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Electrical and Computer Engineering

INVASTIGATION OF SIZE REDUCTION TECHNIQUE OF MICROSTRIP PATCH ANTENNA WITH SAW TEETH SLOTS

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Master Thesis

Supervisor

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INVESTIGATION OF SIZE REDUCTION TECHNIQUE OF MICRO STRIP PATCH ANTENNA WITH SAW TEETH SLOTS

by

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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Mustafa Ahmed Saadi

DEDICATION

First, I would like to express my deepest grateful to Allah Almighty for the power of mind, health, strength, guidance, knowledge and skills to complete this study. This thesis is wholeheartedly dedicated to my beloved parents, who have been my source of inspiration; they always keep tell me that" do not afraid of anything, we are here for you". There are no words to describe my thankful; there is nothing that I can repay for what you have done to me. I will continue to do my best to achieve your expectations. I dedicated this to the person who is waiting for me, who has been supporting me with the kind and pure love. I dedicated this to my lovely sisters, who are my first supporters. Finally, to the family and friends who have been encouraging me during my journey.

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ABSTRACT

INVESTIGATION OF SIZE REDUCTION TECHNIQUE OF MICROSTRIP PATCH ANTENNA WITH SAW TEETH SLOTS

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Nowadays, there is increased use of wireless devices, when the mobility is concerned; the miniaturization techniques of circuits, circuit parts, and antennas are become common besides reducing the dimensions of the devices. However, it ought to be noted that the dimensions reduction should not have any effect on the operating frequencies of the mobile device. In this work, a practical approach of miniaturization technique of rectangular microstrip patch antenna (RMSPA) for wireless application is given to miniaturize the dimensions of a rectangular microstrip patch antenna (RMSPA) by making slots in the patch in the form of saw teeth. Defected ground structure (DGS) is used to enhance the gain of the saw teeth patch antenna (STPA). The rectangular microstrip patch antenna (RMSPA) comprised of a rectangular metallic patch that made of copper with FR-4 as a substrate. Inset-fed line is used as a feeding technique. (RMSPA) has a return loss of -24.06 dB and gain 3.21 at the frequency 2.624 GHz, while

(STPA) has a return loss of -12.76 dB and gain -4.97 at the frequency 1.824 GHz. The enhanced (STPA) has a return loss of -19.94 dB and gain 2.14 at the frequency 1.778 GHz. By using this approach, a miniaturization of 75% is reached.

Keywords: Microstrip rectangular patch antenna, Saw teeth slot, Antenna miniaturization.

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LIST OF ABBREVIATIONS

MSPA	:	Microstrip Patch Antenna
STPA	:	Saw Teeth Patch Antenna
DGS	:	Defected Ground Structure
VSWR	:	Voltage Standing Wave Ratio
GPS	:	Global Positioning System
SAR	:	Synthetic Aperture Radar

LIST OF SYMBOLS

C	:	Speed of light
ε_{reff}	:	Effective permittivity
ΔL	:	Fringing field factor
L_{eff}	:	Effective length
RL	:	Return loss
D	:	Depth of the slots
$Z_{in}(0)$	:	Input impedance at the edge of the patch
$Z_{in}(R)$	:	Input impedance at (R) distance from the edge of the patch
Lp	:	Length of the patch
Wp	:	Width of the patch
Ls	:	Length of the substrate
Ws	:	Width of the substrate
Wf	:	Width of the feed line
Lf	:	Length of the feed line
Lg	:	Length of the notch
Wg	:	Width of the notch
Ht	:	Thickness of the metal
Hs	:	Thickness of the substrate
E	:	Biggest edge in the slot
L1	:	Length 1 of the T-shape DGS
Er	:	Dielectric constant

ε_0	:	Permittivity of the free space
K	:	Wave number
Fr	:	Operating frequency
W	:	Width 1 of the T-shape DGS
T	:	Length 2 of the T-shape DGS
G	:	Width 2 of the T-shape DGS

1. INTRODUCTION

The antenna is one of the most important and necessary element in any wireless system, where it gives the system a mean for receiving and sending signals [1]. Recently, microstrip patch antenna got a considerable interest in the area of wireless and portable devices because they have number of key advantage like small profile, low cost ... etc. There are a lot of ongoing researches on microstrip patch antenna according to these advantages. These ongoing researches include:

- Bandwidth enhancement techniques.
- Controlling of radiation patterns.
- Methods of improving radiation efficiency.
- Enhancing feeder systems.
- Size reduction techniques.

Nowadays, the evolution of microstrip patch antenna is one of the main demands and the dominant factor for developing wireless and portable devices. The usage of micro strip patch antenna has a wide range in the application such as GPS, radar, and satellite. In the new technology, the components that associated with wireless systems have reduced in size considerably; the same thing cannot be said about the antennas. The main cause of this claim is that the antenna dimensions subjected to the law of physics. Any change in micro strip antenna dimensions with regard to the wavelength will have a big effect on the radiation characteristics [2]. Hence any attempt to miniaturize or in another word any change in the size of microstrip patch antenna will be at the cost of other parameters like bandwidth, return loss, and the gain [3-8]. However, as a result of the cost of the wireless applications is count on the overall size, any attempt of reducing the antenna's size will have a big benefit of the commercial side. By using these techniques, a smaller patch antenna can be obtained with a lower frequency. The reducing of the dimensions of the micro strip patch antenna is not being limited to a single frequency. Dual frequency response for many applications, like synthetic aperture radar (SAR) and global positioning systems (GPS) is often required. In this research, an approach of miniaturizing the micro strip patch antenna (MSPA) of a single frequency is presented.

This thesis is ordered into six chapters, where chapter two gives presents an overview of antennas and its types. Also, it presents an overview of the micro strip patch antenna, its disadvantages and advantages, and its feeding techniques. Chapter three presents a literature review of the miniaturization techniques. Chapter four presents and discusses design procedures and the equation that used to do these designs. Chapter five presents the results of the simulations and the parametric sweep. Chapter six presents the conclusion that deduced from the results and also presents the future work.

