DESIGN OF 6G EDGE FED 2X2 ARRAY ANTENNA USING FR4 SUBSTRATE

A PROJECT REPORT

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BONAFIDE CERTIFICATE

Certified that this project report **"Design of 6G Edge Fed 2x2 Array Antenna Using FR4 Substrate"** is the bonafide work of **AJITH SELVAKUMAR. K (921320106010), AKILAN. S (921320106012), EASWARAMOORTHY. S (921320106039), HASMATH ALI. A (921320106050),** who carried out the project work under my supervision.

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ABSTRACT

This project delves into the design and simulation of a dual-band 2x2 dual-array antenna targeting 6G communication systems. The antenna leverages a cost-effective FR4 substrate for practical implementation. CST software serves as the design and performance evaluation platform. The design focuses on achieving two distinct resonant frequencies within the 6G spectrum to accommodate the varied demands of future wireless technologies. Key parameters like S parameter, VSWR, Phase, Efficiency are meticulously analysed using comprehensive CST simulations. The results are presented in detail, including relevant plots and discussions on potential trade-offs and considerations for real-world fabrication. This work serves as a valuable resource for researchers and engineers interested in designing high-performance dual-band antenna arrays for 6G applications using FR4 substrates and CST software.

Keywords: Dual-Band Antenna, 2x2 Array, FR4 Substrate, CST Simulation, S parameter, VSWR, Phase, Efficiency.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

HPBW	Half Power Beam Width
BWFN	Beam Width First Null
PCS	Personal Communication System
FCC	Federal Communication Commission
UWB	Ultra-Wide band
VSWR	Voltage Standing Wave Ratio
CST	Computer Simulation Technology
PCB	Printed Circuit Board

LIST OF SYMBOLS

P (θ)	Normalized Power pattern
Po	Output Power
$\mathbf{F_r}$	Resonant Frequency
$\mathbf{C_r}$	Dielectric Constant
H	Height of the Dielectric Constant
$\boldsymbol{\varepsilon}_{\mathbf{r}}$	Relative permittivity of a material
C	Velocity of Light
$\boldsymbol{\varepsilon}_{\mathbf{reff}}$	Effective dielectric Constant
$\mathbf{L_{eff}}$	Effective Length
$\mathbf{A_L}$	Actual Length
L	Actual Length of Patch
R	Radial Distance
$\boldsymbol{\varphi}$	Elevation angle
$\boldsymbol{\theta}$	Azimuth angle

CHAPTER 1

BASICS OF ANTENNA

1.1 INTRODUCTION

Antennas are vital components in communication systems, enabling the transmission and reception of electromagnetic signals. They come in various shapes and sizes, tailored to specific applications such as wireless communication, radar, and broadcasting. Antennas convert electrical signals into electromagnetic waves for transmission or capture incoming waves to produce electrical signals. Understanding antennas' principles and design considerations is essential for developing efficient communication systems.

1.1.1 DEFINITION OF ANTENNA

There are several definitions of antenna, mud are as follows, an antenna is any device that converts electronic signals to electromagnetic waves (and vice versa) effectively with minimum loss of signals as shown in Figure 1.1.

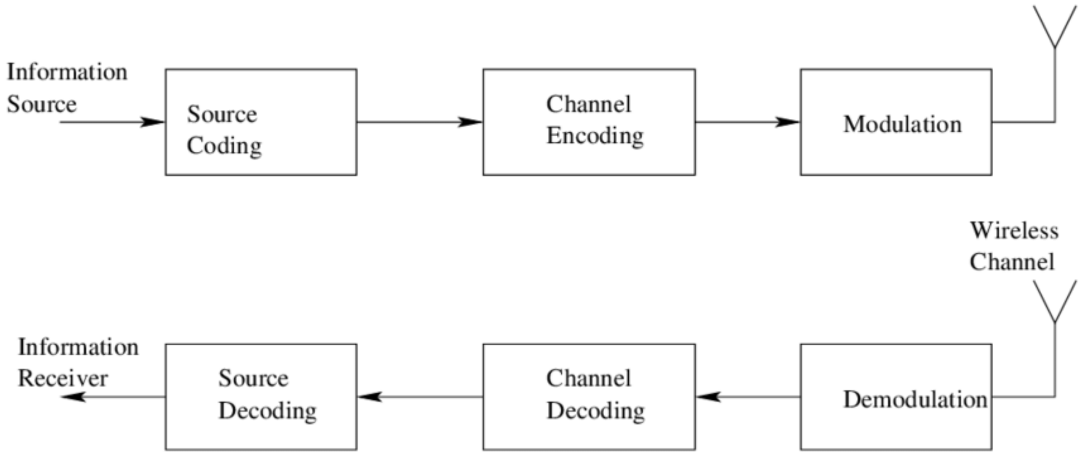


Figure (1.1) Wireless Communication System

An antenna is considered as a region of transition between a transmission line and space. Antenna radiate or couple electromagnetic energy in the desired direction. An antenna may be isotropic or anisotropic.

There is no hard and fast rule for selecting an antenna for a particular frequency range or application. In some application, the same antenna may be used for transmission and reception, while in others transmission and reception of signals require separate antennas.

1.2 ANTENNA PARAMETERS

1.2.1 RADIATION PATTERN

Radiation pattern is a graph that shows the variation of actual field strength of electromagnetic field at all points, which are at equal distances from the antenna**.**

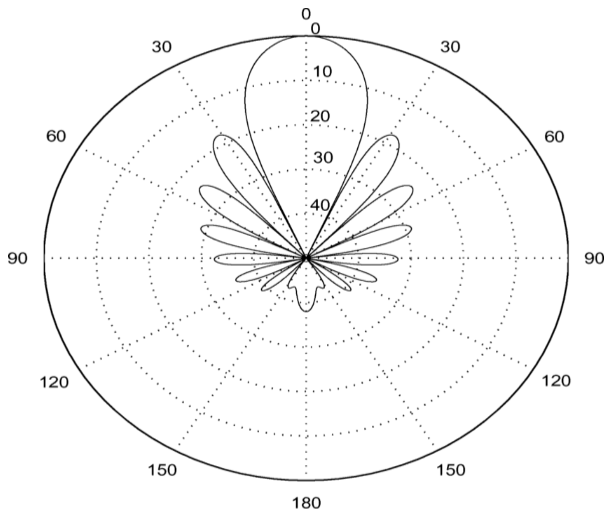


Figure (1.2) Radiation Pattern

Hence the graph is three-dimensional and hence cannot be completely represented on a plain paper. However, to represent the radiation pattern on a plain paper (in two dimensions) a cross section through the three-dimensional pattern is taken. Thus, the two-dimensional pattern obtained by cutting with the horizontal and vertical planes are called 'Horizontal pattern' and 'Vertical pattern' respectively.

1.2.2 FIELD PATTERN

If radiation from the antenna is represented in terms of Field strength, the radiation pattern is called as Field pattern.

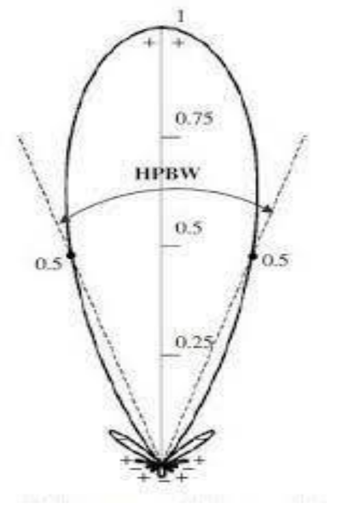


Figure (1.3) Field Pattern

1.2.3 POWER PATTERN

If the radiation in a direction is given in terms of power per unit solid angle, then the resulting pattern is a Power pattern.

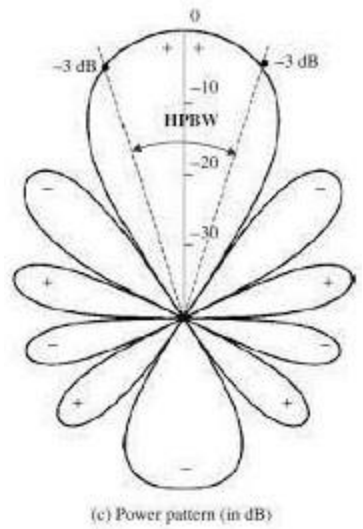


Figure (1.4) Power Pattern

1.2.4 DIRECTIVITY

The directivity of an antenna may be defined as the ratio of maximum radiation intensity of the subject antenna to the radiation intensity of the isotropic antenna. When efficiency is cent percent the gain and directivity are inter changeably used.

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} |F(\theta,\phi)|^2 \sin\theta d\theta d\phi} \qquad \textbf{(1.1)}$$

1.2.5 GAIN

The gain of an antenna is a basic property, which is frequently used as figure of merit. Gain is defined as the ratio of maximum radiation intensity in a given direction to the maximum radiation intensity from a reference antenna produced in the same direction with the same power input**.**

$$G(\theta)=\frac{p(\theta)}{P_o\ /4\Pi} \qquad (1.2)$$

Where,

$P(\theta)$ = Normalized Power pattern

P_o = Output Power

1.2.5 ANTENNA BEAM WIDTH

The Antenna Beam width is the measure of the directivity of an antenna.

Antenna Beam width is divided in to two types namely,

- ❖ Half Power Beam width (HPBW)
- ❖ Beam width First Null (BWFN)

1.2.6.1 HPBW

The angular width in degrees measured on the radiation pattern between points where the radiated power has fallen to half of its maximum value is called HPBW. HPBW is also called 3-db Beam width, because at half power points the power is 3db down form the maximum power value**.**

1.2.6.2 BWFN

The angular width in degrees measured on the radiation pattern between first nulls or first side lobes is called BWFN. BWFN is also called 10-db Beam width, because at beam width first null point is 10db down form the maximum power value.

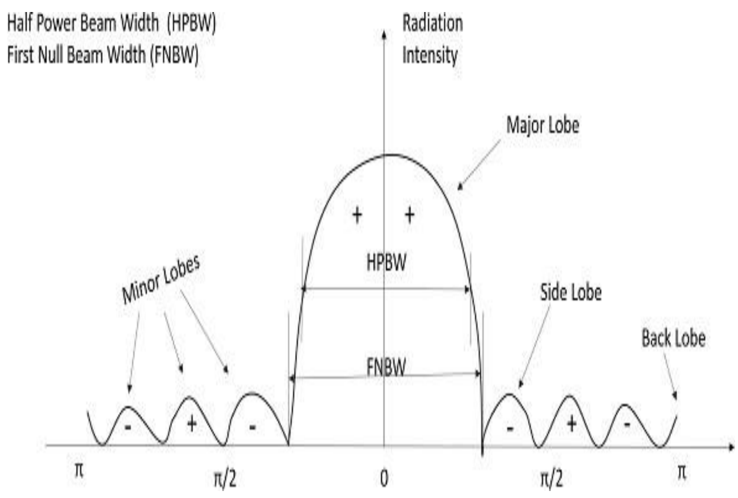


Figure (1.5) Antenna Beam Width

CHAPTER 2

LITERATURE SURVEY

(1) **"Design and Analysis of a Rectangular Microstrip Patch Antenna using Different Dielectric Materials for Sub-6GHz 5G Applications"** S. Bala, Z. Yunusa, S. A. Babale Nigerian Journal of Engineering, Vol. 28, No. 2, August 2021, this paper shows a comparative study of five different substrate materials for designing sub-6GHz 5G antennas. Using Computer Simulation Technology (CST) studio suit 2016, performance parameters such as VSWR, return loss, bandwidth, directivity, gain, and efficiency were analysed for inset feed rectangular microstrip patch antennas operating at 6GHz. Results show that RT Duroid substrate offers the highest radiation efficiency and optimal gain, while FR4 substrate provides the highest bandwidth and return loss. Bakelite substrate achieves the best compact size with a perfect VSWR match. RO4003 and TLC substrates exhibit average performance. Overall, the paper recommends RT Duroid for high gain and efficiency, FR4 for high bandwidth and return loss, and Bakelite for compact size in sub-6GHz 5G antenna design.

(2) **"Design and analysis of rectangular microstrip patch antenna at 2.4 and 5 GHz"** Hamza Abbasi, Muhammad Nihal Naseer, Yasmin Abdul Wahab, Muhammad Mobin Siddiqi, Rozana Aina Maulat Osman, Nurul Ezaila Alias, and Hanim Hussin Conference Paper in AIP Conference Proceedings · July 2021.The Paper describes a study aimed at contributing to wireless communication and networking systems by proposing a rectangular microstrip patch antenna. Initially targeting common mediums like WIFI/WLAN and Bluetooth, the focus shifted to the 2.4 and 5 GHz bandwidths. Using FR4 dielectric substrate, the antenna design and simulation in HFSS V15.0 revealed peaks at the specified frequencies, verified by 3D polar plots. Fabrication involved DipTrace circuit design for Gerber file generation, printing on glossy paper, substrate printing, copper removal, and SMA soldering. Empirical verification via VNA showed significant negative environmental impact on transmission, with return loss quantified at -

13dB and -27dB at 2.4 and 5 GHz respectively. The antenna promises swift, economical data transmission with minimal noise attenuation.

(3) **"Design of 2x2 Wide Bandwidth MIMO Antenna for LTE and 5GSub-6GHz"** Rusdiyanto, D., Astuti, D. W., Muslim, Alam, S., & Adhiyoga, Y. G.JITE(2022), The Paper introduces the design of a 2x2 MIMO microstrip antenna for LTE and 5G Sub-6GHz applications, with a wide bandwidth spanning 2300 MHz to 3600 MHz. Utilizing FR4 substrate with specific dimensions, the antenna's ground length is adjusted to achieve the desired bandwidth, while the resonant frequency is attained using a square slot method on the radiator element. Simulation results demonstrate reflection and isolation coefficients below -10 dB, with achieved bandwidth exceeding 2 GHz. Gain measurements range from 2.98 dBi to 3.87 dBi across the frequency range, meeting the objective of achieving wide bandwidth for LTE and 5G applications.

(4) **"Design of Microstrip Antenna Arrays with Rotated Elements Using Wilkinson Power Dividers for 5G Customer Premise Equipment Applications"**. Ting-Yi Huang and Yun-Jhang Lee Hindawi International Journal of Antennas and Propagation Volume 2024, Article ID 2945195, 15 pages, the paper proposes microstrip antenna arrays for Customer Premise Equipment (CPE) applications in the FR1 frequency range of 5G mobile networks. These arrays, consisting of three FR4 substrates, are optimized separately for antenna elements and feeding networks. Bandwidth-enhancing parasitic elements and Wilkinson power dividers are utilized for broadside coupling and probe feeding, achieving 10 dBi and 12 dBi gain specifications with four and eight elements respectively. Both arrays cover the 5G n78 frequency band with 10-dB return loss. The proposed antenna units and arrays exhibit low profile, high gain, and cost-effective characteristics, suitable for outdoor 5G CPE devices.

(5) **“Design & Analysis of a Micro-strip Patch Antenna for RFID, WiMAX and X-band Applications”** Ms. Dilshad Jahan, Chinmoy Das, Nayan Sarker. 1st International Conference on Advances in Science, Engineering and Robotics Technology 2019 (ICASERT 2019). The paper presents the design and simulation of a patch antenna resonating at 9.968 GHz, suitable for RFID, WiMAX, and X-band applications. With a -10 dB impedance bandwidth of 300 MHz (9.8 GHz to 10.1 GHz), the antenna aims for compact size, light weight, and cost-effectiveness. Using CST Microwave Studio, simulation results demonstrate excellent VSWR (1.208) and gain (5.960 dB), with directivity at 6.015 dBi, return loss at -20.49 dB, and radiation efficiency at 98.14%. FR4 substrate is utilized for simulation and PCB design, and experimental radiation patterns are analysed using the WATS 2002 module, with comparisons made between simulated and experimental results.

(6) **“Design and analysis of MIMO system for THz communication using terahertz patch antenna array based on photonic crystals with graphene”**. Mohamed Elamine Benlakehal, Abdesselam Hocini, Djamel Khedrouche, Mohamed Nasr eddine Temmar, and Tayeb Ahmed Denidni. The paper introduces a novel MIMO antenna system utilizing graphene-based patch antenna arrays for enhancing THz communications channel capacity. It explores the conductivity of graphene and designs MIMO antenna arrays using three approaches: homogeneous, photonic crystals, and optimized photonic crystals. CST simulations show that the optimized photonic crystals substrate significantly improves performance, achieving a peak gain of 11.80 dB and a bandwidth exceeding 614 GHz at 0.65 THz. The 2x2 MIMO system analysis demonstrates that the proposed system with optimized photonic crystals substrate achieves the highest capacity (23.64 bit/s/Hz) and lowest total loss compared to previous studies. The study also investigates various system configurations and antenna spacings.

(7) **“Design and Implementation of Microstrip patch Antenna Arrays for 2.4 GHz Applications”** Gurudev, Dr. Mohammed Bakhar, this paper focuses on designing and implementing microstrip antenna arrays for 2.4 GHz applications. It starts with a single element antenna and evaluates its performance in terms of operating frequency, return loss, gain, VSWR, and radiation patterns. Then, it progresses to a 2x1 patch antenna array and eventually to a 4x1 patch antenna array to enhance gain, bandwidth, and radiation patterns. The design procedure and results of each configuration are discussed, using FR4 substrate material for fabrication. Both simulated and measured results demonstrate comparable performance.

(8) **“A review of beamforming microstrip patch antenna array for future 5G/6G networks”** Muhammad Asfar Saeed and Augustine O. Nwajana School of Electronics, University of Greenwich, London, United Kingdom, TYPE Review PUBLISHED 21 February 2024, the review article examines 5G beamformer Microstrip Patch Antenna array techniques, crucial for achieving high data rates and bandwidth in wireless communication. It covers fundamental concepts and principles of analog, hybrid, and digital beamforming techniques, discussing their advantages, disadvantages, and suitability for 5G applications. Various beamforming techniques, including traditional, massive MIMO, hybrid, and adaptive beamforming, are analysed for their performance trade-offs and applicability in different deployment scenarios. The review also explores feeding methods such as hybrid couplers, Wilkinson power dividers, branch line couplers, and Butler matrices in beamformer smart antennas. Dielectric substrates used in beamformer design are reviewed, providing valuable insights for researchers and engineers in the field of 5G wireless communications and antenna design.

