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DESIGN AND ANALYSIS OF MICROSTRIP ANTENNA WITH FREQUENCY SELECTIVE SURFACE SUPERSTRATE

Mas Mohammed Salih Khudhair AL-QUTBI

Master's Thesis

Supervisor

Asst. Prof. Dr. Abdullahi Abdu IBRAHIM

Istanbul, 2023

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The thesis titled ENHANCEMENT AND ANALYSIS OF MICROSTRIP ANTENNA WITH FREQUENCY SELECTIVE SURFACE SUPERSTRATE prepared by MAS MOHAMMED SALIH KHUDHAIR AL-QUTBI and submitted on 25/04/2023 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

____
Asst. Prof. Dr. Abdullahi Abdu IBRAHIM

Supervisor

Thesis Defense Committee Members:

Asst. Prof. Dr. Abdullahi Abdu IBRAHIM	Department of Electrical and Computer Engineering, Altınbaş University	___________________
Asst. Prof. Dr. Ayça Kurnaz TÜRKBEN	Department of Software Engineering, Altınbaş University	___________________
Asst. Prof. Dr. Tareq MOHAMMED	Department of Computer Science and Information Technologies, University of Kirkuk	___________________

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Mas Mohammed Salih Khudhair AL-QUTBI

Signature

DEDICATION

After the completion of this work, eighteen years of the study journey will have completely passed. During this period, I would not have excelled and reached where I am today except with the grace of God Almighty and the supplication and support of my dear mother, who was patient and sacrificed and spent the years of her youth raising me and following me to be one of the successful on the journey of life... I dedicate the product of this work to the soul of my deceased brother (Mohammad Mohammad Salih al-Qutbi) and to her greatest credit, my dear mother, my sister, and my brother... I would like to take this opportunity to thank the noble and humble person, my brother and supervisor, Dr Abdullahi Abu Ibrahim, who was the best support and help in the completion of this work. Finally, I extend my gratitude to all of my best professors at the bachelor's and master's levels for enriching me with science and knowledge... I hope that this work of mine will serve science andknowledge

The researcher

ABSTRACT

ENHANCEMENT AND ANALYSIS OF MICROSTRIP ANTENNA WITH FREQUENCY SELECTIVE SURFACE SUPERSTRATE

AL-QUTBI, Mas Mohammed Salih Khudhair

M.Sc., Electrical and Computer Engineering, Altınbaş University,

Supervisor: Asst. Prof. Dr. Abdullahi Abdu IBRAHIM

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Recently, wireless communications have significantly advanced in our daily lives, particularly in terms of our ability to perform tasks and communicate without a physical media. The ultimate crucial aspect of via distance communication is the capacity to transmit data over long distances using electromagnetic waves. These systems are simple to install and operate in locations where sending physical media is challenging. As the number of appliances and implementations linked to wireless networks has increased, congestion has occurred, slowing data transmission. Switching to high frequencies can be considered as one of the practical ways introduced by the network developers to satisfy users' demand for quick data transmission. In wireless communication architecture, the receiver or transmitter antenna is among the ultimate essential elements. Whereas, microstrip antennas are one type of antenna that is utilized, but it is necessary to increase these parameters due to their restricted bandwidth and depressed gain. In this thesis, we will introduce a design for regular MPA for the utilisation of 5G based 28 GHz. To obtain the optimum outcomes from the MPA we introduce two scenarios for the purpose of performance improvement. The first one is by employing the Frequency Selective Surface (FSS) that will be fitted over the MPAwith a determined air gap, whereas the FSS will only pass the required frequency and rejectthe others. This will improve the gain but will degrade the bandwidth. While the second oneis the utilisation of the array structure that will boost the total performance of the antenna. On the basis of the obtained outcomes, the use of array arrangement enhances the gain, bandwidth, and return loss. On the other hand, the power loss is increased due to the feeding network.

Keywords: MPA, FSS, Array Antenna, 5G, Wireless Communications.

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ABBREVIATIONS

WLAN	:	Wireless Local Area Networks
GPS	:	Global Positioning System
Wi-Fi	:	Wireless Fidelity
MSA	:	Microstrip Antenna
MS	:	Meta-Surface
MPA	:	Microstrip Patch Antenna
RL	:	Return Loss
BW	:	Bandwidth
FSS	:	Frequency Selective Surface
5G	:	Fifth-Generation
MIMO	:	Multiple-Input Multiple-Output
mmWave	:	Millimetre Waves

1. INCLUSIVE INTRODUCTION

1.1 INTRODUCTIONS

Wireless technology is in and of itself a paradigm changes since it enables people and machines to connect in real-time through a variety of media from essentially any location in the world. This technology is essential for functioning sensor networks, automated roadways, telemedicine, and smart houses. When compared to other subsets of the communications market, wireless communications show the most rapid expansion. Consequently, it has become a popular topic of discussion in the media and among ordinary people. Over the past decade, cellular systems have seen meteoric rise, and there are now about two billion users across the globe. Indeed, cellular phones turn into increasingly important in all aspects of life, including employment, and are swiftly taking the place of the antiquated wireline infrastructure that formerly existed in the developed world. Wireless local area networks are increasingly being used in residential and commercial properties, as well as on college campuses, and are either supplementing or replacing wired networks. They are essential to day-to-day life and business, and they are rapidly replacing aging wireline infrastructure across the industrialized globe. Wireless local area networks (WLANs) are becoming increasingly used in the homes, the businesses places, and the campuses [1], [2], as presented in Figure 1.1.

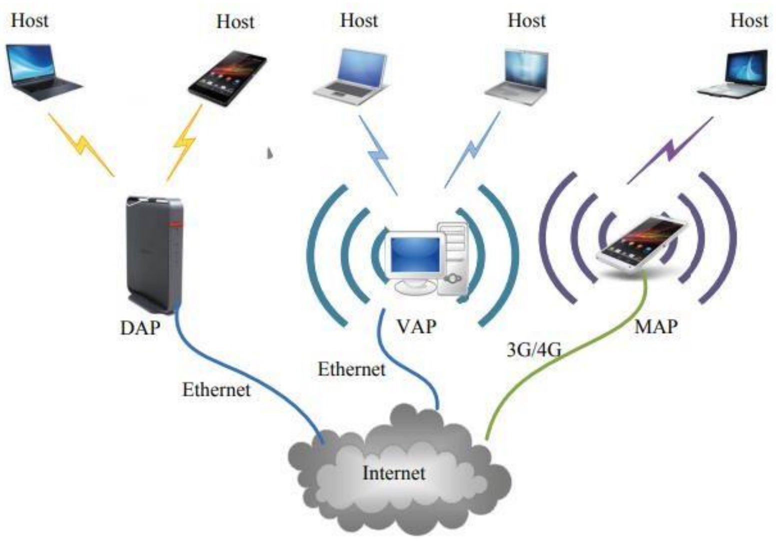


Figure 1.1: Structure of WLAN.

Wireless communications do not limit to be utilized in the WLAN but it used in the various of the applications of the communications, broadcasting and navigations. The meteoric rise of wireless systems and the widespread adoption of laptops and palmtops points to a reason to be optimistic about the future of wireless networks, both as stand-alone systems and as integrated parts of the larger networking infrastructure. The future looks bright for wireless networks, both as individual systems and as components of larger networking infrastructure. This is true for both the individual systems and the larger infrastructure. There are still a lot of substantial technological obstacles to overcome before the establishment of dependable wireless networks that can provide the rendering that is necessary to enable application development [3].

1.2 APPLICATIONS OF WIRELESS COMMUNICATIONS

It is necessary to presents a stable wireless communication infrastructure in order to improve day-to-day living. Over the course of several decades, these technologies have undergone continual improvement thanks to the creation of newer, more advanced iterations. Because of this, the possibility of their being utilized in the future has increased. There are a few different ways in which one can communicate wirelessly. Examples of such technologies include satellite, mobile, and wireless network communications, as well as infrared and Bluetooth. Nevertheless, not all companies are aware of the possibilities that these technologies present. Some of the essential wireless communications applications are listed below [4], [5]:

a. Connecting of Different Devices: Users have the ability to pair a broad variety of electrical devices thanks to Bluetooth. Radio waves with a low energy level and a limited range are used to achieve this goal. These waves are utilized by devices that have the capability to do so in order to interact with and get access to other devices of the same kind. People connect their gadgets by utilizing headphones that have Bluetooth capabilities. This is a risk-free option for drivers that need to make or answer the emergency calls while they are on the road. Additionally, Bluetooth permits the transfer of data between various electronic devices. From any device, such as a desktop computer, tablet, or mobile phone. Printing vital documents is a common task for office professionals who make frequent use of this technology. Without Bluetooth or the Wi-Fi technologies, the Internet of Things won't be able to connect the technological devices in your home. It is possible to link together a variety of devices, including thermostats, phones, computers, cameras, and even lamps. The same may be said for audio and video equipment, such as televisions. This technology is being used in the health and fitness industry to connect a variety of different training gear together. Additionally, it is utilized by medical professionals in order to read data from implanted devices such as pacemakers.

b. Making the Voice/Video Calls: Mobile phone service is utilized by a huge number of people all over the world. Radio signals are to be sent from one cell tower to another in order for this system to work properly. These pillars are connected to one another in order to produce a network that directs the waves on a particular path. The waves can then be triangulated to the telephone antennae of the people who are receiving the call as a result. No matter how broad access to the internet evolves, there will still always be a need for personal contact in the business sector to take place over the phone. This helps both with sales and providing better service to customers.

c. Access to the Internet: The Wi-Fi networks are currently being utilized by a sizable of users in order to have access to the internet and communicate various types of information and devices with one another. Routers in these types of networks make use of radio frequency signals in order to connect the many devices that make up the network. Wireless adapters are required for the devices in order for them to be able to pick up the signals and connect to the internet. It is now possible for multiple people to utilize the internet simultaneously in the workplace.

d. Positioning and Tracking Applications: Spacecraft are able to make contact with terrestrial electronics by utilizing a satellite communication system. This facilitates communication through the use of the telephone and access to the internet. Where it truly comes into its own is with the Global Positioning System (GPS). In addition, the GPS systems can be used to track the persons, pets, and the vehicles.

There are many other applications for the wireless communications to be used in the applications of the smart home or the smart cities, as presented in Figure 1.2.

Figure 1.2: Wireless Communications in Smart Cities.

1.3 EVOLUTION OF WIRELESS COMMUNICATIONS

The communications for the mobile wireless systems have passed by means of a number of different developmental stages over the course of the recent decades, beginning with the debut of the 1st generation (1G) mobile network in the early of 1980s. Because there was significant need for extra network connections all over the world, the specifications for mobile communication rapidly advanced in order to support a larger number of users. As mentioned previously, the transfer of data between locations that do not need to be physically connected is referred to as wireless communication, also referred to simply as wireless. Radio waves are an essential component to the functionality of today's wireless devices. The term "wireless" was emerged twofold in the history of communication, each time with a connotation that was relatively distinct from the other. From the time they were first developed in the late 1890s until the early 1920s, transmission and reception systems that were based on radio waves were invariably referred to as "radio." Examples of such systems include wireless telegraphy. The term was resurrected in the 1980s and 1990s to serve as a means of identifying various electronic devices brought about by the proliferation of wireless technology. Wireless activities enable the provision of services, the most notable of which is long-distance communication, which, in their absence, would necessitate the use of cables. The progression of written communication over the course of time is depicted in Figure 1.3.

In this section, we shall study the evolution of wireless techniques for portable communication over the course of history [6].

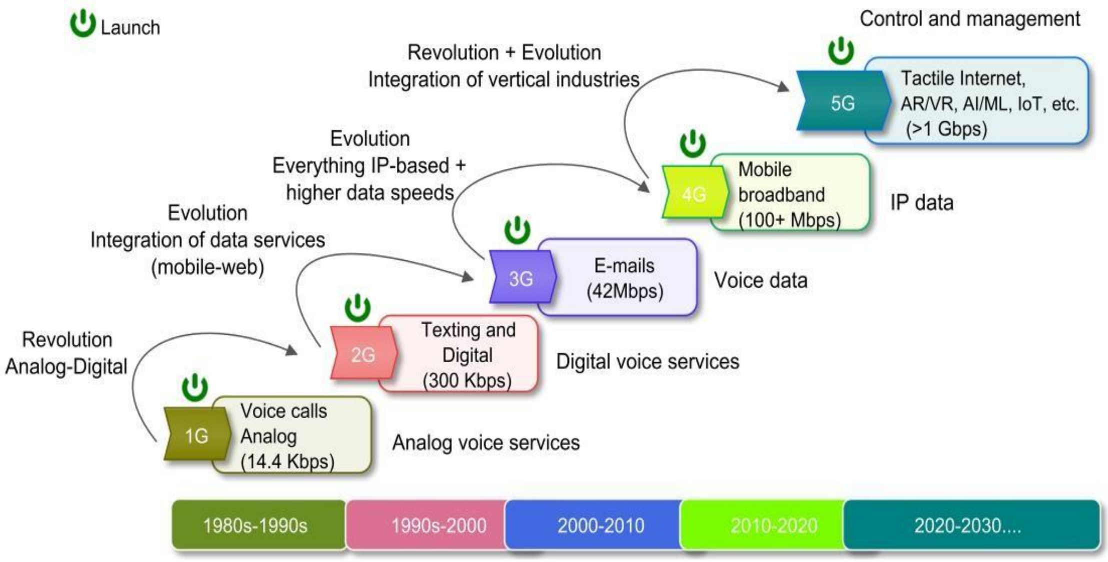


Figure 1.3: Stages of Evolution of Wireless Communications.

The 1980s saw the introduction of an analogue 1G cellular system, which is considered to be the beginning of the historical context. It was supplanted in 1990 by the "global system for mobile communications," often known as the "second generation" (2G) digital network. It supported capabilities such as voice over internet protocol (VoIP), as well as text messaging. However, by 2001, third-generation (3G) networks were offering data rates at very high speeds, rendering the previously available low data rates obsolete. Long term evolution (LTE) networks have, as of the year 2009, begun offering broadband service of the fourth generation, also known as 4G. The implementation of innovative technologies by 4G, such as Multiple-Input Multiple-Output (MIMO) and the Orthogonal Frequency-Division Multiplexing (OFDM), caused a significant paradigm shift, which led to a significant rise in the number of internet users and consumers. The introduction of 5G in 2019 made it possible to extend mobile service beyond individuals and into the sphere of businesses, so turning the entire world into a true global village. It is anticipated that the wireless mobile technology known as the fifth generation, often known as 5G, would represent the absolute apex of wireless communication technologies. The use of cables for the purpose of communication is becoming less common. In recent years, people have found a variety of uses for their mobile phones in addition to its primary function of communication. The fifth generation of wireless technologies has taken things to an entirely new level, allowing individuals to be genuinely mobile. Previous generations of wireless technologies have made it simpler to converse on the phone and transfer information. By the end of 2020, 5G telecommunications networks will start rolling out to consumers and will quickly expand across the world. This technology is expected to unleash a vast 5G Internet of Things (IoT) ecosystem, if the appropriate trade-offs are made between speed, latency, and cost. In this environment, the networks will be able to manage the communication requirements of billions of linked items. The main feature that is characterized by the 5G networks is the rates of data transfers that reached to many of Gbps that lead to the transfer an extensive size data through a piece of second [7], [8].

1.4 MILLIMETER WAVE (MMWAVE) SPECTRUM

The mmWave communication solutions have attracted a lot of attention recently due to the fact that they have the potential to assist the 5G network in managing its high data loads. Bandwidths for mmWave systems are typically close to 250 GHz, and they have the ability to cover frequencies ranging from 30 GHz all the way up to 300 GHz. Even though microwave frequency bands have significantly more available bandwidth, mmWave frequency bands have different behaviors for path loss, diffraction and obstruction, rain attenuation, air absorption, and foliage loss. This is the case even though mmWave frequency bands have significantly more available bandwidth. In comparison to microwave systems, mmWave systems have a significantly larger overall loss when used in a point-to-point link configuration. With mmWave frequencies, on the other hand, the small wavelengths make it possible to deploy a large number of antenna components in the same form factor. This results in enormous increases in spatial processing, which, in theory, can compensate for at least the isotropic path loss. However, because mmWave systems require a large number of antennas, there are a range of computational and practical challenges that must be overcome in order to maintain the predicted boost in performance of mmWave systems. In order to accomplish this goal, this chapter will discuss some of the most significant link-level enabling strategies for the mmWave-based 5G network. The 5G networks are based on the utilise of the higher-frequency bands than their predecessors, as illustrated in Figure 1.4. The 5G uses mmWave frequencies in the low, the mid, and the high-frequency bands as follows [9]-[11]:

a. Low-Frequency Bands: A low-frequency band in the sub-1GHz range makes it feasible to carry on conversations not only inside of buildings but also in the open countryside, in the suburbs, and in the city itself. By utilizing lower frequency bands, it is possible to travel greater distances, albeit at a more gradual rate of data transfer. Their safety is ensured to a high degree.
b. Mid-Frequency Bands: Band of Radiation Having a Moderate Frequency Content More spectrum in the 3.3–4.2 GHz region is used for 5G networks. The 5G technology's large capacity and wide coverage in the mid-frequency band are two of its most notable features. This spectrum band, also known as WRC-23, now includes the higher-frequency ranges of 4.8 GHz, 6 GHz, and 10 GHz.
c. High-Frequency Bands: The usage of mmWave frequency bands ranging from 24 GHz to 100 GHz by the 5G spectrum enables ultra-high speed, increased traffic, high capacity, and a growth in the number of devices that are linked to the cellular network.

