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A COMPACT MICROSTRIP PATCH ANTENNA WITH A GRAPHENE BASED RECONFIGURABLE BANDGAP

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Master's Thesis

Supervisor
Asst. Prof. Dr. Abdullahi Abdu IBRAHIM

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The thesis titled A COMPACT MICROSTRIP PATCH ANTENNA WITH A GRAPHENE BASED RECONFIGURABLE BANDGAP prepared by SALLY MAHDI and submitted on 16/12/2022 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

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I hereby declare that this thesis meets all format and submission requirements of a Master's thesis.

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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.

Sally MAHDI

Signature

DEDICATION

In the long path of study, which started from the elementary stage and reached preliminary studies and eventually in postgraduate studies, I would like to introduce my thank to my Allah Almighty for the unlimited support, protection, and success in my life. I would also like to introduce my deep gratitude to my family, my husband and daughter, and to my dear father and mother for standing by my side throughout my life. Exceptional and special thanks to the professor supervising my thesis, Asst Prof. Dr. Abdullahi Abu Ibrahim, who was the best support for me during my studies and the preparation of this work. Finally, I would like to thank all of my distinguished professors at the university who taught me and guided me.

ABSTRACT

A COMPACT MICROSTRIP PATCH ANTENNA WITH A GRAPHENE BASED RECONFIGURABLE BANDGAP

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Wireless communication has evolved into a necessary component of modern life on all scales, including personal, commercial, and industrial. The primary reason for this is the ease with which a wireless network can be established and maintained, even in difficult environments such as those with high altitudes or rough terrain. The antenna is a critical component in wireless communication systems. Ribbon antennas are widely used because of their low cost as well as the ease with which they can be designed and manufactured. The Federal Communication Commission has recently developed Ultra-Wideband (UWB) technology. This technology operates at frequencies ranging from 1.3 to 10.8 GHz and can be employed for the wide range of low-power implementations. As the broadband network's bandwidth expands, more and more applications operating in close proximity to one another will inevitably cause interference. One method for producing the bandgaps within the UWB range is to change the current allocation of the antenna. In this study, two distinct designs of a miniaturized-sized MP antenna with a graphene-based controllable notches have introduced for the UWB implementations by using the finite integration approach provided by the CST software. The proposed antennas show an optimum impedance matching and a reasonable gain at the operation regime.

Keywords: UWB Technology, CST Software, Notch-Band, Graphene Material.

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ABBREVIATIONS

UWB	:	Ultra-Wide Band
PAN	:	Personal Area Network
MP	:	Microstrip Patch
BW	:	Bandwidth
CST	:	Computer Simulation Technology
WLAN	:	Wireless Local Area Network
PCB	:	Printed Circuit Board
CVD	:	Chemical Vapour Deposition
DC	:	Direct Current
MAV	:	Micro Air Vehicles
RFID	:	Radio Frequency Identification
FBW	:	Fly-By-Wire

1. INTRODUCTION

1.1 INTRODUCTION

Generally, there are wired networks and wireless networks that can be used for communication, and you have access to both guided and unguided forms of written communication. There are many types of wired communication mediums, some of which include Co-centre Cables, Twisted Pair Cables, and Optical Fibre Links. This type of media format is often referred to by the cliche phrase (coordinated medium). On the other hand, distant correspondence requires no authentic media and effectively transmits the message around the room. Because space just concerns signal transmission with little to no coordination, the medium that is employed for the requirements of the Wireless Communication is termed as Unguided Medium. Both aided and unguided correspondence mediums, as well as wired or remote correspondence systems, are available. In the Wired Communication, the medium is a physical station, such as Co-center point Cables, Twisted Pair Cables, and Optical Fiber Links, that drives the transmission from one place to the next. The saying "coordinated medium" depicts this sort of medium [1]. Distant correspondence, of course, requires no genuine media and actually passes the message on through space. The medium that is employed in wireless communication is referred to as a (Unguided Medium) due to the fact that there is no way to steer a signal while it is traveling through space. Marconi built out the first successful radio link between a land-based station and a towing boat in the late 1800s, signalling the beginning of distant interchanges. Since then, remote communication frameworks have been rapidly evolving and improving. The number of mobile customers has increased dramatically in recent years. From a couple thousand in the mid-20th of the 100 years to around 1.5 billion out of 2004, the quantity of portable clients overall has flooded decisively. Due to channel reuse and more extensive recurrence transfer speed, the absolute number of buyers adjusted has developed. Cell frameworks speak with each other through versatile exchanging and utilize public exchanged phone networks straightforwardly. The most generally pitched advantage of remote correspondence networks is that clients might settle on telephone decisions from anyplace whenever. The most important benefit of distant correspondence is its adaptability. Remote correspondence, despite its diversity, provides adaptation and purpose accommodation, making it increasingly popular. Remote correspondence, like cell phone calls, may be made anytime, throughout, and besides a higher throughput. Another significant consideration is the framework. Framework advancement and establishment for wired correspondence frameworks is an costly and tedious undertaking. Remote correspondence framework is straightforward and cheap to set up. Remote correspondence is a possible arrangement in crisis conditions and far off locales where link association is hard to set up [2], [3]. Figure 1.1 illustrates the communications and interactions between the various of appliances in the wireless communications system.

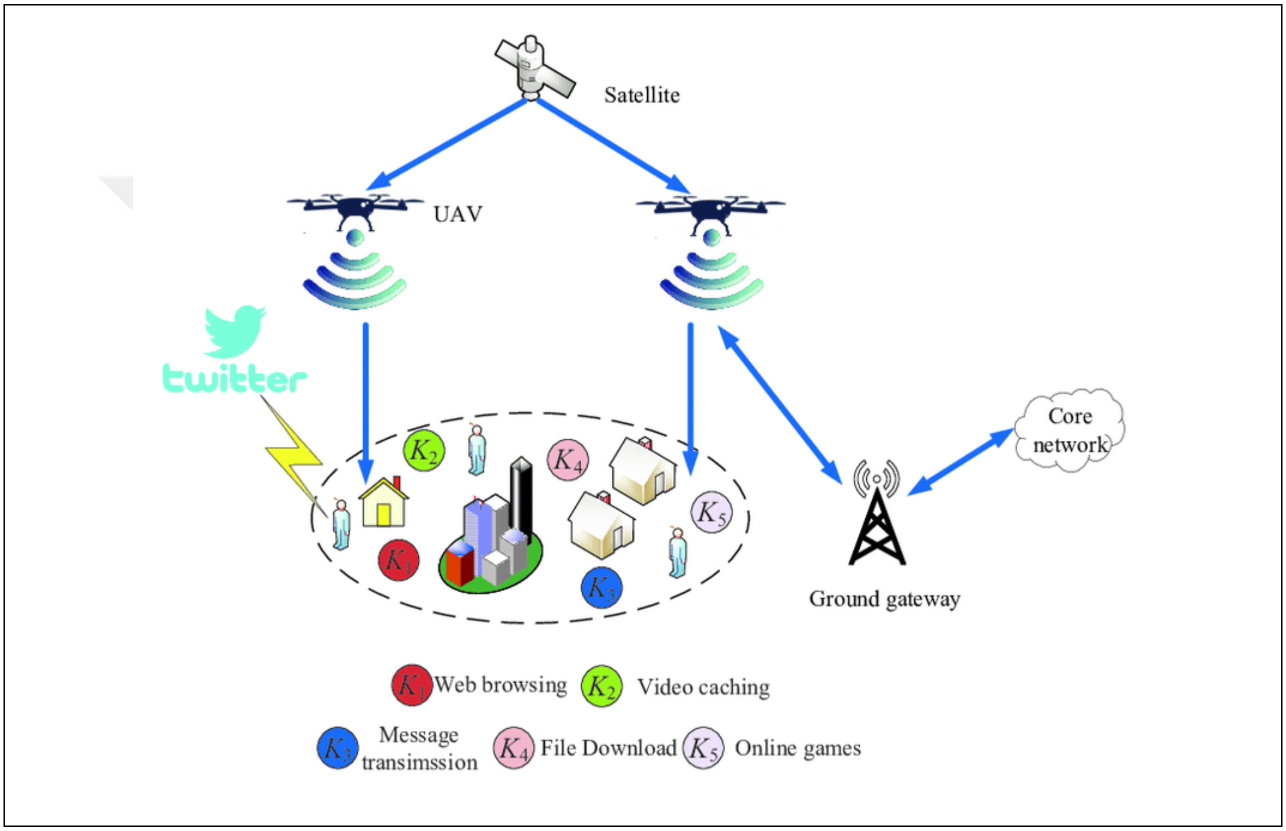


Figure 1.1: Organizations of appliances in wireless communication networks [2].

A cellular network divides a large geographic region into cells, each of which has its own base station. Similar directions can be utilised in another cell without creating an excessive degree of blockage. The cell's format and arranging are intended to minimise interference from adjacent cells, allowing for maximum capacity. Although the cell is commonly portrayed as a hexagon, the actual form depends on the geographic location and radio propagation. The density of users determines which channels are assigned. In the case of the cell contains a large number of clients to serve, more channels are often given. Users going into various cells and changing radio stations must be tracked. Handoff refers to when a mobile phone is switched to a different channel in a different cell. To facilitate client versatility and handoff so a cell phone may be finished effectively, a signaling and call processing technique is required. Another important element of cellular networks is paging [4].

1.2 ULTRA-WIDE BAND (UWB) TECHNOLOGY

UWB is a wireless data transmission technique capable of transporting large amounts of data over short distances of about 10 metres. UWB uses a wide range of frequencies to transmit signals, unlike other distant frameworks that employ range in discrete confined repetition groups. In comparison to existing distant advancements like Bluetooth and WiFi, it is a viable solution for Personal Area Network (PAN) applications. The main advantages of UWB over other technologies are substantially higher data transmission rates (up to 100 Mbps) and longer device battery life. If chipset manufacturing numbers are large enough, it may potentially offer some cost advantages. Many nations have already implemented UWB regulations, and vendors are currently providing compatible chipsets [5]. Figure 1.2 illustrates the some of the variable wireless communications data rate.

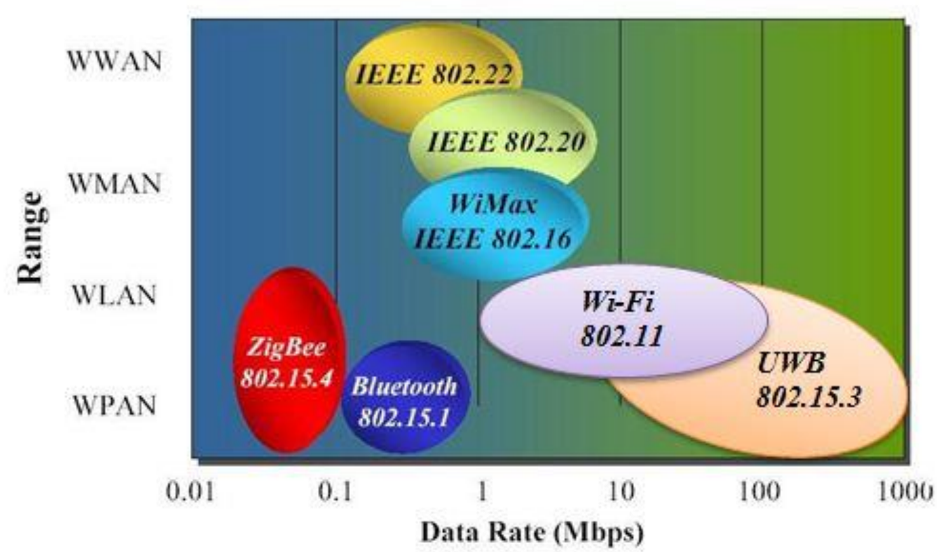


Figure 1.2: Technologies of the wireless communications against data rate [5].

Numerous industry watchers accept UWB will outflank Bluetooth on the grounds that it is quicker, less expensive, consumes less power, is safer, and empowers better area finding and gadget range. UWB innovation is being explored and put resources into by organizations like as the Intel, Apple, Huawei, Samsung, Xiaomi, NXP, Sony, Bosch, and the Xtreme Spectrum. For sure, Apple's iPhone 11 incorporates UWB processors, which empower more noteworthy area accuracy and reach by means of "Season of Flight" estimation. A data transfer capacity (BW) higher than or equivalent to 500 MHz, or a partial transmission capacity (i.e., FBW) more prominent than 20%, is alluded to as UWB, the FBW is given by the following equation [6]:

$$FBW = \frac{BW}{fc} \tag{1.1}$$

Where:

fc: is the center frequency;

BW: is referred to the bandwidth; and

FBW: is referred to the fractional BW.

According to the FCC that has been introduced the UWB frequency regime is covered a wide range of frequency up to 3.1 to 10.6 GHz, as presented in Figure 1.3.

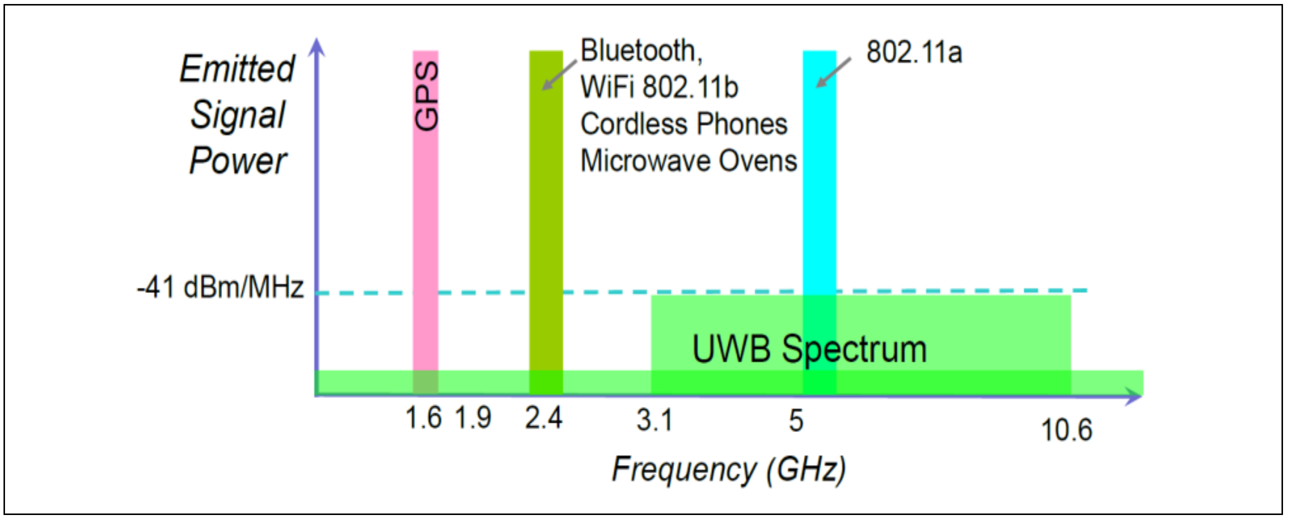


Figure 1.3: Frequency band for UWB [6].

UWB technology innovation extends back to Marconi's utilization of flash hole (brief electrical heartbeats) transmitters for remote correspondence in the main man-made radio. In any case, to limit obstruction with different advances that work in this recurrence range, for example, WiFi and Bluetooth, the permitted power level was set somewhat low. As a result of their low ghostly thickness, UWB signals are less delicate to in-band obstruction from other narrowband flags and are more earnestly to distinguish because of their low power thickness. Business utilization of UWB signals was restricted in 1920. For secure correspondence, UWB innovation was held to safeguard utilizes under profoundly secret activities. It was only after 1992 that UWB started to get notice from established researchers. UWB has become monetarily feasible for short-range, minimal expense correspondence because of headways in rapid microchips and speedy exchanging strategies. Radar frameworks, correspondence, buyer hardware, remote individual region organizations, area, and clinical gadgets were among the main purposes. From that point forward, an exhaustive comprehension of UWB electromagnetics, parts, and framework designing has been acquired gained [7].

1.3 ADVANTAGES OF UWB

UWB transmissions have a far wider bandwidth than the standard narrow-band systems, allowing for the better indoor performance. The advantages of the UWB technology are listed below, as given by [8].

a) Small Power Consuming: The UWB is a low-power scheme, which is important for cell phones' battery duration and ease of use. A solitary coin battery is wanted to drive a sensor that sends a heartbeat once each second for seven years.

b) High Precision: Instead of relying on signal strength, UWB employs techniques such High Precision - Instead of contingent upon the signal intensity, UWB uses techniques like the Time of Flight, the Two-Way Ranging, the Time Difference of Arrival, the Angle of Arrival, and others to measure the range between two devices. With a few radio wires, UWB may likewise decide the point from which the transmission is gotten. Whereas, the user telephone is able limit an item to a situation in space utilizing a careful point and an exact distance.

c) Low Interference Level: Because UWB operates at a frequency within a large bandwidth, there is a good sign of immunity for the interference, which is normal with Bluetooth and Wi-Fi.

d) Super-Fast: While Bluetooth-based area detecting requires no less than two seconds to pinpoint your location, UWB is thousands of times faster, resulting in no latency and a flawless user experience. The characteristic for the UWB technology can be summarized by introducing Figure 1.4.

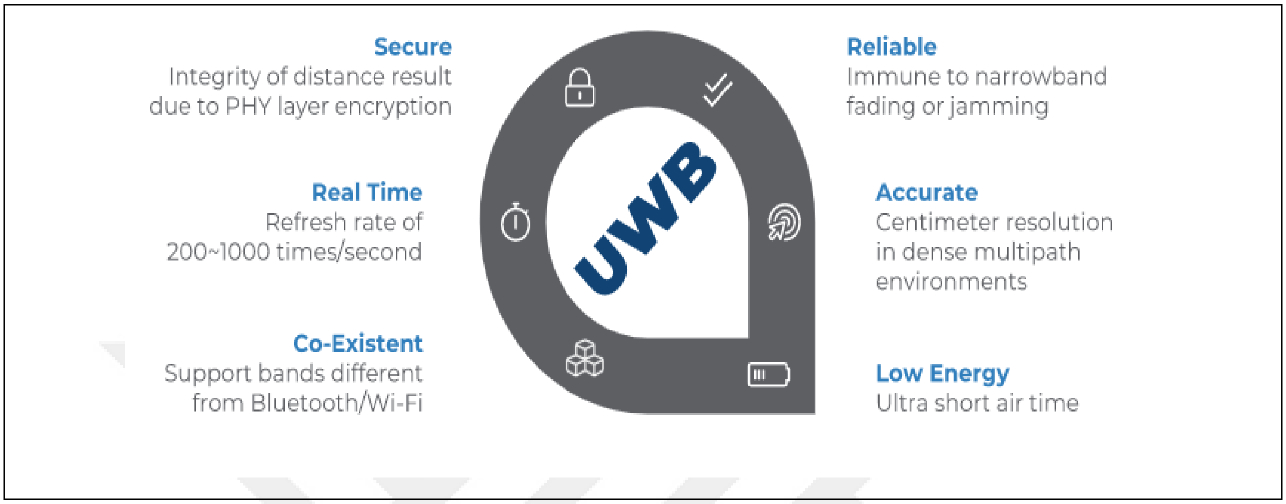


Figure 1.4: Characteristic of UWB technology [8].

