DESIGN AND ANALYSIS OF TRIANGULAR PATCH ANTENNA ARRAY

A PROJECT REPORT

Submitted by

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in partial fulfillment for the award of the

degree of

BACHELOR OF ENGINEERING

in

ELECTRONICS AND COMMUNICATION ENGINEERING

PANIMALAR INSTITUTE OF TECHNOLOGY

ANNA UNIVERSITY: CHENNAI 600 025

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ABSTRACT

This paper presents the design and analysis of a triangular microstrip patch array antenna using Computer Simulation Technology (CST) with varying FR-4 substrates. The antenna is designed on a rectangular FR-4 substrate with dimensions of 10×10 mm, operating within the frequency range of 2 GHz to 3 GHz. The design methodology and simulation results for key parameters such as return loss, gain, directivity, and radiation patterns are comprehensively discussed. The triangular microstrip patch antenna exhibits high performance and is suitable for various wireless communication applications, including UMTS and ISM bands.

Furthermore, this study explores the impact of different FR-4 substrates on the antenna's performance, providing insights into substrate selection for optimizing antenna characteristics. The results highlight the antenna's robustness and efficiency in meeting the requirements of modern wireless communication systems. Additionally, the potential for creating antenna arrays with 2, 4, 6, and 8 elements is discussed, emphasizing scalability and versatility in array configurations for improved communication performance.

Overall, this project contributes to the advancement of microstrip patch antenna technology, offering practical design guidelines and performance evaluation metrics crucial for the development of next-generation wireless communication systems

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LIST OF ABBREVIATIONS

CST	-	Computer Simulation Technology
FR-4	-	Flame Retardant
GHz	-	Gigahertz
UMTS	-	Universal Mobile Telecommunication System
ISM	-	Industrial, Scientific, and Medical
VSWR	-	Voltage Standing Wave Ratio
Db	-	Decibels
HPBW	-	Half Power Beam Width
SWR	-	Standing Wave Ratio
IoT	-	Internet of Things
GPS	-	Global Positioning System
V2V	-	vehicle-to-vehicle
FIT	-	Finite Integration Technique
RF	-	Radio Frequency
EMC	-	Electromagnetic compatibility
EMI	-	Electromagnetic interference
CAD	-	Computer-Aided Design
PTFE	-	Polytetrafluoroethylene
LCP	-	liquid crystal polymer
THz	-	Terahertz
IRNSS	-	Indian Regional Navigation Satellite System

GAGAN	-	GEO Augmented Navigation
WLAN	-	Wireless Local Area Network
ISSCS	-	International Symposium on Signals, Circuits and Systems
ICCEREC	-	International Conference on Control, Electronics, Renewable Energy and Communications
DTV	-	Digital Television
DVB-T2	-	Digital Video Broadcasting Terrestrial second-generation
UHF	-	Ultra High Frequency
CPW	-	Commercial Processing Workload
GND	-	Ground
FSS	-	Frequency Selective Surface
MPA	-	Microstrip Patch Antenna
PTFE		Polytetrafluoroethylene
AF	-	Array Factor

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW OF MICROSTRIP ANTENNA

Antennas play a very important role in the field of wireless communications. It has the advantage of being lightweight, reduced size, low cost, conformability, and ease of integration with active devices. Des Champs introduced the concept of the microstrip antenna in 1953, but the first microstrip antenna was developed by Howell & Munson after 20 years in the early 1970s. This printed patch antennae finds large applications in new wireless communications during its low profile features but its narrow bandwidth features limit the usage from many applications. Presently, ultra-wideband communication has become popular because of the high data transfer rate. The time domain features of short pulses used in ultra-wideband communication systems are in the present research area. Individuals have an interest in electrically small antennae because this kind of antenna enhances the uses of wireless technologies, for communications and sensor networks.

The patch is generally made of conducting material such as copper or gold. Microstrip antennas are becoming very widespread within the mobile phone market and also in bio-medical applications.

Microstrip antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antenna comprises a ground plane, substrate, and a feed-through which field is given to the element and is shown in fig.1.1. The arrays of microstrip elements with single feed or multiple feeds may be used for greater directivity.

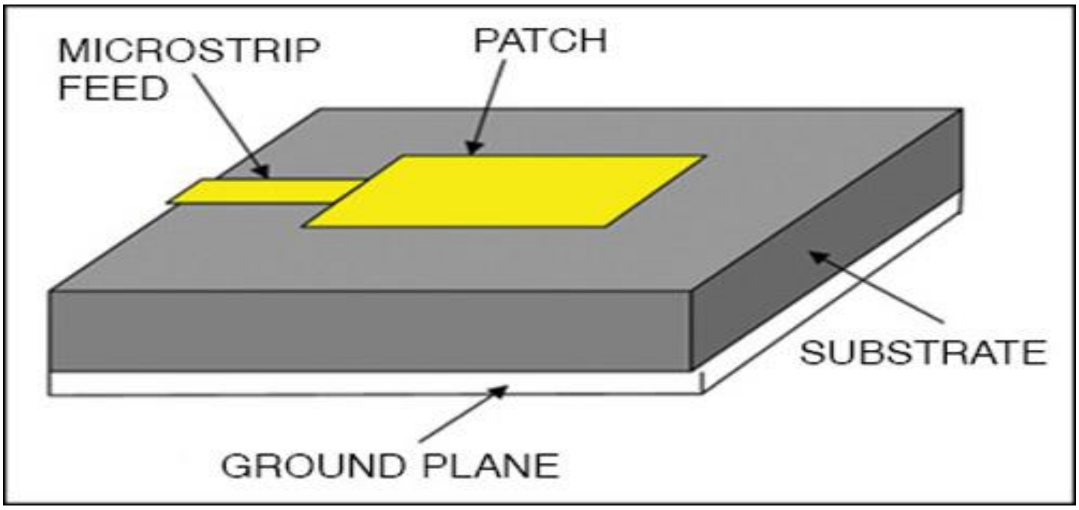


Fig.1.1.Microstrip antenna

The feed lines and matching networks can be fabricated simultaneously with the antenna structure.

The commonly available shapes of patch antennae are rectangular, circular, dipole, triangular, square, and elliptical with rectangular and circular shapes the most common. Commonly available shapes of microstrip patch antenna

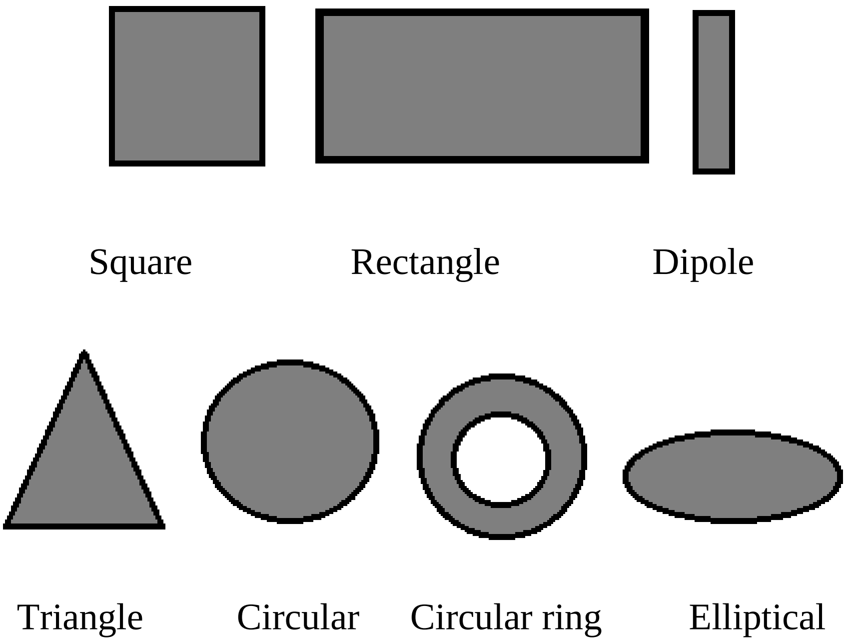


Fig 1.2 Shapes of patch antenna

1.2 APPLICATION OF TRIANGULAR PATCH ANTENNA

Triangular patch antennas are highly versatile components utilized across various industries owing to their compact size, straightforward fabrication process, and reliable performance characteristics. In the realm of wireless communication systems, including Wi-Fi, Bluetooth, RFID, and Zigbee networks, triangular patch antennas excel due to their omnidirectional radiation pattern and moderate gain, making them ideal for short-range communication needs. Similarly, in satellite communication, these antennas are employed for signal transmission and reception in ground stations and satellite payloads, facilitating efficient downlink and uplink operations.

In radar systems, triangular patch antennas contribute to target detection, tracking, and imaging applications, often integrated into radar arrays to enhance performance through advanced beamforming techniques. Their deployment extends into remote sensing endeavors such as environmental monitoring and weather forecasting, where they play a pivotal role in collecting and relaying data from satellites, drones, or ground-based platforms.

Moreover, triangular patch antennas are integral to the functionality of mobile devices like smartphones, tablets, and wearables, providing essential wireless connectivity for cellular, GPS, and NFC functionalities while maintaining a low-profile design. Additionally, their use of RFID tags enables seamless item tracking, inventory management, and access control across various industries.

Beyond telecommunications, triangular patch antennas find applications in medical telemetry systems, facilitating wireless data transmission from wearable sensors to medical devices, thereby enhancing healthcare monitoring capabilities. They also serve crucial roles in aerospace and defense technologies, including aircraft communication, electronic warfare systems, and missile guidance, owing to their robust performance and compact build.

Furthermore, these antennas are essential components within the Internet of Things

(IoT) ecosystem, enabling wireless connectivity and data exchange among interconnected devices in smart home setups, industrial sensors, and other IoT applications.

Lastly, triangular patch antennas are integrated into automotive communication systems for GPS navigation, satellite radio, cellular connectivity, and vehicle-to-vehicle (V2V) communications, illustrating their widespread adoption across diverse sectors due to their reliability, efficiency, and adaptability to challenging environments and operational requirements.

1.3 ADVANTAGES AND DISADVANTAGES OF TRIANGULAR ANTENNA

ADVANTAGES

Triangular patch antennas offer several distinct advantages that make them highly desirable for various applications across industries. Their compact size allows them to fit into space-constrained environments, making them ideal for integration into mobile devices, wearable electronics, and compact communication systems where size matters. Additionally, their low-profile design ensures they can be seamlessly incorporated into devices without adding significant bulk or weight, preserving the overall aesthetics and functionality of the equipment.

The simplicity of their design is another key advantage, enabling cost-effective manufacturing processes compared to more complex antenna types. This simplicity contributes to their widespread adoption and use in diverse applications. Triangular patch antennas can also be engineered for wideband operation, covering a broad frequency range without requiring frequent tuning or adjustments. This versatility allows for their deployment across various communication systems without compromising performance.

Depending on the specific design, triangular patch antennas can exhibit omnidirectional radiation patterns, facilitating uniform signal coverage in all directions. This characteristic is particularly advantageous in applications where signal distribution needs to be consistent and widespread. Furthermore, triangular patch antennas typically offer moderate gain, providing adequate signal strength for short to moderate-range communication without the need for high-power transmission, which can be advantageous for power-efficient systems.

Finally, the cost-effectiveness of triangular patch antennas is a significant factor driving their popularity. Their straightforward design and ease of manufacture translate into lower production costs, especially when produced in large quantities. This affordability makes triangular patch antennas a preferred choice for applications where budget constraints are a consideration, further highlighting their value and versatility in modern wireless communication and technology ecosystems.

DISADVANTAGES

While triangular patch antennas offer several advantages, they also come with certain limitations and disadvantages that need to be considered for optimal deployment in various applications. One notable drawback is their potential for limited bandwidth compared to certain other antenna types, which can restrict their suitability for applications requiring operation over a wide frequency range. This limitation may necessitate careful design considerations to match specific frequency requirements.

Like many compact antennas, triangular patch antennas can be sensitive to nearby objects, particularly metallic or conductive surfaces, which may cause detuning or interference, impacting their performance in certain environments. Additionally, while some designs can provide omnidirectional radiation patterns, others may exhibit directional characteristics, limiting their effectiveness in applications requiring uniform signal coverage in all directions.

The performance of triangular patch antennas is also dependent on the properties of the substrate material used for fabrication, such as dielectric constant and thickness. This substrate dependence may require meticulous design adjustments to achieve desired performance outcomes.

Moreover, triangular patch antennas may be susceptible to environmental factors including temperature variations, moisture, and mechanical stress, which can affect their reliability and performance, especially in outdoor or harsh environments. Achieving optimal impedance matching between the antenna and the transmission line can also pose a challenge, potentially necessitating the use of complex matching networks or impedance matching techniques to maximize efficiency and signal integrity.

Understanding these disadvantages is crucial for engineers and designers when selecting antenna solutions for specific applications, enabling informed decision-making to mitigate potential limitations and optimize performance based on operational requirements and environmental conditions. Despite these drawbacks, triangular patch antennas remain a viable and widely used antenna option across a spectrum of industries due to their compact design, cost-effectiveness, and versatile performance characteristics.

1.4 Antenna characteristics

It is necessary to initiate it by understanding several terms associated with antenna which is formally known as antenna parameters. The important parameters need to be considered to characterize that the antenna is return loss, radiation pattern, half–power beam width, VSWR, antenna efficiency, bandwidth, directivity, and gain.

1.4.1 Return loss

It is a parameter that points out the amount of power that is “lost” to the load and doesn’t return as a reflection. Thus, the return loss S_{11} is a parameter to indicate how well the matching between the transmitter and antenna has taken place. For optimum working return loss graph shows a dip at the operating frequency and has a minimum dB value at this frequency.

1.4.2 Radiation pattern

It is a plot of the far-field radiation properties of an antenna as a function of the spatial coordinates which are specified by the elevation angle (θ) and the azimuth angle (φ). Specifically, it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. It can be plotted as a 3D graph/ 2D polar/ Cartesian slice of this 3D graph. It is an important parameter as it shows the antenna's directivity in addition to gain at various points in space. It serves as the signature of an antenna and enough to realize the antenna that produced it. Because this parameter is so important, software simulations are needed to understand it completely. An isotropic antenna radiates equally in all directions, and its radiated power density 'S' is found by dividing the radiated power by the area of the sphere $4\pi R^2$. It is considered to be 100% efficient. The gain of an actual antenna increases the power density in the direction of the peak radiation. The radiated power density is given by

$$S = \frac{P_0 G}{4\pi R^2} \tag{1.1}$$

where

S	-	Isotropic antenna radiated power density
P_0	-	Input power to the isotropic antenna
R	-	Distance between the antenna

1.4.3 Half-power beam width

It is easily determined from its 2D radiation pattern. Generally, beam width is defined as two identical points which are separated by angular separation in a radiation pattern. If the angular separation between two identical points is one-half value of the beam then it is said to be half the power beam width. How beam width is determined is shown in Figure 1.2.3.

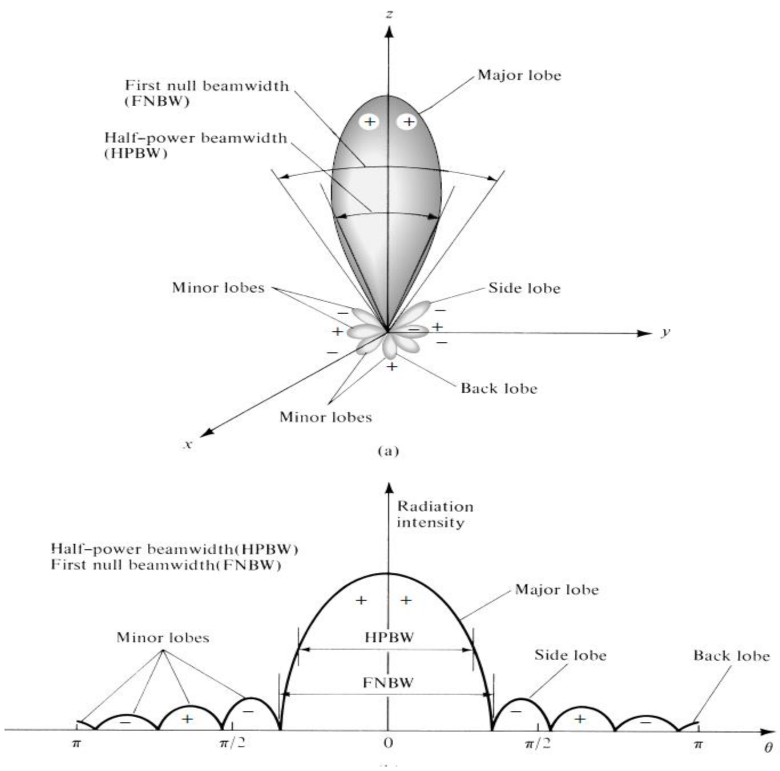


Figure 1.4.1 Determination of HPBW from the radiation pattern

1.4.4 VSWR

VSWR stands for Voltage Standing Wave Ratio and these are also known as Standing Wave Ratio (SWR). This is a function of the reflection coefficient which is to explain the power reflections from the antenna. Considering the reflection coefficient, then the VSWR is defined as

$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{1.2}$$

In the case of antennae, VSWR is always a real and positive integer, and its power transmissions are based on its size. For instance, the smaller the VSWR higher the antenna matching with the transmission line and power generation. In the minimum value of SWR i.e. at 1.0 no power is reflected from the antenna and it remains completely ideal. In regular processes, antennae must fulfill the requirements of bandwidth in terms of given VSWR.

The VSWR is determined by the voltage along the transmission lines leading to an antenna and it is also calculated by using the ratio of peak amplitude to the minimum amplitude of a standing wave as shown in Figure 1.5. Whenever the antenna does not match the receiver, the power reflects, and even its reflection coefficient becomes zero. This causes a reflection voltage wave by creating a standing wave all along the transmission line. Suppose the VSWR is 1.0, there will not be any reflected rays and even voltage will maintain constant magnitude along the transmission line.

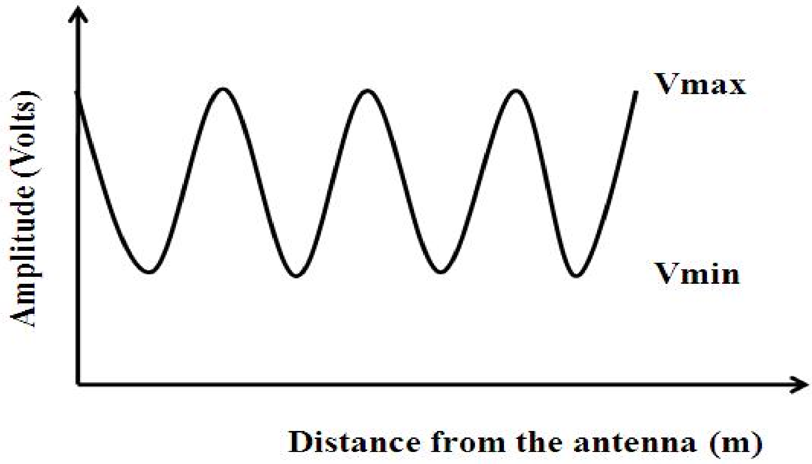


Figure 1.4 Voltage measured along a transmission line

1.4.5Efficiency

The surface integral of the radiation intensity over the radiation sphere divided by the input power P_0 is a measure of the relative power radiated by the antenna or the antenna efficiency.

$$\frac{P_r}{P_0} = \int_0^{2\pi}\int_0^{\pi} \frac{G(\theta,\varphi)}{4\pi}\,\sin\theta\,d\theta\,d\varphi = \eta_e \qquad (1.3)$$

where

P_r is the radiated power.

P_0 is the input power.

$G(\theta,\varphi)$ is the gain in the direction of elevation and azimuth.

η_e is the antenna efficiency.

Material losses in the antenna or reflected power during poor impedance match reduce the radiated power.

1.4.6 Bandwidth

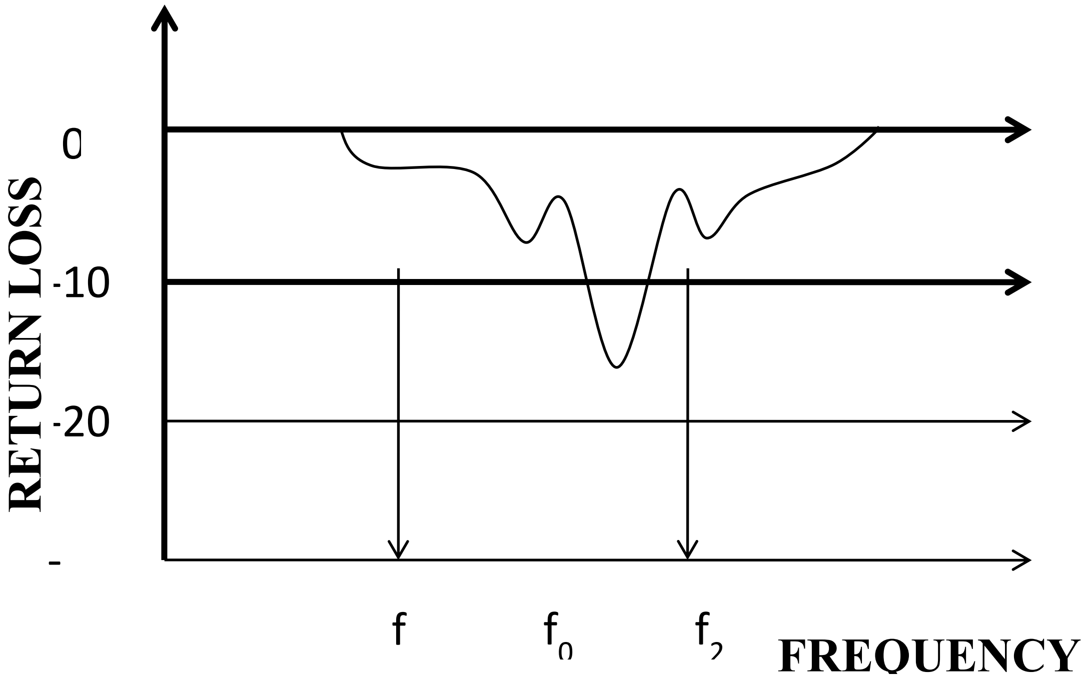


Figure 1.4.2 Return Loss Vs Frequency

Bandwidth is simply defined as a frequency range over which an antenna meets a certain set of specification performance criteria. A significant issue to consider about bandwidth is the performance tradeoffs between all of the performance properties.