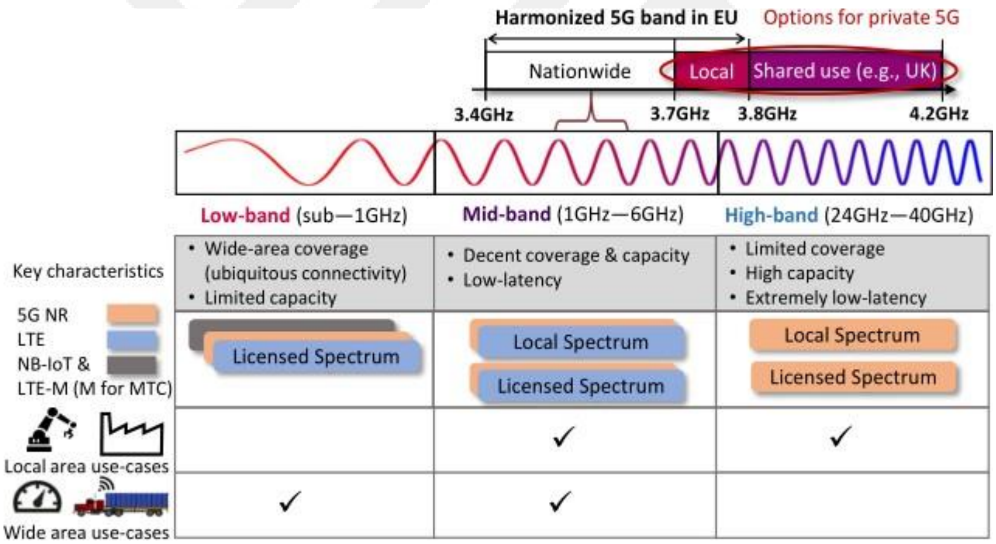


Figure 1.4: Frequency Spectrum Allocation for 5G.

Figure 1.5 illustrates that the lower frequencies, those that fall below 30 GHz, are preferred because of the superior propagation properties they possess. Above 30 GHz, on the other hand, there is a significantly increased availability of spectrum, as well as the possibility for wider transmission frequency bands of the order of 1 GHz or more [12].

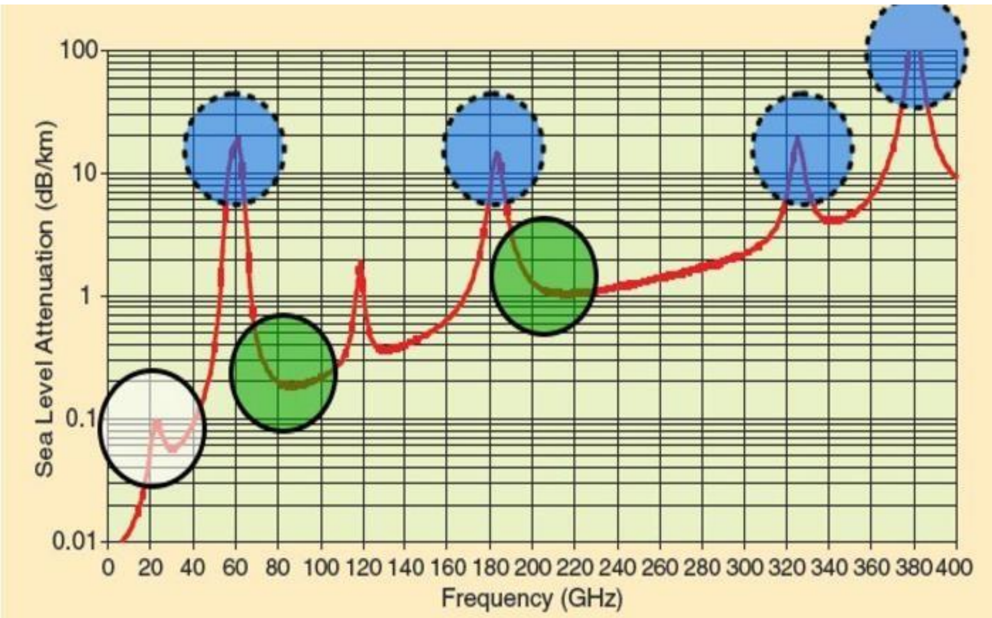


Figure 1.5: Attenuations for the mmWaves Frequencies.

1.5 ADVANTAGES AND DISADVANTAGES OF WIRELESS COMMUNICATIONS

A collection of devices, e.g., computers, or other things that are connected to one another by means of some sort of communication technology via distance communications is referred to as a network. The term "wireless communication" refers to any technique of transmitting and receiving data or sound that does not include the use of cables. The transmission of data takes place along a channel that has been clearly defined in the electromagnetic spectrum. The using of the wireless communications offering several advantages some of which are listed as following [13], [14]:

a. Freeing of the wire’s utilizations: the wireless communication network can be organized without the need for any physical connection such as the cables.
b. Simple to install: the wireless network can be simple to configure and expand due to the wire-free.
c. Networking in remote locations, battlefields, and other sites where hardwiring is impractical allows for better or worldwide coverage.
d. In the term of the flexibility, the wireless networks are more malleable and versatile than their wired counterparts.

e. Because it doesn't necessitate drilling holes in the wall or running wires through the ceiling, the wireless network is less expensive to set up.
f. Wireless networks are both mobile and portable, making them simple to move to a new location and set up as well.

Besides the numerous of the previously mentioned advantages, the wireless communication networks suffer from different of the issues which are listed as follows [15]:

a. Since communications is occurs in the open space, its confidentiality cannot be guaranteed.
b. Unreliability of communications due to the security issues such as jamming or interference.
c. Data transfer speed is relatively less than the cable transmission due to the presence of the path loss.
d. It is essential for wireless networks to have their radio frequencies carefully tuned in order to prevent interference.
e. Even though wireless networks in and of themselves can be relatively inexpensive, the installation cost is high.

1.6 LITERATURE SURVEY

In the section, some of the previous works regarding the design and enhancement of the Microstrip Patch (MP) antennas will be reviewed, as follows:

a. In [16], the authors have been printed a square patch shape over a dielectric material with a dielectric constant = 2.2, dielectric loss tangent = 0.0010 to construct a traditional MP antenna for the 5G based 26 GHz applications. The authors have been carried out the simulations and analyses of the suggested design based on the FEKO software. After modelling the antenna, the authors have obtained a return loss of -33.4 dB, a bandwidth of 3.56 GHz, an antenna gain of 10 dB, and a good radiation efficiency.
b. This work has presented a simple structure of traditional MP antenna and MP antenna array that operates at centered frequencies of 38GHz and 54GHz with BW of 1.94GHz and 2GHz, respectively for the applications of 5G high band applications. The antenna was designed with the goal of making it suitable for use in miniaturized electronics. The low cost of the substrate and the tiny patch size for the antenna makes it a strong

contender for the development of 5G communications technology in the future. It is suggested MP antenna design has been constructed out of a patch and ground from PEC, and of a Rogers RT5880 substrate, which has a standard thickness of 0.508mm, a constant of 2.2, and a loss tangent of 0.0013 as well. To be more specific, a substrate of the MP antenna has dimensions of 6 mm × 6.25 mm and a patch with dimensions of 2 mm × 2 mm is made. The authors have been used a technology known as microstrip-line feeding to ensure the best matching of the impedance. In order to improve the overall antenna performance, the MP antenna array configuration is designed with four rectangular patches. The MP antenna array is used for the applications that are operating at 38.6GHz, 47.7GHz, and 54.3GHz. The parallel feed has been used to feed the array elements, and the resulting bandwidths are 3.5GHz, 2.5GHz, and 1.3GHz, respectively for the operating frequencies [17].

c. This work discussed the design of an MP antenna for the 5G wireless networking. The dimensions of the antenna are 11 × 8 millimeters with 0.5 millimeters in height. The proposed MP antenna has been constructed based on a substrate made of a dielectric substance referred to as Rogers RT / Duroid 5880. The used substrate has a thickness of 0.5 millimeters and a dielectric constant of 2.2. The designed MP antenna has aresonance frequency range that falls somewhere between 28 and 50 GHz. In the HFSS software, the proposed MP antenna model has modeled and analyzed. The gain that theantenna contributes is 2.6 decibels. The designed antenna is powered by using the line feeding line strategy. In order to create the dual-band frequency, a rectangular slot is engraved in the feed line [18].

d. When it comes to implementing 5G, massive MIMO is a key enabling technology among many others. With the advent of private companies like SpaceX and the lofty goals of the Indian Space Research Organization and the United States' own National Aeronautics and Space Administration, the study of radio-emitting celestial bodies has become a necessity in the field of space exploration. Many scientists are drawn to the field of radio location because of its potential to identify the location and speed of objects using radar. Once multiple, unique operating frequencies are desired, one option to examine is using an antenna with multiple bands. The research that is provided here suggests the use of a MP antenna that is capable of functioning on 3-distinct frequencies. These frequencies are 23.9 GHz, 35.5 GHz, and 70.9 GHz. The return loss, voltage standing wave ratio, gain, radiation pattern, and current distribution are all aspects of the antenna that have been analyzed and computed based on the HFSS simulation software. The results that were gathered are validated to ensure that they meet the requirements for the 5G and pacing applications [19].

e. Generally, there has not been any preliminary work done on the design of a triple-band MP antenna that will be used for 5G applications. For the 5G wireless networks, the authors of the paper proposed utilizing of an MP antenna with three separate bands. Due to the material's low relative permittivity, $\varepsilon_r = 2.2$, a coating of Rogers RT Duroid-5880 measuring 0.25 millimeters in thickness is used here. In order to construct and simulate the proposed antenna, the IE3D and the HFSS are both utilized as a part of the simulation process. In the end, the HFSS software does an analysis and makes comparisons of the results. The findings of the simulation indicate that the proposed antenna, despite having a smaller antenna surface and a thinner substrate, offers a reflection coefficient of less than -10 dB in addition to having good gain and bandwidth at (24.4/28/38 GHz) [20].

f. This paper delves into the design and simulation of an MP antenna design to be functioning at 28 GHz in order to make 5G communications more accessible. To obtain the planar structure and perfect impedance matching the quarter wavelength transmission line is connected to the patch of the antenna. The antenna is made up based on the Rogers RT Duroid 5880 material and is ideal for use as the substrate because it has a dielectric constant of 2.2 and a thickness of 0.254 millimeters. After calculating the dimensions of the antenna, the authors have been utilized the HFSS to simulate and visualize the results, which they subsequently analyzed [21].

g. In this paper, the authors have been introduced a novel phased MP antenna array design operating at 28 GHz, which is destined to be implemented in 5G mobile phone networks in the not-too-distant future. The introduced design allows for the construction of antennas using relatively affordable FR-4 substrates, without compromising the antenna's high gain or its efficiency in any way. In order to achieve this goal, a cutting-edge air-filled slot-loop radiator structure is utilized. As a demonstration of the system's viability, 10 individual radiator components have been assembled into a prototype array. Gains of more than 13 dB are achieved by the antenna array within a scanning angle range of 0–50 degrees, while radiation efficiencies of more than –0.5 dB (i.e., 90%) are achieved within this same range. Both simulation and experimental models demonstrate that the S_{11} response of the antenna is less than -10 dB from 27 to 29 GHz. This is the range across which it operates [22].

h. This study offers a low-cost technique of beam-steering a MP antenna based on the use of the passive frequency selective surface (FSS) consisting of a single layer and a phase-shifting surface. The FSS is used to steer the beam of the MP antenna. The proposed antenna is made up by using the low-cost FR-4 substrate, on its top, the square patch has been printed and, on its bottom, the ground plane has been printed. The enhance the parameters performance of the MP antenna a superstrate has been installed above the antenna with a space. The introduced design showed good results, where the antenna gain of 8.9 dBi and 75% antenna efficiency have been reached [23].

i. In this work the researchers were presented a novel design of the graphene-based MP antenna for the applications of 5G high band. The proposed antenna has been designed to operate over a 60 GHz frequency with tunable characteristic. For the purpose of fine-tuning, the suggested configuration makes use of a copper radiating patch that has been printed with 4 stripes of graphene. It is feasible to modify the working frequency of the MP antenna to a particular value by applying a DC voltage to the graphene stripes. Graphene's ability to have a changeable surface impedance makes this a possibility. Through the use of CST, the authors have been investigated how changing the applied voltage can change the antenna's usable frequency range. As a means of enhancing the antenna's radiation properties, FSS has been used [24].

j. To combat COVID-19, we need to work together and use cutting-edge technology. The Internet of Things has contributed to the solution of problems in the healthcare industry and beyond. It strengthens the reliability and accuracy of services and applications. Because the Internet of Things (IoT) has limitations in areas such as range, battery life, security, connections, timing, and multicasting, this work proposed the use of the FSS as a superstrate for rectangular MP antenna. An FSS layout using a rectangular microstrip antenna provides superior performance to a parallel FSS configuration. A 45-degree inclination of the microstrip antenna altered the band stop. Gain, return loss, and directivity are all enhanced by the FSS structure's unified design. To develop, simulate, and verify the proposed antenna, we employ a 3D electromagnetic structure by using the CST studio suite [25].

1.7 THESIS OBJECTIVES

This thesis aims to achieve several goals, which we summarize as follows:

a. Design and analyzing of traditional MPA based on Rogers RT/Duroid 5880 substrate by using the CST package for 5G-based 28 GHz.
b. Optimize the designed antenna parameters performance by creating the 1x4 antenna array configuration with parallel feeding.
c. Create a novel design for FSS and installed over the designed MPA and compare the obtained outcomes.

1.8 THESIS ORGANIZATION

In general, this thesis is organized to consist of five principal chapters discussing and presenting the introduced work, the organisation of each chapter is illustrated as follows:

a. Chapter Two:

This chapter of thesis provides a comprehensive explanation for the principal parameters of antennas. Also, in the second part of this chapter, we will review the Microstrip Patch (MP) antennas, their feeding methods, their analysis methods, and the MP antenna array. Finally, in this chapter, we will also discuss the fundament of the Frequency Selective Surface (FSS), its types, and its usefulness.

b. Chapter Three:

This chapter of this thesis, we will discuss microstrip antennas, their definition, structure, types, methods of power supply, methods of analysis, and their various applications in the daily life of users.

c. Chapter Four:

This chapter of thesis, we will explain the principal stages of the process of designing the proposed MPA and MPAA. In addition, the outcomes after conducting this work will be illustrated in detail and discussed as well in this chapter.

d. Chapter Five:

Finally, this chapter will introduce what we concluded and the future advise.

2. ANTENNAS FUNDAMENTALS AND MICROSTRIP ANTENNAS

In this chapter of thesis, we will review the basics principal for testing the performance of any antenna. Also, in the second part of this chapter, we will review the Microstrip Patch (MP) antennas, their feeding methods, their analysis methods, and the MP antenna array. Finally, in this chapter, we will discuss the fundament of the FSS, its types, and its usefulness.

2.1 ANTENNA CHARACTERISATION

An antenna is a metallic appliance utilise to transmit /receive guided electromagnetic waves and many wireless application systems rely on it for its work nowadays. Antennas are frequency-dependent devices and operate in bands determined according to the design of each device. An antenna should be attuned to the frequency band that the radio system demand to be correlated to operate, in general, the energy made by the source should be completely converted and to be emitted as electromagnetic waves. The signal on its way to the antenna is exposed to losses due to the nature of the carrier medium, either because of the losses of the material from which the transmission line is made called conduction dielectric losses or because of the distractive and the constructive which occurs due to the interference patterns. The losses that are produce by the transmission line and the standing waves are unacceptable, these losses must be eliminated to get the optimum antenna design. Design of the antenna has the potential to influence the fundamentals of the system, which in turn can influence the performance of the system. In a state-of-the-art wireless system, an antenna is used not only for the reception and transmission of energy, but also as a directional device for focusing radiation in one direction while dampening it in another. This allows the antenna to perform dual functions of receiving and transmitting energy [26].

2.2 ANTENNA PRINCIPAL PARAMETERS

This subsection of the current chapter reviews the principal antenna parameters such as radiation pattern (RP), gain, the equivalent circuit of antenna representation, antenna efficiency, antenna polarization, return losses (RL), and bandwidth (BW).

2.2.1 Radiation Pattern (RP)

It is possible to describe the radiation pattern of an antenna as a numeric or mathematical function, or as a graphical representation of the radiation properties of the antenna as a function of space coordinates. The radiation pattern of an antenna is the plot of the power radiated from an antenna per unit solid angle. In most cases, the pattern's aspect can be broken down into two distinct categories: narrow, focused peaks, and wide, directional peaks. The directional antennas each have a radiation beam within them that is referred to as the main lobe, and it is this beam that emits the most radiation. Side, minor, and back lobes are the names given to the unwanted radiation that is emitted in other directions, with the exception of monopoles and dipoles. They represent lost energy for the antennas that are doing the transmitting and potential noise sources for the antennas that are doing the receiving. Figure 2.1 illustrates the radiation pattern produced by a standard antenna [27].

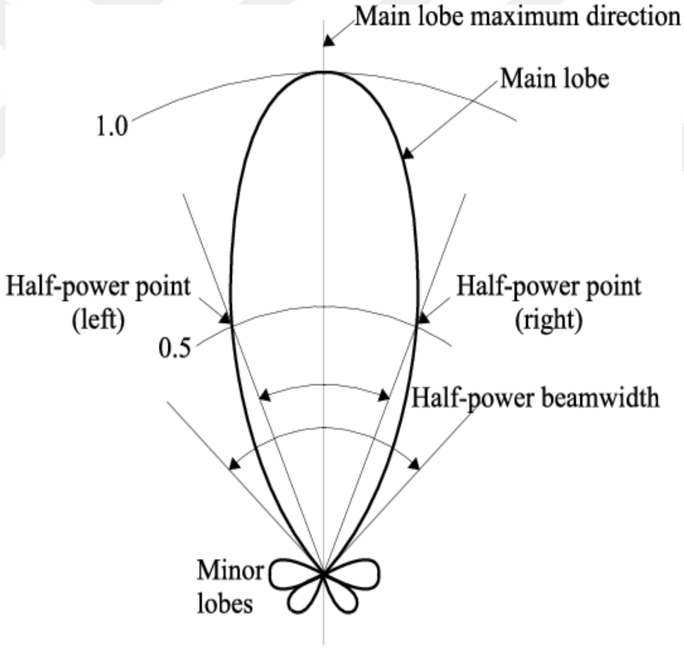


Figure 2.1: The RP of a Generic Directional Antenna.

2.2.2 Antenna Regions

The reactive field, the near field, and the far field make up the primary components of the antenna, respectively. The area close to the antenna is known as the reactive field. This is the region where the field patterns shift quickly with increasing distance. Additionally, this is the region where the radiating and reactive energies combine to appear as an energy-storage reactance without any energy loss. Even at great distances, the reactive fields are not taken into account; only the radiated energy is present, and it is this energy that causes the power to change with direction regardless of the distance. Figure 2.2 provides a visual representation of the antenna regions [28].