1.4 DISADVANTAGES OF UWB

The most significant drawback of UWB is that alternative technologies, such as Wi-Fi or Bluetooth, can communicate with all modern smartphones and tablets. However, since Apple launched the UWB technology in the iPhone 11 in 2019, UWB is likely to quickly become popular. Other smartphone manufacturers are following Apple's lead and implementing UWB in their smartphones; more crucially, UWB will be integrated into location-aware electronics, wearable gadgets, and other applications [9].

1.5 APPLICATION OF UWB

The UWB technology have been employed in a different of the applications in the commercial or personal applications, some of which are summarized as following [10]-[12]:

a) Low data rate applications: UWB transmissions have a very low power spectral density (PSD), allowing them to coexist in the similar spectrum as the tight band technologies without creating excessive the interference. Infrared or ultrasonic procedures are as of now accessible available for indoor applications. Infrared innovation's line-of-sight propagation cannot always be assured. Shadows and light-related interferences can have an impact. The ultrasonic method has a limited penetration. Shadows are less of an issue with UWB technology, as it enables for transmission through obstacles. The government and corporate sectors both benefit from UWB's novel communication approach with reduced data rates. UWB technology, for example, might be utilized to interface PC peripherals like a mouse, screen, console, joystick, and printer wirelessly.

b) High data rate application: Because many UWB applications revolve on existing market demands for high information rate applications, the interesting purposes of UWB frameworks in many circumstances first drew a lot of interest. The need for high-density multimedia applications is growing, necessitating new approaches to make better use of available bandwidth. As demand grows, the UWB framework can fill the accessible data transmission. High-rate applications have several obstacles, including receiver design and jamming resistance. UWB can benefit huge high-resolution television panels. These devices wirelessly feed video material from a video source to a wall-mounted display Web access and interactive media administrations, remote fringe connection points, and area-based administrations are instances of high information rate applications.

c) Home network application: Making a widespread home network environment requires a home network application. The wireless linking of various home electrical gadgets eliminates the clutter of wires in the living room. This is especially crucial when considering the data rate required for top quality TV, which is more than 30 Mbps across a couple of meters. IEEE 1394 is an endeavor to combine amusement, purchaser gadgets, and PCs in the home setting. It has an isochronous mode that ensures information conveyance at a predictable transmission speed. It's critical progressively applications like video communicates. Nonconcurrent mode likewise conveys the suitable information rates and administrations for different gadgets. where information conveyance is guaranteed yet there is no guarantee with respect to when the information will show up. UWB technology can be used to transport isochronous data.

d) Position location and tracking: Position tracking furthermore, area have an assortment of utilizations, remembering distinguishing patients for basic condition, climbers injured in far off regions, checking automobiles, and dealing with an enormous number of things at a retail shopping center. Short-beat UWB techniques offer explicit advantages in exact season of-flight estimation, multipath invulnerability for driving edge discovery, and low prime power needs for broadened activity RF ID RFID) labels for dynamic RF following and situating applications. The target for supporting human-space intercession is to perceive individuals and things the client is pointing towards, as well as the client's objective errand. Knowing where an individual is permits us to decide that they are so near what or what their identity is, and afterward make a speculation concerning what the client is going for. When utilized in a WBAN, this human-space mediation could expand personal satisfaction. A WBAN utilizes an assortment of shrewd sensors to gather patient information and send it to a PDA, which then sends it to a remote server. In the event of a life-threatening illness, such as arrhythmic disturbances, accurate location identification might aid medical professionals in their treatment.

e) Radar: Short-pulse UWB methods offer various radar uses, including improved target acknowledgment, better resistance to co-found radar communicates, expanded identification likelihood for explicit classes of targets, and the ability to recognize very leisurely moving or fixed targets. For micro air vehicles (MAV) applications, UWB is a top technological contender. The capacity to create millions of ultra-wideband pulses per second allows for great penetration in a variety of materials, including construction materials, concrete blocks, plastic, and wood.

f) Smart Car Access: allows you to open a vehicle with your telephone when you approach it, taking into account keyless access and remote beginning.

g) Safe Wireless Payment: such technology is more extra secure than the NFC, and the user can place your telephone in your pocket.

h) Safe Building Access: When you approach a secure location within a building, the doors automatically open.

i) Smart Retail: give helpful information on a product you recently purchased or a great offer for purchasing one.

j) Other Applications UWB: Sensor networks are wireless (military and commercial use) Automobile manufacturing (collision avoidance, roadside assistance) Identification and tagging communication that isn't LoS detection of intrusion. Some of the other UWB are illustrated in Figure 1.5.

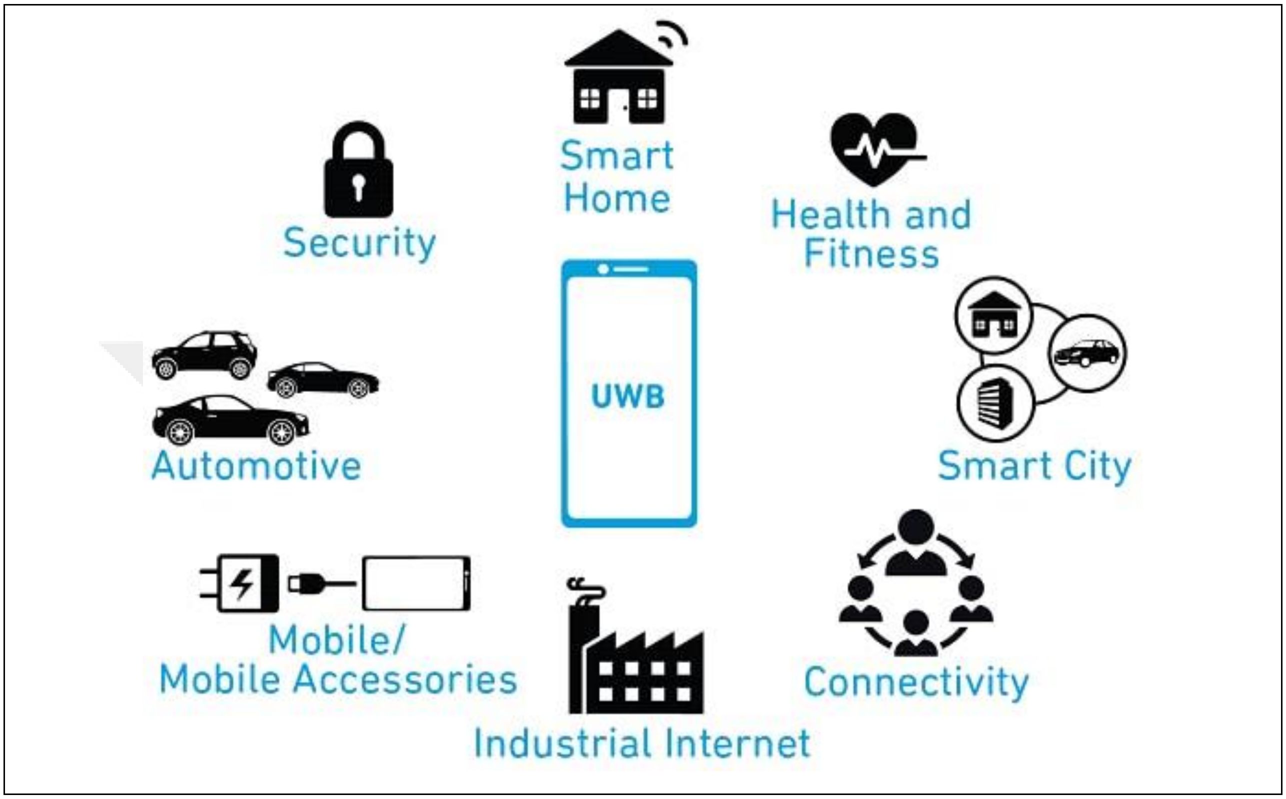


Figure 1.5: Some other UWB applications [12].

1.6 LITERATURE REVEIW

There are many of studies have been prepared by the researchers and authors in kinds of literature focusing on designing, simulating, and analyzing the UWB antennas, some of these studies are listed below:

A UWB based monopole Microstrip Patch (MP) antenna with dimensions of 19.20 mm in length and 28.80 mm in width is described by the authors. For wireless applications, the simulated antenna is recommended. For the purposes of the power feeding for the designed antenna, a 50Ω strip line has been utilized. In order to convey the UWB, a miniature ground plane has employed in this work. The CST software tool is used to carry out the simulation procedure. The simulated outcomes of the impedance bandwidth have been backed up by the measurements. Analyses of the antenna efficiency have been presented along with the results of the group delays and radiation patterns [13].

A planar type of the UWB antenna and the planar UWB antenna with a couple of the rejection bands have been introduced by the authors in this work. The antenna has made from a rectangular shape for the patch inserted on FR-4 type substrate with a 50-ohm strip line for the power feeding purposes. Each corner of the patch has a round-cut, and the ground plane has a slot. The simulated frequency range is 3.42–11.7 GHz besides a return loss of -10 dB. The WLAN and X-bands, which are inserted into the patch and feed, are the rejected bands. The proposed antenna's simulated performance shows increased gain in the passbands, but a significant loss in gain has been noted within the rejected bands. In order to design and simulate the antenna's behaviour at different frequencies, the authors have utilized the HFSS software [14].

For UWB applications, the authors have introduced a new coplanar waveguide-fed compact MP antenna. Through introducing an inverted L-strip within the structure of the regular patch antenna structure, the introduced antenna can reduce its height by about a half-inch. The single radiator was flanked on both sides by an expanse of ground that extended vertically. Consequently, a large amount of unutilized space around the radiator can be effectively saved. Antenna design is based on real-world fabrication and simulation. There is a well correlation and dealing among the practical results and those that have been achieved via the simulation. At a frequency in the range of 2.6-13.04 GHz, the prototype was fabricated with an acceptable impedance matching, good gain, and constant radiation patterns [15].

The authors in this article have been presenting a novel UWB antenna for microwave imaging systems that is highly directive. To improve bandwidth impedance matching, the ground plane incorporates by the Defected Ground Structure approach. The undermost and topmost edges for the square shape patch plane are then etched with stairway slots and square slots to improve the overall performance (i.e., bandwidth, gain, and directivity) even further. The dielectric constant of the proposed microstrip antenna equals 4.3 and it is made from an FR-4 laminate substrate plate. At each resonant frequency studied, the gain, the directivity, the radiation pattern features, and the coefficient of the reflection were all examined via the simulation [16].

A printed UWB MP antenna from hexagonal patch shape with etched small apertures at the ground plane and the patch has been introduced, investigated, and discussed by the authors in this work, along with an analysis of its performance. The WiMAX and the WLAN bands each have been rejected by introducing an S-shape aperture on the patch of the antenna and an inverted U-shaped slot within the ground plane to achieve the band-notch effect. In the terms of the impedance BW, the introduced antenna has a range roughly of 10 GHz (2.4–12.4 GHz) or 135 per cent of the centre frequency. The authors have shown that there is a well dealing among the measured and the simulated values for the design prototype [17].

A compact UWB MP antenna with high directivity has been presented in this work. The UWB was achieved through the use of techniques like partial grounding and patch alteration. A strip feed is inserted straightway to the altered U-shaped patch in the antenna design. Attaching a reverberate trapezium to the strip line on every side of the original U-shaped patch. Two rectangular slots with the reasonable dimensions are etched away from the antenna's feed structure, two parasitic patches are inserted in their place. The utilized fractional ground plane also donates to the UWB regime of the proposed structure. This section of the proposed structure has been altered by utilizing square and triangular slot etching. Finally, the FSS is placed on the behind of the suggested antenna with the help of a specific airgap in among the two structures to improve gain. The performance of a new FSS unit cell is experimentally verified. A maximum gain of 9.7 dBi was measured practically after the antenna and FSS were combined [18].

1.7 THESIS OBJECTIVES

The major objectives of this thesis can be summed up by design two designs of MP antennas that can be operated in the UWB applications with frequency rejection feature to reduce interference between neighboring frequencies. The purpose of designing two types of antennas is to investigate the influence of the characteristics of the substrate on the overall rendering of the designed antennas. For the purpose of creating a variable (i.e., controllable) band rejection property, the graphene is employed.

1.8 PROBLEM STATEMENT

As mentioned in the previous sections of the current chapter, the UWB technology offers high data transfer speed at low power. Despite the advantages mentioned, this large band will be subjected to interference by the frequencies of different applications. Therefore, it is necessary to find appropriate solutions to solve such issues.

1.9 THESIS ORGANIZATION

Generally, this thesis consists of four main chapters that explain the general introduction to the topic, the parameters of the antenna, and finally the design and simulation. The subsections of each chapter are illustrated and summarised as follows:

a) Chapter Two:

In this chapter of the thesis, we will illustrate the general definition for the antenna, essential parameters for the antenna, types of antennas, microstrip antennas, advantages and disadvantages, feeding process for MP antennas, and analyzing techniques for MP antennas. Also, this chapter present the graphene material definition with its application.

b) Chapter Three:

In this chapter of the thesis the principal methodology and the used procedure for the proposed work is presented, demonstrated, and discussed. In addition, the obtained outcomes for the simulated antennas are presented and discussed.

c) Chapter Four:

Finally, this chapter of the thesis is demonstrating the conclusion that we obtained after carried out this study. In addition, this chapter is presenting the recommendations that can be applied to improve this work in the future.

2. ANTENNA FUNDAMENTALS

2.1 ANTENNA DEFINITION

A metallic structure that gathers or potentially communicates radio electromagnetic waves is known as a receiving antenna. The receiving antennas exist in an assortment of sizes and plans, going from little ones that might be found on the rooftop of the homes or the other institutions to those that catch signals from satellites a huge number of kilometers away. The general definition for the antenna is known as a transducer that changes the electrical signals into radiated signals or vice versa [19].

2.2 ANTENNA FIELD REGIONS

Once a signal is sent to the antenna terminals, the antenna responds by producing a field that is associated with the signal. The electromagnetic fields that encompass an antenna can be broken down into three primary regions (see Figure 2.1) the definition of each region is described as follows [20]:

a) FarField or Fraunhofer Region: The far-field, as might be assumed, is the district farthest away from the receiver antenna. Around here, the radiation arrangement does not alter with the distance (R). The power density diminishes as $1/R^2$, whereas the E- and H-handles vanish as 1/R. Radiated fields predominate in the far-field, and just like with plane waves, the E-field and the H-field are normal to both each other and the direction for the prevalence in the farfield. Assume that the ultimate linear dimension for the antenna is considered as the term (D), and the wavelength is (λ), then in order to be within the farfield zone, all of the three of the following provisions should be met:

$$R > \frac{2D^2}{\lambda}$$

$$R \gg D \qquad (2.1)$$

$$R \gg \lambda$$

b) Reactive Near Field Region: Here in this region have the responsive near field in the fast area of the antenna. Around this point, the fields are mainly responsive, which implies the E- and H-fields are 90 degrees out of phase. This area's limitation is usually stated as follows:

$$R < 0.62\sqrt{\frac{D^3}{\lambda}} \tag{2.2}$$

c) Radiating Nearfield Region: The zone that lies among the nearfield and the farfield is known as the radiating near field or the Fresnel region. In this region, the radiating fields are beginning to emerge, while the reactive fields are no longer the dominant force. In this region, on the other hand, the form of the radiation pattern can change noticeably with distance, in comparison to the farfield region. The following is a common description of the border of this area:

$$0.62\sqrt{\frac{D^3}{\lambda}} < R < \frac{2D^2}{\lambda} \tag{2.3}$$

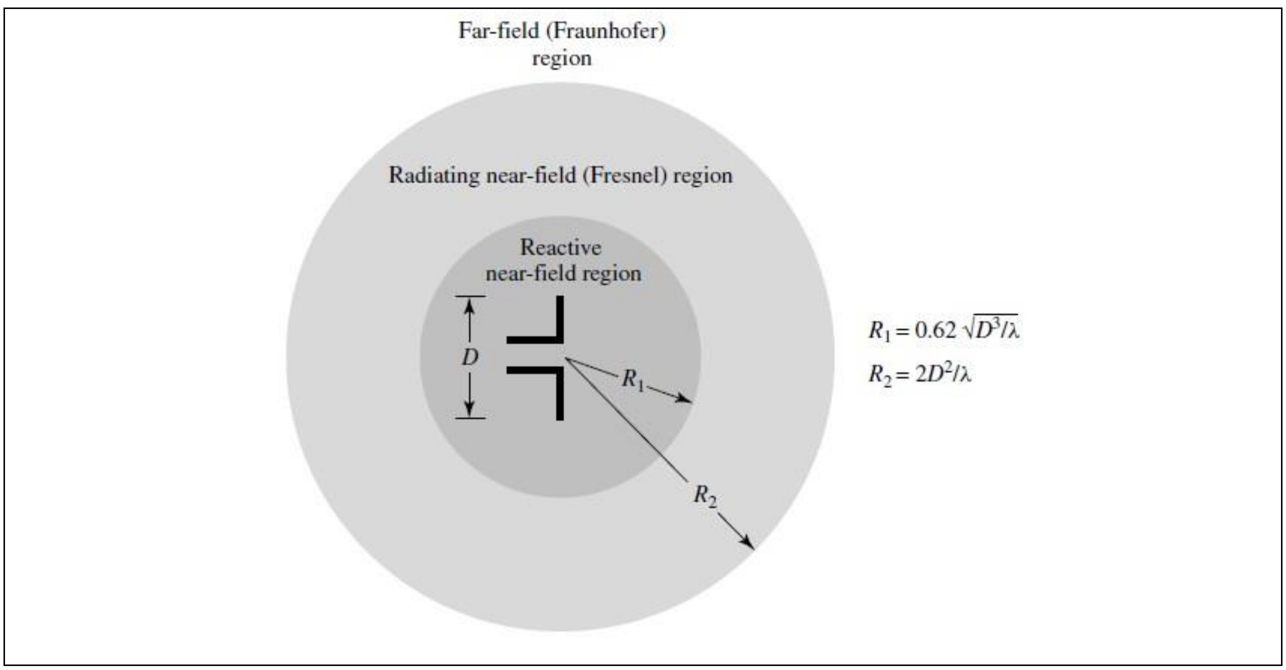


Figure 2.1: Fundamental antenna regions [20].