2. ANTENNAS

2.1. OVERVIEW TO ANTENNAS

The antenna is one of the most important components in any wireless communication system that it is necessary for proper functioning [9]. IEEE gives a definition of antenna as "a part of a receiving or sending system that is designed to receive or send electromagnetic waves" [10]. So the antenna can be considered as a transducer, which converts the information from its voltage form 'guiding device' to electromagnetic form 'free-space' or vice versa.

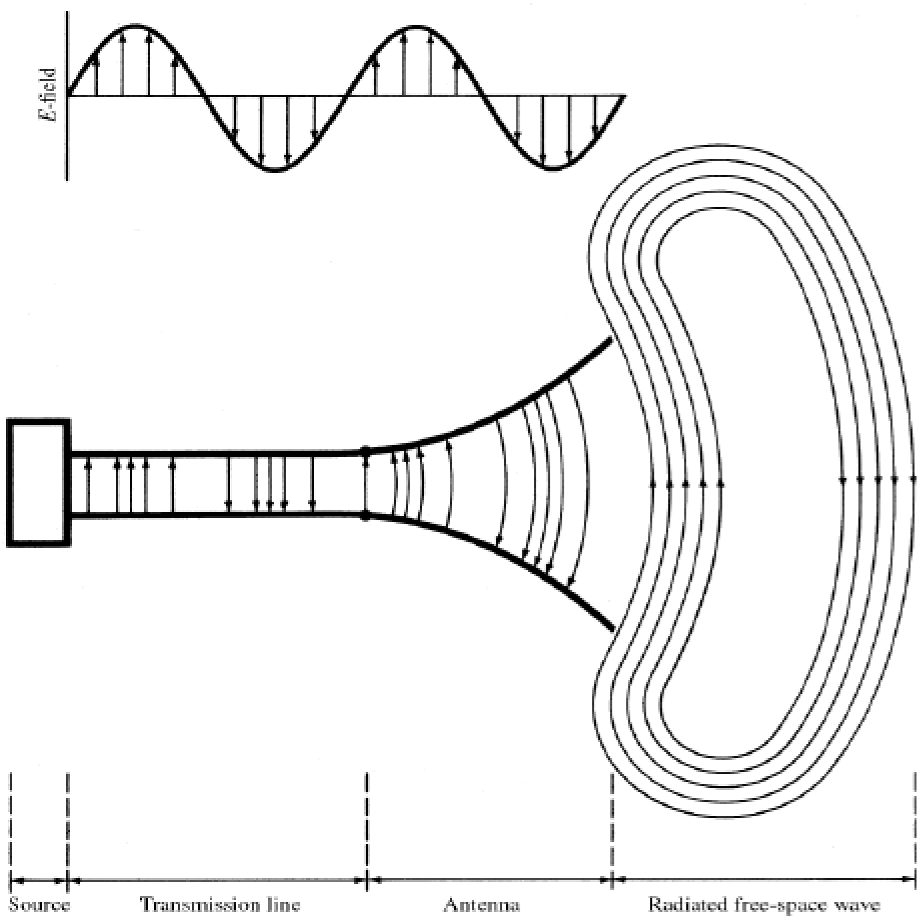

Figure 2.1: Antenna as a transition device [9]

The experiment that done by Faraday in the 1830s, shows the definitive relationship between the magnetism and the electricity [11]. He moved a magnetic through a coil and attached the coil to a galvanometer by using wires. A magnetic field is creating during the movement of the magnet in where this field varying with the time. According to Maxwell's equations, that leads to creating a time-varying electric field in the coil. This experiment summarizes the working principle of the antenna, where the antenna acts as the coil that received the electromagnetic wave (signal) that is detected by the galvanometer. Heinrich Hertz was the first one who introduces antenna technology in 1886, but the initial application was carried out by Guglielmo Marconi in 1901 when he first applied it in a practical communication in radio [12]. This technology has over the years formed the basis of all wireless telecommunication systems where it serves as a building block.

The antenna in transmitting mode is presented as a load connected to a transmission line. Figure 2.2 shows the equivalent circuit of the antenna in sending mode, where the antenna is presented as $Z_A = (R_L + R_r) + jX_A$. Where (Z_A) represent the antenna as a load, the dielectric and conduction losses are presented as Load resistance (R_L), while the imaginary part of the impedance as (jX_A), and the radiation of the antenna is presented as radiation resistance (R_r).

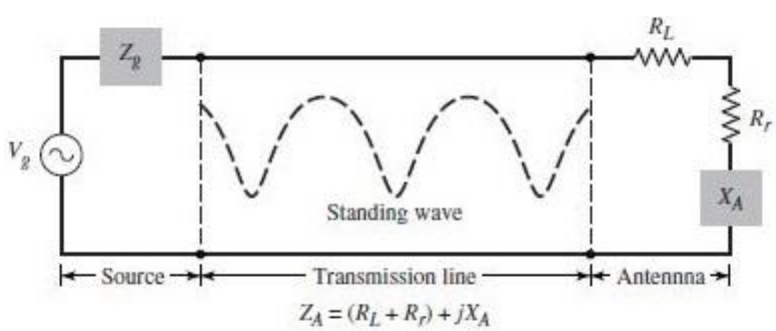

Figure 2.2: Equivalent circuit of antenna [9]

For the ideal conditions, all the energy delivered by the source must be transferred to Rr. This is impossible in the practical system because there are some losses in the transmission line and also some losses according to the mismatch between the antenna and the line [9]. If there is no mismatch and by neglecting the internal impedance of the source, the antenna will receive a full power from the source. Due to the mismatch, some of the travelling waves will reflect inside the transmission line; the reflected waves called standing waves. These waves create with the travelling waves a destructive and constructive interference patterns. If the design of the antenna did not design correctly, it does not act as an energy transporting device; instead, it will work as an energy storage element.