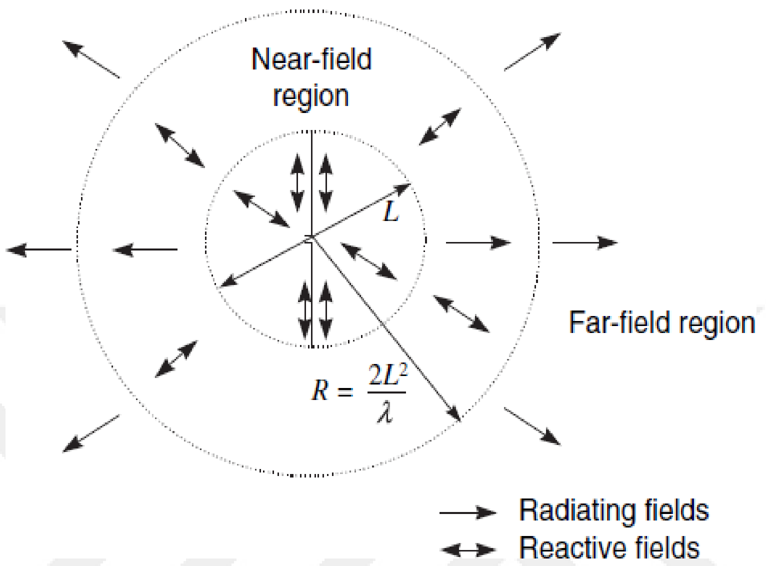


Figure 2.2: The Essential Antenna Regions.

2.2.3 Directivity(D)

The directionality of an antenna can interpreted as the value of D indicates the degree to which it emphasizes radiation coming from one direction during reception, or emphasizes radiation coming from only one direction during transmission. More precisely, in the mathematical form it is defined as [28]:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}}, \tag{2.1}$$

where:

U: is utilized to represent the radiation intensity in ($W/unit\ solid\ angle$);

U_0: is utilized to represent the radiation intensity for the isotropic source in ($W/unit\ solid\ angle$);

P_{rad}: is utilized to represent the total of radiated power in (W).

2.2.4 Antenna Gain

The antenna gain is defined as the ratio between the antenna radiation intensity and the radiation intensity of the isotropic antenna radiating the equivalent total power as acquired by the real antenna. The manufacturers of the antennas have usually specified the antenna gain referring to the maximum value of which symbolized as G. From the antenna directivity and the antenna efficiency, the gain of the antenna can be defined as follows [28]:

$$G = e \times D \tag{2.2}$$

where:

: is utilized to represent the antenna efficiency;

: is utilized to represent the antenna directivity.

From the previously written equation it is clearly the main difference between the gain and directivity of the antenna is the efficiency so, the antenna gain will be often less than the directivity just in case of “100%” efficiency then the gain will be equal the directivity.

2.2.5 Return loss (RL)

When determining whether or not an antenna is functional, RL is an important parameter to take into consideration. This value provides a quantitative measure of the effectiveness with which an antenna transfers power from its source to itself. In addition to that, the impedance matching theory and the maximum power transfer theory are both significant factors. When the RL is expressed in terms of power, it is defined as the ratio of the incident power (Pin) to the reflected power (Pref) at the antenna, as follows: [28]:

$$R.L = 10\log_{10}\frac{\mathrm{r_{in}}}{\mathrm{P}_{\mathrm{re}F}}\,(\mathrm{dB}) \tag{2.3}$$

Or in term of the reflection coefficient (r) by the following equation:

$$R.L = -20\log_{10}|\Gamma|\,(\mathrm{dB}) \tag{2.4}$$

For best impedance matching between the transmitter and the antenna $\Gamma = 0$, this means the total power of the source is transferred to the antenna and no power is reflected back to the source.

2.2.6 Bandwidth (BW)

The BW of the antenna represents its capability to operate across a wide range of frequency. The BW is usually defined as the range over which the gain is kept to be closed with the 3 dB of its maximum value, or the range over which the voltage standing wave ratio is not more than the acceptable ration (i.e., 2:1). The antenna BW is usually expressed as a percentage value of the nominal operating frequency. The antenna radiation pattern may be changed dramatically outside its specified operating BW. The BW usually calculated at the $RL = -10dB$, as illustrated in Figure 2.3, this criterion means a 10% of the power will be reflected to the source and the rest will be transferred toward the antenna [28].

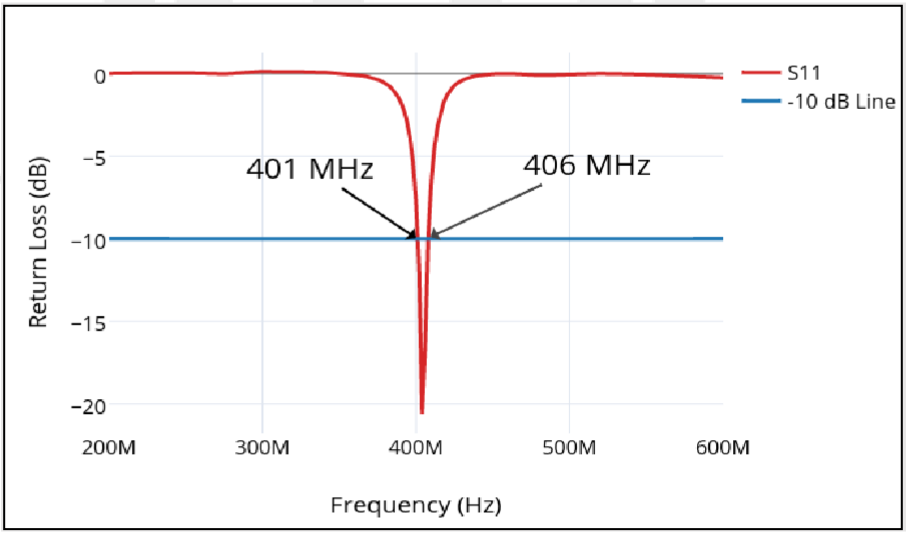


Figure 2.3: Antenna BW Calculation.

The narrow antenna BW can be expressed as the difference of the upper and lower frequency divided by the centre frequency, it can be obtained from the following equation [28]:

$$BW_{narrowband} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% \quad (2.5)$$

$$BW_{ratio} = \frac{f_H}{f_L}, \qquad (2.6)$$

where:

f : is utilized to represents the upper frequency;

f : is utilized to represents the lower frequency;

$BW_{narrowband}$: is utilized to represent the narrow BW;

f_c: is the center frequency, and can be obtained as follows:

$$f_c = \frac{f_H + f_L}{2}, \qquad (2.7)$$

In the case of the $BW_{ratio} > 2$, then we can be considered that the designed antenna is has a broadband, otherwise, the antenna will be termed to be as a narrow BW.

2.2.7 Equivalent Circuit of Antenna

A representation of the equivalent circuit of a transmitter antenna can be seen in Figure 2.4. In a general manner, the antenna circuit consists of a couple of the portions, the first portion is named as the resistive while the latter is called as the inductive. The radiation resistance, denoted by the acronym Rr, and the loss resistance, denoted by the acronym RL, this structure together makes up the resistive portion of the antenna's impedance. It is possible to determine the amount of energy that is emitted by the antenna by using the radiation resistance of the antenna. The amount of power that is lost by the antenna as a result of losses in the conducting and dielectric components is denoted by the term loss resistance which is created naturally due to the properties of the utilized metal. The inductive portion of the antenna impedance is generated due to the dealing with the electric waves that pass through the metal [29].

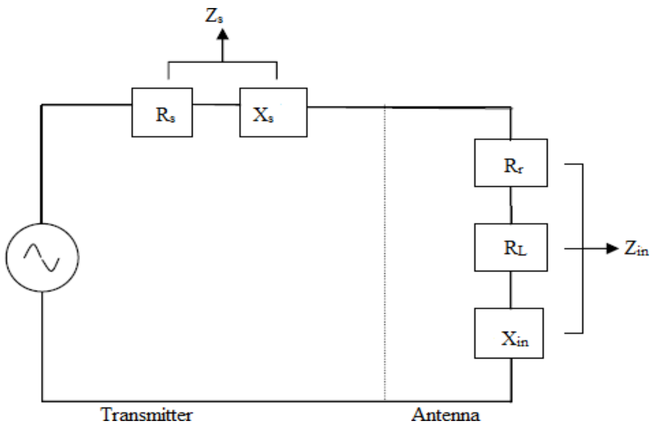


Figure 2.4: Representation for the equivalent circuit of the antenna.

There are a few different ways in which one can describe the input impedance of an antenna. To begin, the impedance that is presented by an antenna is identical to the impedance that is present at the antenna's terminals. The ratio of the terminal voltage to the current provides a description of the relationship between the two. An additional definition of input impedance describes it as the ratio of an electric (E) field to a magnetic (H) field at the same point.

In the mathematical form, the I/P impedance of the general antenna type can be represented by using the following equation [29]:

$$Z_a = R_a + jX_A \tag{2.8}$$

$$R_a = R_r + R_l, \tag{2.9}$$

where:

Z_a: is utilized to represents the antenna impedance;

R_a: is utilized to represents the resistive part of the antenna impedance; and

X_A: is utilized to represents the inductive part of the antenna impedance.

The previous Figure 2.4 illustrates both the radiation resistance R_r and the loss resistance R_l that the antenna possesses. The energy storage models developed by X_A for the antenna near-field are completely made up. Displayed here is the amount of reflected power or phasing mismatch that exists between the voltage and the current. Matching the impedance of two antennas is notoriously challenging due to the requirement that the impedance remains constant across the frequency spectrum. Antennas are typically constructed with an input impedance of 50 Ohm due to the fact that this value is the industry standard [29].

2.2.8 Antenna Efficiency

Another essential factor that is utilized in the examining the antenna performance is called the antenna efficiency (e). Calculating an antenna's efficiency involves dividing the amount of power it receives by the amount of power it radiates. A radio antenna with a high radiation efficiency will dissipate the vast majority of the power it receives as radiation. The vast majority of the energy is either radiated away as a result of an impedance mismatch or is lost due to internal losses that occur in an antenna that has a low efficiency. It is a very useful feature to have an antenna that, regardless of whether it is being used to transmit or receive signals, it maintains the same level of efficiency overall. As a consequence of this, it is possible express antenna efficiency as the proportion of "potential power received from all possible angles;" however, this definition is somewhat more challenging to formulate. It is important to keep in mind that the efficiency of a transmit and receive antenna is the same. We will use this definition of efficiency because it is simpler to consider efficiency in terms of the power that is radiated as opposed to the power that is supplied. It is common knowledge that antennas possess the property of reciprocity between one another. Because only the power that is radiated typically represents a purpose that is either useful or practical, the efficiency of the radiation that an antenna emits can be expressed by utilizing the following equations [30]:

$$e = \frac{\text{Power radiated}}{\text{Power accepted by antenna}} \tag{2.10}$$

$$e = \frac{R_r}{R_r + R_l} \tag{2.11}$$

2.2.9 Voltage Standing Wave Ratio

Another essential factor that is utilized for the examining of the antenna performance is the Voltage Standing Wave Ration (VSWR). If the impedance of the source, denoted by Zs, and the impedance of the antenna, denoted by Za, are complex conjugates, then the maximum amount of power will be transferred from the source to the antenna, as presented by the following equation [30]:

$$Z_s = Z^*{}_{in} \tag{2.12}$$

$$Z_s = R_s + jX_s, \tag{2.13}$$

where:

Z_s: is utilized to represents the source impedance;

R_s: is utilized to represents the resistive part of the source impedance; and

X_s: is utilized to represents the inductive part of the source impedance.

In the case of there aren't enough matching, some of the energy gets reflected back, which creates standing waves, which can be measured using something called VSWR. In the arithmetic manner, the VSWR can be represented by utilizing the following equation [30]:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2.14}$$

where Γ is utilized to represents the reflection coefficient which can be determine by the following equation:

$$\Gamma = \frac{Z_a - Z_s}{Z_a + Z_s} \tag{2.15}$$

A common metric the VSWR is utilized to determine the extent to which there is an impedance mismatch between the source and the antenna. The VSWR also increases along with the growing mismatch in magnitude. Components have to be perfectly matched in order to attain a VSWR value of 1 [30].

2.2.10 Antenna Polarization

The polarization of an antenna is the general orientation of the electromagnetic fields that the antenna generates as energy is radiated away from it. This orientation can be thought of as the "big picture" of the antenna's polarization. These directional fields have an effect on the energy that is either transmitted or received by an antenna. There are different of the antenna polarization, which can be listed as follows [31]:

a. Linear polarisation
b. Circular polarisation
c. Elliptical polarisation

The orientation of the wave that is emitted by an antenna is referred to as its polarization, and it is referred to as an antenna. It is impossible for there to be resonance between two antennas that have different polarizations because of the way that electromagnetic waves behave. Polarization is a property of electromagnetic waves that characterizes the magnitude and direction of the electric field vector as a function of time. Polarization occurs when the electric field vector rotates in a circular fashion. In addition, what polarization means when it refers to "the orientation of the electric field" is actually "the orientation of the electric field for a given position in space." The polarization of a typical straight wire will change, as shown in Figure 2.5, depending on whether or not the wire is installed in a vertical or horizontal orientation. This can be seen when the wire is connected to an outlet [31].

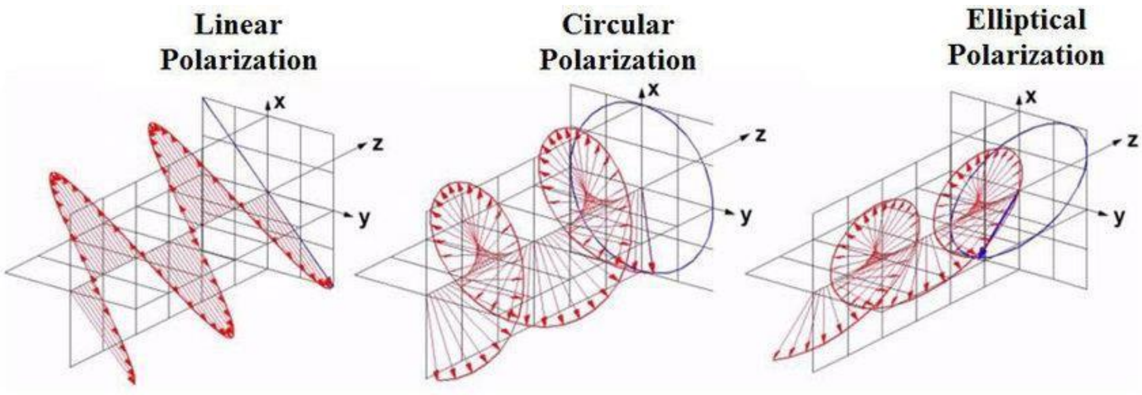


Figure 2.5: Illustration for Different Polarization of The Electromagnetic Waves.

2.3 ANTENNA ARRAY STRUCTURE

Antennas of different shapes and sizes can be arranged in space to form "arrays," which can then be used to produce highly targeted RP. The configuration of the array antenna leads to a productive addition of the fields produced by the individual elements in some directions, while in other directions it leads to a destructive addition of the fields produced by those elements. Even though it is commonly assumed that arrays are made up of uniform elements in order to facilitate analysis and modelling, it is possible to create a configuration in which individual elements exhibit a wide range of properties. This is despite the fact that it is common to assume that arrays are made up of uniform elements to facilitate analysis and modelling. The ability to electronically scan is the primary benefit of an array configuration over a single antenna. This means that the main lobe can be controlled and directed in any direction by adjusting the excitation phase current in each array element. A single antenna only has one lobe, so it is impossible to electronically scan it (phased array antennas). In addition to phased antennas, iterative antennas, also known as "smart antennas," have the ability to steer the main lobes and nulls of their radiation pattern into the direction of the interference or jamming. Linear and planar are the two primary shapes that arrays can have, and they are both depicted in Figure 2.6 [32].

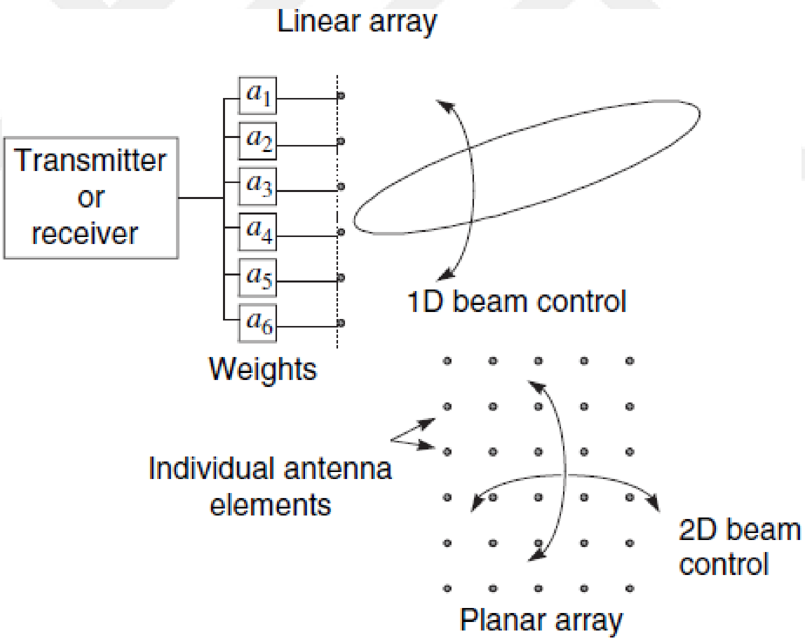


Figure 2.6: Beam Controlling in Linear and Planar Array.

