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A GRAPHENE-BASED MONOPOLE MICROSTRIP ANTENNA WITH TUNEABLE BANDGAP FOR UWB IMPLEMENTATIONS

Mustafa Kareem Najim AL-ASADI

Master's Thesis

Supervisor

Asst. Prof. Dr. Oğuz KARAN

İstanbul, 2023

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The thesis titled A GRAPHENE-BASED MONOPOLE MICROSTRIP ANTENNA WITH TUNEABLE BANDGAP FOR UWB IMPLEMENTATIONS prepared by Mustafa Kareem Najim AL-ASADI and submitted on 29/12/2023 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering

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I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Mustafa Kareem Najim AL-ASADI

Signature

DEDICATION

At the outset, I extend my deepest gratitude to Asst. Prof. Dr. OĞUZ KARAN for his unwavering guidance and counsel throughout my academic journey. His sage advice has illuminated my path, providing invaluable insights and meticulous details that have shaped the fabric of this study. I am particularly grateful for his expert direction in selecting the most fitting methods to develop this work.

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In loving memory of my dear brother, Dr. Mohammed Kareem, whose soul was taken by Allah in a tragic car accident. I dedicate this success to him, believing that if he were here, he would have been my foremost supporter. His special and pure soul in heaven continues to inspire and guide me.

I extend my gratitude to the rest of my beloved family for their unwavering support.

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In conclusion, I take pride in the completion of this thesis amidst the challenges and pressures of the past year, balancing work and study. Alhamdulillah, I have overcome these hurdles and stand proud of this accomplishment.

ABSTRACT

A GRAPHENE-BASED MONOPOLE MICROSTRIP ANTENNA WITH TUNEABLE BANDGAP FOR UWB IMPLEMENTATIONS

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The utilization of Monopole Microstrip Antennas (M-MSAs) is widespread due to their affordability, simplicity in construction, and compact size, allowing seamless integration into various portable applications. Recently, the Ultrawide Band (UWB) technology, widely employed in wireless utilisations, is particularly reliant on this type of antenna. The UWB technology offers an extensive frequency range spanning in the range 3.1-10.6 GHz, catering to a multitude of small-power wireless implementations, including wireless voice transmission, personal localisation, radio frequency recognition, radar, and the HD video transmission. However, the broad nature of this frequency band increases the likelihood of interference. This contribution study seeks to formulate, simulate, and optimise an altered small-sized square M-MSA competent of fulfilling the conditions of UWB technology such as the large bandwidth. The introduced M-MSA design encompasses a square radiated patch, a dielectric material with a stout of 1 mm and 4.7 relative permittivity, a partially ground plane printed on the same face as the patch, and coplanar waveguide feed. To ensure the best compatibility with the UWB full band, certain of alterations to the M-MSA design are made like as a cut on the lower corners of the patch and changing the dimensions. Furthermore, the addition of a U-shaped aperture on the patch is suggested to be etched to create a bandgap within the UWB frequencies, effectively expected to reduce the interference. To obtain the tunability for the developed bandgap, graphene is employed to fill the aperture. In the case of the DC voltage being subjected to the graphene, the bandgap dissipates, while without biasing, the graphene exhibits high impedance, restricting current flow in the aperture. Consequently, the bandgap's impact becomes apparent within the frequency range of 3.87-4.85 GHz. After conducting the simulation and modification process, the obtained results demonstrate a significant improvement in both gain and efficiency. Furthermore, a notable increase in attenuation and degradation of gain is observed within the bandgap region, which was deliberately selected to mitigate interference from various sources such as military fixed communications, mobile communications, unmanned aerial vehicles, short-range radio links, satellite communications, and the low band of 5G.

Keywords: 5G, M-MSA, Coplanar Waveguide, Graphene, UWB.

TABLE OF CONTENTS

Pages

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

IoT	:	Internet of Things
UWB	:	Ultrawide Band
WLAN	:	Wireless Local Area Network
Wi-Fi	:	Wireless Fidelity
EBG	:	Electromagnetic Bandgap
CP	:	Circular Polarisation
CPW	:	Coplanar Waveguide
M-MSA	:	Monopole Microstrip Antenna
MSAs	:	Microstrip Antennas
DC	:	Direct Current
RF	:	Radio Frequency
RFID	:	Radio Frequency Identification
CF	:	Coaxial Feeding
PCF	:	Proximity-Coupled Feeding
ACF	:	Aperture-Coupled Feeding
TLM	:	Transmission Line Model

1. INTRODUCTION

1.1 OVERVIEW

Wireless communication refers to the transmission of data, voice, or video over radio waves without the use of any physical wires or cables. Through Radio Frequency (RF) and microwave, data can be sent without the utilise of the conductors. Over a well-defined channel, the information or data can be transported among different appliances over spaces varying from a few metres to the hundreds of the kilometres. More practically, the term “wireless” indicates the communication that carries place without the need for the wire’s utilisation. For wireless communications, the antennas play a vital role in the transmitter and the receiver for the purposed of completing the transmission manner when utilising wireless communication to send information such as voice or general purposes data. This mode of communication has become increasingly popular in recent years, as it enables users to stay connected while on the move, and eliminates the need for bulky wires and cables. One of the main advantages of wireless communication is its convenience. With wireless technology, users can communicate with each other from any location, as long as they have access to a wireless network. This means that people can work from home or on the go, without being tied to a physical location. Another advantage of wireless communication is its cost-effectiveness. In many cases, the cost of setting up and repairing a wireless network is lower than that of a standard wired network. This is because wireless networks do not require the installation of expensive cables or the hiring of technicians to lay them. Wireless communication has also enabled the development of many innovative applications and devices. For example, smartphones, tablets, and other mobile devices rely on wireless technology to access the internet, send and receive messages, and make phone calls. In addition, the Internet of Things (IoT) has become increasingly prevalent, with wireless sensors and devices being used to monitor and control everything from traffic lights to home appliances. Overall, wireless communication has become an essential part of modern life, enabling people to stay connected and access information from anywhere at any time. Its versatility and convenience have made it an indispensable technology as well as it is probable to continue to take a major position in shaping the future of communication and information technology [1]-[3].

Wireless communications are recently utilized in the different of the utilizations in factories, homes, power generations, and other applications, as exhibited in Figure 1.1.

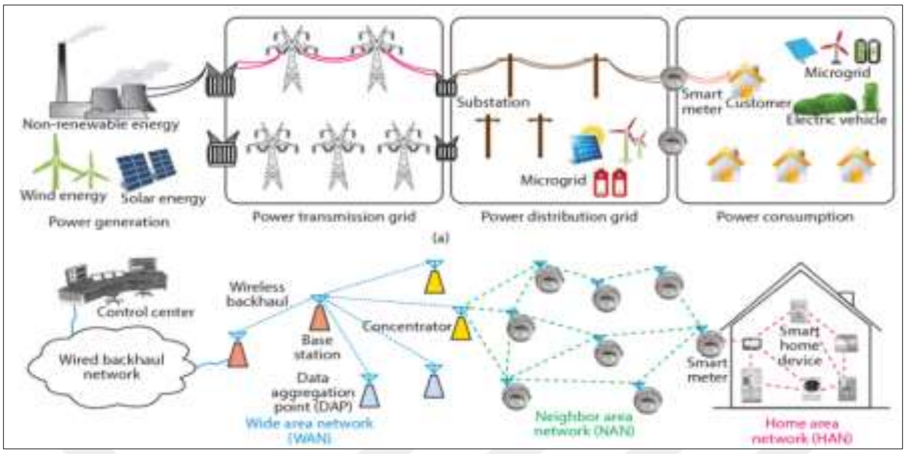


Figure 1.1: Interaction of Applications in Wireless Network.

1.2 ADVANTAGE OF WIRELESS COMMUNICATIONS

With the recent growth in technology applications, wireless communications have played a vital role in various applications due to their advantages, which are listed as follows [4], [5]:

1.2.1 Convenience

Wireless communication offers the convenience of communicating on the go without being tied down by physical cables or wires. This allows us to stay connected from anywhere at any time, whether it's for work or personal reasons.

1.2.2 Cost-Effectiveness

Setting up and repairing a wireless communication network could be more cost-effective than the known wired network. This is because wireless networks don't require expensive cables, which can be costly to install and maintain.

1.2.3 Increased Productivity

Wireless communication can increase productivity in various industries, especially those that require mobility. For instance, healthcare workers can use wireless devices to access patient records on the go, while salespeople can easily connect with clients and access customer data remotely.

1.2.4 Improved Efficiency

Wireless communication enables real-time data exchange and allows for seamless collaboration, making it easier to manage workflows and streamline processes. This can help to optimize the functional efficiency, minimise errors, and enhance the total productivity.

1.2.5 Enhanced Flexibility

With wireless communication, users have more flexibility and freedom to work from anywhere, without being restricted by the limitations of physical cables or wires. This can lead to raise job satisfaction and the optimal work-life balance. Overall, wireless communication has many advantages that make it an indispensable technology for businesses and individuals alike. It offers convenience, cost-effectiveness, increased productivity, improved efficiency, and enhanced flexibility, among other benefits.

1.3 DISADVANTAGE OF WIRELESS COMMUNICATIONS

While wireless communication has many advantages, there are also some disadvantages that should be taken into account [6], [7]:

1.3.1 Interference

Wireless communication signals can be disrupted or interfered with by various factors such as walls, weather conditions, and other electronic devices. This can lead to a decrease in signal quality, slower connection speeds, and dropped calls.

1.3.2 Security Issues

Wireless communication networks can be vulnerable to security breaches, such as hacking and unauthorized access. This can lead to the loss of sensitive data, identity theft, and other cyber threats.

1.3.3 Limited Range

Wireless communication signals have a limited range, which means that users need to be within a certain distance of the network to access it. This can be a disadvantage in large or remote areas where network coverage may be limited.

1.3.4 Battery Life

Wireless devices require a power source to operate, which means that their battery life is limited. This can be a challenge for users who need to stay connected for extended periods, especially if they don't have access to a power source.

1.3.5 Cost

Wireless communication can be more expensive than wired communication, especially in terms of data plans and device costs. This can be a disadvantage for individuals and businesses on a tight budget. The wireless communication has many advantages, there are also some potential drawbacks to consider. Interference, security risks, limited range, battery life, and cost are all factors that need to be taken into account when using wireless communication technology.

1.4 ULTRAWIDE BAND (UWB) TECHNOLOGY

UWB technology can be interpreted as a communication technology for the wireless implementations that enables the transmission of large amounts of data over short distances. UWB uses a broad spectrum of radio frequencies, allowing for faster data transfer rates and increased bandwidth. One of the main benefits of UWB technology is its high-accuracy location capabilities. The UWB able for the accurate determine the location of objects within a few centimetres, leading to make it proper for implementations such as indoor positioning, asset tracking, and security systems. UWB technology also has low power consuming, which makes it proper for utilise in the battery-powered appliances like the wearables, smart sensors, and IoT devices. Its low power consumption also makes it an energy-efficient alternative to other wireless technologies such as Wi-Fi and Bluetooth. Another advantage of UWB technology is its resistance against the interference that presence by the other wireless signals. UWB signals can coexist with other wireless signals without causing interference, making it ideal for use in environments with high wireless traffic. One potential disadvantage of UWB technology is its limited range, which is typically less than 10 meters. This makes it unsuitable for applications that require longer-range communication. One of the many advantages offered by UWB technology is its pinpoint location accuracy, in addition to its low power requirements and resistance to electromagnetic interference. Due to its limited range, however, it is not ideally suited for every application. In spite of the fact that this is the case, UWB technology is gaining traction in a variety of industries and is on track to become an essential component of wireless communication in the years to come. UWB technology occupies a frequency in the range of 3.1-10.6 GHz, as shown in Figure 1.2 [8], [9].

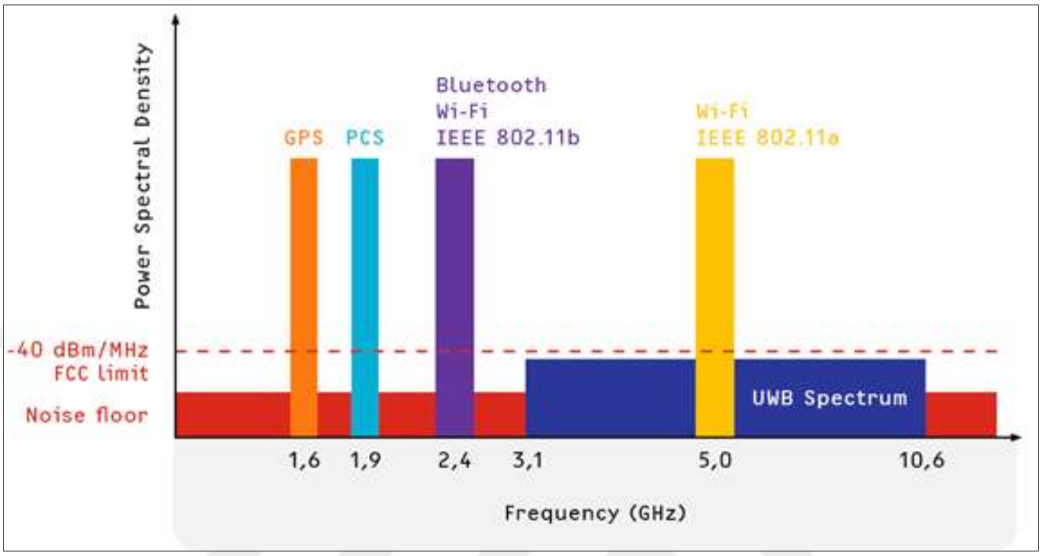


Figure 1.2: Frequency Allocation for UWB.

1.5 PROPERTIES OF UWB TECHNOLOGY

The UWB technology is a wireless communication technology that uses a broad spectrum of radio frequencies to enable high-bandwidth data transfer and high-precision location capabilities. Here are some of the key properties of UWB technology [10], [11]:

1.5.1 Wide Bandwidth

UWB technology uses a broad spectrum of radio frequencies to transmit signals, which allows for high-bandwidth data transfer and faster communication speeds.

1.5.2 Low Power Consuming

The UWB technology utilises a very low power consumption, making it a perfect solution for the battery-powered appliances such as the wearables, sensors, and IoT devices.

1.5.3 High-Precision Location Capabilities

UWB technology enables high-precision location capabilities with accuracy within a few centimetres. This makes it ideal for indoor positioning and navigation, asset tracking, and security systems.

1.5.4 Resistance to Interference

UWB signals are less likely to be disrupted or interfered with by other wireless signals, making it an ideal solution for environments with high wireless traffic.

1.5.5 Regulations

Due to worries about interference with other wireless signals, UWB technology is subject to regulations in some countries.

1.5.6 Small-Range Transmission

UWB technology has a constrained range that is typically less than 10 m. This makes it perfect for applications requiring short-range communication, like data transfer and indoor positioning. Overall, the UWB technology has many of the desirable properties, including wide bandwidth, low power consumption, high precision location capabilities, resistance to interference, and short-range communication. However, its limited range and regulatory restrictions need to be taken into account when considering its suitability for specific applications, as summarized in Figure 1.3.

Figure 1.3: UWB Technology Properties.

1.6 UWB TECHNOLOGY APLICATIONS

The UWB technology has a utilized in the wide range of the applications across various industries. Here are some of the key UWB technology applications [12], [13]:

1.6.1 Indoor Positioning and Navigation

UWB technology enables high-precision indoor positioning and navigation, make it ideal for the implementations such as asset track, inventory management, and security systems.

1.6.2 Wireless Data Transfer

UWB technology provides high-bandwidth wireless data transfer, allowing for faster and more efficient data exchange between devices. This makes it ideal for applications such as file transfer, video streaming, and gaming.

1.6.3 Automotive Industry

UWB technology can be used in the automotive industry for various applications such as keyless entry, remote start, and collision avoidance systems.

