G communication applications. It provides a bandwidth of 3.04 GHz and percentage bandwidth is 102.2%. Antennas with a %bandwidth of >50% are referred to as ultra wideband antenna.

The four-port configuration is adopted here such that the isolation achieved between them is less than −15 dB throughout the operating band. The Envelope correlation coefficient between likely polarized antennas is 0.015 which is way less than the threshold value 0.51 and diversity gain is very close to 10dB.

Hence, this antenna provides a satisfactory result and becomes a potential candidate for 5G telemetry, communication systems and devices.

2.8. References

[1] S. Saxena et al. “MIMO antenna with built-in circular shaped isolator for sub-6 GHz 5G applications”, Electronic Letters, Volume 54, Issue 8, pp. 478-480, April 2018.

[2] M. Ameen, O. Ahmad, R. Kumar Chaudhary, “Single Split-Ring Resonator Loaded Self-Decoupled Dual-Polarized MIMO Antenna for Mid-band 5G and C-band Applications”, International Journal of Electronics and Communications (2020), doi: https://doi.org/10.1016/j.aeue.2020.153336

[3] Sreenath Reddy Thummaluru et al. “Isolation and frequency reconfigurable compact MIMO antenna for wireless local area network applications”, IET Microwaves, Antennas & Propagation, Volume 13, Issue 4, p. 519 – 525, March 2019, DOI: 10.1049/iet-map.2018.5895www.ietdl.org

[4] X. Tang et al., "Ultra-Wideband Patch Antenna for Sub-6 GHz 5G Communications," 2019 International Workshop on Electromagnetics: Applications and Student Innovation Competition (iWEM), 2019, pp. 1-3, doi:10.1109/iWEM.2019.8887933.

[5] Antenna Theory: Analysis and Design by Constantine A. Balanis