B.TECH PROJECT FOUNDATION REPORT ON

MIMO ANTENNA IN 5G COMMUNICATION

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR 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) have carried out their B. Tech project foundation report, entitled "**MIMO antenna in 5G Communication**" that is fulfilled, under my supervision. They have worked during the academic year 2021 to 2022.

Kaushik Mandal 28/01/2022

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ACKNOWLEDGEMENT

It is my pleasure to take the opportunity of expressing my gratitude of all those people who have their support, collaboration and encouragement to carry my project work in the Institute of Radiophysics and Electronics, University College of Science and Technology, University of Calcutta.

Firstly I express my sense of reverence of gratitude to my project guide **Dr. Kaushik Mandal**, Asst. Professor of Radiophysics and Electronics department , University of Calcutta, for his inspiring guidance, constructive criticism and valuable suggestion, congenial discussion and constant encouragement throughout the project work. I would also thank to **Mrityunjoy Kumar Roy**, Ph.D. scholar at **Institute of Radiophysics and Electronics** for providing constant help throughout the project work.

Nabanita Saha

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7th Semester, B.Tech

Institute of Radiophysics and Electronics

Project Work (2022)

Contents

CHAPTER-I

Contents

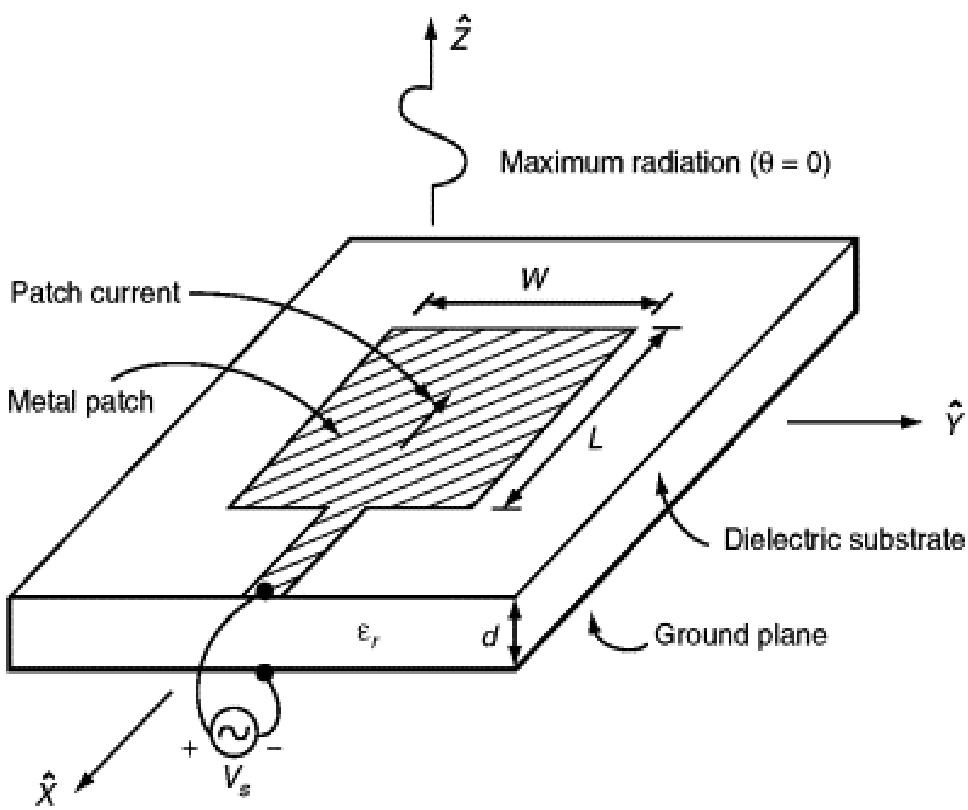
CHAPTER-II

CHAPTER-I

A. About Microstrip Patch Antenna

A.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 microstrip antenna consists of a dielectric substrate of certain thickness *d*, having a complete metalization on one of its surfaces and of a metal "patch" on the other side. The substrate is usually thin ($d \ll \lambda$). The microstrip 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 microstrip 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 microstrip 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.



A.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.

A.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.

A.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

A.4. Common antenna parameters:

- S-parameter: Describe the input-output relationship between ports or terminals in an electrical system.
- VSWR: Numerically describes how well the antenna is impedance matched to the radio or transmission line it is connected to.
- 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.
- Polarization: It is defined as the direction of the electromagnetic fields produced by the antenna as energy radiates away from it.
- Gain: Key performance number which combines the antenna's directivity and electrical efficiency.

A.5. Antenna Design and Placement Constraints

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

B. About 5G Communication

B.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.