2.3 ANTENNA PARAMETERS

It is necessary to understand the fundamental of key antenna parameters in order to successfully select and employ antennas in practice for any application. All wireless systems, from the Internet of Things devices to microwave and millimetre-wave imaging systems like radio telescopes, require antennas in order to function properly. Antennas are the very significant element of a wireless system because they are responsible for converting the flow of electrons into electromagnetic radiation in a symmetrical way that has been meticulously planned. An antenna's precise behaviour is determined by the geometry of the conductors and dielectrics that make up its structure. Antennas come in a broad variety to meet the requirements of a broad range of implementations. The radiation parameters and network parameters are the pair of the primary classifications of antenna behaviour, respectively. Generally speaking, these parameters are only given for the frequencies that fall within the BW of an antenna. Simply put, the frequency range that a manufacturer has specified as being compatible with an antenna is what is meant by its bandwidth. In general, antennas display a behaviour known as broadband, which can sometimes extend beyond the antenna's own bandwidth. Radiation parameters are utilised for the purpose of presenting the operating of the antenna as it transforms electronic energy into electromagnetic energy and vice versa. The behaviour of an antenna interconnect and ports, which are used to connect an antenna to transmitters, receivers, interconnect, and measurement devices, is characterized by the network parameters. Electromagnetic waves, also known as antenna radiation, are created when electrons that have been produced by a time-varying signal that contains sufficient high-frequency components pass through a conductor that does not have a shield around it. The term far-field that was mentioned previously refers to the antenna electromagnetic radiation pattern that occurs at a certain range away from the antenna, at which point the E and H fields of the pattern are perfectly orthogonal. In most cases, the measurements of an antenna's parameters are carried out in the farfield. Many of the important parameters, which will be covered in the following subsections, are used to describe the behaviour of the radiation that is emitted by an antenna [21].

2.3.1 Radiation Pattern

The radiation patterns for the antenna are graphic representations of the various segments that make up the antenna's radiation features. Typically, the graphic expression of the antenna's directional characteristic is referred to as the antenna pattern. It is a illustration of the comparative assertiveness of the energy radiation or the portion of the E or H fields' strength as a function of the direction of the antenna. In other words, it shows how strong the E or H fields is. The directivity of a radar antenna can be graphically displayed using antenna radiation pattern, which can then be employed to estimate the rendering of the antenna. Each type of antenna has its own radiation pattern, such as the directional and omnidirectional antenna. Whereas, the directional antenna, in contrast to an omnidirectional antenna, which radiates uniformly in all directions of a plane, prefers one direction and, as a result, achieves a longer range in this one direction with lower transmission power. An omnidirectional antenna radiates uniformly in all directions of a plane. A graphical representation of the preference obtained through measurement is provided by the antenna radiation pattern [22]. Figure 2.2 illustrates the description radiation pattern for the generic antenna.

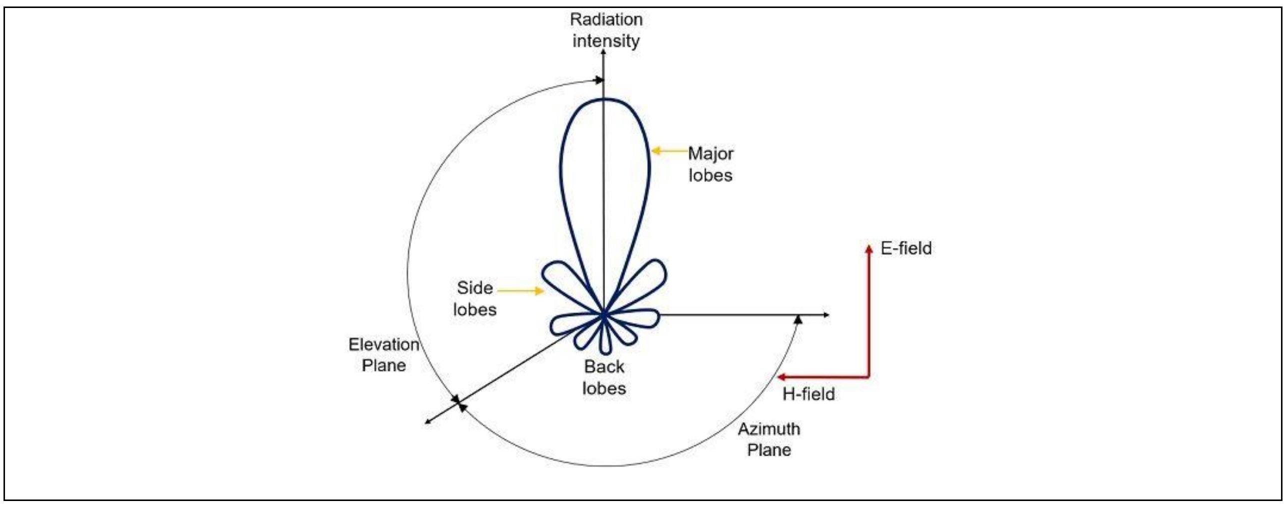


Figure 2.2: Structure for the generic antenna radiation pattern [22].

2.3.2 Antenna Gain

The is the measure of the ability of an antenna to radiate in any direction supplement or undersized strongly than would be possible with a hypothetical antenna is referred to as the antenna's gain. If it were possible to construct an antenna in the shape of an ideal sphere, it would emit radiation in an equal and balanced manner in the whole of the present direction. An isotropic antenna is a hypothetical term for such an antenna, but in practice, there is no such thing as an isotropic antenna. Despite the fact that the theoretical counterpart's gain is utilised to evaluate the gain of a real antenna, the gain of a real antenna is typically reported in dB. An omnidirectional antenna has a gain of 2.1 dB over the structure of the isotropic antenna, which is a well-known fact. The gain in the transit facedown distance from a normal oriented omnidirectional antenna comes at the expenditure of the transmission overhead and beneath it. This is due to the antenna's vertical orientation rather than horizontal orientation. It has a pattern that resembles a doughnut in appearance. Gains of more than 20 dB are possible when configuring directional antennas in various ways. These cut out a sizeable portion of the omnidirectional pattern produced by an omni antenna and have the potential to seriously increase the distance over which it can project its signal. Excessive gain antennas have the potential to be much critical to offensive position displacement brought on by the presence of wind, which is one of their primary drawbacks. The yagi antennas, the dish antennas, the luneberg lenses, and the phased arrays are some examples of the many different arrangements that can lead to successful directional RF signal communication. The other examples include phased arrays [23].

2.3.3 Antenna Directivity

Directivity is described as the proportion of the radiation intensity in a certain direction from an antenna to the radiation intensity that is averaged out in the overall directions. Directivity is usually measured in dB. The absolute power that is really radiated by the means of the antenna is divided by 4, and that number is equal to the average radiation intensity. Once, the direction isn't determined very precisely, the direction in which the radiation intensity is greatest is presumed to be the correct one. To be more specific, the value of D for a nonisotropic source is equal to the proportion of its radiation density in a given direction relative to the value for an isotropic source. In order to represent the D of the antenna the following mathematical equation can be utilised [24]:

$$D = \frac{U}{U_o} = \frac{4\pi U}{P_r} \tag{2.4}$$

Where:

D: is refers to the directivity of the antenna;

U: is refers to the intensity of the radiation;

U_o: is refers to the intensity of the radiation for the isotropic antenna; and

P_r: is refers to the radiated power.

2.3.4 Antenna Equivalent Circuit

Figure 2.3 provides a visual representation of the antenna that is associated with the transmitter equivalent circuit. The resistance of the radiation, denoted by R_r, and the resistance of the loss, denoted by R_L, can be expressed as two separate sections when referring to the resistive component of the antenna. In general, the power that is consumed by the R_r is the power that is actually radiated by the means of the antenna, and the power that is wasted inside the structure of the antenna due to the disposition of the metal that was utilised in the configuration of the antenna is denoted by R_L [24].

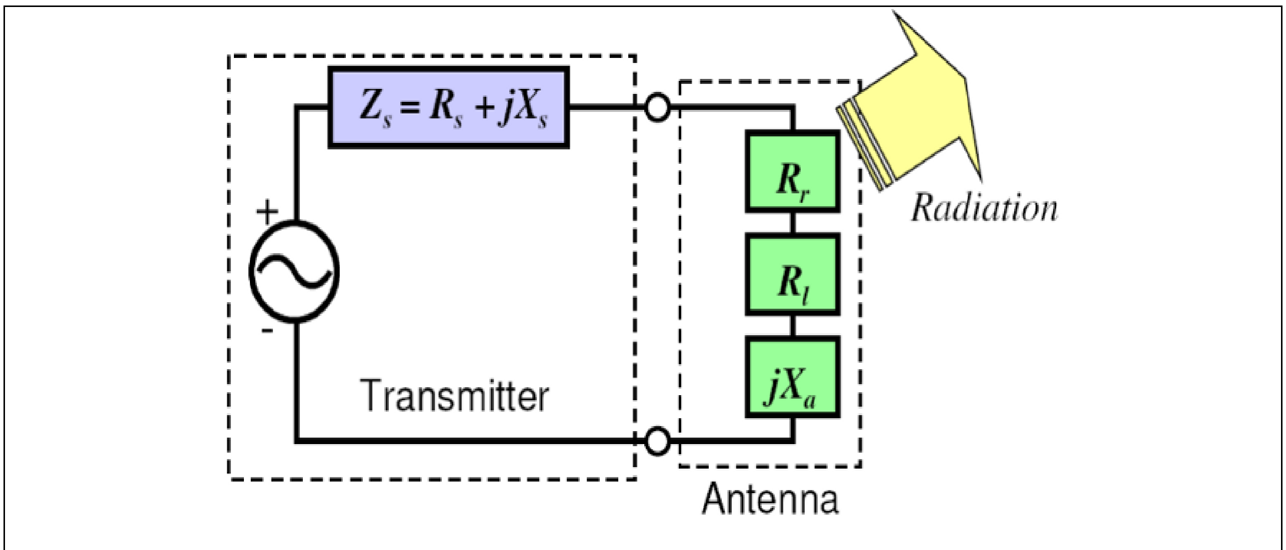


Figure 2.3: Equivalent electric circuit for the antenna [24].

Following is a mathematical expression that can be used to describe the input impedance for the antenna [25]:

$$Z_a = R_r + R_l + jX_a \tag{2.5}$$

where:

Z_a: is referring to the impedance for the antenna in (Ω); and

X_A: is referring to the reactance for the antenna in (Ω).

Because only the power that is radiated normally describes a reasonable or practical purpose, it is required to express the efficiency of the antenna's radiation, which can be defined as following:

$$e = \frac{P_r}{P_{in}} = \frac{R_r}{R_r + R_L} \tag{2.6}$$

Where:

e: is referring to the efficiency of the antenna; and

P_{in}: is referring to the input power that received by the antenna.

As a direct consequence of this, an antenna that has a high radiation efficiency appears to have a high associated R_r in comparison to the R_L. In order for an antenna to function properly, the source and the antenna should have the capacity to transfer the maximum amount of power to one another. Once the impedance of the antenna, denoted by the symbol Z_a, is matched to that of the transmitter will the power transfer be at its maximum (Z_s). In the event that the matching amidst the impedances is not successful, some of the power may be reflected from the antenna to the source direction. This contributes to the figuration for the standing waves, which can be interpreted by the means of a parameter called as the Voltage Standing Wave Ratio (VSWR). The VSWR is used to measure the degree to which there is a mismatch amidst the antenna side and the source of the electrical wave. Therefore, a higher value of the VSWR indicates a higher level of impedance mismatching, whereas a minimum value indicates that the impedance is matched well. The acceptable range of the VSWR typically falls within the range of 1:2. The ideal case has a VSWR of unity, which indicates that the antenna is receiving the full amount of power transmitted by the source, or, to put it another way, that the reflection coefficient is equal to zero. The VSWR can be described in the following way [26]:

$$VSWR = \frac{1 + |\Gamma|}{1 - |\Gamma|} \tag{2.7}$$

$$\Gamma = \frac{Z_a - Z_S}{Z_a + Z_S} \tag{2.8}$$

Where:

Γ: is referring to the reflection coefficient.

2.3.5 Antenna Polarization

Antenna polarization depicts how a wave front's electric field (E-field) or appealing field (H-field) affects it. If the field lines oscillate within a single hub, they are referred to as directly energize. If not at 0° or 90°, a straight captured receiving antenna can be flat (0°), vertical (90°), or cross energized. Round polarization is a type of curved polarization in which the E-field lines form a circle and perfectly rotate around the origin. It is critical to have polarization-matched receiving and transmitting wires, else a portion of the transmission force will be lost due to the polarized mismatch. This is known as the polarization misfortune factor (PLF), which can be depicted with the equation [28]:

$$PLF = cos^2\emptyset \tag{2.9}$$

2.3.6 Antenna Return Loss

Return loss (S_{11}) is an amount that is frequently utilized in RF circuits, particularly in situations where impedance matching is essential. The fraction of a signal that is returned to its source as a direct result of an impedance mismatch is referred to as the return loss. The return loss method is similar to the VSWR, but it is utilized extensively in implementations where feeders are not utilized, or where feeders are very short in comparison with a wavelength; as a result, the concept of standing waves is not applicable in these situations. In most cases, implementations involving circuits make benefit from return loss, while feeders and transmission lines make usage of VSWR.

Return loss is defined as the reduction in power that is present in a signal that has been returned or reflected as a result of a break or discontinuity in a transmission line or an optical fiber. The standard unit of measurement for this is the decibel. To put it another way, if all of the power were to be transferred to the load, there would be a return loss that was infinite. If, on the other hand, there is a termination that is open or has a short circuit, then all of the power will be returned, and there will be no return loss. The S_{11} can be interpreted as, a mismatch on the transmission line can cause a certain amount of power to be reflected back at the antenna port, and this phenomenon is measured by the S_{11} parameter. The amount of energy that is delivered to the antenna is not measured by the S_{11} when it is connected to a network analyzer; rather, it measures the amount of energy that is returned to the analyzer [29].

2.3.7 Antenna Bandwidth

The ability of an antenna to function across a wide spectrum of frequencies is referred to as its bandwidth, abbreviated as BW. The antenna's input impedance, radiation pattern, side lobe rate, polarisation, beamwidth, and gain are all approximately comparable to their values when measured at the centre frequency. This frequency range could be considered the antenna's bandwidth. It could also be considered the frequency range on either side of the centre frequency. The ratio of the high frequency to the low frequency can be thought of as the BW ratio. The BW ratio of an antenna is the ratio of the difference in frequency to the centre frequency. In light of the interpretation that came before, the BW could be characterized as follows [30]:

$$BW = \frac{f_2 - f_1}{f_o} \times 100\% \tag{2.10}$$

$$BW_r = \frac{f_2}{f_1} \tag{2.11}$$

Where:

BW_r : is referring to the BW ratio;

f_2 : is referring to the higher frequency;

f_1 : is referring to the lower frequency;

f_o : is referring to the centre frequency.

In the case of the $BW_r \geq 2$, later the antenna can be considered as a wideband and otherwise, the antenna is considered as a tight BW. The utilized approach to estimate whether the antenna functioned accurately at the needed frequency bands, this is done by the means of determining the VSWR or the S_{11} pattern. To function in the correct manner the following condition should be satisfied $S_{11} \leq -10$ dB. Figure 2.4 shows the calculation for the antenna BW from the S_{11} pattern.

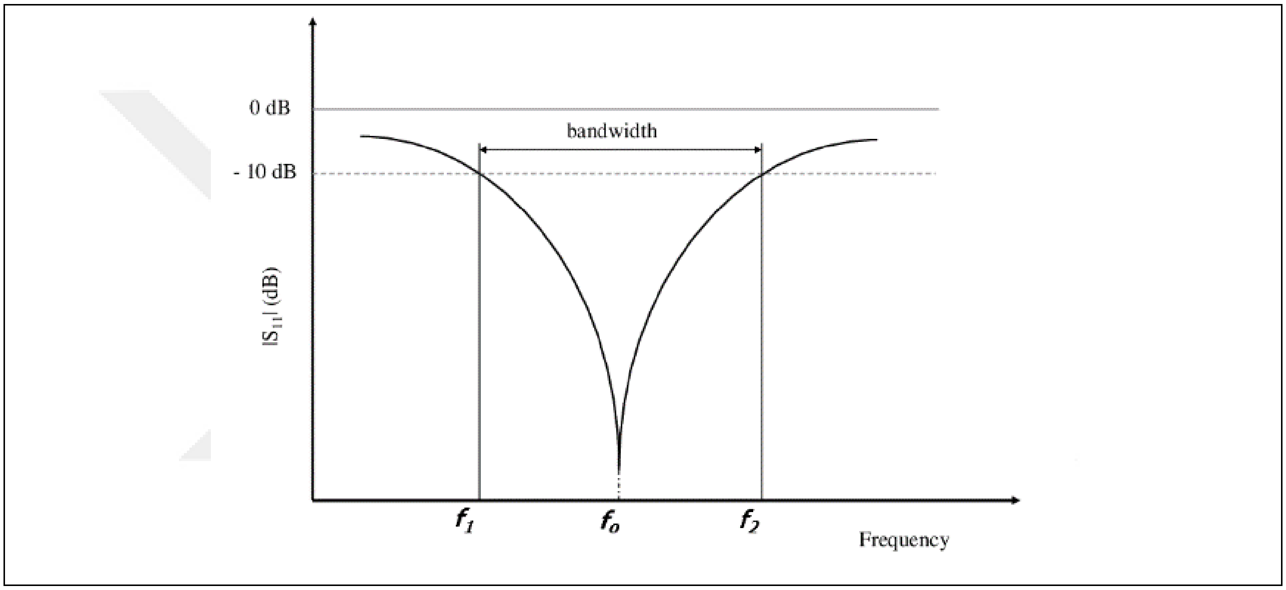


Figure 2.4: Calculation of antenna BW from S_{11} [30].

2.3.8 Types of Antenna Polarization

Antenna in dealing with the electromagnetic wave that is radiated through it, the expression of the polarization is utilized. It is the direction of the electric field vector of the electromagnetic wave that is radiated by the antenna with a negligible quantity of losses. The polarization of the antenna is considered as an essential parameter that is needs to be taken into consideration during the process of selecting or installing the antenna. It is merely connected to the properties that are exhibited by wave polarization. The wave that is radiated or received by the means of the antenna in a particular direction is connected to the antenna's polarization in either case. On the other hand, when the direction of travel is not specified, antenna polarization is determined by looking at the direction in which the gain is greatest. The illustration of electromagnetic waves in free space that can be found below, in Figure 2.5, includes both the electric and magnetic field components [31].

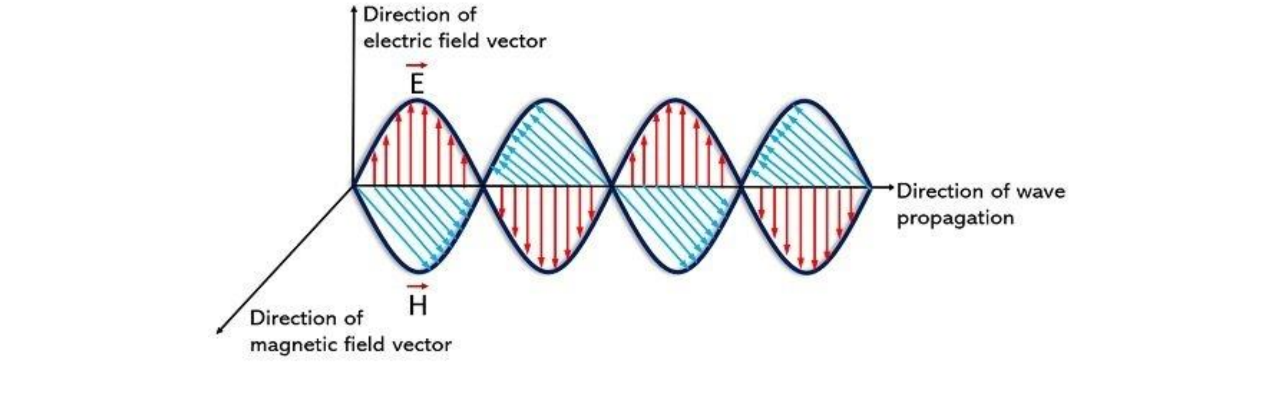


Figure 2.5: Illustration for the E and H-fields for the wave in free space [31].