1.6.4 Healthcare

UWB technology can be used in healthcare for applications such as patient monitoring, tracking medical equipment, and assisting with surgical procedures.

1.6.5 IoT Systems

UWB technology is an ideal solution for IoT applications that require low-power, high-bandwidth wireless communication. This includes smart home devices, wearables, and sensors.

1.6.6 Security Systems

UWB technology can be utilise in the security systems for implementations such as access control, surveillance, and tracking of personnel and assets. Overall, the UWB technology has many potential applications across various industries, including indoor positioning and navigation, wireless data transfer, automotive, healthcare, IoT, and security systems. Its high-precision location capabilities and resistance to interference make it an ideal solution for many. applications, while its limitations in range need to be taken into account when considering its suitability for specific use cases.

1.7 ADVANTAGES OF UWB TECHNOLOGY

UWB technology is the superior select for the wide range of wireless communication utilisations due to its numerous advantages. The following are some of the significant benefits of the UWB technology:

1.7.1 High Bandwidth

The UWB technology provides high-bandwidth data transfer rates, enabling faster and more efficient communication between devices [14], [15].

1.7.2 High-Precision Location Capabilities

UWB technology enables high-precision location capabilities, allowing for accurate positioning and navigation within a few centimetres.

1.7.3 Low Power Consuming

The UWB technology utilises a small power consumption, making it a suitable solution for the wearables, sensors, and IoT devices.

1.7.4 Resistance to Interference

UWB signals are less likely to be disrupted or interfered with by other wireless signals, making it an ideal solution for environments with high wireless traffic.

1.7.5 Security

UWB technology provides a high level of security due to its low probability of interception and its ability to operate in encrypted mode.

1.7.6 Cost-Effective

UWB technology is a cost-effective solution for the wireless transmission applications because it low-power consumption and depressed -cost components. Because of its many advantages, such as high bandwidth, high precision location capabilities, low power consumption, resistance to interference, security, and cost-effectiveness, UWB technology is a desirable solution for a broad range of the wireless communication employments. These are just a few of the numerous benefits that make UWB technology so appealing. Its widespread use in fields as diverse as healthcare, transportation, the IoT, and security systems demonstrate its potential as a game-changing innovation in wireless communication. The widespread use of the technology has demonstrated this potential.

1.8 DISADVANTAGES OF UWB TECHNOLOGY

The UWB technology has the potential to offer a great number of benefits; however, its limitations should be taken into consideration prior to its implementation. The following is a list of some of the most significant drawbacks of UWB technology [16], [17]:

1.8.1 Short Range

UWB technology has a limited range of normally around and less than 10 m. This makes it unsuitable for applications that need long-range communication, such as cellular networks.

1.8.2 Regulatory Restrictions

UWB technology is subject to regulatory restrictions in some countries due to concerns over interference with other wireless signals.

1.8.3 Complexity

UWB technology is a complex technology that requires specialized knowledge and expertise to develop and deploy.

1.8.4 Limited Availability

UWB technology is not widely available in commercial products, making it difficult to find compatible devices and components.

1.8.5 Interference with other Wireless Signals

While UWB signals are less likely to be disrupted or interfered with by other wireless signals, they can still interfere with other wireless signals in certain situations. When determining whether or not UWB technology is appropriate in a given situation, keep in mind that the technology has some drawbacks in general. A number of factors must be considered when evaluating its applications, including its limited range, regulatory constraints, complexity, rarity, and the possibility that it will interfere with other wireless signals. It is a promising technology for many wireless communication applications due to its many advantages, including high bandwidth, high precision location capabilities, low power consumption, resistance to interference, security, and cost-effectiveness.

1.9 PROBLEM FORMULATION

Due to the presence of the considerable band of frequency for the UWB technology so there is a great chance of the accruing of interference from the other available applications like mobile, Wi-Fi, Low band of 5G, and WLAN. In order to eliminate and minimize the interference level the bandgaps are suggested to be utilized.

1.10 PREVIOUS STUDIES

In the literature, the researchers and authors have been designed as well as simulated various types of antennas that have been introduced for the UWB employments, some of these investigations and researches are reviewed as follows:

a) It has been determined that a small UWB microstrip antenna with band-notch properties can be designed, simulated, and analysed successfully by the authors. The FCC bandwidth standards for UWB applications were considered at the designing of the antenna, which has size of 28x29 mm^2. By utilising a resonant U-shaped aperture, it is able to effectively filter out the IEEE 802.11a band (5.15-5.825 GHz) while covering a frequency range that extends from 3.1 to 10.6 GHz. The notch-filtering feature could not have been realised without the aperture being implanted at the required frequency [18].

b) The researchers in this paper have presented the completed design and implementation of a compact UWB antenna with a rectangular notch that can control both the centre frequency and notched bandwidth for the wireless area network band. The antenna achieves UWB characteristics by truncating the lower portion of the rectangular microstrip patch, while the notch characteristics are achieved by incorporating electromagnetic bandgap (EBG) structures. These structures are composed of two rectangular metallic conductors positioned behind the radiator and connected to the patch through shorting pins. By fine-adjusting the resonant frequency of the EBG and combining them, a highly selective rectangular notch was achieved at the WLAN band. The result is an antenna with excellent filtering capabilities that can be easily integrated into wireless communication systems. Overall, this paper presents a promising approach to achieving effective notch filtering in UWB antennas [19].

c) The researchers in this study have presented a planar UWB antenna design that uses a low-cost FR-4 dielectric with dimensions of 49.0x35.0x1.60mm^3. The antenna is capable of producing S_{11} values below -10 dB in a frequency band ranging from 1.49 to 12.6GHz, which comprises the bands of the RF spectrum. The introduced antenna achieves of 97.00% efficiency at 1.780 GHz and a peak gain of 4.2 dBi at 7.78GHz, with an impressive BW of 10.990 GHz. To test the manufactured antenna, the researchers utilized a VNA instrument and found that the measured S11 values closely matched the simulation results. This antenna design is particularly suited for UWB applications such as RF-energy harvesting and spectrum sensing. Overall, the study provides valuable insights into the development of cost-effective and efficient UWB antennas for a range of applications [20].

d) The researchers of this study were introduced a brand-new UWB antenna system with circular polarisation (CP). The antenna had an altered inverted L-shaped radiating patch and a coplanar waveguide (CPW) feed structure. A single-layer non-uniform frequency selective surface (FSS) made up of rectangular conductive patches was created and integrated with the CP antenna in order to enhance the CP characteristics and gain of the antenna. The antenna's 10 dB return loss bandwidth with the FSS ranged from 3.7 to 11.1 GHz, according to measurements. The measured peak gain ranged from 4-9.4 dBi, which is an increase of about 3dBi compared to the antenna without the FSS matrix. The measured 3dB axial ratio bandwidth was 58.15%, covering 5 to 9.1GHz. Overall, this study offers a promising strategy for incorporating FSS structures into UWB antennas to improve their performance [21].

e) The researchers of this study put forth a procedure of the design for a microstrip array antenna for the UWB that makes use of a stepped line cut and U-aperture structure for 5th-generation millimetre-wave use. The proposed design adopted the proximity-coupled method to increase the antenna's bandwidth. To determine the bandwidth improvement, the performance of the simulated antenna was compared to that of the conventional antenna array configuration. In comparison to the conventional design, numerical and simulation results revealed a significant improvement in bandwidth performance. The proposed antenna had a gain of 8.71 dB, a bandwidth of 4.47 GHz, and a frequency band of 28 GHz. These results suggest that the proposed antenna design can be applied to millimetre-wave applications for 5th generation technology. Overall, this study offers a promising strategy for improving UWB microstrip array antenna performance for upcoming millimetre-wave applications [22].

f) The researchers presented a novel design for a small microstrip UWB antenna that has a small and efficient design in this study. The antenna is capable of operating at a wide frequency range from 4.1 to 10 GHz. The researchers explored the antenna parameter through frequency domain analysis to demonstrate its effectiveness as a radiating element. Additionally, the study showcases a method to analyse the impact of time-domain Gaussian pulse stimulation on UWB systems. The modeling forecasts aligned with the actual measurements, revealing exceptional linear transmission capabilities in the UWB time domain [23].

1.11 OBJECTIVES OF THIS WORK

The objectives and contributions of this study are summarized based on an analysis of relevant literature, which are listed as following:

a) The essence of this study is summarized by designing a small-sized Monopole Microstrip Antenna (M-MSA) capable of covering the fundamental band of UWB.

b) Creating a bandgap to minimise the interference from neighbouring frequencies by engraving a small U-shaped aperture on the M-MSA will be functioned as a filter to reject/attenuate certain frequencies.

c) Utilising the graphene material to make the bandgap controllable by applying DC voltage on the material.

1.12 ORGANISATION OF THESIS

In general, this study is made up of four principal chapters, the outline of each one is summarized in the following points:

a) Chapter Two: This chapter presents the overall definition of antennas, the principal parameters for the different type of antennas, analysis methods and feeding approaches for microstrip antennas. Additionally, it introduces the definition of graphene, along with its implementations and features.

b) Chapter Three: This chapter outlines the work procedure (i.e., working plan) and optimization process for the proposed work. Furthermore, it presents the results obtained from the CST antenna analysis and simulation software.

c) Chapter Four: This chapter presents the achievements obtained through the completion of this work. Additionally, it highlights recommendations for future developments.

2. FUNDAMENTALS OF ANTENNA

2.1 DEFINITION OF ANTENNA

Antennas are devices that are used to transmit and receive radio frequency (RF) signals. They are essential components of wireless communication systems and are utilise in a broad range of the applications, including broadcasting, satellite communication, mobile communication, and radar systems. An antenna works by transforming the electrical signals to the form of the electromagnetic waves and vice versa. These waves can travel through the air, space, or other mediums and carry information over long distances.

2.2 HISTORY OF ANTENNAS

The history of the antennas is vestige back to the late 1800s when Heinrich Hertz conducted experiments that demonstrated the existence of electromagnetic waves. In the early 1900s, Guglielmo Marconi used antennas to transmit radio signals across the Atlantic Ocean, which marked the beginning of wireless communication. Since then, antennas have continued to evolve and improve, with new designs and technologies being developed to meet the changing needs of the communication industry. One of the earliest types of antennas was the dipole antenna, which comprise of a couple metal rods that are placed in the parallel form to each other. This type of antenna was widely used in the early days of radio communication and is still used today in some applications. Other types of antennas that were developed over time include the loop antenna, the patch antenna, and the helical antenna, among others. Modern antennas come in a wide range of forms and sizes, and they are designed to meet specific requirements for different applications. For example, antennas used in mobile communication systems need to be small and lightweight, while antennas used in satellite communication need to be able to withstand the harsh conditions of space. Advances in antenna design and technology have also led to the development of smart antennas, which can dynamically adjust their radiation patterns to optimize the signal quality and improve communication efficiency. In conclusion, antennas are an essential part of modern communication systems, and their history can be traced back to the early days of radio communication. The evolution of antenna design and technology has played a crucial role in enabling the wireless communication to become a ubiquitous and an essential part of the modern life [24], [25].

2.3 TYPES OF ANTENNAS

There are various sorts of the antennas that are utilised in different of the applications. One of the most common types is the dipole antenna, that is comprises of a couple of conductive rods placed in the parallel to each other. Another widely used type is the patch antenna, which is a flat rectangular or circular structure that can be printed onto a circuit board. Loop antennas are another type that consists of a single wire or a loop of wire that is bent into a specific shape. Yagi antennas are directional antennas that comprise of several elements organised in a specific pattern, and they are often used for point-to-point communication. Helical antennas are another type that is commonly used for satellite communication and GPS systems. Other types of antennas include horn antennas, parabolic antennas, and fractal antennas, among others. Each type of antenna has its unique characteristics and is designed to meet specific requirements for different applications. The choice of antenna depends on factors such as frequency range, radiation pattern, gain, size, weight, and cost, among others. Advances in antenna design and technology have led to the development of smart antennas, which can adjust their radiation patterns dynamically to optimize signal quality and improve communication efficiency [26], [27]. Figure 2.1 presents some sorts of the popular antennas.

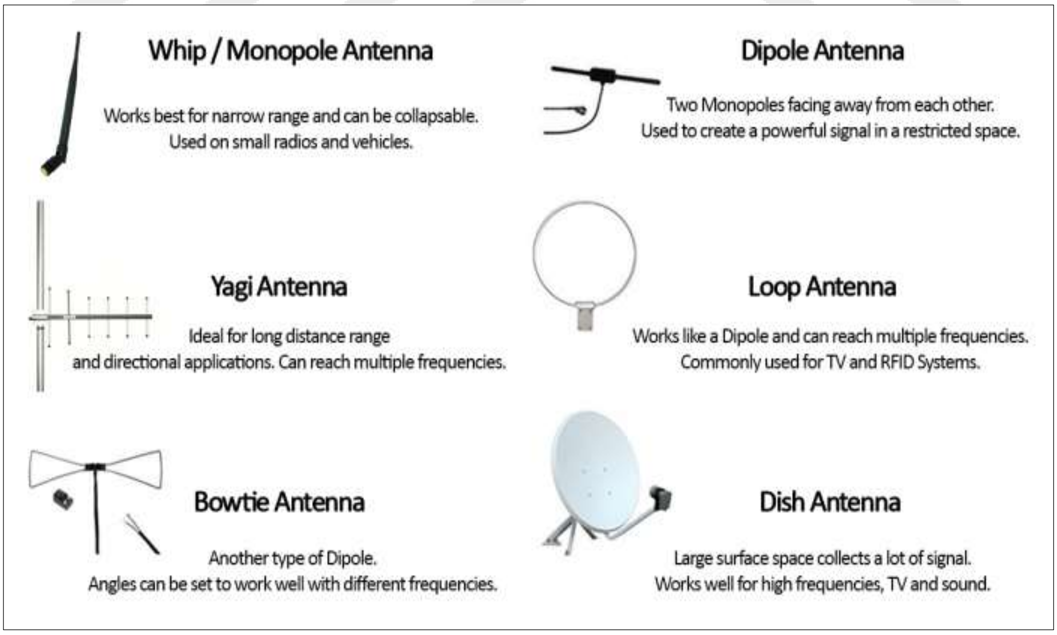


Figure 2.1: Popular Types of Antennas.

2.4 ANTENNA ESSENTIAL PARAMETERS

In order to examine the performance of any available antennas it is necessary to study the essential parameters owned by the antenna itself and characterise its performance. The following subsections study these parameters.

2.4.1 Radiation Pattern

The antenna radiation pattern is a graphical illustration of how electromagnetic waves are radiated from an antenna in free space. It interprets the directional features of the antenna and provides important information about the antenna's performance. The radiation pattern can be viewed as a 3D plot or as a 2D pattern projected onto a plane. The radiation pattern of the antenna could be influenced by a variety of factors, including the antenna's physical design, operating frequency, and the surrounding environment. The shape of the radiation pattern can be broadly classified into three types: omnidirectional, directional, and multi-directional. An omnidirectional radiation pattern is circular, with radiation emitted in all directions, while a directional radiation pattern has a main lobe in one direction with lower radiation in other directions. Multi-directional radiation pattern shows a combination of these two types, with multiple lobes radiating in different directions. In conclusion, understanding the antenna radiation pattern is crucial for selecting the appropriate antenna for a specific application and designing the antenna system to optimize the overall performance. Figure 2.2 shows the organization of the universal radiation pattern for a the antennas [28].

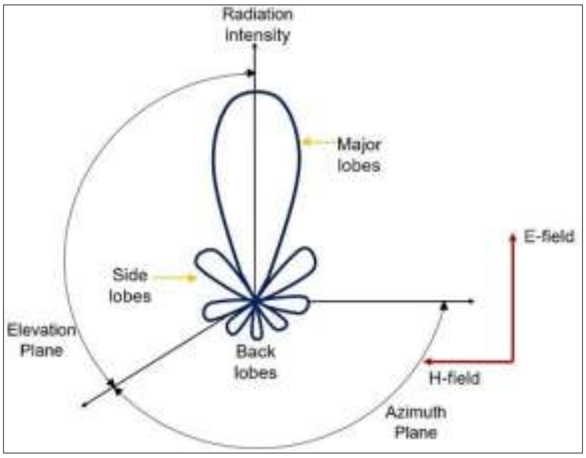


Figure 2.2: Arrangement of Radiation Pattern for Universal Antenna Type.