In all situations, the required performance properties of an antennae are achieved only by the limited frequency bandwidth. Bandwidth range is the significant aspect of the performance requirements, selected antenna type, and its size relative to the operating wavelength. Normally, optimum antenna performance is achieved at the center frequency of the operating band.

$$\text{Bandwidth} = \frac{f_2 - f_1}{f_0} \times 100\% \qquad (1.4)$$

where

f_2 - Upper frequency

f_1 - Lower frequency

f_0 - Center frequency

1.4.7 Directivity

The measure of the concentration of radiation in the direction of the maximum is said to be known as directivity.

$$\text{Directivity} = \frac{\text{maximum radiation intensity}}{\text{average radiation intensity}} = \frac{U_{max}}{U_0} \qquad (1.5)$$

Directivity and gain differ by efficiency, but directivity is easily estimated from patterns. Directivity is technically a function of angle but the angular variation is described by its radiation pattern. The average radiation intensity can be found from a surface integral over the radiation sphere of the radiation intensity divided by 4π, the area of the sphere in steradians:

$$\text{radiation intensity} = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi} U(\theta,\varphi)\theta d\theta d\varphi = {}_0 \qquad (1.6)$$

Directivity is defined for an arbitrary direction D(θ, φ) as radiation intensity divided by the average radiation intensity, but when the coordinate angles are not specified, directivity is calculated at Umax.

1.4.8 Gain

Antenna gain is the maximum real power radiated in a particular direction. It is defined as the ratio between radiation intensity in a particular direction to the average radiation intensity of the antenna.

$$G = 4\pi \frac{U(\theta,\varphi)}{P_{in}} \tag{1.7}$$

where,

$U(\theta,\varphi)$ - Radiation intensity in a particular direction.

P_{in} - Input power to the isotropic antenna.

1.5 FEEDING TECHNIQUES

The role of feeding is very important in the case of efficient operation of the antenna to improve the antenna input impedance matching. Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories-contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling, and proximity coupling (both non-contacting schemes).

1.5.1 MICROSTRIP LINE FEED:

In this type of feed technique, a conducting strip is connected directly to the edge of the Microstrip. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

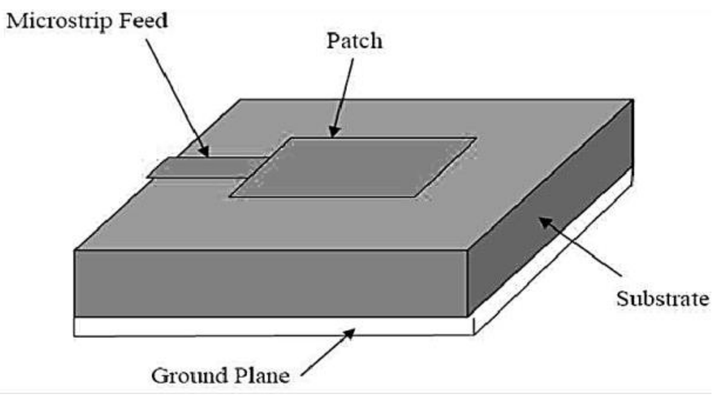


Fig 1.5.1 Microstrip line feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset positions. This is achieved properly by controlling the inset position. Hence this is an easy feeding scheme since it provides ease of fabrication and simplicity in modeling as well as impedence matching. However, as the thickness of the dielectric substrate being used, increases, surface waves, and spurious feed radiation also increase, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross-polarized radiation.

1.5.2 CO-AXIAL FEED:

Coaxial probe feeding is a very common technique used for feeding Microstrip patch antennas. The conductor of the coaxial cable extends through the dielectric and is soldered to the radiating metal patch, while the outer conductor is connected to the ground plane. The advantage of this feeding scheme is that the feed can be placed at any desired location on the patch to match cable impedance with the antenna input impedance. The main aim of using probe feeding is it enhance the gain and provide narrow bandwidth and impedance matching.

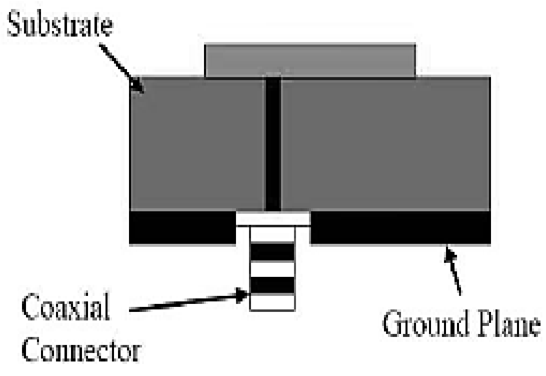


Fig 1.5.2 Co-axial feed

1.5.3APERTURE COUPLED FEED

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

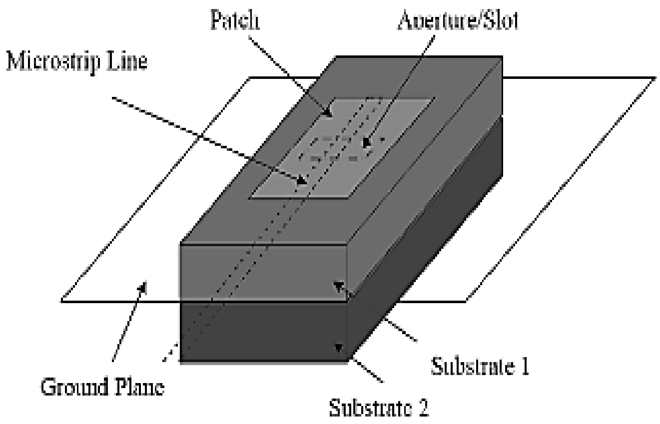


Fig 1.5.3 Aperture coupled feed

The connecting apertures usually center under the patch, leading to lower cross-polarization due to the symmetry of the configuration. the amount of coupling from the feed line to the patch is determined by the shape, size, and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high-dielectric material is used for the bottom substrate and a thick, low-dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides a narrow bandwidth.

1.5.4 PROXIMITY COUPLED FEED

This type of feed technique is also called the electromagnetic coupling scheme. Two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13), due to an overall increase in the thickness of the microstrip patch antenna. This scheme also provides a choice between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

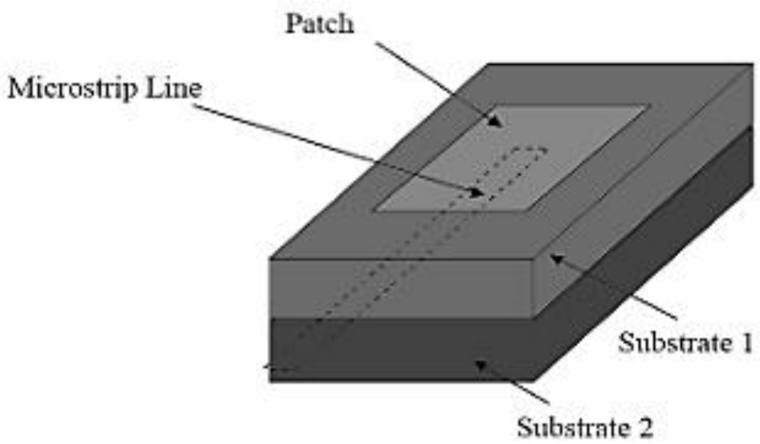


Fig 1.5.4 Proximity coupled feed

Matching can be achieved by controlling the length of the feed line and width-to-width ratio of the patch. The major disadvantage of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna.

The characteristics of the different feed techniques are summarized below in Table 1.5.1

Table 1.5.1 Different feeding technique

Characteristics	Microstrip line feed	Coaxial feed	Aperture coupled feed	Proximity coupled feed
Spurious feed radiation	More	More	less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling are needed	Alignment required	Alignment required
Impedance matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

1.6 TRIANGULAR ANTENNA ARRAY

Triangular array antennas are a type of antenna configuration that consists of multiple individual antenna elements arranged in a triangular pattern. This arrangement allows for improved signal reception and transmission capabilities.

One of the advantages of triangular array antennas is their ability to provide directional coverage. By adjusting the phase and amplitude of the signals transmitted by each antenna element, the overall radiation pattern of the array can be shaped to focus the signal in a specific direction. This can be useful in applications such as wireless communication systems, radar systems, and satellite communication.

Triangular array antennas also offer increased gain compared to single-element antennas. Gain refers to the ability of an antenna to focus its radiation pattern in a particular direction. By combining the signals from multiple antenna elements, the overall gain of the array can be significantly enhanced, resulting in improved signal strength and coverage. Additionally, triangular array antennas can provide diverse reception. By using multiple antenna elements, the array can receive signals from different directions simultaneously, reducing the impact of fading and improving overall signal quality. Overall, triangular array antennas are a versatile and powerful solution for various communication and radar systems. Their ability to provide directional coverage, increased gain, and diversity reception makes them an excellent choice for applications that require reliable and efficient signal transmission and reception.

1.7 PROBLEM STATEMENTS

- Design and optimize a triangular patch antenna for use in a wireless communication system operating in the 5G frequency range.
- The antenna should have a compact form factor and omnidirectional radiation pattern while achieving high efficiency and gain. Additionally, it should be robust to environmental factors and capable of withstanding temperature variations and mechanical stress.
- The goal is to maximize the antenna's performance in terms of signal coverage and reliability, taking into account the constraints of size, cost, and manufacturing complexity.

1.8 OBJECTIVES

- The design objectives for a triangular patch antenna encompass a range of critical considerations aimed at achieving optimal performance and functionality across various applications. Firstly, determining the antenna's frequency operation involves establishing the desired operating frequency range and ensuring resonance at specific frequencies within this range to facilitate efficient signal transmission and reception.

- Radiation characteristics play a pivotal role in antenna design, encompassing factors such as directivity, radiation pattern, and polarization. These characteristics are tailored to meet specific application needs, ensuring reliable and effective signal propagation.
- Bandwidth is another key objective, requiring the antenna to possess sufficient bandwidth to cover the required frequency spectrum without sacrificing performance. Impedance matching is crucial for optimizing power transfer efficiency between the antenna and feeding network, enhancing overall system efficiency.
- Size and compactness considerations are essential for designing antennas suitable for integration into small devices or systems while maintaining performance standards. Achieving an optimal balance between antenna size and gain is imperative, necessitating careful geometry and feeding technique optimization.
- Ensuring robustness and stability involves designing the antenna to withstand environmental factors such as temperature variations, moisture, and mechanical stress, ensuring consistent performance over time and under varying conditions.
- Fabrication and manufacturing constraints are also integral to antenna design, requiring optimization for ease of production while adhering to specific manufacturing capabilities and limitations.

1.9 Tool Used

1.9.1 CST STUDIO SUITE :

CST Studio Suite is a powerful software package widely used for electromagnetic simulation and analysis in the field of antenna design and RF/microwave engineering. Developed by Computer Simulation Technology (CST), the suite provides a comprehensive set of tools and features for designing, optimizing, and analyzing complex electromagnetic systems. One of the key strengths of CST Studio Suite is its capability to perform 3D electromagnetic simulations based on the Finite Integration Technique (FIT). This technique allows accurate modeling of electromagnetic fields, interactions, and wave propagation within intricate geometries and complex structures. The software supports a wide range of applications, including antenna design, microwave components, RF circuits, EMC/EMI analysis, and high-frequency devices.CST Studio Suite offers a user-friendly interface that facilitates the creation and manipulation of CAD-based models for electromagnetic simulation. Users can import geometry from various CAD formats or create custom geometries directly within the software. The suite includes extensive libraries of predefined materials and components, enabling quick setup and modeling of different antenna configurations and structures.

For antenna design and analysis, CST Studio Suite provides tools to visualize and optimize key parameters such as radiation patterns, impedance matching, and bandwidth. Advanced simulation capabilities allow users to evaluate antenna performance under various operating conditions, including different frequencies, polarization, and environmental factors.Moreover, CST Studio Suite offers integration with other simulation tools and workflows, allowing seamless coupling with circuit simulators, thermal analysis software, and system-level simulation platforms. This interoperability enhances the overall design process and enables comprehensive multi-physics simulations.

The suite also includes post-processing tools for analyzing simulation results, generating graphical outputs, and extracting performance metrics. Users can visualize field distributions, S-parameters, far-field patterns, and other relevant data to gain insights into antenna behavior and performance.

Overall, CST Studio Suite is a versatile and comprehensive software solution for electromagnetic simulation and antenna design, providing engineers and researchers with the tools necessary to develop and optimize innovative antenna systems for a wide range of applications in communications, aerospace, automotive, and beyond.

CHAPTER 2
LITERATURE REVIEW

In 2021, Sahereh Sahandabadi; Esam Abdel-Raheem; and Shahpour Alirezaee discussed “ Wireless Power Transfer using Triangular Patch Microstrip at 2.4GHz” In their paper, a triangular microstrip patch antenna is used to transfer wireless power at 2.4 GHz. First, the simple patch antenna is studied and its performance is investigated. Then, the new design is introduced to boost the efficiency and transmission coefficient of the simple patch antenna. Since the simple patch aimed to operate at 2.4GHz, its dimension is optimized to be 56mm with a reflection coefficient of -28.2 dB at the resonance frequency. An identical patch acting as a receiver is then placed at a 50mm distance from the main patch acting as a transmitter to enable us to measure the power transferred to the receiver antenna. The transmission coefficient between the two simple patches is -3.5 dB at the resonance frequency of 2.4 GHz. Furthermore, the proposed array is designed and simulated yielding a reflection coefficient of -28 dB at 2.4 GHz. The same procedure for the simple patch is followed to obtain the transmission coefficient of -0.55 dB at 2.4 GHz. The simulation results show 89% efficiency for the proposed structure compared to the 44% efficiency of the single patch

“Triangular antenna arrays “ was written by K. Bibl, he describes Antenna arrays in an equilateral triangle configuration can simultaneously provide optimum correlation between antennas at almost vertical incidence as well as substantial suppression of low incidence angle interference and high two-dimensional location finding resolution. In all configurations, the use of a center antenna is beneficial for all three requirements: test of consistency of phase data over the whole antenna array, indicating single sources for each Doppler line, as well as maximum interference suppression and optimization for the direction finding resolution.

Recently the development of technology in telecommunications systems, especially Digital Television (DTV), is growing very rapidly. In Indonesia, the adopted technology is Digital Video Broadcasting Terrestrial Second generation (DVB-T2) which has been utilized since 2012. It uses the UHF frequency range that is the same as analog television. One device that is used to support the DVB-T2 application is the antenna. It should inherit wide enough bandwidth as well as high gain to obtain good performance in receiving the DTV signal. In this paper, the design of a linear triangular microstrip patch array antenna for DTV application is proposed. The design adopts CPW-fed, parasitic patch, and air gap methods to obtain wide bandwidth and relatively high gain. The proposed antenna has been fabricated and measured. The actual obtained bandwidth of this antenna is about 400.2 MHz. The values of VSWR, return loss, and gain are about 1.25, -18.79 dB, and 3.21 dB respectively, and have a unidirectional radiation pattern with elliptical polarization. The proposed antenna has been used to receive DTV signals and has shown good results. This was described by Muthia Dwifarina Arza; Yuyun Siti Rohmah; Radial Anwar in his paper "Design and Realization of Linear Array Triangular Patch Microstrip Antenna for Digital Television".

Yahya S. H. Khraisat and Melad M. Olaimat "Comparison between rectangular and triangular patch antennas array" microstrip array antennas, suitable for wireless communication applications, are presented. This paper demonstrates several shapes of microstrip array antennas, such as rectangular and triangular patch antenna arrays. Specifically, 4×1, 2×1, and single elements of both shapes are designed and simulated by a full wave simulator (IE3d). Moreover, this paper presents a comparison between both rectangular and triangular antenna arrays. Since the resonance frequency of these antennas is 2.4 GHz; these antennas are suitable for ISM band and WLAN.

Md. Ashraful Islam and etal… (2023) Describe about "Design and analysis the performance of triangular patch antenna for THz applications" in Multidisciplinary Science Journal . Modern technology advancement requires a more extensive data rate to convey information more rapidly than ever. Improved bandwidth can satisfy the need for high-speed transmission demand. To achieve significantly increased bandwidth for a high data rate communication, the antenna design at the THz band is essential. The microstrip patch antenna is one of the most prominent antennas for THz band applications such as future 5G communication systems and advanced wireless communication systems. This paper proposed a triangular patch antenna for THz applications where FR4 is used at the substrate as an insulator and Graphene at the patch as a conductor. Moreover, we improve the performance of the proposed antenna by modifying the shape of the patch and ground (GND) layer. We modify the patch shape by cutting the corner edge of the triangular patch. Moreover, the GND layer is modified with horizontally partial ground. The size of the proposed antenna is set to 160×120 μm2. We analyze the performance of the proposed antenna using CST simulation software. Based on the simulation results, the proposed antenna with a modified patch and GND shape show a wide bandwidth of 1.27 THz and minimal return loss of -33.22 dB at a resonant frequency of 2.28 THz. Additionally, the gain and efficiency of the suggested antenna show good improvement. Therefore, the proposed triangular patch antenna with a modified patch and GND shape is expected to be suitable for high-speed THz applications.

“ Metamaterial based broadband microstrip antenna” was proposed by Hüseyin Akçelık and etal…, in 2013, In this paper, a broad bandwidth and high gain rectangular patch antenna using a planar-patterned metamaterial concept is proposed. The top patch has separated micro triangular patterns with periodic gaps while the ground plane is etched with crossed strip-line gaps. The patterned metal patch and ground plane form a coupled capacitive-inductive circuit of negative index metamaterial. Extended bandwidth from a few hundred megahertz to a few gigahertz is demonstrated. In addition, experimental and theoretical power reception performances of metamaterial and patch antennas for different selected frequencies are compared.

“Equilateral Triangular Slot-based Planar Rectangular Antenna for Millimeter-wave Applications”,was theorized by M. Usman Tahir in 2012, The design of an equilateral triangular slot-based planar rectangular antenna is presented for wideband millimeter-wave (mm-wave) applications. The front side of the proposed antenna is composed of a rectangular patch radiator with an equilateral triangular slot fed using a 50Ω microstrip feeding line, while the bottom side of the antenna consists of a partial ground plane. To achieve maximum impedance matching in the operating bandwidth, the position of the feeding line is shifted from its normal location. The overall dimensions of the antenna are noted to be 6.5×8.5 mm 2. From the simulation results, it is demonstrated that the -10 dB impedance bandwidth of the proposed antenna is 16.86 GHz, ranging from 22.28 GHz to 39.14 GHz, while at -15 dB, it is equal to 12.82 GHz in the frequency range of 24.18-37 GHz. The gain of the proposed antenna fluctuates in the range of 3.89-6.86 dBi with an antenna efficiency of >85%.

“Design of a triangular fractal patch antenna with a slit for IRNSS and GAGAN applications”, S. Arivazhagan, K. Kavitha, H.U. Prasanth, 2013 International Conference on Information Communication and Embedded Systems (ICICES) In this paper, a triangular fractal patch antenna with a slit is designed for IRNSS and GAGAN applications using ADS software. India intends to develop a satellite-based navigation system known as the Indian Regional Navigational Satellite System (IRNSS) for positioning applications. The design of the IRNSS antenna in the user sector is indispensable. GPS Aided and Geo Augmented Navigation (GAGAN), a satellite-based augmentation system for India, erected over the GPS is anticipated to provide flawless navigation support over the Asia-Pacific regions. The desired antenna has been deliberate on dielectric constant ε r = 4.8 and substrate thickness h = 3.05 mm. The feed location of the antenna has been selected to produce the circular polarization. The self-similar property in the antenna exhibits multi-band resonant frequencies. These specifications should be satisfied at the frequency .

“Gain enhancement of a microstrip patch antenna using a novel frequency selective surface” Adeline Mellita, D S Chandu, S S Karthikeyan, 2017 Twenty-third National Conference on Communications (NCC) A novel frequency selective surface (FSS) is proposed for the gain enhancement of a printed dipole antenna operating in the 5 GHz WLAN band. The proposed FSS is polarization-independent and angularly stable. The design has an array of triangular patches that resonate together at the designed frequency. By placing the FSS below the antenna, it acts as a reflector, and the gain of the antenna is enhanced by 4.54 dBi within 5-5.2 GHz. The proposed FSS and printed dipole antenna are simulated using a full-wave simulator and their prototypes are fabricated and measured. Good concordance between the simulated and measured results is obtained.