The losses of the antenna, the standing waves, and the line are undesirable. By choosing low-loss lines, the line losses can be reduced. The losses of the antenna can be reduced by minimizing RL [11]. The standing waves can be minimized by removing the mismatch between the antenna and the line. The antennas in receiving mode it also can be represented by the same equivalent circuit that shown in Figure 2.2, where R_r represents the received energy.

2.2. TYPES OF ANTENNA

The wireless antenna can be categorized into six categories namely: lens antennas, reflector antennas, aperture antennas, wire antennas, array antennas and printed antennas. In this subsection, a brief introduction to these types will present.

2.2.1. Wire Antenna

The most basic type of antenna is the wire antenna, and it can be designed into different shapes that are categorized into a helix, straight wire and loop [1]. This type of antennas is mostly used in space crafts, in buildings, ships and automobiles. The simplest type of wire antenna is the dipole antenna which is made of a conductive wire rod [13]. The wire is designed in such a fashion that its length is 1/2 the size of the antenna's wavelength that it is required to emit. In the design of the antenna, the wire rod is cut into two parts at the center where an insulator is used to separate the two segments. The ends of the two divided rods are connected to a coaxial cable such that the connections are done at the furthest points [1]. The voltages for the radio frequency are applied to the middle where the conductors meet. For any given resonant dipole, the half-length design enables the achievement of the shortest size possible.

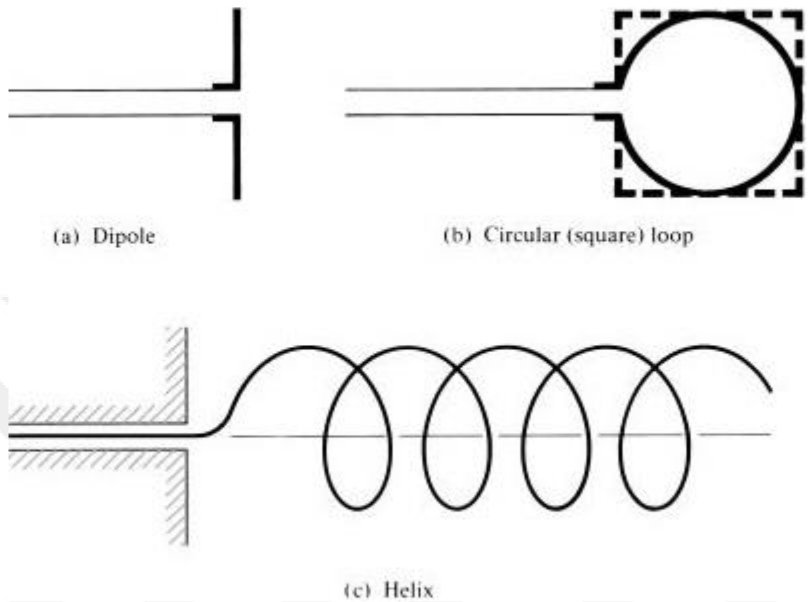

Figure 2.3: Wire antenna configurations [1]

There is also the monopole antenna which unlike the dipole antenna is not divided into two segments [10]. It is made of a conductor that assumes the shape of a rod, and it is straight. In its application, it can either be mounted to a ground plane or conductive surface, and it can also be mounted vertically or not depending on the preference. Generally, the monopole is thought of like half of a dipole antenna. If the monopole antenna has a quarter wavelength, then it is necessary to ensure that a ground system is applied. The dipole antenna has its fair share of advantages and disadvantages. Some of the advantages are that it enables obtaining of signals that are balanced and it also does not require a tuner so that it can function effectively.

2.2.2. Aperture Antennas

In conditions where higher frequencies are required, the aperture antenna is applied, and they come in the form of an aperture or slot that is mounted on a metal plate [14]. The frequency, in this case, ranges from 3 to 30 GHz. It is for this type of antennas to be mounted on a spacecraft and aircraft because they can be effectively placed on the surface. Some examples of aperture antenna are horn antennas and slotted waveguide antennas.

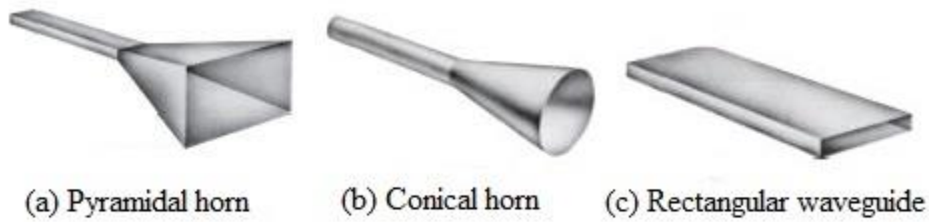

Figure 2.4: Aperture antenna configurations [14].

Aperture antennas have some advantages such as its length is reasonable and it is matched with directivity and size. However, it has some disadvantages like the antenna could work well with a combination only.

2.2.3. Printed Antennas

The standard photolithography technology is used in the designing and manufacture of the printed antennas. A microstrip patch antenna (MSPA) is the most popular one of printed antennas, which comprises of a grounded metallic ground plane [15]. The size and the shape of the patch determined the performance and frequency of this type of antenna. Some of the main reasons why this type of antennas is common are because they have easy handling and economic properties. They can be easily fabricated and are also available at a cheap cost [14]. Furthermore, the printed antennas can be integrated within circuits easily. Besides, the technology ensures that printed antennas are conformal to both non-planar and planar surfaces onto which they can be mounted [15]. Their properties make their use applicable in many applications such as mobile devices and on the surface of missiles, aircraft, satellites and space-crafts.