The classification for the types of the antenna polarization is illustrated in Figure 2.6 and listed as follows [31]:

a) Linear polarization: is a type of polarization that refers to the situation in which all of the waves have a similar arrangement in space, either vertically or horizontally.

b) Circular Polarization: An antenna is said to have circular polarization if it is organized to radiate in all oof the planes, including the horizontal, the vertical, and all planes in among.

c) Elliptical Polarization: Similar to circular polarization, elliptically polarized waves are created by combining two linearly polarized waves. In this case, however, the two linearly polarized waves are superimposed. Recent discussions on circularly polarized waves have revealed that the amplitude of the two linearly polarized waves must be exactly the same.

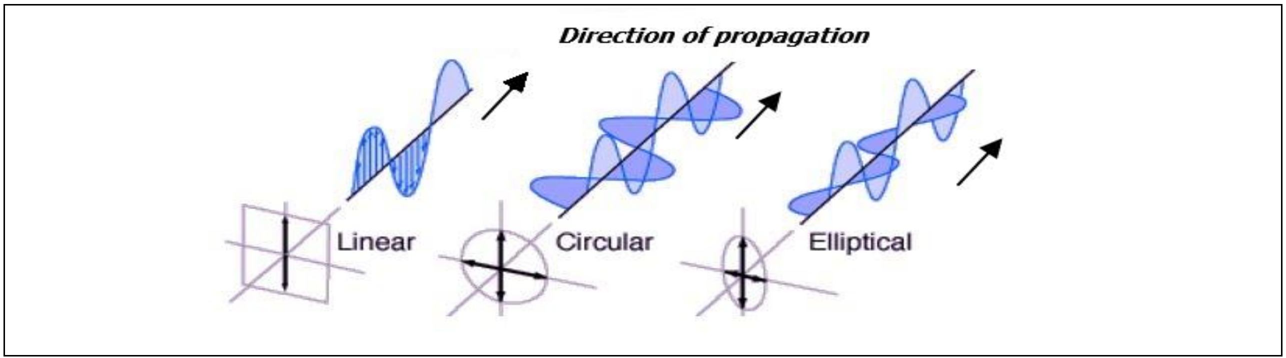


Figure 2.6: Types of the antenna polarization [31].

2.4 MICROSTRIP ANTENNAS

In the field of telecommunications, a microstrip antenna, which is also referred to as a printed antenna, is typically understood to refer to an antenna that was fabricated on a printed circuit board employing the method called the photolithographic for the printed circuit board (PCB). It can be thought of as an internal antenna. The microwave frequency range is where they are utilized the most. Each microstrip antenna consists of a patch antenna made of metal foil cut into a variety of shapes and a ground plane made of metal foil that is adhered to the top surface of a PCB. The ground plane is attached to the underside of the PCB using adhesive, and the patch antenna is attached to the top surface of the PCB. The vast majority of microstrip antennas are built as arrays of multiple patches that are organized in a two-dimensional plane. Transmission lines made of foil microstrips are frequently utilized in order to make the connection between the antenna and the RF apparatus. In either scenario, the antenna and the ground plane are the locations where the radio frequency current is applied (or where the received signal is generated, in the case of receiving antennas). Microstrip antennas have experienced a meteoric rise in popularity over the past few years for a variety of reasons, including their thin planar profile, which makes them ideal for incorporation into the surfaces of consumer products, aircraft, and missiles; their simplicity of fabrication using printed circuit techniques; their compatibility with on-board integration with the rest of the circuit; and the possibility of adding active devices to the antenna, such as microwave integrated circuits, to the antenna. The microstrip antennas have evolve extremely widespread due to their thin planar profile, which allows them a portion of an antenna. In general, the microstrip antenna type is consists of a dielectric material named as the substrate. On the top of the substrate, the patch of the antenna is installed and at its bottom, the ground plane is made. Usually, the patch and the ground are made by the mean of the conducting material such as the copper, silver, gold or the all of the present conductive materials. Figure 2.7 shows the general architecture for the microstrip antennas [32].

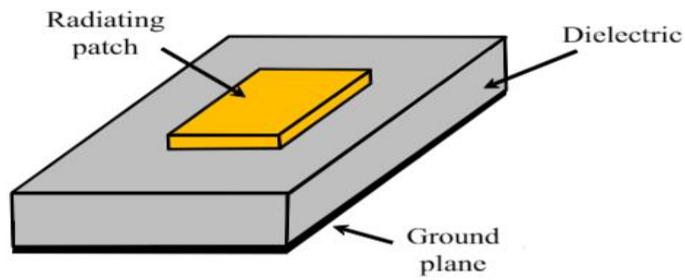


Figure 2.7: General structure for microstrip antenna [32].

2.4.1 Advantages of MP Antennas

The utilization of microstrip antennas comes with a number of benefits and a number of drawbacks, all of which will be enumerated in the following subsection [33], [34].

A. Advantages:

a) Because of the low cost of production, it can be produced in enormous quantities.

b) Dual and triple frequency operations are possible.

c) Microwave integrated circuit is easily integrated.

d) This antenna is smaller in size; thus, it will fit in tiny spaces and gadgets.

e) Low price.

f) Reasonable performance

g) Light in weight and volume, with a low mass.

h) Both linear and circular polarization is supported.

i) Microstrip patches come in a several of the forms, including rectangles, triangles, and squares, all of which are readily etched.

j) Microstrip antennas are simple to combine with MICs and MMICs.

k) When installed on a hard surface, they are extremely durable.

B. Disadvantages of Microstrip Antenna:

a) It offers a lower gain.

b) Limited power handling.

c) Its excitation of surface waves.

d) Superfluous radiation from feeds and intersections.

e) It has a more elevated level of cross-polarization radiation.

f) It offers low efficiency.

g) It offers tight BW.

2.4.2 Feeding Techniques

Feeding strategies are divided into two categories. One is called the conducting method and the second one is called the nonconducting method. The first category is called conducting because the power is transferred into the antenna by the means of a strip line or coaxial While the second category is called as the nonconducting due to the patch of the antenna receiving the source power by the means of the radiation like the proximity and the aperture coupled. The both of techniques will be clearly discussed in the next subsections [35].

2.4.2.1 Coaxial probe feed

The coax cable consists of conductors the first one is called the inner core which is considered as the heart of the cable. While the second one is referred to as the shield conductor. The configuration of the coaxial probe feeding mechanism is shown in Figure 2.8. The patch is nourished by a coaxial feed coming up from the base (SMA connector). The external shield of the coax is the one that is attached to the ground plane, while the internal core is the one that is attached to the radiating patch by the means of a gap drilled in the substrate. This process of feeding the antenna makes it possible for the feed to be placed at any location on the patch in order to acquire the desired level of impedance matching [35].

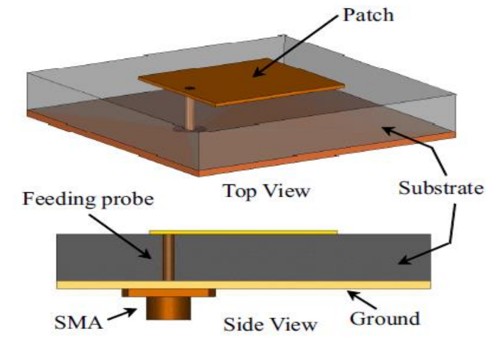


Figure 2.8: Arrangement for the coax feeding [35].

One of the most important disadvantages of this type of feeding is the difficulty of modelling and manufacturing. In addition, this method does not make the antenna planner because of the use of solder and the presence of the cable connector.

2.4.2.2 Line feeding

In this feeding process directly attached to the perimeter of the patch is a strip line that conducts electricity. As can be seen in Figure 2.9, the line impedance of the feed line is set to 50 ohms, and it is attached to the correct location on the edge of the patch in order to provide a precise impedance match among the feed line and the radiating patch. The fact that the feed line and patch can be engraved on the upper of a similar substrate is the primary benefit of the feeding procedure. As a result, the arrangement can be flattened out into a planar configuration [35].

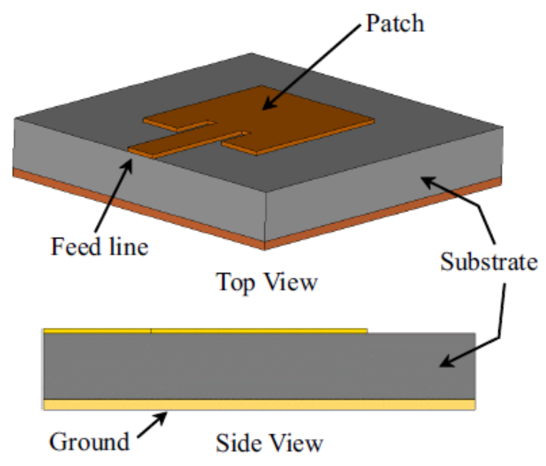


Figure 2.9: Arrangement for the line feeding [35].

The presence of additional radiation from the feed line, which is typically undesirable and affects the radiation pattern of the antenna, is the primary drawback of this type of antenna feeding method. This is the main disadvantage of this type of antenna feeding method.

2.4.2.3 Aperture coupled feeding

In order to solve the previously mentioned problems that were related to the additional feed radiation and the non-planar structure; the non-conducting schemes for the feeding can be applied. In this method of the antenna feeding procedure, a couple of substrates are utilized. Whereas, the antenna structure is composed of multiple layers. As can be noted from Figure 2.10, a conducting ground plane sits among the feed line and the patch. This keeps the two components physically distinct usually. By the means of a short rectangular slot inserted at the ground plane, radio frequency power is transmitted from the strip line to the patch. The antenna efficiency of this feeding procedure is lower when compared to that of other techniques, despite the fact that this method is very simple for the modelling and eliminates the presence of additional radiation from the feed [35], [36].

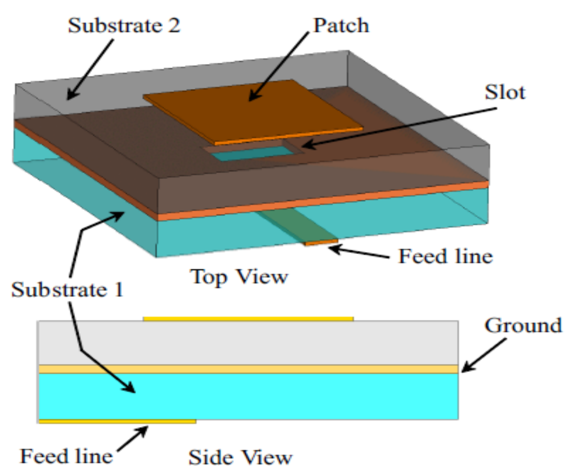


Figure 2.10: Arrangement for the aperture coupled feeding [36].

The main drawback of this feeding scheme is the fabrication and modelling difficulties. Also, due to the pair of the substrates the overall size of the antenna is raised.

2.4.2.4 Proximity coupled feeding

In this particular form of feeding, couple of the dielectric substrates are utilized, and the feed line is positioned in among the couple of the substrates, as exhibited in Figure 2.11. Over the supreme of the upper substrate is where the radiating patch is located. The ability to supply a very high BW is the primary benefit of utilizing this feed procedure. This scheme also supplies options for a couple of distinct dielectric media, one of which can be employed for the patch, and the other can be used for the feed line, in order to optimize the performances of each component [37].

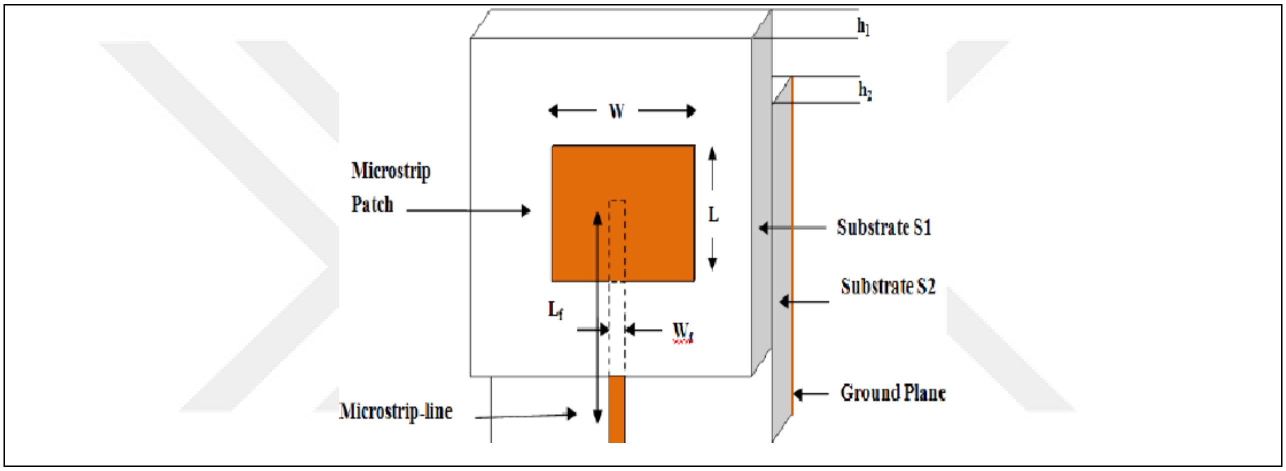


Figure 2.11: Arrangement for the proximity coupled feeding [37].

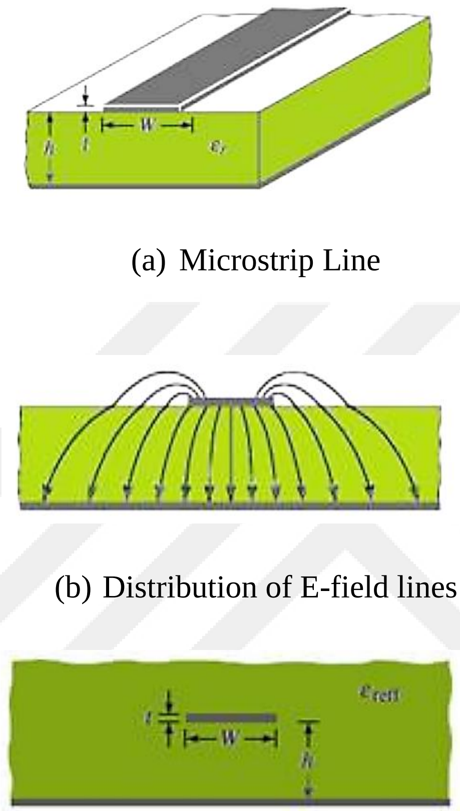
Controlling the length of the feed line and the width-to-line ratio of the patch is a couple of the variables that can be used to achieve matching. The fact that these couple dielectric layers require to be properly aligned makes this feed scheme particularly challenging to fabricate, which is the feed scheme's most significant drawback. In addition to this, there is a general thickening that takes place throughout the antenna.

2.4.3 Analysis Techniques

In order to model and analyse the MP antennas in the mathematical form, there are three methods that can be used which are the transmission line, the cavity, and the full-wave method.

2.4.3.1 Transmission line technique

The MP antenna is represented in this model by a couple of the slots with a size of width (W) and thickness (h), which are kept apart by the means of a transmission line with length L. The microstrip is essentially a line that is not homogeneous and is composed of pair of the dielectrics, which are typically air space and the substrate, as illustrated in Figure 2.12 [38].



(a) Microstrip Line

(b) Distribution of E-field lines

(c) Effective dielectric of the substrate

Figure 2.12: Representation for the MP antenna in the transmission line modelling [38].

As a result, as can be seen in Figure 2.12-b, the majority of the E-field lines are located in the substrate, while some of the lines extend into the surrounding air. Because of this, the pure transverse electromagnetic mode of transmission is not supported by this transmission line. This is due to the fact that the phase velocities in the air and the substrate would be different from one another. Alternately, the quasi-TEM mode would end up being the most important mode of propagation. Therefore, in order to account for the fringing and the wave propagation in the line, it is necessary to obtain a value for the effective dielectric constant, which is denoted by $\varepsilon_{r_{effective}}$. Because the fringing fields around the edge of the patch are not confined in the dielectric substrate but are also spread in the air, the value of $\varepsilon_{r_{effective}}$ is a little less than the value of the ε_r. This is because the previously mentioned Figure 2.12 above presents that the fringing fields are spread out in the air [38].

2.4.3.2 Cavity technique

A cavity model has been developed for the purpose of researching MP antennas. This model is based on the assumption that the space between the microstrip patch and the ground plane is a resonance cavity, with electric conductors forming the ceiling and floor and magnetic walls along the edge of the conductor. Figure 2.13 illustrates this cavity model. This supposition is supported by the observation that there is a distance separating the patch and the ground plane [39].

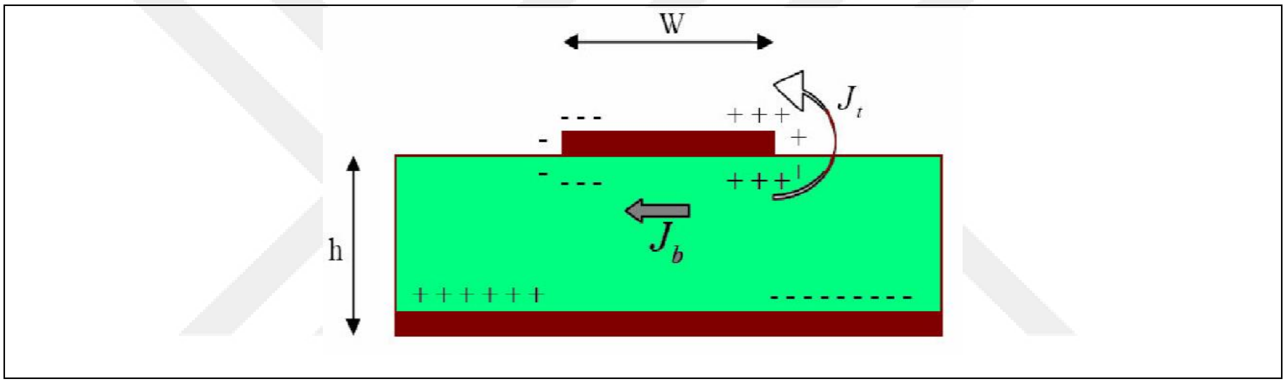


Figure 2.13: Charge distribution at the MP antenna [39].

The assumption for the cavity MP antenna analysis method is made on the basis of the below-presented points:

a) There are only 3 components for the field in the area that is encompassed by the cavity: the E-component along with the z-axis (Ez) and two components of the H-field along the x and y-axis.

b) In the MP antenna due to the h is extremely thin which usually in the limit of ($h << \lambda$); so that, the field in the inner area doesn't differ with the z-coordinates for all of the frequencies.

c) At no point does the electric current that is flowing through the microstrip patch have any component that is normal to the edge of the patch.