B.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

B.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

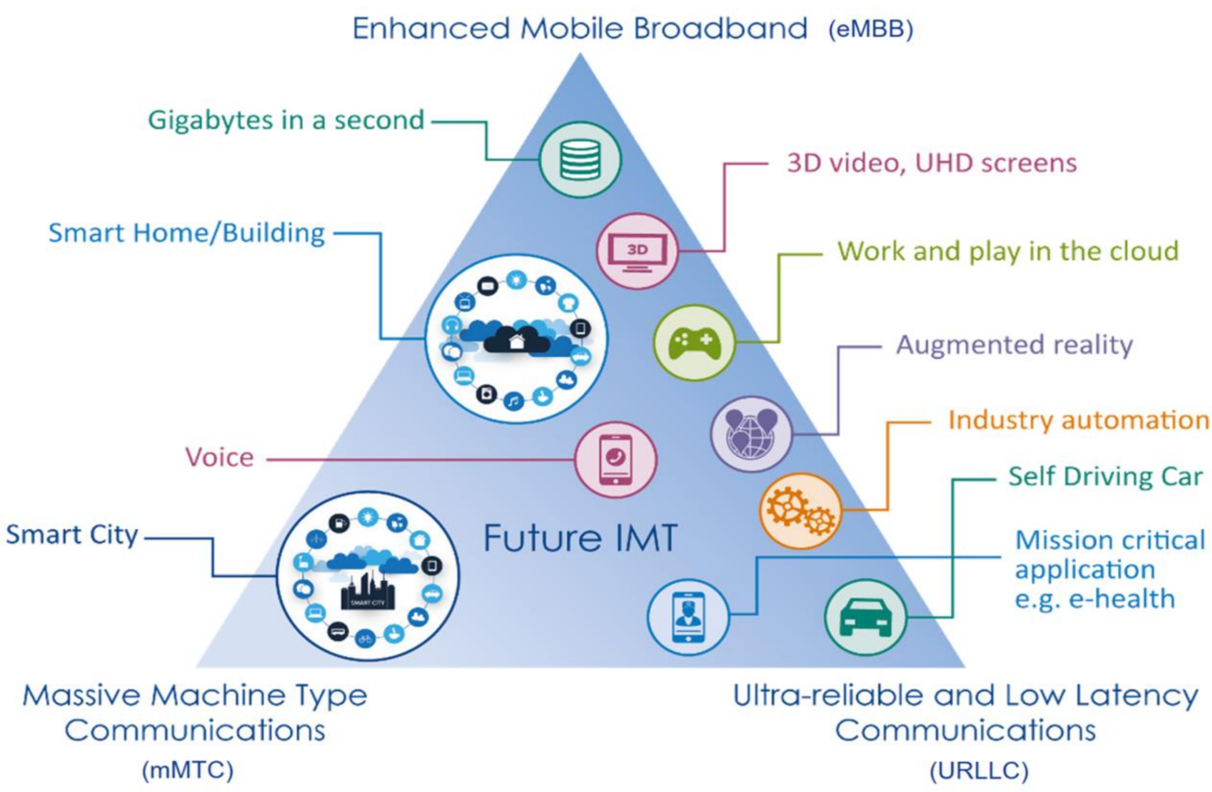
Sub 6GHz Band : Mid Band (1GHz to 6GHz)

B.4. 5G usage scenario

➢ <u>eMBB:</u> 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.

➢ <u>mMTC:</u> 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.

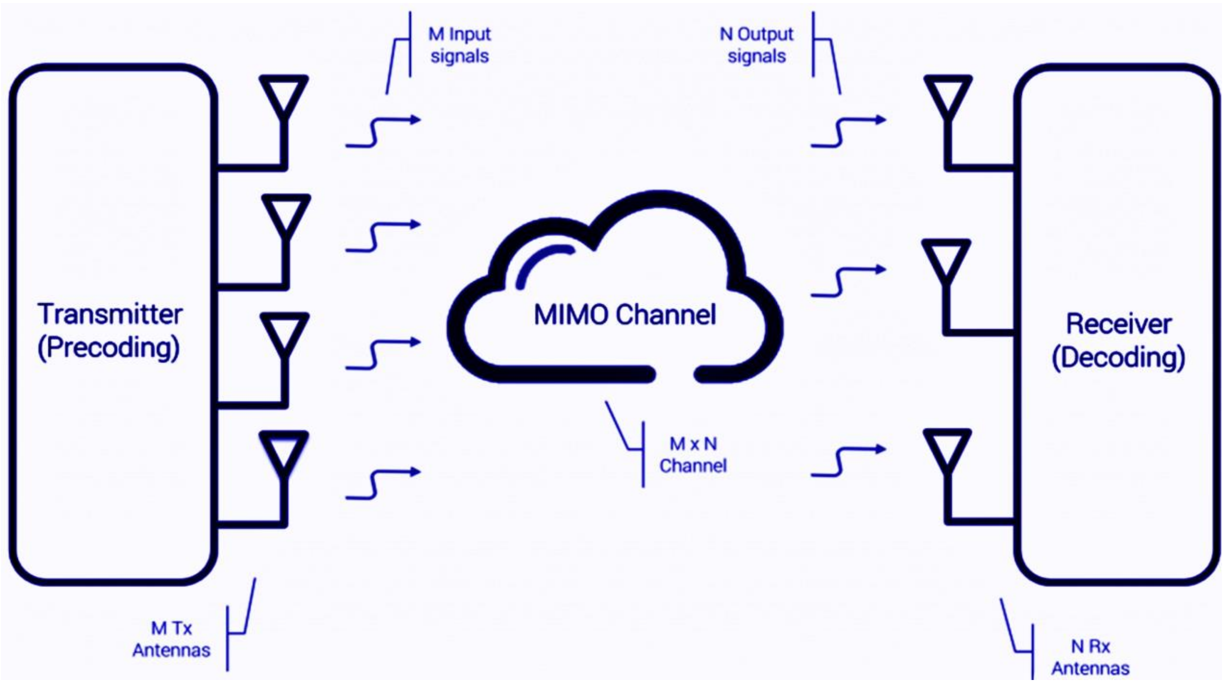
➢ <u>URLLC:</u> Technologies that require more bandwidth with ultra-reliable low latency (full URLLC) will require the 5G Core deployment for full end-2-end latency reduction. Mission critical applications that are especially latency-sensitive will also require wide coverage.



C. About MIMO Technology

C.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.



C.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.

C.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.

★ Total active reflection coefficient (TARC): 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:

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

★ 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.

D. Design Procedure of Rectangular Microstrip Patch Antenna (RMSA)

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

Specify: ǫr , 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 microstrip 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.

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

A. Sub 6 GHz Band for 5G Communication

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

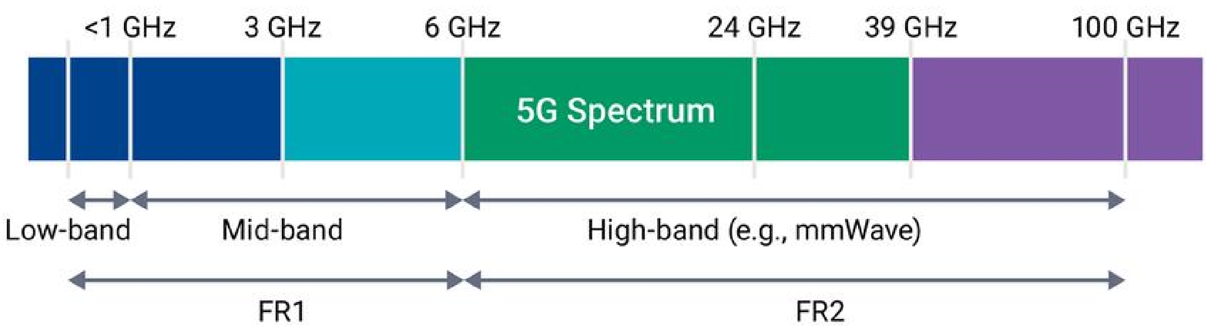
In 5G technology, two kinds of frequency bands are classified. First are Sub-6 GHz bands where the frequency transmitted from cell phone towers are less than 6GHz frequency. This is very similar to 4G, where the frequencies transmitted from cell phone towers are below 6GHz.