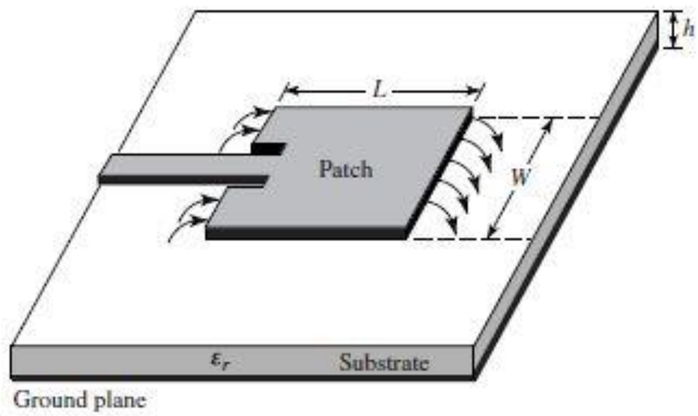

Figure 2.5: Patch antenna [14]

2.2.4. Array Antennas

There are instances where it may be necessary to seek specific radiation characteristics that cannot be achieved using an independently designed single radiating element. For this reason, it becomes necessary to geometrically arrange several radiators to achieve the desired results [16]. In this arrangement, the technology is designed in such a manner that each radiation element produces the maximum amount of radiation in desired directions or direction. At the same time, the amount of radiation in other directions is maintained at minimal levels [17]. With consideration of the application, the radiating elements are arranged in a linear or planar grid.

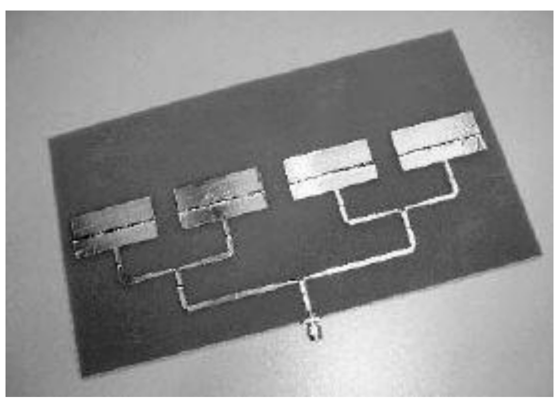

Figure 2.6: Array antenna [16]

2.2.5. Reflector Antennas

There are cases where transmission may be required to cover very long distances in which case a reflector antenna is used [18]. One feature of reflected antenna is that it is built in such a fashion that it has a large diameter which is useful because it enables the antennas to receive or transmit signals over long distances due to the high gain. Some instances of reflector antennas application are in satellite communication and space exploration.

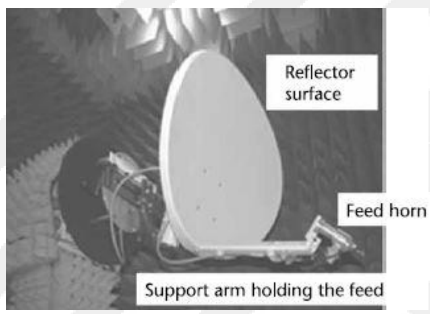

Figure 2.7: Reflector antenna [18]

Reflector antennas are classified according to their feed arrangements and reflectors such as the multiple-reflector, dual-reflector, and single-reflector configurations using specially shaped surfaces or conventional surface profiles to get the desired radiation patterns.

2.2.6. Lens Antennas

Lens antennas utilize that is used in the divergence of energy through collimation which ensures that energy does not spread in directions that are not desired [19]. This property enables the transformation of divergent energy into plane waves by the antenna which is achievable through the suitable geometrical configuration of the lenses and also using the right material. In the classification of lens antennas, the process depends on the construction material.

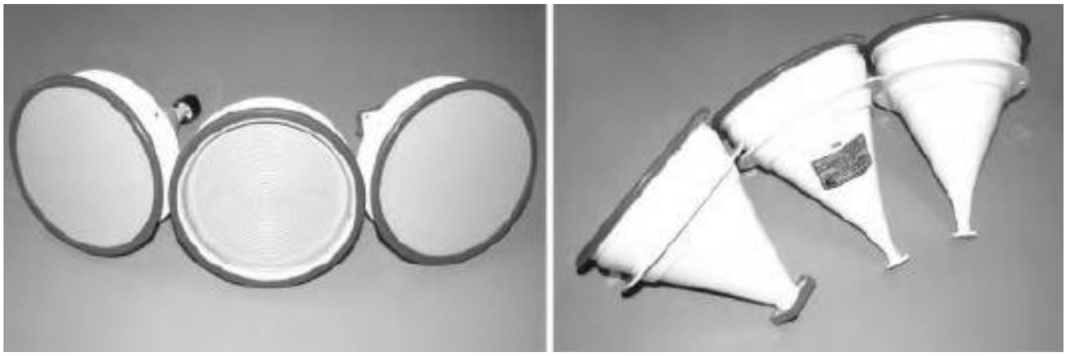

Figure 2.8: Lens corrected horn antennas [19].

2.3. ANTENNA CHARACTERISTICS

There are too many important parameters in order to define the characteristics of antenna, such as directivity, return loss, radiation pattern, gain, polarization, antenna efficiency, input impedance and others which are well defined in the literatures [1], [9], [10]. However, in order to satisfy the content of this thesis, some important parameters will be explained.

2.3.1. Radiation Pattern

The main and major characteristic of the antenna is the radiation pattern. As it is an important characteristic of the antenna, it can be defined as the graphical representation of the properties of radiation of the antenna. The antenna is graphically surrounded by the sphere which is evaluated by the electromagnetic fields at the same equivalent measure of distance to the radius of the sphere [9]. The radiation pattern, being a graphical representation of the properties of radiation of an antenna, it represents the antenna in three dimensions; three graphical dimensions. They represent the antenna in three dimensions being as a function of the angular direction. The E-plane of the patch antenna is the plane that has in it the field vector. On the other hand, H-plane is the plane that has the H-vector in it. The appropriate angle of the dipole where the H-plane is concerned is 90 degrees.