With the edge extended a little to take into the consideration the presence of the fringing field, this model does an adequate job of investigating microstrip resonators. In order to begin calculating the field that exists within the cavity, the first step is to determine the underlying mechanism of the cavity. Figure 2.13 illustrates how a charge distribution will be established on the upper and lower planes of the MP antenna when the antenna is connected to a microwave source. This will occur when the MP antenna is used. Two opposing forces—attractive forces and repulsive forces—regulate how the charge is distributed throughout the system. Because of the attractive force that exists between the opposite charges that are located on the patch and the ground plane, a current density, denoted by the symbol (J_b), is produced inside of the dielectric that is located at the base of the patch. As a result of this, a new density of current has been designated as (J_t). Charges that are identical to one another are attracted to one another; this attraction produces a force of repulsion that tends to push charges upward, beginning at the bottom of the patch, moving around the perimeter of the patch, and arriving at the top of the patch.

2.5 UWB ANTENNAS

Over the course of the past ten years, several incoming kinds of omnidirectional UWB antennas have been created in tandem with the miniaturization of wireless system components and the increase in operating frequency. Both the UWB planar monopole antenna and the UWB engraved monopole antenna, as can be seen in Figure 2.14, are largely derived from the fundamental regulations of conventional UWB antennas such as the biconical antenna, the cone-disc antenna, the cage antenna, and so on. This can be seen by comparing the two types of antennas to one another. These two kinds make up the majority of the UWB monopole antenna. They are able to supply practically the same BW and radiation performances as traditional UWB antennas, but with much smaller volumes because they are based on multiple techniques that improve omnidirectional radiation and dimension lowering, respectively [40].

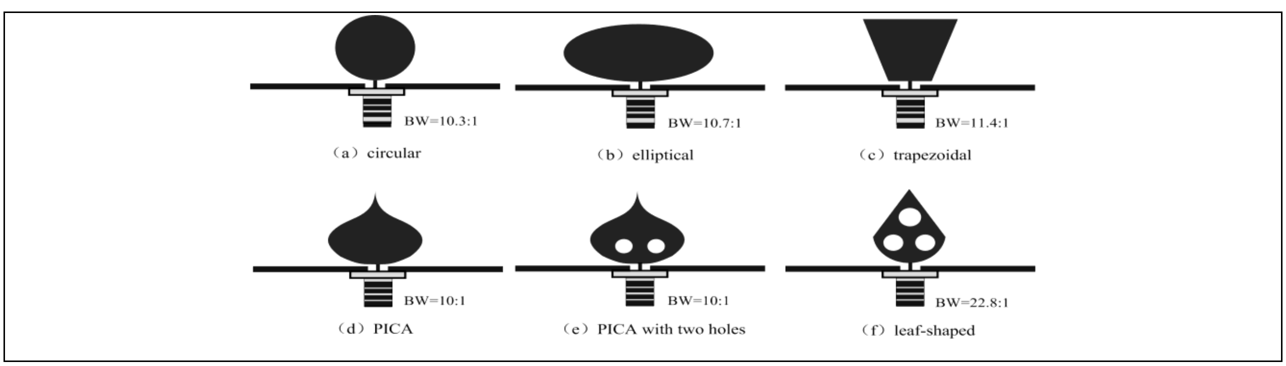


Figure 2.14: Some of monopole-based UWB antennas [40].

It was first reported in 1976 that the planar monopole antenna could be used for UWB applications. This capability can be utilized today. It can be implemented by switching out a wire monopole for a planar monopole, which is then placed above a ground plane and is usually fed by a coaxial probe. In this way, it can perform as designed. Because of their excellent wideband performance, numerous planar monopole antennas have been utilized up until this point. In this investigation, a comparison was made between the bandwidths of several different planar monopoles. The shapes of these monopoles could be anything from circular to elliptical to trapezoidal to rectangular. Figure 2.15 depicts a number of different examples of antennas, each of which has an impedance bandwidth ratio that ranges anywhere from 2:1 to more than 10:1.

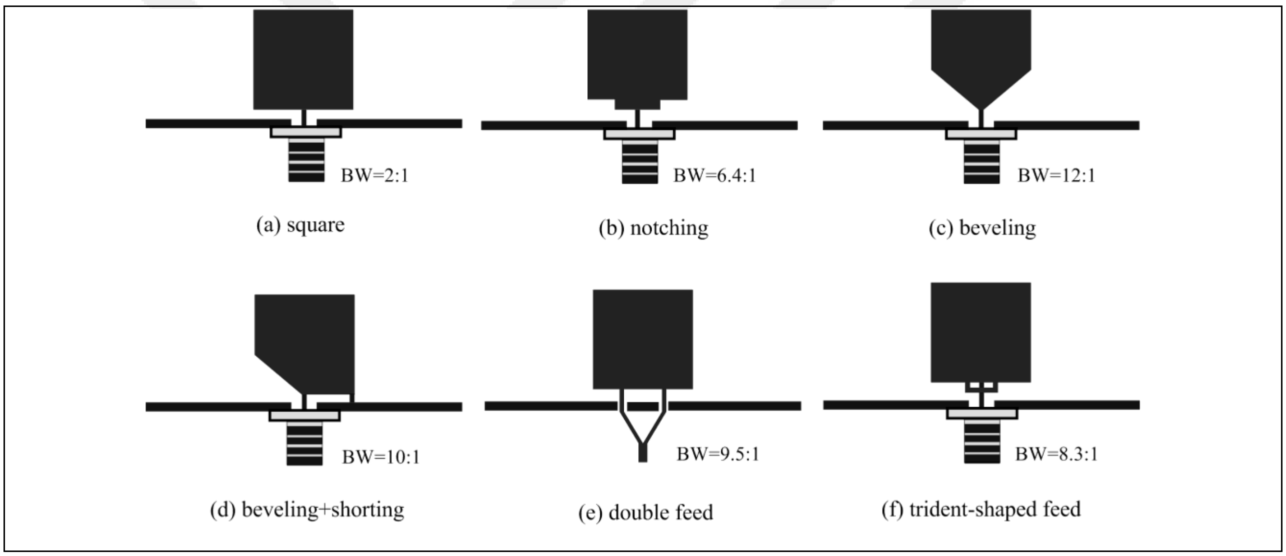


Figure 2.15: Some of square shape monopole-based UWB antennas [40].

The results show that compared to other monopole shapes, circular and elliptical monopoles have significantly better bandwidth performance, with both shapes achieving an impedance bandwidth ratio of greater than 10:1 (Elliptical monopole: 1.2113 GHz and Circular Monopole: 1.1712 GHz). For many research projects, the best option was a trapezoidal planar monopole antenna installed above the ground plane. They were also able to achieve a bandwidth ratio of 11:1 or higher. The planar inverted cone antenna (PICA) is a fascinating alternative to the usual antenna designs. The theoretical bandwidth-to-impedance ratio for this architecture is greater than 10:1, and the ratio for patterns is close to 4:1. Figure 2.15 demonstrates how the PICA was modified by adding two circular holes to improve the pattern bandwidth ratio. Without sacrificing any of the modification's impedance performance, this tweak yields a notable improvement in the radiation pattern. This improvement allows the two-circular-hole PICA antenna to radiate in an omnidirectional pattern with a very low cross-polarization and a BW ratio of up to 7:1 as reported in [40].

The previously mentioned planar types for the monopole antennas are able to achieve a UWB characteristic based on a variety of approaches, but they all require a vertical ground plane. This results in an increase in the size of the antenna and makes it difficult to integrate it with monolithic microwave integrated circuits. The Printed or the engraved UWB-based monopole antennas are more common for use in the portals wireless appliance implementations because they are simpler to integrate than planar UWB monopole antennas. This is one reason why they are additionally popular. Monopole patches and ground planes are the two components that make up the engraved UWB monopole antenna most of the time. Both are engraved on one face of the substrate, either the same face or the opposite face (i.e., bottom), as shown in Figure 2.16, and a microstrip or CPW feedline is utilized in order to power the monopole patch. Since multiple of the investigations have presented this sort of antenna with the wideband features in 2004, a variety of engraved monopole antennas have been investigated in the years that followed, with the primary focus being on the geometries of the monopole and the ground plane [40].

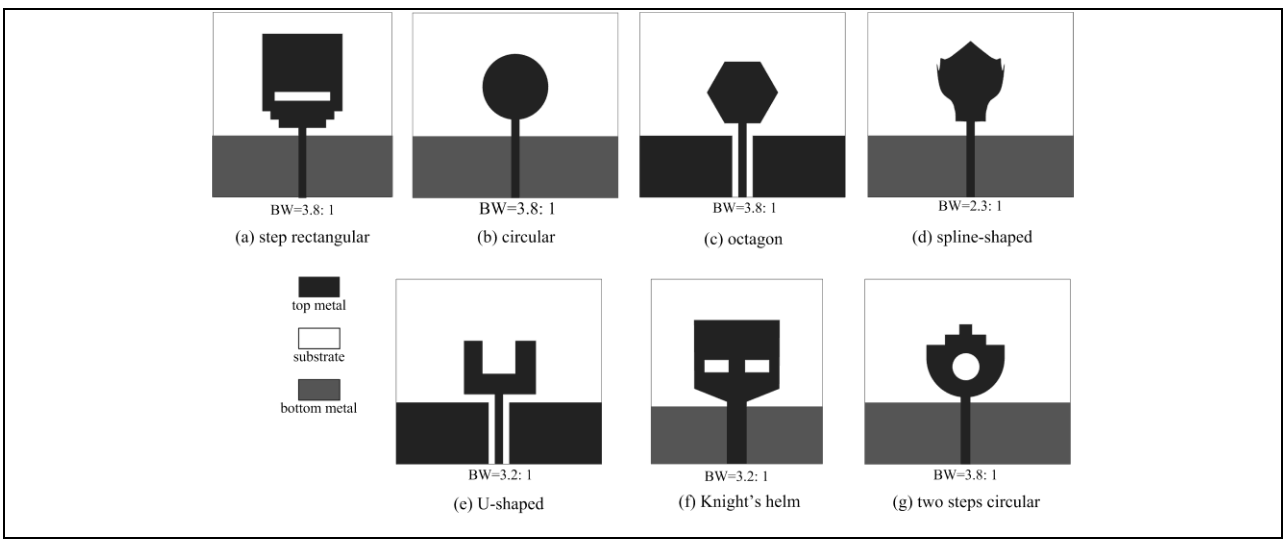


Figure 2.16: Some of printed UWB antennas [40].

2.6 GRAPHENE MATERIAL

The graphene material is a modern innovation for the electrical, electronic, and other applications. The graphene a formed from a one-atom-thick sheet of the carbon atoms and organised in the shape of a hexagonal lattice, as demonstrated in Figure 2.17 [41].

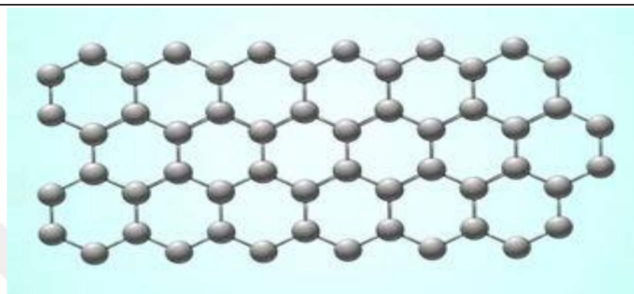


Figure 2.17: Structure for graphene [41].

Graphene is the fundamental component necessary for the formation of the numerous other forms of carbon, such as the graphite or the carbon nanotubes. It is possible to wrap the graphene into zero-dimensional fullerenes, roll it into the form of the carbon nanotubes, and find graphite in kind as a freely manner piled form. All of these transformations are possible with graphene as illustrated in Figure 2.18 [42].

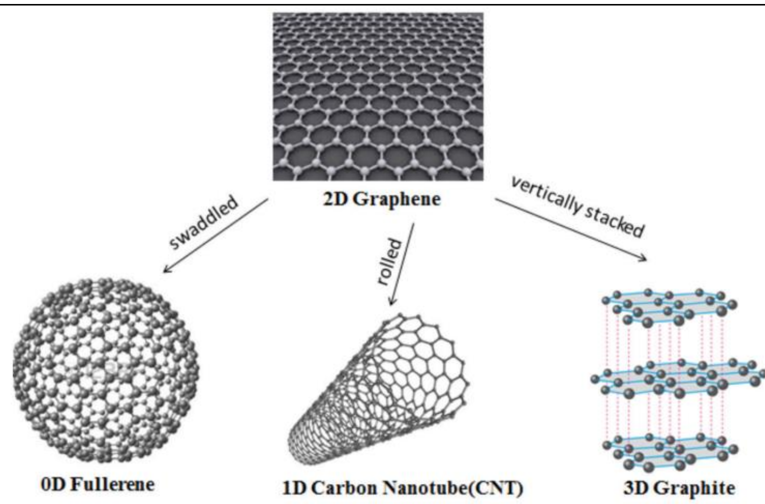


Figure 2.18: Many other carbon allotropes can be built from graphene [42].

At the University of Manchester in 2004, Andre Geim and Konstantin Novoselov accomplished the first successful production of pristine graphene via mechanical peeling. This graphene was then electrically characterized. Up until recently, researchers had a hard time obtaining graphene films with a large surface area using the mechanical peeling procedure. Therefore, in order to synthesize graphene, a large number of researchers investigated and tested various methods, including chemical vapour deposition (CVD) on metal substratum, epitaxial outgrowth on SiC, and reduction from graphene oxide flakes. Graphene constructed by CVD exhibited unique features, and it was successful in producing graphene with a large surface area and of a high grade despite having only a scarce sheet [42].

2.6.1 Characteristics of Graphene Material

Graphene is a substance with exceptionally intriguing properties. These properties, along with the wealth of carbon in nature, have made graphene an exceptionally concentrated on material with extraordinary conceivable outcomes. The following are some of the grapheme's most notable characteristics [43]:

a) High thermal conductivity

b) High electrical conductivity

c) Tunable electric surface impedance

d) High flexibility and adaptability

e) High hardness

f) High block

g) It is unaffected by ionizing radiation

h) It is incapable of supporting the growth of microscopic organisms

i) It also uses less electricity than other compounds.

2.6.2 Types of Graphene

There are different types of graphene some of which are named according to the method of preparation. Below some of the types of graphene are listed [43], [44]:

a) graphene oxide

b) flawless graphene

c) functionalized graphene

d) graphene quantum spot

e) lessened graphene oxide.

Among various 2D materials, graphene has gotten broad examination consideration in the last 2 thirty years because of its entrancing properties.

2.6.3 Applications of Graphene

Graphene is a staggeringly varying material and can be gotten together with various parts (counting gases and metals) to convey different materials with various unparalleled properties. Researchers from one side of the planet to the other continue to ceaselessly research and patent graphene to acquire capability with its various properties and expected applications, which include [45]:

a) Super power batteries

b) Semiconductor applications

c) High power CPUs

d) Supercapacitors

e) DNA sequencing

f) Water channels

g) Radio antennas

h) Touchscreens (for LCD or OLED shows)

i) Sun powered cells

j) Spintronics-related items

k) Filter for microwaves

2.6.4 Graphene Electric Conductivity

Once discussing graphene in the context of the fields of communications and electronics, the parameter that is considered to be of the utmost significance is the conductivity for the electric current. The electric conductivity is a function of the direct current (DC). Once a voltage is made on the thin graphene layer its conductivity is boosted to be high. In order to represent the conductivity of graphene the Kubo form is applied as follows [41]:

$$\sigma_{AC} = \frac{-Jq^2 k_B T}{\pi\hbar^2(\omega - J\tau_t{}^{-1})}\left(\frac{u_c}{k_B T} + 2ln\left(e^{-\frac{\mu_c}{k_B T}} + 1\right)\right) \qquad (2.12)$$

Where:

σ_{AC}: is indicating to the conductivity of graphene at the intra band;

ω: is indicating to the radian frequency;

u_c: is indicating to the chemical potential for the material;

τ_t: is indicating to the time of relaxation;

T: is indicating to the temperature inside the room;

q: is indicating to the elementary of the charge;

$\hbar$: is indicating to the Planck's constant (reduced form);

k_B: is indicating to the Boltzmann constant.

The u_c of the graphene has a relation with the carrier density that could be obtained by the means of the following equation:

$$uc = \hbar v_{fermi}\sqrt{3.14n}, \qquad (2.13)$$

Where:

v_{fermi} = is indicating to the Fermi velocity which is equals $1{\times}10^6$ (m/s).

The value of n (i.e., carrier density) can be directly adjusted through made a DC on the layer of the graphene and can be obtained mathematically by following equation:

$$n = \frac{\epsilon_o \epsilon_r \; V_{DC}}{dq} \qquad (2.14)$$

Where:

ϵ_o: is indicating to the permittivity in air;

ϵ_r: is indicating to the relative permittivity;

d: is indicating to the height of the graphene layer;

q: is indicating to the charge of the electron.

In order to obtain the surface impedance for the material the inverse for the value of Z_G is applied to obtained the equivalent of the impedance, as presented in the following equation:

$$Z_G = 1/\sigma_{AC} \qquad (2.15)$$

3. ANTENNA DESIGNING STRATEGY AND RESULTS DISCUSSION

In this chapter of the thesis, we will present the fundamental and required steps for simulating, designing, improving, and analysing the proposed antennas. Furthermore, we will discuss and present the results obtained after completing the design and improvement process using the CST program's time analyser that is responsible for the antenna simulation process, which provides us with an integrated environment for design and optimisation.

3.1 ANTENNA DESIGN

In this section of the chapter, we will go over, clarify, and discuss the preliminary steps for the proposed antennas design. Beginning with the first design for the regular MP antenna, then etching the slot in order to build the band-rejection feature, and finally introducing the graphene material so that it is compatible with the engraved slot. Later, we will use the same method as for the first design to create a second design with a different shape and properties in order to compare their performance.

3.1.1 UWB-Based Regular MP Antenna Design

The configuration of the introduced design for the antenna is a type of the standard rectangular shaped MP antenna; however, the size (i.e., the dimensions) of the patch and the partial ground plane have been modified in a few different ways. It is essential to select a group of fundamental parameters specific to the introduced antenna in order to get the process of designing an antenna off to the right start. These parameters are specific to the antenna itself and can be summed up as the frequency of the operation, the input impedance, and the characteristic of the dielectric material that is utilized for the proposed antenna substrate. The process of designing an antenna involves the accurate selection of the necessary parameters, which are presented in Table 3.1.

The first step in calculating the dimensions of an antenna is to choose the fundamental parameters that are presented in Table 3.1. This is accomplished with the assistance of the MATLAB program and the equations that are presented below, which are derived from the method of transmission line analysis [46]:

Table 3.1: Chosen essential parameters for the MP antenna design.