2.4.2 Directivity of Antenna

Antenna directivity refers to the potency of the antenna to focus the transmitted or received electromagnetic waves in a specific direction. Directivity is an important characteristic of antennas, as it determines the efficiency of the antenna in transmitting or receiving signals in a individual direction. Antennas with high directivity are better suited for long-distance communications, as they can transmit or receive signals over longer distances with minimal signal loss. The directivity of the antenna is specified by the shape and size of the antenna, as well as the frequency of the signal being transferred or drawn. The directivity of an antenna is regularly measured in decibels (dB) or in terms of its gain, that is interpreted as the ratio of the radiation intensity in a fixed direction to that of a reference antenna. Antennas with higher gain have higher directivity and are more suitable for long-range communication applications. In conclusion, antenna directivity is a critical parameter in determining the rendering of an antenna system, and it is essential to consider this characteristic when selecting an antenna for a specific application. In the mathematic expression the directivity equation can be write as follows [29]:

$$D = \frac{U}{Uo} = \frac{4\pi \mathrm{U}}{P_r} \tag{2.1}$$

Where:

D: is indicating for the antenna directivity;

U: is indicating for the antenna radiation intensity; and

P_r: is indicating for the total radiated power from the terminals of antenna.

2.4.3 Gain of Antenna

Antenna gain is a fundamental concept in the aspect of antenna investigation and engineering. It is interpreted as the proportion for the antenna radiation intensity in a particular way to the radiation intensity that would be generated by a presumptive isotropic antenna radiating the same total power. This means that antenna gain represents the degree to which an antenna is eligible to direct its radiated energy in a specific direction, rather than radiating energy uniformly in all directions. Antenna gain is typically measured in decibels (dB) or popularly in (dBi) referring to the isotropic antenna, with respect to a reference antenna, such as an isotropic radiator or the dipole antenna. A high-gain antenna will radiate more energy in a specific direction, which can be useful in applications where signal strength and range are important. Antenna gain is a critical parameter that determines the performance of an antenna system, and it is important to choose an antenna with the appropriate gain for a given application in order to acquire optimal performance. There is a relation between the antenna gain and directivity linked together by the efficiency. In order to express the antenna gain in a parametric form the following equation can be applied [30]:

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

Where:

G: Is indicated to the gain of an antenna; and

e: Is indicated to the total efficiency of an antenna.

2.4.4 Return Loss of Antenna

Antenna return loss or S_{11} is an important parameter that is utilise to measure the effectiveness of an antenna in transmitting and receiving signals. It is realized as the proportion of the power that is transmitted by the antenna to the power that is reflected back due to impedance mismatch between the antenna and the transmission line. In other words, return loss is a specified of how much power is lost due to reflection at the antenna interface. Return loss is typically measured in decibels (dB), and a lower return loss value refers to a higher degree of impedance match amidst the antenna and the feeding line. Antenna return loss is a significant parameter to theorize when designing or selecting an antenna for a particular application. A high return loss indicates that the antenna is efficiently transferring power to the transmission line, which results in a more reliable and effective communication link. The antenna return loss can be improved by adjusting the impedance matching among the antenna and the feed line [31].

2.4.5 Equivalent Circuit of Antenna

An antenna equivalent circuit is a theoretical circuit that represents the electrical behaviour of an antenna in terms of its various components. It is a simplified model of the antenna that can be used to analyse and design the antenna for a specific application. The equivalent circuit consists of various components such as resistors, capacitors, and inductors that represent the antenna's radiating element, feedline, and impedance-matching network. The equivalent circuit helps in understanding the impedance characteristics of the antenna, which is crucial for optimizing its performance. By analysing the equivalent circuit, it is possible to calculate the impedance of the antenna at a specific frequency and match it to the transmission line, which results in more efficient power transfer and better performance. The antenna equivalent circuit is an important tool in the design and analysis of antennas, and it allows engineers to optimize the performance of the antenna for a particular application. In general, the antenna consists of a couple of portions, the first portion is the resistive while the second portion is the reactive portion. The resistive portion is divided into the radiated resistance R_r which really radiates the power and the latter is the R_L which is the loss resistance that is related with the loss of the metal and dielectric as well. Figure 2.3 illustrates the valent circuit for the generic antenna [32].

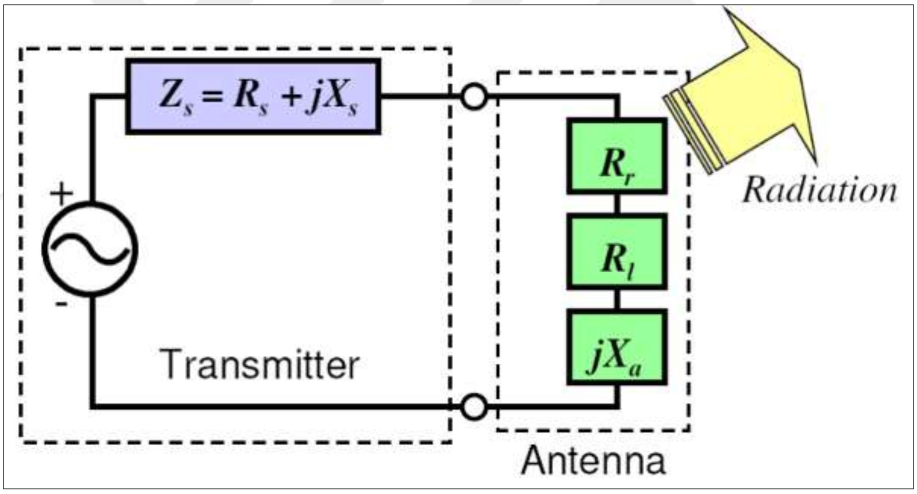


Figure 2.3: Representation for Antenna Valent Circuit.

The concept of portion impedance imaginary can serve as a means to simulate the energy storage that takes place within the antenna's near-field area. This parameter reveals the amount of power reflection, voltage and current phase shift. Achieving perfect impedance matching in antennas is challenging from a practical perspective, since impedance must remain constant throughout the frequency range. Hence, it is typical to opt for a standard input impedance of 50 ohms during antenna design.

2.4.6 Efficiency of Antenna

Antenna efficiency refers to the ratio of the aggregate of power that radiated by an antenna to the aggregate of whole power supplied to it. In other words, it represents how effectively an antenna converts the input power into radiated power. A perfectly efficient antenna would have an efficiency of 100%, meaning all of the input power is converted into radiated power. However, in reality, no antenna is perfectly efficient, and losses due to factors such as resistance, radiation pattern, and impedance matching can reduce its efficiency. Antenna efficiency is a critical parameter in the design of wireless communication systems, as it directly affects the range and quality of the signal transmitted and received. Therefore, it is essential to maximize antenna efficiency through careful design and optimization to achieve optimal system performance. In the term of mathematic expression, the following equation can be applied [33]:

$$e_a = \frac{P_r}{P_i} \tag{2.3}$$

$$e_a = \frac{R_r}{R_L + R_r} \times 100\% \tag{2.4}$$

Where:

P_r: is indicating for the antenna radiated power;

P_i: is indicating for the input power to the input terminals of antenna;

e_a: is indicating for the antenna efficiency;

R_r: is indicating for the radiation resistance; and

R_L: is indicating for the losses resistance;

As shown in the prior equation above, reducing the losses related with the antenna can enhance its efficiency. In an ideal scenario, an antenna with 100% efficiency would transmit all of the power delivered to it. However, in practice, an antenna can only radiate around 50-60% of the supplied power, making it impossible to achieve perfect efficiency.

2.5 MICROSTRIP ANTENNAS (MSAS)

The MSAs are a kind of the flat-panel antenna that is widely used in wireless communication systems due to their compact size, low profile, and ease of integration with printed circuit boards. They are also known as patch antennas and consist of a metal patch placed above a ground plane, with a dielectric substrate in between. The patch and the ground plane are usually made of copper, while the substrate can be made of various materials, such as fibreglass, Teflon, or ceramic. The patch is usually fed by a microstrip transmission line, which is also printed on the substrate. The history of microstrip antennas dates back to the 1950s, when researchers first began to explore the use of printed circuit technology for microwave circuits. However, it was not until the 1970s that the first microstrip antennas were developed. In 1972, Robert E. Munson and his colleagues at the Ohio State University published a paper titled "Microstrip Antennas," which described a novel design for a flat-panel antenna that used a rectangular patch on a ground plane. The antenna had a bandwidth of 2%, and was used for military applications, such as satellite communication and radar systems. Today, microstrip antennas continue to be an active area of research, with numerous advancements being made in their design, performance, and applications. Some of the recent trends in microstrip antenna research include the use of novel materials, such as graphene and metamaterials, for enhancing the antenna performance, and the development of multi-band and wideband designs for supporting multiple wireless standards. Figure 2.4 illustrate the universal architecture for the MSAs [34].

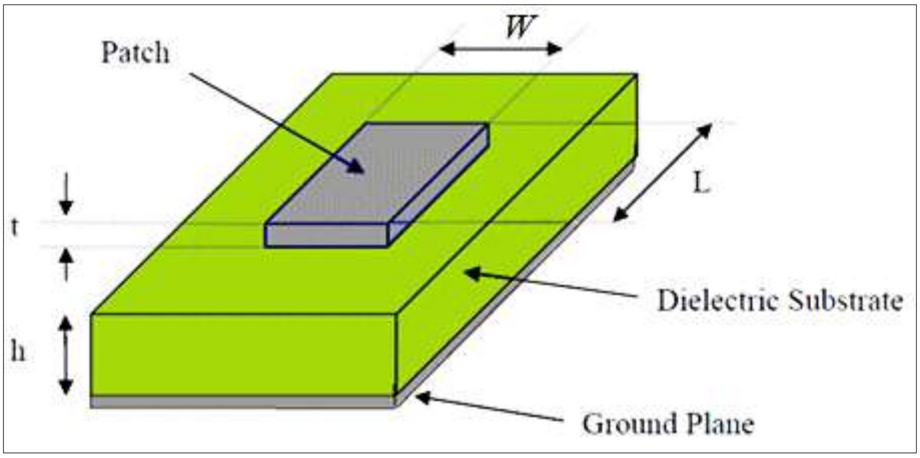


Figure 2.4: Generic Framework for MSA.

The shape of the patch is a significant factor that affects the rendering of microstrip antennas. There are several different shapes that can be used for the patch, each with its own advantages and disadvantages. The extreme popular shapes are rectangular, circular, and triangular patches. The popular shapes for the patch of the antenna can be listed as follows [35]:

a) Rectangular patches are the simplest and most widely used shape for microstrip antennas. They are easy to fabricate, have a wide bandwidth, and can be easily tuned by calibrating the size and position of the patch. However, they have some drawbacks, such as poor radiation patterns and high cross-polarization levels.

b) Circular patches are another popular shape for microstrip antennas. They offer improved radiation patterns and lower cross-polarization levels compared to rectangular patches. However, they are more difficult to fabricate and tune and have a narrower bandwidth.

c) Triangular patches are less common than rectangular and circular patches but can offer some advantages in certain applications. They have better radiation patterns than rectangular patches and can be used to create dual-band or wideband antennas. However, they are also more difficult to fabricate and tune and have a narrower bandwidth than rectangular patches.

In addition to these basic shapes, there are also numerous variations and hybrid designs that can be used for microstrip antennas, as shown in Figure 2.5. For example, fractal-shaped patches can be used to create antennas with improved performance and reduced size. Multiple patches can also be combined to create array antennas, which can offer higher gain and directivity than single-patch antennas. The choice of patch shape ultimately depends on the specific requirements and constraints of the application, and careful design and optimization are necessary to achieve optimal performance [36].

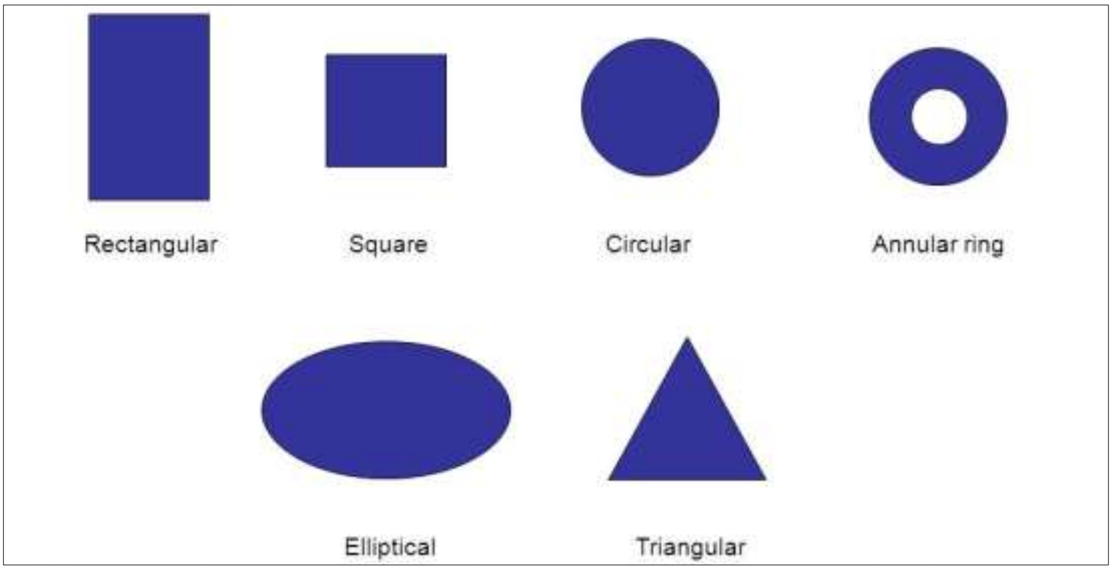


Figure 2.5: Possible Utilized Shapes for Antenna Patch.

2.5.1 Applications of MSAs

The MSAs have a wide range of implementations in various fields of wireless communication and sensing systems due to their compact size, low profile, and ease of integration with other electronic components. Microstrip antennas are used in a wide variety of applications, the most popular of which are as follows: [37], [38]:

a) Mobile devices: Microstrip antennas are widely used in mobile phones, tablets, and other portable devices for wireless communication, such as Wi-Fi, Bluetooth, and GPS. Due to their small size and low power consumption, they are ideal for these applications.

b) Wireless LANs: Microstrip antennas are used in WLAN for indoor and outdoor communication. They offer high gain and directivity, which improves the signal quality and coverage.

c) Satellite communication: Microstrip antennas are used in satellite communication systems for uplink and downlink transmission. They offer high gain and low profile, which makes them ideal for space applications.

d) Radar systems: Microstrip antennas are used in radar systems for target detection and tracking. They offer high gain and directivity, which improves the resolution and accuracy of the radar.

e) RFID systems: Microstrip antennas are used in RFID systems for wireless identification and tracking of objects. They offer high sensitivity and low power consumption, which makes them ideal for these applications.

f) Biomedical applications: MSAs are used in biomedical sensing systems for non-invasive monitoring of physiological parameters, such as heart rate, respiration, and blood glucose level. They offer high sensitivity and low interference, which makes them ideal for these applications. Finally, the MSAs utilises in a wide aspect of implementations in various fields of wireless communication and sensing systems. Their small size, compact profile, and easiness of integration make them ideal for these implementations, and ongoing research is focused on improving their performance and expanding their range of applications.