The omnidirectional antenna pattern is known as the type of the antenna pattern that is demonstrated where there is no kind of variation that is seen from the radiated E/H fields. The antenna pattern is most of the times plotted in the dB. Superfine features of the antenna pattern can be obtained when using a logarithmic scale when plotting. The patch antenna has a pattern that is a recurring pattern, where many of the base patch antennas have the major lobe and then the minor lobes which are also referred to as the side lobes. The back lobe is a side lobe which is occurring on the immediate opposite direction of the main major lobe. There are four major patch antenna pattern types that are;

- Omnidirectional antenna pattern type. This is an antenna pattern type where the response to the radiation is always constant in only one of the principal planes of the patch antenna.
- Isotropic antenna pattern type. This is an antenna pattern type where the patch antenna radiates gives out radiation in all directions in equal and the same measure in the 3D space. This is used to prove how the patch antennas are directive even though it is impossible to prove it in a theoretical manner.
- Broadside antenna pattern type. This is an antenna pattern type where the major and the main beam of the antenna are usually normal to the axis or to the plane that has the antenna.
- End-fire antenna pattern type. This is an antenna pattern type where the main and major beam of the antenna is usually contained in the plane or is parallel to the plane that is containing the patch antenna.

2.3.2. Directivity

The directivity is the measure of the quantity of the concentration given off by the antenna in a certain given direction. There has to be known antenna for the directivity of the antenna to be measured, and the known antenna is always an isotropic radiator. In technical terms, the directivity of an antenna is a function of a specific angle that can be plotted in either 2D or a 3D plot. The directivity of the antenna also shows the representation of the power which is added and that is collected in a given specific direction that equals an isotropic radiator. The additional power that is collected or transmitted does not come from nothingness. The additional power comes from the directivity in the other directions. The patch antenna has more products geared towards one specific direction where there are other responses in other directions. The extra additional power is obtained at the expense of the directivity in other directions. Usually, the patch antenna's directivity is estimated at a value ranging from 2 to 7 dB, and they are placed horizontally when viewing the microstrip and at the same time it is found that the linear polarization is evidenced in the fields when the radiation pattern is normalized [13].

2.3.3. Gain

The gain denotes what proportion power is transmitted within a certain direction to the power that transmitted of an isotropic source in the same direction. The gain is used commonly more than the directivity because it takes under consideration the particular losses that occur. If the gain of an antenna is three dB, this implies that the power that received far away from the antenna is going to be twice as much as what would be received from a lossless isotropic antenna with the identical input power. The gain is related to the efficiency of the antenna and the directivity by Equation 2.1:

$$D = \varepsilon_R \text{ G} \tag{2.1}$$

Except for dB, there are other units for antenna gain, those are:

- dBi: describes the gain relative to an isotropic antenna.
- dBd: describes the gain relative to a dipole antenna.

2.3.4. Antenna Impedance

The antenna input impedance is a key concept to put under consideration for the system RF will have to interface to the antenna. It is disadvantageous for the impedance of the antenna to be unmatched to the system [14]. This is because when the impedance is mismatched; there will be a lack of proper transmission of power to and from the antenna. The improper transmission of power is brought at the reflection produced when the impedance is not matched.

2.3.5. Surface Current

The surface current is an actual electric current that is induced by an applied electromagnetic field. The electric field pushes charges around. The patch antenna has an open-end circuit that makes the current at its end equal to 0. While, the current is maximum at the center of the patch antenna; therefore, this makes the current zero at the farthest ends. It shows the amount of the impedance on the surface.

2.3.6. Gain or Directivity in dB

The dB units are the most appropriate units to express any changes in magnitude orders. The dB units give room for the calculations in multiplications and divisions to be replaced by simple addition and subtraction calculations. This is seen in the case of radio systems where the dB units are used to express quantities since the quantities are subject to a variance of many magnitude orders. There is always a reference where a dB quantity is involved. In the case of directivity where the patch antenna is involved, the average intensity of radiation that is transmitted by the isotropic radiator is the denominator which in turn is the reference. From the previous statement, it can be observed that directivity is usually the comparison of the microstrip patch antennas. An isotropic radiator is a reference when finding the directivity of the patch antenna. An isotropic radiator becomes the reference by replacing the dB with the unit dBi. The dBi units are used when there is another reference that is used apart from an isotropic radiator.

2.4. OVERVIEW TO MICROSTRIP PATCH ANTENNA

Microstrip antennas which are also known as patch antennas have become common because they provide the major benefit in that they provide the possibility that they can be printed on a circuit board directly [15]. The microstrip patch antenna is designed in such a fashion that it has two sides one which is the radiating side while the other is the grounded side. The patch antenna is shown in Figure 2.9. The radiating side has a patch that is made of gold or copper, and it can be designed into any shape depending on preference (rectangular, circular, and other shapes).

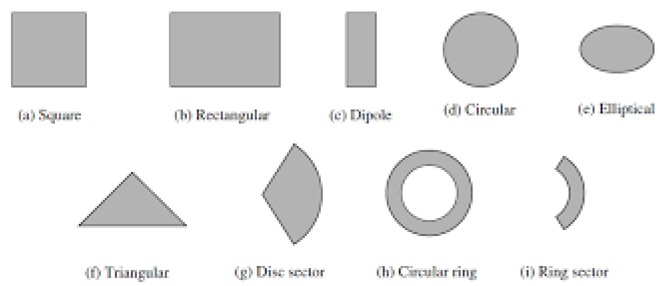

Figure 2.9: Types of patch [20]

Modern technology enables the patch antennas to be used widely in the mobile market especially because they can be obtained at a low cost, can be fabricated easily and also their profile is low [10]. Their functioning is highly effective because they are made of high conductivity metal usually copper which is used in making the ground plane and the transmission line. The size of the microstrip patch antenna is represented by dimensions L, W and H whereby *L* represents the length, *W* is the width and H is the height. The height represents the thickness of the circuit board on which the microstrip is placed. The dielectric board has a certain measure of permittivity (ε_r) [29]. Although the thickness of the circuit board is important, it should be noted that the thickness should always be smaller than the operational wavelength. Usually, the height should be $1/40^{th}$ of the wavelength which is 0.025λ when expressed as a fraction. If the value is greater than that, then the efficiency of the microstrip becomes downgraded. To determine the frequency that the patch antenna will operate with, it is important to adjust the length of the antenna, and the following Equation can be used.