(9) **“Towards a full design of a super-wide band slotted antenna array using graphene material for future 6G applications”.** Oumaima El Hassani , Adil Saadi Control, Piloting and Supervision of Systems, Moulay Ismail University of

Meknes, National School of Arts and Crafts, 50050, Morocco, The study focuses on designing and analyzing various antenna configurations for 6G wireless communication systems, leveraging the terahertz (THz) frequency spectrum. Initially, graphene material integration is explored in single antennas, with analysis of return loss, VSWR, gain, and directivity. Parametric investigation of substrate thicknesses using different materials is conducted. To enhance directivity and gain, five antenna array architectures are utilized in both serial and parallel configurations. Additionally, a sixteen-antenna array (2*8 array) is implemented by doubling structural dimensions, meeting the requirements of 6G telecommunications for gain and directivity.

CHAPTER 3
MICROSTRIP ANTENNA

3.1 INTRODUCTION

Microstrip antennas have several advantages over conventional microwave antenna and therefore are widely used in many practical applications. All Microstrip Antennas can be divided into four categories which is given in Fig 3.1.

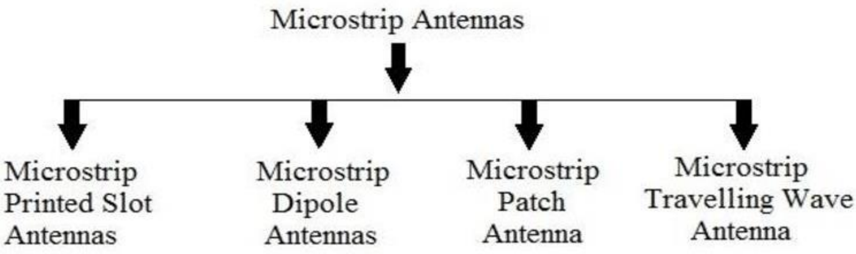


Figure (3.1) Classification of Microstrip Antennas

3.1.1. MICROSTRIP PATCH ANTENNA

Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. The patch is generally made of conducting material such as copper or gold and can take any possible shape (conventional types are square rectangle, circle and triangle). The principle of transmission line model of triangular microstrip antenna is depicted in the Fig 3.2

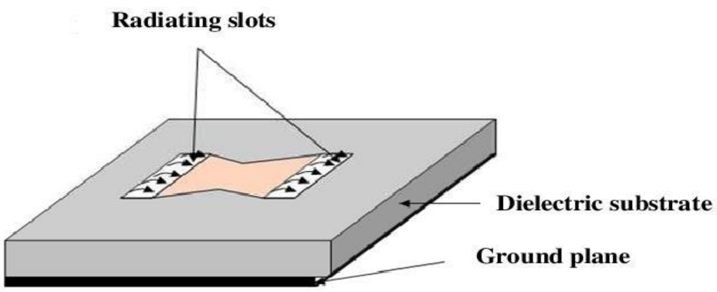


Figure (3.2) Principle of Transmission Line Model

A patch antenna is a narrowband, wide-beam antenna fabricated by photo etching the antenna element pattern in metal trace on the dielectric substrate. The recent studies of microstrip patches revealed that the triangular patch has a radiation characteristic similar to a rectangular patch, but with reduced dimensions.

The dielectric substrates usually used are

- Duroid
- Rexolite
- Alumina
- Silicon

A substrate of low dielectric constant (ε_r < 2.5) is preferred in order to reduce the fringing fields. In order to avoid the losses, the dielectric substrate having permittivity (ε_r> 9) can be used.

3.2. MICROSTRIP PATCH ANTENNA PARAMETERS

The Parameters important for the design consideration of the Microstrip patch antenna are

- Resonant frequency (f_r)
- Dielectric Constant (C_r)
- Height of the Dielectric Constant (h)

- Patch Dimensions

3.2.1. RESONANT FREQUENCY (f_r)

The personal communication system (PCS) uses the frequency range from 1850-1990MHz. After the Federal Communication Commission (FCC)'s authorization of frequency band of 3.1 to 10.6 GHz for unlicensed radio applications, ultra-wideband (UWB) technology become the most promising candidate for a wide range of applications that will provide significant benefits for public safety, business and consumers, and attracted a lot attention both industry and academia

3.2.2. DIELECTRIC CONSTANT (C_r)

A substrate of low dielectric constant (C_r< 2.5) is preferred in order to reduce the fringing fields.

3.2.3. HEIGHT OF THE DIELECTRIC CONSTANT (h)

The Microstrip antenna to be used in cellular phones, it is essential that the antenna is not bully. Hence the optimum value should be chosen as the height of the dielectric substrate.

3.2.4. CALCULATION OF THE WIDTH (W)

The width of the Patch is given by

$$W = c/(2f\_0 \sqrt{((\varepsilon\_R + 1)/2)}) \quad (3.1)$$

Where,

C= velocity of light ($3 * 10^8$ meter/sec)

3.2.5. CALCULATION OF EFFECTIVE DIELECTRIC CONSTANT (εreff)

The Effective Dielectric Constant of the substrate is defined as the fraction with which the dielectric constant of the substrate varies when the metal patch is placed or embedded in it. The Effective Dielectric Constant is given by

$$\varepsilon_e = \frac{(\varepsilon_r+1)}{2} + \left[\frac{(\varepsilon_r-1)}{2}\right] \times \left[\frac{1}{\sqrt{(1+\frac{12h}{w})}}\right] \quad \textbf{(3.2)}$$

3.2.6. CALCULATION OF THE EFFECTIVE LENGTH (L_{eff})

The Effective Length of the Patch is defined as the length over which the electric field exists. The Effective Length of the Patch is given by

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad \textbf{(3.3)}$$

3.2.7. CALCULATION OF THE LENGTH EXTENSION (ΔL)

The Extension Length of the Patch is defined as the length over which the fringing field exists. The fringing field is defined as the small electric field that radiates outside the actual length of the Patch.

3.2.8. FRINGING FIELD

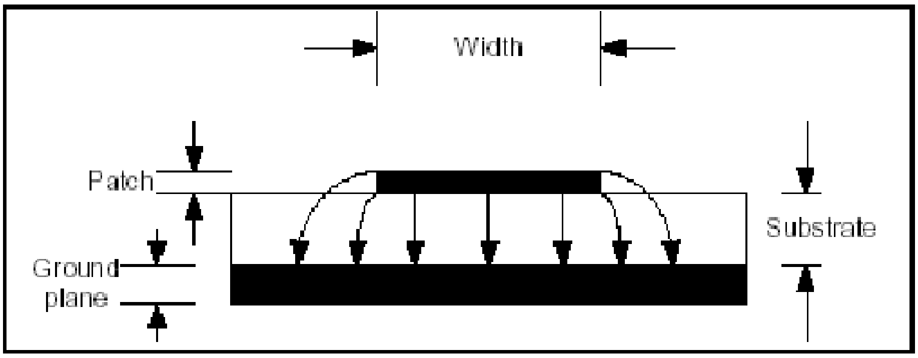


Figure (3.3) Fringing Field

The Extension Length of the Patch is given by

$$\Delta L = 0.412h \frac{\left(\varepsilon_{eff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad \textbf{(3.4)}$$

3.2.9. CALCULATION OF ACTUAL LENGTH OF PATCH (L)

The Actual Length of the Patch is defined as the difference between the Effective Length and the Extension Length of the Patch. The Actual Length of the Patch is given by

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \quad \textbf{(3.5)}$$

3.3. TYPES OF FEEDING TECHNIQUES

The feeding techniques are categorized into the following

- Microstrip line Feed
- Probe Feed
- Aperture coupled Feed
- Proximity coupled Feed

3.4. ADVANTAGES AND DISADVANTAGES:

Microstrip antenna is a low-profile antenna that has light weight and is very easy to installation due to which it is very popular in handheld wireless devices such as cell phones, pagers and in some high-performance communication systems such as in satellite, missile, spacecraft, aircraft etc. Some of the major advantages of microstrip antenna are given below

- Inexpensive and easy to fabricate
- Can be planted easily on any surface
- Can easily get reconfigurable characteristics
- Can easily design antenna with desired polarization
- Mechanically robust, Resistant against vibration and shock.
- Suitable to Microwave Integrated Circuits (MICs)
- For high gain and directivity

Array of antennas can be easily formed Conversely microstrip antennas also have a number of disadvantages and limitations when compared to other antennas. Some of the major disadvantages of microstrip antennas are written below:

- High quality factor
- Cross polarization
- Poor polarization efficiency.
- Suffers from spurious feed radiation.
- Narrow impedance bandwidth (5% to 10% without any technique)
- High Dielectric and conductor losses.
- Sensitive to environment conditions like temperature and humidity.
- Suffers from surface wave when high dielectric constant material is used
- Low gain and power handling capability.

There are various methods to overcome this limitation, bandwidth of microstrip antenna can be increase by using some special methods like defected ground plane strategy, stacked patches, slotted patches, parasitic patch. Gain and the power handling ability of antenna can be improved by making an antenna array.

3.5. APPLICATIONS

After a number of limitations due to the several advantages microstrip antenna found very useful in different applications. Microstrip antenna widely used in the defense systems like missiles, aircraft, satellites and rockets. Nowa day's microstrip antenna is used in commercial sectors due to its expensiveness and easy to manufacture benefit by advanced printed circuit technology. Due to the development and ongoing research in the area of microstrip antenna it is expected that in future after some time most of the conventional antenna will be replaced by microstrip antenna. Some of the major applications of microstrip antennas are:

3.5.1. MOBILE COMMUNICATION

Antenna used in mobile applications should be light weight, small size Microstrip antenna possesses this entire requirement. The most of mobile applications are handheld gadgets or pocket size equipment, cellular phones, UHF pagers and the radar applications in vehicles like car, planes, and ships. Various types of designs are made and used for radar applications like marine radar, radar for surveillance and for remote sensing.

3.5.2. SATELLITE COMMUNICATION

In satellite communication antenna should have the circular polarization. One of the major benefits of microstrip antenna is that one can easily design an antenna with require polarization by using dual feed networks and different techniques. Parabolic antennas are used in satellite communication to broadcasting from satellite. A flat microstrip antenna array can be used in the place of parabolic reflector

3.5.3. GLOBAL POSITIONING SYSTEM

Initially the satellite-based GPS system are used for only in military purposes but now a day's GPS found a large application in everyone's life and now used commercially. GPS found an essential requirement in vehicles, ships and planes to track the exact location and position 24 satellites are working in GPS encircling the earth in every 12 hours at altitude 20.200 km. GPS satellite using two frequencies in L- band to transmit the signal which is received by thousands of receivers on earth. The receiver antenna should be circularly polarized. An omnidirectional microstrip antenna has wide beam and low gain can be easily design with dual frequency operation in L- band.

3.3.4 DIRECT BROADCAST SATELLITE SYSTEM

In many countries direct broadcasting system is used to provide the television services. A high gain (-33db) antenna should be used at the ground by the user side. A parabolic reflector antenna is generally used are bulky requires space and affected by snow and rain. An array of circularly polarized microstrip antenna can be used for direct broadcasting reception which are easy to install. has less affect from snow and rain and cheaper also.

3.5.5. ANTENNA FOR PEDESTRIAN

For pedestrian applications antenna should be as small as possible due to space constraints. Low profile, light weight and small structure antennas are generally used in the handheld pocket equipment. Microstrip antenna is the best candidate for that. Various types of techniques can be used to reducing the size of antenna like short circuiting the patch or using the high dielectric constant material. But it has a drawback that smaller antenna leads to poorer efficiency.

3.5.6. RADAR APPLICATION

Radar application such as Manpack radar, Marine radar and Secondary surveillance radar requires antenna with appropriate gain and beam width. An array of microstrip antenna with desired gain and desired beam width can be used. For some application such as sensing the ocean wave speed and direction and for determining the ground soil grades Synthetic Aperture radar method is used. Two arrays of patch antennas separated by a proper distance are used in this system.

3.5.7. APPLICATION IN MEDICAL SCIENCE

In medical science for treating the malignant tumours microwave energy is used to induce hyperthermia. The microwave energy radiator used for this should be adaptable to the surface being treated and should be light weight**.**

CHAPTER 4

ARRAY ANTENNA

4.1 ARRAY ANTENNA

Microstrip antennas are used in arrays as well as single elements [1, 8, and 13]. By using array in communication systems, we enhance the performance of the antenna like increasing gain, directivity scanning the beam of an antenna system, and other functions which are difficult to do with the single element. Feeding of microstrip array antenna is by series-feed network figure (4.1.a), or corporate feed network figure (4.1.b).

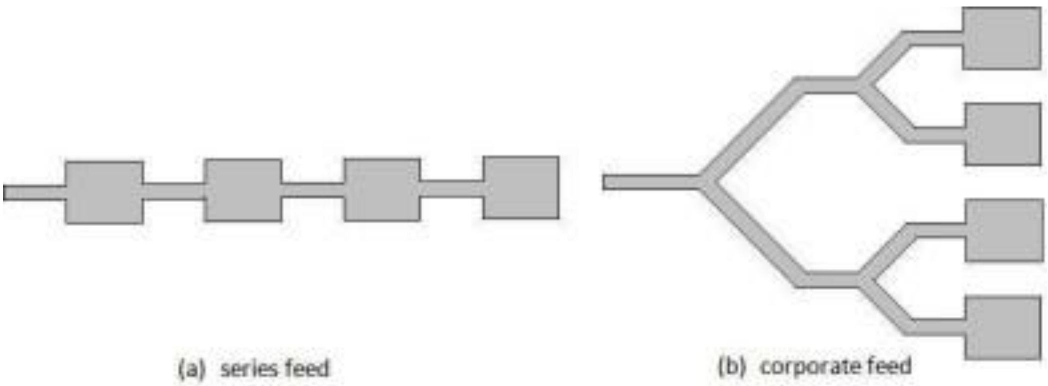


Figure (4.1) Feed arrangement for microstrip patch array

4.2 LINEAR ARRAY

We have studied a simple array consist of two elements, now if we put more elements in the line of our two elements array, we build a linear array, figure (4.2)

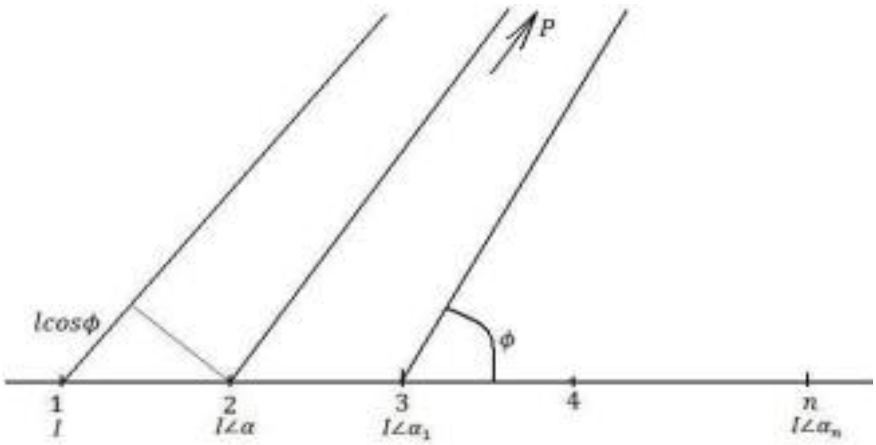


Figure (4.2) Uniform linear array of n elements

Now consider figure (4.2) of a simple linear array with equal separation between elements l and equal current in magnitude and equal difference in phase I

$$I, I\angle\alpha, I\angle\alpha_1, I\angle\alpha_2, \ldots\ldots I\angle\alpha_n$$

Field at point P is:

$$\boldsymbol{E} = \boldsymbol{E}_1[\mathbf{1} + \boldsymbol{e}^{jf} + \boldsymbol{e}^{j2f} + \boldsymbol{e}^{j3f} + \cdots \boldsymbol{e}^{jnf}] \qquad \textbf{(4.5)}$$

The magnitude of E is:

$$\mathbf{E} = \boldsymbol{E_o}\left|\frac{\sin\frac{nf}{2}}{\sin\frac{f}{2}}\right| \qquad \textbf{(4.6)}$$

Where $\boldsymbol{f} = \boldsymbol{\beta l cos}\phi + \boldsymbol{\alpha}$ **(4.7)**

The quantity E = $E_o\left|\frac{\sin\frac{nf}{2}}{\sin\frac{f}{2}}\right|$ is known as the array factor and it determines the shape

Radiation the pattern.

The equation (4.7) has a maximum when $\boldsymbol{f} = \mathbf{0}$ **so** $\boldsymbol{\beta l cos}\phi = \boldsymbol{\alpha}$**.**

The phase of each element in this array can be controlled by phase shifter, and the amplitude of the elements is adjusted by an amplifier or attenuator.

CHAPTER 5

PROPOSED METHODOLOGY

5.1 DESIGN OF 2X2 MICROSTRIP ARRAY ANTENNA FOR 6G EDGEFED ARRAY ANTENNA USING FR4 SUBSTRATE

5.1.1 INTRODUCTION:

The design of a 2x2 microstrip array antenna for 6G communication systems represents a significant endeavour in the pursuit of high-performance wireless connectivity. Leveraging the insights provided by the abstract, this section elaborates on the specific design considerations and methodologies employed in developing such an antenna system.

5.1.2 ANTENNA GEOMETRY AND CONFIGURATION:

The 2x2 microstrip array antenna configuration consists of multiple radiating elements arranged in a grid pattern. Each element is strategically positioned to achieve desired radiation characteristics and coverage patterns. The geometry of the radiating patches, feed network, and substrate dimensions are carefully optimized to facilitate dual-band operation and efficient energy transfer.

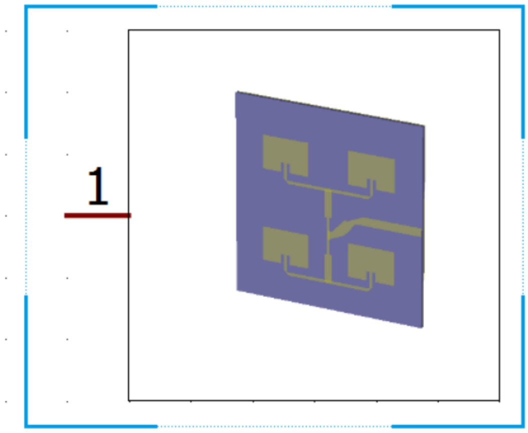


Figure (5.1) Schematic representation

5.1.3 EDGE FED ARRAY ARCHITECTURE:

The edge fed array architecture is chosen for its advantages in simplifying feeding network design and enhancing antenna performance. By feeding the antenna elements along the edges, impedance matching and signal distribution are facilitated, leading to improved overall efficiency and radiation characteristics. This architecture also offers flexibility in controlling the phase and amplitude of signals across the array, enabling beam steering and shaping capabilities.

5.1.4 DUAL-BAND OPERATION:

Achieving dual-band operation within the 6G spectrum is a key design objective aimed at accommodating the diverse requirements of future wireless technologies. By carefully tuning the dimensions and parameters of the antenna elements, resonance at two distinct frequencies is achieved, allowing simultaneous transmission and reception of multiple signals. This capability enhances spectrum utilization and throughput, enabling efficient communication in dynamic and congested environments.