2.5.2 Types of MSAs

There are several types of MSAs that are popularly used in wireless communication and sensing systems. Some of the extremely used types are listed as following [39], [40]:

a) Rectangular microstrip antenna: The rectangular microstrip antenna is the most basic and widely used type of MSA. It comprises of a rectangular patch on a ground plane, with a feed point located at one end of the patch. This kind of antenna is simple to fabricate and offers a wide bandwidth.

b) Circular microstrip antenna: The circular MSA is similar to the rectangular MSA, but with a circular patch instead of a rectangular one. This type of antenna offers better radiation patterns and lower cross-polarization levels than rectangular microstrip antennas, but has a narrower bandwidth.

c) Patch array antenna: The patch array antenna consists of multiple microstrip antennas arranged in a grid or linear array. This type of antenna offers higher gain and directivity than single microstrip antennas, and is often used in radar and communication systems.

d) Dual-polarized microstrip antenna: The dual-polarized microstrip antenna consists of two microstrip antennas oriented at right angles to each other, with separate feed points for each polarization. This type of antenna is used in applications where both horizontal and vertical polarization are required, such as satellite communication.

e) Monopole microstrip antenna: is a kind of antenna that is comprises of a single patch on a ground plane, with a feed point located at one end of the patch. This species of antenna offers several advantages opposed the other species of the known antennas, containing the low profile, the ease of embedding with the other electronic elements, and high radiation efficiency. Monopole microstrip antennas are commonly used in wireless communication and sensing applications, such as in mobile phones, satellite communication, and radar systems.

f) Printed dipole antenna: The printed dipole antenna consists of two conductive strips printed on a dielectric substrate, with a feed point located between the strips. This type of antenna offers good bandwidth and radiation patterns, and is often used in mobile communication and RFID systems.

g) Fractal MSA: The fractal MSA is a shape of the popular antennas that are uses a fractal geometry for the patch design. This type of antenna offers improved performance and reduced size compared to traditional microstrip antennas, and is often used in compact wireless communication devices.

In the summary, there are several types of microstrip antennas that are regularly used in wireless communication and sensing systems, each with its own advantages and disadvantages. The cucumber of antenna type counts on the specific requirements and constraints of the application, and careful design and optimization are necessary to achieve optimal performance.

2.5.3 Monopole MSA

A monopole MSA is a species of the antenna that involves of a single patch on a ground plane, with a feed point located at one end of the patch. The patch is usually in the shape of a strip or a rectangular and is mounted above the ground plane by a dielectric substrate. Monopole MSAs offer several advantages as compared with the other sorts of the antennas, including low profile, ease of the incorporation with the other electronic pieces, and high radiation efficiency. One of the main advantages of monopole microstrip antennas is their low profile. The antenna can be designed to be very thin, which makes it ideal for applications where space is limited, such as mobile phones and other portable devices. The low profile also reduces the amount of interference with other electronic components in the device, which can improve the overall performance. Another advantage of monopole microstrip antennas is their ease of integration with other electronic components. The antenna can be fabricated on the same substrate as other electronic components, which simplifies the manufacturing process and reduces the overall cost. In addition, the antenna can be designed to operate at a specific frequency or frequency range, which makes it ideal for wireless communication and sensing applications. Monopole MSAs also offer high radiation efficiency, which means that a large percentage of the input power is radiated as electromagnetic waves. This is due to the fact that the antenna is mounted above a ground plane, which acts as a reflector and enhances the radiation efficiency. This makes monopole microstrip antennas ideal for applications where high gain and directivity are required, such as in satellite communication and radar systems. In summary for this section, monopole MSAs offer several advantages over other types of antennas, involves the compact profile, easiness of embedding with the other available electronic elements, and finally the high radiation efficiency after applying the optimisation approaches. These advantages make them ideal for a broad range of the wireless communication and sensing employments, and ongoing research is focused on improving their performance and expanding their range of applications. Figure 2.6 presents the generic configuration for the monopole MSA [41].

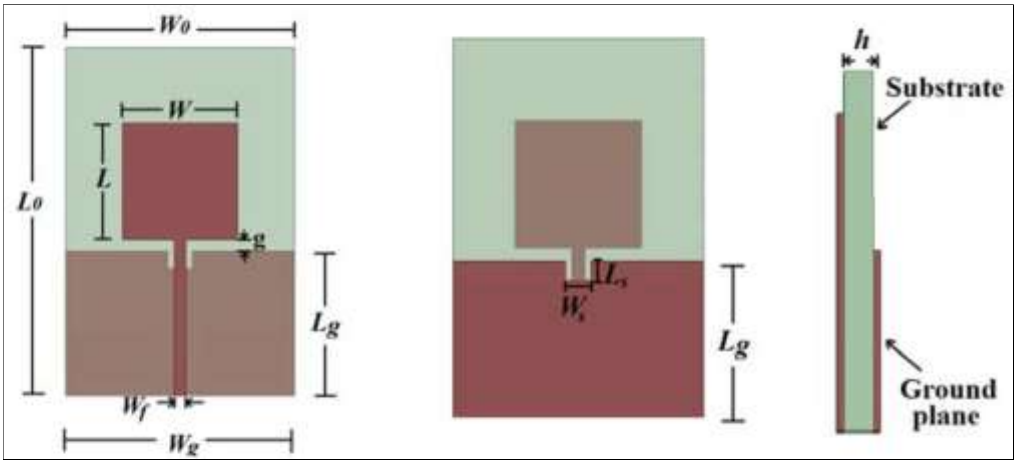


Figure 2.6: Configuration for Monopole MSA.

2.6 MSA ADVANTAGES AND DISADVANTAGES

The MSAs have several concessions over other sorts of antennas. One significant advantage is their low profile and compact size, which makes them suitable for use in space-limited applications. They are also relatively easy to fabricate using printed circuit board (PCB) technology, making them cost-effective and allowing for easy integration into electronic systems. Another advantage of MSAs is their ability to provide high gain, directivity, and radiation efficiency, which makes them highly effective in wireless communication systems. They also exhibit excellent impedance matching, which ensures that the antenna can efficiently transfer energy to and from the transmitter or receiver, resulting in improved overall system performance. The MSAs can be designed to function across a broad range of the available frequencies, making them highly versatile and suitable for a wide range of the implementations, including mobile communication, satellite communication, and military communication systems. Like any technology, MSAs have some disadvantages that should be considered when deciding on their use. One significant disadvantage is their relatively low power-handling capacity, which limits their ability to handle high power levels. This means that they may not be fit for the high-power implementations such as radar systems or long-range communication systems. Another potential issue with MSAs is their sensitivity to nearby objects and structures. Since they are a surface-mounted technology, they can be affected by nearby conductive materials, which can alter their performance or cause interference. Additionally, MSAs have a relatively narrow bandwidth compared to other types of antennas, which can limit their ability to operate over a wide frequency range. This means that they may not be suitable for applications that require a broad frequency response. Finally, while MSAs are relatively easy to fabricate, their performance can be highly dependent on the quality of the fabrication process. Small variations in the manufacturing process can significantly affect their performance, which can make them challenging to optimize for specific applications [42].

2.7 MSA FEEDING

In order to feeding the MSA with the electric power from the source there are several methods can be utilised which are the conducting and non-conducting methods, the definition of each method is summarised in the following points.

2.7.1 MSA Line Feeding

The MSAs can be fed in several ways, including the Microstrip Line Feeding (MSLF) method. In this method, the antenna is fed by a transmission line that is linked with the antenna's radiating element. The microstrip line is a sort of the transmission lines that are used to transport signals in high-frequency circuits. It comprises of a conductive strip that is segregated from the ground plane by a dielectric substrate. The strip acts as the signal conductor, while the ground plane acts as a reference plane. The MSLF method is popular because it is relatively easy to implement and can provide good impedance matching. It also allows for the use of PCB technology, which is a cost-effective way to produce antennas. One of the extremely significant benefits of the MSLF approach is that it provides a straightforward way to match the antenna's impedance to the transmission line's impedance. This helps to reduce signal reflection and improve overall system performance. Additionally, the utilise of the microstrip line can help to minimise the size and weight of the antenna, making it proper for the utilisation for the applications where space and weight are critical factors. The MSLF method is a popular and effective way to feed microstrip antennas, and it has been widely adopted in the several of the wireless communication systems; Figure 2.7 present the structure of MSLF [43].

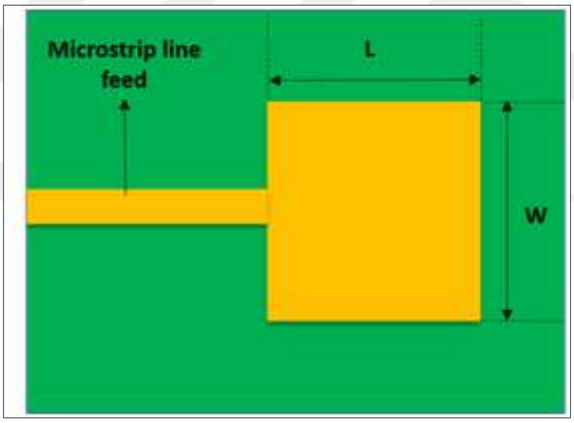


Figure 2.7: Structure for MSLF.

2.7.2 Coax Feeding

Another popular feeding method for microstrip antennas is the Coaxial Feeding (CF) method. In this method, the antenna is fed utilising a coax cable that is connected to the radiating element. A coaxial cable is a sort of transmission line that comprises of a central conductor encompassed by a dielectric plastic, which is in turn surrounded by an outer conductor. The outer conductor serves as the ground reference, while the central conductor carries the signal. The CF method is widely used in high-frequency applications because it provides excellent shielding and low signal loss. One of the important advantages of the CF method is that it can handle high power levels, making it suitable for use in applications that require high output power. It also provides good impedance matching, which helps to minimize signal reflection and improve overall system performance. Additionally, the use of a coaxial cable allows for elasticity in the placement of the antenna and the location of the transmitter or receiver. However, the CF method can be more challenging to implement than the microstrip line feeding method, as it requires careful attention to the geometry of the feed point and the matching network. Overall, the CF method is an effective way to feed microstrip antennas and is commonly used in various wireless communication systems, including satellite communication and radar systems; Figure 2.8 structure for CF method [43], [44].

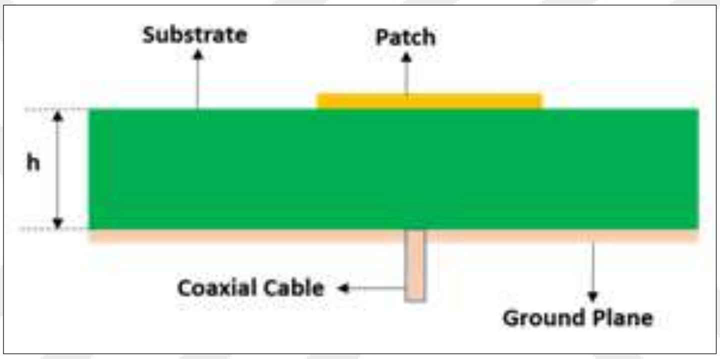


Figure 2.8: Structure for CF Method.

2.7.3 Proximity Coupled

The proximity-coupled feeding (PCF) method is another popular technique for feeding microstrip antennas. In this method, the antenna is supplied by a microstrip transmission line that is located parallel and close to the radiating element. The connection among the microstrip line and the antenna is achieved through the electric field, and the proximity of the line to the radiating element ensures efficient energy transfer. The PCF method provides excellent impedance matching and can produce high radiation efficiency. It also has the advantage of reducing radiation losses, which can improve the gain and the directivity for the antenna. The method can be used to produce broad bandwidths and is suitable for applications that require multi-frequency operation. One of the important benefits of the PCF method is that it can be easily adapted to produce circularly polarized radiation. Additionally, it allows for greater flexibility in the placement of the antenna and can be used to produce arrays of antennas that are closely spaced. However, the PCF method can be more challenging to implement than other feeding methods, as it requires careful attention to the geometry of the transmission line and the radiating element. Overall, the PCF method is an effective way to feed microstrip antennas and is broadly utilise in the variety of the wireless communication systems, including the requirements of the mobile communication and satellite communication. Figure 2.9 presents the structure for the PCF [43], [44].

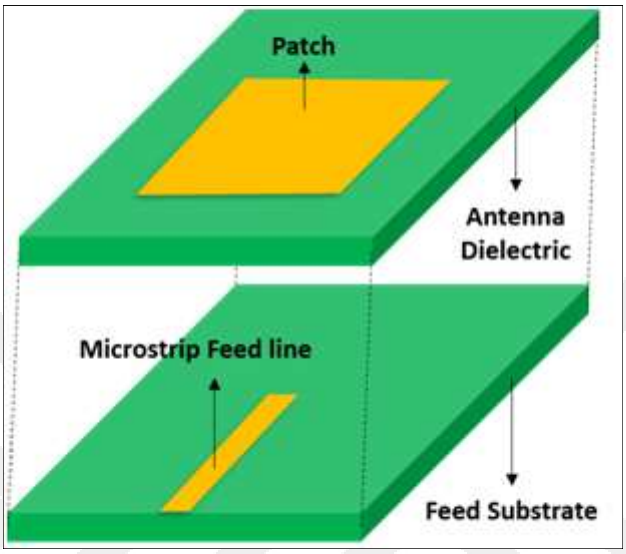


Figure 2.9: The Structure for PCF Method.

2.7.4 Aperture Coupled

The aperture-coupled feeding (ACF) method is another popular technique for feeding microstrip antennas. In this method, the antenna is fed by a microstrip transmission line that is located underneath a patch aperture, which is placed over the radiating element. The connection between the microstrip line and the antenna is achieved through the electromagnetic field that passes through the aperture. The ACF method provides excellent impedance matching and can produce high radiation efficiency. It also has the advantage of reducing radiation losses, which can improve the directivity and the gain for. The method can be used to produce broad bandwidths and is suitable for applications that require multi-frequency operation. One of the significant advantages of the ACF method is that it can produce circularly polarized radiation with ease. Additionally, it allows for greater pliability in the placement for the antenna, as the microstrip line can be located away from the radiating element. However, the ACF method can be more challenging to implement than other feeding methods, as it requires careful attention to the design of the aperture and the matching network. Overall, the ACF method is an effective way to feed microstrip antennas and is regularly employs in the multiple of the wireless communication systems, including satellite communication and radar systems; Figure 2.10 present the structure for the ACF method [43], [44].

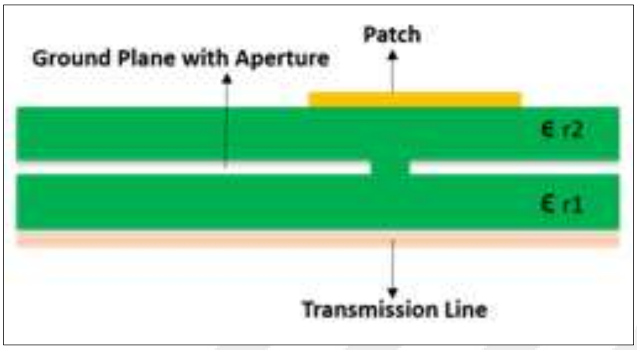


Figure 2.10: The Structure for the ACF.

2.8 ANALYSIS OF MSA

The analysis of MSA is essential in understanding their performance and optimizing their design. One common method for analysing microstrip antennas is the finite element method (FEM), which uses numerical techniques to solve the electromagnetic field equations that govern the behaviour of the antenna. The FEM can strictly surmise the resonant frequency, radiation pattern, and impedance characteristics of the antenna. Another popular method is the method of moments (MoM), which uses the integral equations to solve for the current appropriation over the antenna and the resulting electromagnetic field. The MoM is well-suited for analysing large and complex structures, and it can be used to model antennas in the presence of other objects or structures. Additionally, the transmission line model (TLM) can be used to analyse microstrip antennas, which involves modelling the antenna as a series of interconnected transmission line segments. The TLM can predict the resonant frequency and the radiation pattern of the antenna and can also be used to optimize its design. Overall, the analysis of the MSAs is crucial in their design and optimization for various wireless communication applications, and different analysis methods can be employed depending on the complexity of the antenna and the desired level of accuracy [44].