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 **Midband**.

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

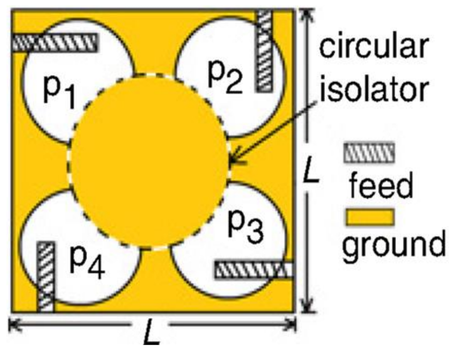


- **We are interested in designing a MIMO antenna that works in sub 6GHz band or Midband (1-6 GHz).**

B. Literature Review

B.1 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.2. 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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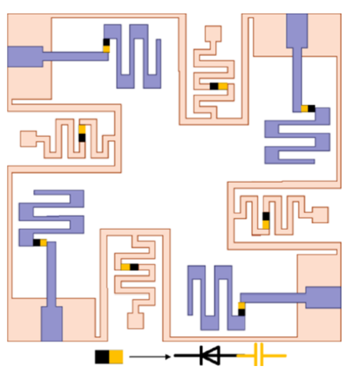
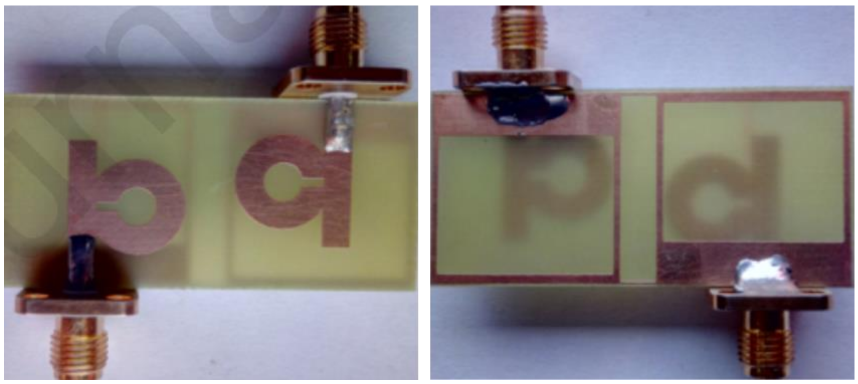


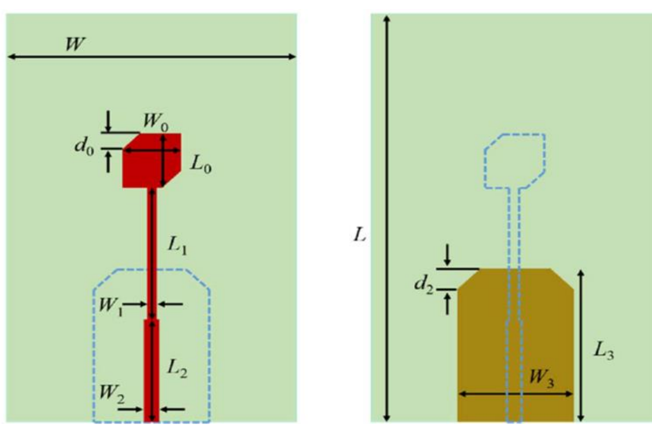
B.3. Single Split-Ring Resonator Loaded Self-Decoupled Dual-Polarized MIMO Antenna for Mid-band 5G and C-band Applications [3]

- 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.



B.4. 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



C. 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

D. Software Used to Design Microstrip Patch Antenna

D.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.

D.2. Advantages

CST Studio Suite is used in leading technology and engineering companies around the world. It offers considerable product to market advantages, facilitating shorter development cycles and reduced costs. Simulation enables the use of virtual prototyping. Device performance can be optimized, potential compliance issues identified and mitigated early in the design process, the number of physical prototypes required can be reduced, and the risk of test failures and recalls minimized.

E. Our Work

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

Length = 21.484023919693 mm,

Width = 27.922505310634 mm,

Height = 0.035 mm

Feed line dimensions are:

Length = 14.5 mm,

Width = 5.5845010621268 mm,

Height = 0.035 mm

Materials Details:

Dielectric Material – FR4

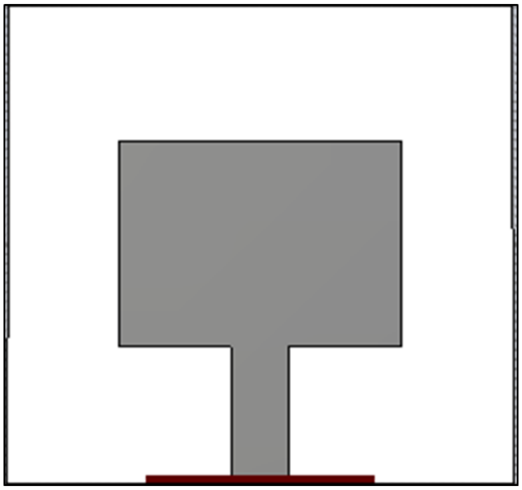
Patch and Ground – Copper

*** (Design Parameters and Materials Details are same for all 6 designs)**

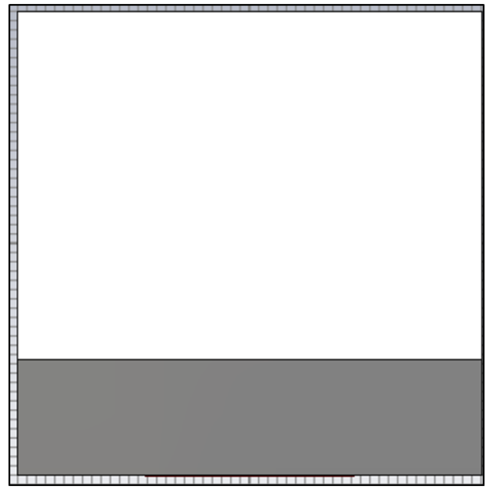
We have put the antennas in six arrangements:

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

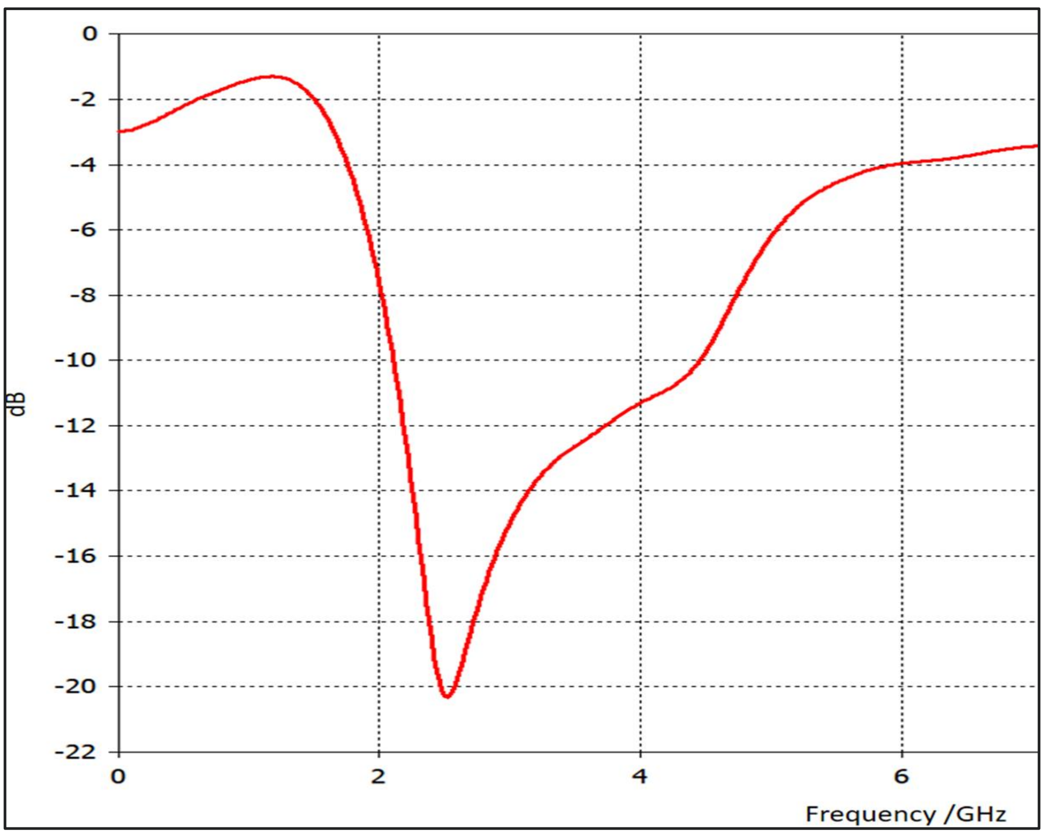
E.1. Single Monopole



Front View



Back View

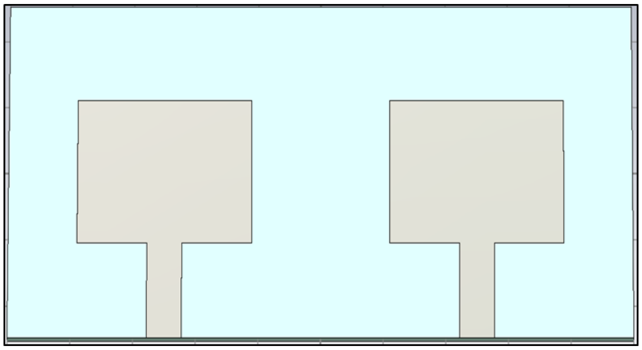


S Parameters (S_{11})