5.1.5 SIMULATION AND PERFORMANCE EVALUATION

CST software serves as the primary platform for design optimization and performance evaluation of the antenna system. Through comprehensive simulations, key parameters such as return loss, radiation patterns, gain, and isolation between antenna elements are meticulously analysed. Iterative refinement based on simulation results allows for fine-tuning of the antenna design to meet specified performance metrics and requirements

5.2 1-DIMENSIONAL RESULTS:

The major parameters of the 1-Dimensional results are,

- **Z-Matrix**
- **VSWR**
- **S-Parameter**
- **Reference Impedance**
- **Power**
- **Port Information**
- **Materials**
- **Effiencies**
- **Adaptive meshing.**

5.2.1 Z -MATRIX

5.2.1.1 INTRODUCTION

The Z Matrix, or impedance matrix, is a fundamental tool in characterizing the electrical behaviour of antenna arrays. In the context of a 2x2 Edge fed array antenna using FR4 substrate, the Z Matrix provides valuable insights into the impedance relationships between different ports or nodes within the antenna system.

5.2.1.2 LINEAR Z MATRIX

The linear Z Matrix represents the impedance values between each pair of ports in the antenna array. It is typically represented as a square matrix, with each element corresponding to the impedance between a specific pair of ports. For a 2x2 Edge fed array antenna, the linear Z Matrix would consist of four impedance values arranged in a 2x2 matrix format.

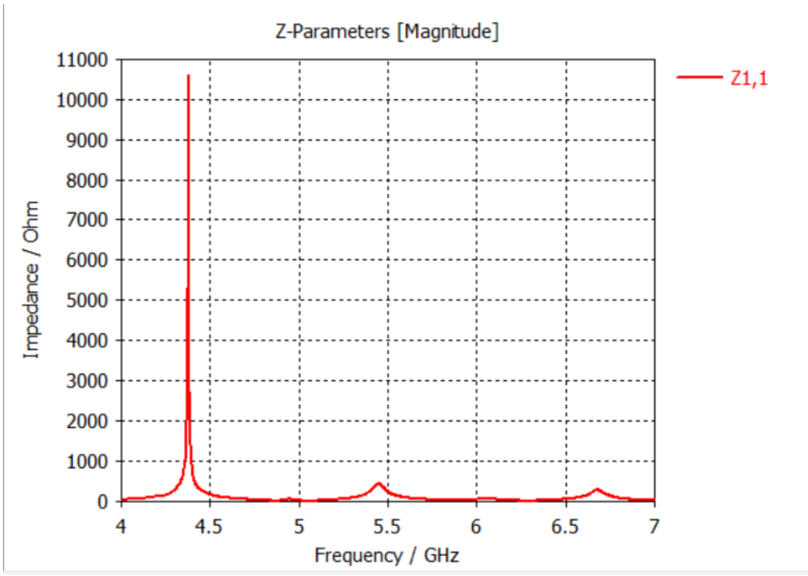


Figure (5.2) Linear Z Matrix

For example, if we denote the impedance between Port 1 and Port 2 as Z_{12}, between Port 1 and Port 3 as Z_{13}, and so on, the linear Z Matrix would be represented below.

$$[Z] = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

Figure (5.3) Linear Z matrix Representation

Each impedance value in the matrix reflects the complex impedance seen by the corresponding port, taking into account factors such as radiation resistance, feedline impedance, and mutual coupling between antenna elements.

5.2.1.3 Z MATRIX IN DBW

The Z Matrix can also be represented in decibels with respect to a reference power level (dBW). This representation provides a logarithmic scale of impedance values, making it easier to visualize and interpret variations in impedance across the antenna array.

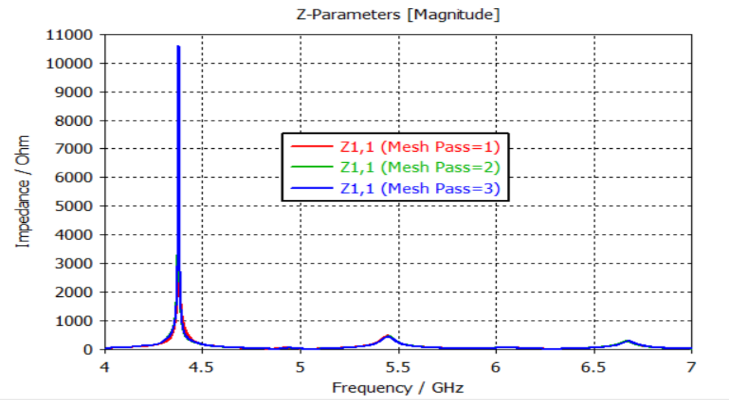


Figure (5.4) Z-matrix in dBW

Converting the linear impedance values to dBW scale involves taking the logarithm of the ratio of the impedance value to the reference power level in watts. The resulting dBW values indicate the relative impedance levels between different ports, with positive dBW values indicating higher impedance and negative dBW values indicating lower impedance**.**

5.2.2 VSWR

Voltage Standing Wave Ratio (VSWR) is a critical parameter in antenna design, representing the ratio of the maximum voltage to the minimum voltage along the transmission line. In the context of a 2x2 Edge fed array antenna utilizing FR4 substrate, VSWR provides valuable insights into the efficiency of power transfer and impedance matching within the antenna system.

5.2.2.1 VSWR GRAPH

The VSWR graph illustrates the variation of VSWR across the frequency spectrum of interest. It depicts how well the antenna system is matched to the transmission line and the surrounding environment. A lower VSWR value indicates better impedance matching and reduced signal reflections, resulting in more efficient power transfer and improved antenna performance.

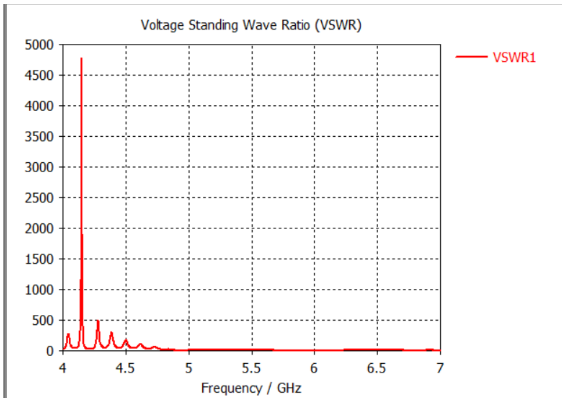


Figure (5.5) VSWR Graph

5.2.2.2 VSWR AT 3 MESH VALUES

In addition to the standard VSWR graph, VSWR can also be evaluated at specific mesh values within the antenna array. For a 2x2 Edge fed array antenna, VSWR may be analysed at multiple mesh points to assess the uniformity of impedance matching and standing wave patterns across the array.

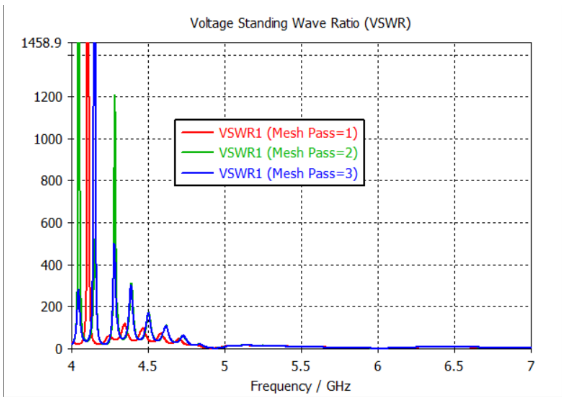


Figure (5.6) VSWR at 3 Meshes

VSWR at Mesh 1:

This represents the VSWR value at the first mesh point within the antenna array. Analyzing VSWR at this point provides insights into impedance matching and power transfer efficiency at the individual antenna element level.

VSWR at Mesh 2:

Similarly, VSWR at the second mesh point within the array is evaluated to assess impedance matching and standing wave characteristics at a different location within the array. Variations in VSWR between mesh points may indicate non-uniformities in antenna performance or impedance matching.

VSWR at Mesh 3:

VSWR at the third mesh point serves as another reference for evaluating impedance matching and standing wave behaviour across the antenna array. Consistency in VSWR values across multiple mesh points is indicative of uniformity in antenna design and performance.

5.2.3 S-PARAMETERS

S-Parameters, or scattering parameters, are essential tools for characterizing the behaviour of multi-port networks, including antenna systems. In the context of a 2x2 Edge fed array antenna utilizing FR4 substrate, S-Parameters provide valuable insights into signal transmission, reflection, and coupling between antenna elements.

5.2.3.1 LINEAR S-PARAMETER GRAPH

The linear S-Parameter graph illustrates the magnitude and phase of S-Parameters across the frequency spectrum of interest. It provides a comprehensive view of how signals propagate through the antenna system and interact with various components and ports. Each S-Parameter (S11, S12, S21, S22) represents a specific aspect of signal behaviour, such as reflection coefficient, transmission coefficient, and coupling between ports.

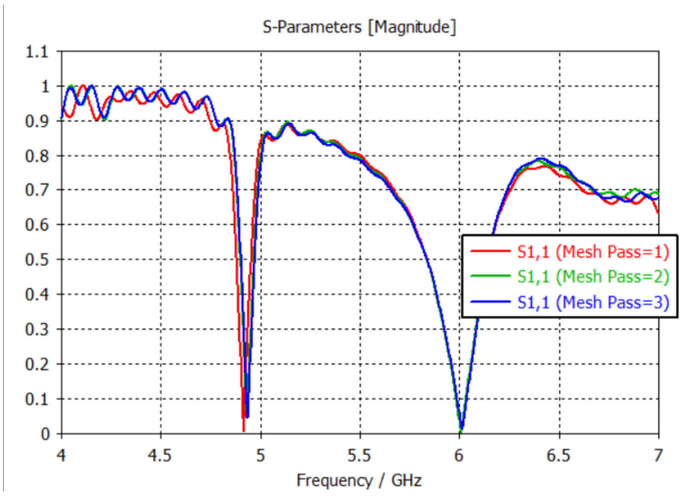


Figure (5.7) Linear S Parameter Graph

5.2.3.2 S-PARAMETER DBW GRAPH

The S-Parameter dBW graph presents the same information as the linear graph but on a logarithmic scale in decibels with respect to a reference power level (dBW). This representation allows for easier visualization and interpretation of signal attenuation, amplification, and isolation characteristics across the frequency spectrum.

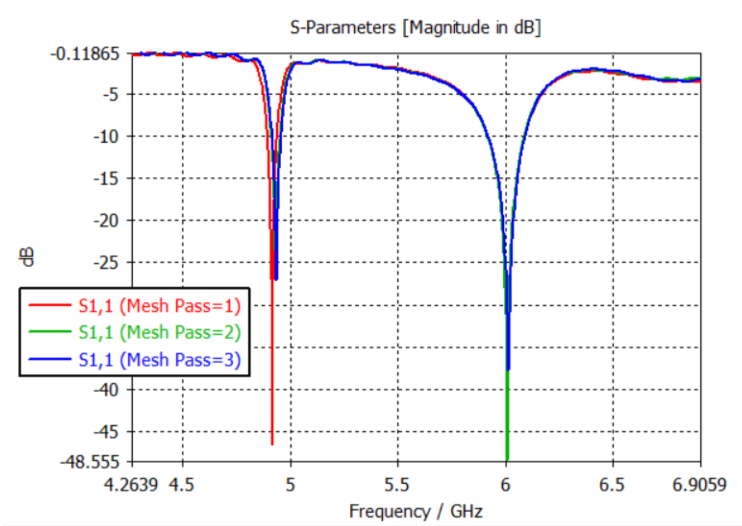


Figure (5.8) S Parameter dBW Graph

5.2.4 REFERENCE IMPEDANCE OF 50 OHMS

In the design and analysis of antenna systems, the reference impedance serves as a standard value against which the impedance of the antenna or transmission line is measured. A common reference impedance used in RF systems is 50 ohms. This reference impedance plays a crucial role in ensuring efficient power transfer, impedance matching, and signal integrity within the antenna system.

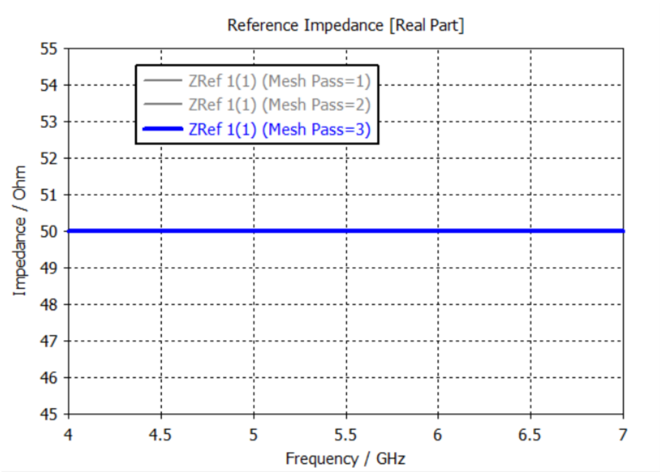


Figure (5.9) Reference Impedance

5.2.4.1 IMPORTANCE OF REFERENCE IMPEDANCE

Impedance Matching:

A reference impedance of 50 ohms allows for easy impedance matching between different components of the antenna system, such as the antenna elements, transmission lines, and RF circuits. Matching the impedance of these components to the reference impedance minimizes signal reflections and ensures maximum power transfer, resulting in improved antenna performance and efficiency.

Standardization:

The use of a standardized reference impedance, such as 50 ohms, facilitates compatibility and interoperability between different RF components and systems. This standardization simplifies system integration, testing, and troubleshooting, leading to faster development cycles and reduced costs in antenna design and deployment.

Signal Integrity:

Maintaining a consistent reference impedance throughout the antenna system helps preserve signal integrity and fidelity, especially in high-frequency applications. By minimizing impedance variations and discontinuities, signal distortion and loss are reduced, resulting in improved communication reliability and data throughput.

Measurement and Calibration:

Reference impedance standards, such as 50 ohms, are commonly used in RF measurement equipment and calibration procedures. Calibration against a known reference impedance ensures accurate measurement and characterization of antenna performance parameters, such as return loss, VSWR, and S-parameters.

5.2.5 PORT INFORMATION

Port information encompasses various parameters and characteristics associated with the ports of the antenna array. Understanding port information is essential for optimizing antenna performance, impedance matching, and signal transmission/reception.

5.2.5.1 WAVE IMPEDANCE

Wave impedance represents the characteristic impedance of the transmission line connected to the antenna port. It influences how efficiently electromagnetic waves propagate along the transmission line and interact with the antenna elements. Graphical data illustrating wave impedance provides insights into impedance matching and signal transmission efficiency.

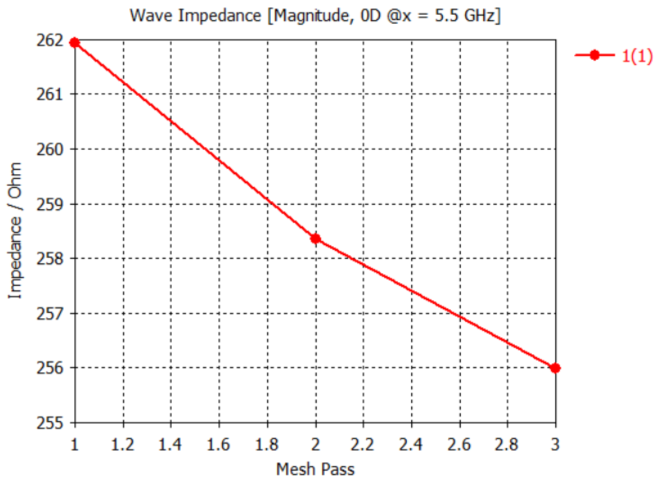


Figure (5.10) Wave Impedance

5.2.5.2 LINE IMPEDANCE

Line impedance refers to the impedance seen by the transmission line at the antenna port. It includes the combined impedance of the transmission line, feed structure, and impedance transformation networks. Graphical data depicting line impedance aids in optimizing impedance matching and minimizing signal reflections at the antenna port.

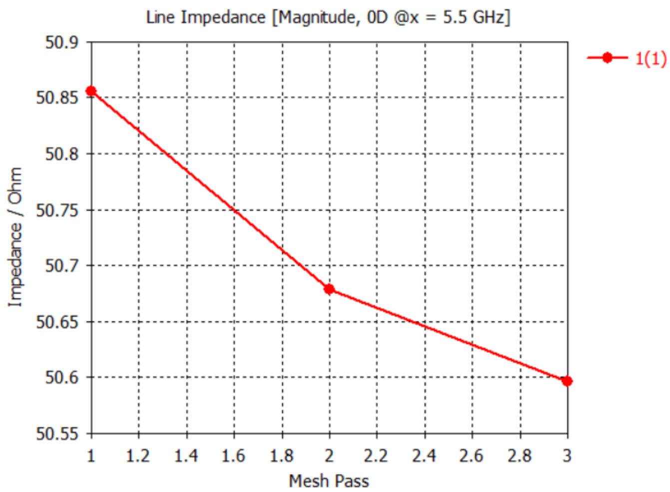


Figure (5.11) Line Impedance

5.2.5.3 GAMMA

Gamma, or reflection coefficient, quantifies the amount of electromagnetic energy reflected back from the antenna port. It is a measure of impedance mismatch between the antenna and the transmission line. Graphical data showing gamma values help identify impedance mismatches and assess the effectiveness of impedance matching techniques.

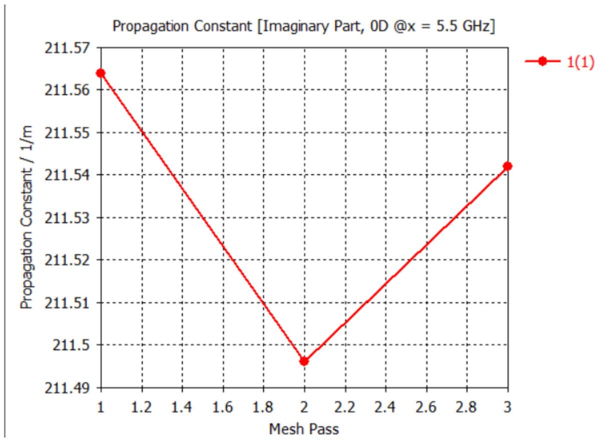


Figure (5.12) Gamma

5.2.5.4 EFFECTIVE DIELECTRIC CONSTANT

Effective dielectric constant characterizes the effective permittivity of the substrate material surrounding the antenna port. It influences the propagation velocity of electromagnetic waves and affects the overall performance of the antenna system. Graphical data illustrating effective dielectric constant assists in optimizing substrate materials and dimensions for improved antenna performance.