2.8.1 Transmission Line Analysis Method

Despite the fact that its reliability can considered somewhat smaller than that of existing types, the transmission line approach is the extreme significant, widely used, and common method. This model is the simplest to grasp, but it also has the lowest level of precision and adaptability. The MSA is represented as a rectangular patch with two elongated notches (apertures) separated by an arc of length L and with width w and height h dimensions, respectively. The length of L of the arc separating the notches corresponds to the length of the MSA. The MSA is represented in the transmission line model as two apertures of different widths, separated by a low-impedance Zc line of length L. The input performance of a rectangular patch antenna can be determined using this method. The rectangular MSA is the primary user of this model, as opposed to the other patch configurations. In this model, the MSA is depicted by a transmission line of length L, at its centre which is a pair of apertures, each of which has a width of (w) and a height of (h) as mentioned previously. The MSA is depicted in Figure 2.11 for the transmission line model.

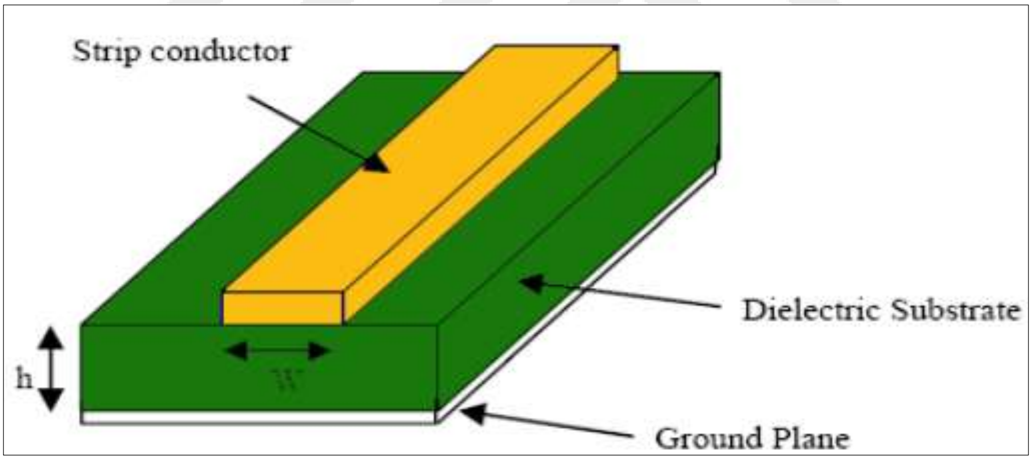


Figure 2.11: MSA in the Transmission Line Technique.

The MSA can be viewed as a non-uniform transmission line composed of two different dielectric materials. Typically, one dielectric material is the substrate, while the other is air. Hence, the effective value for permittivity should be determined utilising the interpreted equation below [45]:

$$\varepsilon_{re} = 0.5(\varepsilon_r + 1) + 0.5(\varepsilon_r - 1)\left[1 + \frac{12h}{W}\right]^{-0.5} \quad (2.5)$$

Where:

ε_{re}: is describing the substrate effective constant; and

ε_r: is indicating for the substrate relative permittivity.

When the radiant patch of the antenna is excited by an electric current, it generates fringing that enlarges the effective dimensions of the antenna beyond its physical size. Therefore, this increased length can be represented mathematically in the following manner [46]:

$$\Delta L = 0.412h \frac{(\varepsilon_{re} + 0.3)\left[\frac{W}{h} + 0.264\right]}{(\varepsilon_{re} - 0.258)\left[\frac{W}{h} + 0.8\right]} \tag{2.6}$$

Where:

ΔL: is indicating for the length extension.

Then the factual MSA patch length can be represented in a mathematical manner by utilising the following relations [46]:

$$L_{e=} \frac{C}{2f_o\sqrt{\varepsilon_{re}}} \tag{2.7}$$

$$L_p = L_e - 2\Delta L \tag{2.8}$$

Where:

L_e: is indicating for the patch length effective;

C: is indicating to light-speed in free space;

L_p: is indicating to the principal MSA patch length; and

f_o: is indicating to the frequency of operation or resonant frequency.

For the purpose of the calculating of the MSA patch width the following mathematical relation can be utilise [45]:

$$W_p = \frac{C}{2f_r\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \tag{2.9}$$

In order to supply the MSA with electric power via the feeding strip line it is necessary to calculate the dimensions for this strip line, the following equation can be applied to construct the width for the strip line [45], [46]:

$$\begin{aligned} W_{ST} = \frac{2h}{\pi}\Bigg\{ &(\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}) - 1 - \ln\left(2(\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}) - 1\right) \\ &+ \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln\left((\frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}) - 1\right) + 0.39 - \left(\frac{0.61}{\varepsilon_r}\right)\right]\Bigg\} \end{aligned} \tag{2.10}$$

Where:

W_{ST}: is describing the width for strip line; and

Z_0: is describing the strip line impedance.

2.8.2 Cavity Analysis Method

The transmission line modelling explained in the previous section is user-friendly but has several drawbacks. It is suitable for rectangular patch designs, as it does not consider the field variation in the radiating walls. To address these limitations, the cavity model can be applied. In this model, the dielectric substrate's internal part is treated as a cavity surrounded by electric walls on the top and bottom. This approach is supported by the thin substrate condition ($h \ll \lambda$) as depicted in Figure 2.19. When an electric field is subjected to the MSA, the allocation of the charge appears on its upstairs and downstairs surface, as well as on the under-most of the antenna ground plane. Two mechanisms controlling the charge spreading: which are an attractive and a repulsive. The ground plane and the opposite charges on bottom portion of the patch create an attractive that maintains the charge concentration at the patch's bottom. The repulsive is happen amidst the similar charges at the bottom surface of the patch, which results in confirmed charges being compress up from the under most toward the upmost. This movement of charges generates currents flowing at the upmost and the under most surfaces of the MSA patch [44]-[46].

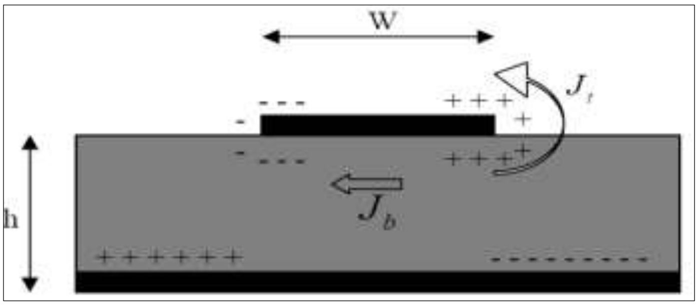


Figure 2.12: Charge Distribution on the MSA Surface.

2.8.3 Full-wave Analysis Method

The Method of Moments is a technique that offers a full-wave analysis of the MSA. It leverages surface currents to modelling the MSA and the extent of the polarisation currents to simulating the dielectric sheet fields. By employing the integral equations for the unknown currents and the MoM, these electric field integral equations are transformed into the matrix equations. These matrix equations can be determined by applying of the different known algebraic approaches to obtain the solution [45], [46].

2.9 UWB ANTENNAS

The UWB antennas are a sort of the antennas that can operate over a broad frequency range, regularly ranging from a few hundred megahertz to several gigahertz. This allows them to transmit and receive signals from a variety of wireless devices. These antennas have the ability to send and receive signals at high data rates over relatively short distances. The design of UWB antennas is extremely important if one wishes for them to be able to function effectively across a broad spectrum of frequencies. Monopole antennas, dipole antennas, and printed antennas are the most common varieties of UWB antennas. Monopole antennas are common because of their straightforward construction and straightforward integration, whereas dipole antennas are utilized due to the wideband and omnidirectional radiation patterns that they offer. The low-profile design and cost-effectiveness of printed antennas make them a popular choice for many applications. UWB antennas have a variety of uses, including in radar and imaging system applications, as well as in the realm of wireless communication. Research is still being conducted in this area to find ways to improve both the design and performance of UWB antennas. The functionality of UWB antennas is essential to the success of the applications being discussed here [47]; Figure 2.13 illustrates some of the available antennas for the UWB technology.

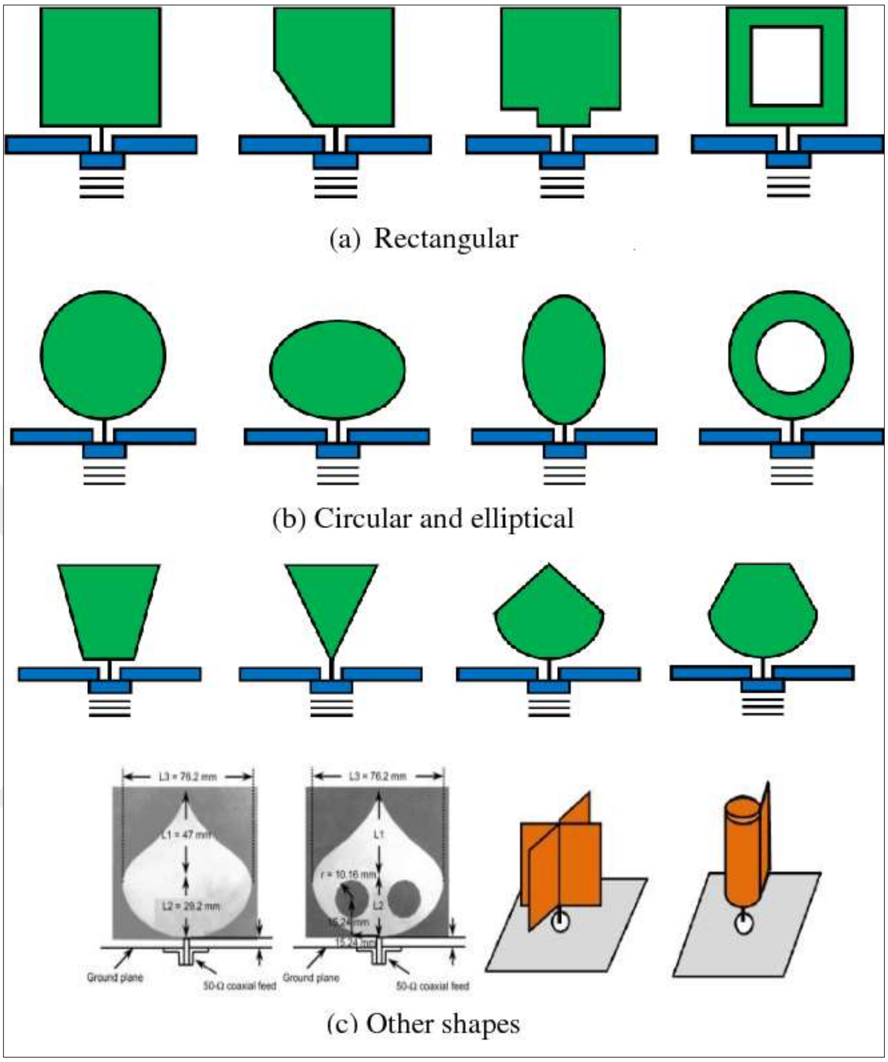


Figure 2.13: Popular of UWB Antennas.

2.10 GRAPHENE MATERIAL

Graphene is a 2D material composed of carbon atoms organised in a honeycomb lattice, as illustrated in Figure 2.14. It is considered a unique material due to its exceptional electrical, mechanical, and thermal properties. The electrical conductivity of graphene is superior to that of most materials, making it highly proper for utilise in electronic devices. Additionally, it has high carrier mobility, allowing for fast electron transport. The mechanical properties of graphene are also noteworthy, as it is one of the strongest materials known. Graphene's thermal properties are equally impressive, with high thermal conductivity and the ability to dissipate heat effectively. Furthermore, graphene is a highly flexible and transparent material, making it an attractive option for use in flexible electronics, touch screens, and solar cells. The use of graphene has extended beyond electronics, with potential applications in areas such as biomedicine, water filtration, and energy storage. However, there are still challenges to be addressed in the large-scale production and integration of graphene into various applications. Despite these challenges, the potential benefits of graphene make it a highly promising material with numerous possibilities for future research and development [48].

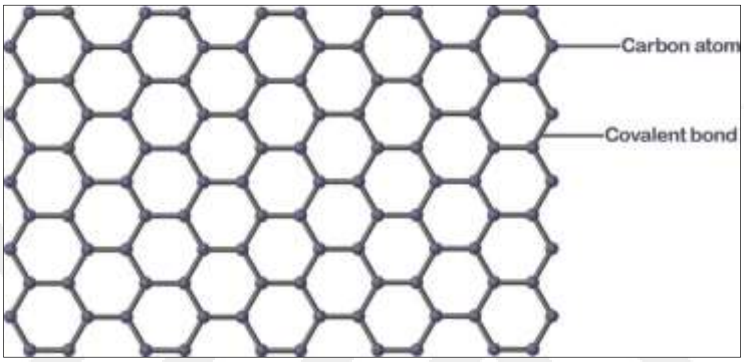


Figure 2.14: Organisation of Graphene Material.

2.10.1 Graphene Material Properties

Graphene is a 2D allotrope of carbon with a remarkable property that make it a charming material for the broad range of the various applications. Some of the most notable properties of graphene are [48], [49]:

2.10.1.1 High strength

Graphene is incredibly strong, with a tensile strength of up to 130 (GPa). This strength is due to the strong covalent bonds between carbon atoms in the material.

2.10.1.2 High electrical conductivity

Graphene is a perfect conductor for electricity, with an electrical conductivity of up to 200,000 S/cm. This high conductivity is due to the fact that electrons can move through graphene with very little resistance.

2.10.1.3 High thermal conductivity

Graphene is also a perfect conductor of heat, with a thermal conductivity of up to 5,000 W/mK. This high thermal conductivity is due to the fact that phonons (heat-carrying particles) can move through graphene with very little resistance.

2.10.1.4 Large surface area

Graphene has a large surface area per unit mass, which makes it an attractive material for use in energy storage applications. Its surface area can reach up to 2,630 square meters per gram.

2.10.1.5 Flexibility

Graphene is flexible and can be bent, twisted, and rolled without breaking. This property makes it ideal for use in flexible electronics and other applications where flexibility is important.

2.10.1.6 Transparency

Graphene is transparent, allowing light to pass through it. This property makes it an attractive material for use in transparent electrodes in displays, solar cells, and other applications.

2.10.1.7 Barrier properties

Graphene is an excellent barrier material, preventing the passage of gases and liquids. This property makes it useful for applications such as water filtration and gas separation.

2.10.1.8 Biocompatibility

Graphene is biocompatible, meaning that it does not elicit a negative response from the body's immune system. This property makes it attractive for use in biomedical applications.

Overall, the unparalleled features of graphene making it a highly sought-after material with significant potential for revolutionizing many industries. However, its widespread adoption is still limited by the high cost of production and challenges associated with large-scale manufacturing.

2.10.2 Graphene Material Applications

As defined previously the Graphene is a two-dimensional allotrope of carbon with remarkable properties that make it an appealing material for a broad range of the applications. Some of the most notable applications of graphene are [49]:

a) Electronics: for the electronics the Graphene is an excellent conductor for the electricity, and its high electron mobility makes it a promising material for use in electronic devices. It can be used in transistors, integrated circuits, touchscreens, and resilient displays.

b) Energy storage: Graphene's large surface area and high electrical conductivity make it an emerging material for the energy storage applications. It can be used in supercapacitors and batteries to enhancing their energy density and charging times.

c) Composites: Graphene can be used as a reinforcing agent in composites to improve their mechanical properties. It can be added to polymers, metals, and ceramics to make them stronger, lighter, and more durable.

d) Sensors: Graphene's sensitivity to changes in its environment makes it a useful material for sensors. It can be used in gas sensors, biosensors, and pressure sensors.

e) Biomedical applications: Graphene's biocompatibility and ability to interact with biological molecules make it a promising material for use in biomedical applications. It can be used in drug delivery, tissue engineering, and biosensors.

f) Water filtration: Graphene oxide membranes can be used to filter water and remove impurities. They are highly efficient and can filter out a wide range of contaminants.

g) Aerospace: Graphene's lightweight and high strength make it a promising material for use in aerospace applications. It can be used to make stronger and lighter aircraft components.

h) Coatings: Graphene can be used in coatings to improve their durability and resistance to wear and tear. It can be added to paints, varnishes, and coatings for a wide range of applications.