“Triangular and Circular Dual Band Microstrip Antenna for WLAN Application”, Azhari Asrokin, Mohd Kamal Abd. Rahim, Mohd Haizal Jamaluddin, Mohd Riduan Ahmad, 2006 International RF and Microwave Conference Wireless local area network (WLAN) applications nowadays have become more popular especially those operating in the 2.4 GHz ISM band. There are a lot of efforts to combine the WLAN and a/b/g bands. Such new designs either provide inadequate coverage of the frequency band or are not suitable for integration in some portable devices. This paper describes the design of the triangular and circular dual-band microstrip antenna using the scaling factor and inset feed technique. The antennas were designed to operate in the indoor WLAN ISM band at 2.4 GHz and 5.2 GHz. The scaling factor of 1.05 has been chosen for the design starting from the lowest resonating frequency at each band. The antennas have been fabricated on the FR4 photo board with epsiv r = 4.7, substrate height of 1.6 mm, and tan delta = 0.019 using the wet etching technique

“Resonant frequencies of triangular microstrip resonators using the novel formulation for effective side length”, Esmat A. F. Abdallah, Deena A. Salem, Essam A. Hashish, Mostafa El-Said, 2002 9th International Symposium on Antenna Technology and

Applied Electromagnetics In this paper, a novel factor is used to cater to the fringing field effect in triangular resonators. This factor is valid for both equilateral (symmetric) and non-equilateral (non-symmetric) triangular resonators. The problem of obtaining the resonant modes of the resonator is solved using the finite element method. Finally, the procedure is used to obtain the resonant frequencies of shapes other than equilateral triangular resonators namely: equilateral triangular resonators with curved vertices for different curvature ratios and isosceles triangular resonators.

"Truncated tip triangular microstrip patch antenna", Ashvini Chaturvedi, Yogesh Bhomia, Dinesh Yadav, Proceedings of the 9th International Symposium on Antennas, Propagation and EM Theory,2010 This paper presents a design of a triangular microstrip antenna with a truncated tip and experimentally studied on Ansoft Designer v-2.2.0 software. This design technology is achieved by cutting all three tips of the triangular microstrip antenna and placing a single coaxial feed. A triangular patch antenna is designed on an FR4 substrate of thickness 1.6 mm and relative permittivity of 4.4 and mounted above the ground plane at a height of 6 mm. Bandwidth as high as 11.07% is achieved with stable pattern characteristics, such as gain and cross-polarization, within its bandwidth.

Our project revolves around the development and analysis of an 8-element triangular array antenna. This antenna configuration holds promise for various applications due to its potential for enhanced performance in terms of impedance bandwidth, antenna gain, and return loss. By investigating these parameters, we aim to assess the effectiveness of the proposed antenna design in meeting the desired performance criteria. The design of our antenna involves careful consideration of several factors, with the choice of an 8- element triangular array being a key decision. The triangular arrangement offers advantages such as improved directivity and radiation pattern control compared to other array geometries. Additionally, the specific number of elements in the array is chosen to strike a balance between antenna complexity, performance, and practical considerations

CHAPTER 3
DESIGN AND SIMULATION

INTRODUCTION

Designing and simulating a triangular array antenna operating at 2.4 GHz frequency on an FR4 substrate involves a systematic approach to achieve desired performance characteristics. The design of a triangular array antenna for operation at 2.4 GHz frequency on an FR4 substrate begins with defining the antenna geometry, which includes determining the size and arrangement of antenna elements to achieve the desired radiation pattern and bandwidth.

Simulation tools such as electromagnetic simulation software (e.g., CST Microwave Studi) are employed to model the antenna structure, simulate its electromagnetic behavior, and analyze key performance metrics such as impedance matching, return loss, VSWR, radiation pattern, and antenna gain.

3.1 Design Of Microstrip Patch Antenna

The Microstrip Patch Antenna (MPA) comprises a very thin (t<< λ_0, where λ_0 is free space wavelength) conductive patch, which may assume any different form printed on top of a thin grounded dielectric [2, 5, 9]. The antenna is designed in such a way that its maximum radiation pattern is normal to the patch. This is skillfully decided by properly selecting the mode of excitation beneath the patch. For a rectangular patch, the length "L" of the element is usually $\frac{\lambda_0}{3} < L < \lambda_0/2$. The Strip (patch) and the ground plane are separated by a dielectric sheet called the substrate. The dielectric constant ranges from $2.2 \leq \varepsilon_r \leq 12$. The ones to have superior antenna operations are the ones with thick substrates [10].

The three essential parameters considered for designing a rectangular MPA are

(i) Frequency of operation (f_0) = 10 GHz

(ii) Dielectric constant of the substrate (ε_r) = 2.2 also the Rogers 5880 substrate material has the loss tangent value of 0.0004

(iii) Height of the dielectric substrate (h) = 10mil

(iv) Thickness of the conductor = 17µm

The proposed Microstrip Patch Antennas are designed on Rogers RT Duroid 5880 as it is a popular industry-wide standard substrate material [34]. These materials are glass microfiber-reinforced PTFE composites specifically useful for exacting stripline and microstrip circuit applications. The motive for selecting this material is because of its lowest electrical loss, low moisture absorption, isotropic, uniform electrical properties over the frequency, and excellent chemical resistance. The physical measurements for designing the MPAs are performed based on the following equations [11, 12, 15,31]. The length and width of the MPA is given by equation (5) and (6)

$$L= 0.49\frac{\lambda}{\sqrt{\varepsilon_r}} \qquad (5)$$

$$W = \frac{c}{sf_0\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (6)$$

The effective dielectric constant,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12\frac{h}{w}\right]^{-1/2} \qquad (7)$$

Due to the fringing effects h > 1), the electrical p of the microstrip antenna loos greater than the physical of the pat along its length and has been extended on each ed by a distance incrementanceΔLwhicha function of the effective dielectric constant ε_{reff} and the width -to- height ratio (W/h),

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \qquad (8)$$

Since the length has been extended on both sides by ΔL, the effective length becomes

$$L_{eff} = L + 2 \qquad (9)$$

The resonant frequency (center frequency),

$$f_r = \frac{v_0}{2L\sqrt{\varepsilon_r}} \tag{10}$$

Where v_0 is the speed of light in free space. The antenna must be effectively designed to exhibit high gain at the frequency of operation, thereby increasing the efficiency of the receiver. The layout of different antenna arrays is shown in Figure 1 (a) to (d). (include the correct dimensions of each antenna array)The antenna's size is 6.8 mm x5 mm, and the distance between the antennas' edges is 38.8 mm (0.75). The antennas are fabricated on a ground plane of 100 mm and 50 mm.

For the triangular patch antenna array design, the dimensions and layout follow a structured approach to optimize performance across various configurations. Each triangular patch measures approximately 13.3mm x 9.7mm, tailored for specific applications and resonance frequencies within the array. These triangular patches are fabricated on a ground plane measuring 20mm x 25mm, offering a stable base for radiation.

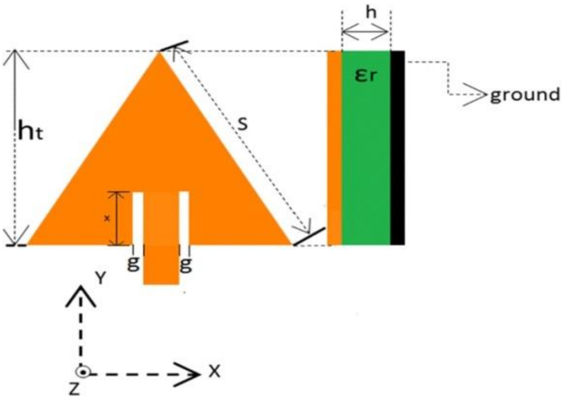
In the 1x2 antenna array setup, the design expands to accommodate two triangular patches spaced apart by 0.75 λ0, enhancing directivity and gain. The inter-element spacing is strategically determined to achieve optimal performance, maintaining uniformity in dimensions and layout for consistent results. Quarter wave transformers and 50Ω feedlines, similar to those in the single patch design, are integrated into this array configuration.

Scaling up to the 1x4 antenna array, the ground plane expands to 38mm x 61mm, supporting four triangular patches arranged with precision. The established dimensions for the patches, inter-element spacing, and feed lines are retained to preserve performance metrics across the array's larger footprint.

In the 2x2 array configuration, the ground plane measures 61mm x 58mm, providing ample space for two sets of two triangular patches. This arrangement leverages the principles of array theory to further enhance directional characteristics and overall efficiency.

For the largest configuration, the 4x4 antenna array, the ground plane expands significantly to 136mm x 134mm. Within this array, sixteen triangular patches are strategically positioned, maintaining uniformity in dimensions and spacing. The adherence to standardized measurements ensures consistent performance across the array, delivering enhanced capabilities for wireless communication and sensing applications.

Throughout these array designs, meticulous attention is paid to maintaining coherence in patch dimensions, inter-element spacing, and feed line characteristics. This systematic approach enables the realization of robust and scalable triangular patch antenna arrays tailored for diverse operational requirements within modern wireless communication and sensor networks.



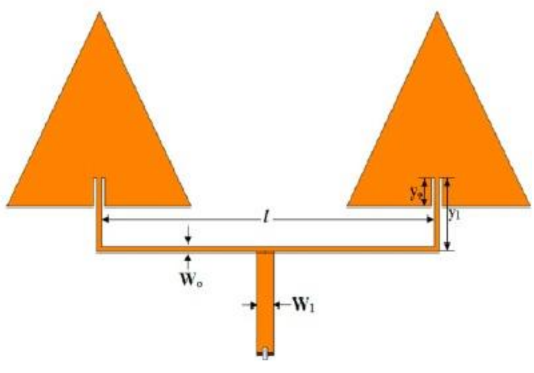
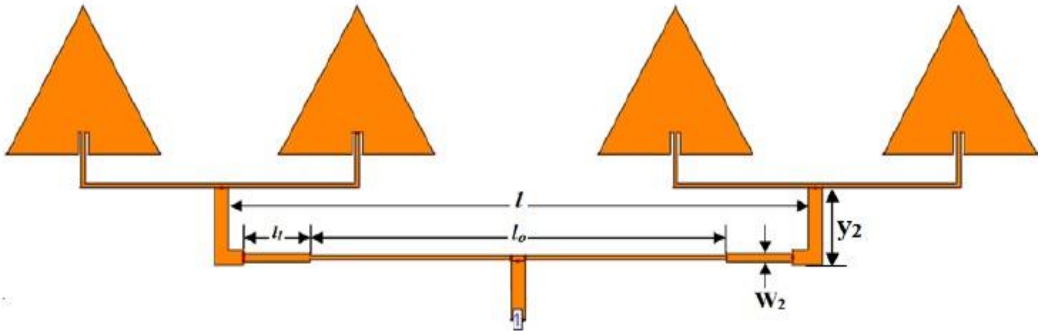


Figure. 3.1. a)Single patch layout **3.1.b) 1x2 antenna array layout**



3.1 c). 1x4 antenna array layout

The overall field of the array is determined by the vector addition of the fields radiated by the elements. This takes up that the current in each of the distinct elements is alike ignoring the coupling effect and it usually depends on the separation between the elements. The total field radiated by two elements assuming no coupling between the elements is equal to the sum of the two and in the y-z plane is given by equation (11)

$$E_t = E_1 + E_2 = \hat{a}_\theta j\eta k l I_0 \{ e^{-j[kr_1 - (\frac{\beta}{2})}) / r_1 \, cos\theta_1 + e^{-j[kr_1 - (\frac{\beta}{2})} / r_2 \cos\theta_2 \} \quad (11)$$

Where β is the difference in the phase excitation between the elements. Equation (11) reduces

$$E_t = \hat{a}_\theta j\eta k l I_0 (e^{-jkr}/4\pi r) \, cos\theta [\, e^{\frac{j(kdcos\theta+\beta)}{2}} + e^{-\frac{j(kdcos\theta+\beta)}{2}}]$$

$$E_t = \hat{a}_\theta \, j\eta k l I_0 (e^{-jkr}/4\pi r) \, cos\theta \{ 2 \cos [1/2(kdcos\theta + \beta)] \} \quad (12)$$

It can be stated that from equation (12), the total field of the array is equal to the field by a single element positioned at the origin multiplied by a factor which is referred to as the Array Factor (AF). Thus for a two-element array of constant amplitude, the array factor is given by equation (13)

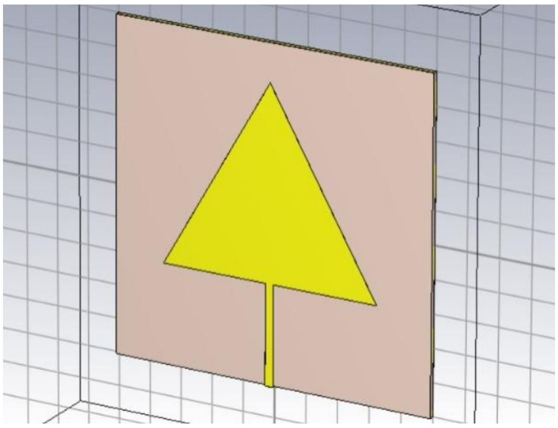
$$AF = 2 \cos [½ (kdcos\theta + \beta)] \quad (13)$$

This is the normalized form and can be written as given in equation (14)

$$AF = \cos [½ (kdcos\theta + \beta)] \quad (14)$$

The array factor is a function of the geometry of the array and the excitation phase, by varying the separation between the elements "d" and or the phase "β". Though the above equation has been illustrated for a two-element array, it can also be extended relevant to any number of array elements that need not have similar magnitudes, phases, and spacing between them.

3.2 Design of Fundamental Patch Antenna



S.no	Antenna Dimension	Value
1.	Resonant frequency(f)	2.4 Ghz
2.	Triangle patch length (a)	48.9
3.	Ground plane length (lg)	100 mm
4.	Ground plane width(wg)	100 mm
5.	Thickness(t)	0.035
6.	Height(h)	1.6

Table : 3.2.1 Antenna dimension

Figure 3.2.1 Simple Triangular patch antenna

The design of a fundamental triangular patch antenna involves several key dimensions and parameters to achieve optimal performance. The antenna typically consists of a triangular-shaped conducting patch mounted on a dielectric substrate, which is often made of materials like FR4.

To begin with, the key dimensions of the triangular patch antenna include the length of each side of the triangle, denoted as a, and the height of the triangle h. The side length determines the overall size of the antenna, which in turn affects its resonant frequency and bandwidth. The height h of the triangle influences the impedance matching and radiation characteristics of the antenna.

Additionally, the substrate thickness t is another critical dimension affecting the antenna's performance. The dielectric constant ε_r of the substrate material plays a crucial role in determining the antenna's impedance and resonant frequency.

The feeding technique, often through a microstrip feed line connected to the patch, is also a critical aspect of the design. The position of the feed line along the edge of the patch and its width influences the impedance matching and bandwidth of the antenna.

In summary, the design of a fundamental triangular patch antenna requires careful consideration of dimensions such as *a*, *h*, and *t*, along with substrate properties like εr. Optimizing these parameters ensures desired antenna characteristics such as resonant frequency, bandwidth, and radiation pattern for specific wireless communication applications.

3.3 Study of Triangular Patch Antenna for Optimum Performance at 2.4

3.3.1 Microstrip Trianglar Feedline:

Microstrip feedlines are commonly used in planar antenna designs, including triangular patch array antennas. The feedline is typically etched onto the same substrate as the triangular patches in this configuration. The feedline connects each patch to the transmission line, providing the necessary RF signal to excite the antenna elements. Microstrip feedlines offer ease of integration, low profile, and the ability to control impedance matching

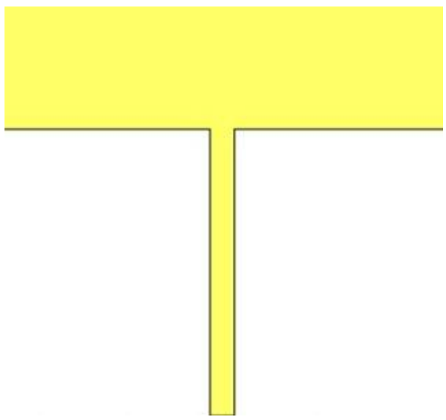


Figure 3.3.1 Triangular Microstrip feedline

3.3.2 Coaxial Feed:

Coaxial feed involves using coaxial cables to connect each triangular patch to the transmission line. A coaxial connector is attached to each patch, with the center conductor connected to the patch and the outer conductor serving as the ground plane. The coaxial feed provides good impedance matching and isolation between antenna elements. This configuration is suitable for applications where low-loss transmission and high isolation between elements are critical

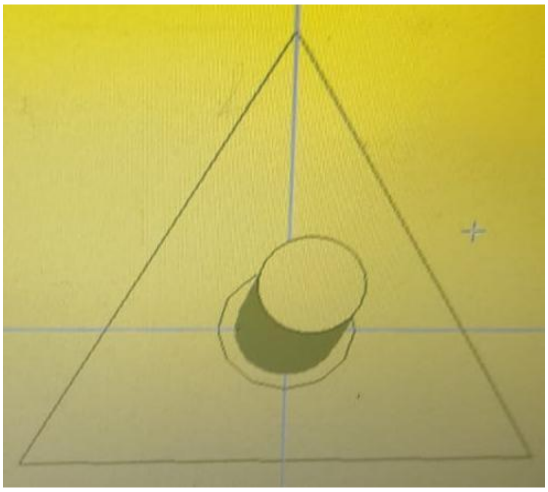


Figure 3.3.2 Triangular coaxial feedline

3.3.3 Corporate Feed:

Corporate feed involves combining signals from a single feedline and distributing them to multiple patches in the array. A power divider network is used to split the signal and feed it to each patch element. Corporate feed simplifies the feeding structure and reduces the number of feedlines required, especially in large array configurations.

However, it may introduce additional losses and impedance-matching challenges compared to individual feedlines.

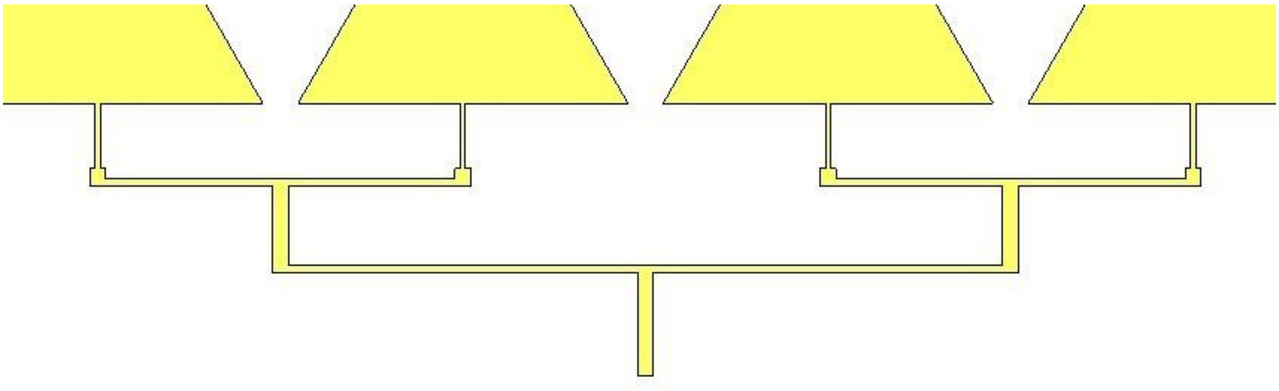


Figure 3.3.3 Triangular corporate feedline

3.3.4 Inset Feed:

Inset feeding involves directly connecting the feedline to the patch antenna element within a specific distance from the edge of the patch. By adjusting the position of the feed point along the edge of the patch, designers can control impedance matching and radiation characteristics. While inset feeding offers simplicity in design and fabrication, achieving precise impedance matching may require careful tuning of the feed position. Additionally, mutual coupling between adjacent elements can affect antenna performance, especially in densely packed arrays.

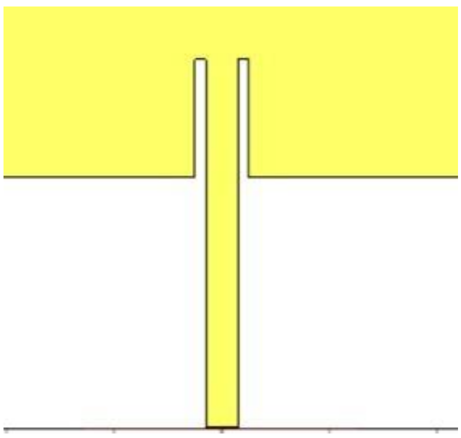


Figure 3.3.4 Triangular inset feedline

3.3.5 Quarter-Wave Feedline

Quarter-wave feedlines use transmission lines approximately one-quarter wavelength long to match the high impedance of the antenna element to the characteristic impedance of the transmission line. This impedance transformation results in efficient power transfer and reduced spurious radiation, improving antenna efficiency. Quarter-wave feedlines can be implemented using various transmission line technologies, such as microstrip lines, stripline, or coaxial cables. However, they may require more complex design and fabrication compared to inset feeding techniques, and the length of the feedline may restrict the physical layout of the antenna system, particularly in compact or miniaturized designs.