As a result of the fact that beam steering can be carried out in a single plane, it is possible to synthesize an omnidirectional pattern by using a linear array. The planar array setup, on the other hand, has two control dimensions, which means that it is possible to construct a slim pencil frame using this configuration. A uniform linear array is an array that has elements that are equally spaced apart and an increasing phase between each successive element. This type of array also has an increasing phase between each successive element. Constructing an array of this kind requires the least amount of effort. It is possible to calculate the patternof the entire array by taking the product of the patterns of the array's individual elements and multiplying that product by an array factor (AF). The array antennas' overall performance is primarily impacted by the primary factors, which are [32]:

a. The distance separation inter alia the neighboring elements
b. Array shape structure (i.e., linear, circular, or planar structure of radiating elements)
c. Each component's current amplitude, and its resulting excitement
d. Each element's excitement phase
e. The pattern of radiation that is emitted by each individual element

2.3.1 Array Factor (AF)

In the case that the designed array is isotropic, the beampattern will be equivalent to the array factor (or at least the square of the AF). When the "array factor" and the "element factor," both of which describe the beampattern of a single element, are multiplied, a rough estimate of the overall beam pattern for other array element types is obtained. Array factors and element factors both describe the beampattern of a single element. We will not differentiate between the terms "array factor" and "beampattern" because the orientation of our sensors does not matter. Keep in mind that the array factor is the discrete-time Fourier transform of the element excitations; this is an extremely important fact to keep in mind. The value at this point will be referred to as the spatial frequency. The assumption that a Fourier relationship exists between the beampattern and the excitation is a common practice in many of the algorithms that are used in the signal processing industry. By exploiting this connection, one can apply Fourier theory to derive a great deal of information about arrays. Working with arrays is not the only application for this Fourier relationship, despite the fact that it is most commonly associated with working with them. When attempting to characterize an antenna's far-field characteristics, one must invariably use the Fourier transform for the excitation current. When attempting to describe interference that occurs between the N elements of an array, the AF, which is a function of the listed variables [32], [33]:

a. The geometric arrangement of the radiating parameters that are made up of the array

b. The excitement for the elements in the array organisation
c. The number of the individual elements in the array
d. The distance inter alia the elements in the array
e. The operating frequency of the array

This indicates that it is possible to achieve the same AF pattern with a wide variety of antenna types, despite the fact that the resulting radiation patterns will appear quite differently in each case. The final pattern for the uniform linear array is depicted in Figure 2.7, and it appears to be the product of the AF and the radiating pattern of a single element. This can be seen by comparing the two patterns [33].

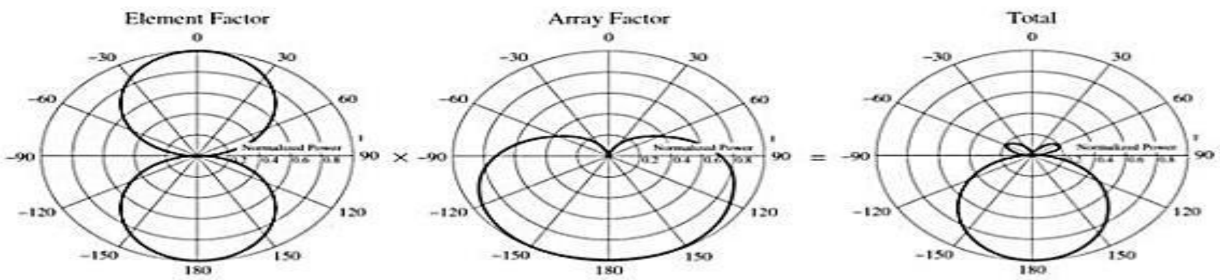


Figure 2.7: Pattern Two-Element Array of Horizontal Dipoles.

The AF for the organization of the array could be expressed in the arithmetic manner by utilizing the following equation [33]:

$$AF = \sum_{n=1}^{N} a_n e^{i(n-1)\psi}, \tag{2.16}$$

where:

$$\psi = kd\cos\theta + \beta \tag{2.17}$$

k: is utilized to represents the wave number;

d: is utilized to represents the separation within the elements in array;

θ: is utilized to represents the angle of the major beam of the array;

β: is utilized to represents the phase shift of the individual elements; and

a_n: is utilized to represents the excitation coefficient for the separated elements.

2.3.2 Mutual Coupling

Mutual coupling is the term utilised to express the practicability by which individual antenna elements in an array engage in electromagnetic interaction with one another. The current that flows through an antenna is dependent not only on the excitation of the element that makes up the antenna itself but also on the excitation of the elements that surround it. The strength for the mutual coupling between the various elements of an antenna array decreases as the distance between them increases. The mutual coupling in an array leads to the following issues [34]:

a. Variations in the RP of the array caused by this effect
b. Variations in the impedance for the input of the various antenna elements that make up an array

The nature of a system's mutual coupling can be described in a number of different ways, including through the use of mutual impedance, S-parameters, a coupling matrix, or a pattern of embedded elements. In order to minimize this effect many of the approaches can be used such as adjusting the separation between the elements, using the electromagnetic band gap structure, and the metamaterial [34].

2.3.3 Antenna Array Feeding

There are many different ways to feed an antenna array, and the final configuration that is selected is based on a number of criteria, such as bandwidth, the required antenna gain, beamwidth, grating/side lobe level, power handling capability, and polarization. There are also many different approaches to feeding an antenna array. The most common utilized feeding structures are [35]:

a. Parallel Feed Technique:

As can be seen in Figure 2.8, a parallel feed in one dimension is essentially a treelike topology of power splitters that operate in opposite directions. The most common kind of parallel feed is indicated as a corporate feed. The power can be distributed in an even manner across all of the elements using the parallel feed, which has the advantage of not incurring any additional losses in the process. This indicates that the BW for the parallel-feed microstrip array is restricted besides the BW of the patch element as well as the matching for the impedance for the power-splitting feeding lines. Bandwidths of 1% or less can be generated by the array that is fed in a series, while bandwidths of 15% or more can be generated by the array that is fed in parallel [35].

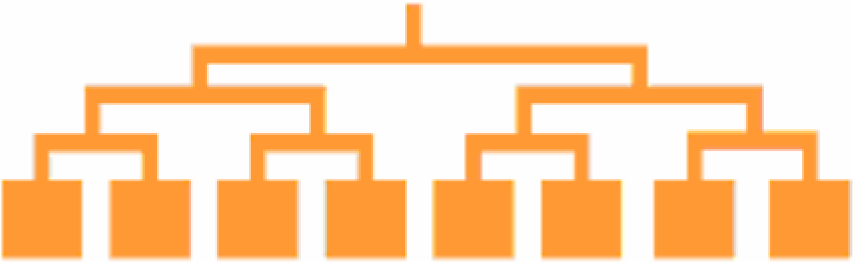


Figure 2.8: Structure of Parallel Feeding.

Parallel feeding has a number of significant drawbacks, one of the most significant being that it requires long transmission lines to be installed between the input port and the individual radiating patch elements. This causes a significant amount of power to be lost and reduces the array's overall efficiency. This is the typical method by which the radiating patches in the array antenna are matched to their respective feed lines (e.g., inset feed technique). The minimum number of radiating elements required for a symmetric corporate feed network is 2^n in the network, where n is an integer. Alterations to the amplitude and phase of each element of the parallel-feed array can be made with the relative ease. The completed performance for the array is susceptible to changes in or failures of any of the individual elements due to the fact that states the feeding mode in the serially feed configured array antenna is cascaded from one element to the next [35].

b. Series Feed Technique:

In this type of the feeding organisation, there are a large many of distinct patches are arranged in a row and fed through a single transmission line in a sequential fashion. As canbe found from Figure 2.9, the process of feeding is carried out in a cascading fashion, with movement occurring from one element to the next and so on. Although the series feed produces the smallest amount of spurious radiation, it also possesses the poorest polarisationcontrol and the smallest BW of any of the three of the feeding methods [36].

Figure 2.9: Structure of Series Feeding.

Despite the fact that there are more discontinuities required in the parallel arrangement, the series arrangement has lower radiative losses than the parallel arrangement. This is due to the fact that the parallel arrangement calls for a greater number of discontinuities to be implemented. For the purpose of achieving a best balance of bandwidth, radiation losses, Ohmic losses, and space, it is popular practice to utilise a combination of the two types of feeding, as shown in Figure 2.10. This is done in to guarantee that we get the very best outcomes we possibly can [36].

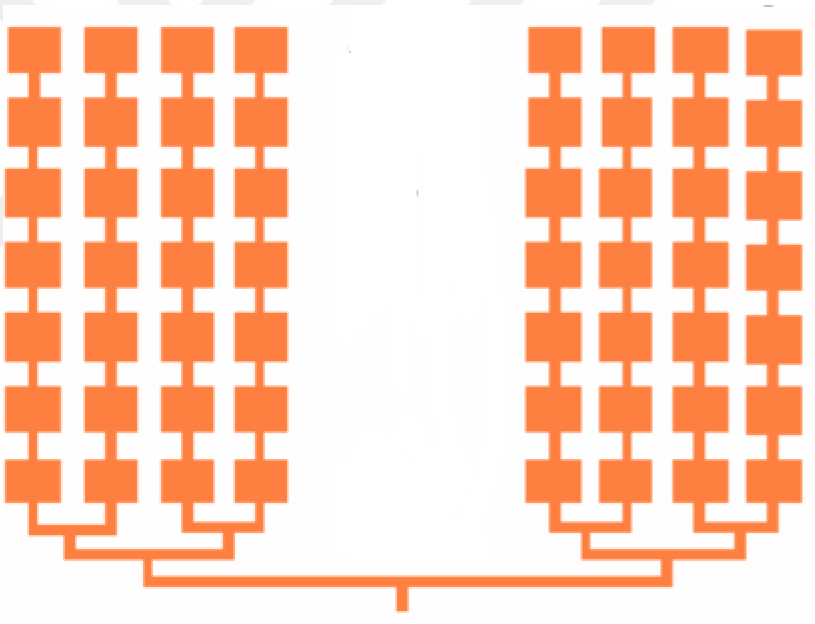


Figure 2.10: Structure of Hybrid Array Feeding.

3. MICROSTRIP ANTENNAS AND ITS APPLICATIOS

This chapter of the thesis, discusses the microstrip antennas, their definition, structure, types, methods of power supply, methods of analysis, and their various applications in the daily life of users.

3.1 MICROSTRIP ANTENNAS (MSA)

In 1953, Deschamps made the initial suggestion for the MSA. However, the technology did not become readily accessible until Munson and Howell developed their practical antennas in the 1970s. Whereas, prior to that time, it was largely unavailable. The many advantages of MSA, such as its portability, small size, and the amenability to the fabrication of printed-circuit technology, inspired the development of a large number of different MSA configurations. According to such advantages, the growing demand for compact and unobtrusive antennas increased to facilitate personal and mobile communications has propelled the MSA to the forefront of the communications industry. Radiation can be emitted from the fringing fields that form between the edge of the MSA patch and the ground plane when the MSA is patched. Whereas a rectangular patch with a length (L) that is slightly less than ($\lambda/2$) is required in order to excite the fundamental TM_{10} mode. The (λ) is utilised to represent the wavelength in the dielectric medium, which can be expressed in terms of the free-space wavelength as (λ_o) [37].

The fringing fields around the patch are what cause the radiation, and these fields can be made stronger by making the patch wider (W). For the purposes of the fringing field amplification, whenever there is a decrease in the substrate's (ε_r) or when the thickness of the substrate itself is increased (h). MSA uses more exhaustive microstrip patches on thicker, less conductive substrates than conventional methods [38].The MSAs are inherently restricted in the frequency range that they can cover. In most cases, the bandwidth of an MSA falls somewhere in the range of 4 to 7 per cent. In order to produce MSA, a wide variety of experimental approaches have been investigated. The techniques employed are, in essence, different iterations of three fundamental approaches to increasing impedance bandwidth, which are [38], [39]:

a. Antenna enlargement, this can be accomplished in a few different ways: by modifying the geometry of the patch (for example, by making it thicker with a larger h), or by modifying the dielectric constant of the substrate, or by incorporating additionally coupled resonators.
b. The designing of an external matching circuit.
c. Modifying the antenna's geometry with shorts and slots to introduce or move existing resonances.

Due to the many advantages that MSAs offer, they can be applied in a diverse range of contexts. MSAs are typically utilized for telemetry and communications antennas in missiles due to the thin and conformal design requirements of these types of antennas. Microstrip radiator arrays are typically utilized in the construction of radar altimetry instruments. Another common item found on aircraft is an antenna designed for use with cellular phones and satellite navigation systems. Microstrip arrays have been implemented in a few different satellite imaging systems. Patch antennas have been utilized on ships and buoys in order to facilitate communication with satellites. MSAs are frequently used in complex weapon systems due to their small size. This is because MSAs can be easily concealed. MSAs are utilized in a wide range of different wireless technologies, including but not limited to pagers, GSM/GPS, and many others [40].

3.2 MICROSTRIP PATCH ANTENNA (MPA)

Generally, the MPA, in its simplest form, resembles the one described in Figure 3.1, in which a ground plane is located on the opposite side of a dielectric substrate bearing a radiating patch.

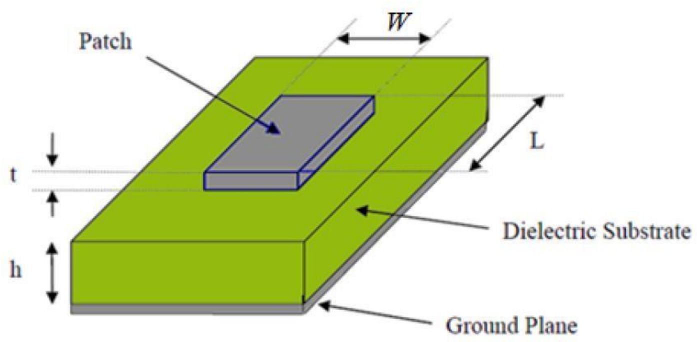


Figure 3.1: Generic Structure for The MPA.

Conductors of any kind can be used to make the patch, though copper and gold are the most common choices. The radiating patch and feed lines are typically etched into or printed onto the dielectric substrate. As can be seen in Figure 3.2, the patch most commonly takes the form of a standard shape, such as a square, rectangle, circle, triangle, or ellipse. This is presented to make analysis and performance prediction easier.

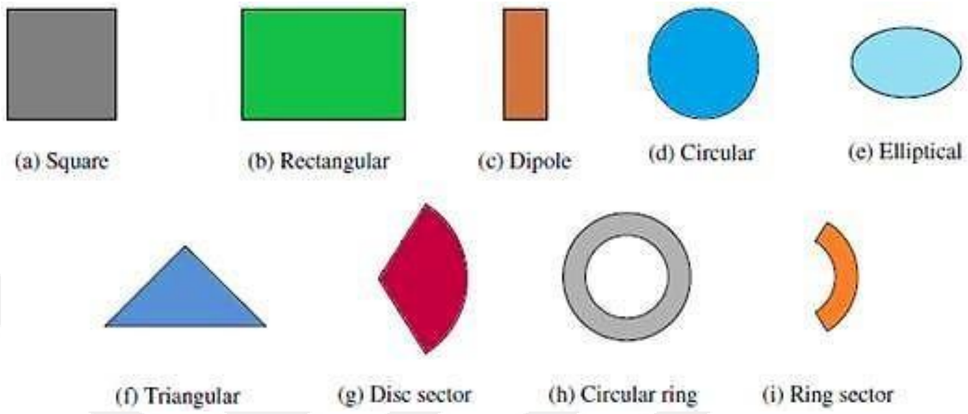


Figure 3.2: Commonly Utilised Shapes for The Patch.

The majority of the radiation that is generated by MPAs is caused by fields that are located in the area that is bordered by the patch and the ground plane. It is possible to enhance the performance of an antenna in terms of its efficiency, bandwidth, and radiation by using a thick dielectric substrate that has a low dielectric constant. Utilising this configuration would result in an increase in the antenna's overall dimensions. When higher dielectric constants are used, the design of a compact MPA becomes more difficult. This is because using higher dielectric constants results in less efficiency and narrower bandwidth. As a direct consequence of this, compromises need to be made between the antenna's performance and its size [41].

3.2.1 Characteristics and Restrictions of MSAs

This subsection of the chapter introduced to presents the characteristics that are possessed by the MSAs and the defections and limitations that are restricted the performance of the mentioned antennas.

a. Characteristics

In a general manner, the MSAs and their arrays are utilised in a wide variety of radio frequency and microwave systems, such as those utilised in communications, radar, navigation, remote sensing, and biomedical applications. Because of the unique characteristics that they possess, radiators with a patch or patch-like design have been the focus of a significant amount of research. They offer a wide variety of advantages, including the following [42]:

i. The MSAs have a low profile, usually, the total thickness of such antennas is slightly less than ($0.03\lambda_o$).
ii. Lightweight, MSAs are commonly produced by the means of the perfect electrical conducting material in the form of the foil printed on a dielectric substrate.
iii. The MSAs have the ability to shape themselves into different substrates. The surface of the MSA, which may be planar or non-planar, can bend or stretch to perfectly match the dielectric substrate it is mounted on.
iv. The price is extremely reasonable. Because of their low cost, printed circuit techniques are frequently used in the fabrication of the MSAs. Whereas the antenna's substrate is typically the most expensive component of such antenna types.
v. integrating with the electronic systems that are already in place. The integration of the MSAs along with other planar circuits on the PCB which is characterised as a simple process that can be finished in its entirety in an easy form.
vi. Versatility, by adjusting the shape of the antenna and the feeding configuration, the MSA can take on a wide range of characteristics such as impedance, resonant frequency, radiation pattern, polarization, and operating mode. This can be accomplished by modifying the patch's shape. The antenna can be modified in a variety of ways, including loading and slotting the patch, introducing parasitic elements, installing shorting pins, and using varactor diodes.
vii. It is possible to make them small enough for service in wireless individual communication.
viii. By modifying their structures, the MSA can be met and operated for the dual-band and triple-band.

b. Limitations and restrictions

The MSAs present a number of challenges and issues when compared to other, more common types of the antenna designs. The following are some of the most serious drawbacks associated with them [43]:

i. The MSAs has a tight bandwidth
ii. The MSAs have an inferior efficiency
iii. The MSAs have a small gain and are commonly referred to poor gain
iv. The MSAs have unwanted radiation emitted from the feeds and junctions causing an interference with the original pattern
v. Poor ability to withstand power, (i.e., power handling)
vi. Half-space radiation is the norm for the MSAs

One of the merits that characterised the antenna performance is called the quality factor (Q), if the Q of the antenna is high, then the antenna will have a narrow bandwidth and will be inefficient. The Q referring to the losses related with the antenna. The MSAs have an exceptionally high Q, whereas, the Q of dielectric substrates with greater thickness is lower. However, as the thickness increases, a more significant attribution for the total output of the source is transferred to a surface wave. As the thickness increases, so does this proportion. Surface waves are effectively lost as power and degrade antenna performance because they are scattered when they encounter dielectric bends. Photonic bandgap structures, on the other hand, have the ability to reduce the effect of surface waves. Using an array configuration for the elements can help with problems like low gain and low power handling capacity, among other things [43].