$$f_r \approx \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{c}{2L\sqrt{\varepsilon_o \varepsilon_{r\mu_o}}} \tag{2.2}$$

From Equation 2.2, it is possible to deduce that it is a requirement that the wavelength should be twice as much as the length of the antenna or the latter should be half as much as the former when they are placed in the dielectric circuit board. While the length determines the frequency, the width is responsible for controlling the input impedance. It implies that adjusting the width so that it is large, the effect is that the resulting bandwidth. When Equation one is used and a square patch antenna is inputted, the input impedance that will be obtained is 300 Ohms. If the width is increased, then the impedance can be reduced, but it would require a very wide patch so that an input impedance of 50 Ohms can be achieved. This may not be practical because it leads to the consumption of a lot of space which may be valuable. The other aspect that is considered when dealing with the width, is the radiation pattern [32]. In order to calculate the radiation pattern after normalization, the following equations can be used.

$$E_\theta = \frac{sin\left(\frac{kW \sin\theta \sin\emptyset}{2}\right)}{\frac{kW \sin\theta \sin\emptyset}{2}} \; cos\left(\frac{kL}{2}\sin\theta\cos\emptyset\right)\cos\emptyset \tag{2.3}$$

$$E_\emptyset = \frac{sin\left(\frac{kW \sin\theta \sin\emptyset}{2}\right)}{\frac{kW \sin\theta \sin\emptyset}{2}} \; cos\left(\frac{kL}{2}\sin\theta\cos\emptyset\right)\cos\theta\sin\emptyset \tag{2.4}$$

Whereby the wavenumber (*k*) is calculated using the Equation 2.5

$$k = \frac{2\pi}{\lambda} \tag{2.5}$$

And the fields' magnitude can be calculated using Equation 2.6

$$f(\theta,\emptyset) = \sqrt{E_\theta^2 + E_\emptyset^2} \tag{2.6}$$

2.5. RADIATING OF PATCH ANTENNA AND THE FRINGING FIELD

To explain how the microstrip patch antenna radiates, first, the fringing field must be explained because the fringing field around the patch antenna is the main responsible for the radiation. In order to understand the fringing fields in microstrip antenna and its effect during the designing of the patch antenna, it is essential to consider an assumption of a condition with a given set of parameters. The assumption will be as follow, assumed the material into which the substrate is composed, which it is assumed that it FR-4 which has a permittivity of 4.3, and assumed that the length is 27.5 mm and the width is 35.4 mm. Given these conditions, through appropriate calculations [1], the resonant frequency of the patch would equal to 2.5GHz. For these conditions to be fulfilled, it is necessary that the height must be 1.6 mm.

It is important to note that microstrips are designed to produce higher frequencies and therefore it is essential to ensure that they are small in size. It is also necessary to ensure that the bandwidth of the microstrip antenna is small. An example of such microstrip antennas is patchy rectangle antennas which are recognized for their narrowband. This makes their bandwidth amount 3% and although they are meant to attain frequencies of 2.5 GHz. However, its resonant is calculated at 2.4 GHz which results from fringing fields that are situated around the antenna. The resulting factor is that it makes the rectangular patch seem longer. Therefore, it becomes necessary to modify the patch antenna by 2-4% which enables the achievement of the desired frequency and resonance. The fringing fields can be explained better using the side view image of the patch antenna in Figure 2.10.

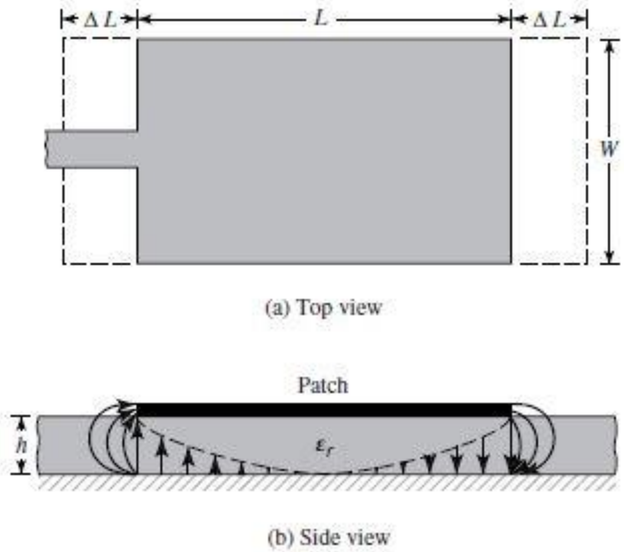

Figure 2.10: Side view of a patch antenna [14]

The patch antenna has an open-end circuit that makes the current at its end equal to 0. Theoretically, the current is maximum at the center of the patch antenna; therefore, this makes the current zero at the farthest ends [14]. For this reason, the impedance is found to be highest at the ends since the current is lowest at the feeds. The voltage reflection coefficient is calculated at the resonant frequency because patch antennas can be viewed as transmission lines with open circuits. The reason why the voltage is maximum at the midsection is that when the transmission process takes place, the current and voltage are found to be out of phase. Considering the parameters that have been assumed for the sake of this explanation, given that when the transmission starts at a voltage +V, it follows that the voltage must be minimum at the patch's end since the current and the voltage have already been determined to be out of phase. The fringing concept is demonstrated by the fields located below the patch. The microstrip derives its radiation from the fringing fields which can be explained by their +y direction. For this reason, the fringing fields that occur in the E-fields end up, adding up in phase thereby generating the radiation. From Figure 2.10, it is notable that the current also adds up in phase, but the radiation becomes cancelled.