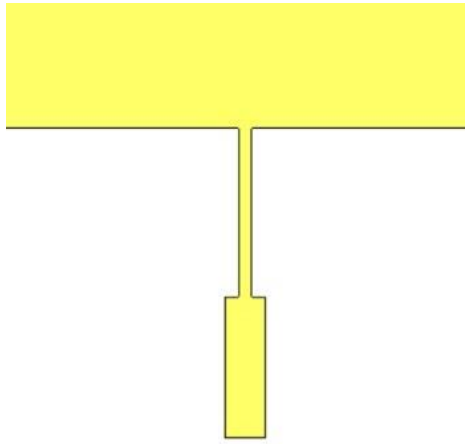


Figure 3.3.5 Triangular quarterwave

3.4 Design of the Triangular Patch Array Antenna at 2.4 GHz

Quarter-wave array antennas come in various configurations depending on the number of elements in the array. Here are descriptions of 1, 2, 4, 6, and 8-element quarter-wave array antennas:

3.4.1 Single Element Quarter-Wave Array

The single-element quarter-wave array is an antenna system that consists of only one radiating element. Usually, the radiating element is a quarter-wavelength monopole or dipole antenna. The element is fed at the base using a quarter-wave transmission line, which helps in providing impedance matching between the feedline and the antennaelement. This type of configuration is generally used in applications where a simple, omnidirectional radiation pattern is required, such as in wireless communicationsystems. In our project, we have developed a single element with a dielectric constant of 4.4 FR-4 substrate. The patch dimension is a=43.5.

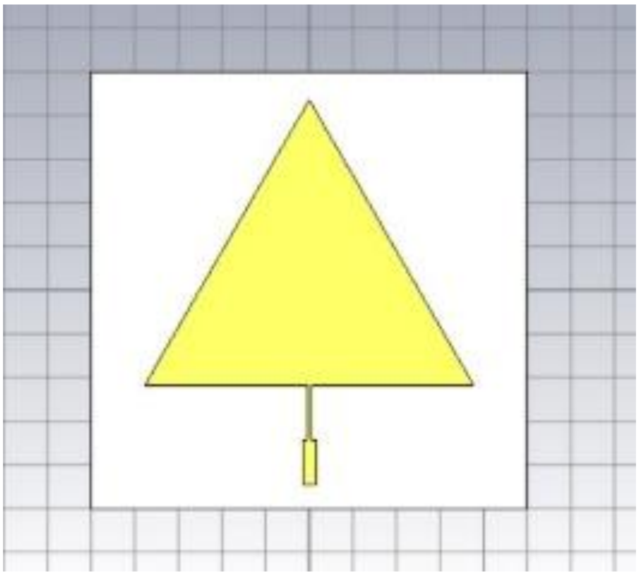


Figure: 3.4.1. Single Element Quarter-Wave Array

3.4.2 Two-Element Quarter-Wave Array:

The two-element quarter-wave array is made up of two quarter-wavelength elements that are positioned at a certain distance from each other. The elements are synchronized to generate constructive interference in the desired direction
and destructive interference in other directions, resulting in a directional radiation pattern. This setup is commonly used in applications that require moderate directional gain, such as point-to-point communication links. The dimensions of

the ground and substrate are lg=120 and wg=220 respectively, while the patch dimension a is 43.5

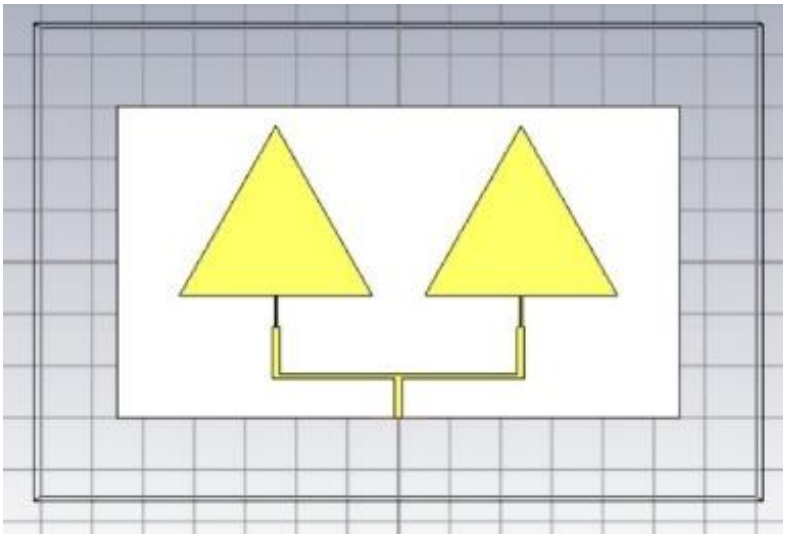


Figure 3.4.2. Two-Element Quarter-Wave Array:

3.4.3. Four-Element Quarter-Wave Array:

The four-element quarter-wave array consists of four quarter-wavelength elements arranged in a linear or planar configuration. The elements are typically fed with equal
amplitude and progressive phase differences to create a narrow beam radiation pattern with increased gain in the desired direction. This configuration offers improved
directivity and gain compared to two-element arrays. It is commonly used in applications that require higher gain and narrower beamwidth, such as radar systems and wireless base stations. The dimensions for the ground and substrate
of the 4-element quarter-wave feed are lg=250 and wg=207.5, and the patch a is 42.5 in length.

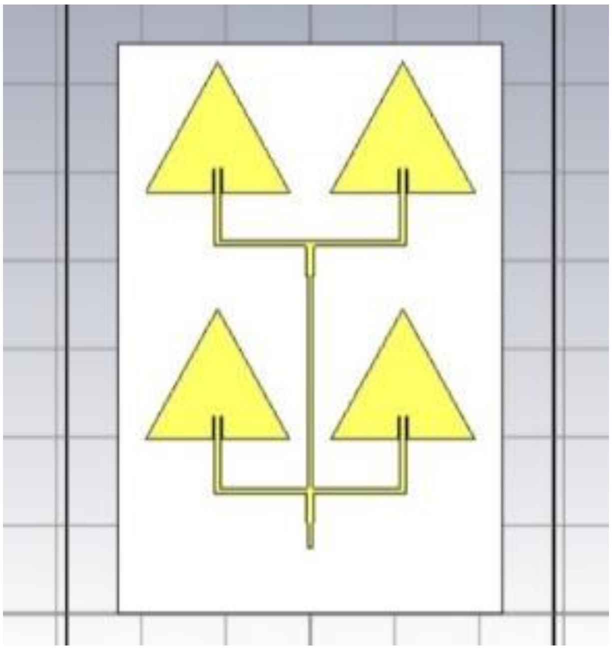


Figure 3.4.3 four-Element Quarter-Wave Array:

3.4.4. Six-Element Quarter-Wave Array:

The six-element quarter-wave array is composed of six quarter-wavelength elements that are arranged in a linear, planar, or circular configuration. These elements are fed with appropriate amplitude and phase distributions to shape the radiation pattern following the specific requirements of the application. In this particular case, we have provided the length (LG) and width (wg) of the ground and substrate as 200 and 300 respectively. The length of the patch 'a' is 36 each. This configuration provides further improvement in gain and directivity when compared to four-element arrays. It can be used in applications requiring even higher gain and more precise beam shaping, such as satellite communication systems.

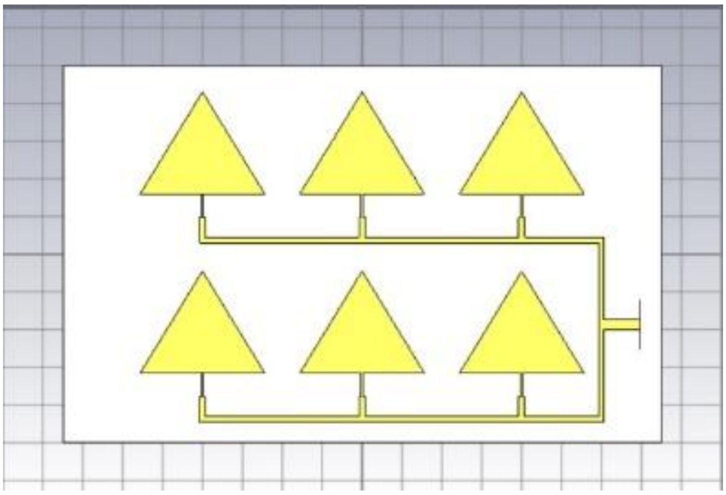


Figure 3.4.4. Six-Element Quarter-Wave Array:

4.4.5. Eight-Element Quarter-Wave Array:

The eight-element quarter-wave array comprises eight quarter-wavelength elements arranged in a linear, planar, or circular configuration. It offers even higher gain and more precise control over the radiation pattern compared to six-element arrays. Eight-element quarter-wave arrays are commonly used in applications requiring very high gain and directional control, such as phased array radar systems and long-range communication links. These are just a few examples of quarter-wave array configurations, each offering different levels of gain and directivity

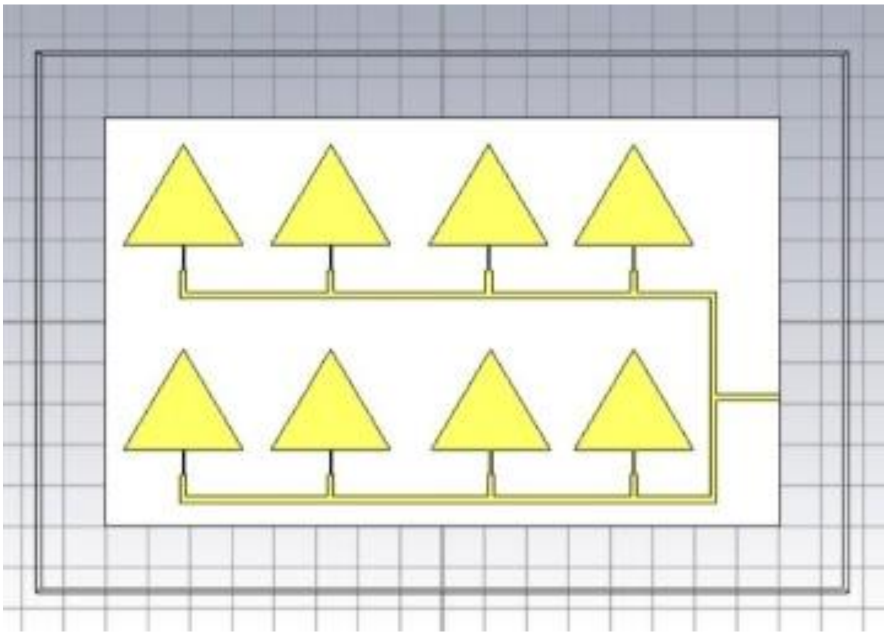


Figure 4.4.5. Eight-Element Quarter-Wave Array:

CHAPTER 4

RESULTS AND DISCUSSIONS

INTRODUCTION

The results and discussion section of analysis on a triangular array antenna typically focuses on key performance metrics such as return loss, VSWR (Voltage Standing Wave Ratio), and gain. These parameters are essential for evaluating the effectiveness and efficiency of the antenna design. Here is a brief introduction to what this section may entail:

In this section, we present the results and discuss the performance of a triangular array antenna based on the calculated return loss, VSWR, and gain. These metrics are critical indicators of the antenna's operational characteristics and effectiveness in radiating electromagnetic waves.

4.1 Return loss

The analysis of return loss in the context of antenna arrays, such as the quarter-wave feed array you're examining, is crucial for understanding how effectively the antenna system can transmit electromagnetic waves. Return loss is a measure of how much of the transmitted energy is reflected toward the source, typically measured in decibels (dB). A higher return loss value indicates less energy is being reflected, which generally implies better performance.

Let's break down the data we've provided and discuss the implications:

The provided return loss values for different configurations of the antenna array offer valuable insights into its performance characteristics. Starting with a single element, the return loss is measured at -17.33 dB. As the number of elements in the array increases, we observe a trend where the return loss generally decreases: -11.06 dB for 2 elements, -12.263 dB for 4 elements, -26.7789 dB for 6 elements, and significantly lower at -43.0652 dB for 8 elements.

This trend highlights the efficiency gains associated with larger antenna arrays. A lower return loss value signifies reduced energy being reflected back towards the source, indicating that larger arrays are more effective at radiating energy forward rather than wasting it through reflection. The substantial decrease in return loss from 2 to 8 elements suggests a notable enhancement in energy transmission efficiency with increased array size.

Decreasing Return Loss with More Elements: The trend you've observed is that the return loss generally decreases as the number of elements in the array increases. This trend suggests that larger arrays are more efficient at radiating energy forward rather than reflecting it toward the source.

Significance of Return Loss Values: return loss closer to 0 dB indicates that a significant portion of the transmitted energy is being reflected, which is less desirable as it means more energy is wasted. A higher negative return loss value (i.e., a larger negative dB value) indicates better performance, as less energy is being reflected and more is being effectively radiated.

Phase and Amplitude Control: The behavior of the return loss concerning the number of elements can be attributed to the constructive and destructive interference patterns controlled by the phase and amplitude of each element in the array.

Beam Steering: Larger arrays can potentially offer better beam steering capabilities, directing the transmitted energy more precisely towards the desired direction with less energy being lost due to reflections.The gradual decrease in return loss as the number of elements increases suggests that larger arrays are generally more efficient in terms of energy transmission.

This information can be valuable in optimizing the design of antenna arrays for specific applications. For instance, in applications where minimizing energy wastage and maximizing directivity are critical (e.g., in radar or communication systems), using a larger array might be more beneficial.

In summary, the analysis of return loss across different configurations of the quarter-wave feed array antenna provides insights into its performance characteristics and highlights the importance of array size and configuration in optimizing energy efficiency and radiation pattern control.