3.2.2 Dielectric Materials

In order to manufacture the MSAs the dielectric materials (i.e., substrates) should be utilised which can be made from a wide range of dielectric materials. The RF/microwave band dielectric constant usually is made up to be in the range of ($2.2 \leq \varepsilon_r \leq 16$), the dielectric loss tangent ($0.0001 \leq \tan б \leq 0.06$), also known as the important factors to take into account include the purchase price, the imaginary component of the dielectric constant, and the frequency at which the dielectric breakdown occurs. Plastics are frequently used in radio frequency (RF) and microwave bands despite the fact that they have poor dielectric properties, substantial thermal expansion coefficients, poor dimensional stability, and high thermal conductivity as compared to materials such as ceramic and sapphire. This is due to the low cost, ease of manufacture, and good surface adhesion of plastics. When choosing the material for the substrate, it is important to take into account the influence that the dielectric constant has on the radiation properties. When the dielectric constant is high, the radiation emitted from the MSA is typically quite low.

Thicker substrates with a lower dielectric constant are preferred for good antenna performance. This is because they allow for higher efficiency, a wider bandwidth, and loosely bound fields for radiation into space. This, however, comes at the cost of a larger MSA size. A thin substrate with a high dielectric constant is preferred for use in microwave circuitry because it leads to smaller element sizes and requires tightly bound fields to minimize unwanted radiation and coupling. This is due to the higher dielectric constant of a thin substrate. This trade-off, however, results in a lower level of efficiency as well as a reduction in bandwidth due to the higher losses associated with this substrate type. In order to use the common practice of incorporating MSAs into larger microwave circuit boards, a balance between antenna performance and circuit design must be found [44].

3.2.3 Analysing Methods for MSAs

In order to understand the MSAs structures and the operation principles there are three major methods utilised for the analysis which are listed as follows:

a. Transmission Line Approach

As can be seen in Figure 3.3, this method of analysis represents the MPA as two slots, separated by the means of a strip line is has a length of (L) of constant length with width (W) and a height of (h). A microstrip is effectively a line with two different dielectric materials, so it is not a homogeneous conductor. Typically, air and the substrate are used as these dielectrics [45].

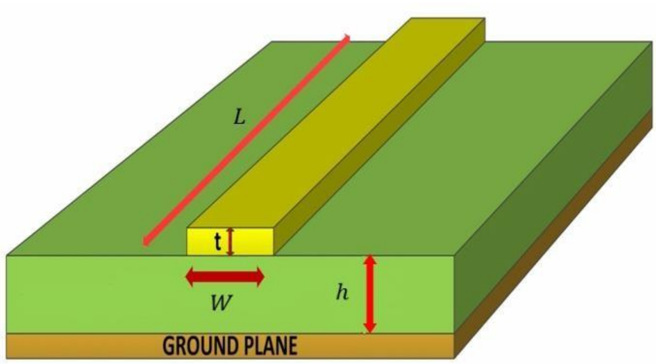


Figure 3.3: Representation for the MPA.

As a result, the plurality of the E-field lines are embedded in the substrate, as shown in Figure 3.4, while other lines have at least some of their lengths floating in free space. Because the phase velocities in free space and the substrate are so dissimilar, the transmission line in question would be incapable of supporting the refined transverse electric-magnetic mode of transmission. If something like this happened, the quasi-TEM mode would become the most important mode of propagation [45].

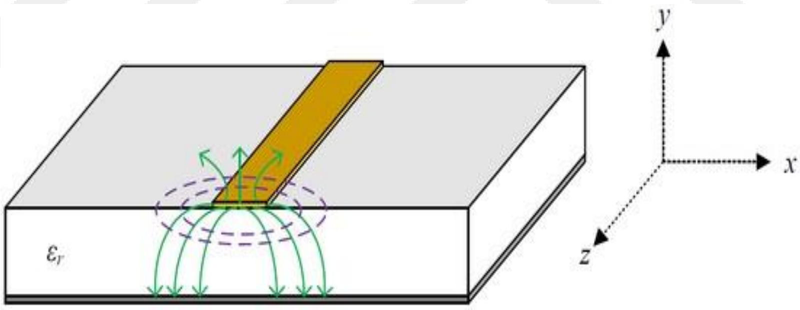


Figure 3.4: Propagation of The E-Field Lines.

To account for both fringing and wave propagation in the line, a value for the effective dielectric constant, denoted by the symbol (ε_{reff}), must be determined. Because the patch's fringing fields cause almost all of its periphery to be distributed in the air rather than contained within the dielectric substrate, its effective permittivity ε_{reff} is typically only a hair lower than ε_r. As a result, the effective permittivity of the patch is slightly lower than er. The fringing fields can be found in a variety of locations throughout the atmosphere. In the mathematical form, the ε_{reff} can be interpreted by the means of the following equation [45]:

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}[1 + 12\frac{h}{W}]^{\frac{-1}{2}} \qquad (3.1)$$

Where:

ε_{reff}: is utilised to describe the effective dielectric constant;

ε_r: is utilised to describe the dielectric constant;

h: is utilised to describe the thickness of the substrate; and

W: is utilised to describe the width of the slot.

In Figure 3.5, we can see the patch is mounted on a substrate that is taller than it is wide. The antenna's dimensions are as follows: (L) in length and (W) in width, and (h) in height. We've set up the coordinate axes so that everything is horizontal: length is x, width is y, andheight is z [45].

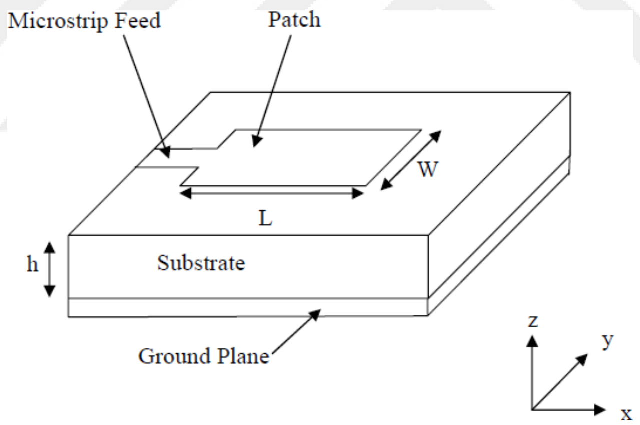


Figure 3.5: Organization of MPA.

The radiated patch length must be less than 0.5λ in order to operate in the primary (TM_{10}) mode. The patch's field varies along its length for the first 0.5λ cycles, but there is no diversity along its width, according to the TM_{10} mode. Figure 3.6 depicts the MPA as two slots separated by an L-length transmission line with open circuits at both ends. The current is lowest along the patch's width, which also happens to be where the voltage is highest due to the patch's open ends. The voltage of the patch is greatest along its width. The normal and tangential components of the field can be distinguished by considering the fields at the edge in relation to the ground plane [45].

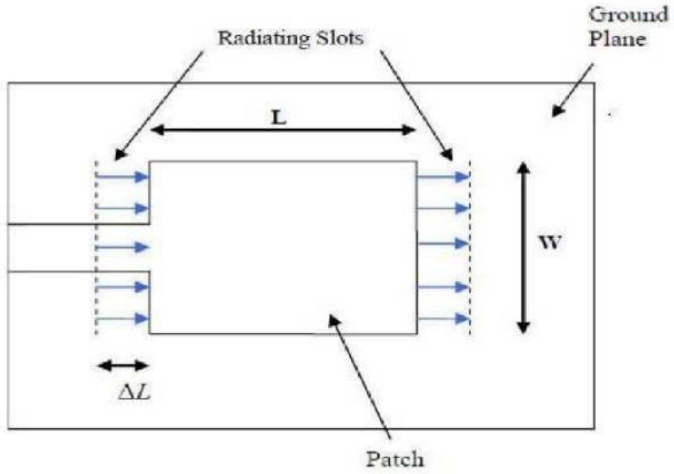


Figure 3.6: Top View for the MPA.

Because of the patch's length, the E-field components along the two edges perpendicular to the patch's width are out of phase with one another (0.5λ). As shown in Figure 3.7, as a result, they cancel each other out when moving in the broadside direction. Figure 3.7 shows the phase alignment of the tangential components, which is particularly convincing. This alignment demonstrates that the outgoing fields converge to provide the maximum radiated field in a direction normal to the structure's surface [45].

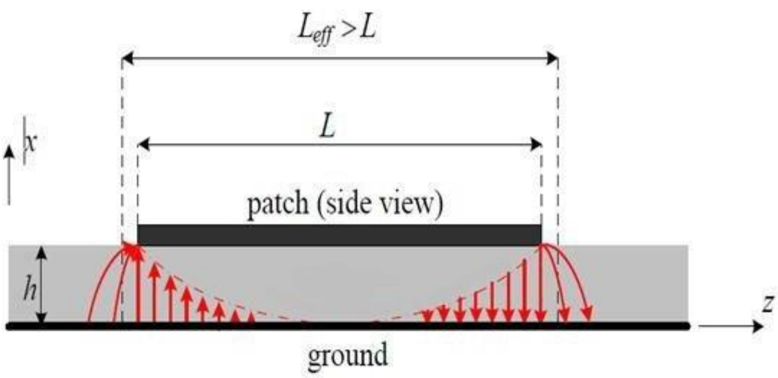


Figure 3.7: The Interaction Between E-Filed Lines in The MPA.

Because of its limited length and width, the patch causes fringing in the fields that border it. This is previously shown in Figure 3.6 for the microstrip antenna's two radiating slots in the longitudinal direction. Along the same lines, width is an important consideration. The width of the fringing is proportional to both the depth of the substrate and the size of the patch. Fringing in the principal E-plane (xy) is determined by the substrate's dielectric constant as well as the patch's width in relation to its height (W/h). Because the presence of the fringing effects, the patch of the MPA appears to have dimensions that are significantly larger than they actually do when viewed from an electrical perspective. This is demonstrated in Figure 3.8 for the primary E-plane, which is the xy-plane. The dimensions of the patch along its length have been extended at both ends by a distance ΔL, which is a function of the ε_{reff} and the ratio of the (W/h) [45].

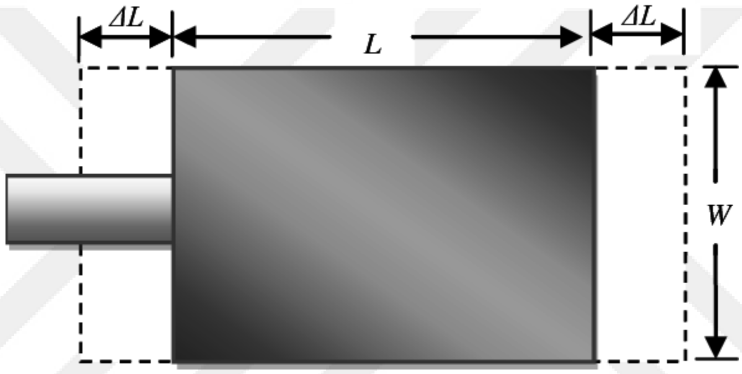


Figure 3.8: Effective Length for The Patch of The MPA.

To represent the expansion in the length due to the fringing in the mathematical form, the following equation is utilised [45]:

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff} + 0.3)\left[\frac{W}{h} + 0.264\right]}{(\varepsilon_{reff} - 0.258)\left[\frac{W}{h} + 0.8\right]} \tag{3.2}$$

Where, the ΔL is utilised to describe the extension for the patch length due to the presence of the fringing.

After that, to extract the principal and real length of the antenna patch, whereas the effective length is usually greater than the real length because of the fringing on the both edges of the patch, we can apply the following equation [46]:

$$L_e = \frac{3 * 10^8}{2 f_o \sqrt{\varepsilon_{reff}}} \quad (3.3)$$

$$L_e = L + 2\Delta L \quad (3.4)$$

Where:

L_e: is utilised to describes the effective patch length; and

L: is utilised to describes the real patch length.

Finally, we can find the width of the antenna to complete the design. We can use the mathematical equation that was created for this purpose according to Balanis's, as follows [46]:

$$W = \frac{3 * 10^8}{2 f_o \sqrt{0.5 * (\varepsilon_r + 1)}} \quad (3.5)$$

b. Cavity Modelling Approach

The transmission line models introduced and discussed in the section preceding this one is simple to implement; however, they do have a few of the drawbacks, which will be discussed in this section. If you use it as the foundation for the design of the rectangular MPA, you can avoid the field differences at the radiating borders. This makes its use efficient and effective. Using the cavity model tactically may be able to help you overcome these difficulties. This framework's explanation will be condensed into the following paragraphs. The interior region of the dielectric substrate is modelled as a cavity with electric walls at both the top and bottom of the structure. These electric walls are located in the structure's centre. The following considerations can be taken into account for applications involving thin dielectric substrates, including ($h << \lambda$) support for this method [47].

a. Because the substrate is so thin, the fields in the internal zone do not jumble about very much in the z-direction (in other words, in a manner that is typical of the patch).
b. In the region that is bounded by the patch metallization and the ground plane of the MPA, the electric field is only z-directed, whereas the magnetic field contains only the transverse components at that location (Hx and Hy). This assertion is the conceptual

foundation for the top and bottom electric walls, so it's important to ensure an understanding of its significance.

When power is applied from the source to the MPA, charge distributions appear on the topmost and down surfaces of the patch, as well as at the bottom of the ground plane's bottom surface. Examine Figure 3.9, which is shown below. Attractive forces and repulsive forces are the two mechanisms that work together to govern the distribution of charge. Attractive methods contribute to the upkeep of stable charges at the base of the patch; these ways include the ground plane as well as any competing charges that may be present there. In order to accomplish this effect, the elevation of the ground plane will remain unchanged. The repellent properties of the bottom shell of the patch are identical to those of the patch itself. As a result of this, certain charges move up from the bottom of the patch to the top of the patch. Currents are flowing along the upper and lower margins of the patch as a result of the movement of the charges [47].

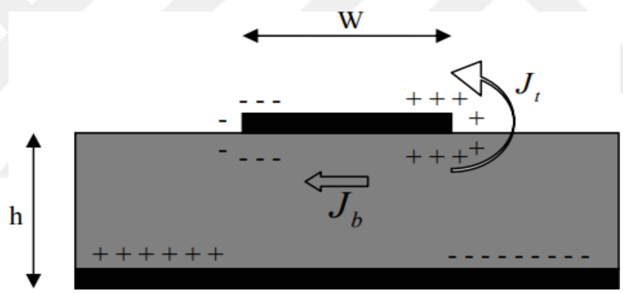


Figure 3.9: Allocation for the Charges on the MPA Patch.

Because the elevation-to-width ratio in the cavity model is so small (i.e., the thickness of the substrate to the W), attractive means predominate, causing the majority of charge condensation and current to lie beneath the patch exterior. This is due to the fact that the W is much larger than the thickness of the substrate. As the height-to-width ratio was reduced further, the current on the patch's top surface approached zero, preventing the generation of any tangential E-field components to the patch edges. The current flowing on the top surface of the patch would be much smaller than the current flowing on the bottom surface of the patch. This was unavoidable as a result of the height-to-width ratio being reduced even further [47].

c. Full-Wave Analysis Modelling

The approach of the moments is considered as one of the strategies that was used to offered the MPAs with a comprehensive wave analysis. Surface currents are used in this method to model the multipole approximation (MPA), and volume polarisation currents are utilised to simulate the substrate sheet fields. It has been demonstrated how to obtain integral equations for these unknown currents and how to convert these integral equations to matrix equations using the "Method of Moments." The results can then be obtained by solving these matrix equations using various algebraic approaches. In most cases, a portion of the software, such as the Ansys HFSS, can be used to perform the analysis [48].

3.2.4 Methods for Feeding MPAs

MPAs can be fed utilising a variety of methods that are available and possible. These methods are typically divided into two categories: contacting and non-contacting. In the case of contacting methods, radio frequency power is fed to the terminal of the antenna radiated patch via connecting segments such as those printed on the same dielectric microstrip line. The radiation coupling, also known as the electromagnetic field coupling, is used to carry power from the strip line to the radiating patch in the second category, also known as the non-contacting method. This method belongs to the approach's non-contact subcategory. The strip line, the coaxial probe (both types are considered contacting types), the aperture coupled, and the proximity coupled are the four most popularly used feed strategies (both classified as non-contacting schemes) [49].

a. Line Feeding

Figure 3.10 depicts one type of feeding strategy, which involves directly connecting a conducting strip to one of the microstrip patch's edges. This specific feeding strategy appears to be effective due to the good impedance matching. This type of feed arrangement has the distinct advantage of being able to etch the feed over the same antenna substrate in order to produce a planar arrangement. The width of the conducting strip is noticeably narrower than that of the patch, and this type of feed arrangement has the distinct advantage of being able to produce a planar arrangement. This particular sort of feed arrangement has the specific advantage over other types of feed arrangements in that it is capable of creating a higher frequency response [49].

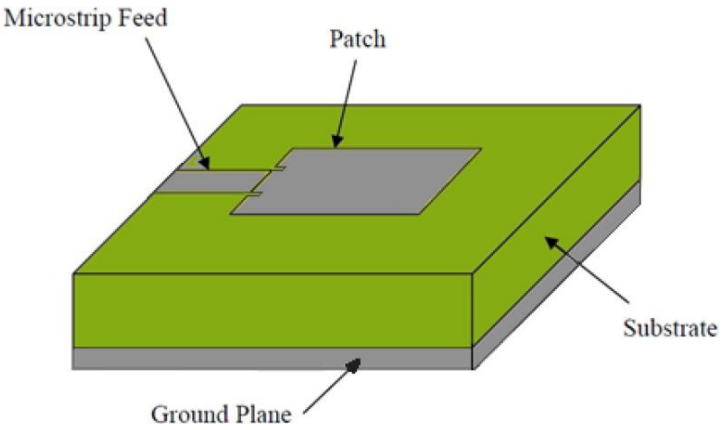


Figure 3.10: Structure of Line Feeding.