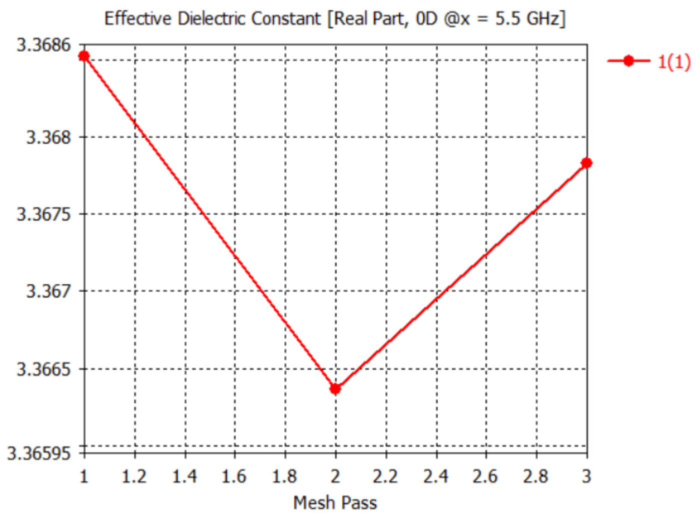


Figure (5.13) Effective Dielectric Constant

5.2.5.5 DISTANCE (-40DB)

Distance (-40dB) represents the distance from the antenna port at which the signal strength attenuates by 40 decibels (dB). It indicates the extent of signal propagation and coverage area of the antenna system. Graphical data showing distance (-40dB) provides insights into antenna coverage patterns and spatial distribution of signal strength.

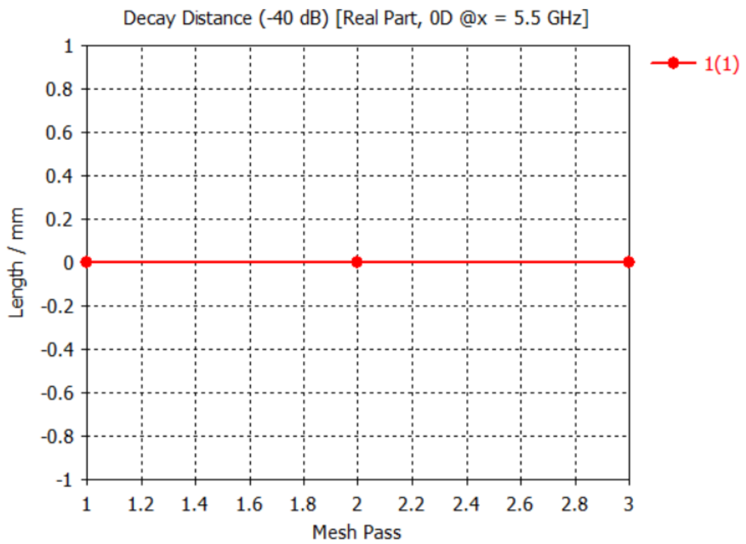


Figure (5.14) Distance (-40dB)

5.2.6 MATERIALS: FR-4 (LOSSY)

FR-4 is a widely used substrate material in the fabrication of printed circuit boards (PCBs) and microstrip antennas due to its excellent electrical properties, mechanical stability, and cost-effectiveness. However, FR-4 exhibits lossy characteristics, which can impact the performance of antennas, especially at high frequencies. Understanding the dispersive behaviour of FR-4 is crucial for optimizing antenna designs and mitigating signal losses.

5.2.6.1 DISPERSIVE BEHAVIOUR

The dispersive behaviour of FR-4 refers to its frequency-dependent electrical properties, such as permittivity (dielectric constant) and loss tangent. These properties vary with frequency, affecting how electromagnetic waves propagate through the substrate material.

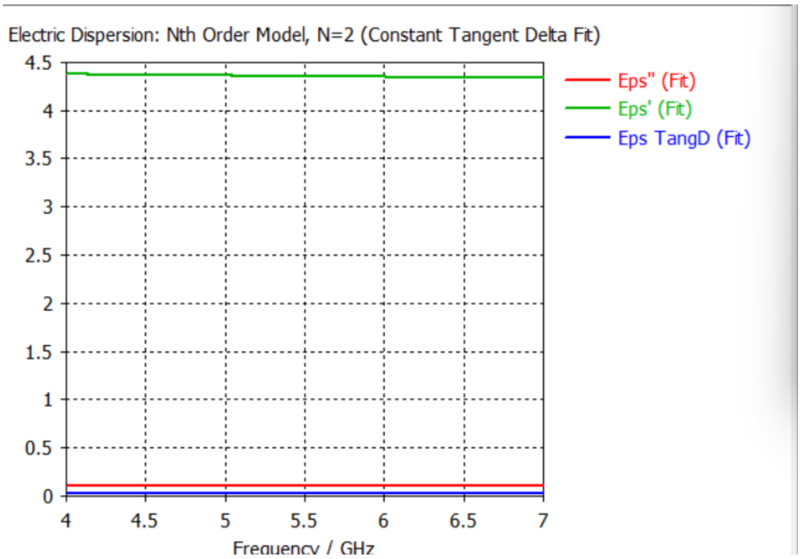


Figure (5.15) Graphical Data: Electric Dispersion Nth Order

5.2.6.2 EPS (FIT)

Eps (Fit) represents the frequency-dependent permittivity of FR-4 substrate material. It characterizes how the dielectric constant changes with frequency and influences the propagation velocity of electromagnetic waves. Graphical data depicting Eps (Fit) provides insights into the dispersive behaviour of FR-4 and helps engineers model and optimize antenna designs for specific frequency ranges

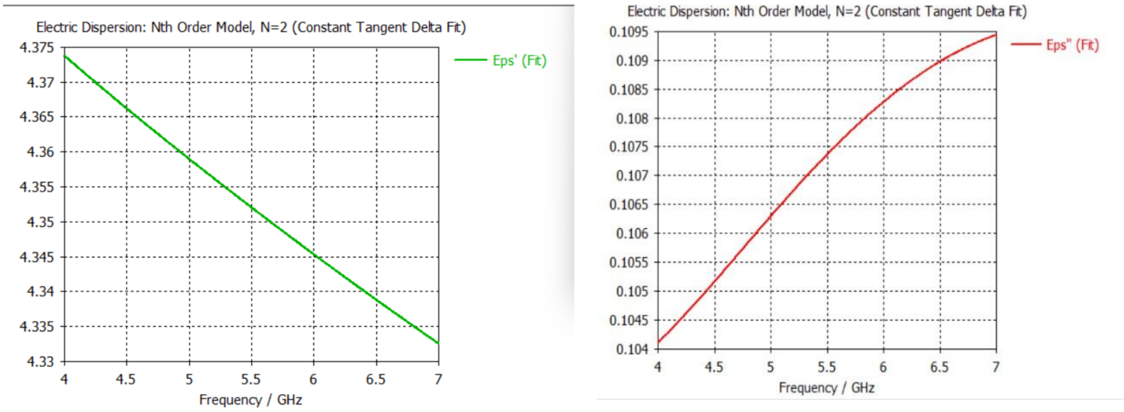


Figure (5.16.a,b) Eps fits

5.2.6.3 EPS (TANGD)

Eps (TangD) represents the frequency-dependent loss tangent of FR-4 substrate material. It quantifies the amount of energy lost as heat during signal propagation through the substrate. Graphical data illustrating Eps (TangD) aids in assessing the lossy characteristics of FR-4 and optimizing antenna designs to minimize signal losses and maximize efficiency.

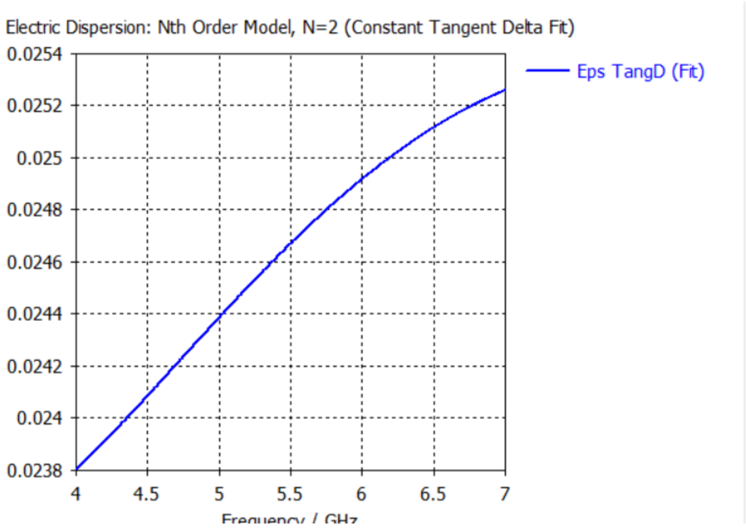


Figure (5.17) Eps (TangD)

5.2.7 MATERIALS: COPPER (ANNEALED)

Copper is a commonly used conductor material in antenna fabrication due to its excellent electrical conductivity and mechanical properties. Annealed copper, in particular, undergoes a heat treatment process to enhance its ductility and conductivity. However, even annealed copper exhibits losses, especially at high frequencies, which can impact antenna performance. Understanding the surface impedance of annealed copper is crucial for assessing these losses and optimizing antenna designs.

5.2.7.1 SURFACE IMPEDANCE

Surface impedance characterizes the electrical properties of a conductor material, specifically its resistance and reactance per unit length. For annealed copper, surface impedance plays a significant role in determining the losses incurred as electromagnetic waves propagate through the conductor.

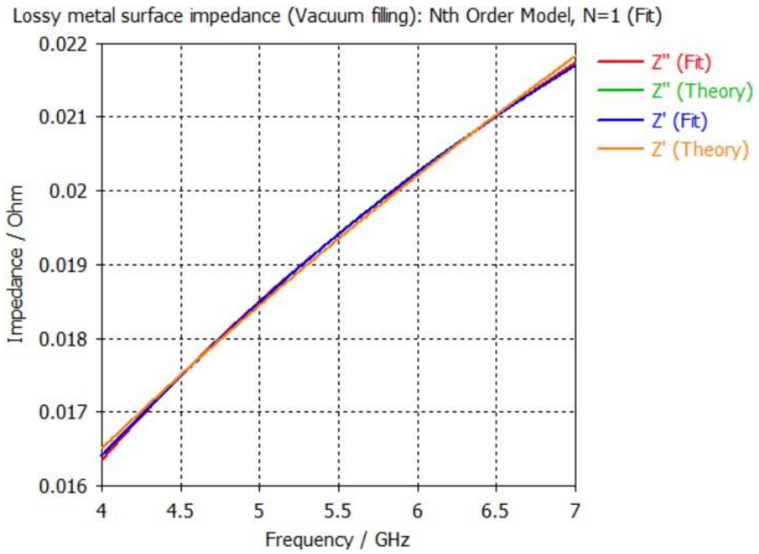


Figure (5.18) Surface Impedance

5.2.7.2 Z'' FIT

Z" Fit represents the fitted value of the imaginary part of the surface impedance (reactance) of annealed copper as a function of frequency. It quantifies the losses incurred by the material due to its finite conductivity and skin effect. Graphical data depicting Z" Fit provides insights into how losses vary with frequency and aids in optimizing antenna designs to minimize signal attenuation and maximize efficiency.

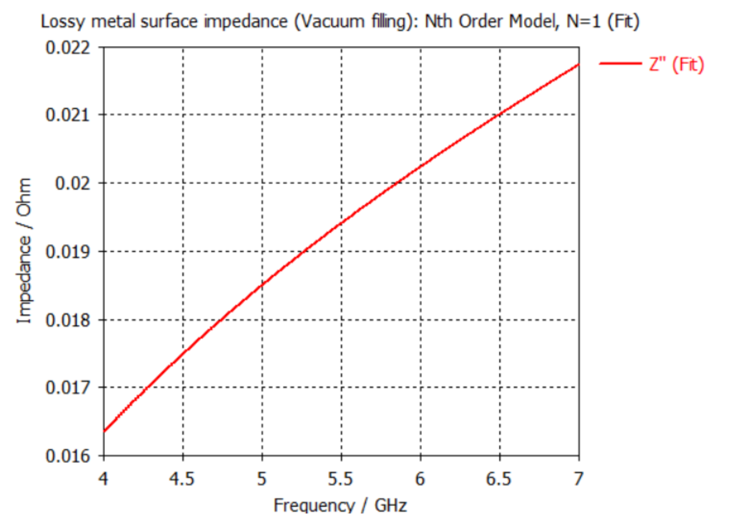


Figure (5.19) Z" Fit

5.2.7.3 Z'' THEORY

Z" Theory represents the theoretical value of the imaginary part of the surface impedance (reactance) of annealed copper based on theoretical models or calculations. It serves as a reference for comparing with experimental or simulated data and validating the accuracy of antenna design simulations.

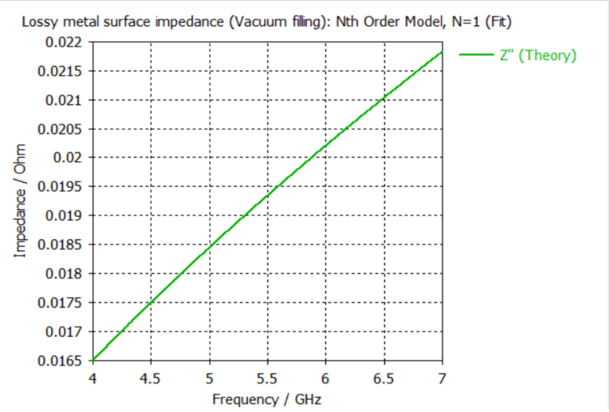


Figure (5.20) Z" Theory

5.2.7.4 Z' FIT

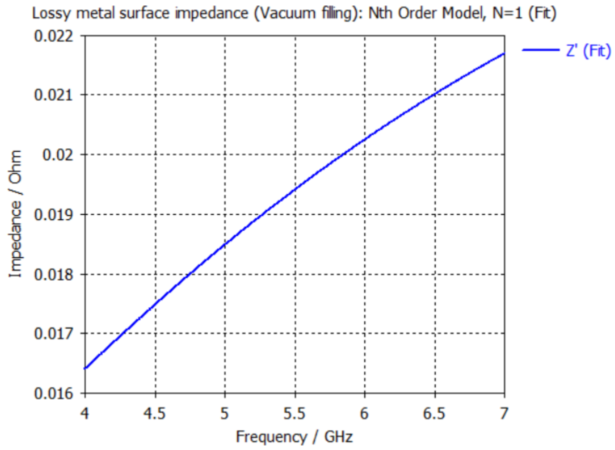


Figure (5.21) Z' Fit

Z' Fit represents the fitted value of the real part of the surface impedance (resistance) of annealed copper as a function of frequency. It quantifies the resistive losses incurred by the material and influences the overall efficiency of the antenna system. Graphical data illustrating Z' Fit helps engineers understand how resistive losses affect antenna performance and optimize designs accordingly

5.2.7.5 Z' THEORY

Z' Theory represents the theoretical value of the real part of the surface impedance (resistance) of annealed copper based on theoretical models or calculations. Similar to Z" Theory, it serves as a reference for comparing with experimental or simulated data and validating the accuracy of antenna design simulations.

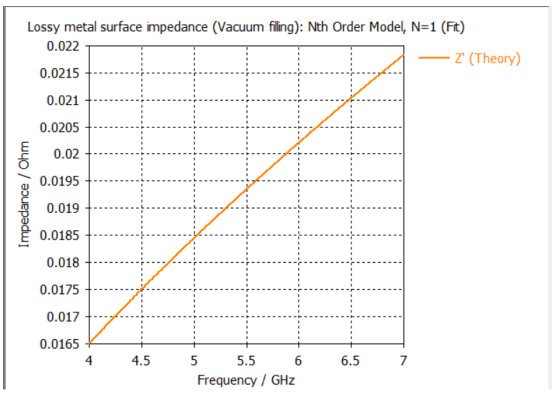


Figure (5.22) Z' Theory

5.2.8 EFFICIENCIES

Efficiencies represent the overall effectiveness of the antenna system in converting input power into useful radiated electromagnetic energy.

5.2.8.1 EFFICIENCIES (LINEAR)

Graphical representation of efficiencies in linear scale combines total efficiency and radiation efficiency to provide a comprehensive view of the antenna system's performance. It helps engineers assess the effectiveness of the antenna design and identify factors contributing to efficiency gains or losses.

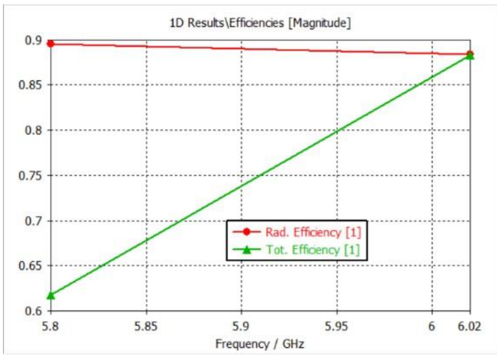


Figure (5.23) Efficiencies (Linear)

5.2.8.2 EFFICIENCIES (DBW)

Efficiencies in dBW scale offer a logarithmic representation of overall efficiency levels, facilitating easier comparison and assessment of antenna performance across different operating conditions or design parameters. It aids in optimizing antenna designs for maximum efficiency and effectiveness in various communication and radar applications.

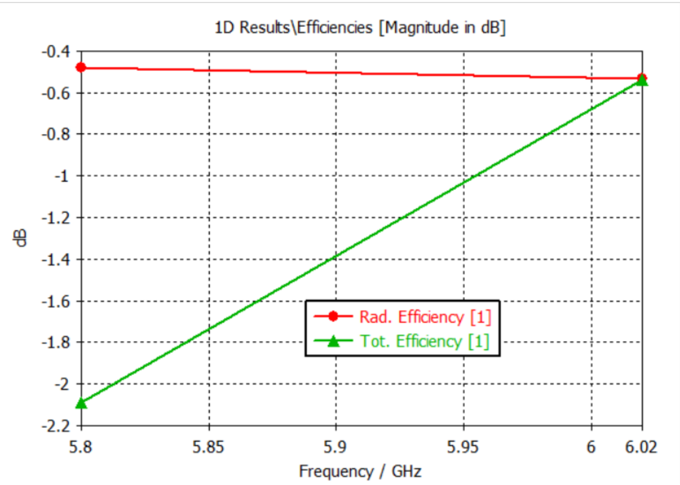


Figure (5.24) Efficiencies (in dBW)

5.2.8.3 RADIATION EFFICIENCIES (LINEAR):

Graphical representation of radiation efficiencies in linear scale illustrates the efficiency of the antenna system in radiating electromagnetic energy. It focuses specifically on the portion of input power that contributes to radiation and provides insights into antenna performance in terms of radiation effectiveness.