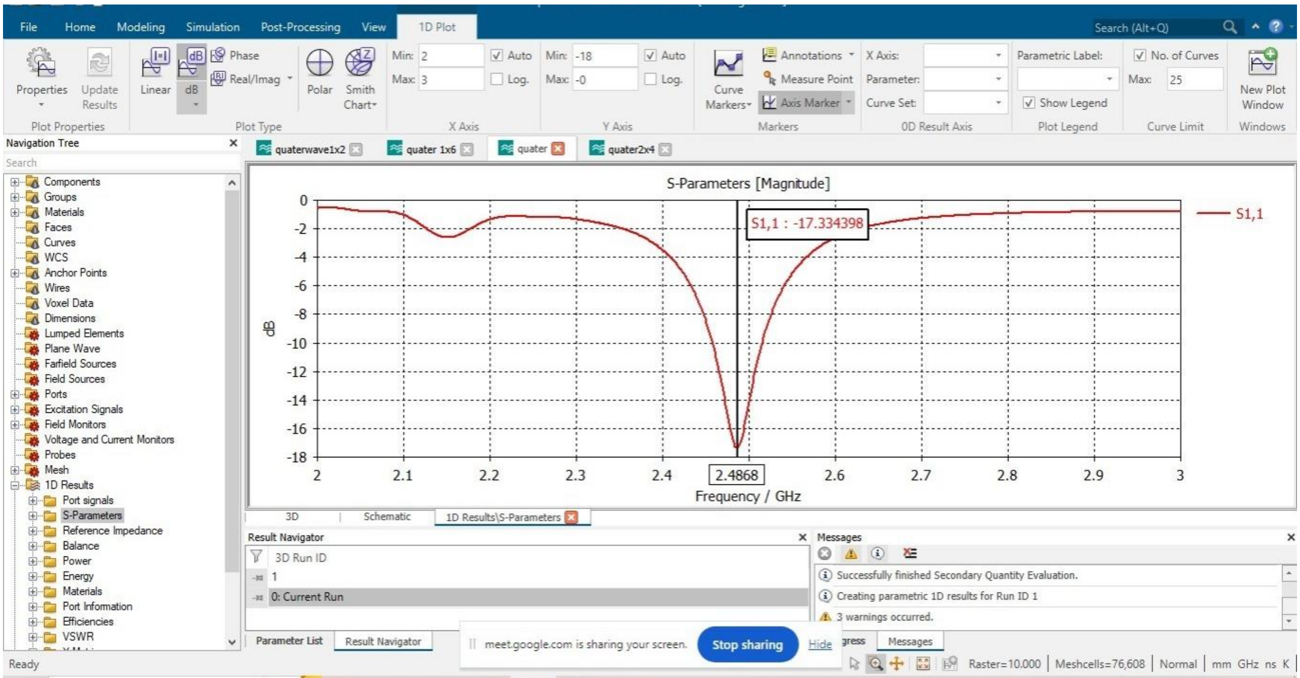


Figure 4.1.1.Return loss for 1 element Triangular Quarter wave feed

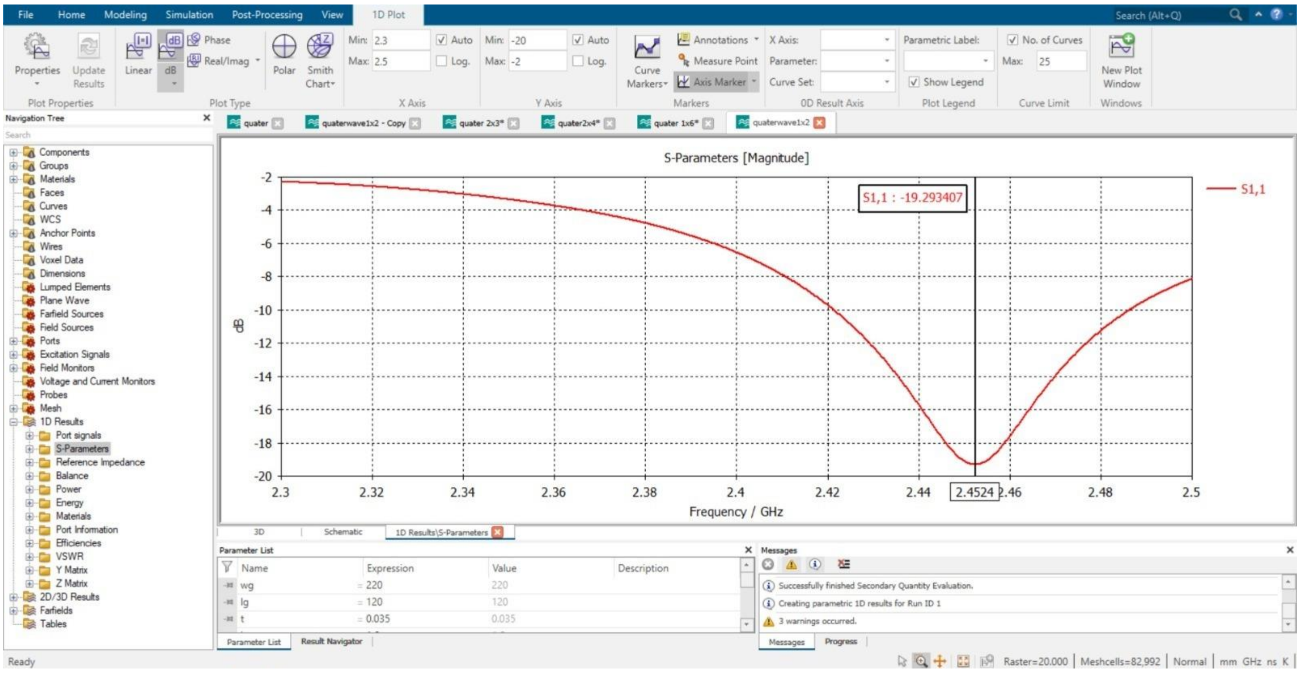


Figure 4.1.2 Return loss for 2 element(1x2) Triangular Quarter wave feed

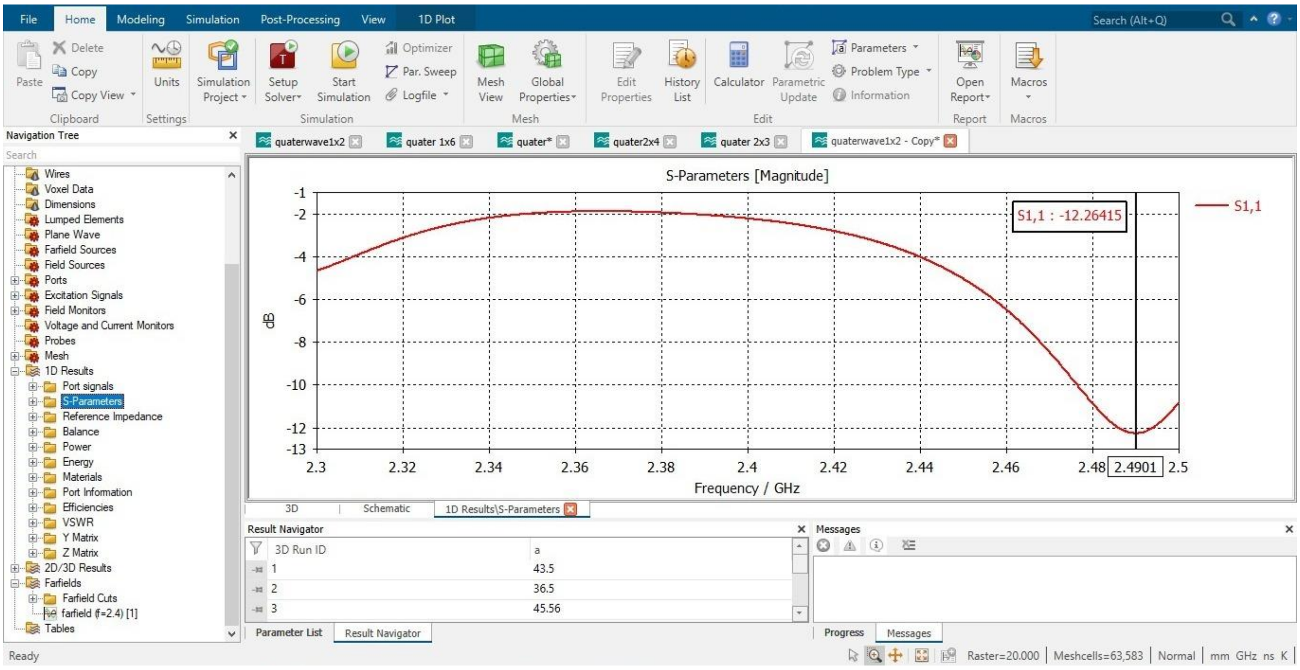


Figure 4.1.3 .Return loss for 4 element(2x2) Triangular Quarter wave feed

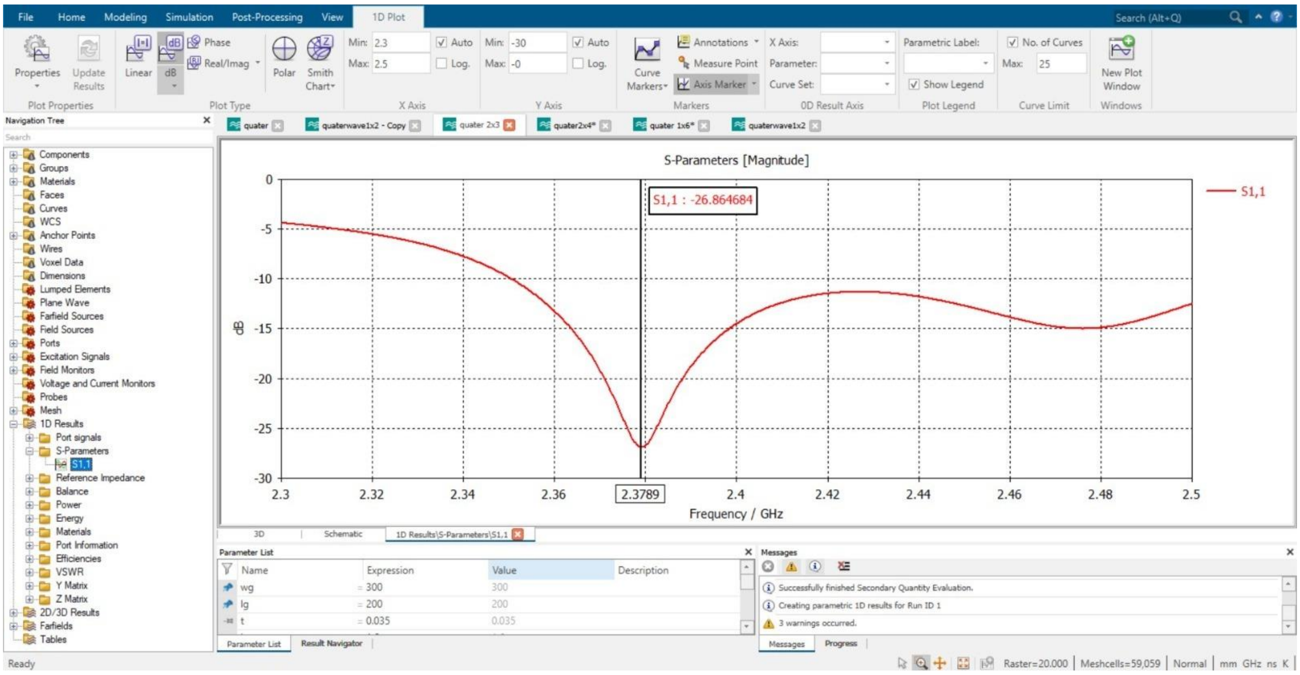


Figure 4.1.4 Return loss for 6 element(3x2) Triangular Quarter wave feed

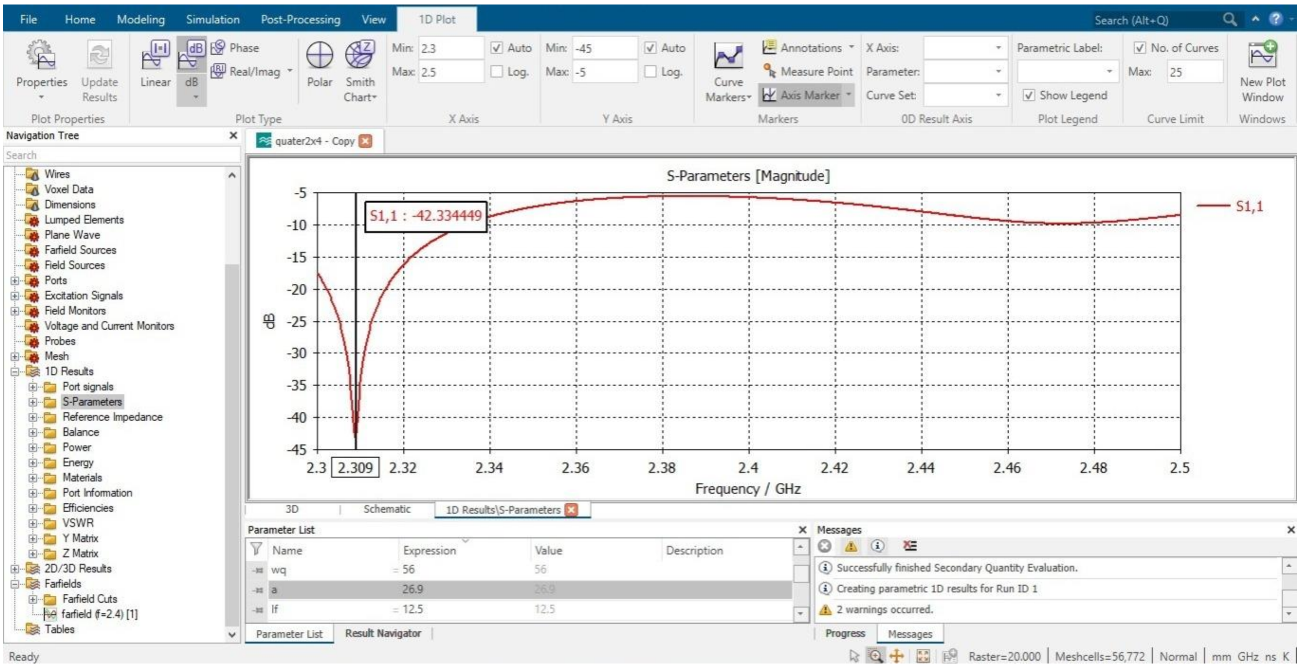


Figure 4.1.5 .Return loss for 8 element(4x2) Triangular Quarter wave feed

4.2 VSWR

The Voltage Standing Wave Ratio (VSWR) is indeed a crucial metric in antenna design and performance evaluation, particularly for assessing the efficiency of power transmission and impedance matching within an antenna system. Let's delve into the significance of the computed VSWR values for the antenna operating at 2.4 GHz using FR-4 material:

VSWR is a measure of how well the impedance of the antenna system matches the impedance of the transmission line and source/load. It is calculated as the ratio of the maximum voltage to the minimum voltage along the transmission line.

A VSWR value closer to 1 indicates minimal signal reflection and excellent impedance matching, which translates to efficient power transfer from the source to the load.Single Element (1x1) VSWR: The VSWR value of 1.3145 for the single-element antenna suggests decent impedance matching, although slightly higher than optimal (closer to 1). This indicates that there is room for improvement in minimizing signal reflection.

Increasing Elements and VSWR: 2 Elements (1x2): VSWR of 1.2433 indicates improved impedance matching compared to the single element configuration.4 Elements (2x2): VSWR of 1.6443 suggests slightly degraded performance in impedance matching compared to the single-element and 2-element configurations.6 Elements (2x3): VSWR of 1.095 shows a significant improvement in impedance matching, approaching the ideal range (closer to 1). 8 Elements (2x4): VSWR of 1.0154 is very close to 1, indicating excellent impedance matching and efficient power transfer for this configuration.

The trend observed in VSWR values with increasing elements indicates the impact of array configuration on impedance matching and power transmission efficiency. Configurations with higher numbers of elements (e.g., 6 elements and 8 elements) demonstrate superior impedance matching and lower VSWR, suggesting optimized power transmission and reduced signal reflection.

By designing antennas to achieve low VSWR values, engineers can minimize signal reflection and maximize power transfer efficiency. The choice of material (FR-4 in this case) and the array configuration play significant roles in determining VSWR values and overall antenna performance.

In summary, the computed VSWR values for the antenna design operating at 2.4 GHz using FR-4 material demonstrate the impact of array configuration on impedance matching and power transmission efficiency. The values falling within the desired range (especially with higher element counts) indicate commendable impedance matching and efficient power transfer, underscoring the importance of meticulous antenna design for reliable and effective communication systems.

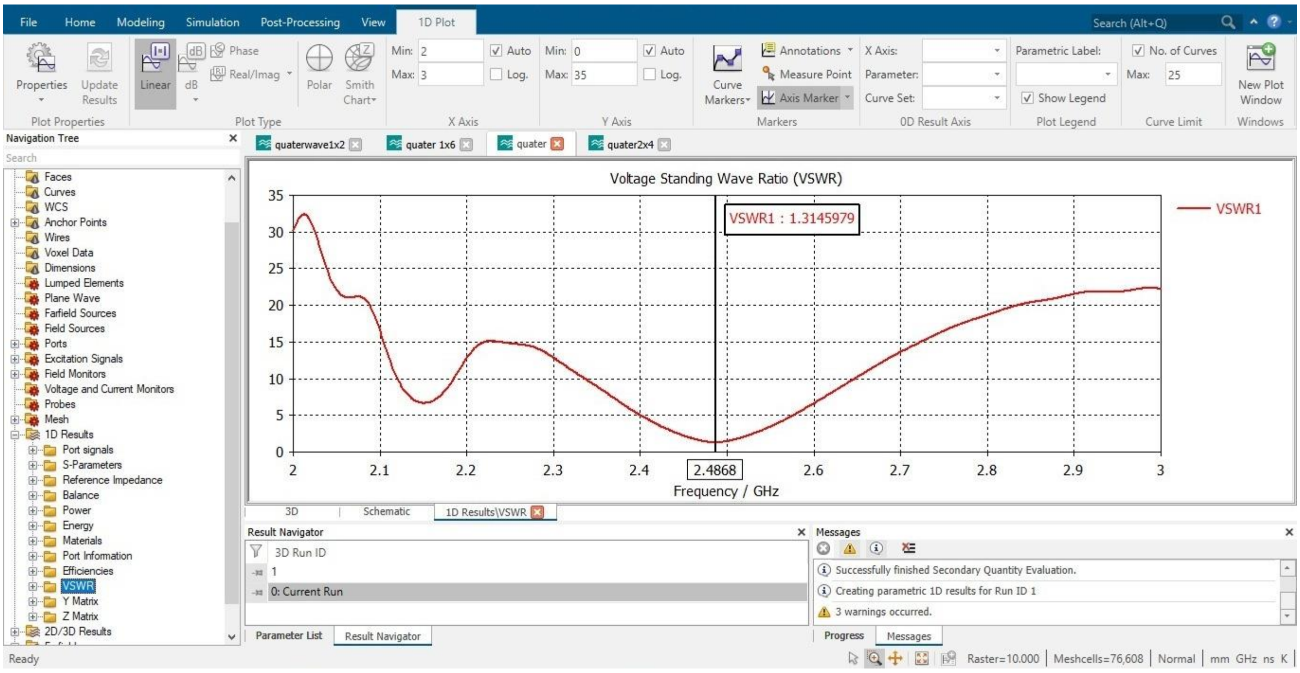


Figure 4.2.1 VSWR for Single element Triangular Quarter wave feed

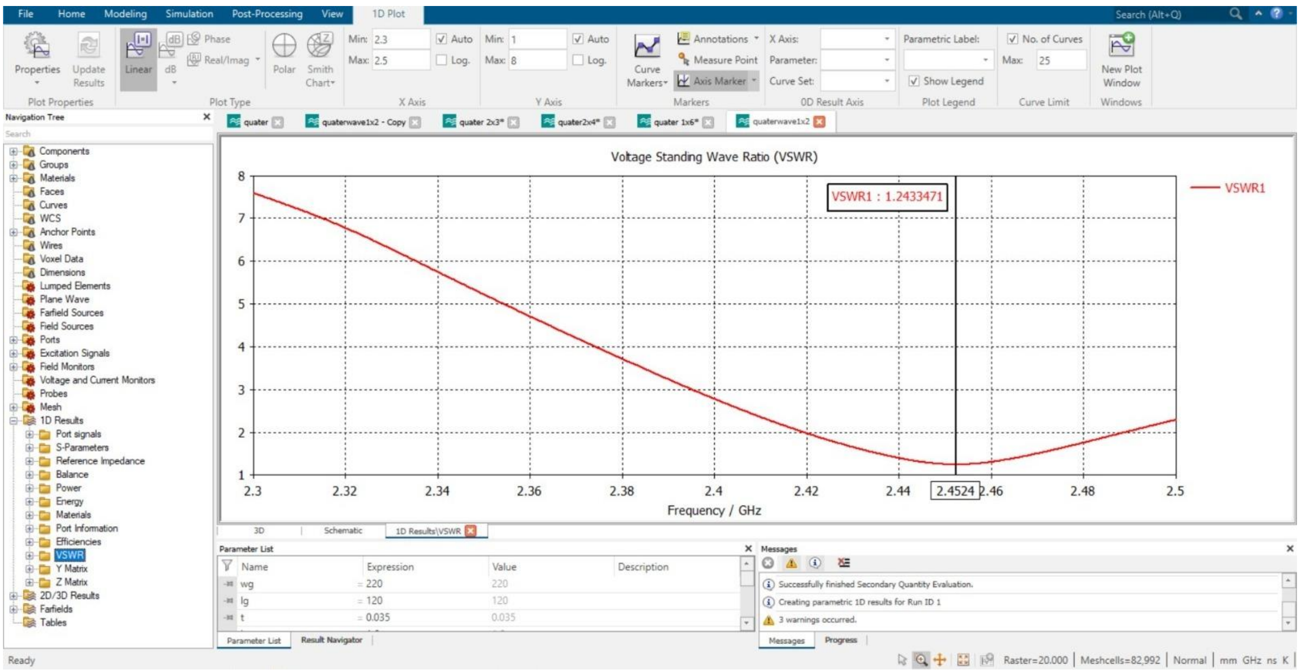


Figure 4.2.2 VSWR for 2 element(1x2) Triangular Quarter wave feed

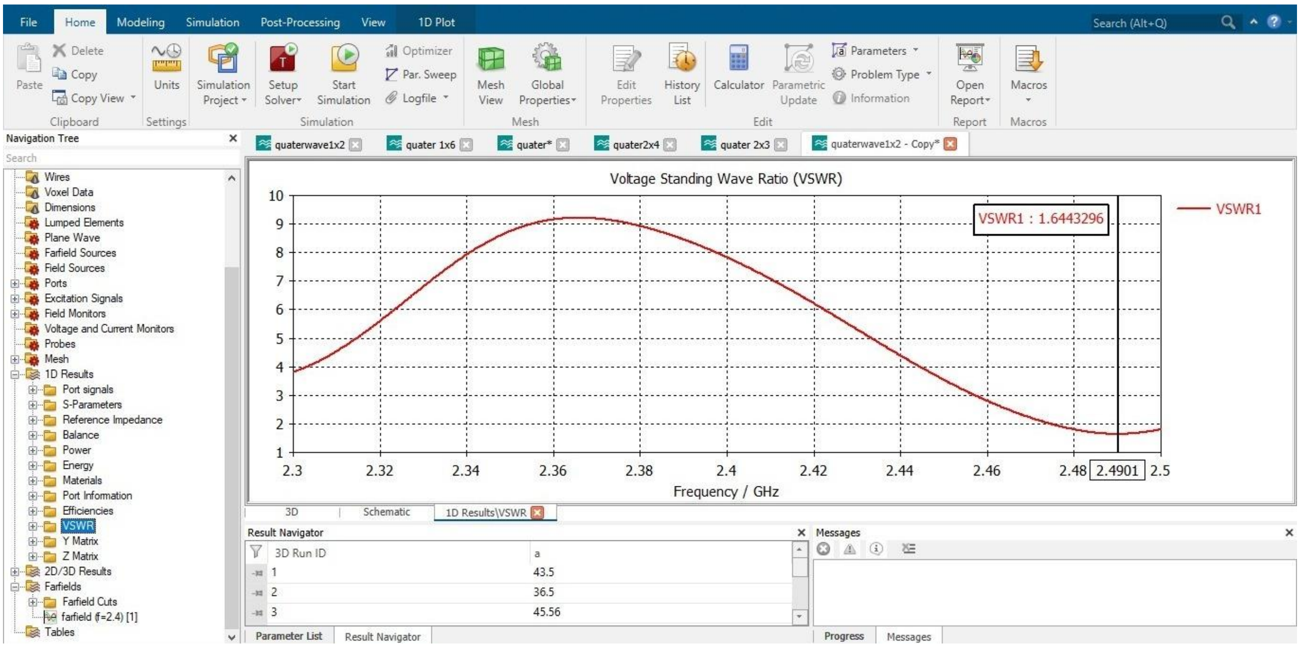


Figure 4.2.3 VSWR for 4element(2x2) Triangular Quarter wave feed

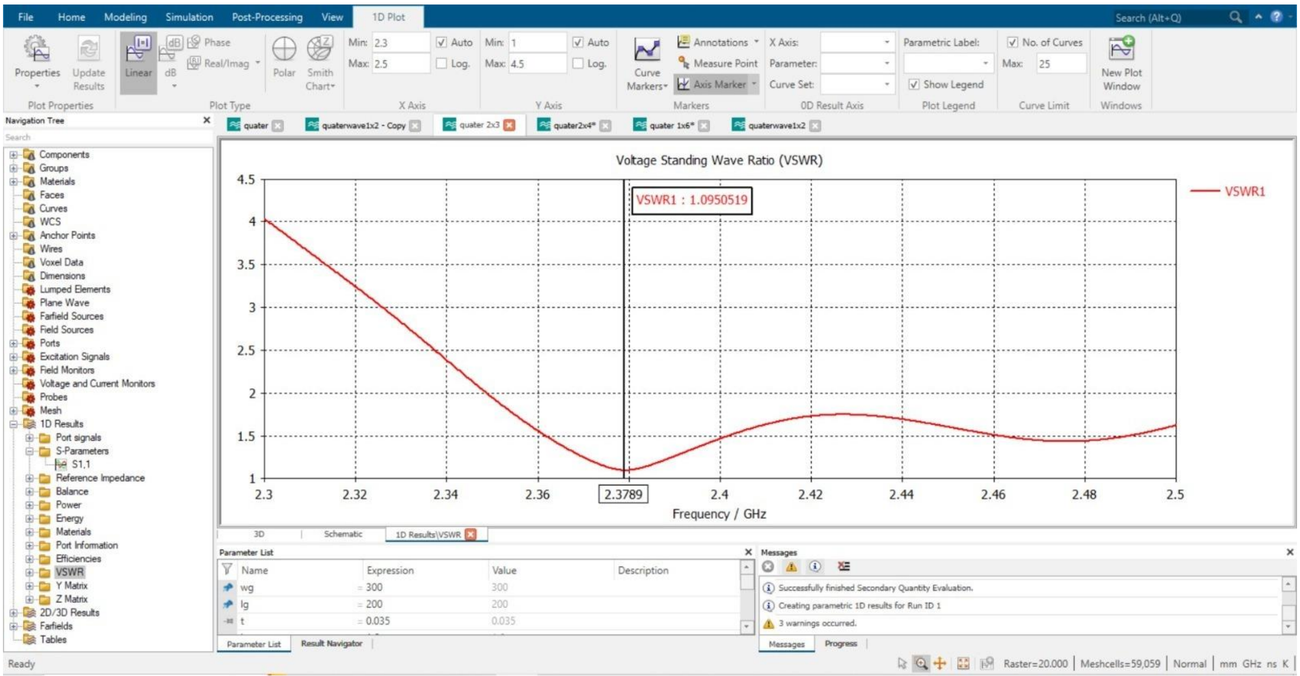


Figure 4.2.4 VSWR for 6 element(3x2) Triangular Quarter wave feed

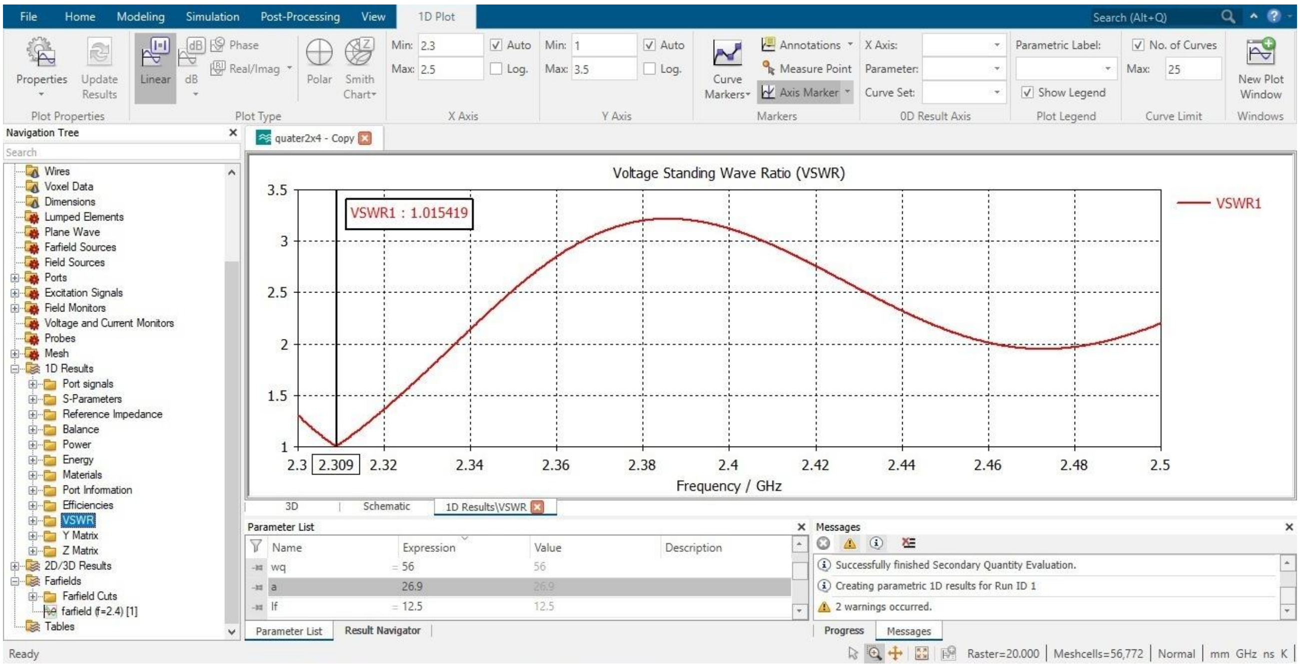


Figure 4.2.5 VSWR for 8 element(4x2) Triangular Quarter wave feed

4.3 Simulation of the Antenna Impedance and Return Loss

The simulation of antenna impedance and return loss for a triangular antenna array operating at 2.4 GHz on an FR-4 substrate using CST software involves a detailed analysis to assess the antenna's performance characteristics. The goal is to achieve impedance matching with a target impedance of 50 ohms and to evaluate how the array configuration affects return loss across different element counts (1, 2, 4, 6, and 8 elements).