The patch's inset small shear was designed to eliminate the need for any other type of matching element in order to match the impedance of the strip line to that of the patch. This is accomplished by exerting sufficient control over the inset's position. The ease of fabrication, simplicity of modelling, and ease of impedance matching all contribute to this being a simple feeding strategy. Surface waves and extra radiation from feeding both increases as the height of the dielectric substrate being used increases. This has the effect of lowering the antenna's BW. Radiation from the feed source also produces cross-polarized radiation, which is undesirable [49].

b. Coaxial Feeding

For the purpose of feeding MPAs, coaxial feeding, also known as the probe method, is a common technique. The core conductor of the coaxial connector is shown in Figure 3.11 passing through the dielectric before being soldered to the radiated patch. In contrast, the ground plane is connected to the conductor outside of the connector, also known as the sheath [49].

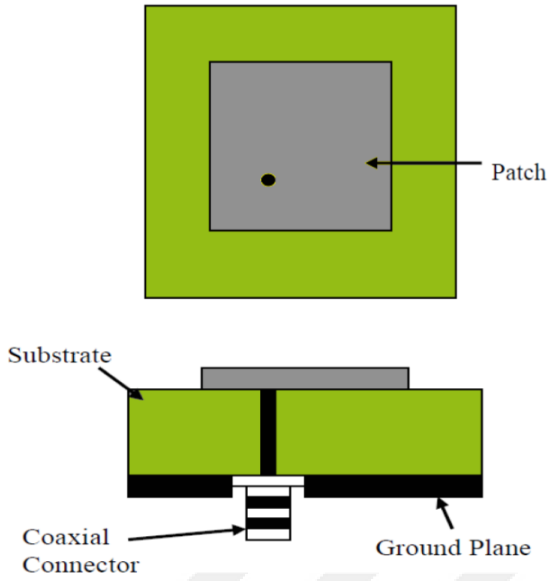


Figure 3.11: Structure of the Probe Method.

The main advantage of this type of feeding scheme is that it allows the user to place the feeding wherever they want within the radiated patch in order to match the patch's input impedance. This feeding method is simple to implement and produces little to no dummy radiation. It is also difficult to model because a hole must be drilled in the substrate and the connector emerges from the ground plane, making thicker substrates with holes completely planar ($h > 0.02\lambda o$). Its main weakness, on the other hand, is that it has a limitedbandwidth and requires a substrate hole to be drilled. Furthermore, for thicker substrates, anincrease in probe length results in an additional inductive input impedance, complicating matching. Both the strip powering line and the coaxial feed have a number of disadvantageswhen used on a thick dielectric substrate with a wide BW, as demonstrated in the previous section. These issues can be addressed using the non-contacting feed techniques discussed in the previous section [50].

c. Aperture Coupled Feeding

As shown in Figure 3.12, the ground plane acts as a barrier between the radiating patch and the strip feeding line used in this feeding strategy. Cutting a small manhole or aperture into the bottom of the ground plane enables coupling between the patch and the feed line [50].

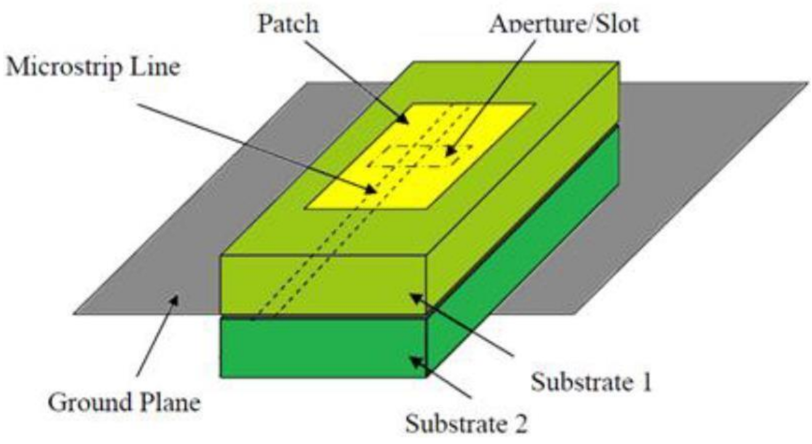


Figure 3.12: Structure for Aperture Coupled Method.

In the majority of instances, the coupled aperture is canted beneath the patch. This positioning makes the configuration more symmetrical, which reduces cross-polarisation. Form, dimensions, and location of the aperture all play a role in determining the amount of coupled amidst the feeding strip and the patch. In contrast, the ground plane physically separates the patch from the feeding line, thereby reducing the amount of spurious radiation. In order to maximize the amount of radiation emitted by the patch, it is customary to use a material with a high dielectric constant for the base (i.e., lower) substrate and a material with a lower dielectric constant of the top substrate. The fact that this feed technique requires multiple layers, resulting in an increase in the antenna's overall thickness, makes it difficult to fabricate, which is the technique's primary drawback. In addition, this feeding strategy provides a narrow BW [50].

d. Proximity Coupled Feeding

Figure 3.13 depicts a schematic representation of this feed method, which is also known as the electromagnetic coupling scheme. The radiating patch is mounted on the upper substrate in this configuration, and the feed line is located among a couple of the dielectric substrates below it. In addition to increasing the overall height of the MPA, this feed method eliminates spurious feed radiation and provides a relatively wide frequency range. It also has the advantage of increasing the antenna's overall thickness. The performance of each component in this design can be fine-tuned by utilising optional dielectric medium for the patch and feeding line [50].

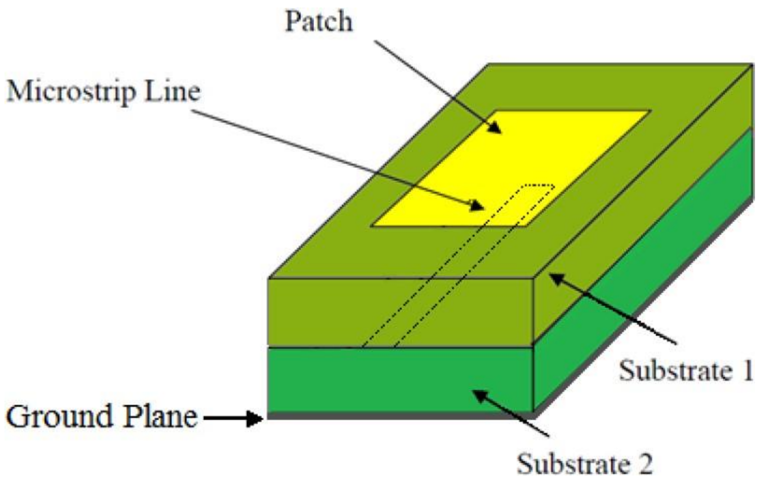


Figure 3.13: Structure for Proximity Coupled Method.

Both the width-to-length ratio of the patch and the length of the feed line are variables that can be altered in order to achieve a matching quality that is satisfactory. This feed scheme is difficult to fabricate because it requires precise alignment of the two dielectric layers that make up the circuit. Additionally, the depth of the antenna's overall profile has increased [50].

e. Coplanar waveguide feeding

A coplanar waveguide feed, shown schematically in Figure 3.14, has also been used to excite the MSA. The MSA is thrilled in both of these ways. The coplanar waveguide is created by etching the ground plane of the MSA using this method. Light is coaxially fed along the line until it reaches a slot, the length of which is set to be between 0.25 and 0.29 of the slot wavelengths. The length of the slot determines how far the light can travel along the line. The method's primary disadvantage is the high radiation produced as a result of the relatively longer slot, which results in a low front-to-back ratio. By making the slot smaller and giving it a loop shape, we can increase the front-to-back ratio [51].

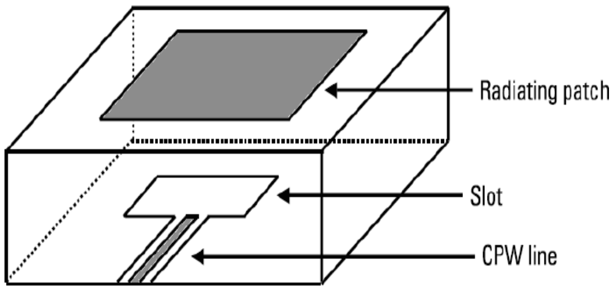


Figure 3.14: Structure for Coplanar Method.

3.3 FREQUENCY ELECTIVE SURFACES (FSS)

This category of materials is referred to collectively as Metasurfaces (MSs). The MSs are a type of planar metamaterial that has a thickness of less than one wavelength and is simple to fabricate using techniques such as the lithograph and the nano-printing. Both of the metamaterials and MSs are expanding fields of study due to the fact that they enable the controllable variation of electromagnetic or optical responses in space. These responses include scattering phase, amplitude, and polarization, among other characteristics. With the appropriate chosen for the materials and design, the ultra-thin structure of MSs has the potential to significantly cut down on the detrimental and unfavourable losses that occur along the direction in which waves propagate. By analysing the underlying operating principle of the array element, MSs can be segmented into distinct classes based on the polarization response of the surface (FSS, high impedance, perfect absorber, reflecting, etc.). As stated in the definition, FSSs are considered one form of MSs because they only exhibit an electric response. because the only thing that may be required to tune the frequency selectivity of the transmission/reflection characteristics is electrical polarization. Such surfaces are made up of planar and periodical arrays from a metallic individual patches or strips of varying shapes. The construction of these surfaces is inspired by antenna and microwave engineering theories. When measured against the wavelength, the patch's thickness is found to be negligible, despite being significantly larger than the metal's surface. As a result, by arranging perfect conducting resonant elements in a thin array, a perfect approximation of such a structure can be made. Furthermore, this approximation is accurate. In the field of EM science, extensive research is being conducted on 2D periodical structures with planar metallic array components (patches or apertures) in the substrate. At a specific resonant frequency, these structures exhibit transmission and reflection. The configuration of the array element influences whether or not a plane wave travelling in its direction is reversed totally or only partly. This occurs when the frequency of the plane wave coincides with the operating frequency of the FSS components. Because an FSS can either permit or obstruct the passage of electromagnetic waves of a specific frequency in open space, it is best classified as a spatial filter. Figure 3.15 depicts the equivalent circuits and filter responses of the low-pass and the high-pass FSSs (LP- and HP-FSS) from [52], [53].

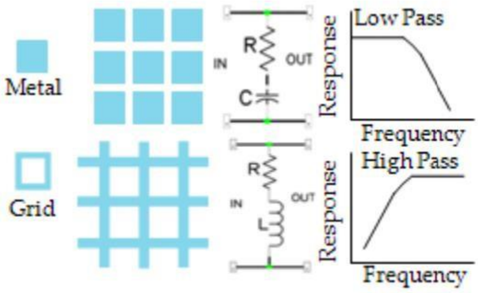


Figure 3.15: Equivalent circuits and filter responses for FSS.

Capacitance is generated in the gaps between the FSS elements despite the fact that the FSS patches generate resistance (R) and inductance (L) low-pass. In the example of L, the length of two parallel wires, and capacitance(C), generated by a parallel plate capacitor, the physical significance of these passive values can be altered by applying a simple electrostaticprinciple. Doing so will lead to the intended outcome. Using these capacitive and inductiveparts together, you can design a filter with the characteristics you need. The values of L andC will change, however, if the FSS's dimensions are altered. By shining light on the FSS's unit cell, electromagnetic waves can generate a circuit with the same resonance characteristics as the original. To calculate the resonance frequency, we use Equation 3, where L and C stand for the equivalent inductance and capacitance of an FSS unit cell [54]:

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{3.6}$$

Figure 3.16 depicts the overall classification of the FSS element groups, which are divided into four distinct classes. The first group includes N-poles like the dipole, triple, square-spiral, and Jerusalem cross; the second group includes looped shapes like the circle, square, and hexagon; the third group includes solid interiors or patch shapes of various shapes; and the fourth group includes irregular shapes (combinations of above all). FSS designers can use array elements from any of these categories, and they frequently use a combination of the different types depending on the application. When subjected to angular perturbation, the resonance responses of a high-quality element should remain relatively unchanged. In most cases, choosing a group-2 element with a larger loop area is advantageous and will result in increased bandwidth. Even simpler configurations, like circular and square loops, have been used to advance loaded elements with three or four legs. The use of hexagonal loop structures benefits wideband applications greatly. The FSS method has achieved resonance when the diameter (i.e., circumference) of the loop element equals a full wavelength. By modifying the geometry of these loop elements, it is possible to achieve a bandwidth that spans a wide range, ranging from the narrow band of loaded three- or four- legged elements to the ultra-wideband of hexagon loops [55].

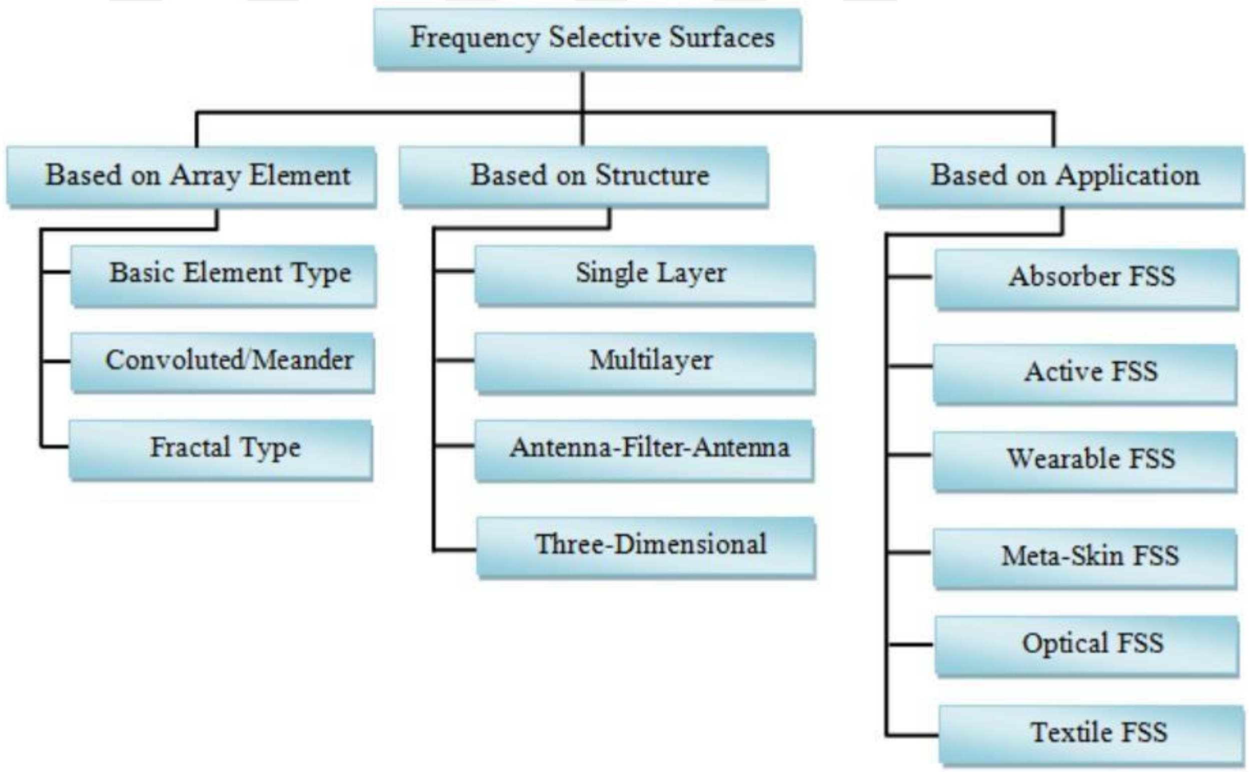


Figure 3.16: General Classification for FSS.

However, the inter-element spacing in almost all FSS types can be adjusted to change the bandwidth; for this spacing to be effective, it must be relatively small in comparison to the wavelength. The main resonance will be pushed downwards as the incidence angles change if the inter-element spacing is greater than half the wavelength. If the distance between the elements is greater than half the wavelength, this is the case [55].

3.4 OPERATION PRINCIPLE OF FSS

In accordance with the principles of circuit theory, both capacitive and inductive FSS structures can be compared to microwave filters. As mentioned previously, the FSS filtering features can be divided into four primary categories, each of which serves a particular purpose. Low pass FSS filters permit a narrower frequency range to pass through the configuration while permitting a broader frequency range to pass unimpeded. The operation of a high-pass FSS filter is analogous to the opposite of a low-pass FSS filter, according to the Babinet principle. Similarly, an FSS filter with a stopband eliminates unwanted frequencies while an FSS filter with a passband restricts the frequency range that is permitted to pass. FSSs are constructed with periodic arrays of engraved metal patches and/or slots on a dielectric substrate in order to provide the desired resonant function. The step in the design process that carries the heaviest burden of responsibility is the selection of the appropriate FSS array elements, shapes, dimensions, and substrate materials [55], [56].

4. ANTENNAS DESIGN AND IMPROVEMENTS

In this part of the thesis, we will explain the fundamental stages of the process of designing the proposed MPA and MPAA. In addition, the outcomes after conducting this work will be illustrated in detail and discussed as well in this chapter.

4.1 PROPOSED METHODOLOGY

In this work, a compact-sized MPA from a rectangular-shaped patch is introduced for the utilisation of the requirements of the high band 5G communications at 28 GHz. The employment of such a band will enable users to obtain big amounts of data besides a high rate, thereby minimising the waiting time, and facilitating the work. For the purpose of the performance enhancement of the introduced MPA, the array structure is suggested to be utilised. Finally, to ensure to the best outcomes another approach is introduced by utilising the FSS structure is applied to be installed over the regular MPA. The proposed scenarios are for the antennas and FSS is presented in Figure 4.1.

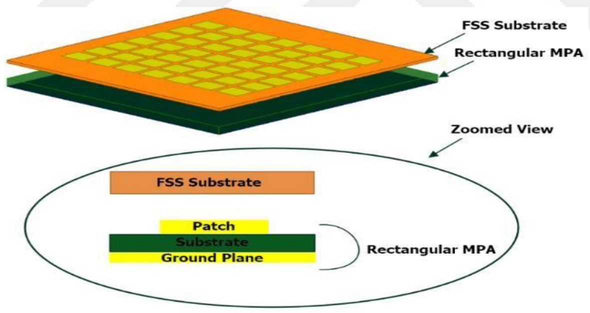


Figure 4.1: Structure for the Introduced Work.