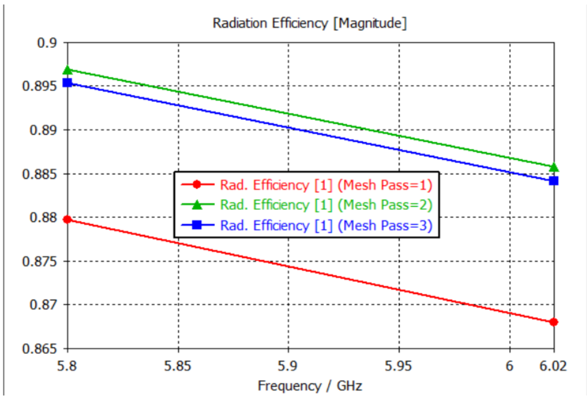


Figure (5.25) Radiation Efficiencies (Linear)

5.2.8.4 RADIATION EFFICIENCIES (DBW)

Radiation efficiencies in dBW scale offer a logarithmic representation of radiation efficiency levels, facilitating easier comparison and assessment of radiation performance across different frequency bands or design parameters. It aids in identifying areas of improvement and optimizing antenna designs for enhanced radiation efficiency.

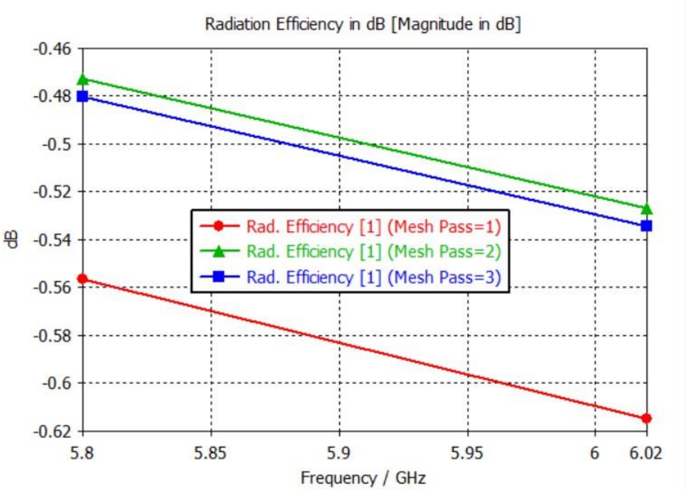


Figure (5.26) Radiation Efficiencies (dBW)

5.2.8.5 TOTAL EFFICIENCY (LINEAR)

Graphical representation of total efficiency in linear scale illustrates the efficiency of the antenna system in converting input power into radiated electromagnetic energy. It provides insights into the overall effectiveness of the antenna design and helps identify areas for improvement.

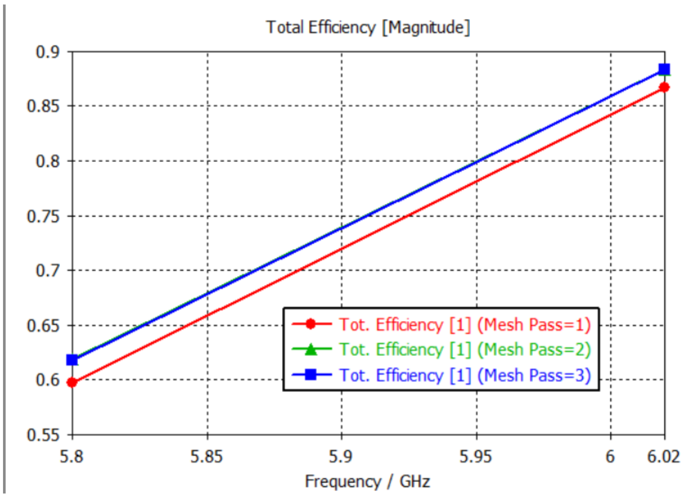


Figure (5.27) Total Efficiency (Linear)

5.2.8.6 TOTAL EFFICIENCY (DBW)

Total efficiency in dBW scale offers a logarithmic representation of efficiency levels, allowing for easier comparison and visualization of efficiency variations across different frequency bands or design parameters. It aids in assessing the performance of the antenna system more comprehensively.

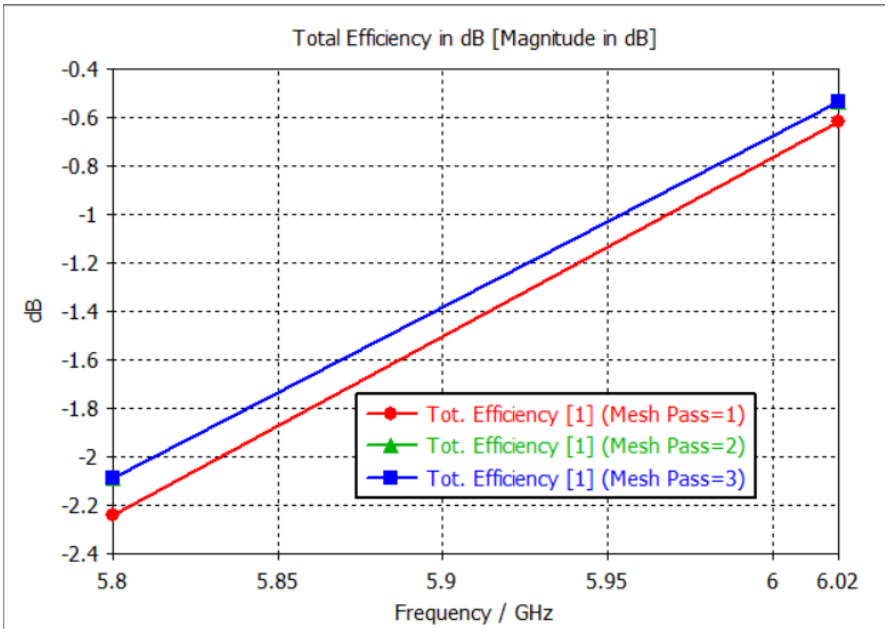


Figure (5.28) Total Efficiency in dBW

5.2.9 S-PARAMETER BALANCE

S-parameter balance is a critical factor in evaluating the symmetry and performance consistency between different ports or elements within an antenna array. Achieving S-parameter balance ensures uniform power distribution and consistent signal transmission or reception characteristics across the array.

5.2.9.1 S-PARAMETER BALANCE (LINEAR):

S-parameter balance in linear scale illustrates the relative power levels between different ports or elements within the antenna array. It offers a straight forward representation of signal imbalances and aids in identifying areas for improvement in terms of symmetry and consistency across the array.

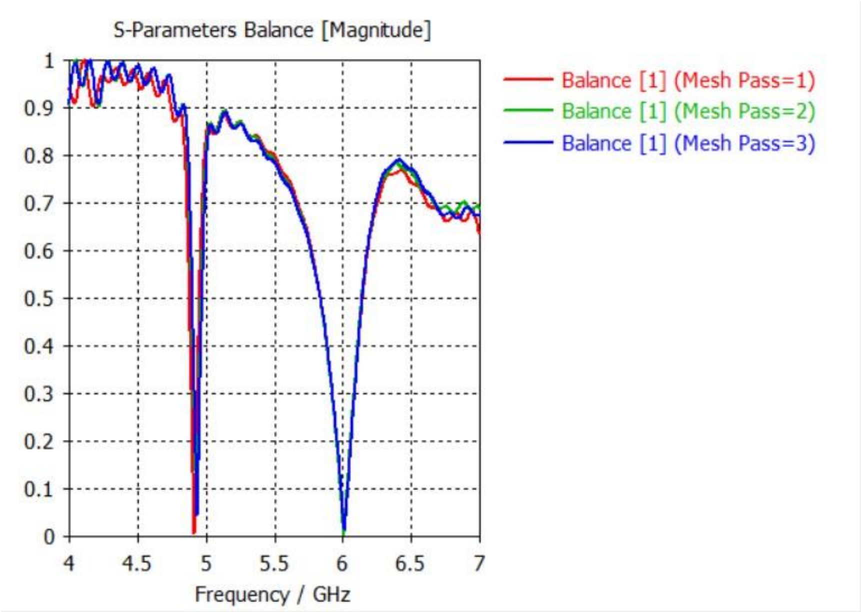


Figure (5.29) S-parameter balance (Linear)

5.2.9.2 S-PARAMETER BALANCE (DBW)

Graphical representation of S-parameter balance in dBW scale provides insights into the magnitude of imbalances between different ports or elements within the antenna array. It helps identify variations in signal transmission or reception characteristics and assesses the symmetry and consistency of the antenna system.

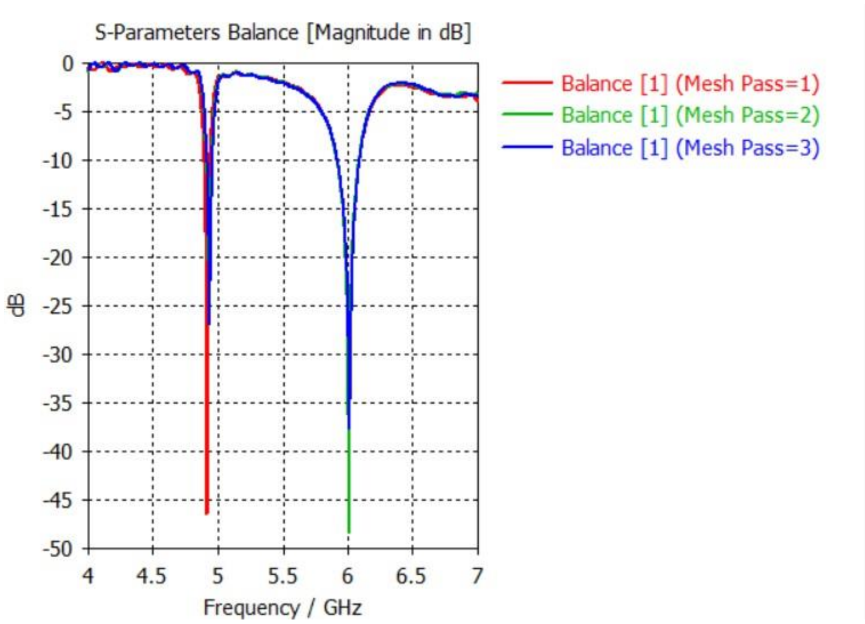


Figure (5.30) S-parameter balance (in dBW)

5.2.10 ADAPTIVE MESHING

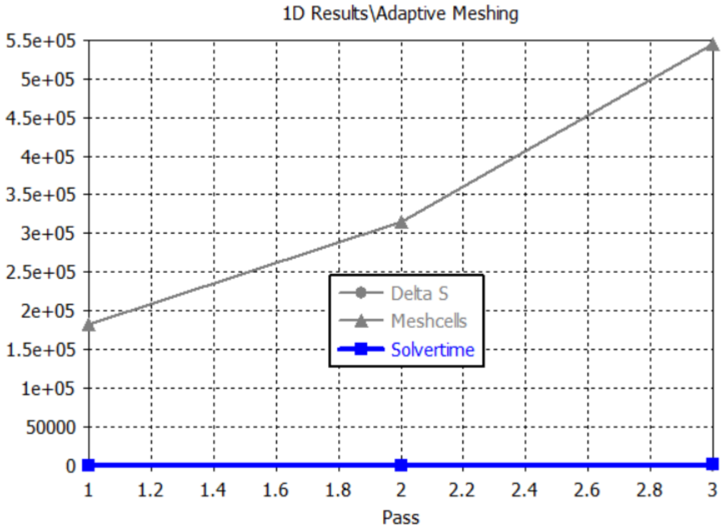


Figure (5.31) Adaptive Meshing

Adaptive meshing is a technique used in electromagnetic simulations to dynamically adjust the mesh resolution based on the complexity and characteristics of the antenna structure. By refining the mesh in regions of high field variation or geometric complexity and coarsening it in regions of low variation, adaptive meshing improves simulation accuracy and efficiency.

5.2.10.1 S-PARAMETER ANALYSIS WITH ADAPTIVE MESHING

S-parameter analysis involves the characterization of signal transmission and reflection properties of an antenna system. With adaptive meshing, S-parameter analysis becomes more accurate and efficient as the mesh resolution adapts to the electromagnetic field distribution and geometric features of the antenna structure.

5.2.10.2 S-PARAMETER IN LINEAR SCALE

Graphical representation of S-parameters in linear scale illustrates the magnitude and phase of signal transmission and reflection coefficients between different ports or elements within the antenna array. Adaptive meshing ensures that the mesh resolution is optimized to capture fine details and variations in the S-parameter responses accurately.

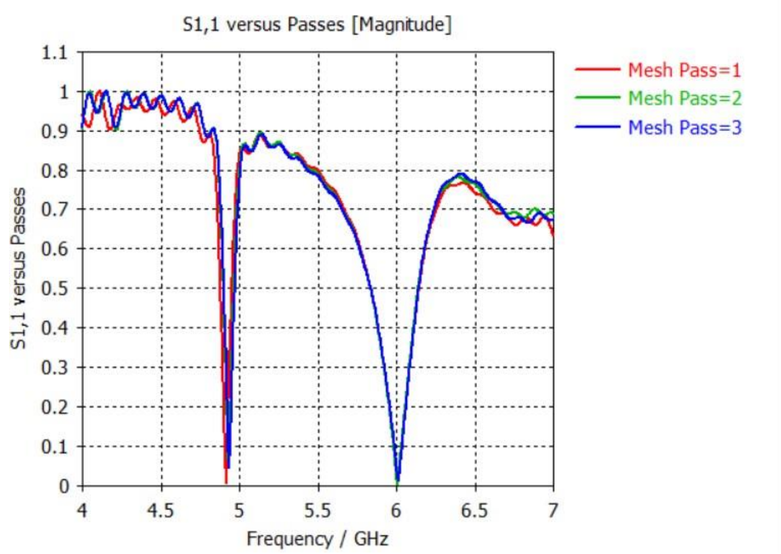


Figure (5.32) S-parameter in Linear scale

5.2.10.3 S-PARAMETER IN DBW SCALE

S-parameter representation in dBW scale offers a logarithmic view of signal transmission and reflection characteristics, making it easier to visualize and analyse variations in S-parameter magnitudes across different frequency bands or design parameters. Adaptive meshing enhances the accuracy of dBW- scale S-parameter analysis by refining the mesh resolution where necessary to capture subtle variations in signal behaviour.

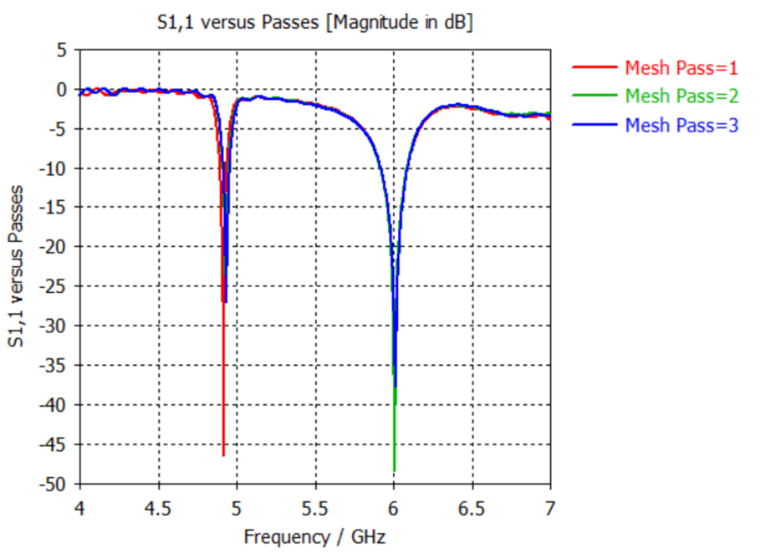


Figure (5.33) S-parameter in dBW

5.2.10.4 BENEFITS OF ADAPTIVE MESHING IN S-PARAMETER ANALYSIS

ACCURACY IMPROVEMENT

Adaptive meshing improves the accuracy of S-parameter analysis by dynamically adjusting the mesh resolution to capture fine details and variations in electromagnetic field distribution within the antenna structure.

EFFICIENCY ENHANCEMENT

By concentrating computational resources where they are most needed, adaptive meshing reduces simulation time and computational cost associated with S-parameter analysis, making it more efficient and scalable for complex antenna designs.

ROBUSTNESS TO GEOMETRIC COMPLEXITY

Adaptive meshing enables S-parameter analysis to handle geometrically complex antenna structures with ease, ensuring accurate characterization of signal transmission and reflection properties even in regions of high geometric complexity or variation.

5.2.10.5 PORT IMPEDANCE ANALYSIS WITH ADAPTIVE MESHING

In antenna simulations utilizing adaptive meshing techniques, the analysis of port impedance plays a crucial role in understanding how electromagnetic signals interact with the antenna structure at specific ports. Port impedance characterization provides insights into impedance matching, signal transmission, and reflection properties, which are essential for optimizing antenna performance.

5.2.10.6 SOLVER TIME

Solver time refers to the computational time required to solve the electromagnetic field equations governing the behaviour of the antenna structure. With adaptive meshing, solver time is optimized by dynamically adjusting the mesh resolution to focus computational resources where they are most needed, reducing overall simulation time.

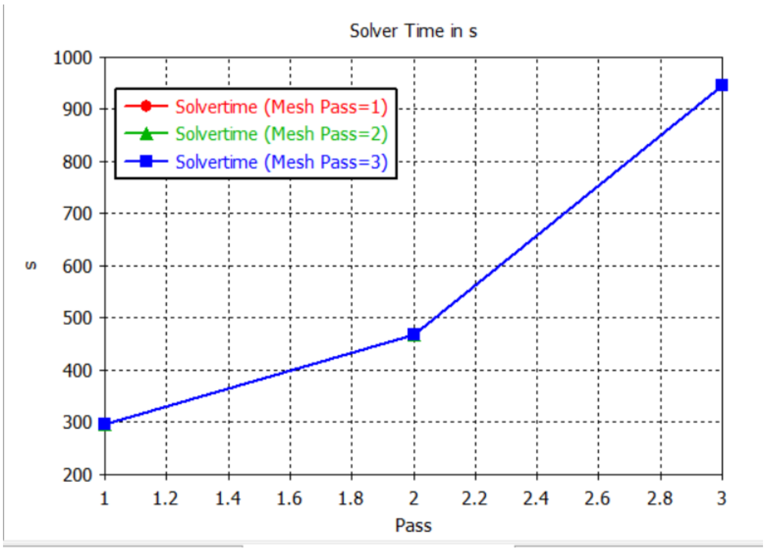


Figure (5.34) Solver Time

5.2.10.7 PORT IMPEDANCE

Port impedance quantifies the electrical characteristics of the antenna port, including resistance and reactance. It reflects how well the port impedance matches the characteristic impedance of the transmission line connected to the port. Adaptive meshing ensures accurate characterization of port impedance by refining the mesh resolution in regions of high field variation or geometric complexity.