To begin, the antenna geometry and material properties are defined within the CST software environment. This includes specifying the dimensions and layout of the triangular antenna array on the FR-4 substrate, taking into account parameters such as substrate thickness, dielectric constant, and conductor properties. The simulation setup includes the configuration of the feed network, considering how each antenna element is connected to ensure proper impedance matching.

Next, the CST software performs electromagnetic simulations to predict the impedance characteristics of the antenna array at 2.4 GHz. The simulation results provide insights into the real and imaginary parts of the antenna impedance, indicating how closely the antenna's impedance matches the desired 50-ohm target impedance. Deviations from this target impedance can be identified and addressed through design modifications or tuning.

Simultaneously, the simulation predicts the return loss at 2.4 GHz for each array configuration (1, 2, 4, 6, and 8 elements). Return loss quantifies the amount of power reflected from the antenna system due to impedance mismatches. Lower return loss values indicate better impedance matching and improved energy transfer efficiency.

By systematically analyzing the impedance and return loss for different array sizes using CST software, antenna designers can optimize the array configuration to achieve desired performance metrics. This simulation-driven approach enables fine-tuning of the antenna design to meet specific requirements for applications such as wireless communication, radar systems, or satellite communication, ensuring reliable operation and efficient signal transmission. The insights gained from these simulations guide iterative design improvements, ultimately leading to the development of high-performance antenna systems tailored to specific operational needs.

4.4 Gain and Directivity

The gain of an antenna signifies its ability to concentrate radiated power in a specific direction compared to an isotropic radiator that radiates equally in all directions. In the context of the triangular patch antenna design operating at 2.4 GHz with FR-4 material and different array configurations, the gain values highlight the antenna's directional efficiency.

The gain performance of a triangular array antenna at 2.4 GHz frequency shows a notable trend as the number of elements in the array increases. Beginning with a single-element configuration achieving a gain of 5.28 dB, we observe a steady improvement in gain with larger arrays.
With 2 elements, the gain increases to 7.2 dB, demonstrating the benefit of incorporating additional elements for enhanced radiation efficiency. The gain continues to improve significantly with 4 elements, reaching 11 dB, indicating effective utilization of the array configuration to focus and direct electromagnetic energy.
As we progress to 6 elements, the gain slightly reduces to 10.4 dB, suggesting a potential optimization point where further additions of elements may not linearly increase gain due to factors such as spacing and interference patterns within the array. Finally, with 8 elements, the gain peaks at 10 dB, indicating that additional elements beyond a certain point may not significantly contribute to gain improvement.

This trend underscores the antenna's capability to focus and direct transmitted or received power more efficiently as the array size grows. Higher gain values for larger arrays indicate improved directivity, with more power being concentrated in the desired direction rather than being dispersed indiscriminately.

The increase in gain with additional elements reflects the antenna's enhanced ability to shape the radiation pattern, offering greater coverage or beam directionality as required by specific applications. These gain values are crucial metrics in antenna design, influencing the antenna's performance in communication systems where efficient power transmission and reception in specific directions are essential for reliable and effective signal propagation. Overall, the observed gain values for the triangular patch antenna demonstrate its effectiveness in concentrating radiated power directionally, illustrating the practical benefits of using array configurations to enhance antenna performance in various wireless applications.

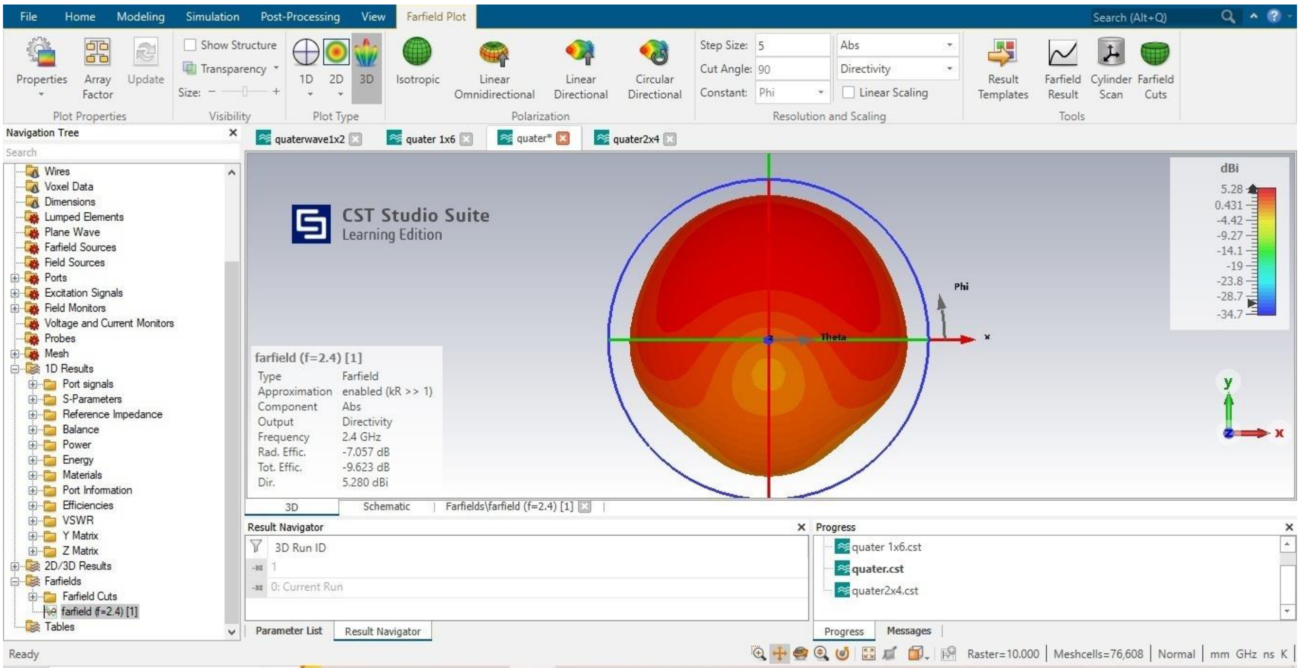


Figure 4.4.1 Gain and Directivity for a single element of triangular quarter wave feed

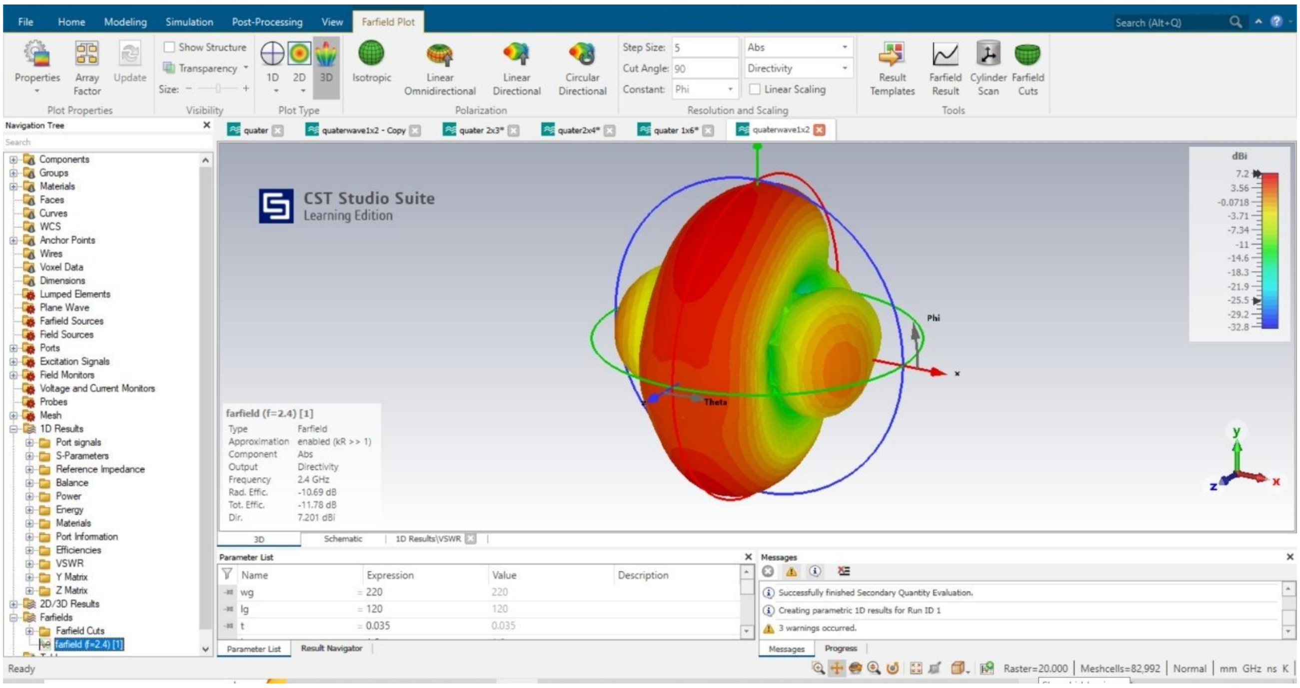


Figure 4.4.2 Gain and Directivity for 2 elements (1x2)of triangular quarter wave feed

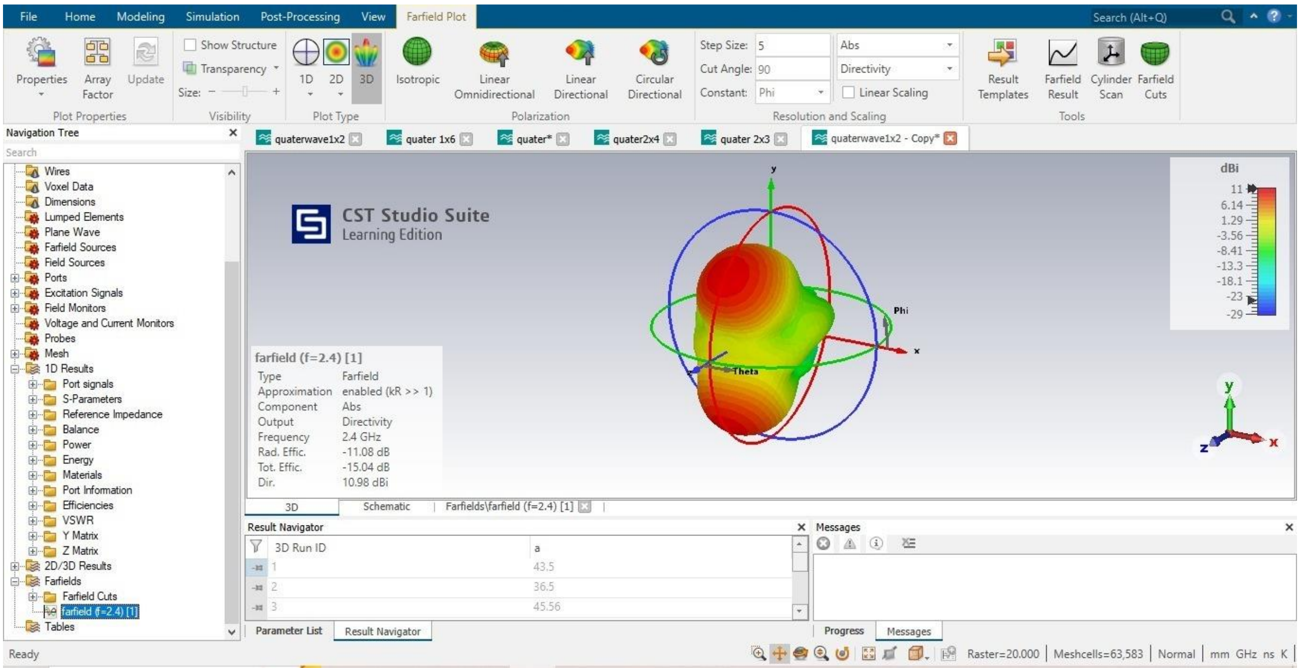


Figure 4.4.3 Gain and Directivity for 4 elements (2x2) of triangular quarter wave feed

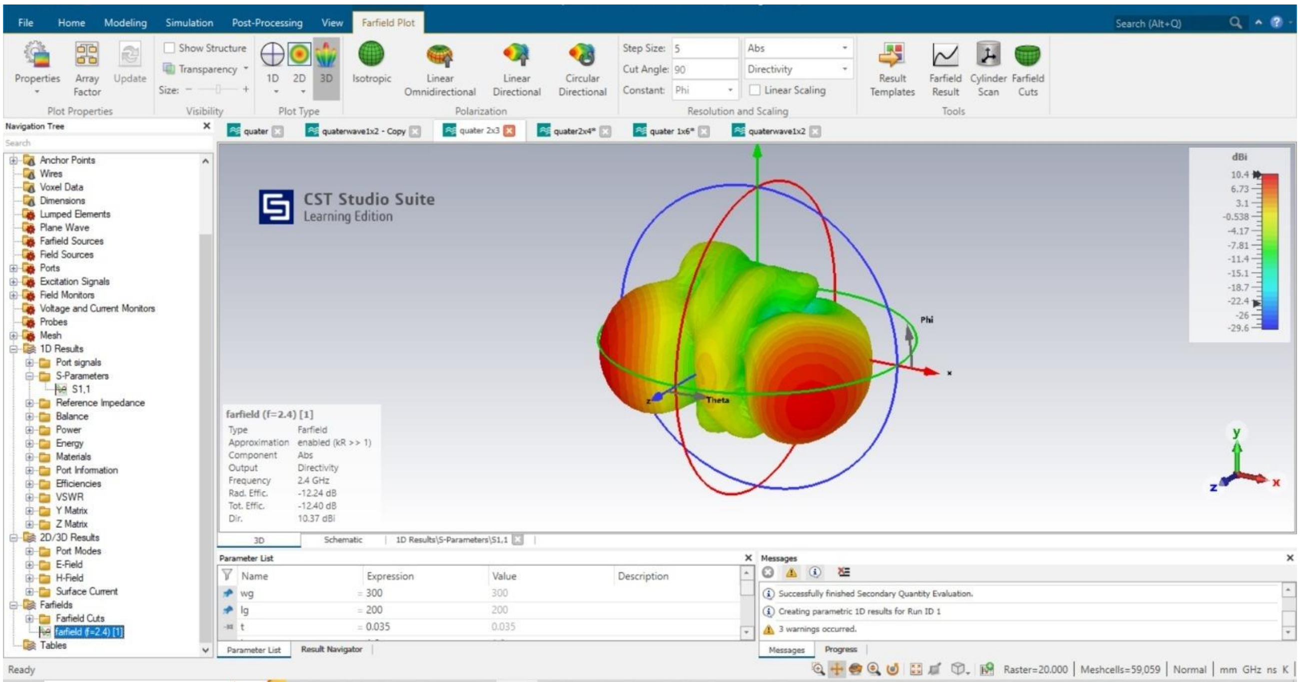


Figure 4.4.4 Gain and Directivity for 6 elements (3x2) of triangular quarter wave feed

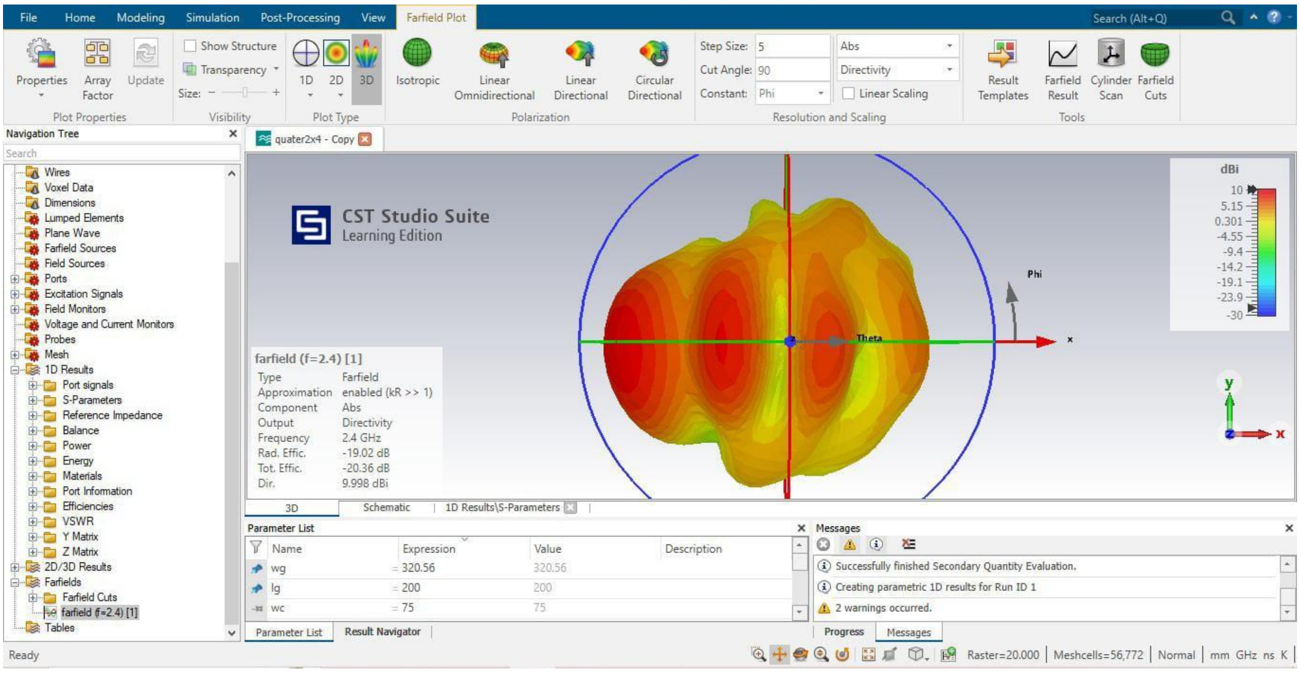


Figure 4.4.5 Gain and Directivity for 8 elements (4x2)of triangular quarter wave feed

4.5 Radiation Pattern and Side lobes

Analyzing the beamwidth and sidelobe levels of the radiation pattern for an antenna array operating at 2.4 GHz with an FR-4 substrate offers critical insights into the antenna's directional performance and radiation characteristics. Beamwidth refers to the angular width of the main lobe of the radiation pattern, indicating the antenna's ability to focus energy in a specific direction. A narrower beamwidth implies better directivity and concentration of transmitted/received power. Meanwhile, sidelobe levels represent the level of radiation outside the main lobe, which ideally should be minimized to avoid energy wastage and interference.

For the specified antenna design, examining these parameters provides valuable information on its effectiveness in directing energy toward the intended target while suppressing radiation in unwanted directions. A narrower beamwidth suggests enhanced directionality, essential for applications requiring precise signal focusing, such as point-to-point communication or radar systems. Additionally, low sidelobe levels indicate reduced interference and better spectral efficiency by minimizing energy radiated in unintended directions, thus enhancing overall system performance.

By optimizing the array configuration, antenna elements, and substrate properties like FR-4, engineers can tailor beamwidth and sidelobe levels to meet specific application requirements, ensuring efficient energy utilization and reliable communication performance. This comprehensive understanding of beamwidth and sidelobe levels is fundamental in antenna design, guiding the development of high-performance systems for diverse wireless communication applications.