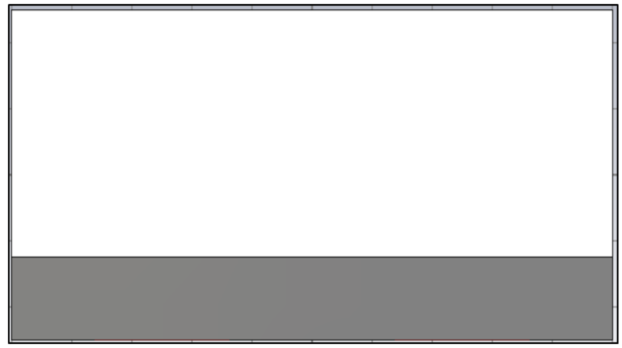
Operating band : 2.1087 – 4.4534 GHz

Band Width : 2.3447 GHz

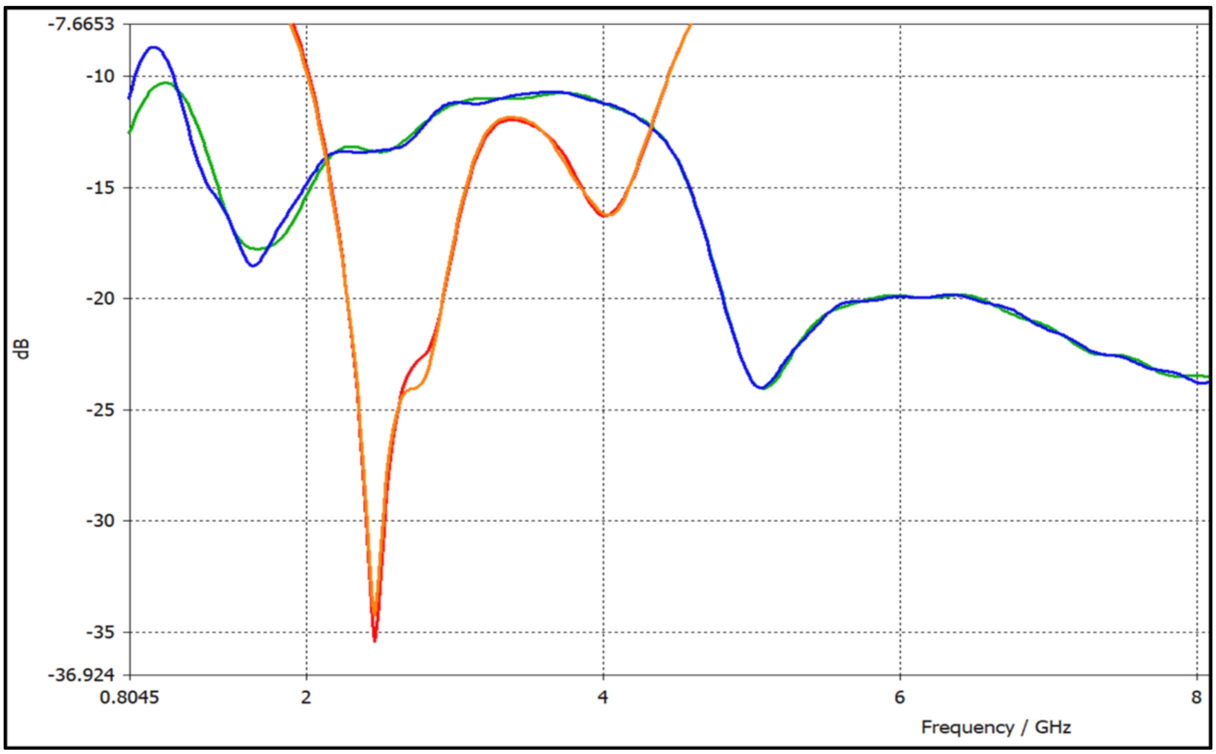
E.2. Two Monopoles Side by Side



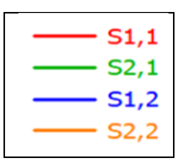
Front View



Back View



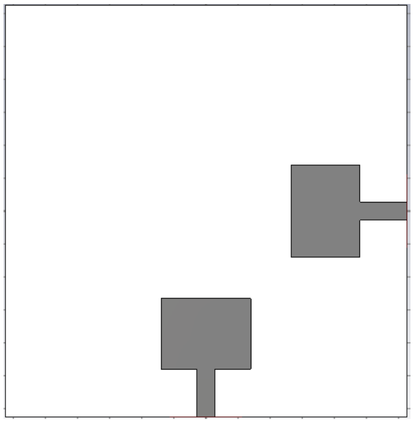
S Parameters



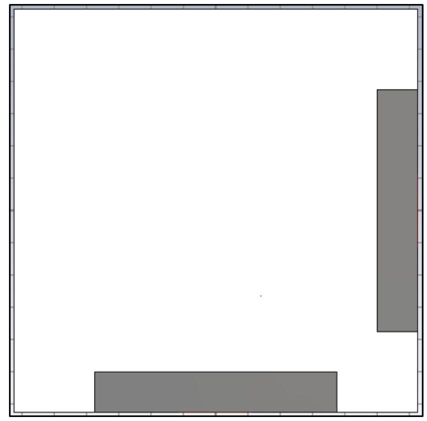
Colour Indicator for all S Parameter Graphs

Operating Band: 2.0063 – 4.4407 GHz
Band Width: 2.4344 GHz
Maximum S21: -11 dB

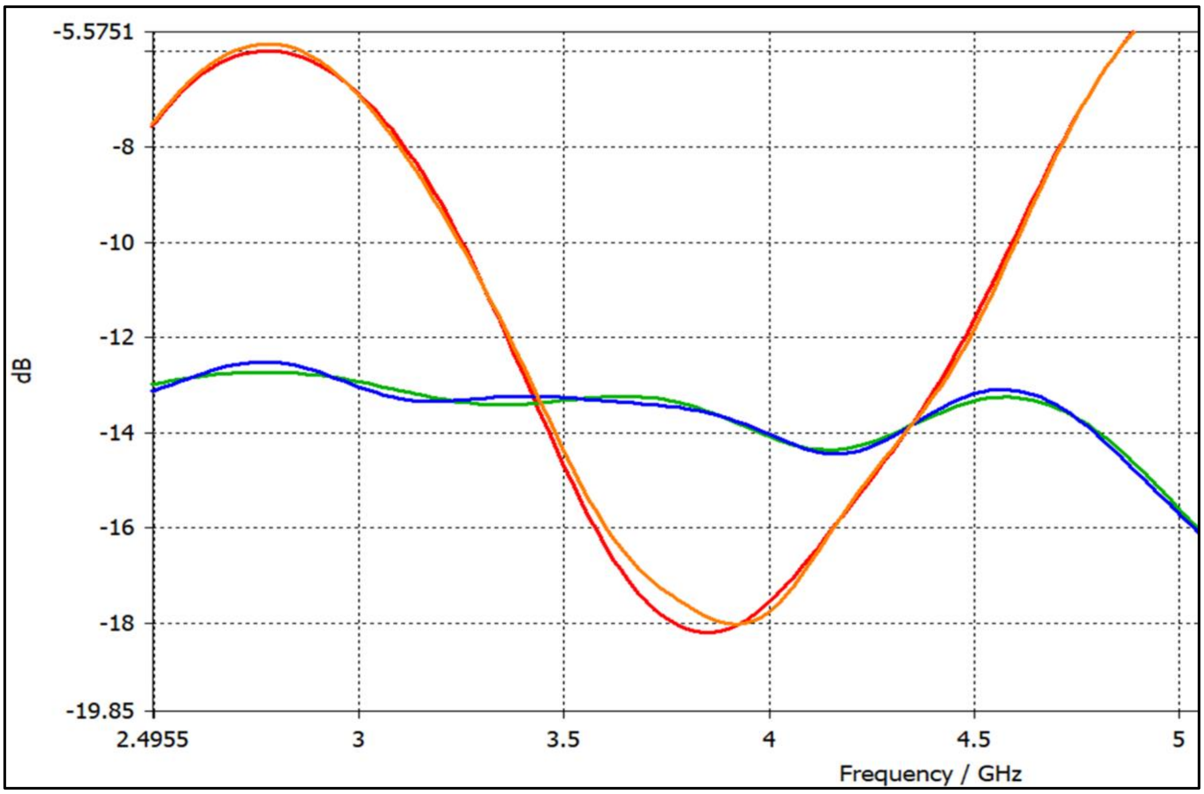
E.3. Orthogonal placement of Two Monopoles