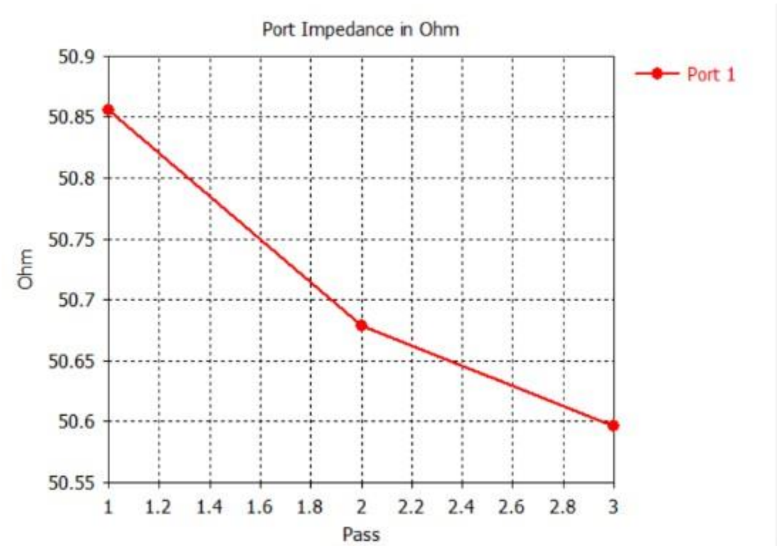


Figure (5.35) Port Impedance

5.2.10.8 PORT 1 AT MESH VALUES

Analyzing port impedance at specific mesh values provides insights into how impedance characteristics vary across different elements or regions within the antenna structure. Adaptive meshing optimizes the mesh resolution to capture fine details in the electromagnetic field distribution at the antenna port, enabling accurate characterization of port impedance at various mesh points.

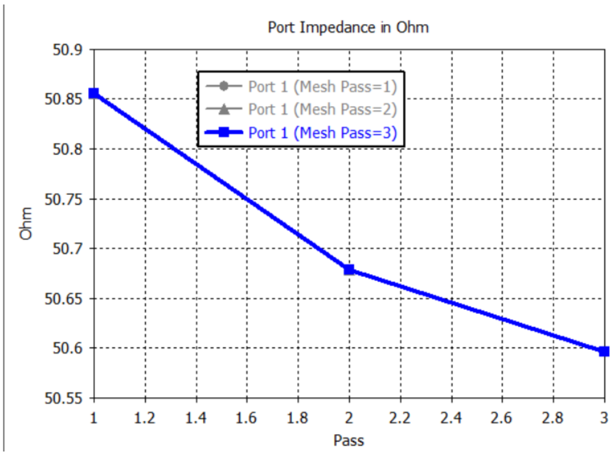


Figure (5.36) Port 1 at Mesh Values

5.2.10.9 MESH CELLS

Mesh cells represent the computational elements used to discretize the antenna structure for electromagnetic simulations. With adaptive meshing, the number and size of mesh cells are dynamically adjusted based on the electromagnetic field distribution and geometric features of the antenna structure, optimizing computational resources and simulation accuracy.

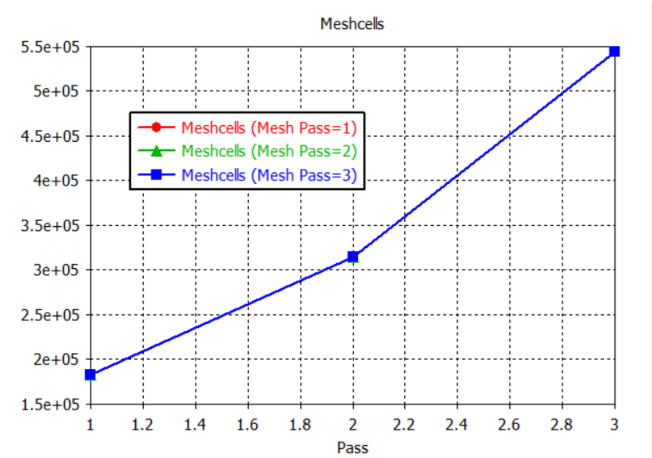


Figure (5.37) Mesh Values

5.2.10.10 DELTA S

Delta S represents the change in port impedance between adjacent mesh cells. Analyzing delta provides insights into how port impedance varies spatially within the antenna structure. Adaptive meshing ensures that delta S is accurately captured by refining the mesh resolution in regions of significant impedance variation, enabling precise characterization of impedance changes at different locations.

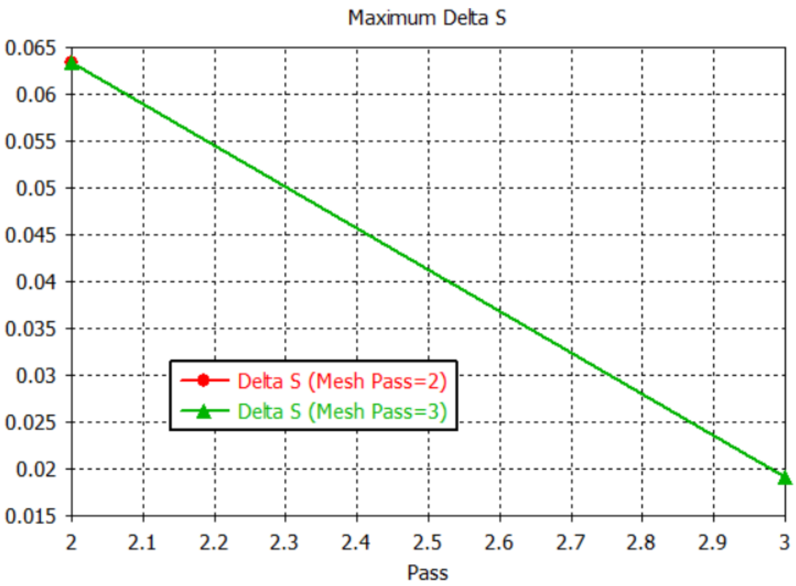


Figure (5.38) Delta S

CHAPTER 6

2-DIMENSIONAL AND 3-DIMENSIONAL RESULTS

6.1 H-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=6.02 GHZ) AND (F=5.8 GHZ)

H-field analysis provides valuable insights into the distribution and magnitude of the magnetic field across the antenna structure at specific frequencies. By examining the H-field at different frequencies, engineers can understand how the antenna behaves under different operating conditions and optimize its design for improved performance.

6.1.1 H-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=6.02 GHZ)

At the simulated frequency of 6.02 GHz, H-field analysis reveals the distribution and magnitude of the magnetic field across the antenna structure. Engineers can observe how the magnetic field is distributed along the radiating elements, feedlines, and ground plane, providing insights into the antenna's radiation characteristics and impedance matching properties at this specific frequency.

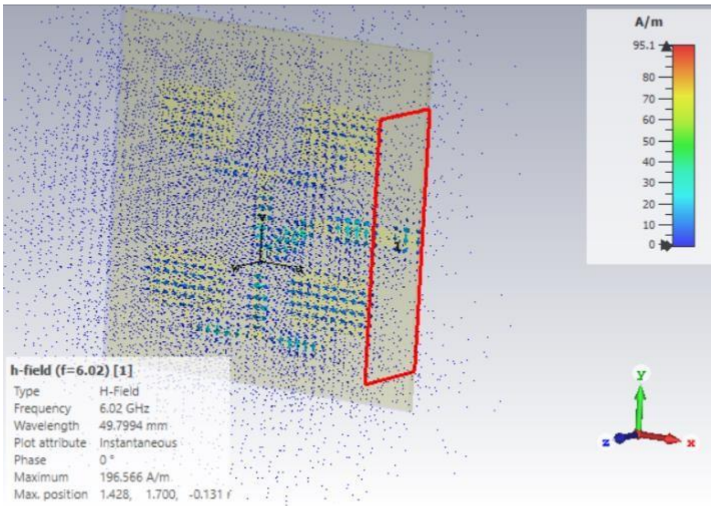


Figure (6.1) H-Field Analysis Of 6.02 Ghz

6.1.2 H-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=5.8 GHZ)

At the simulated frequency of 5.8 GHz, H-field analysis provides a different perspective on magnetic field distribution and behaviour compared to the previous frequency. Engineers can observe changes in the magnetic field distribution patterns, possibly indicating variations in antenna resonance, radiation pattern, or impedance matching characteristics at this frequency.

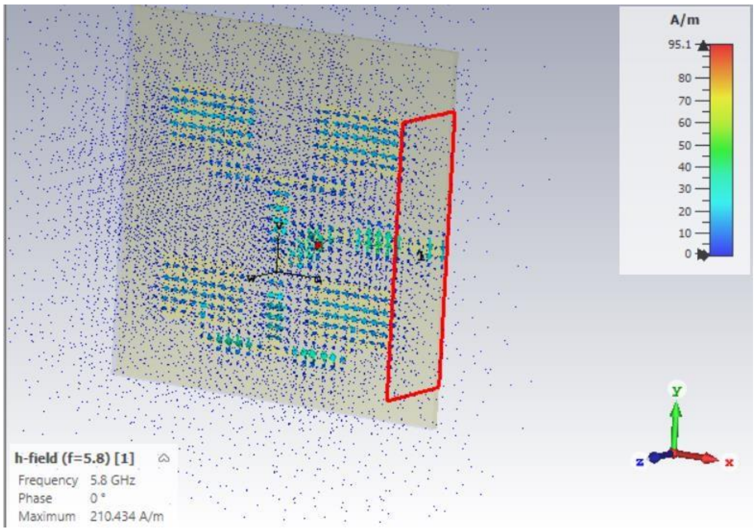


Figure (6.2) H-field Analysis of 5.8 GHz

6.2 E-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=6.02 GHZ) AND (F=5.8 GHZ)

E-field analysis provides valuable insights into the distribution and magnitude of the electric field across the antenna structure at specific frequencies. By examining the E-field at different frequencies, engineers can understand how the antenna behaves under different operating conditions and optimize its design for improved performance.

6.2.1 E-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=6.02 GHZ)

At the simulated frequency of 6.02 GHz, E-field analysis reveals the distribution and magnitude of the electric field across the antenna structure.

Engineers can observe how the electric field is distributed along the radiating elements, feedlines, and ground plane, providing insights into the antenna's radiation characteristics and impedance matching properties at this specific frequency.

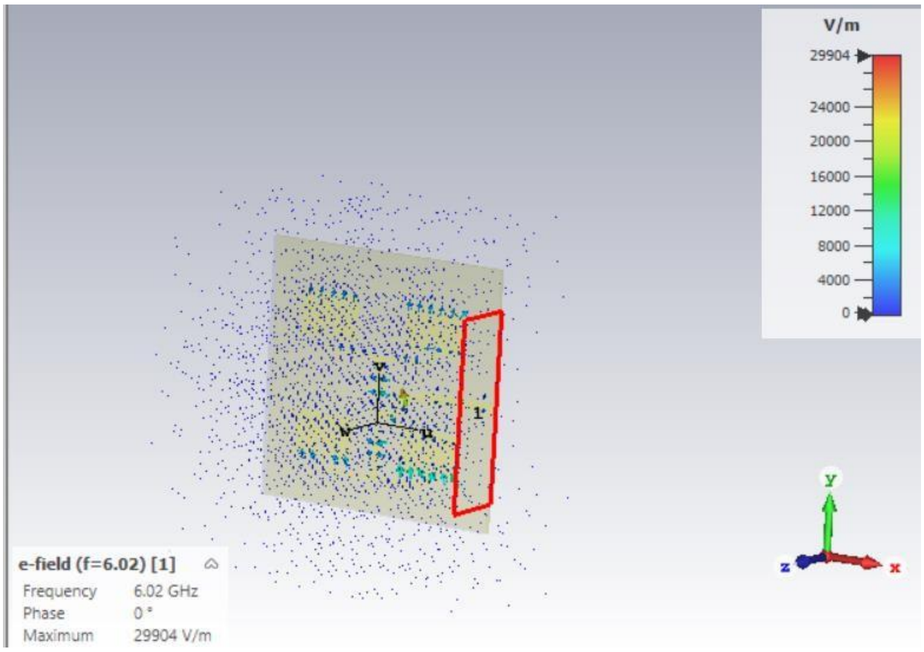


Figure (6.3) E-Field Analysis of 6.02 GHz

6.2.2 E-FIELD ANALYSIS FOR SIMULATED FREQUENCIES (F=5.8 GHZ)

At the simulated frequency of 5.8 GHz, E-field analysis provides a different perspective on electric field distribution and behaviour compared to the previous frequency. Engineers can observe changes in the electric field distribution patterns, possibly indicating variations in antenna resonance, radiation pattern, or impedance matching characteristics at this frequency.

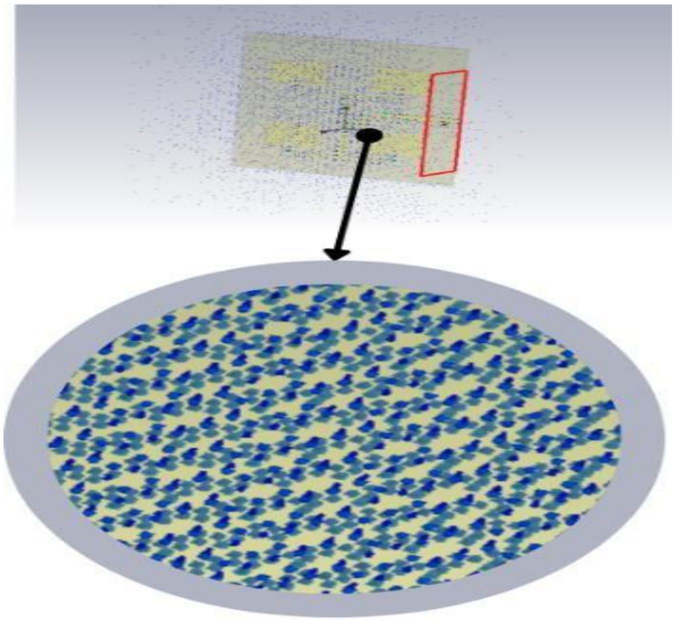


Figure (6.4) E-Field Analysis of 5.8 GHz

CHAPTER 7

FAR FIELD RESULTS

7.1 INTRODUCTION

The far-field analysis of a 6G edge-fed 2x2 array antenna on an FR4 substrate involves assessing its radiation properties at 5.8 GHz and 6.02 GHz. The radiation pattern, directivity, and efficiency are evaluated through numerical simulations, including electromagnetic software modelling. At 5.8 GHz, the radiation pattern's main lobe direction, side lobes, and beamwidth are analysed, alongside directivity calculation and efficiency assessment. Comparatively, at 6.02 GHz, changes in the radiation pattern are examined, directivity is recalculated, and efficiency is estimated. The analysis aims to understand performance variations between the frequencies, potentially informing design modifications or optimizations for improved antenna functionality.

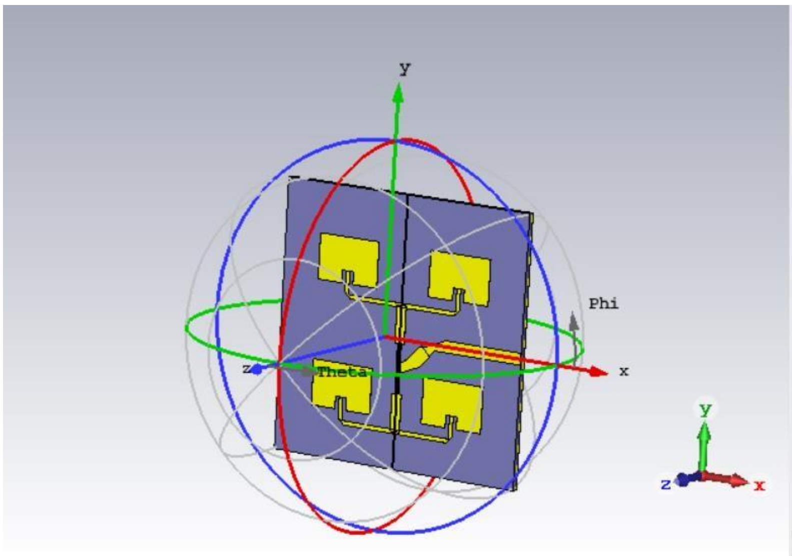


Figure (7.1) Far field Representation

The following methods initiate the representation:

- Polar Representation:
- Cartesian Representation
- 2D Representation

- 3D Visualization

7. 2 POLAR REPRESENTATIONS:

7.2.1 POLAR COORDINATES: FREQUENCY: 5.8 GHZ

- Radial distance: $\boldsymbol{R}$
- Azimuth angle: $\boldsymbol{\theta}$
- Elevation angle: $\boldsymbol{\varphi}$

Polar plot showcasing the radiation pattern, illustrating the main lobe direction and side lobes. Polar representation of electric and magnetic field vectors, depicting polarization characteristics.