4.2 REGULAR MPA DESIGN

This section presents the process for the design of the regular MPA from a rectangular-shaped patch. For the purpose of the introduced method, we require to select the principal parameters for the MPA which are:

a. Resonant or operating frequency (f_r): This is the principal frequency over which the antenna is worked. In this work, the value of f_r is selected as 62 GHz to have functioned for 5G mobile communications.

b. The substrate material constant (ε_r): This is defined as the relative permittivity for the substrate that is characterised by the industrialisation company. In the work, the utilised material is Rogers RT-3003which has an ε_r=3.

c. The thickness (i.e., height) of the substrate (h): This is the height of the substrate that is characterised by the industrial company. In this work, the h for the MPA is selected to be h=0.1mm.

After choosing and completing the process of specifying the previously mentioned elemental parameters, the process of calculating the antenna's overall size (i.e., dimensions) commences. For this purpose, the simple transmission line analysis method that was described and given in section (3.2.3-a) beside the MATLAB software for method equation evaluation is utilized. After acquiring the dimensions, the simulation process is initiated by constructing the regular MPA's 3D structure within the CST software framework. Figures 4.2 depict the dimensions description for the regular MPA coupled with the feeding. The simulated regular rectangular-shaped MPA is exhibited in Figure 4.3.

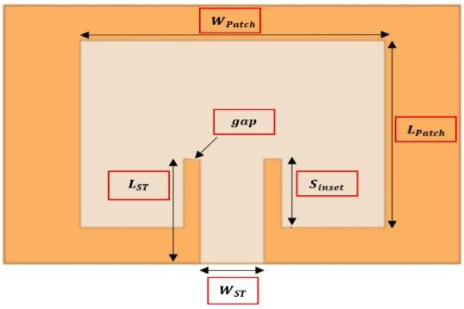


Figure 4.2: Structure for Regular MPA.

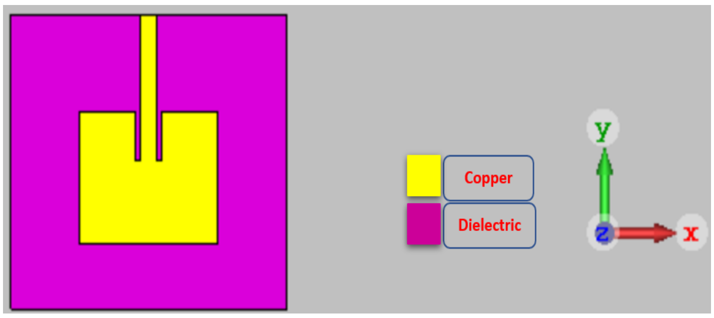


Figure 4.3: MPA with Rectangular-Shaped In CST Software.

In order to ensure the best outcomes, performance, and boosting up the simulation as well as fabrication the correction for the MPA parameters (i.e., parameter sweeping) is utilised.

This strategy is summarised by increasing and decreasing the dimensions of the MPA by trial-error method till obtain the optimum outcomes. Figure 4.4 illustrates the MPA after applying the parameters correction process and the determined dimensions for the rectangular shaped regular MPA are set in Table 4.1.

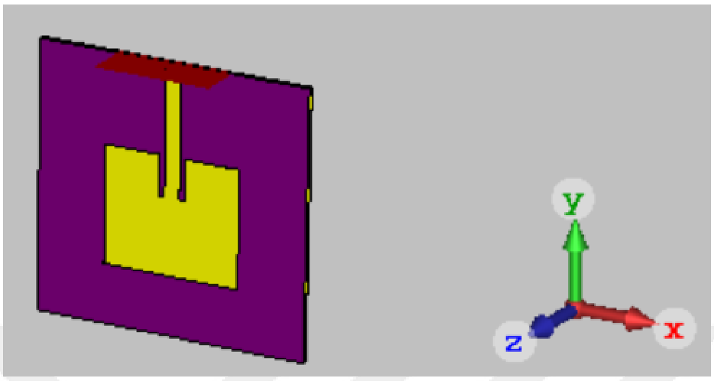


Figure 4.4: MPA after Parameter Correction Process.

Table 4.1: Dimensions for the Designed MPA.

Parameter	Equations Value	Corrected Value
Width for the patch (W_{Patch})	3.7880	3.41
Length for the patch (L_{Patch})	3.0501	3.01
Width for the substrate ($W_{Substrate}$)	7.5760	6.82
Length for the substrate ($L_{Substrate}$)	6.1002	6.02
Width for the strip line (W_{ST})	0.3120	0.38
Length for the strip line (L_{ST})	3.3765	3.37
Strip line inset (S_{inset})	1.1231	1.04
Separation between patch and strip (g)	0.1302	0.15

4.3 DESIGN PROCESS FOR FSS ELEMENTS

This structure aims to improve the gain for the regular MPA to get the most out of the antenna. This done by pass just the frequencies that we need. The FSS superstrate is introduced over the typical MPA and it is separated by a specific distance from a calculated air gap. Due to its superior performance compared to the other shapes available, the square-shaped FSS structure is employed in this work. The proposed FSS design consists of 0.07 mm thick copper that is printed over 0.125 mm thick Rogers RT-5880 dielectric material with an ε_r of 2.2. Figure 4.5 and Table 4.2 provide representatives for the simulated single-element dimensions and the single-cell FSS design that is being introduced in this work, respectively.

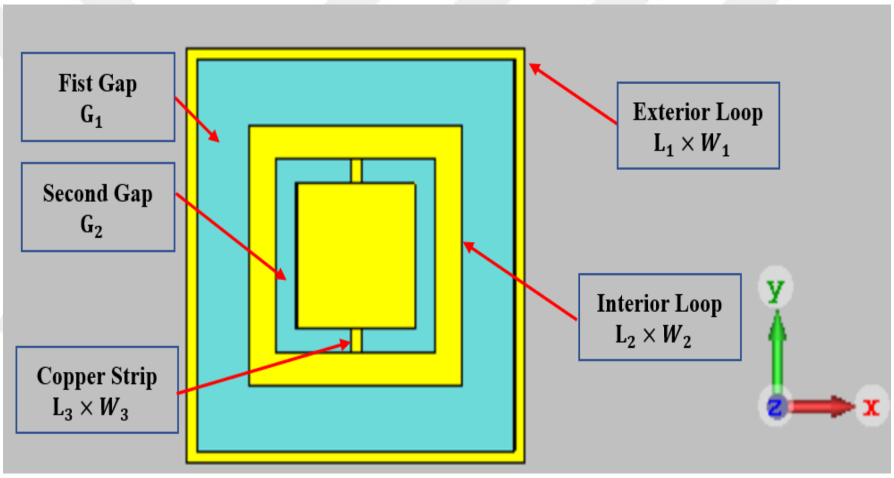


Figure 4.5: Single-Element FSS Structure.

Table 4.2: Sized for the Single-Element FSS Structure.

Dimension	Size (mm)
Exterior Loop ($L_1 \times W_1$)	3.40×0.10
Interior Loop ($L_2 \times W_2$)	2.14×0.27
First Gap (G_1)	0.53
Second Gap (G_2)	0.20
Copper Strip ($L_3 \times W_3$)	0.20×0.10

After the design of the single-element FSS structure has completed the implementation of the FSS 2D matrix is made by copying the single -element as a single cell at the 2D matrix organisation. The implemented matrix of the FSS is comprised from a 3×4 elements, as exhibited in Figure 4.6.

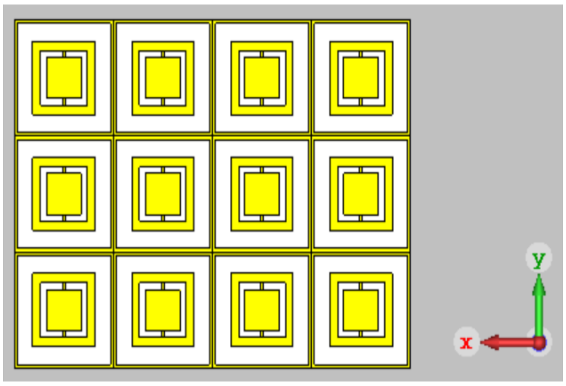
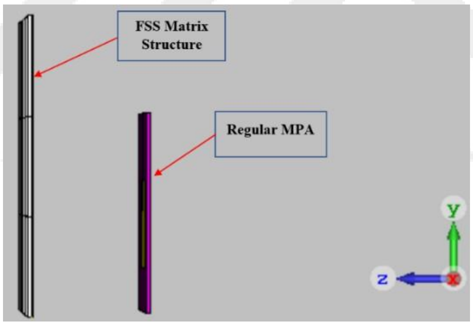
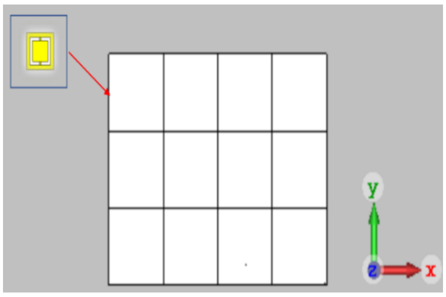


Figure 4.6: Completed Structure For FSS Matrix.

After the 2D matrix of FSS structure has completed, it placed above the regular MPA design with a distance of 4.5 mm, as exhibited in Figure 4.7.



(a) Side view appearance



(b) Front view appearance

Figure 4.7: Designed Structure For MPA And FSS.

For the purpose of testing the performance of the introduced FSS structure, the s-parameter pattern should be measured. Whereas, the S_{11} should be less than or equal to -10 dB. It is worth to mentioned that the designed FSS is able to covered triple bands of frequency which are 28.5, 54 and 60.2 GHz that are employed for the 5G communications, as shown in Figure 4.8. In this work we select the 28 GHz band because it is actually utilised in many of countries for the providing of 5G service for the users.

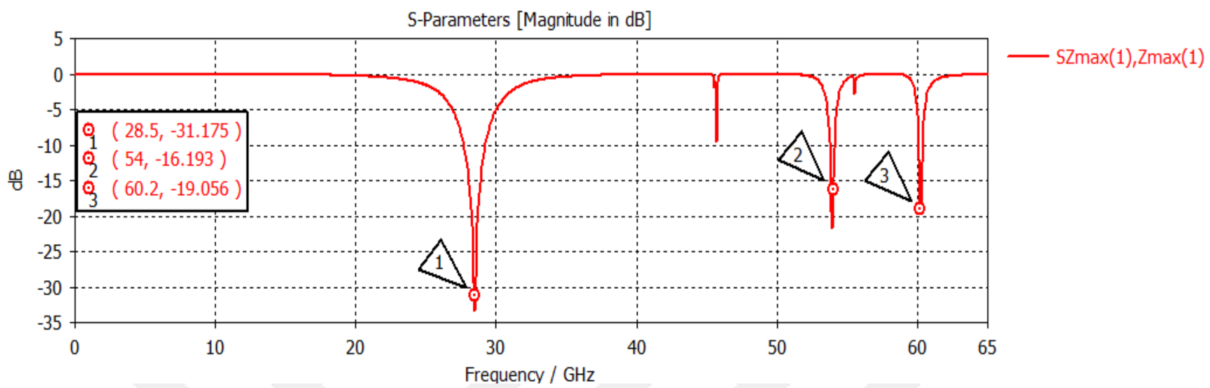


Figure 4.8: S-Parameters Outcomes for The Designed FSS.

4.4 DESIGN PROCESS FOR MPAA

On the basis of the studies that have been made in the literature, the nature of the MPA is characterised to have a poor gain because of the existence of the dielectric materials that are employed as the substrate. Many procedures have been utilised to improve its gain; in our work, the second scenario is the utilisation of the array configuration with a parallel (i.e., corporate) feed to improve the parameters. The design strategy is typically based on the utilisation of a special software provides a completed strictures called Antenna Magus software that is helps us to transform the completed 1×4 MPAA structure to the CST environment. In order to design the 1×4 array feeding network, we should enter three functional parameters like the MPA design, which are:

a. f_r = 28 GHz;
b. ε_r=3; and
c. h = 0.1 mm.

Due to the increase in the amount of the copper material that is utilised for the purpose of the implementation of the feeders of the array, the loss in power will be greater than that in the regular MPA. So, here we select the value of the dielectric material less than that of the

MPA. Figure 4.9 exhibits the feeder of the MPAA after exporting from the Antenna Magus software to be in the CST environment.

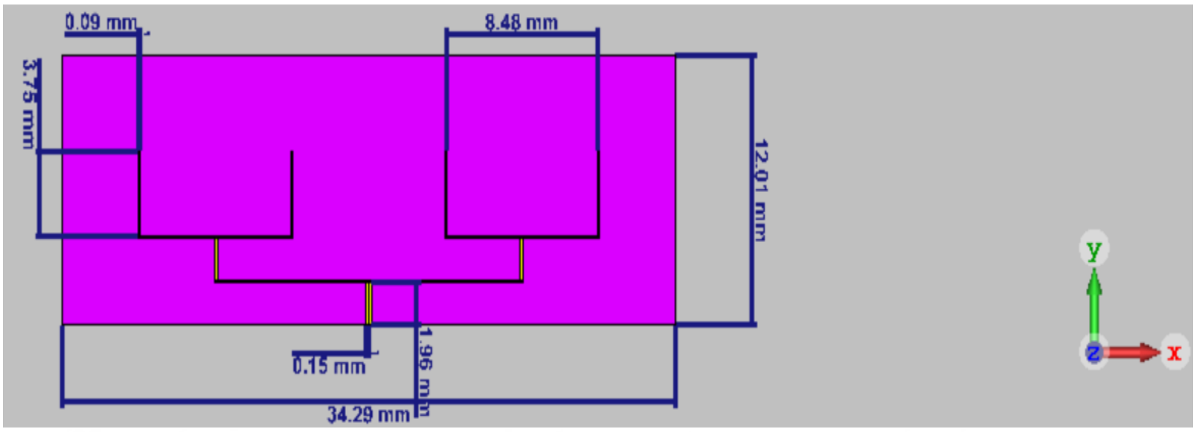


Figure 4.9: Structure for Parallel Feed.

After the design of the feeding network, the elements for the MPAA from a single rectangular MPA are created by copying and pasting the design of the previous MPA, as exhibited in Figure 4.10. It is recommended that the corporate feed be utilised because the current is spread and divided in the network equally for each component, which contributes to an improvement in performance.

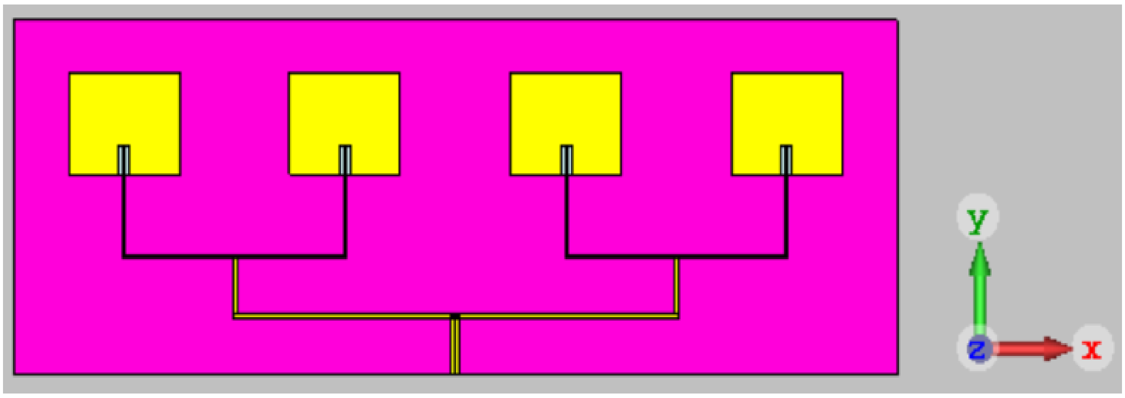


Figure 4.10: Structure for 1×4 MPAA.

4.5 OUTCOMES FOR THE PROPOSED STUDY

This portion of the chapter including an explanation and presentation for the proposed study. The outcomes including the RL, BW, and gain for both MPA and MPAA as well.

4.5.1 MPA and MPAA RL

Because of an impedance mismatch between the source and the antenna feed line, a portion of the electric power that is provided to the antenna is reversed or returned to the source that supplied the power. This phenomenon is referred to as the RL, and it can be summed up and expressed as the amount of power that is lost by the antenna. When these losses are less than or equal to -10 dB, the antenna is said to be functioning correctly. This indicates that the antenna has received the majority of the electrical power supplied by means of the source, which is 90% of the supplied power, and that the remaining 10% of the supplied power is reversed back to the source due to a mismatch in impedance. Scientists and manufacturers of antennas both came to this criterion. This subsection illustrates the RL for the RL for the MPA and MPAA before as well as after parameter correction process.

a. RL for MPA

The formulated RL outcomes for the regular rectangular MPA before the process of the dimension's correction are given in Figure 4.11.

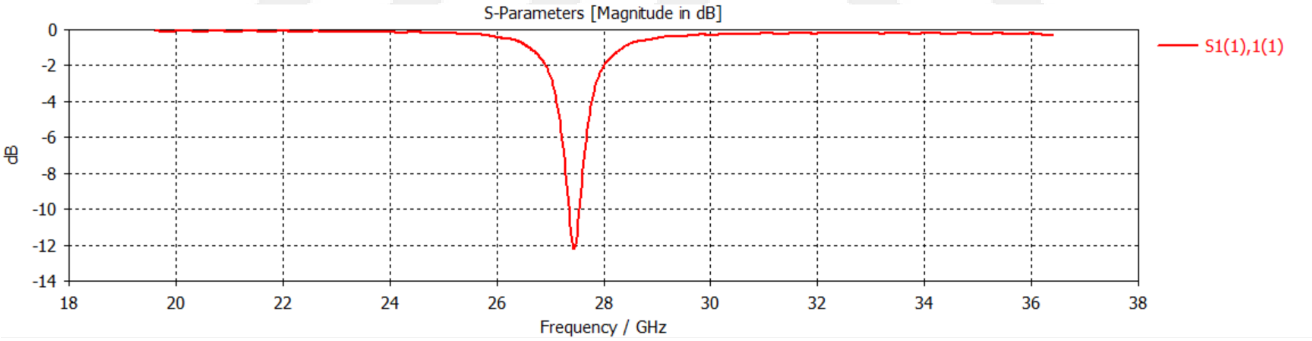


Figure 4.11: RL for the Regular Rectangular MPA Before Dimensions Correction Process.