Parameter	**Description**
Operation frequency (f_o)	8 GHz
Input Impedance (R_{in})	50 Ω
Substrate Type	FR-4
	Dielectric constant ($\in_r$= 4.3)
	Substrate height ($h = 1.6\ mm$)
Metal Type	Copper

$$W_{patch} = \frac{3x10^8}{2f_o\sqrt{\frac{(\epsilon_r + 1)}{2}}} \tag{3.1}$$

$$\epsilon_{re} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W_{patch}}\right]^{-0.5} \tag{3.2}$$

$$\Delta_{length} = 0.412h\frac{(\epsilon_{re} + 0.3)\left[\frac{W_{patch}}{h} + 0.264\right]}{(\epsilon_{re} - 0.258)\left[\frac{W_{patch}}{h} + 0.8\right]} \tag{3.3}$$

$$L_{ef} = \frac{3x10^8}{2f_o\sqrt{\epsilon_{ref}}} \tag{3.4}$$

$$L_{patch} = L_{ef} - \Delta_{length} \tag{3.5}$$

$$W_{strip} = \frac{2h}{\pi}\left\{\frac{377\pi}{2Z_f\sqrt{\epsilon_r}} - 1 - \ln\left(2\frac{377\pi}{2Z_f\sqrt{\epsilon_r}} - 1\right) + \frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln\left(\frac{377\pi}{2Z_f\sqrt{\epsilon_r}} - 1\right) + 0.39 - \left(\frac{0.61}{\epsilon_r}\right)\right]\right\} \tag{3.6}$$

$$L_{strip} = 3.96 \times W_{strip} \tag{3.7}$$

$$W_{SUB} \cong 2 \times W_{patch} \tag{3.8}$$

$$L_{SUB} \cong 2 \times L_{patch}, \tag{3.9}$$

where:

W_{patch} : is referred to the actual width for the patch;

ϵ_{re} : is referred to the effective dielectric constant;

Δ_{length} : is referred to the expanding in the length due to the presence of the fringing effect;

L_{ef} : is referred to the effective patch length;

L_{patch} : is referred to the actual patch length;

W_{strip}: is indicates to the strip line width;

L_{strip} : is indicates to the strip line length;

W_{SUB} : is indicates to the substrate width, and finally; and

L_{SUB} : is referred to the length of the substrate.

The following equation can be used to calculate the dimensions of the partial ground plane, which is used to accommodate the entire UWB frequency range (i.e., 3.1–10.6 GHz) [47]:

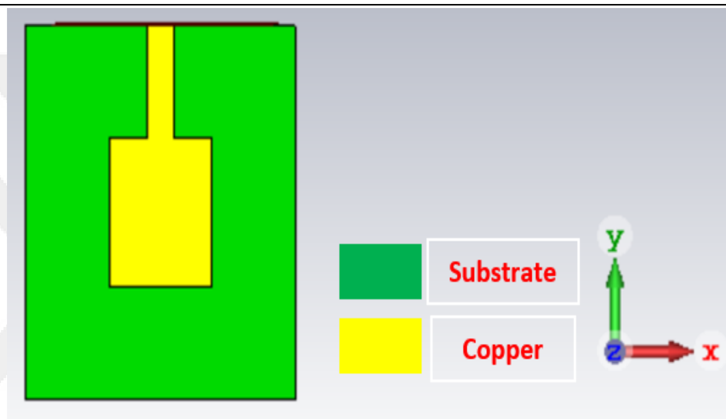
$$L_{Ground} = \frac{0.36 \times C_o}{f_o\sqrt{\epsilon_{re}}}, \tag{3.10}$$

where:

L_{Ground} : is a length indicator for the subsurface layer; and

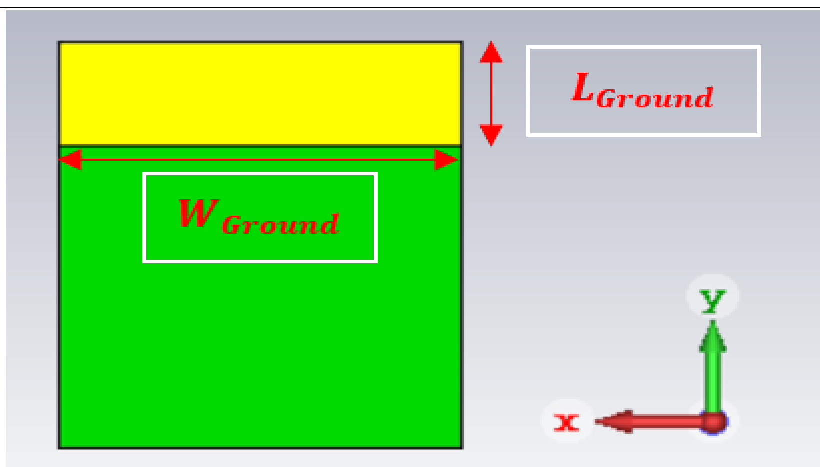
C_o : represents the speed of light in vacuum in m/s.

After completing all of the necessary steps for calculating the dimensions of the antenna using the aforementioned equations and the MATLAB program, the process of simulating the antenna within the simulation program can begin (i.e., CST). The partial ground plane of the regular rectangular antenna is depicted in Figure 3.1, which was generated by simulation software. The antenna generated this image. The simulation results show that the MP antenna has some mismatching and does not cover the entire UWB regime. This is due to the fact that it does not cover the entire frequency range. It can make adjustments to the measured dimensions of the antenna by using the sweeper in the CST. The dimensions of the antenna before and after the modification are shown in Table 3.2.



(a) Front View

Figure 3.1: Simulated MP antenna in CST.



(b) Back View

Figure 3.2: Simulated MP antenna in the CST.

Table 3.2: Calculated and optimized dimensions for the antenna.

Parameter	Calculated Value in (mm)	Altered Value in (mm)
W_{patch}	11.5180	11.60
L_{patch}	8.3680	14.10
L_{Ground}	6.8870	8.40
W_{Ground}	23.0360	30.0
W_{strip}	3.1290	3.0
L_{strip}	12.3930	10.50

3.1.2 UWB with Notch-Band Characteristics

Because UWB technology has such a wide coverage area, neighbouring frequencies from wireless communication networks may cause interference. This is due to the large coverage area provided by UWB technology. The frequency bandgaps have been placed within the UWB regime to mitigate the effects of such a challenge. To accomplish this, a slot is etched onto the antenna patch repeatedly using the same shapes. The following equation is used to rule out the possibility of using a specific frequency [48]:

$$f_{rejection} = \frac{3x10^8}{4(L_1 + L_2)\sqrt{\frac{\epsilon_r + 1}{2}}}, \quad (3.11)$$

where:

$f_{rejection}$: is referred to the bandgap; and

L_1 & L_2 : are respectively, represents size for the slot dimensions (i.e., length and width).

After determining the dimensions of the slot, we restart the simulation of the proposed antenna. Figure 3 shows a standard MP antenna with an etched slot.

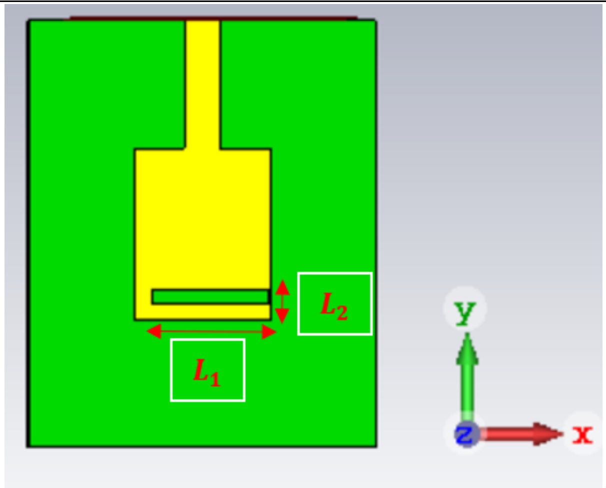


Figure 3.3: Proposed MP antenna design.

3.1.3 UWB with Controllable Notch-Band Characteristics

The unique properties of graphene make it a versatile material. One of the most significant advantages it has in the realm of communications and electronics is that its electrical current conductivity is significantly higher than that of other materials, giving it a significant advantage over those other materials. When the bias voltage is high, the material's conductivity increases, and when the bias voltage is low, it decreases. Taking advantage of this property, graphene was used to fill in the hole left by the patch. Because the graphene layer behaves as a conductor when the bias voltage is applied, the entire size of the antenna can be used while ignoring the slot. Because the graphene layer is a two-dimensional material, this is possible. When the bias voltage is not applied, the graphene sheet exhibits the slot effect because the high resistance prevents current from flowing through it. The terms "ON" and "OFF" refer to the bias voltage and the non-bias voltage, respectively. The graphene contained within the CST is analyzed and modeled using the equations presented in section (2.5.4). Graphene is represented as an ohmic layer impedance in the CST, which means it has both a real and an imaginary part. The value of graphene is calculated by using the ($z = 1/\sigma$). As a result, we will create two distinct CST materials: one for the ON state and one for the OFF state. The proposed antenna configuration, depicted in Figure 3.3, includes the graphene slot as an integral part of the design.

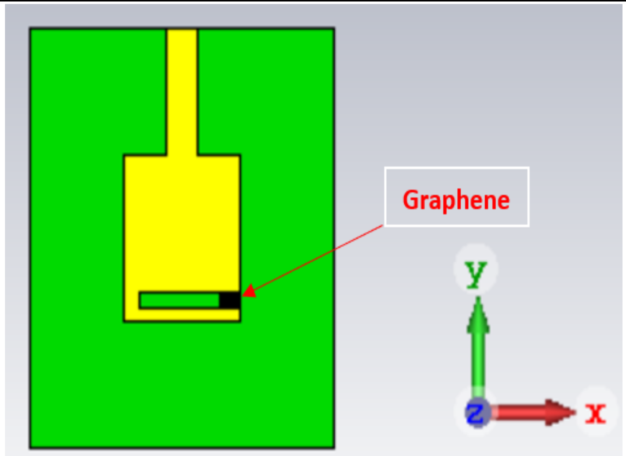
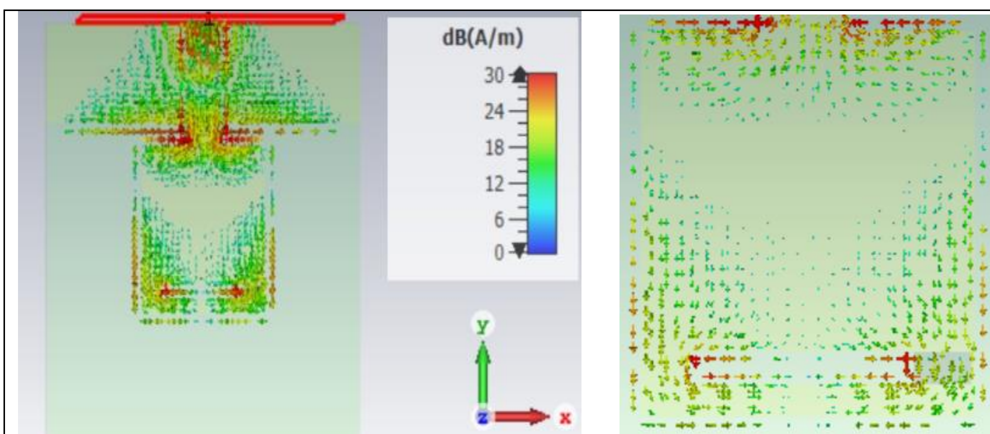


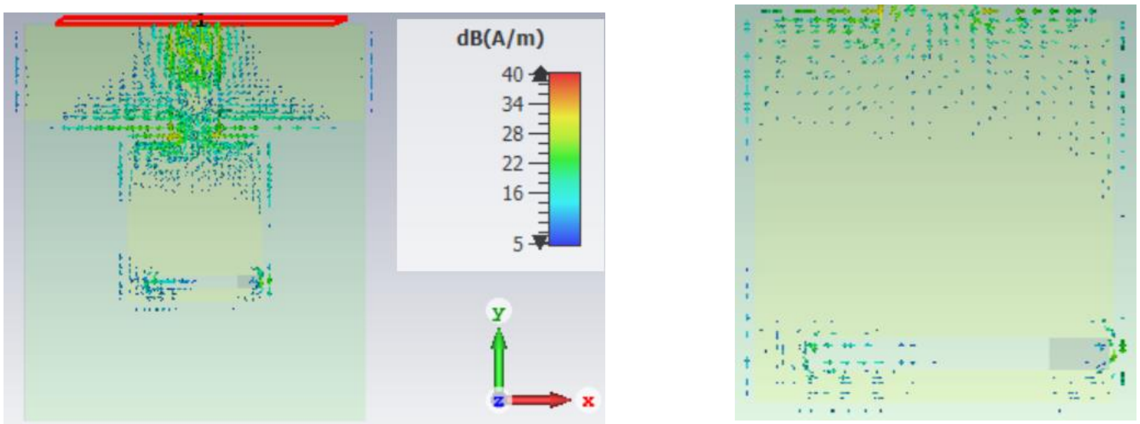
Figure 3.4: Proposed MP antenna with 1.2×2 mm graphene layer.

In order to prove that the conductivity of the graphene sheet of the electric current changes with the change of the DC voltage. We create a current monitor through the simulation program as shown in Figures 3.5 and 3.6. We note that in the case of the applied voltage, which is called the operating state or the ON case, the current passes through the graphene sheet, and this proves that the surface resistance of the material decreases and the conductivity increases, and on the contrary, in the case of no voltage (OFF state) the current isn't pass through the sheet due to the hight impedance of the material.



(a) Current over the patch (b) Zoomed view

Figure 3.5: Current distribution over the patch in the ON case.



(a) Current over the patch (b) Zoomed view

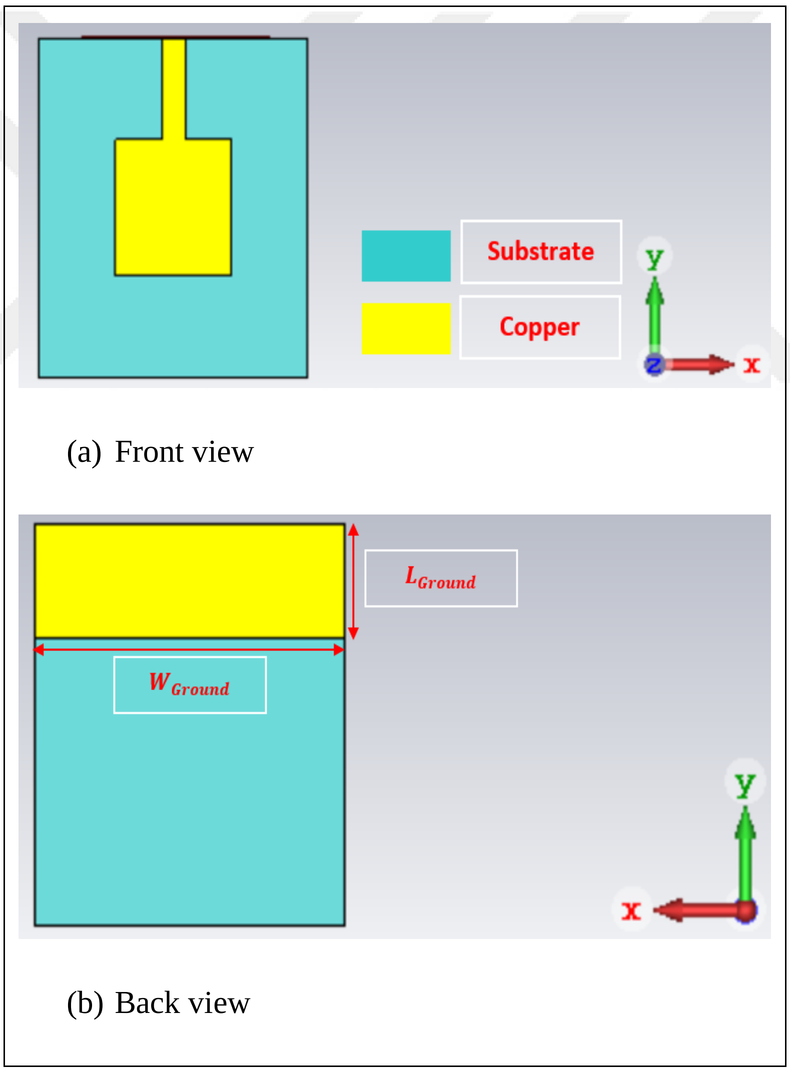
Figure 3.6: Current distribution over the patch in the ON case.

In order to study the effect of changing the dialectic type for the antenna substrate, the shape of the slot, and the graphene slot on the entire antenna performance an additional structure is introduced based on the Rogers RO4003C substrate which is has the same FR-4 thickness but with lower $\in_r$ and loss tangent. The principal parameters for the second structure of the proposed work are presented in Table 3.3.

Table 3.3: Chosen parameters for the 2nd MP antenna design.

Parameter	**Characterization**
Operation frequency (f_o)	7.5 GHz
Input Impedance (R_{in})	50 Ω
Substrate Type	Rogers RO4003C
	Relative permittivity ($\in_r$= 3.5)
	Substrate thickness (h = 1.6 mm)
Metal Type	Copper

After the primary parameters have been determined, the calculations for the MP antenna dimensions can begin. These calculations are performed with the aid of the equations that have been applied in Section (3.1.1) of this chapter. It is essentially to produce a ground plane for the antenna that is only partially complete in order to covering the whole band for the UWB technology regime. This also makes it possible to transmit in an omnidirectional transmission. The partial ground dimensions are obtained via the same procedure that has been done in the design of the first antenna. Figure 3.7 presents the second design for the regular MP antenna within the simulation program.



(a) Front view

(b) Back view

Figure 3.7: The 2nd design for the UWB-based regular MP antenna.

The outcomes for the simulation present that the MP antenna possess some mismatching and does not cover the entire UWB regime. This is due to the fact that it does not cover the entire frequency range. In order to overcome this issue, the antenna shape and size should be altered. The shape alteration for the simulated antenna is started by cutting the edges corners at the strip line side and engrave a small slot in the ground plane, as presented in Figure 3.7. The dimensions for the second design before and after alteration process are presented in Table 3.4.

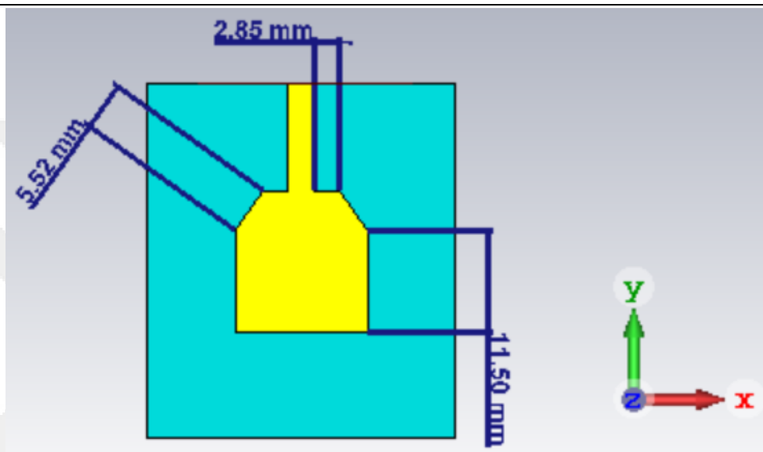


Figure 3.8: Altered second for the UWB-based regular MP antenna**.**

Table 3.4: Calculated and altered antenna dimensions for the second MP antenna.