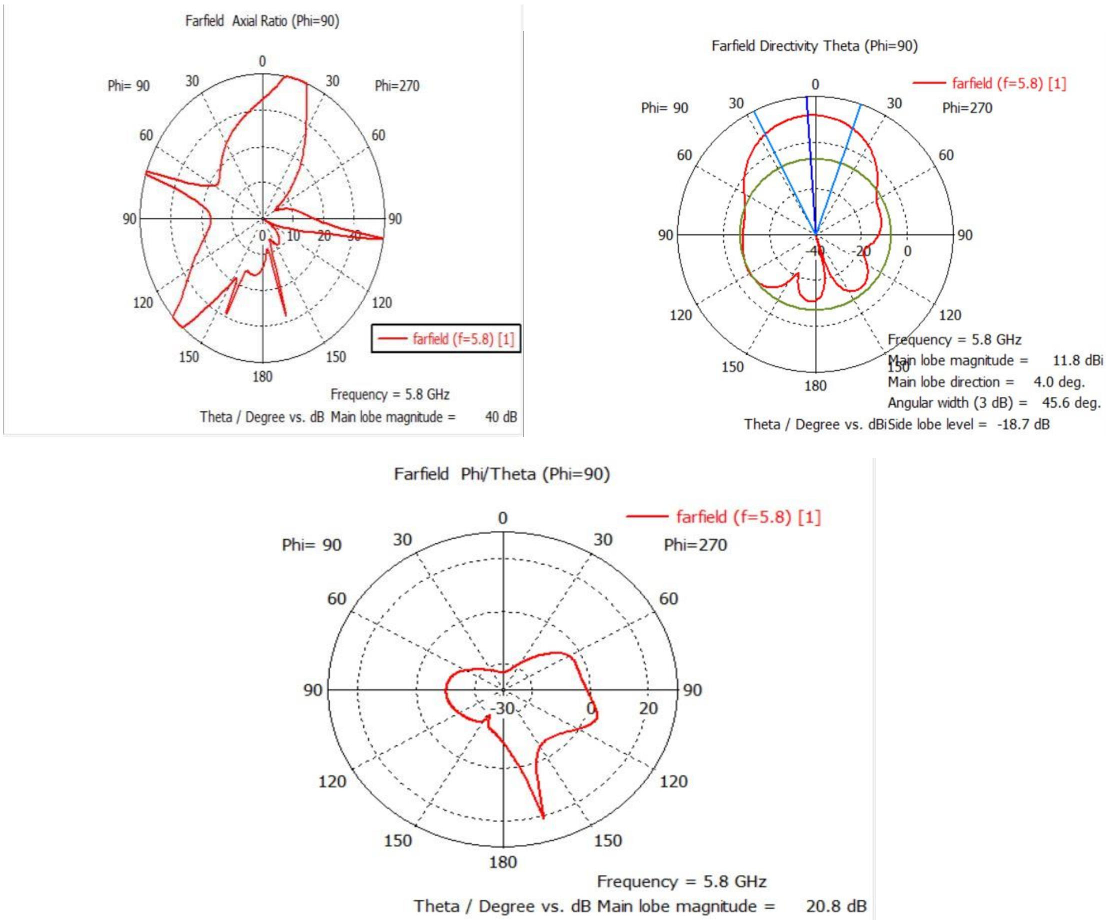


Figure (7.2) Polar Representation (f=5.8GHz)

7.2.2 POLAR COORDINATES: FREQUENCY: 6.02 GHZ

- Radial distance: $\boldsymbol{R}$
- Azimuth angle: $\boldsymbol{\theta}$
- Elevation angle: $\boldsymbol{\varphi}$

Polar plot depicting the radiation pattern, highlighting changes in main lobe direction and side lobe levels. Polar representation of electric and magnetic field vectors, showing alterations in polarization at the new frequency.

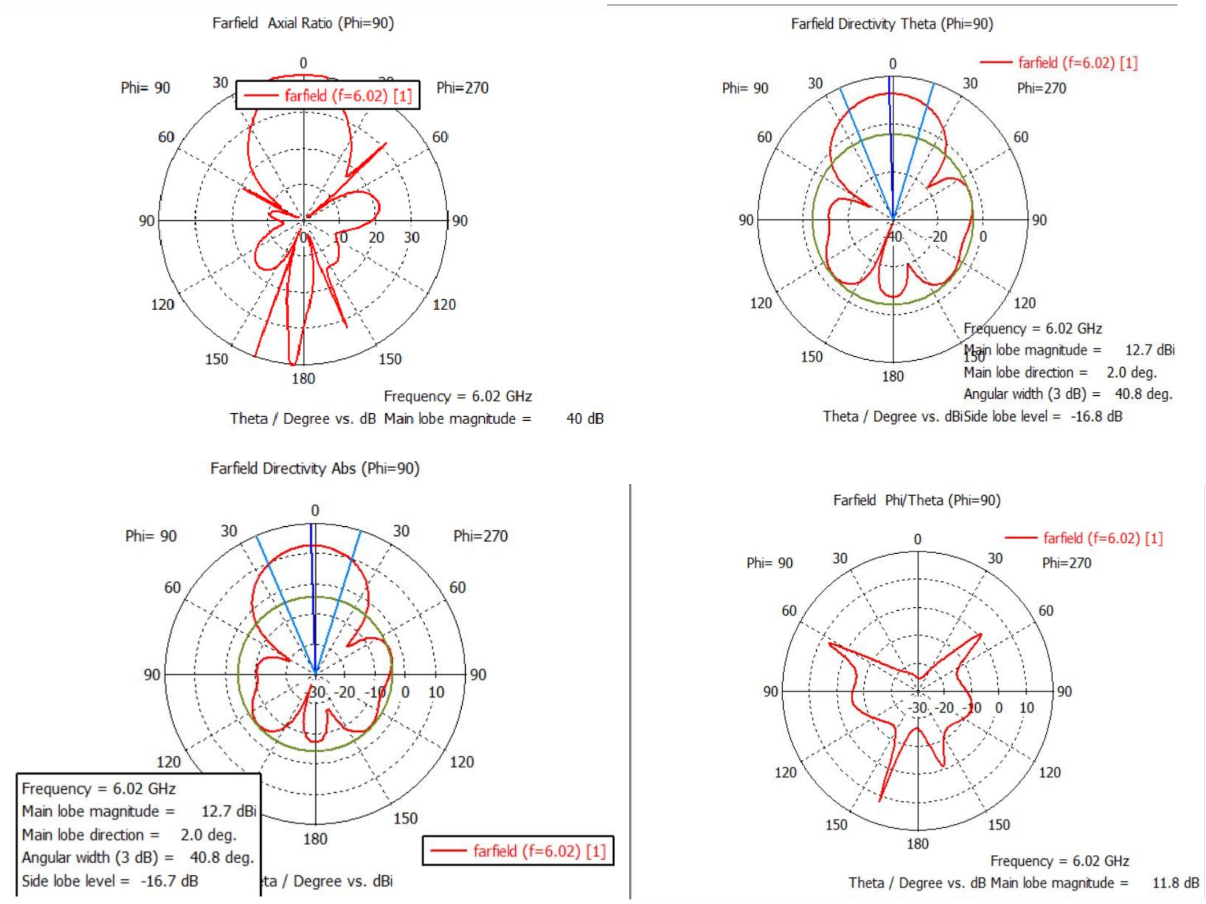


Figure (7.3) Polar Representation (f=6.02GHz)

7.3 CARTESIAN REPRESENTATION

7.3.1 CARTESIAN COORDINATES: FREQUENCY: 5.8 GHZ

x, y, and z components for antenna element positions. Cartesian field plots illustrating the distribution of electric and magnetic fields in the x, y, and z directions. Visualization of the array configuration and phase differences between elements.

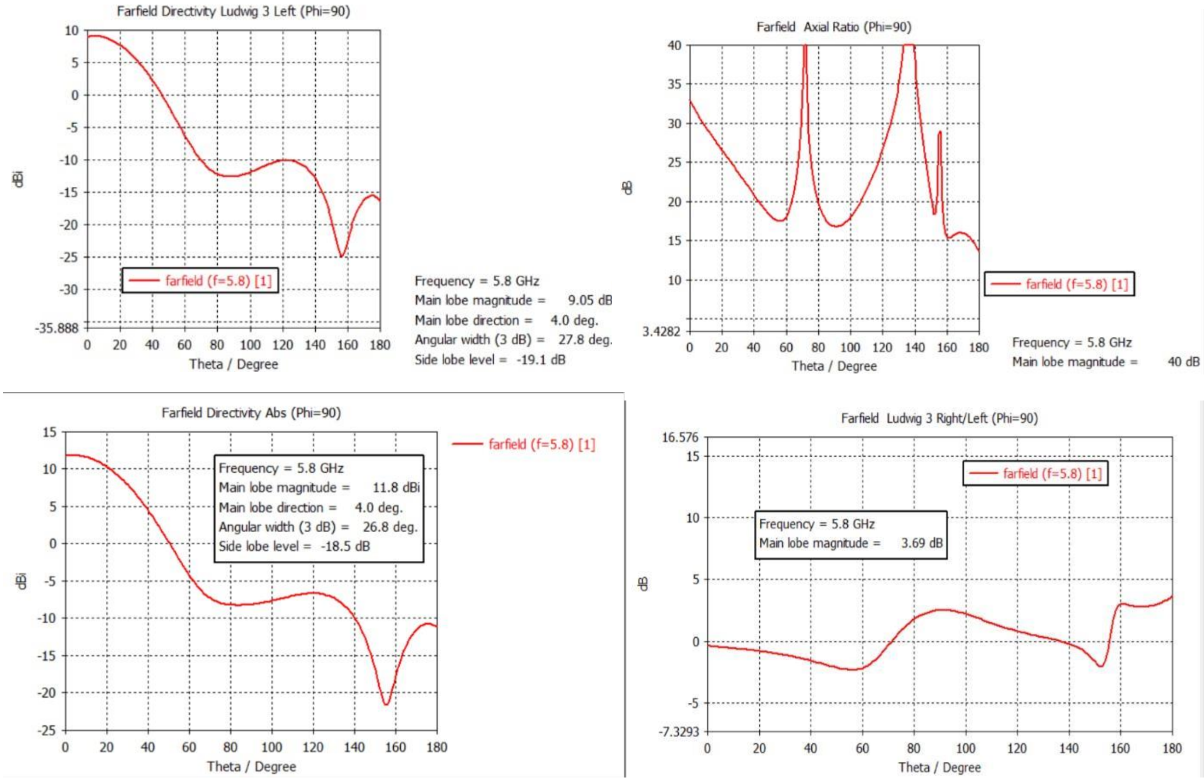


Figure (7.4) Cartesian Representation (f=5.8GHz)

7.3.2 CARTESIAN COORDINATES: FREQUENCY: 6.02 GHZ

x, y, and z components for antenna element positions. Cartesian field plots show adjustments in the distribution of electric and magnetic fields in the x, y, and z directions. Updated visualization of the array configuration and phase differences for the new frequency

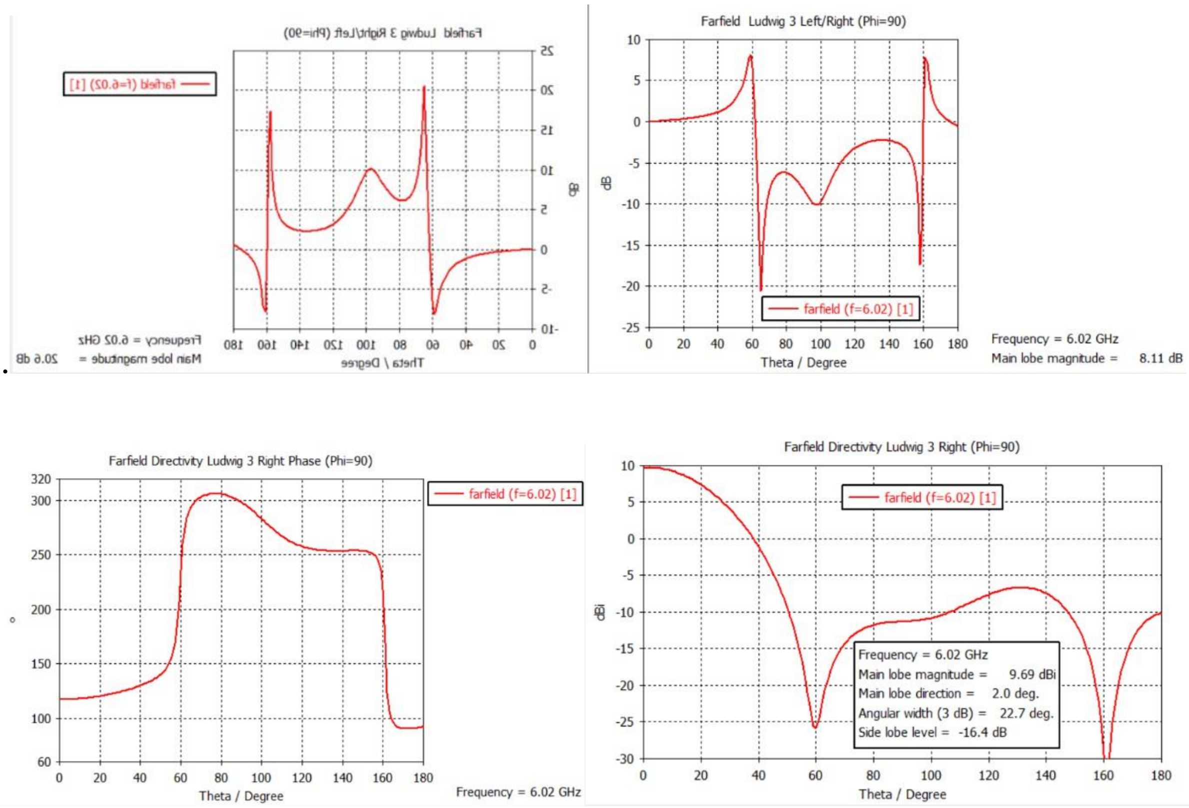


Figure (7.5) Cartesian Representation (f=6.02GHz)

7.4 2D REPRESENTATION

7.4.1 2D REPRESENTATION: FREQUENCY: 5.8 GHZ

2D plots representing the antenna's radiation pattern in the azimuth and elevation planes. Contour plots displaying the magnitude and phase of the electric and magnetic fields in the vicinity of the antenna array.

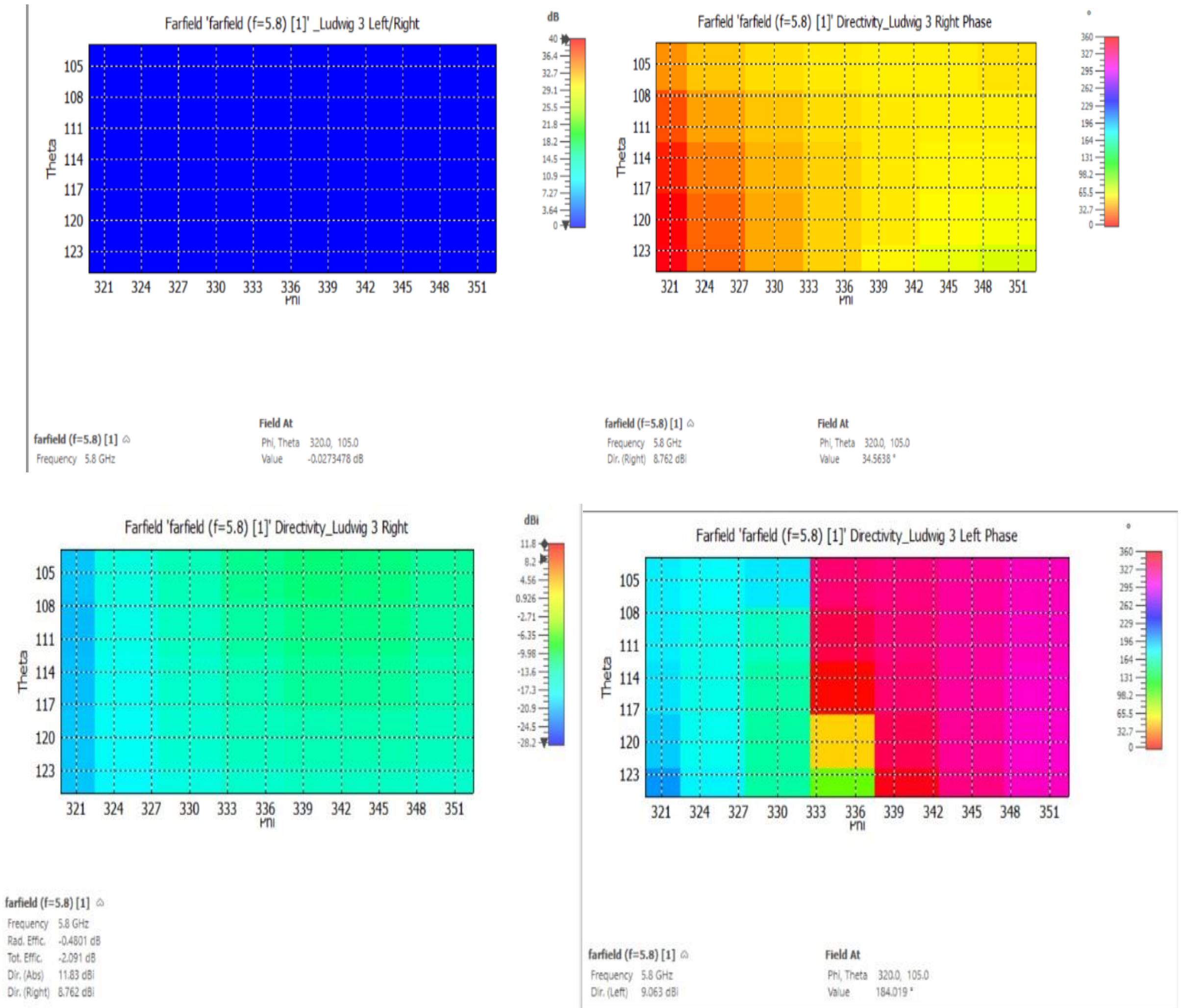


Figure (7.6) 2D Representation (5.8GHz)

7.4.2 2D REPRESENTATION: FREQUENCY: 6.02 GHZ

Updated 2D plots illustrating changes in the antenna's radiation pattern and beamwidth in the azimuth and elevation planes. Contour plots reflecting alterations in the magnitude and phase of the electric and magnetic fields at the new frequency.