When we look at the previous Figure 4.11, we notice that the resonance frequency is far from the required frequency, and here we conclude that the antenna that we designed suffersfrom a mismatch problem, which we talked about at the beginning of this part. Therefore, itis necessary to conduct a corrective process of adjusting the antenna dimensions through the method of trial and error. Figure 4.12 shows the MPA RL after the correction process is made.

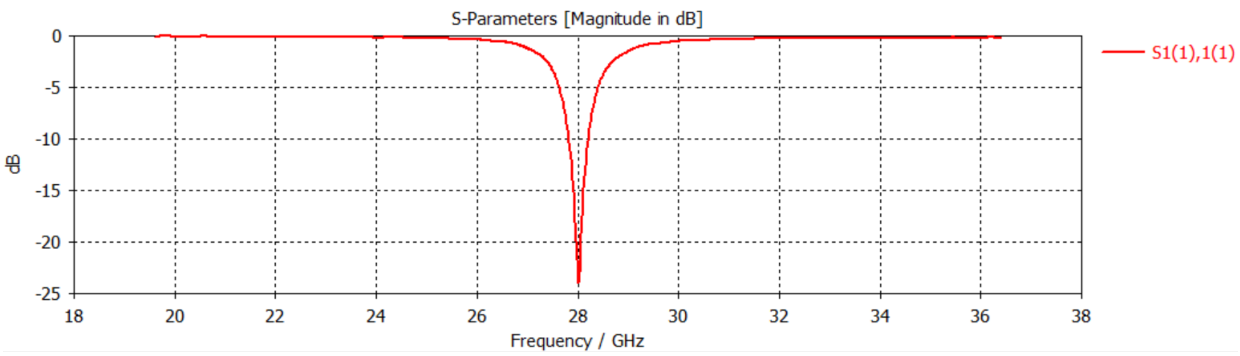


Figure 4.12: MPA RL After The Correction Process Applied.

From the shown Figure 4.12 it is worth to mention that, the MPA mismatching problem is solved after applied the correction process for the MPA dimensions and the required f_r=28 GHz is reached.

b. RL for MPA and FSS

The formulated RL outcomes for the regular rectangular MPA and the FSS structure after the process of the dimension's correction are given in Figure 4.13.

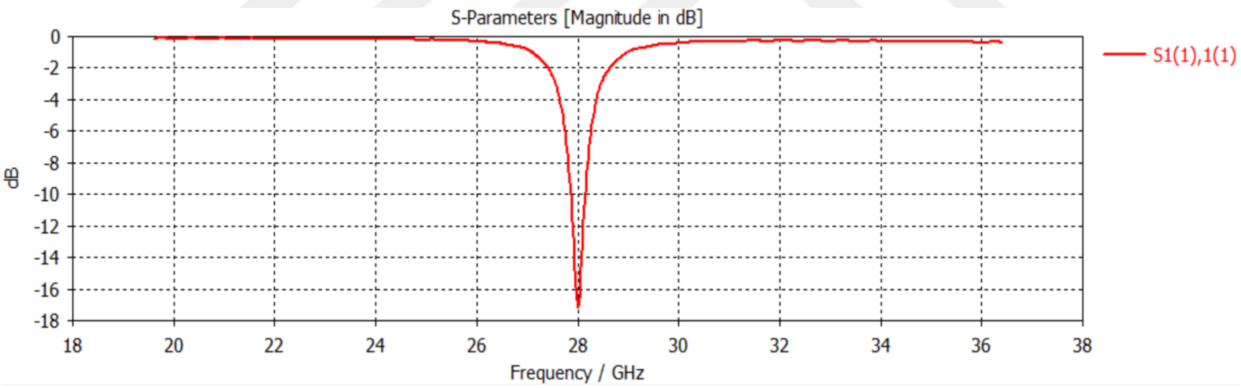


Figure 4.13: RL for MPA and FSS.

As seen from the latter Figure 4.13 the RL of the MPA with FSS is less than that of the optimised version, so that, in order to enhance the matching, the distance between the FSS and MPA can be controlled but this will affect the gain of MPA.

c. RL for MPAA

The formulated RL outcomes for the MPAA structure after the process of the dimension's correction are given in Figure 4.14.

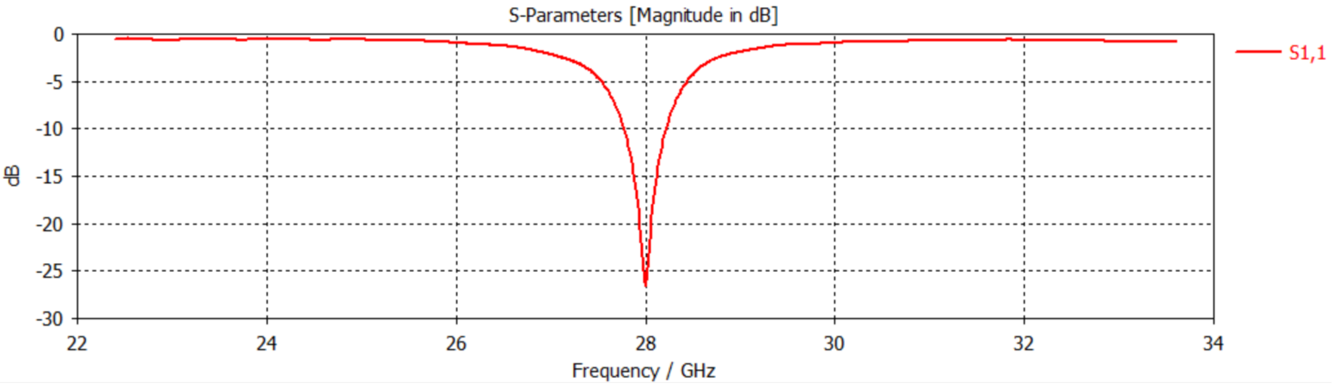


Figure 4.14: RL for MPAA.

As seen from the latter Figure 4.14 the RL of the MPAA is better than both cases of corrected parameter's MPA and MPA with FSS.

4.5.2 MPA and MPAA BW

In a nutshell, the antenna's BW can be understood as the grouping or set of frequencies on the left and right sides of the antenna f_r in the RL pattern over which the antenna parameters have around the same values as those calculated at the centre of the antenna (i.e., f_r). Utilising the measurement illustration lines that are provided by the simulation software is the typical method for calculating the BW from the RL pattern at the RL=-10dB setting.

a. BW for MPA

Before the correction parameters process the BW isn't useful to be calculated because the f_r of the antenna is far than the required frequency. The formulated BW outcomes for the regular rectangular MPA after the process of the dimension's correction is equals 393 MHz, as given in Figure 4.15.

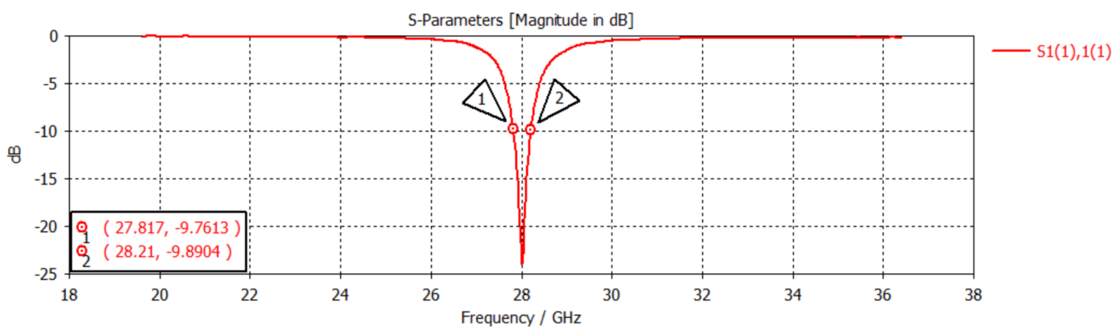


Figure 4.15: MPA BW after the Correction Process Applied.

b. BW for MPA with FSS

The formulated BW outcomes for the regular rectangular MPA with FSS equals 284 MHz, as given in Figure 4.16.

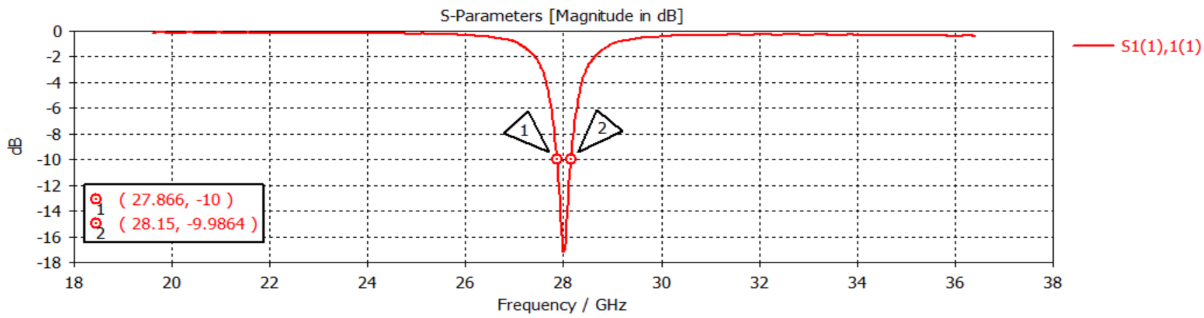


Figure 4.16: BW for MPA and FSS.

c. BW for MPAA

The formulated BW outcomes for the MPAA equals 444 MHz, as given in Figure 4.17 which is clearly greater than that of MPA and MPA with FSS.

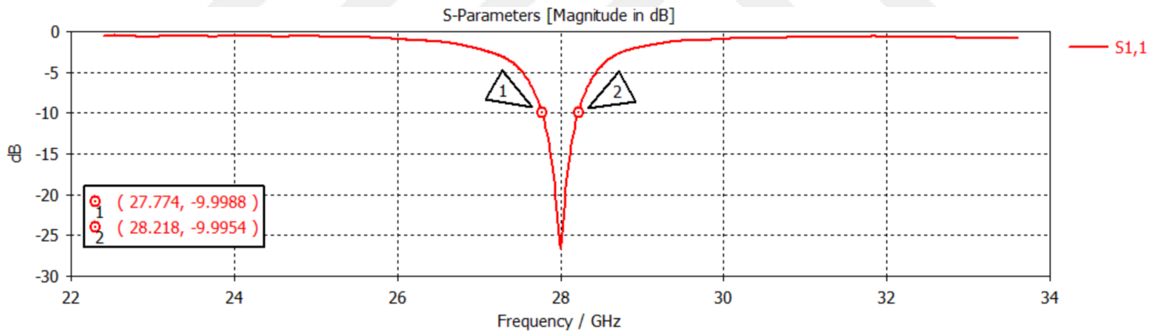


Figure 4.17: BW for MPAA.

4.5.3 MPA and MPAA Gain

One of the ultimate significant parameters for any type of antenna is the antenna gain. It demonstrates the antenna's capability to convert electric power into radiated power or vice versa. For the regular MPA, the gain is determined by a combination of two different factors. The first is the MPA substrate's height, and there is a proportional relationship between the gain and the height. With the increase in height, there is an increase in the gain. The second is the substrate constant, and there is an inversely proportional relationship between the substrate dielectric constant and the antenna gain. The antenna gain is proportional to the dielectric constant of the substrate.

a. Gain for MPA

The formulated gain outcomes for the regular rectangular MPA after the process of the dimension's correction which is equals 6.04 dBi, as given in Figure 4.18.

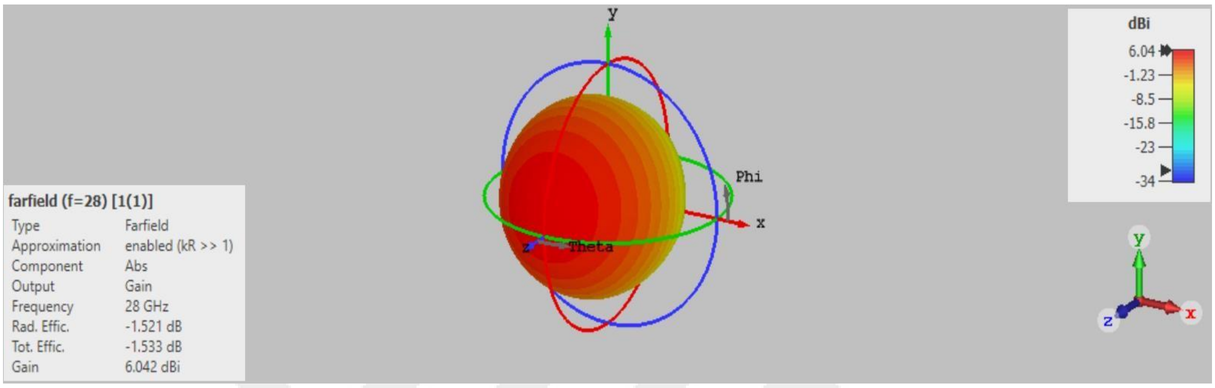


Figure 4.18: Gain for MPA.

b. Gain for MPA with FSS

The formulated gain outcomes for the regular rectangular MPA with FSS is equals 9.65 dBi, as given in Figure 4.19.

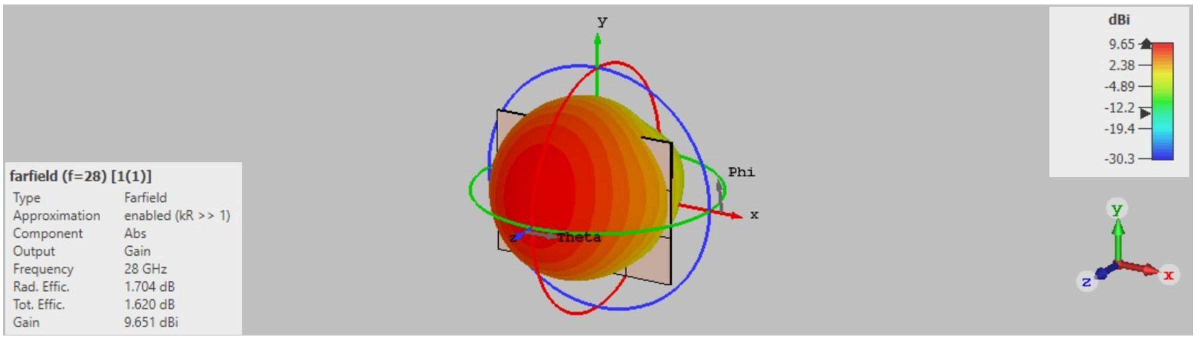


Figure 4.19: Gain for MPA with FSS.

c. Gain for MPAA

The formulated gain outcomes for the regular rectangular MPA with FSS is equals 12.2 dBi, as given in Figure 4.20.

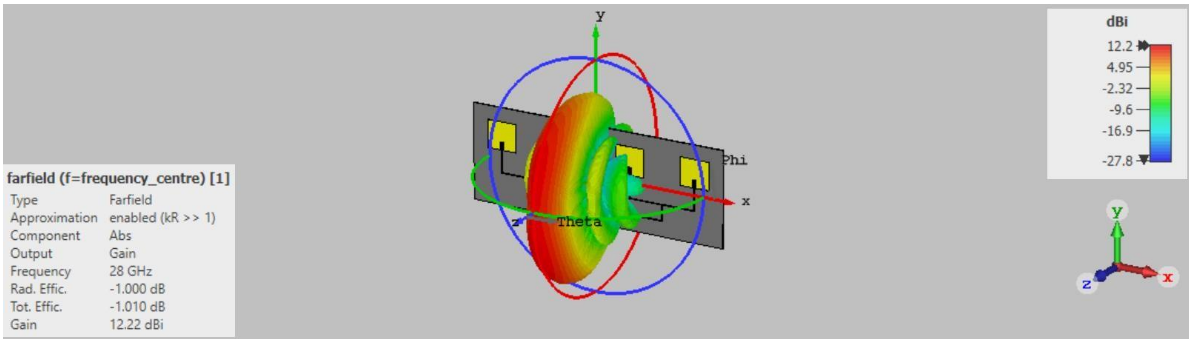


Figure 4.20: Gain for MPAA.

In the comparison with the previous designs, the gain is enhanced particularly when utilising the array structure. Table 4.3 summarised the obtained outcomes for the previous designs.

Table 4.3: Outcomes Summary.

Parameter	RL	BW	Gain
Optimised MPA	-23 dB	393 MHz	6.04 dBi
MPA with FSS	-17 dB	284 MHz	9.65 dBi
MPAA	-26 dB	444 MHz	12.2 dBi

5. CONCLUSION AND FUTURE ADVISE

5.1 CONCLUSION

Wireless communication has advanced dramatically in recent years, becoming an essential component in our modern life. As a result, the amount of implementations linked to wireless networks has skyrocketed, contributing to congestion and a minimising in the speed at which data can be transmitted. It was suggested by the operators of the networks to employ high frequencies, particularly licensed and unlicensed ones, to be used due to their ability to provide extremely fast data transfer speeds and wide ranges. Whereas, currently the 28GHz is applied actually in many countries around the worldwide. This was done in order to solve the previously mentioned problem. The most of MPA have a number of problems, the majority associated to their small gain and narrow BW. In this study we used the CST antenna analysing software to simulate and design a compact regular MPA for use by for 5G networks operating for mobile communications on the 28GHz frequency band. It has been proposed that the FSS passband superstate be utilised and installed on top of the regular antenna to solve the problems associated with the regular MPA. The addition of the FSS superstrate has resulted in significant improvements in antenna gain. Furthermore, an additional design for array structure array antenna to evaluate and compare the performance of the MPA with FSS and MPA in the array structure. Based on the simulation outcomes, we concluded that the antenna parameters were marginally improved when utilising the array structure.

5.2 FUTURE ADVISE

Because of the breadth of this field, the study of antennas encompasses a wide range of design and optimization strategies. There are several adjustments that can be made to develop and improve the performance of this work, and some of these are summarised below:

a. Building a stopband FSS matrix and installing it beneath the conventional rectangular MPA to improve the antenna's parameters.
b. Situating the FSS matrix over the MPAA structure and studying the antenna performance.

c. Utilising the graphene material to implementing a tuneable antenna.

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