The reason for this occurrence is that the added current occurs in the opposite phase and in the opposite direction which is the reason why the radiation is cancelled. This is the explanation as to why the transmission line does not radiate the antenna radiates yet. The radiation that occurs at the antenna is attributed to voltage rather than current thus the voltage distribution in microstrip antennas become advantageous. This principle of radiation is the reason why there is a difference between microstrip antennas which are "voltage radiators" whereas wire antennas are "current radiators." As far as the permittivity is concerned, there is a trade-off between the amount of radiation and the size of permittivity. The principle is that the smaller the permittivity, the better the radiation is generated, and the opposite is also true. It is true because when the permittivity is small, the fringing fields extend far from the patch whereas when the permittivity is high, the fringing level becomes less.

2.6. FEEDING METHODS OF PATCH ANTENNA

At the end of designing, the feeding of the microstrip patch antenna (MSPA) is done. The main reason for this, it becomes possible to achieve high impedance for the input value by adjusting the dimensions of the feed. However, it is still possible to do a modification to the antenna so that better results can be obtained. Microstrip patch antenna has various methods for feeding. These feeding techniques are often classified into 2 groups, non-contacting and contacting [14]. In the contacting group, the power is fed the patch directly by employing a metallic element. In the non-contacting group, the electromagnetic field is coupling with the patch.

The most three famous feed techniques that used to feed micro strip patch antenna (MSPA) are the coupling technique, coaxial probe, and microstrip line. The following subsections will discuss various techniques for feeding the patch antenna.

2.6.1. Microstrip Line Feed Technique

In this technique, a strip line is connected to the edge of the patch as shown in Figure 2.11 and Figure 2.12. The width of the patch is larger as compared to the width of the strip line. This technique has some advantages, where it is simple in modeling and ease of fabrication. This technique has two types; inset feed and Quarter-Wavelength Transmission Line feed. These types are discussed in the following subsections.

2.6.1.1. Inset feed

As noted earlier, the current is found to be low at the ends of the patch antenna. As the distance decreases towards the mid-section, the current increases in magnitude. Therefore, it implies that it is possible to minimize the input impedance if the current is fed closest to the center. This can be achieved by including an inset feed that is shown in Figure 2.11 [20].

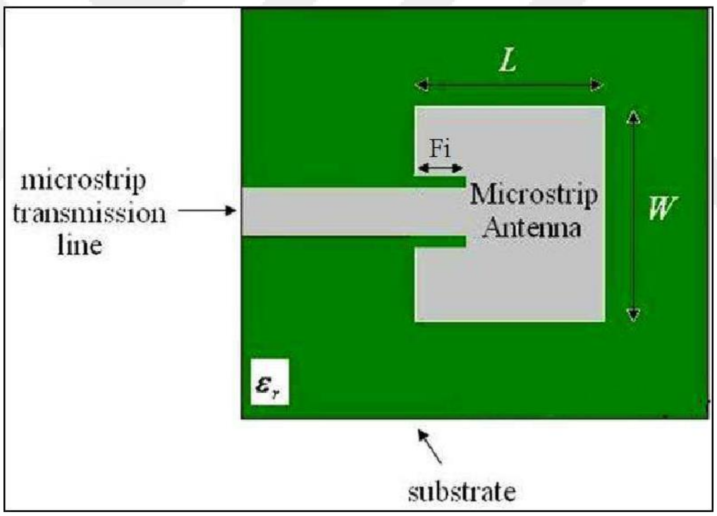

Figure 2.11: Inset feed indicated by R [20]

The current is found to have a sinusoidal distribution which implies that if the distance is increased further away from the end, then the current will be increased. Notably, the voltage also experiences an increase by the same magnitude. The relationship between these parameters is represented by Z=V/I while the scaling of the impedance is represented by the Equation 2.1

$$Z_{in}(R) = cos^2\left(\frac{\pi R}{L}\right) Z_{in}(0) \tag{2.7}$$

2.6.1.2. Quarter-wavelength transmission line feeding

A Quarter-Wavelength Transmission Line of characteristic Z1 can also be used to match the Z_o represented in Equation 2.2. The matching is indicated in the Figure 2.12.

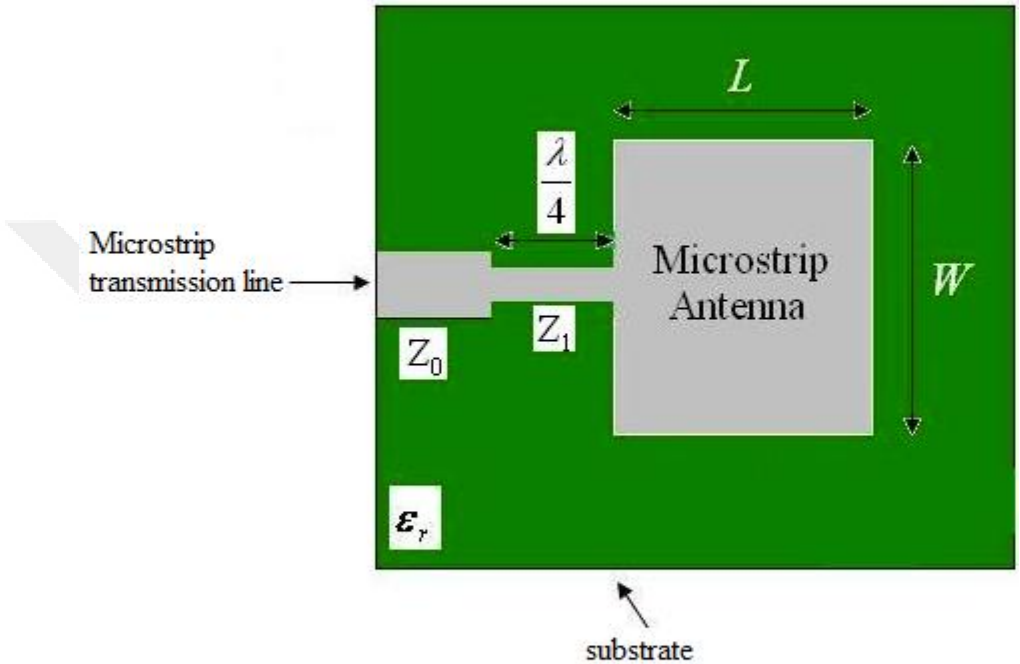

Figure 2.12: Quarter wavelength matching [20]