Finally, graphene has the potential to revolutionize many industries, and its unique properties make it a highly sought-after material. However, its widespread adoption is still limited by the high cost of production and challenges associated with large-scale manufacturing. Figure 2.15 illustrates some of the graphene material applications in different aspects.

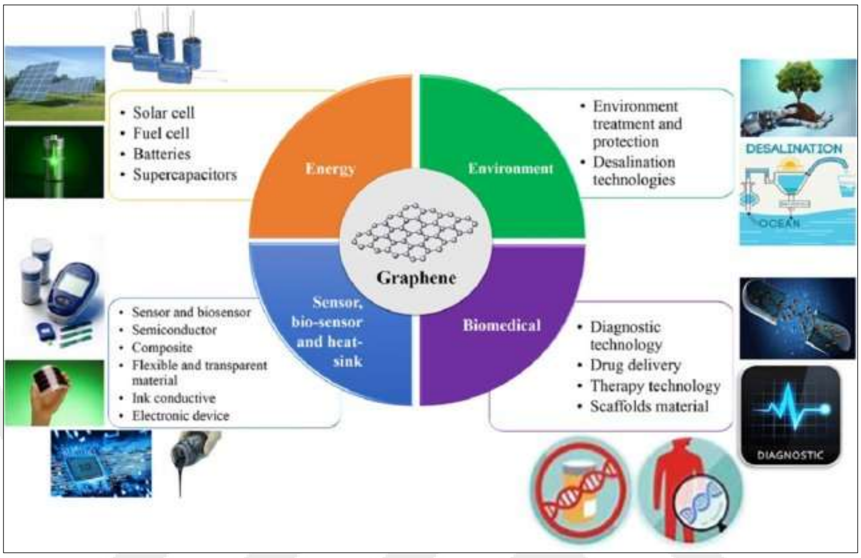


Figure 2.15: Applications of Graphene in Industry.

2.10.3 Graphene Material Types

The organization of the Graphene is a 2D allotrope of carbon, but there are different types of graphene that can be produced with varying of the properties. Here are some of the types of graphene [50]:

a) Monolayer graphene: This is a single sheet of graphene atoms arranged in a hexagonal lattice. It has the highest electrical and thermal conductivity of any material known.

b) Multilayer graphene: This is several sheets of graphene banked on the top of each other. It has different properties than monolayer graphene, such as lower electrical conductivity and a wider bandgap.

c) Graphene oxide: This is graphene that has been chemically modified with oxygen-containing groups. It has lower electrical conductivity than pure graphene but is more hydrophilic, making it useful for applications such as water filtration.

d) Reduced graphene oxide: This is graphene oxide that has been treated to remove some of the oxygen-containing groups. It has properties similar to pure graphene but may have some residual oxygen-containing groups.

e) Graphene nanoribbons: These are narrow flakes of graphene with a widths less than 10 nanometres. They have unique electronic properties due to their size and shape.

f) Graphene quantum dots: These are small pieces of graphene with dimensions less than 10 nanometres in all directions. They have unique electronic and optical properties and are being investigated for use in electronics and biomedical applications.

g) Graphene foam: This is a 3D, porous material made of interconnected graphene sheets. It has high surface area and is being investigated for utilise in energy storage and catalysis applications.

In general, the various types of graphene each offer a unique set of properties as well as a variety of possible applications. The study of new types of graphene and the modification of their properties to better suit a variety of applications is something that is ongoing in the research community. Figure 2.16 illustrates the physical structure for some types of the graphene material which are all taking the shape of the hexagonal with some features different from each type to the other [50].

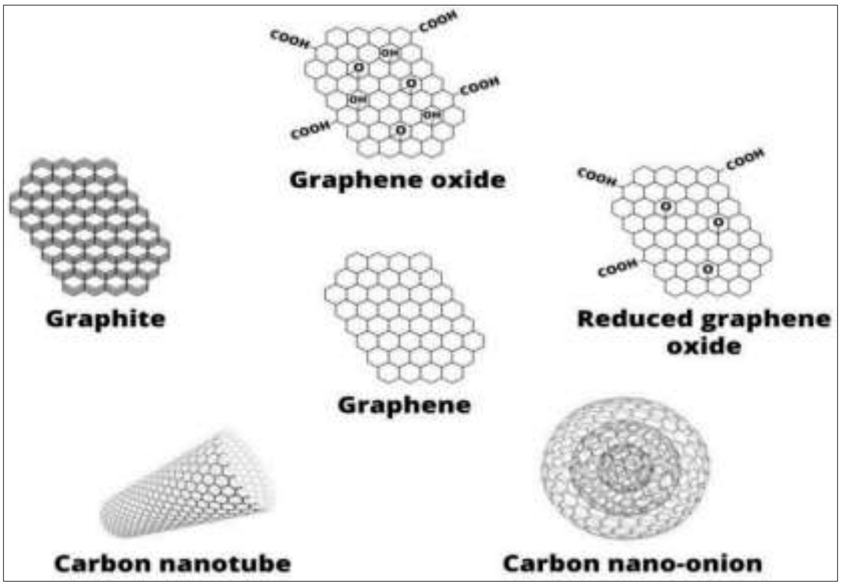
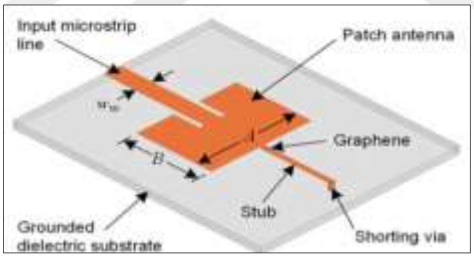


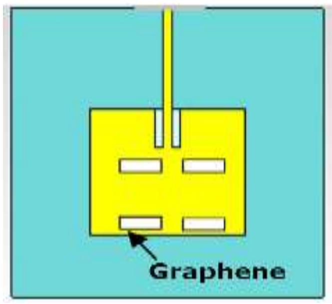
Figure 2.16: Structure of Graphene Material Types.

2.10.4 Graphene Material in MSA Field

The abnormal features of graphene such as high conductivity, high carrier mobility, and high thermal conductivity. These properties make it an attractive material for use in the design of MSAs. Whereas, today the MSAs are broadly employed in modern communication systems due to their low profile, lightweight, and ease of integration with other circuits. Graphene-based MSAs offer several advantages over traditional MSAs. The use of graphene as a conducting material in the design of MSAs can improve their radiation efficiency, reduce their size, and increase their bandwidth. Graphene also offers the possibility of tuning the antenna's properties by changing its doping level, which can be used to optimize its performance for specific applications. Furthermore, the high thermal conductivity of graphene can also be used to enhance the heat dissipation of MSAs, which is particularly important for high-power applications. Overall, the use of graphene in the design of MSAs has the prospect to revolt in the field of the wireless transmission, and researchers are actively exploring its application in this area. The graphene can utilise to create a tuneable frequency MSA by creating a stub or implanting a aperture of the material with the MSA patch, as shown in Figure 2.17 [50], [51].



(a) MSA with connected stub by graphene

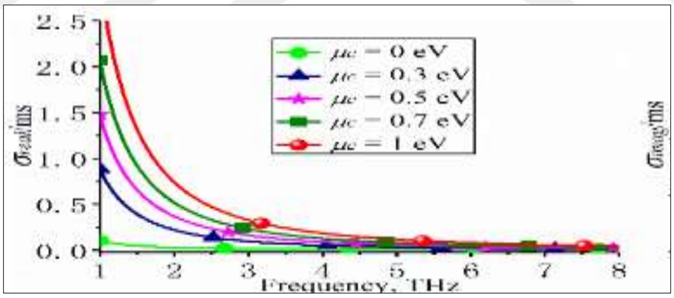


(b) MSA with graphene apertures

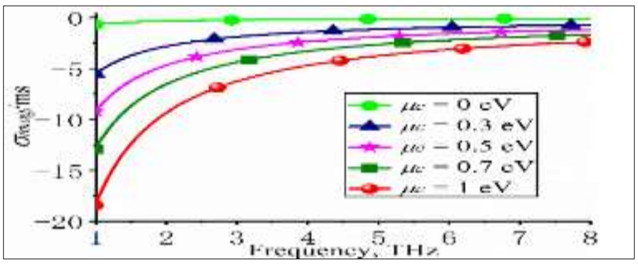
Figure 2.17: Graphene-Based Tuneable MSA.

2.10.5 Graphene Material Electric Conductivity

Graphene is a unique material known for its exceptional electrical conductivity. The arrangement for the carbon atoms in the material makes graphene highly conductive, allowing it to transport electrons with minimal resistance. In fact, graphene has the highest electrical conductivity of any known material at room temperature. This property is due to the delocalization of electrons within the lattice structure of graphene, which allows them to move freely through the material. Furthermore, the absence of impurities in graphene also contributes to its high conductivity, as it prevents the scattering of electrons. Due to its remarkable electrical properties, graphene has potential implementations in the broad range of fields, comprising electronics, energy storage, and sensors. However, despite its promising properties, the mass production and integration of graphene into practical devices still face significant challenges. This material has a unique feature regarding the electric super conductivity which characterized as a variable conductive. Once a DC voltage is given to the sheet of the material the charge carriers are increased contributing a decrease in the surface impedance which in turn make the surface conductivity high. Figure 2.18 illustrates the response for the conductivity with the electric field (i.e., DC voltage) [52].



(a) Real portion of conductivity



(b) Imaginary portion of conductivity

Figure 2.18: Variable Conductivity of Graphene.

As shown from the shown Figure 2.16 the conductivity of the material can be adjusted as required by utilising a DC source which changing the chemical potential of the material the leading to risen in the overall conductivity.

2.10.6 Graphene Electric Conductivity Analysis

In the case of discussing the applications of graphene in the fields of communication and electronics, one of the most crucial parameters is its ability to conduct electric current. Graphene's conductivity is dependent on the DC laid to it. When a voltage is applied to the tender layer of graphene, its conductivity increases significantly. To represent graphene's conductivity, the Kubo form is utilised in the following manner [53]:

$$\sigma_{AC} = \frac{-jq^2 k_B T}{\pi \hbar^2 (\omega - j{\tau_t}^{-1})} \left(\frac{\mu_c}{kT} + 2ln\left(e^{-\frac{\mu_c}{kT}} + 1 \right) \right) \tag{2.11}$$

Where:

σ_{AC}: is demonstrates the conductivity of graphene at the intraband level;

ω: is pointing to the frequency measured in radians;

μ_c: is an indication of the chemical potential of graphene;

τ_t: is indicating for the time of relaxation;

T: is providing information regarding the temperature contained within the room;

q: is indicating to the charge elementary;

$\hbar$: is referred to the Planck's (reduced constant formation);

k: is referred to the Boltzmann constant.

The μ_c has a special relationship associated with the density of carriers that can be determined by the utilising of the mathematical equation below [53]:

$$\mu_c = \hbar \times v_{fer} \times \sqrt{\frac{22n}{7}} \tag{2.12}$$

Where:

v_{fer}: is referred to the Fermi velocity which is constant and equals 1×10^6 (m/s); and

n: is referred to carrier density.

The parameter n can be easily modified by giving a direct current to the graphene flake. Mathematically, can be determines utilising the following expression [54]:

$$n = \frac{\varepsilon_o \varepsilon_r V_g}{dq} \tag{2.13}$$

Where:

ε_o: is referred to the permittivity of the air;

ε_r: is describing the dielectric constant;

d: is indicating to thickness (i.e., height) of graphene;

q: is indicating to the electron charge; and

V_g: is referred to the DC voltage.

For the purpose of calculating the surface impedance for the graphene the following mathematical relation is utilised [54]:

$$Z_{Grapgene} = 1/\sigma_{AC} \tag{2.14}$$

3. PROPOSED ANTENNA SIMULATION AND ANALYSIS

In this particular chapter of the dissertation, we shall expound upon the foundational and essential procedures necessary to simulate, devise, refine, and scrutinize the suggested antenna. Additionally, we shall deliberate upon and unveil the outcomes procured upon accomplishing the design and enhancement phases via the utilization of the CST software's temporal analyser, which assumes responsibility for the antenna simulation method and offers us a unified milieu for development and refinement.

3.1 M-MSA DESIGN

In this specific section of the chapter, we shall thoroughly examine, elucidate, and converse about the preliminary measures required for the proposed antenna's creation. We will commence by formulating the primary design for the typical M-MSA, followed by the introduction of a U-shaped aperture carving procedure to establish the band-rejection characteristic, and ultimately integrating the graphene component to render it compatible with the engraved aperture. The layout of the proposed antenna's design is structured as a conventional M-MSA from a rectangular shape. In order to initiate the antenna design process correctly, it is crucial to choose a set of key parameters that are exclusive to the antenna. These parameters encompass the frequency of operation, the I/P impedance, and the characteristics of the dielectric material employed as an antenna substrate. It is imperative to recognize and determine these parameters at the outset of the design process to ensure the proper functionality of the antenna, as presented in the Table 3.1.

Table 3.1: Functional Parameter for MSA Design.

Parameters	**Definition**
Centre Frequency	6 GHz
Input Impedance	50 Ω
Substrate Specifications	$\varepsilon_r = 4.7$
	$h = 1\ mm$
Conductive Material Type	Copper

After that we trying to calculate the proposed antenna dimensions by utilising the equation of the basic transmission line method that was described in the previous chapter (2.8.1) with the help of MATLAB software. In this design of UWB-based MSA it is necessary to meet the UWB technology requirements (i.e., frequency range and omni-directional pattern). In order to develop MSA with the mentioned criteria the ground plane must designed to be in the from a partial one or utilising the Coplanar Waveguide (CPW)feeding. In this way the ground plane is situated over the surface of the antenna (i.e., the ground plane and the patch will be engraved over the same face of the substrate). Table 3.2 presents the dimensions for the initial M-MSA design and Figure 3.1 illustrates the initial M-MSA within the environment of the simulation software.

Table 3.2: Calculated M-MSA Dimensions.

Parameter	**Interpretation**
Width for patch (W_P)	17.76 (mm)
Length for patch (L_P)	13.58 (mm)
Width for substrate (W_S)	35.52 (mm)
Length for substrate (L_S)	27.16 (mm)
Width for ground plane (W_G)	12.38 (mm)
Length for ground plane (L_G)	16.76 (mm)
Width for strip line (W_{STRIP})	2.2 (mm)
Length for strip line (L_{STRIP})	17.74 (mm)
Ground-Patch spacing (d)	0.001(mm)

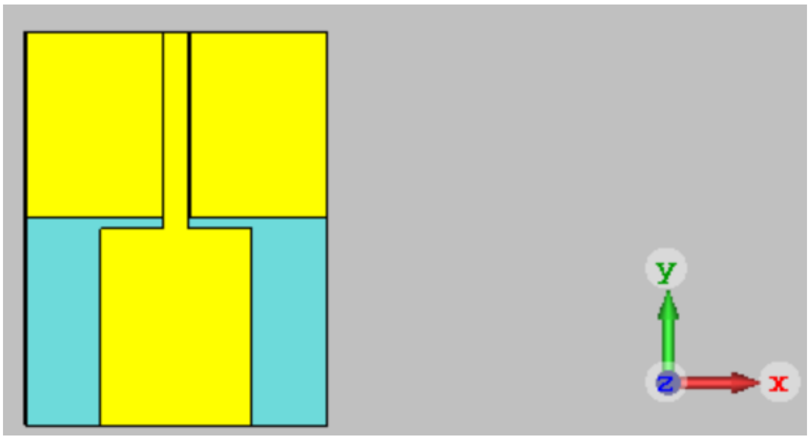


Figure 3.1: Simulated M-MSA.