Front View



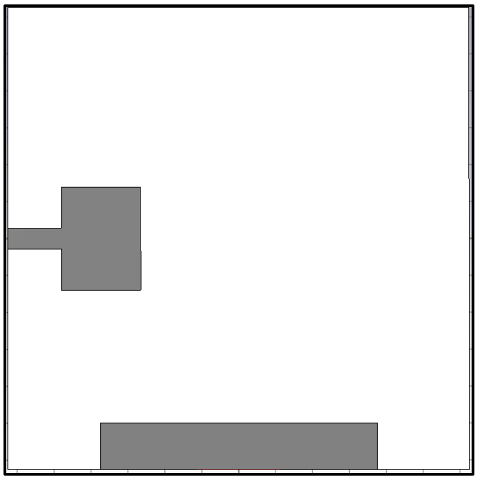
Back View



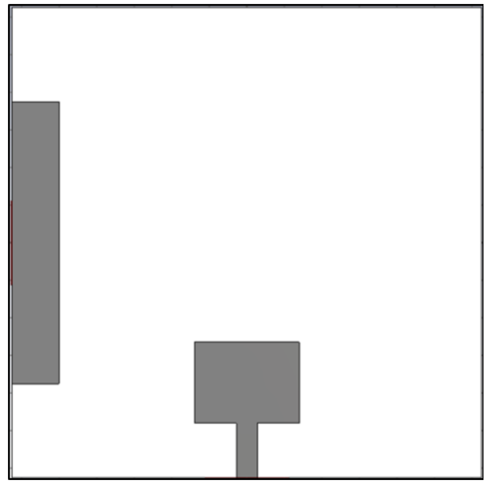
S Parameters

Operating Band: 3.2505 – 4.6002 GHz
Band Width: 1.3497 GHz
Maximum S21: -13 dB

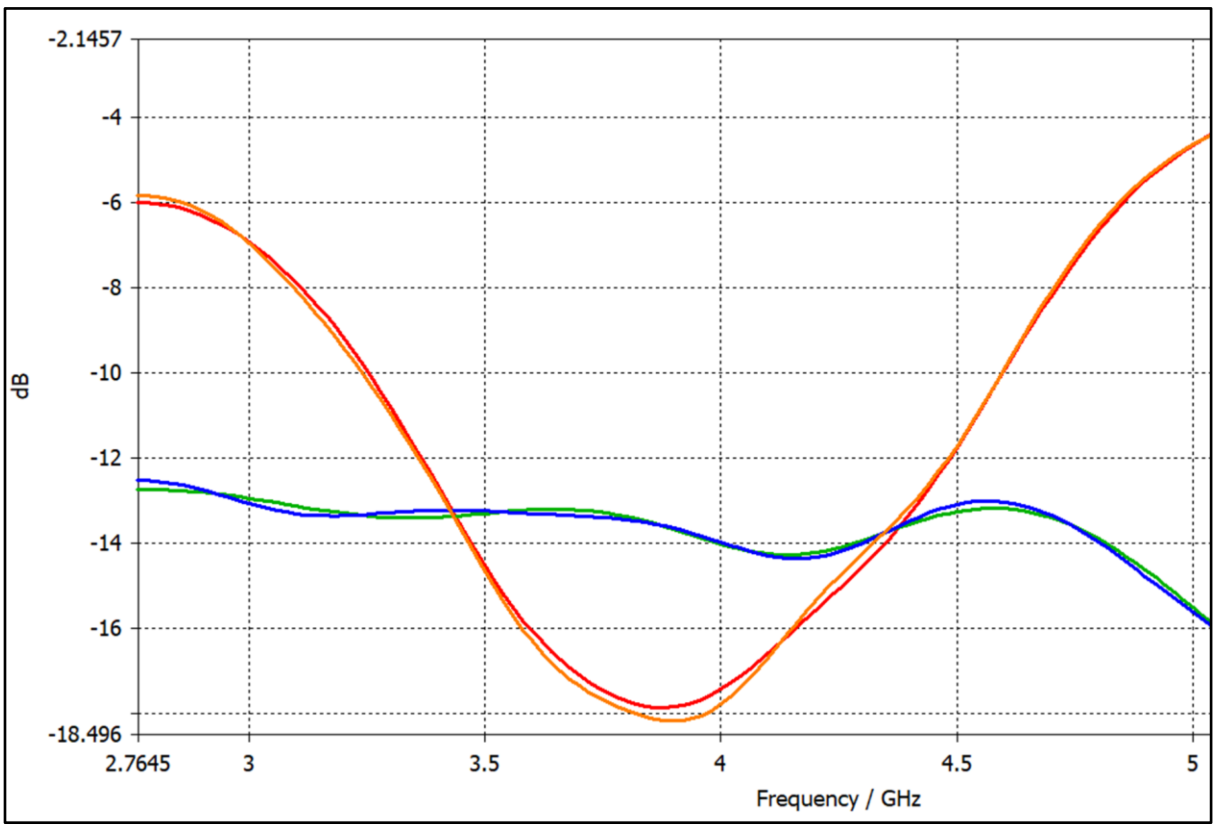
E.4. Two Monopoles orthogonally opposite side of the Substrate