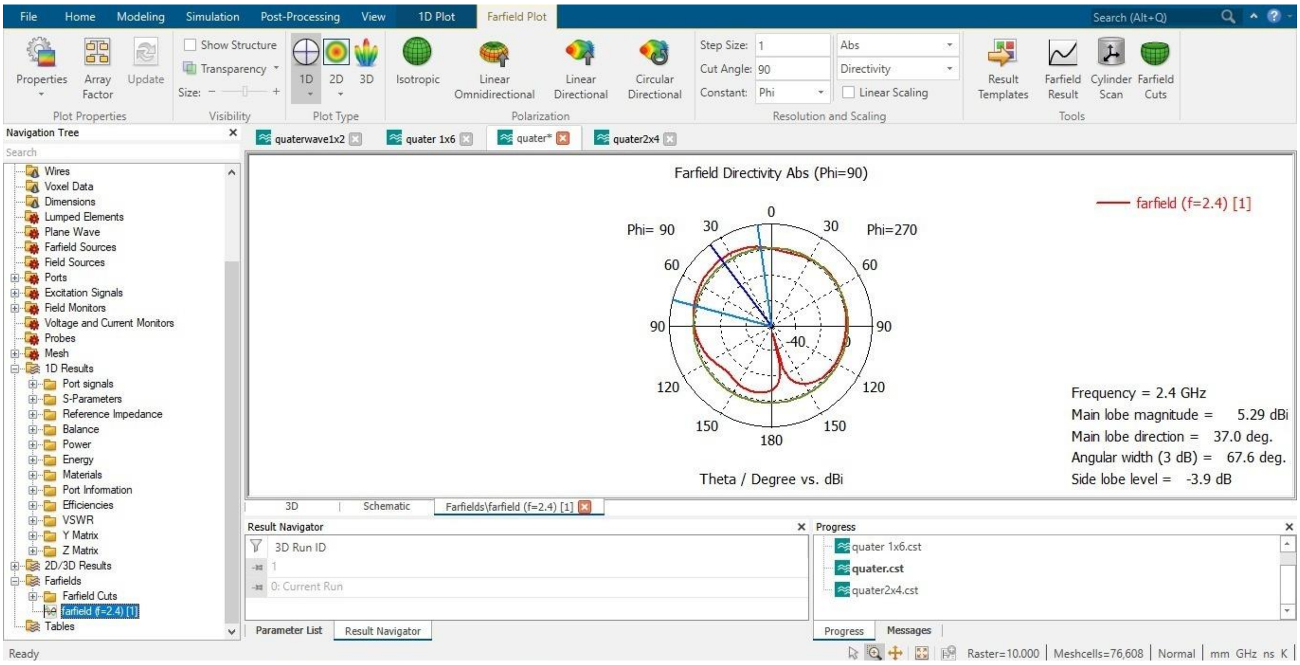


Figure 4.5.1 Radiation pattern and side lobe for single element triangular quarter wave feed antenna

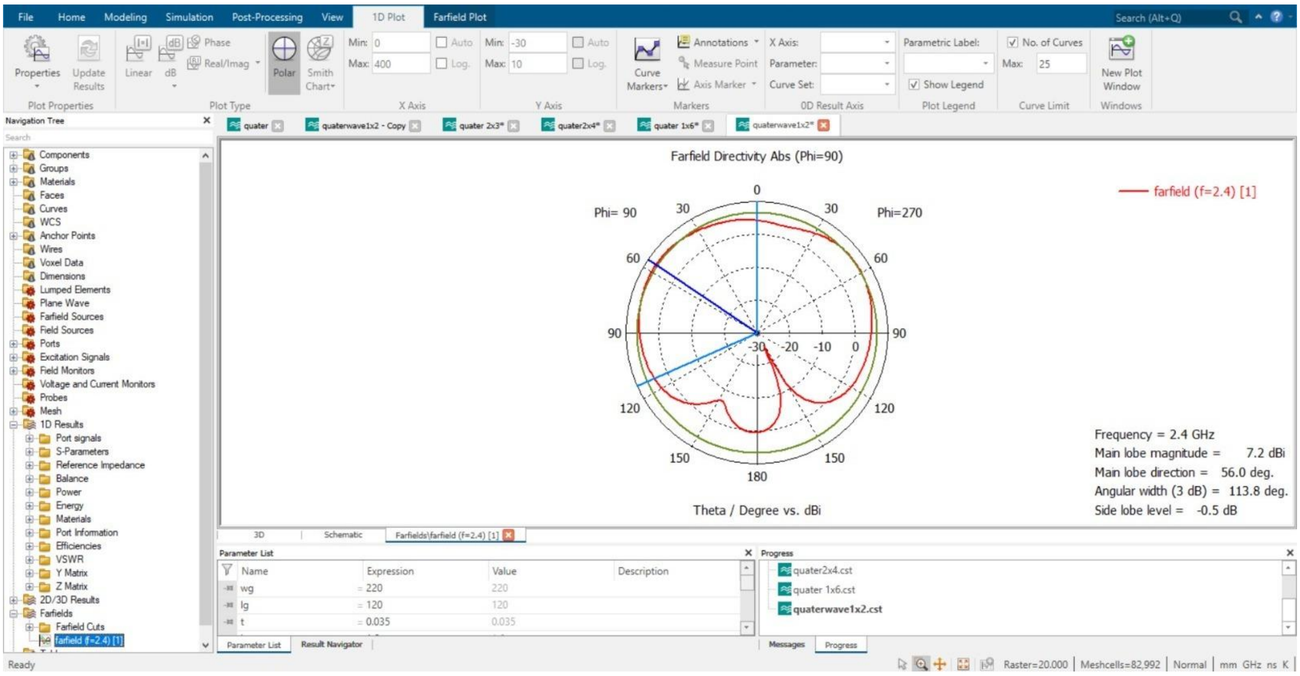


Figure 4.5.2 Radiation pattern and side lobe for 2 elements (1x2) triangular quarter wave array antenna

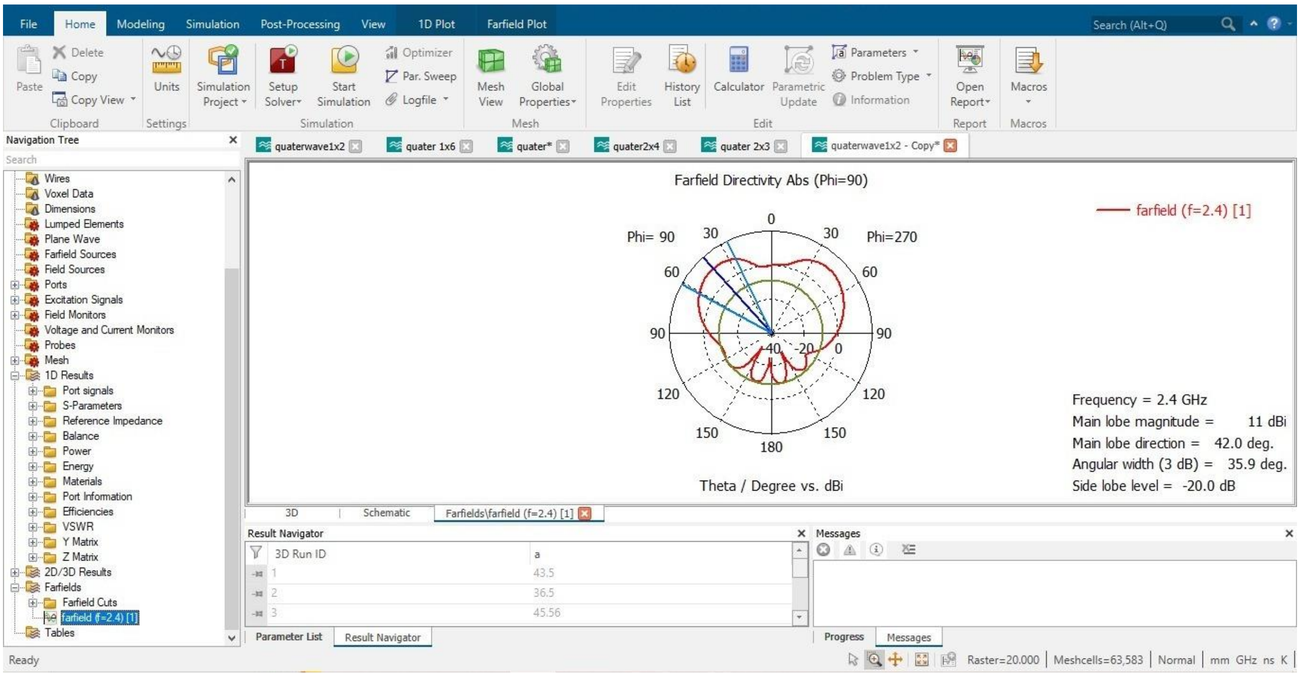


Figure 4.5.3 Radiation pattern and side lobe for 4 elements (2x2) triangular quarter wave array antenna

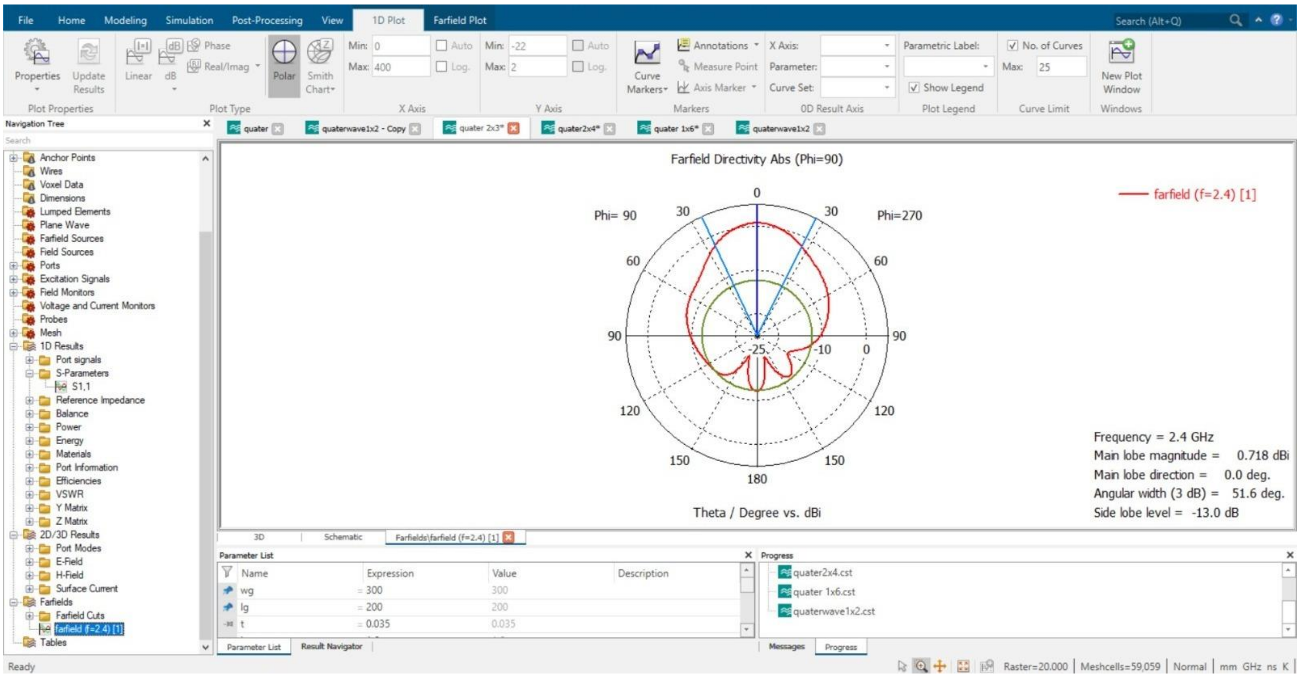


Figure 4.5.4 Radiation pattern and side lobe for 6-element (3x2) triangular quarter wave array antenna

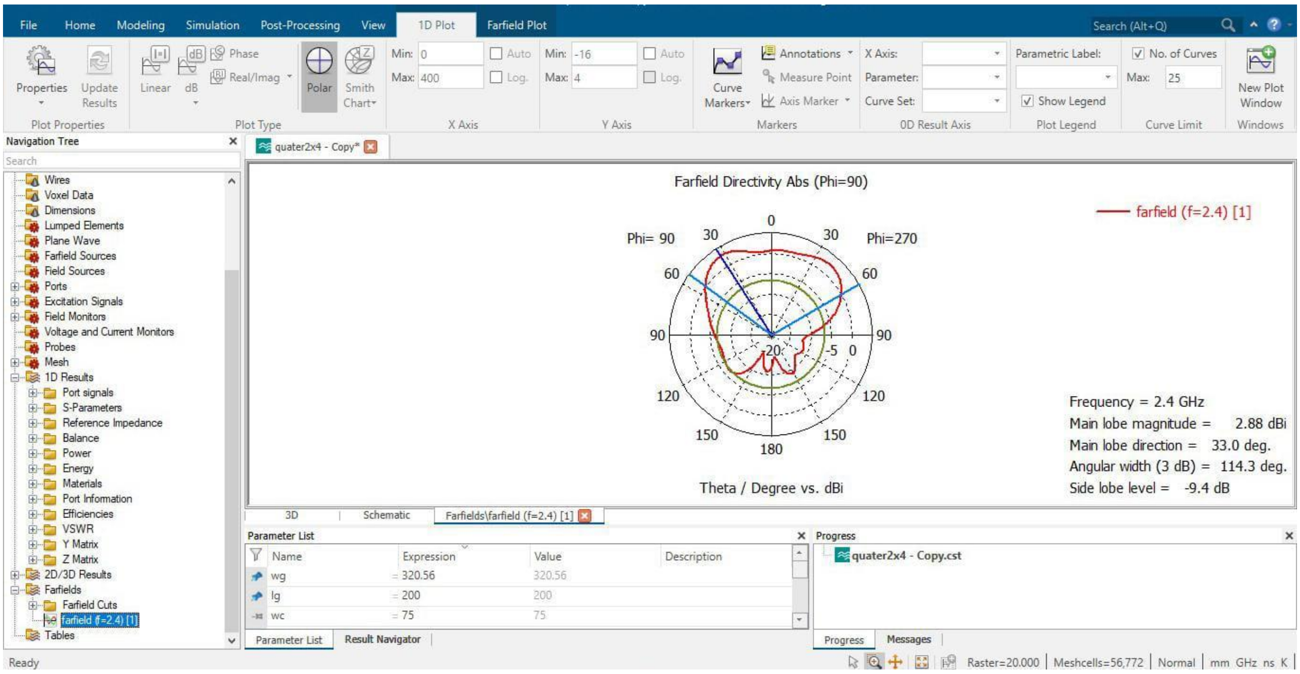


Figure 4.5.2 Radiation pattern and side lobe for 8 elements (4x2) triangular quarter wave array antenna

4.6 Fabrication and Testing Results

After identifying that the gain, return loss, and VSWR of the 8-element component were meeting our requirements, a decision was made to proceed with its fabrication. The fabrication process for this component began with a thorough review of design specifications and parameters to pinpoint any potential performance issues. Following this analysis, adjustments were made to optimize the design for enhanced gain, return loss, and VSWR characteristics. Once the revised design was finalized, the fabrication process commenced, involving meticulous assembly and integration of components according to the updated specifications.

ARRAY TYPE	RETURN LOSS	VSWR	GAIN
1	-17.3343	1.3145	5.28
1X2	-19.2934	1.2433	7.2
2X2	-12.2618	1.6443	11
2X3	-26.8646	1.095	10.4
2X4	-42.3344	1.0154	10.3

Table 4.6.1 Summarizes the simulation results, providing a concise overview of the findings

Quality control measures were rigorously implemented throughout the fabrication stages to ensure that each element met the desired performance criteria. This included stringent testing and validation post-fabrication to verify the functionality and adherence of the component to performance standards. This comprehensive approach to fabrication aimed to deliver an 8-element component that not only met but exceeded the required specifications for gain, return loss, and VSWR. By enhancing these key performance metrics, the overall reliability and effectiveness of the component in its intended application were significantly improved, ensuring optimal performance under operational conditions

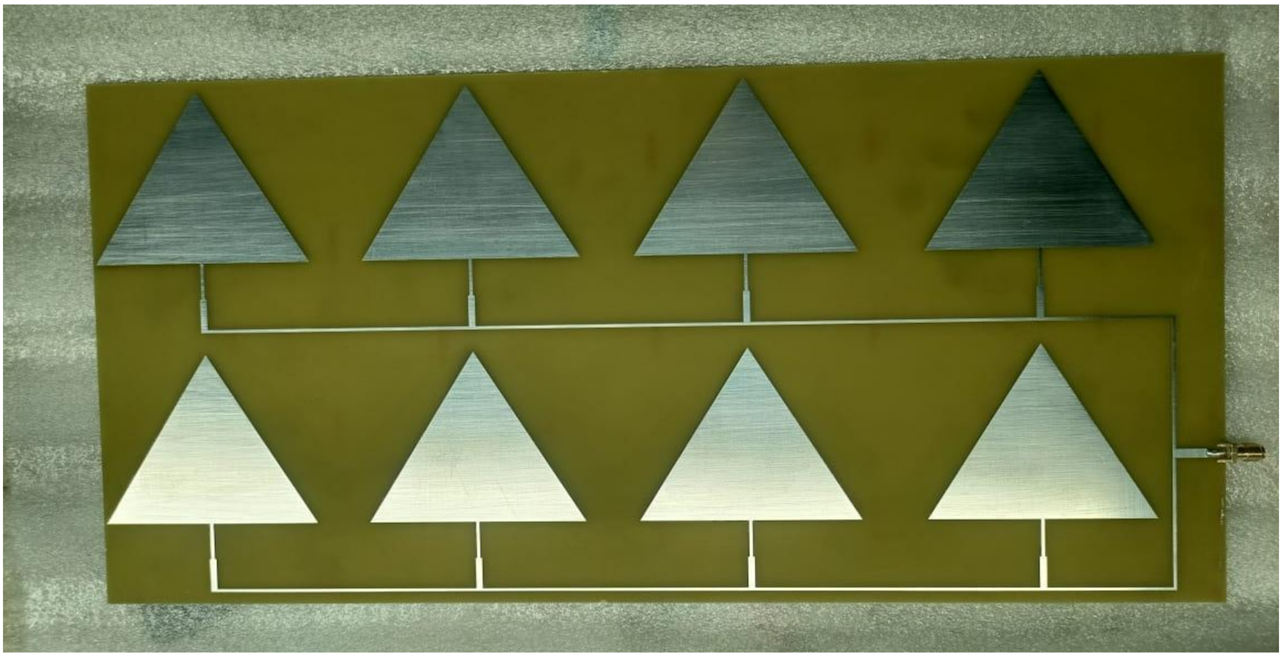


Figure 4.6.1 fabrication of an 8 element triangular array antenna(front view)

CHAPTER 5

CONCLUSIONS & FUTURE SCOPE

CONCLUSIONS

The study and design of the triangular patch antenna array, particularly utilizing a quarter-wave feed, have yielded significant advancements in our understanding of its operational properties and capabilities. Through meticulous modeling, simulation, and optimization, we have successfully crafted an array configuration that meets specific requirements, including desired radiation patterns, gain, and bandwidth. By leveraging techniques such as beamforming and impedance matching, we have further enhanced the array's directional characteristics and efficiency, resulting in improved performance across various applications.

Critical considerations such as feed network architecture and substrate material selection have played pivotal roles in developing a practical and reliable antenna system. Our project underscores the importance of systematic design methodologies in creating efficient antenna arrays for diverse applications, spanning radar and remote sensing technologies to wireless communication systems.

Moving forward, the insights gained from this endeavor will pave the way for continued advancement and innovation in triangular antenna array design. These insights will enable the realization of sophisticated and high-performance antenna systems to meet the evolving demands of modern communication and sensing technologies.

FUTURE SCOPE

Miniaturization and integration of antennas, particularly triangular microstrip patch antennas, are crucial for meeting the demands of compact and multifunctional devices. To achieve further size reduction while maintaining or enhancing performance, advanced techniques can be explored. One promising approach is utilizing metamaterials or engineered substrates with tailored electromagnetic properties to achieve miniaturization through effective refractive index control. Additionally, the adoption of advanced manufacturing techniques like additive manufacturing (3D printing) enables intricate antenna designs with reduced size and integrated functionalities.

Triangular microstrip patch antennas are well-suited for multiband and wideband operation due to their geometric versatility. To enhance bandwidth characteristics and support operation across multiple frequency bands, innovative design methodologies and materials can be leveraged. For instance, fractal-based or meander line structures integrated within the antenna geometry can broaden the bandwidth. Moreover, employing novel substrate materials with low dielectric constants can aid in achieving wider bandwidth while maintaining compactness.

CHAPTER 6

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DESIGN AND ANALYSIS OF TRIANGULAR PATCH ANTENNA ARRAY

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Abstract:
This paper presents the design and analysis of a triangular microstrip patch array antenna using Computer Simulation Technology (CST) with varying FR-4 substrates. The antenna is designed on a rectangular FR- 4 substrate with dimensions of 10×10 mm, and it operates within the frequency range of 2 GHz to 3 GHz. The design methodology and simulation results for key parameters such as return loss, gain, directivity, and radiation patterns are discussed comprehensively. The triangular microstrip patch antenna offers high performance and is suitable for various wireless communication applications including UMTS and ISM bands. The study provides valuable insights for the development of efficient microstrip patch antennas for modern wireless communication systems with arrays of 2, 4, 6, and 8 elements.
Keywords: Array, CST, Substrate, Gain, 2.4Ghz.