Due to the limited BW of the M-MSA, the primary design doesn't cover the whole band of the UWB the corrections on the shapes should be made. The first step is summarised by cutting the lower corners and changing the total dimensions, as exhibited in Figure 3.2. For such modifications, there aren't specific rules or mathematical modelling but here we are dependent on trial and error till obtaining the optimum results. Table 3.3 demonstrates the new dimensions for the M-MSA after parameters and shape modifications.

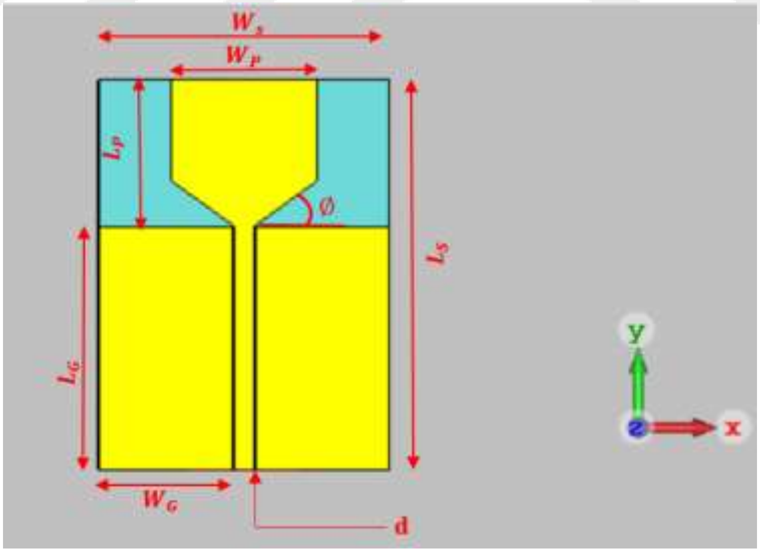


Figure 3.2: Simulated M-MSA After Modification Process.

After applied the required modifications on the dimensions and the shape we met with the characteristic of the UWB technology.

Table 3.3: Modified M-MSA Dimensions.

Parameter	Interpretation
Width for patch (W_P)	16.14 (mm)
Length for patch (L_P)	16.14 (mm)
Width for substrate (W_S)	31 (mm)
Length for substrate (L_S)	40.71 (mm)
Width for ground plane (W_G)	14.15 (mm)
Length for ground plane (L_G)	24.5 (mm)
Width for strip line (W_{STRIP})	2.69 (mm)
Length for strip line (L_{STRIP})	24.5 (mm)
Ground-Patch spacing (d)	0.23 (mm)

3.2 M-MSA WITH NOTCH-BAND CHARACTERITICS

A notch-band refers to a frequency range in which the antenna exhibits significantly reduced or suppressed performance. This frequency range, often referred to as a "notch," is deliberately designed to attenuate or reject signals within a specific range. The purpose of incorporating a notch-band in a UWB antenna is to mitigate interference from specific frequencies or unwanted signals. It allows the antenna to maintain its wide bandwidth characteristics while selectively attenuating signals within the notch frequency range. This can be useful in scenarios where certain frequency bands need to be avoided or rejected, such as licensed bands or sources of interference. Various techniques, such as adding reactive components, resonant structures, or introducing filtering elements, can be used to achieve a notch-band in a UWB antenna. These design elements are meticulously engineered to produce a narrowband response within a wideband antenna structure. In this work, we suggest utilizing the U-shaped aperture to generate a certain bandgap. The selection of the U-aperture position is made based on the current distribution and with the help of a trial-and-error approach till reaches to the notch at the required frequency band. Figure 3.3 illustrates the current on the M-MSA patch.

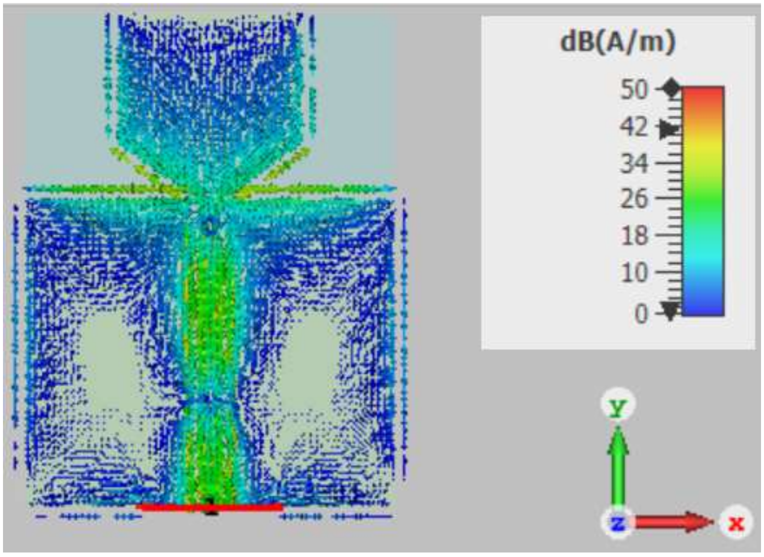


Figure 3.3: Current Distribution Over the M-MSA Patch.

As demonstrated in previous Figure 3.3, the allocation of the maximum current is presence in the strip feed line and the border of the ground plane. So, we select the position of the U-shape aperture in the location of small current at the middle of the M-MSA patch, as exhibited in Figure 3.4.

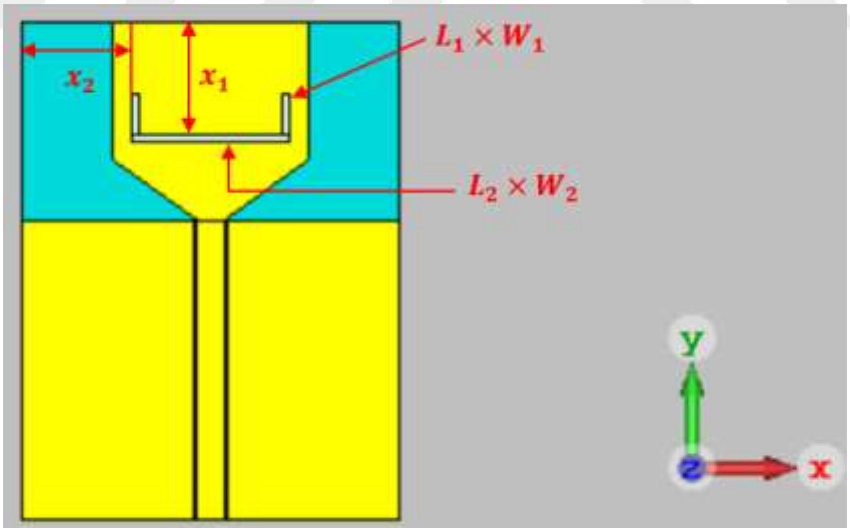


Figure 3.4: M-MSA with U-Shape Aperture.

The completed size description and the location for the engraved U-shape aperture on the surface of the radiated patch of the antenna is presented in Table 3.4.

Table 3.4: Dimensions for the Designed U-Aperture.

Parameter	Interpretation
Right arm length (L_1)	3.21 (mm)
Right arm width (W_1)	0.65 (mm)
Horizontal aperture length (L_2)	0.65 (mm)
Horizontal aperture width (W_2)	12.91 (mm)
Distance between U-aperture and upper patch edge (x_1)	9.04 (mm)
Distance between U-aperture and left patch edge (x_2)	1.6 (mm)

3.3 M-MSA WITH GRAPHENE-BASED NOTCH-BAND CHARACTERITICS

In some cases, the M-MSA is needed to cover the total band of the UWB system, and in other cases reject some bands like military fixed communications, mobile communications, unmanned aerial vehicles, radio links, satellite communications, and the low band of 5G to minimize the available interference from such sources. For this purpose, we exploit the variable conductivity that possesses by the graphene material. In this study, the U-aperture is filled with flakes of graphene to function as a controllable switch that is in an on state when applied DC voltage is to the graphene layer and in an off state when no biasing is applied. In the case of the DC is subjected on the layers the surface impedance is lessening and allowing the current to pass through the U-aperture here the antenna will cover the entire band of the UWB system. While in no subjected voltage its impedance will be high and prevent the current from passing then the notch is created. Figure 3.5 illustrates the designed M-MSA with graphene material.

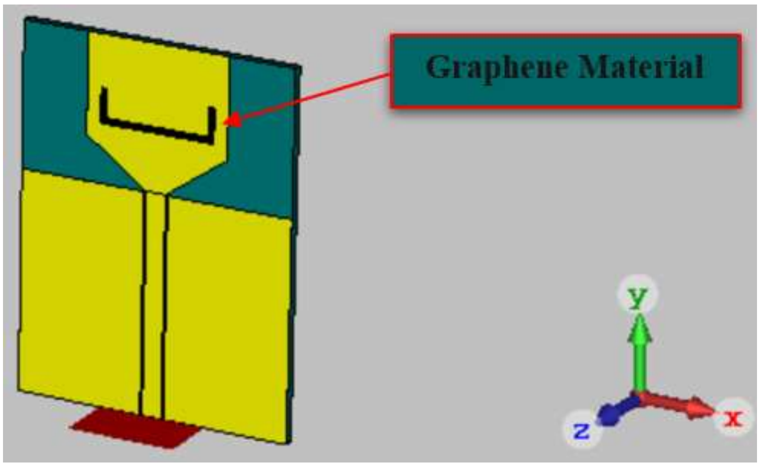


Figure 3.5: Simulated M-MSA with Graphene U-Aperture.

The graphene material is simulated by the means of CST software as a sheet of an ohmic impedance. The values for the ON and OFF states are calculated based on the equations of the graphene conductivity that have been presented in section (2.10.6) with the help of the MATLAB program. Table 3.5 presents the values of the ON/OFF impedance and constant values.

Table 3.5: Parameters for Graphene Material Modelling.

Parameters	Values
μ_l	2.70 m^2/Vs
D	4.0 eV
Graphene thickness (t)	10.0 nm
Room temperature (T)	295 Kelvin
V_{DC_on}	40.0 V
Z_{S_on}	4.145 +J0.360 $\Omega/$
V_{DC_off}	~0.0 V
Z_{S_off}	36533+J1.51$\Omega/$

3.4 ACHIEVED RESULTS

In this section, we will interpret and discuss the obtained results following the finishing of the simulation procedure by the CST workspace for all cases of designs. The results include the M-MSA return loss (S_{11}), the M-MSA BW, the M-MSA gain, and the M-MSA radiation pattern.

3.4.1 Results for Primary Design

In this subsection, we will present the results for the primary M-MSA design before the parameters and shape modifications process.

3.4.1.1 M-MSA S_{11}

An important factor used to evaluate the effectiveness and impedance matching of an antenna system is antenna S_{11}. It measures the power that is reflected back toward the source due to imperfections in the antenna, transmission line, or environment. The S_{11}, which is frequently expressed in decibels (dB), is an important sign of how well an antenna transmits or receives electromagnetic signals. However, impedance mismatches do happen in real-world situations, which causes some of the signals to be reflected back. Greater inefficiency and more power are lost as a result of reflections, as indicated by higher S_{11}values. Engineers can assess and improve antenna performance for better signal transmission and reception by measuring return loss. Commonly the S_{11} should be less than or equal -10 dB which means the M-MSA extradited a 90% of power of the source and the remainder is reflected back to the source. Figure 3.6 shows the acquired S_{11}results for the primary M-MSA design.

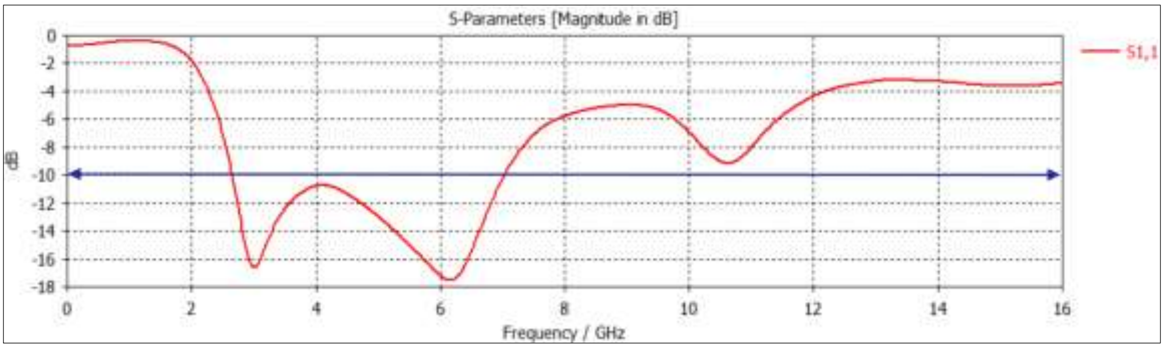


Figure 3.6: The S_{11} for the Primary M-MSA Design.

From the former Figure 3.6, it is clear that the simulated M-MSA doesn't cover a total band of the UWB systems. Whereas, the operating regions are only below the horizontal blue line. So, to overcome this problem the parameters and shape corrections process is applied.

3.4.2 Results for Optimised M-MSA Design

In this subsection, we will present the results for the M-MSA design after the parameters and shape modifications process.

3.4.2.1 M-MSA S_{11}

Figure 3.7 illustrates the archived S_{11} results for the simulated M-MSA after modification the dimensions and shape.

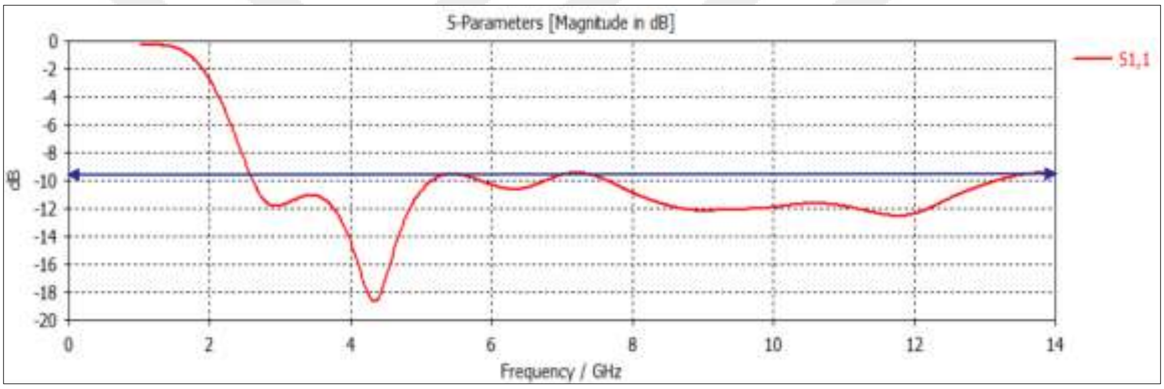


Figure 3.7: The S_{11} Results for the Simulated M-MSA After Optimisation.

As presented in the recent Figure 3.7 the antenna covered the completed band of the UWB. This is due to applying the optimisation process on the dimensions and the shape of our M-MSA design.

3.4.2.2 M-MSA gain

Under typical conditions, M-MSA exhibits a low gain due to the influence of substrate characteristics such as height and dielectric constant. Specifically, the gain improves when the height (h) is increased, but worsens when the dielectric constant is increased. Since the primary design before the optimization process isn't covering the completed UWB frequency so there isn't a need to measure its gain. Figure 3.8 presents the M-MSA gain after the optimisation procedure.