Front View



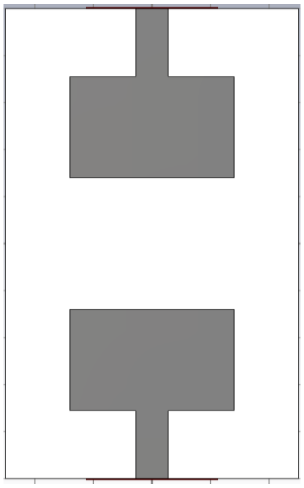
Back View



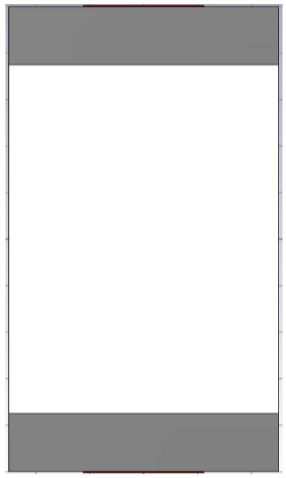
S Parameters

Operating Band: 3.2396 – 4.5971 GHz
Band Width: 1.3575 GHz
Maximum S21: -13.5 dB

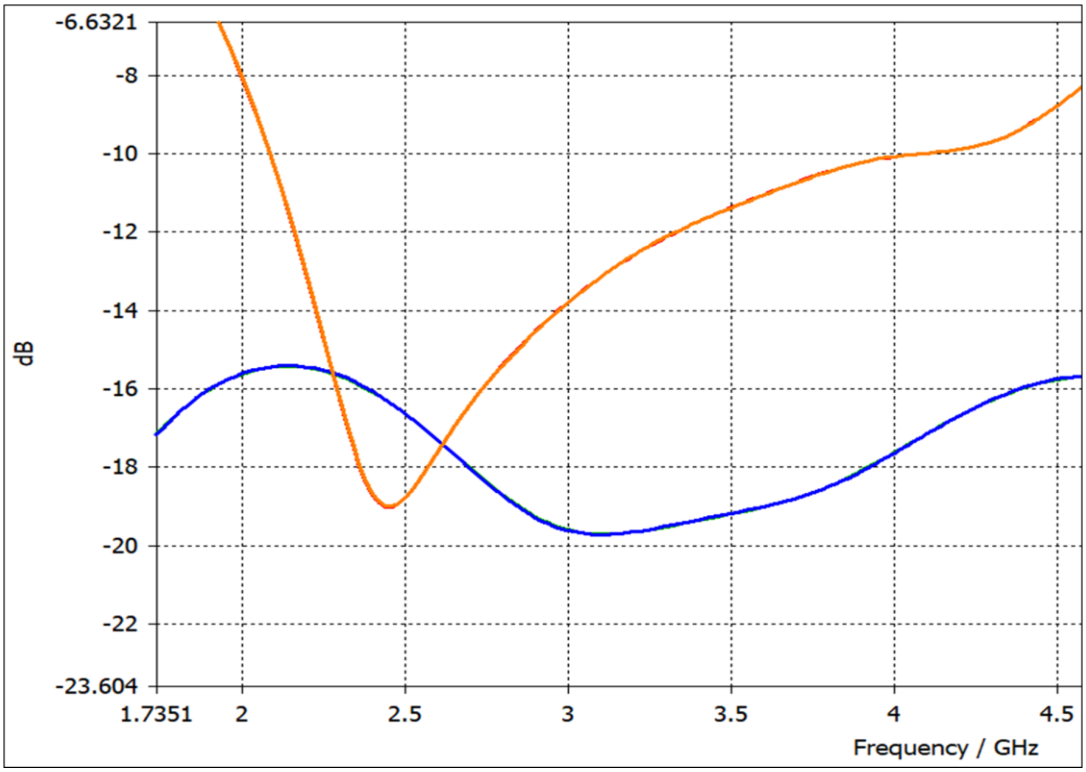
E.5. Two Monopoles opposite along X axis



Front View



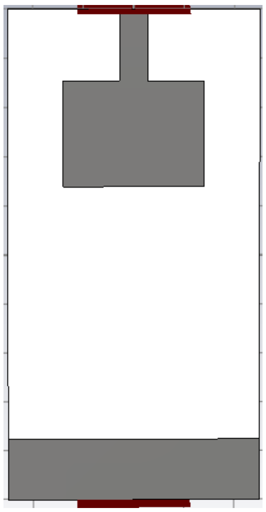
Back View



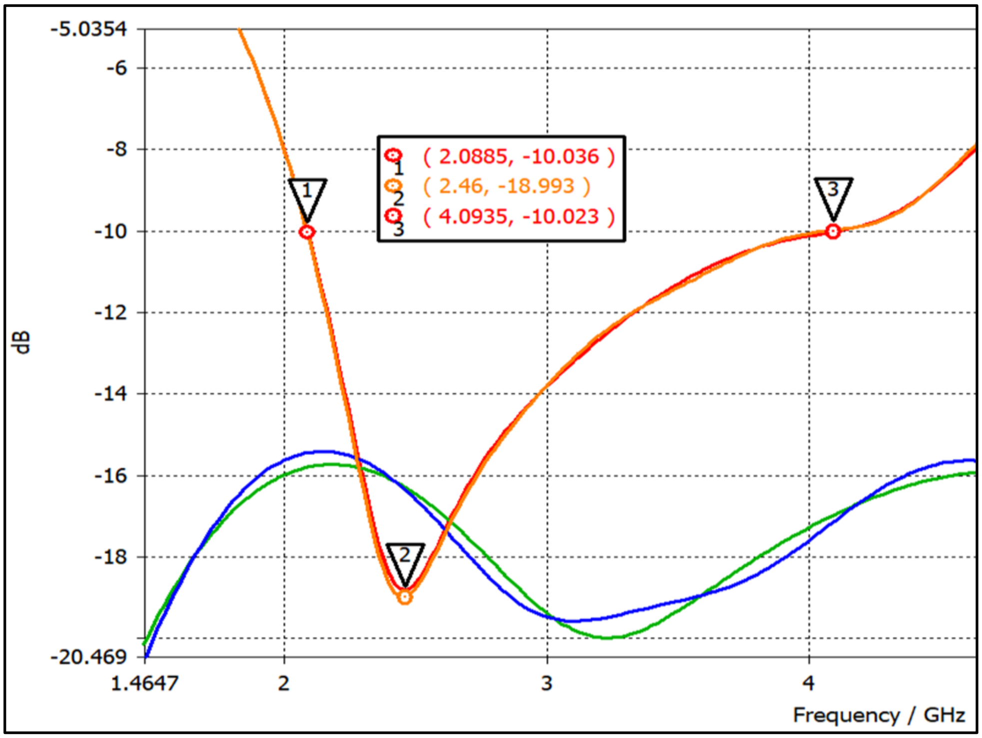
S Parameters

Operating Band: 2.0838 – 4.1218 GHz
Band Width: 2.038 GHz
Maximum S21: -16 dB

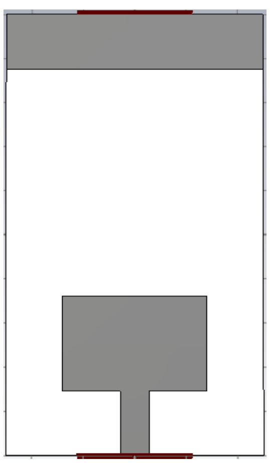
E.6. Two Monopoles opposite along Z axis