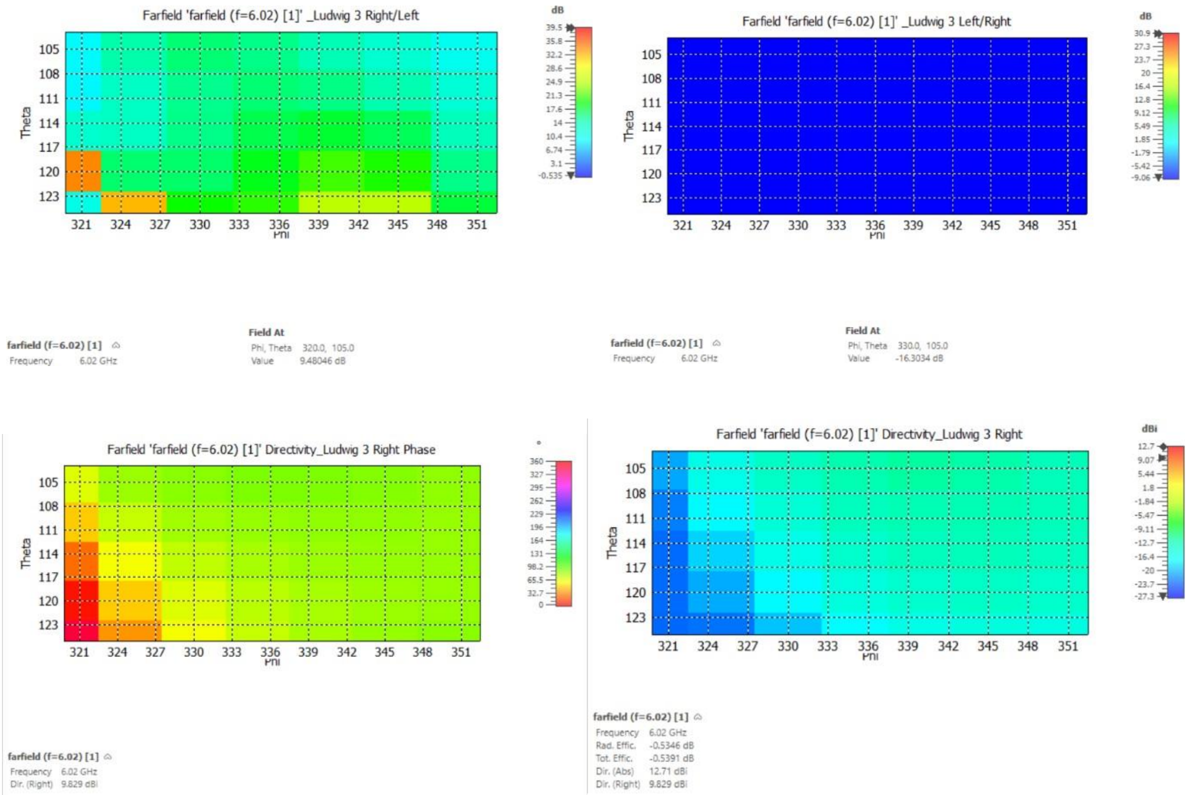
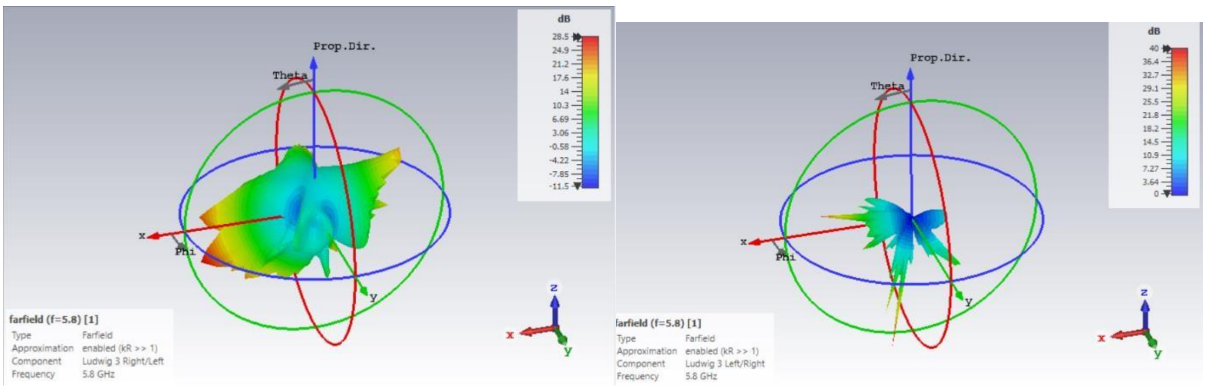


Figure (7.7) 2D Representation (6.02GHz)

7.5 3D VISUALIZATION

7.5.1 3D VISUALIZATION: FREQUENCY: 5.8 GHZ



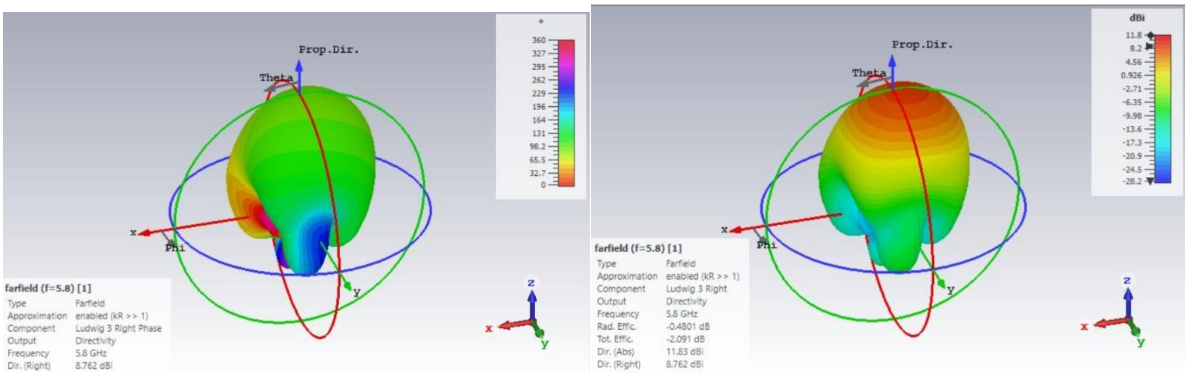
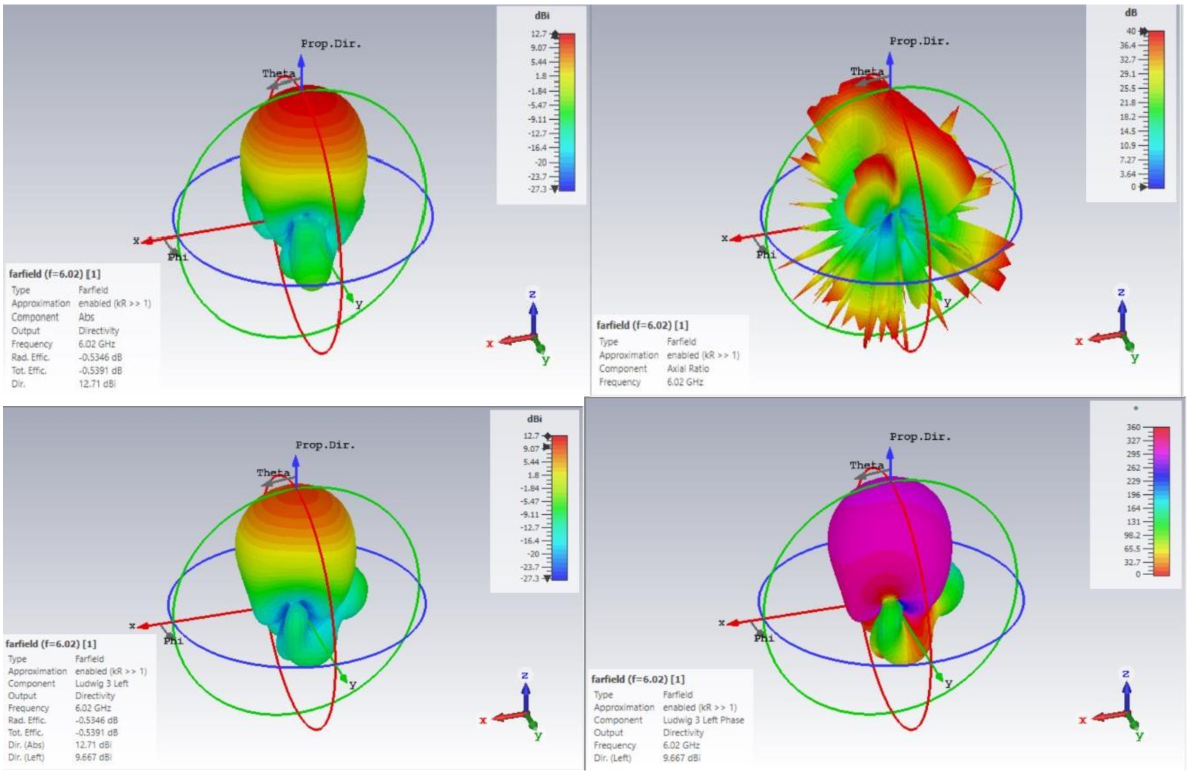


Figure (7.8) 3D Representation (5.8GHz)

Three-dimensional rendering of the antenna array, showing its geometry and spatial distribution of radiation. Visualization of the radiation pattern in space, highlighting main lobes, side lobes, and nulls.

7.5.2 3D VISUALIZATION: FREQUENCY: 6.02 GHZ



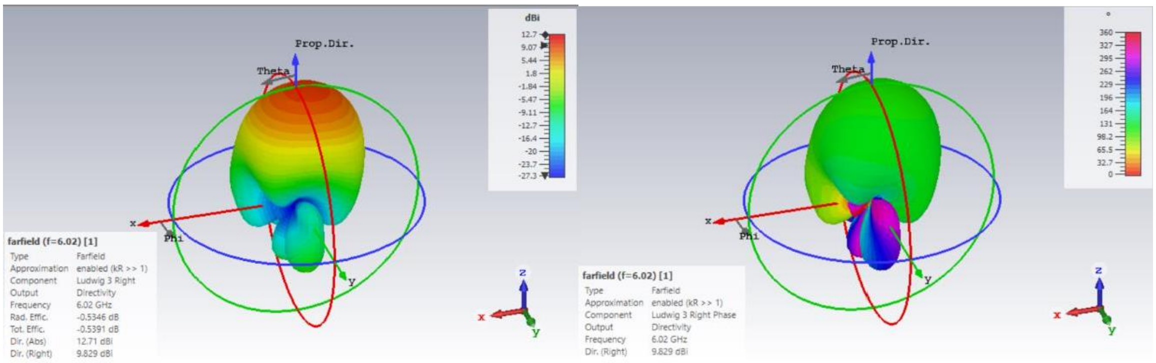


Figure (7.9) 3D Representation (6.02GHz)

Updated three-dimensional representation of the antenna array, capturing modifications in its geometry and radiation characteristics.3D visualization of the radiation pattern, showcasing shifts in main lobe direction and changes in side lobe levels at the new frequency.

CHAPTER 8
RESULTS & DISCUSSION

The simulated antenna is fabricated and measured results are captured by Agilent technologies microwave vector network analyzer. Fabricated antenna is tested and antenna parameter such as VSWR, Phase plot and S-parameter frequency are get measured.

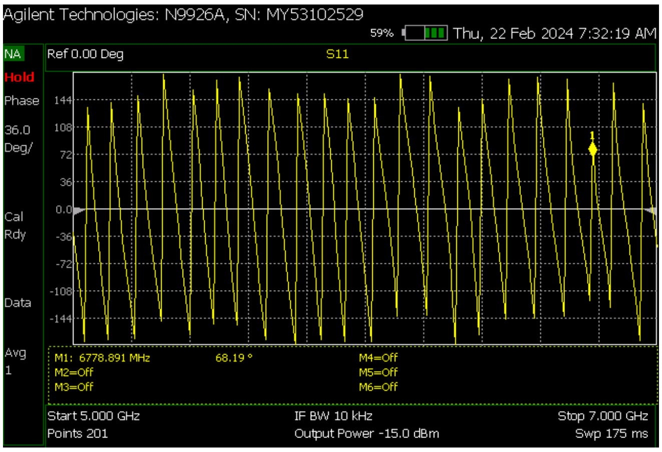


Figure (8.1) Phase Plot of 2x2 antenna using Network Analyzer

The above figure represents the Phase plot of 2x2 antenna using Network Analyzer.

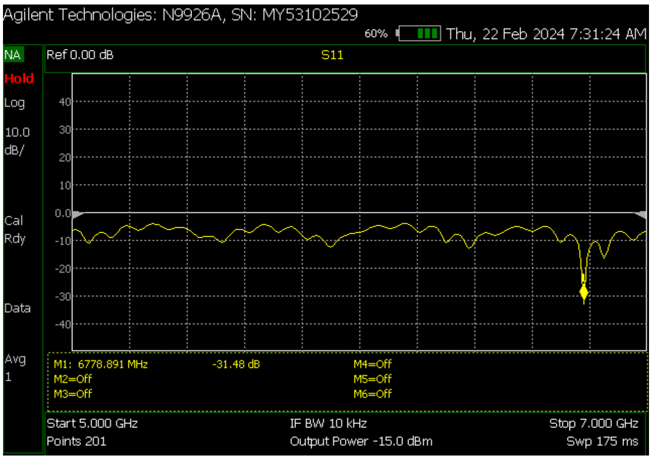


Figure (8.2) S_{11} Parameter at 6.7 GHz using Network Analyzer

The above figure represents S_{11} Parameter at 6.7 GHz using Network Analyzer.

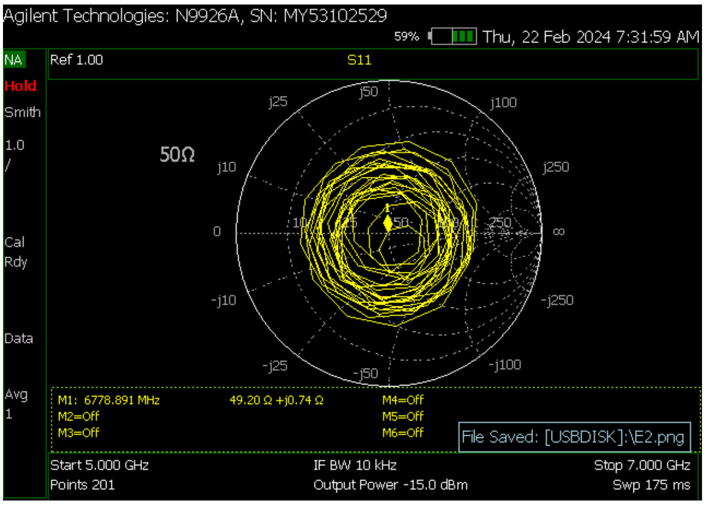


Figure (8.3) VSWR Wave Impedance using Network Analyzer

The above figure represents VSWR Wave Impedance using Network Analyzer.

COMPARATIVE ANALYSIS:

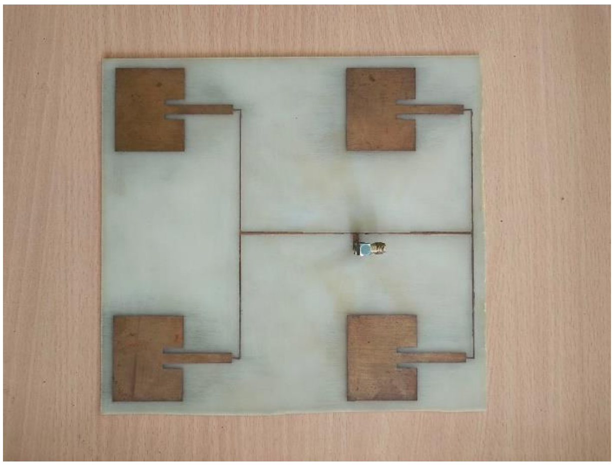


Figure (8.4) 3G 2x2 Array Antenna

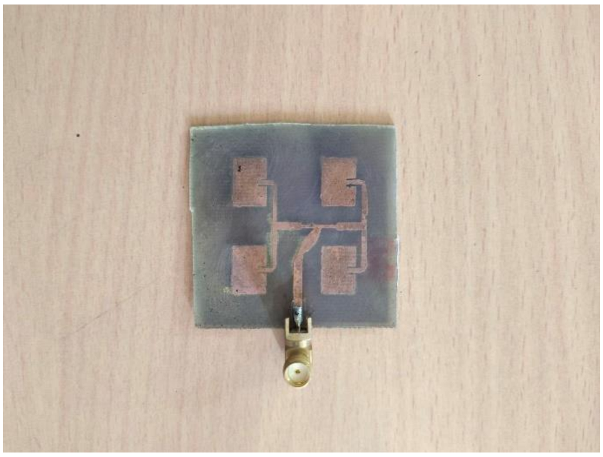


Figure (8.5) 6G 2x2 Array Antenna

Comparing the performance of a 3G 2x2 microstrip patch antenna and a 6G 2x2 microstrip patch antenna would involve evaluating various parameters such as bandwidth, gain, efficiency, radiation pattern, and size. Generally, the 6G antenna is expected to have broader bandwidth, higher gain, and improved efficiency compared to the 3G antenna, reflecting advancements in antenna design and technology with the evolution of wireless generations. However, specific results would depend on the design specifications and implementation of each antenna.

MERITS AND DEMERITS

The merits of a 6G 2x2 microstrip patch antenna include potentially higher data rates, increased capacity for simultaneous connections, and improved spectral efficiency due to advancements in technology and frequency usage.

On the other hand, the demerits of a 3G 2x2 microstrip patch antenna might include slower data rates, limited capacity for connections compared to newer generations, and potentially less efficient use of spectrum, leading to lower overall performance compared to newer technologies like 6G.

6G technology is expected to utilize higher frequencies and advanced modulation techniques, allowing for more efficient use of the spectrum and with advancements in signal processing and antenna design, 6G can potentially offer significantly higher data rates compared to previous generations.

Whereas, 3G technology typically offers lower data rates compared to newer generations, restricting the bandwidth available for high-speed applications.

6G aims to minimize latency, enabling real-time applications like remote surgery, autonomous vehicles, and augmented reality to operate seamlessly. Advanced antenna technologies and beamforming techniques in 6G can enhance signal reliability, even in challenging environments.

6G antennas may support multiple functionalities such as communication, sensing, and localization, enabling a wide range of applications beyond traditional connectivity.

As more users connect to 3G networks, congestion becomes a significant issue, leading to slower speeds and degraded performance, especially in densely populated areas.

With the evolution of mobile technologies, older 3G antennas may not be compatible with newer devices or network standards, limiting their usefulness in modern communication ecosystems.

3G networks may have limited coverage compared to newer technologies, especially in rural or remote areas where infrastructure upgrades may be lacking. Older antenna technologies in 3G devices may require higher power levels to maintain connectivity, leading to faster battery drain compared to more energy-efficient options available in newer generations.

CHAPTER 10

CONCLUSION AND FUTURE SCOPE

CONCLUSION

The design of the 6G edge Fed 2x2 array antenna using FR4 substrate is a promising solution for various applications requiring high-frequency performance. The analysis of the one-dimensional, two-dimensional, and far-field results collectively demonstrates the antenna's efficiency, directivity adjustability, and high-power levels, respectively. The design has potential for further improvement, making it an exciting avenue for future research. Future work on this design can focus on optimizing the antenna's directivity, exploring different substrate materials and designs, and investigating its applications in different fields such as medical imaging, remote sensing, and telecommunications. Such investigations will require further refinement of the design and optimization to meet the specific needs of these applications. Additionally, the comparison of the efficiency at different energy-fed levels reveals that the antenna's efficiency decreases slightly as the energy fed is reduced. This highlights the importance of considering antenna efficiency in the design and optimization of the antenna for different applications. Overall, the design of the 6G edge Fed 2x2 array antenna using FR4 substrate is a highly promising solution that can provide high-quality performance and lead to further advancements in the field of antenna technology.

FUTURE SCOPE

The future scope of a 6G edge-fed 2x2 array antenna using FR4 substrate is promising. It could potentially offer improved performance in terms of data transmission rates, network capacity, and coverage compared to previous generations. Additionally, its use of FR4 substrate could lead to cost-effectiveness and easier integration into devices. However, advancements in materials, manufacturing techniques, and signal processing will likely play key roles in maximizing its potential.

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