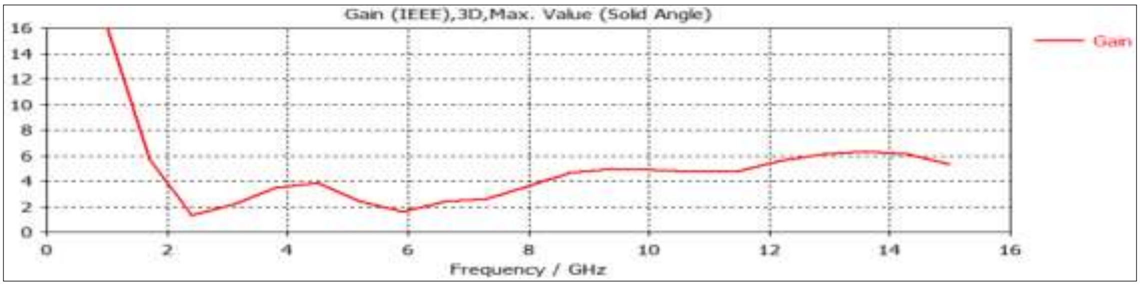


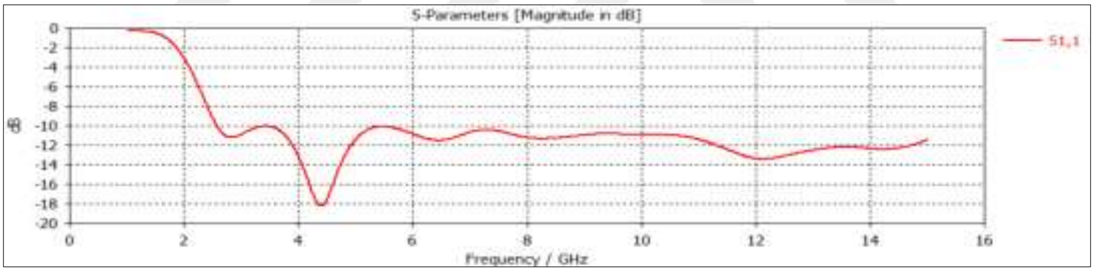
Figure 3.8: Total Band Gain for the Proposed Antenna After the Modification Process.

3.4.3 Results for M-MSA Design with Graphene

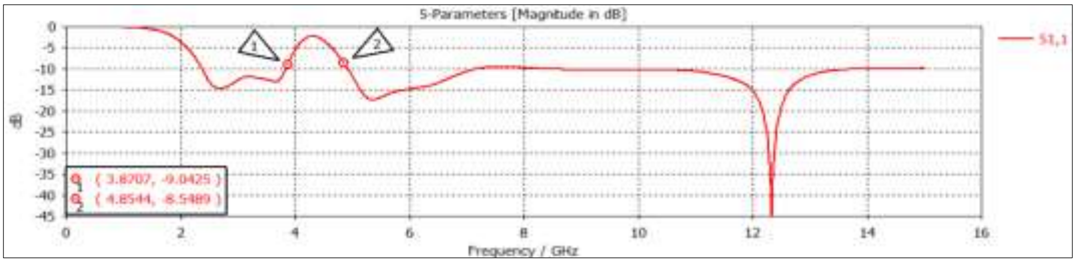
In this subsection, we will present the results for the M-MSA design after the engraving a small U-shaped aperture at the patch of the M-MSA.

3.4.3.1 M-MSA S_{11}

Figure 3.9 illustrates the archived S_{11} results for the simulated M-MSA after modification by adding the U-shaped aperture with graphene material at both ON/OFF cases.



(a) Graphene at ON state



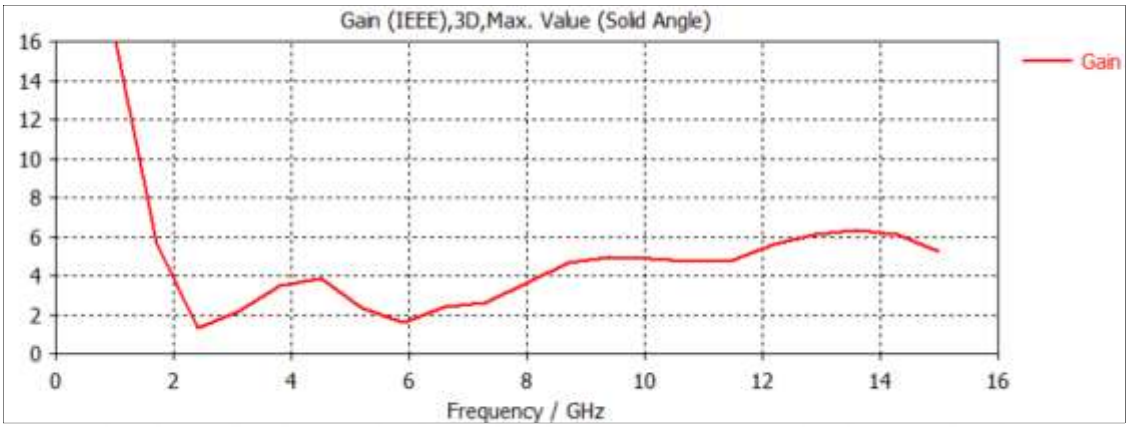
(b) Graphene at OFF state

Figure 3.9: The S_{11} for the M-MSA with U-Shaped Aperture and Graphene.

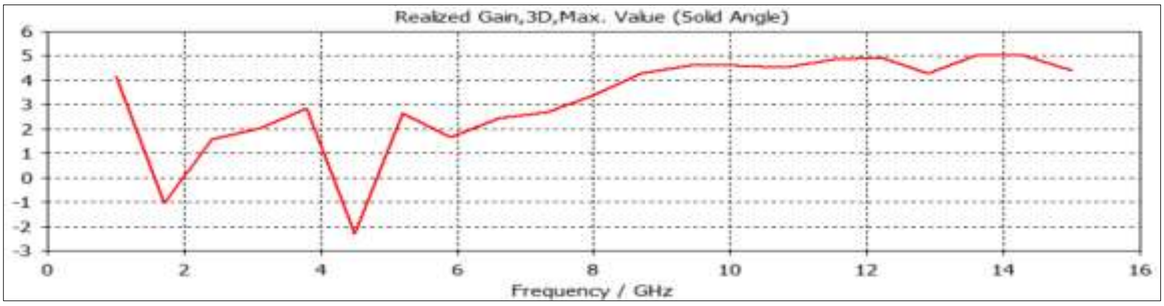
According on the reached results that exhibited in Figure 3.9 above, the graphene U-shaped apertures is acts as a controllable switch in the ON case the simulated M-MSA is working at the whole band of the UWB system and in the OFF case the effect of the aperture is appeared and created a bandgap in the UWB system aimed to reduce the interference in the range of 3.87-4.85 GHz.

3.4.3.2 M-MSA gain

Figure 3.10 illustrates the archived gain results for the simulated M-MSA after modification by adding the U-shaped aperture with graphene material at both ON/OFF cases.



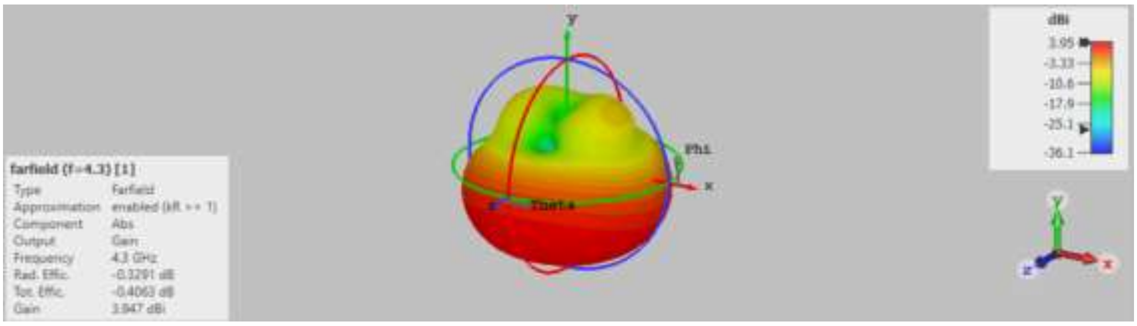
(a) Graphene at ON state



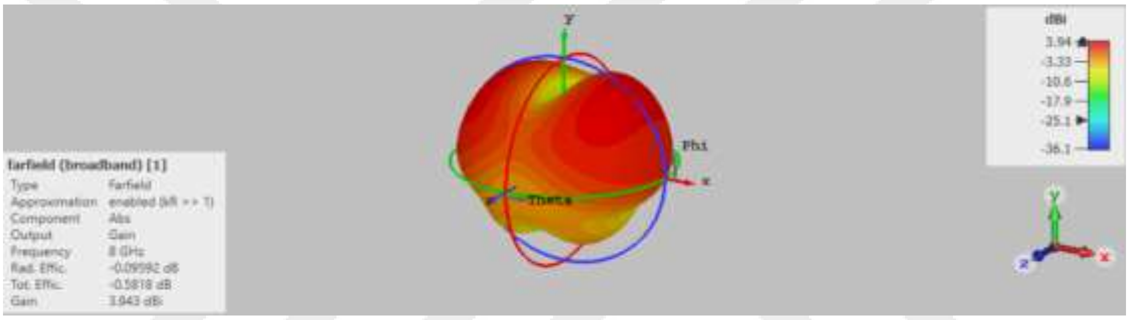
(b) Graphene at OFF state

Figure 3.10: The Gain for the M-MSA with U-Shaped Aperture and Graphene.

As exhibited in Figure 3.10, the obtained gain results at the OFF case in decreased to be around the zero at the bandgap region; this demonstrates that the simulated M-MSA will doesn't operate correctly due to the poor gain and operated in the rest of the band due to there isn't effect for the U-aperture at the rest of the band. In order to study the performance for the simulated M-MSA at the ON and OFF states a gain monitoring is established by the CST software at f_r=4.3 GHz which is the centre of the bandgap, as exhibited in Figure 3.11.



(a) Gain at ON case, f_r= 4.3 GHz



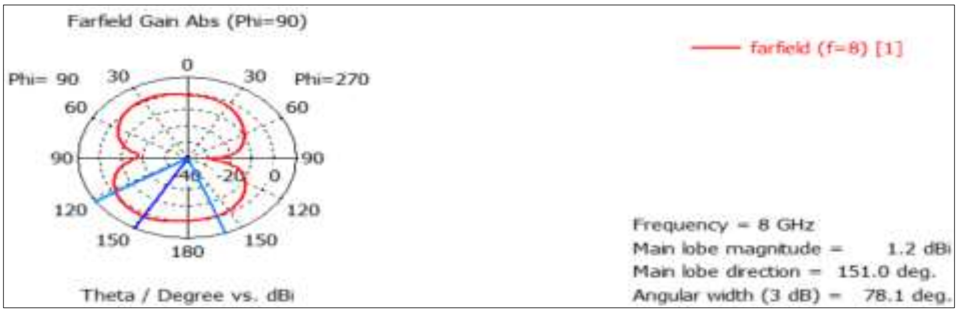
(b) Gain at OFF case, f_r= 4.3 GHz

Figure 3.11: The 3D Gain Results at $\boldsymbol{f_r}$= 4.3 GHz.

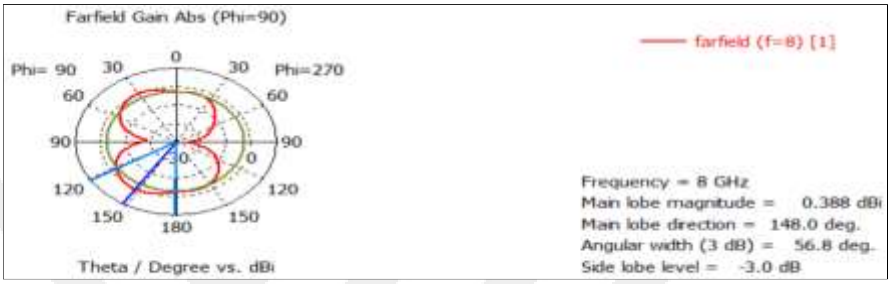
As presented in Figure 3.11 it is clearly that the maximum gain in the ON and OFF cases are approximately similar but the direction of the maximum gain is different in the both cases.

3.4.3.3 M-MSA radiation pattern

In this section, we will present the obtained outcomes regarding the radiation pattern of the M-MSA utilising a graphene as an engraved U- aperture in the context of UWB. The results showcase the performance of the M-MSA in both unbiased (i.e., OFF) and biased (i.e., ON) scenarios at f_r=8 GHz. Figure 3.12 depict the achieved radiation pattern of the M-MSA in the biased condition, demonstrating a satisfactory omnidirectional pattern.



(a) ON state



(b) OFF state

Figure 3.12: Radiation Pattern for the M-MSA with Graphene.

To showcase the effectiveness of the proposed study, a comparison is presented to highlight the advancements made in this work compared to existing literature, as presented in Table 3.6.

Table 3.6: Comparison Between the Proposed Work and the Designed in the Literature.

Ref.	Size (mm^3)	Tuneable Bandgap	Tuning Method	Structure
[55]	44×44.4×0.01	No	N/A	Easy
[56]	48×50×1	Yes	Physical	Easy
[57]	28×18×0.8	Yes	Physical	Complicated
[58]	38×42×0.5	Yes	Physical	Complicated
[59]	8.5×22×0.8	Yes	Physical	Complicated
[60]	16×25×1.52	Yes	Physical	Easy
Proposed	**40.71×31×1**	**Yes**	**Electrically**	**Complicated**

4. CONCLUSION AND RECOMMENDATIONS

This chapter presents the findings and conclusions derived from the completion of this work. It also provides recommendations for future research and developments.

4.1 CONCLUSION

The M-MSA antennas have gained significant popularity due to their convenient construction, cost-effectiveness, and compact size, making them highly suitable for integration into portable devices. Among the prominent technologies that utilize these antennas is UWB technology, which finds application in a wide range of wireless applications. UWB technology offers an exceptionally broad frequency band, spanning from 3.1 to 10.6 GHz, and is employed in numerous low-power consuming wireless implementations like the wireless audio, the personal localisation, indoor networks, radar, and the high-resolution video transmission. Conversely, due to the extensive bandwidth of this frequency range, there is a substantial possibility of interference occurrence. To address this issue, this study focuses on the development, simulation, and optimization of a modified compact square M-MSA that fulfils the UWB requirements. The simulated M-MSA configuration comprises a square radiating patch, a substrate, and a partial ground plane, all printed on the same surface. The feeding mechanism utilizes a coplanar waveguide. To ensure compliance with the UWB range, certain modifications were implemented in the shape of the M-MSA. Specifically, cuts were made in the corners of the square patch, located at both lower edges adjacent to the feeding side. In conclusion, a U-shaped aperture was incorporated into the radiating patch to establish a bandgap within the UWB system, effectively reducing interference. To achieve the tunability of this bandgap, the implanted aperture was filled with graphene material. By applying a DC bias to the graphene, the bandgap can be eliminated. Conversely, in the absence of biasing, the graphene exhibits high impedance, impeding current flow through the aperture. As a result, the bandgap effect becomes prominent within the frequency range of 3.87-4.85 GHz. The simulated M-MSA showed a reasonable gain in the operating region (i.e., 2.5-15 GHz) and varies from 1.288 to 6.284 dBi.

4.2 RECOMMENDATIONS

In order to enhance the designed work, there are multiple of the recommendations that can be made in the future. These recommendations can be summed up as following:

a) In the future, the development of advanced antennas can be enhanced through the utilization of practical techniques such as designing, testing, and conducting measurements within a fully anechoic chamber room. This includes measuring parameters such as the M-MSA gain, S_{11}, and traditional pattern.

b) To enhance the completed antenna performance, a widely recognized method known as FSS can be employed. FSS, also referred to as FSS superstrate/substrate, acts as a passband/bandstop filter by allowing only the desired frequency to pass/reject through while reflecting unwanted leakage from the ground plane. The FSS superstrate/substrate serves as a passive component as it does not require an external feeding source. By integrating this superstrate/substrate with the proposed M-MSA, the overall antenna performance can be significantly expected to be improved.

c) To improve the overall M-MSA parameters, one of the known and commonly used approach is the antenna array structure. Which comprise of many of the single element’s feeds by a feeding network together. This technique effectively enhances the antenna's gain, efficiency, and bandwidth.

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