Front View

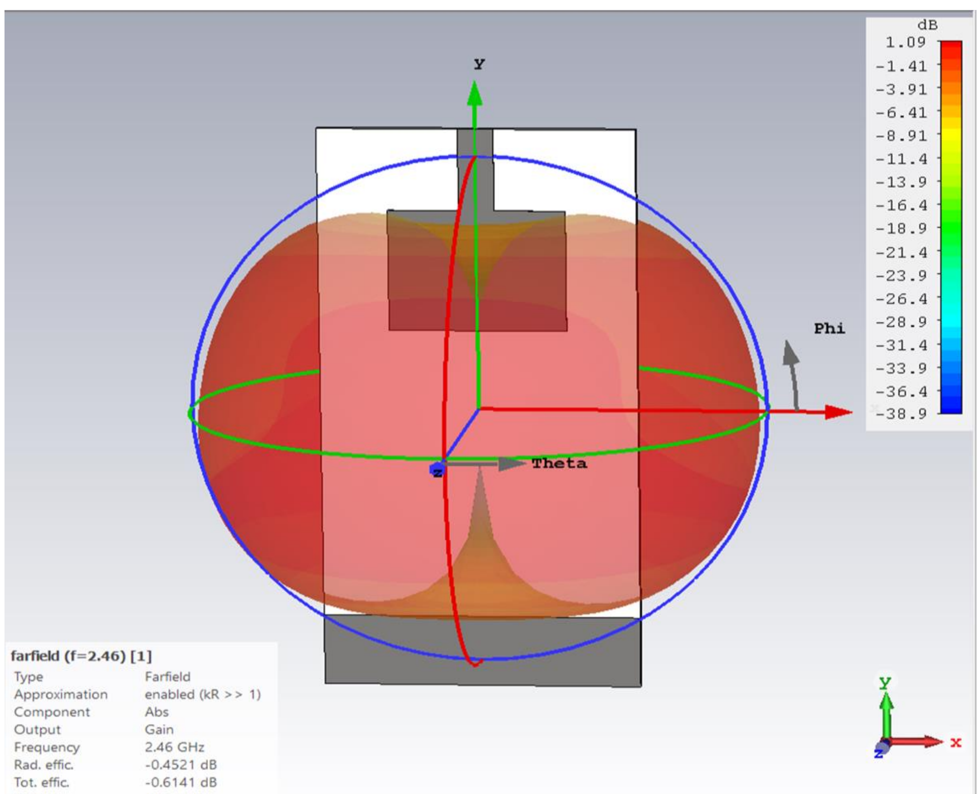


S Parameters



Back View

Band Width: 2.0144 GHz
Maximum S21: -16 dB



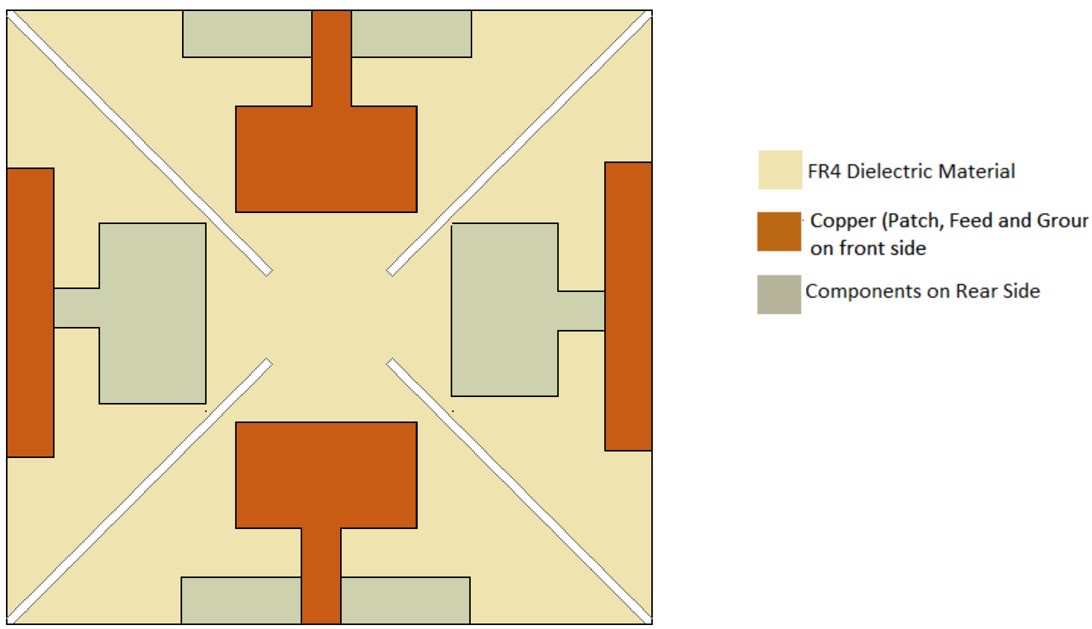
Radiation Pattern

F. Conclusion

- ★ We observe from the S_{11} and S_{22} parameters that the monopoles work independently very well when placed alone or at 180° angle with each-other.
- ★ From S_{12} and S_{21} parameters, we get that isolation between the antennas is best when they are placed at opposite sides of the dielectric substrate and make 180° angles between them.
- ★ We get the operating band at 2.0885 - 4.0935 GHz for best performance.
- ★ Far field gain is around 1.09 dB.

G. Future Work

- ❖ Design modification for better isolation and better performance.
- ❖ Measurement of the antenna parameters for validation of the simulation results.
- ❖ Fabrication of the final design.



Structure that we are thinking as the final design

There are 4 monopole patch antennas placed symmetrically with its corresponding ground plane on the opposite side of the substrate.
Two antennas placed opposite to each-other (180 degree), on each side of the substrate. Basically if we assume a square x-y plane then two pairs of antennas along a straight axis are perpendicular to each other on two opposite sides of the substrate.
For even better isolation we cut the substrate between each antenna.

H. References

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