Parameter	**Calculated (mm)**	**Optimized (mm)**
W_{patch}	13.33333	15
L_{patch}	9.96249	16
L_{Ground}	7.69712	11.5
W_{Ground}	26.66666	35
W_{strip}	0.89998	2.9
L_{strip}	12	12

After the alteration parameter, there is a slight mismatching in the UWB pattern. In order to overcome the present problem a small cut wthin the ground plane of the antenna with a dimension of 1.5×6 mm^2, as presented in Figure 3.9.

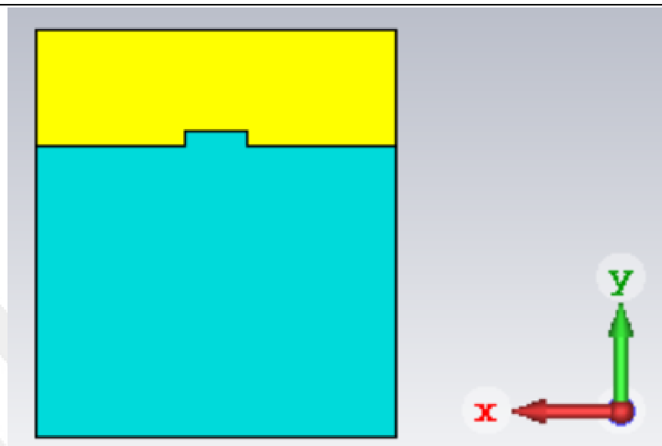


Figure 3.9: Ground plane for the second antenna design.

In order to create the band gap in the frequency regime of the UWB for the purpose of the interference, a rectangular shape slot is introduced in the lower brink of the patch of the antenna with dimensions of 2×8 mm^2, as presented in Figure 3.10. Again, the variable conductivity property of the graphene is exploited to produce a controllable bandgap by applying the bias voltage to the sheet of the graphene material. In the ON case, the graphene conductivity is high so the benefit of the bandgap will be not present and in the OFF case the graphene conductivity is poor, so the current isn't passed through the slot and the bandgap will be generated according to the size and position of the slot.

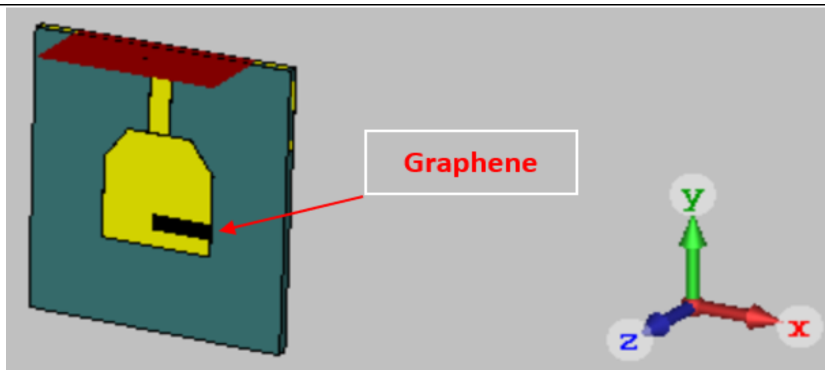
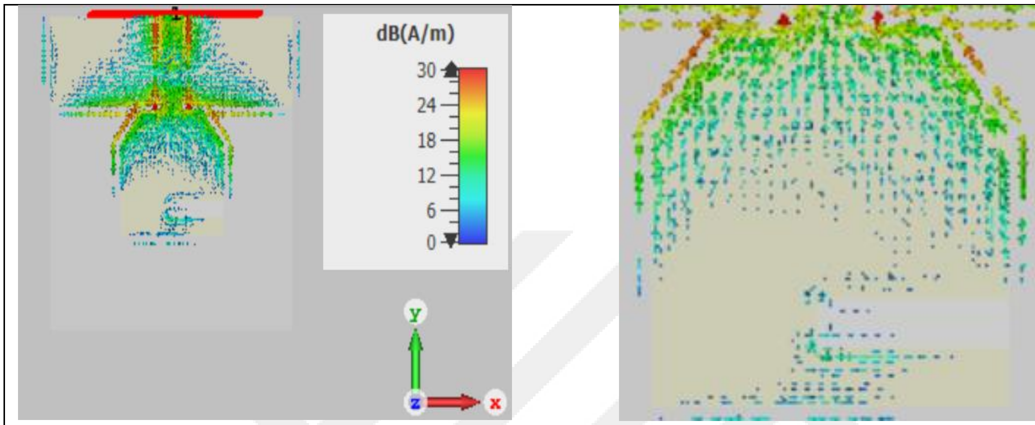


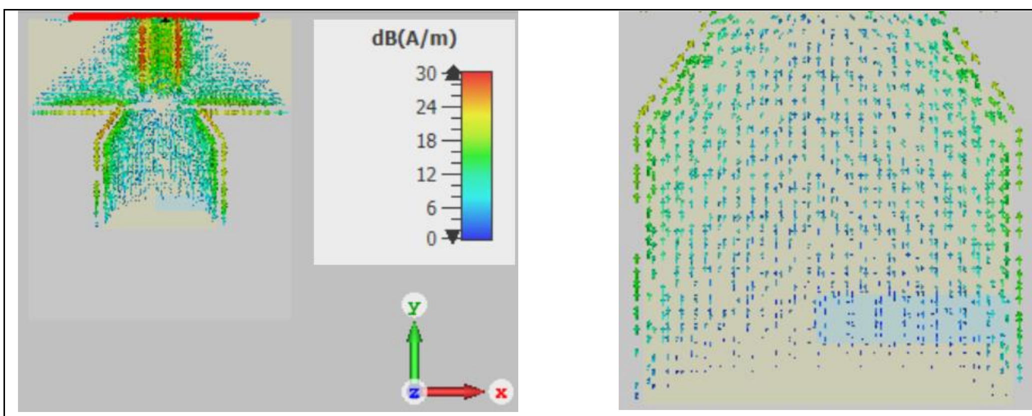
Figure 3.10: Second design for the proposed work.

In order to prove that the conductivity of the graphene sheet for the electric current is changes with the change of the DC voltage. Again, we create in the same previously made procedure for the first design a current monitor through the antenna simulation program as shown in Figures 3.11 and 3.12.



(a) Current over the patch (b) Zoomed view

Figure 3.2: Current allocation over the patch in the OFF case for the second design.



(a) Current over the patch (b) Zoomed view

Figure 3.3: Current allocation over the patch in the OFF case for the second design.

From the previous Figures 3.11 and 3.12, we note that in the case of the applied voltage, which is called the operating state or the ON case, the current passes through the graphene sheet, and this proves that the surface resistance of the material decreases and the conductivity increases, and on the contrary, in the case of no voltage (OFF state) the current isn't pass in the sheet due to the high impedance of the material. Also, the current dispersion over the patch is varied and rearranged in the both cases.

3.2 OBTAINED RESULTS

This section of the chapter demonstrates a presentation and discussion of the achieved outcomes from the antenna simulation program (i.e., CST) for the return loss, bandwidth, and the gain.

3.2.1 Return Loss (S_{11})

The S_{11} is one of the very important and elemental antenna parameters which are widely used when designing and examining the antenna. So, it is a mensuration of the amount of power that is bounced back to the source that supplies the power. The reason for this type of loss is due to the presence of the mismatch in the impedance between the antenna, the source and the strip line as well. Antenna designers set a standard for this type of an antenna loss, which is that the acceptable value is S_{11}<-10 dB. As the S_{11}= -10 dB explains that 90% of the power that is provided by the source is received by the antenna terminals and the remainder is reflected in the direction of the source.

3.2.1.1 The S_{11} for the first design

This subsection presents the S_{11} for the first antenna design, before the parameter's alteration and shape modification process, a mismatch issue is observed and the simulated antenna doesn't cover the UWB regime, as interpreted in Figure 3.13.

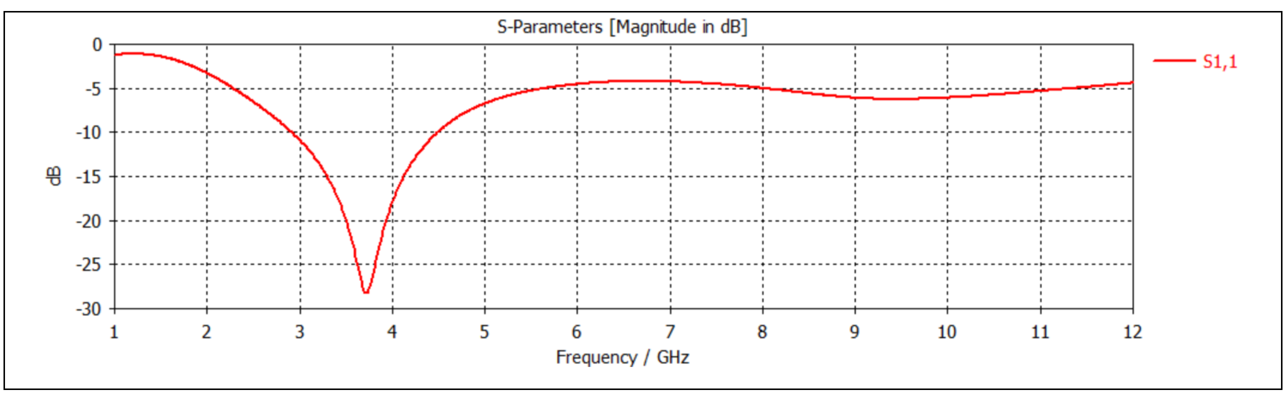


Figure 3.4: The S_{11} for the 1st rectangular MP antenna design before alteration process.

For the purpose of the covering the whole band for the UWB regime, the shape and parameter alteration process is applied by the trials. Figure 3.14 interprets the simulated rectangular MP antenna after applied the shape and parameter alteration process.

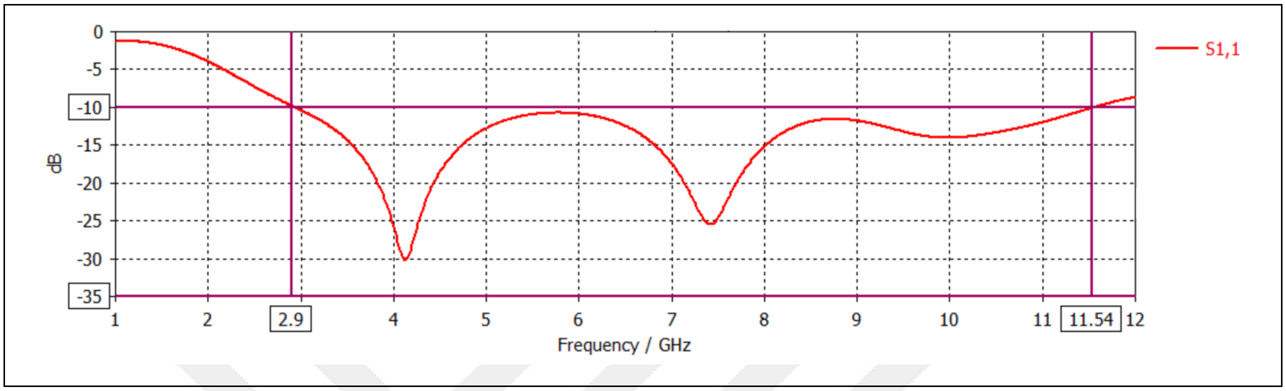


Figure 3.5: The S11 for the 1st rectangular MP antenna design after alteration process.

After the process of making a rectangular slit in the brink of the patch and placing a small piece of graphene material, a controllable bandgap will be created according to the value of the DC voltage that will be applied (in other words, depending on the ON and OFF state) and as interpreted in Figures 3.15 and 3.16.

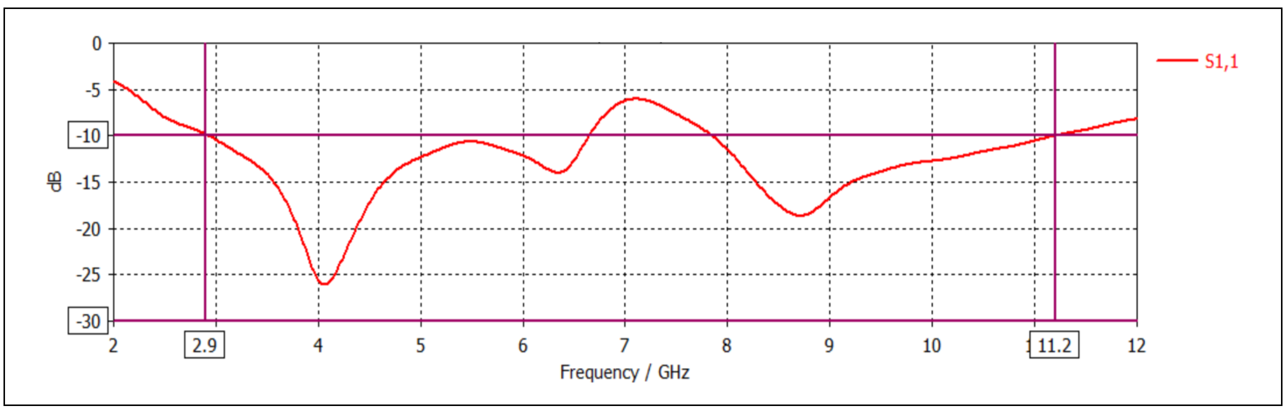


Figure 3.6: The S_{11} for the 1st design of the proposed antenna in OFF case.

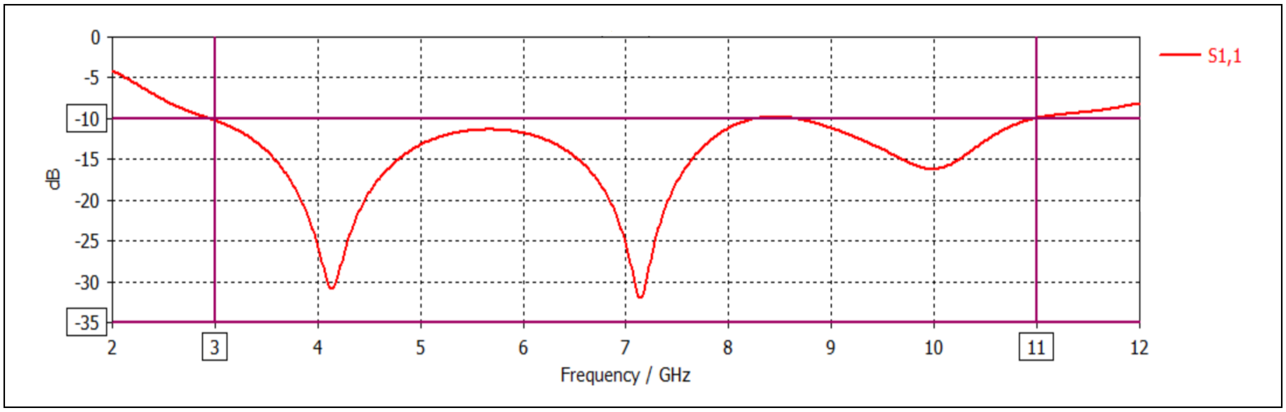


Figure 3.7: The S_{11} for the 1st design of the proposed antenna in ON case.

In the case of switching OFF, it can be seen from the previously presented above (Figure 3.14) that there is a bandgap in the frequency for the frequencies in the range of 6.65-7.85 GHz which is employed for the applications of 5G, fixed satellite, and mobile satellite. This bandgap is beneficial to minimise the interference from the previously mentioned applications. In order to shift the bandgap location, the shape of the slit and the graphene sheet can be changed or the shape of the antenna.

3.2.1.2 The S11 for the second design

This subsection presents the S_{11} for the second antenna design, before the parameter's alteration and shape modification process, a mismatch issue is observed and the simulated antenna doesn't cover the UWB regime, as interpreted in Figure 3.17.

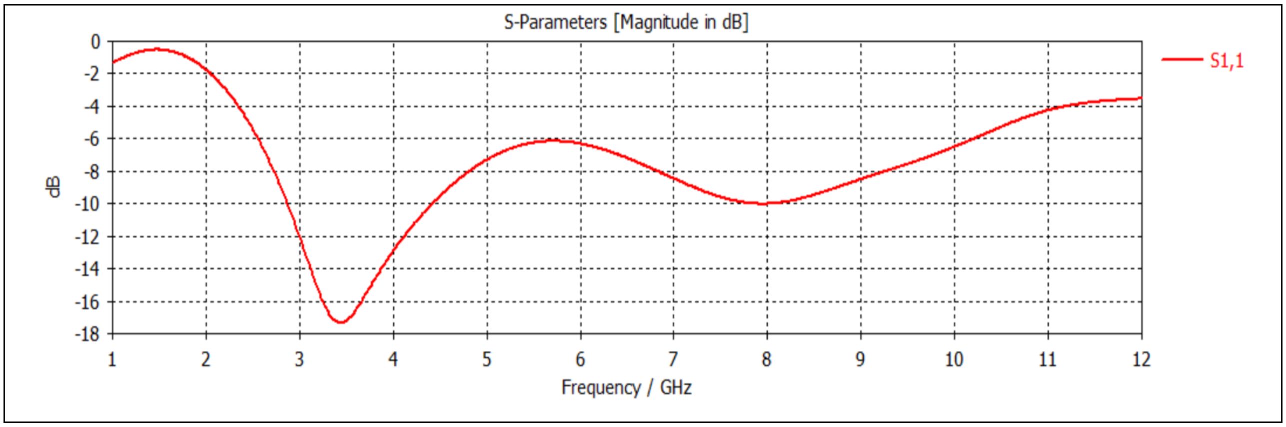


Figure 3.8: The S_{11} for the 2nd antenna design before alteration process.

Eventually, for the purpose of covering the whole band of the UWB regime, in the same previous procedure for the first design the shape and parameter alteration process is applied by the trials. Figure 3.18 interpreted the second simulated rectangular MP antenna after applied the shape and parameter alteration process.