I. INTRODUCTION:
In the realm of modern wireless communication systems, the demand for compact, high-performance antennas continues to surge. Microstrip patch antennas have emerged as promising candidates owing to their low profile, lightweight, and compatibility with integrated circuit technologies. The utilization of antenna arrays further enhances their capabilities in terms of gain, directivity, and beam steering. This report delves into the comprehensive design and analysis of a microstrip patch antenna array comprising 2, 4, 6, and 8 elements. By exploring various design parameters and optimization techniques, this study aims to achieve enhanced performance metrics while ensuring the efficient utilization of resources. Through rigorous simulation and analysis, the report seeks to provide valuable insights into the intricate intricacies of microstrip patch antenna arrays, thereby contributing to the advancement of wireless communication systems. The structure includes a single patch and an array consists of a triangular surface on a grounded dielectric substrate. The single antenna configuration is a Single patch with microstrip leads. to Measure the power transmission capacity of the antenna, It can be a single antenna or an array antenna An identical antenna is placed at a distance 'd' from the antenna. original. That is, the antenna may not be present are aligned in the direction of each other's maximum gain. of the same procedure applies to array antennas. It consists of four triangular faces and a food network. The feeding network distributes energy evenly. Guarantees correct alignment from entry point to point. Any antenna. The operating frequency is 2.4GHz, The substrate is FR4 and the dielectric constant is 4.3.

1.1 PARAMETRIC ANALYSIS
Parametric analysis for a triangular patch array antenna involves studying how changing various parameters affects the antenna's performance. Here's a general guide on how we might conduct such an analysis:

S.no	Antenna Dimension	Value
1.	Resonant frequency(f)	2.4 Ghz
2.	Triangle patch length (a)	48.9
3.	Ground plane length (lg)	100
4.	Ground plane width(wg)	100
5.	Thickness(t)	0.035
6.	Height(h)	1.6

Table 1.1 List of Parameters.

1.1.1 Dimensions of the Triangular Patches:
Length: The length of each side of the triangular patch. It determines the resonant frequency and radiation characteristics.
Width: The width of the patch, measured perpendicular to the length. It affects the input impedance and bandwidth.
Height: The thickness or height of the patch above the substrate. It influences impedance matching and bandwidth.
Spacing Between the Patches:
The distance between adjacent patches in the array. It affects mutual coupling between elements, radiation pattern, and sidelobe level.

1.1.2 Substrate Material Properties:

Dielectric Constant (ε_r): The relative permittivity of the substrate material. It affects the resonant frequency, impedance matching, and dimensions of the patches.

Loss Tangent (tan(δ)): The lossiness of the substrate material. It affects the antenna's efficiency and bandwidth

1.1.3 Feed Position and Type:

Feed Location: The position where the feed is placed on each patch (e.g., center, corner). It affects impedance matching and radiation patterns.

Feed Type: The type of feed used (e.g., microstrip line, coaxial feed). It affects impedance matching, radiation pattern, and polarization.

Number of Patches in the Array:

The total number of triangular patches arranged in the antenna array. It affects the overall radiation pattern, gain, and impedance matching.

1.1.4 Shape of the Patches:

Equilateral Triangle: All sides and angles of the triangular patches are equal. This shape offers symmetric radiation patterns.

Right Triangle: One angle of the triangular patch is a right angle (90 degrees). It may offer different radiation characteristics compared to equilateral triangles.

By varying these parameters, engineers can tailor the performance of the triangular patch array antenna to meet specific requirements such as desired operating frequency, radiation pattern, gain, bandwidth, and impedance matching.

II. TYPES OF FEEDLINE

Triangular array antennas can be fed using various feedline configurations, each offering different advantages and characteristics. Here we described some common feedline configurations used for triangular array antennas:

a. Microstrip Feedline:

Microstrip feedlines are commonly used in planar antenna designs, including triangular patch array antennas. The feedline is typically etched onto the same substrate as the triangular patches in this configuration. The feedline connects each patch to the transmission line, providing the necessary RF signal to excite the antenna elements. Microstrip feedlines offer ease of integration, low profile, and the ability to control impedance matching.

b. Coaxial Feed:

Coaxial feed involves using coaxial cables to connect each triangular patch to the transmission line. A coaxial connector is attached to each patch, with the center conductor connected to the patch and the outer conductor serving as the ground plane. The coaxial feed provides good impedance matching and isolation between antenna elements. This configuration is suitable for applications where low-loss transmission and high isolation between elements are critical

c. Corporate Feed:

Corporate feed involves combining signals from a single feedline and distributing them to multiple patches in the array. A power divider network is used to split the signal and feed it to each patch element. Corporate feed simplifies the feeding structure and reduces the number of feedlines required, especially in large array configurations.

However, it may introduce additional losses and impedance-matching challenges compared to individual feedlines.

d. Inset Feed:

Inset feeding involves directly connecting the feedline to the patch antenna element within a specific distance from the edge of the patch. By adjusting the position of the feed point along the edge of the patch, designers can control impedance matching and radiation characteristics. While inset feeding offers simplicity in design and fabrication, achieving precise impedance matching may require careful tuning of the feed position. Additionally, mutual coupling between adjacent elements can affect antenna performance, especially in densely packed arrays.

e. Quarter-Wave Feedline

Quarter-wave feedlines use transmission lines approximately one-quarter wavelength long to match the high impedance of the antenna element to the characteristic impedance of the transmission line. This impedance transformation results in efficient power transfer and reduced spurious radiation, improving antenna efficiency. Quarter-wave feedlines can be implemented using various transmission line technologies, such as microstrip lines, stripline, or coaxial cables. However, they may require more complex design and fabrication compared to inset feeding techniques, and the length of the feedline may restrict the physical layout of the antenna system, particularly in compact or miniaturized designs.

III. PROPOSED METHODOLOGY

a. DESIGN AND ANALYSIS OF THE ARRAY

Quarter-wave array antennas come in various configurations depending on the number of elements in the array. Here are descriptions of 1, 2, 4, 6, and 8-element quarter-wave array antennas:

3.1.1. Single Element Quarter-Wave Array

The single-element quarter-wave array is an antenna system that consists of only one radiating element. Usually, the radiating element is a quarter-wavelength monopole or dipole antenna. The element is fed at the base using a quarter-wave transmission line, which helps in providing impedance matching between the feedline and the antenna element. This type of configuration is generally used in applications where a simple, omnidirectional radiation pattern is required, such as in wireless communication systems. In our project, we have developed a single element with a dielectric constant of 4.4 FR-4 substrate. The patch dimension is a=43.5.

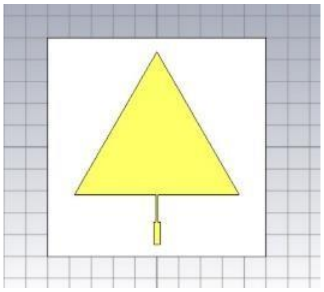

Figure 3.1: Single element quarter wave feed array antenna

3.1.2. Two-Element Quarter-Wave Array:

The two-element quarter-wave array is made up of two quarter-wavelength elements that are positioned at a certain distance from each other. The elements are synchronized to generate constructive interference in the desired direction and destructive interference in other directions, resulting in a directional radiation pattern. This setup is commonly used in applications that require moderate directional gain, such as point-to-point communication links. The dimensions of the ground and substrate are lg=120 and wg=220 respectively, while the patch dimension a is 43.5

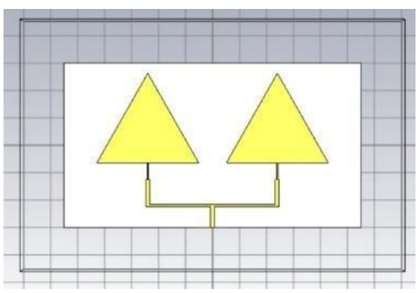

Figure 3.2: 2-element quarter wave feed array antenna

3.1.3. Four-Element Quarter-Wave Array:

The four-element quarter-wave array consists of four quarter-wavelength elements arranged in a linear or planar configuration. The elements are typically fed with equal amplitude and progressive phase differences to create a narrow beam radiation pattern with increased gain in the desired direction. This configuration offers improved directivity and gain compared to two-element arrays. It is commonly used in applications that require higher gain and narrower beamwidth, such as radar systems and wireless base stations. The dimensions for the ground and substrate of the 4-element quarter-wave feed is lg=250 and wg=207.5, and the patch a is 42.5 in length.

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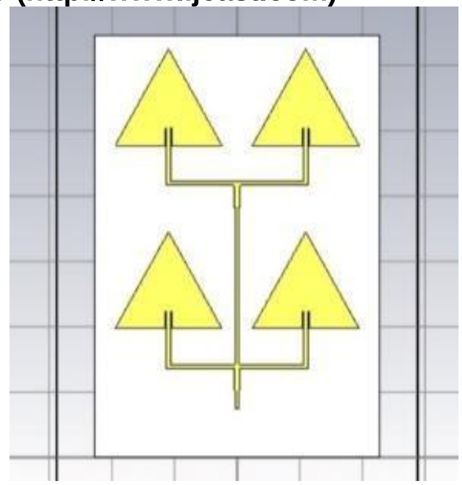

Figure 3.3: 4-element quarter wave feed array antenna

3.1.4. Six-Element Quarter-Wave Array:

The six-element quarter-wave array is composed of six quarter-wavelength elements that are arranged in a linear, planar, or circular configuration. These elements are fed with appropriate amplitude and phase distributions to shape the radiation pattern following the specific requirements of the application. In this particular case, we have provided the length (lg) and width (wg) of the ground and substrate as 200 and 300 respectively. The length of the patch 'a' is 36 each. This configuration provides further improvement in gain and directivity when compared to four-element arrays. It can be used in applications requiring even higher gain and more precise beam shaping, such as satellite communication systems.

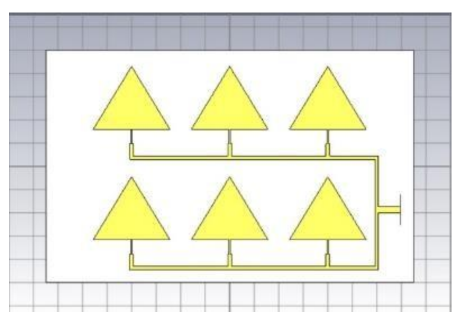

Figure 3.4: 6-element quarter wave feed array antenna

3.1.5. Eight-Element Quarter-Wave Array:

The eight-element quarter-wave array comprises eight quarter-wavelength elements arranged in a linear, planar, or circular configuration. It offers even higher gain and more precise control over the radiation pattern compared to six-element arrays. Eight-element quarter-wave arrays are commonly used in applications requiring very high gain and directional control, such as phased array radar systems and long-range communication links. These are just a few examples of quarter-wave array configurations, each offering different levels of gain and directivity.

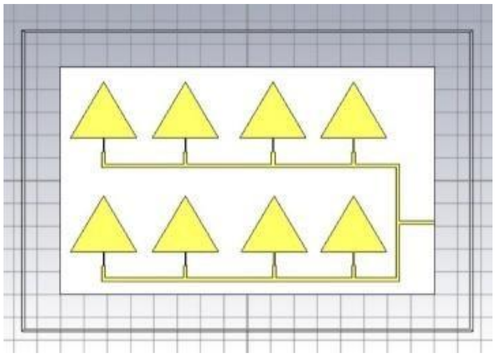

Figure 3.4: 8-element quarter wave feed array antenna

IV. RESULT & DISCUSSION

a. : Return loss: The analysis of the return loss remains a primary focus, which involves examining the shape and directionality of the electromagnetic waves emitted from the triangular array. To compare the S parameter or return loss of a 1-element and 8-element quarter-wave feed array antenna, we can consider the return loss for each element. The return loss for a single element is -17.33, for 2 elements it is -11.06, for 4 elements it is -12.263, for 6 elements it is - 26.7789, and for 8 elements it is -43.0652. These findings suggest that the return loss has gradually decreased as the number of elements has increased.

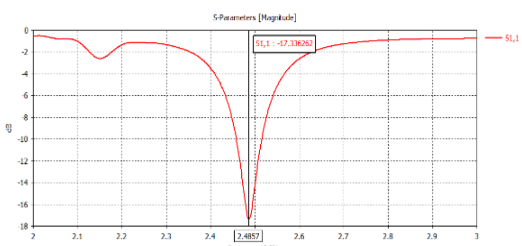

Figure 4.1.1: S-parameter of 1 element quarter wave feed

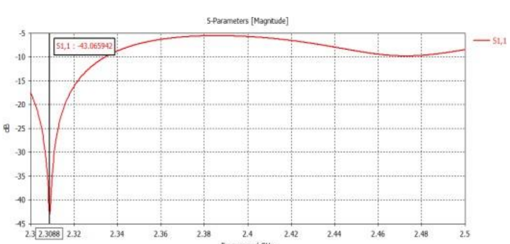

Figure 4.1.2: S-parameter or return loss of 8 element quarter wave array.

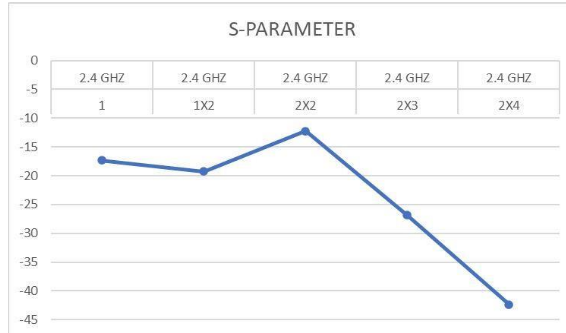

Figure 4.1.1: S-parameter quarter wave feed array antennas

b. : Gain: Gain is a term used to denote the increase in power density of a directional antenna when compared to an isotropic antenna. An isotropic antenna radiates equally in all directions whereas a directional antenna has the ability to focus and direct the transmitted or received power in a specific direction.

In Figure 4.2.3, you can see the gain values for the triangular patch antenna design which uses FR-4 for different arrays. The gain is measured at 2.4 GHz. The proposed design achieves a gain of 5.28 dB for a single element, and 7.2, 11, 10.4, and 10 for 2, 4, 6, and 8 elements respectively. This demonstrates the antenna's efficiency in concentrating the radiated power in a specific direction.

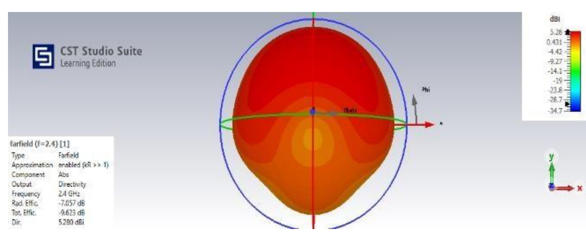

Figure 4.2.1: Gain of 1 element quarter wave feed

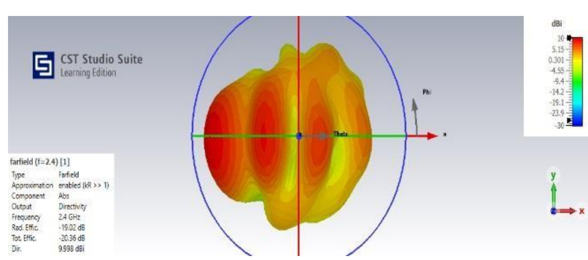

Figure 4.2.2: Gain of 8 element quarter wave feed

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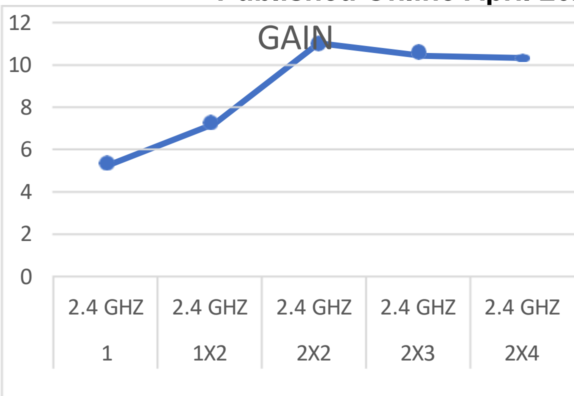

Figure 4.2.3: GAIN of quarter wave feed array antennas

c. : VSWR: The Voltage Standing Wave Ratio (VSWR) stands as a critical metric for assessing the efficiency of power transmission from a power source to a load via a transmission line within an antenna system. It plays a central role in evaluating antenna performance, with an optimal range typically falling between 1 and 2. Values closer to 1 denote superior impedance matching and more effective power transfer. Additionally, VSWR measurement provides valuable insights into the impedance characteristics of the transmission line and the antenna's efficacy in power transfer. By meticulously designing antennas to achieve low VSWR values, signal reflection is minimized, and power transfer is maximized, thus contributing to reliable and efficient communication.

The results of the computed VSWR values for the antenna design operating at a frequency of 2.4 GHz are shown in Figure 4.3.3. For the antenna that was built using FR-4 material, the VSWR values for a single element and for 2, 4, 6, and 8 elements are determined to be 1.3145, 1.2433, 1.6443, 1.095, and 1.0154 respectively. These values fall within the desired range, indicating that antenna designs have commendable impedance matching and efficient power transmission..

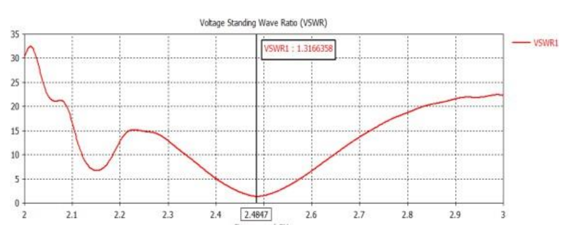

Figure 4.3.1: VSWR for 1 element quarter wave array.

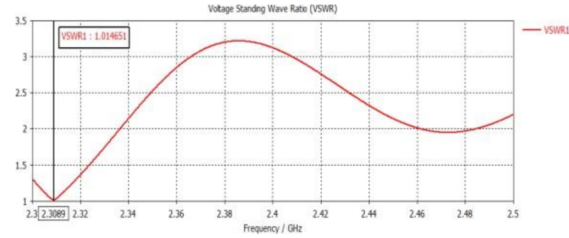

Figure 4.3.2: VSWR for 8 element quarter wave arrays.

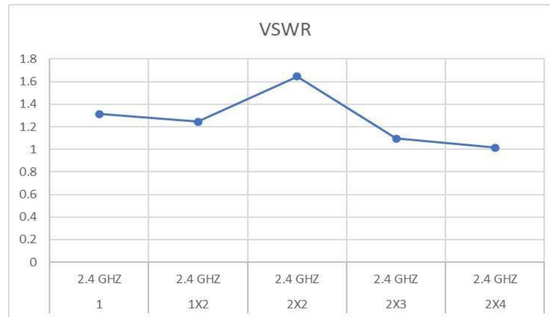

Figure 4.3.3: VSWR of quarter wave feed array antennas

d. : Beamwidth and Sidelobe Levels: Examining the beamwidth and sidelobe levels of the radiation pattern would provide insights into the array's ability to focus energy in the desired direction while minimizing unwanted radiation in other directions.

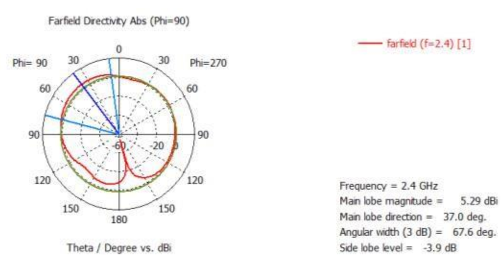

Figure 4.3.3: Antenna pattern of singe quarter wave feed

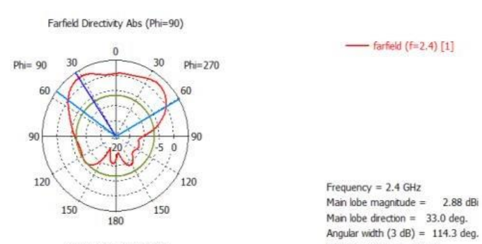

Figure 4.3.3: Antenna pattern of 8 quarter wave feed

Table 2 summarizes the simulation results, providing a concise overview of the findings.

Array	S-PARAMETER	VSWR	Gain	FREQ
1	-17.3343	1.3145	5.28	2.4 Ghz
1X2	-19.2934	1.2433	7.2	2.4 Ghz
2X2	-12.2618	1.6443	11	2.4 Ghz
2X3	-26.8646	1.095	10.4	2.4 Ghz
2X4	-42.3344	1.0154	10.3	2.4 Ghz

V. CONCLUSION

In conclusion, the study and design of the triangular antenna array have significantly advanced our understanding of its operational properties and capabilities. Through meticulous modeling, simulation, and optimization, we have crafted an array configuration that meets specific requirements, including desired radiation patterns, gain, and bandwidth. By employing techniques such as beamforming and impedance matching, we have further refined the array's directional characteristics and efficiency, enhancing its performance across various applications. Critical considerations such as feed network architecture and substrate material selection have contributed to developing a practical and reliable antenna system. This project underscores the importance of systematic design methodologies in the creation of efficient antenna arrays for diverse applications, spanning radar and remote sensing technologies to wireless communication systems.

Moving forward, the insights gained from this endeavor will pave the way for the continued advancement and innovation in triangular antenna array design, enabling the realization of sophisticated and high-performance antenna systems to meet the evolving demands of modern communication and sensing technologies

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