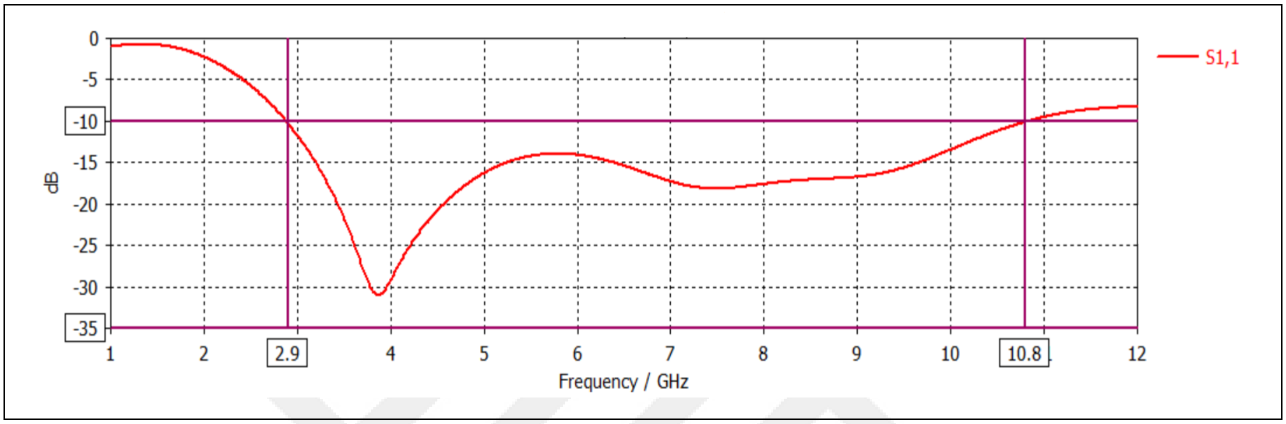


Figure 3.9: The S_{11} for the 2nd rectangular MP antenna design after alteration process.

After the process of making a rectangular slit in the brink of the patch of the second and placing a small piece of graphene material, a controllable bandgap will be created according to the value of the DC voltage that will be made on the material (in other words, depending on the ON and OFF state) and as interpreted in Figures 3.19 and 3.20.

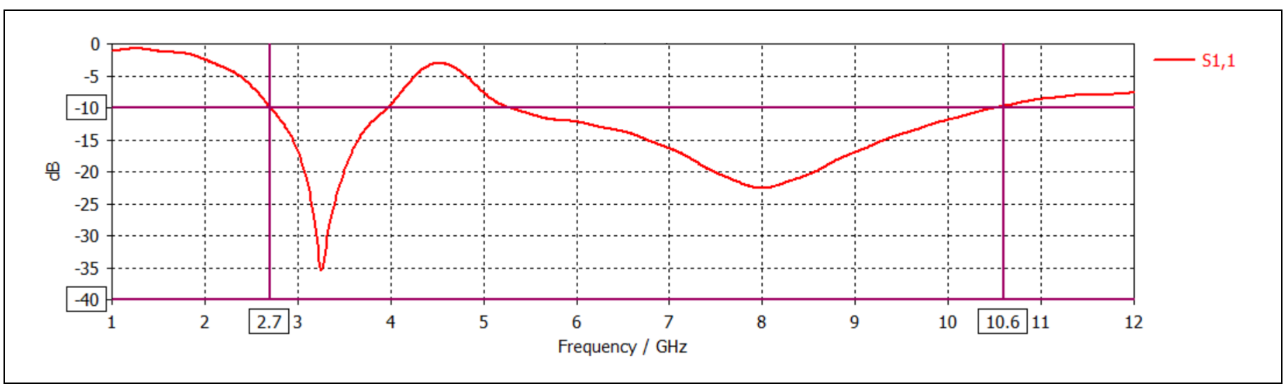


Figure 3.10: The S_{11} for the 2nd design of the proposed antenna in OFF case.

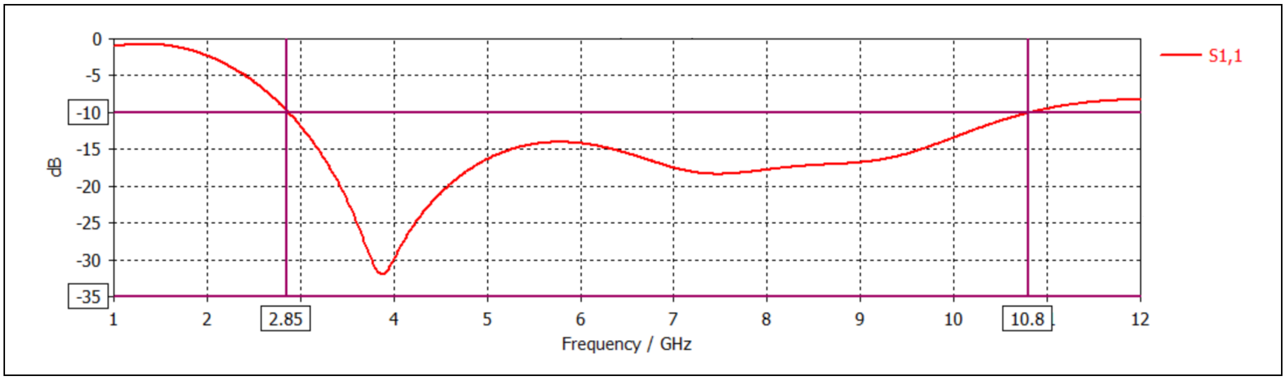


Figure 3.20: The S11 for the 2nd design of the proposed antenna in ON case.

In the case of switching OFF, it can be seen from Figure 3.18 above that there is a bandgap in the frequency for the frequencies in the range of 4-5.3 GHz which is for the applications of 5G, weather radar, surface ship radar, and some of the communications satellites (e.g., GPS and amateur radio). This bandgap is beneficial to minimise the interference from the previously mentioned applications.

3.2.2 Antenna Gain

Gain is another metric of the basic and significant parameters to that should be consider when designing an antenna. The gain represents the antenna's ability to convert an electrical signal into a radiant signal and vice versa. The gain is also an important factor in the wireless transmission process, as the losses between the transmitter and receiver decrease with the increase in the gain of the transmitter and receiver antenna.

3.2.2.1 The gain for the first design

This subsection interprets the gain for the first design of the proposed UWB antenna. In order to compare the results obtained from the design of the two antennas, it will be difficult to compare the results at all frequencies. Therefore, the comparison will be done at only one frequency. Figure 3.20 shows the outcomes for the gain of the first antenna at $f_o = 4$ GHz which is equals 0.649 dBi.

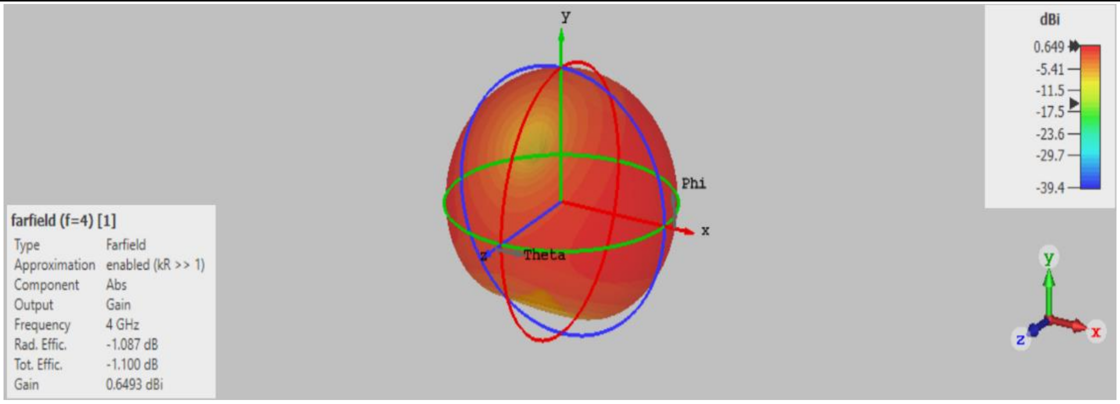


Figure 3.11: Gain result for the 1st antenna design at $f_o = 4$ GHz.

Since the range covered by the antenna is large, and for the purpose of studying and monitoring the gain along this range, a wide gain monitor is created through the simulation program for the ON and OFF case, as interpreted in Figures 3.22 and 3.23.

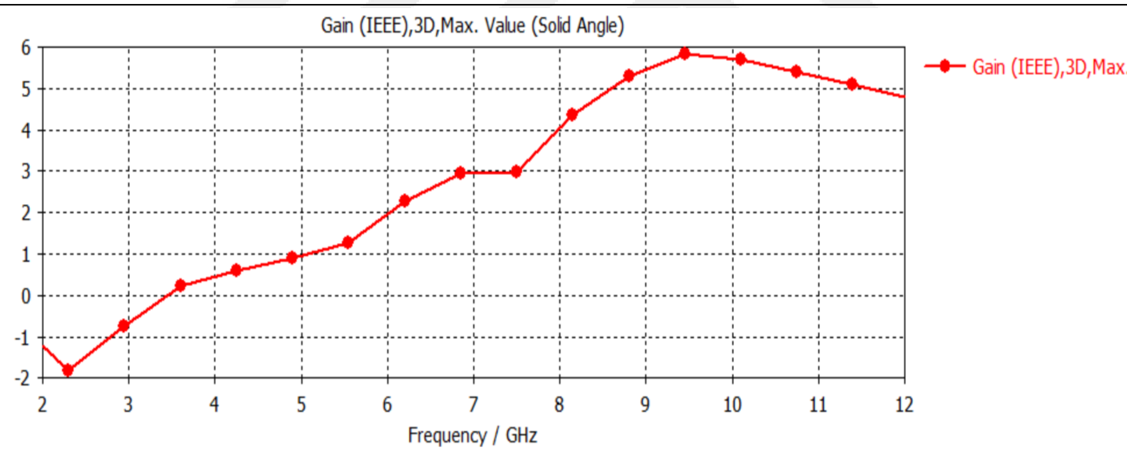


Figure 3.12: Gain results vs frequency at OFF case for the 1st design.

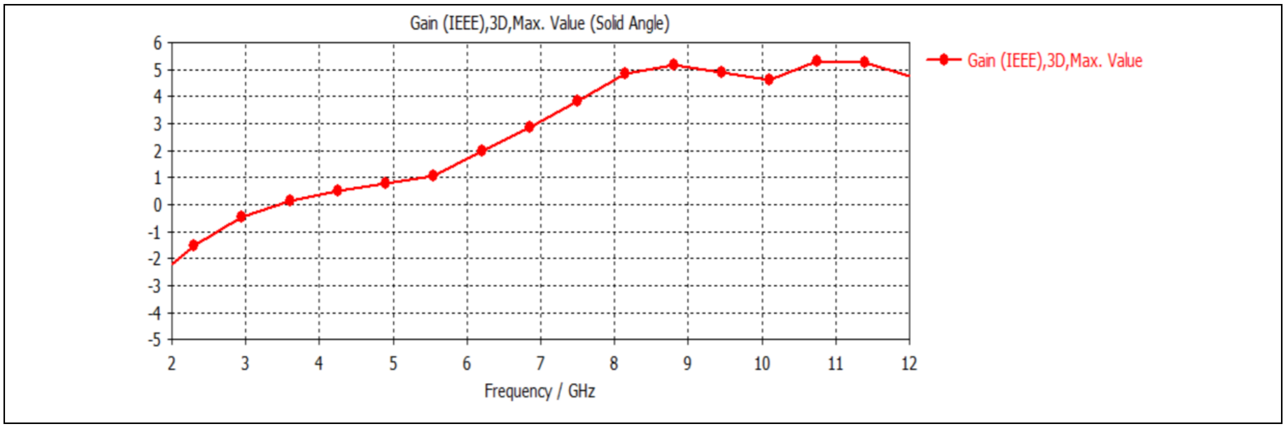


Figure 3.13: Gain results vs frequency at ON case for the 1st design.

3.2.2.2 The gain for the second design

This subsection interprets the gain for the second antenna design of the simulated antenna. In order to compare the results obtained from the design of the two antennas, it will be difficult to compare the results at all frequencies. Therefore, in the same previous manner, the comparison will be done at only one frequency. Figure 3.24 interprets the outcomes of the gain for the second antenna at f_o = 4 GHz which is equals 2.2 dBi.

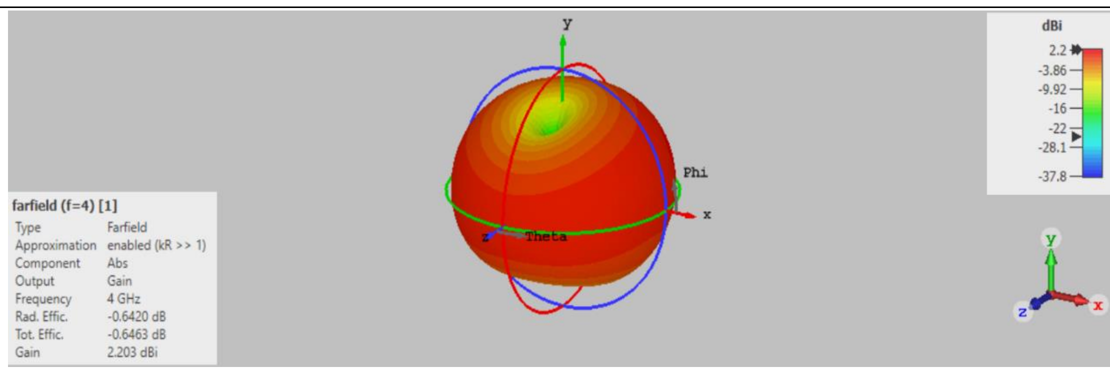


Figure 3.14: Gain result for the 2nd antenna design at $\boldsymbol{f_o = 4}$ GHz.

In the comparison between the first proposed antenna design that has been made on the basis of the FR-4 substrate, the antenna gain is equalled to 0.649 dBi, while in the second proposed antenna design the gain is equalled to 2.2 dBi. The risen is due to the quality of the Rogers substrate which is characterised by the excellent efficiency and the slightest loss tangent, but it has a higher cost. This is what proves the efficiency of the Roger substrates, which were studied in the many research studies that have been made in the literature and as described by [49].

Since the range covered by the antenna is large, and for the purpose of studying and monitoring the gain along with this range, in the same previously applied procedure, a wide gain monitor is created through the simulation program for the ON and OFF case, as interpreted in Figures 3.25 and 3.26.

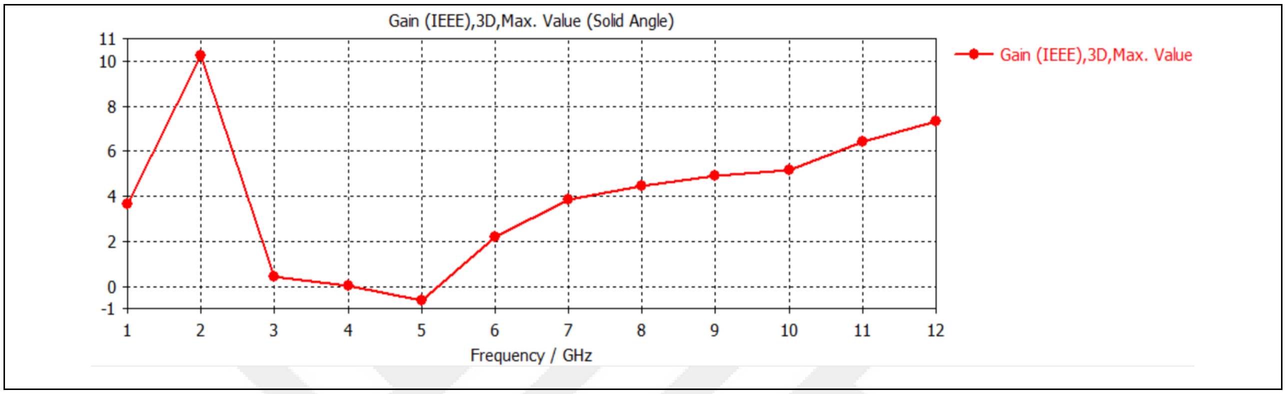


Figure 3.15: Gain results vs frequency at OFF case for the 2nd design.

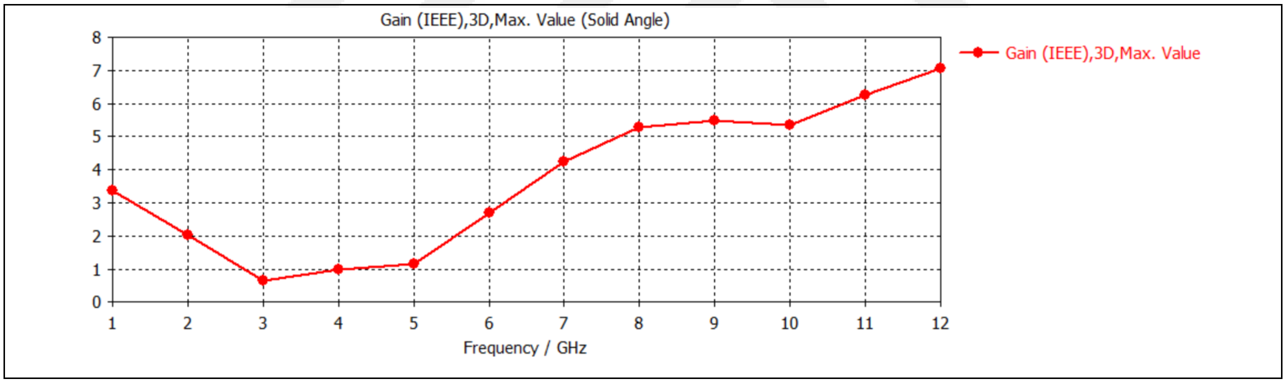


Figure 3.16: Gain results vs frequency at ON case for the 2nd design.

In order to summarize the obtained results from antenna simulation software for both designs, Table 3.5 is introduced.

Table 3.5: Comparison results for both antenna designs.

Design	**Frequency Range**	**Bandgap**	**Gain at f_o = 4 GHz**
First Design	3-11 GHz	6.65-7.85 GHz	0.649 dBi
Second Design	2.85-10.8 GHz	4-5.3 GHz	3.2 dBi

4. CONCLUSION AND FUTURE WORK

4.1 CONCLUSION

In addition to the requirements for obtaining the high data rates that users want to obtain, many of the promising technologies and solutions have appeared and are still emerging. One of them is the UWB technology developed by FCC which provides bandwidth between 3.1 GHz to 10.6 GHz with a consumption of a low power within the limits of indoor applications. In the field of wireless communication, whereas the antennas are one of the most important basic elements that contribute to the completion of the wireless communication system. The most of the known utilized antennas is the MP antennas. Such types of the antennas are characterised by its small size and low manufacturing cost. In this work, two modified shapes of regular rectangular MP antennas have been introduced and simulated for the UWB-based implementations. In order to minify the interferences in the UWB frequency spectrum, a bandgap in the frequency has been created by etching a slot in the lower brink for the antenna patch and a thin layer of the graphene is placed in the slot to control the bandgap. Additionally, the performance comparison of the FR-4 and Rogers's substrates has been made for the two simulated antennas. The obtained results have shown a good impedance matching in the UWB regime with controllable bandgap and good gain.

4.2 FUTURE DEVELOPMENTS

In the present work, small-sized MP graphene-based controllable frequency bandgap antennas have been designed and simulated for UWB applications. This work discussed the utilizing of the graphene material to control the frequency bandgap. While the MP antennas have several issues associated with poor gain and low efficiency. In order to develop the simulated MP antennas, the following points can be considered in the future:

a) Fabricate and test the simulated antennas.

b) Employing the graphene to construct the artificial magnetic conductor to be place under the patch of the antenna that is contributes an improvement in the performance of the antenna.

Embedding the metamaterials within the structure of the simulated antennas to improve their performance.

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