In this scenario, three parameters are considered namely transmission line, input impedance, and the antennas impedance. The relationship is indicated in Equation 2.2.

$$Z_{in} = Z_0 = \frac{Z_A^2}{Z_A} \tag{2.8}$$

Whereby (Z_{in}) represent input impedance, (Z_0) represents transmission line; (Z_A) represents impedance of the antenna, and (Z_1) represents variant impedance.

The objective in this scenario is to manipulate the values so that matching is achieved between the transmission line and the input impedance [1]. In order to cause variation that will result in matching, the variant impedance is altered so that the desired results are obtained. To alter the variant impedance, the quarter-wavelength strip's width is changed. As the strip is getting wider, the impedance Z0 will get lower and vice versa.

2.6.2. Coaxial Probe

This technique is very famous for feeding the patch antenna. It is also possible to feed a microstrip antenna using a probe so that the feeding process takes place from underneath. In this method, the outer conductor connected to the ground plane. While, there is an extension of the center conductor, which it goes up to the patch [21]. To control the impedance, adjust the position of the coaxial probe, and this is considered as an advantage of this method. However, it has some disadvantages like the bandwidth is narrow and making the antenna more inductive when the substrate height is increased, this lead to matching problems. It is also important to note that radiation in unwanted directions will take place because even the probe will radiate if height increases exceedingly.

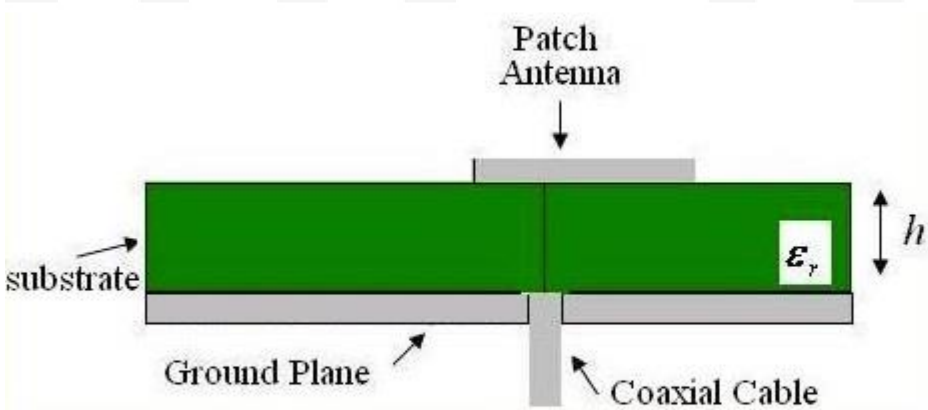

Figure 2.13: Probe feeding [21]

2.6.3. Coupled Feeds

The feeding method discussed in the previous section has some disadvantages regarding the width requirement in the microstrip antenna. For this reason, it is necessary to consider non-contacting feed techniques which have the capability of mitigating negative implications of using these techniques [20]. The proximity coupled feeds and the aperture feeds are the examples of the coupled feeds that are non-contacting techniques.

2.6.3.1. Proximity coupled feed

When using this technique, the patch antenna is designed in such a way that it has two dielectric substrates whereby the feed-line is located between the two substrates. In the case of the radiating patch, it is placed on top of the upper substrates surface [21]. Where there is a microstrip patch antenna that has radiating properties, the feed-line to the patch antenna is usually on the top surface of the two dielectric substrates. This feeding technique is preferred to other techniques because it offers many benefits. Some of these benefits include: it does not require any physical contact whatsoever between the element and the radiating surface. Another benefit of the proximity coupled method is that there is no drilling that is required and there is minimal spurring during emission of the radiation. This method is efficient because it enables to achieve high levels of radiation which is brought about by the increased width of the patch. The technique enables increasing the bandwidth by up to 13%. Using the proximity coupled feed technique enables optimization of the performance of the substrates. It makes it possible to optimize the performance of the feed technique separately from the performance of the patch. Although the technique has many advantages, two main advantages are associated with the technique. Also, the use of two different substrate layers increases the width of the patch.

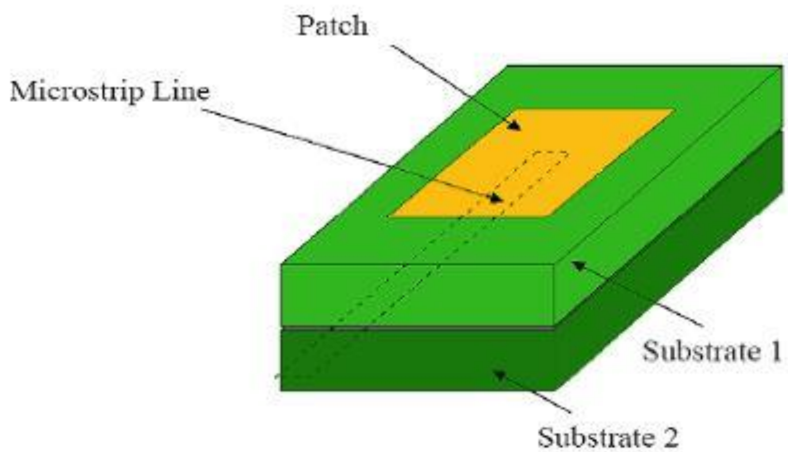

Figure 2.14: Proximity coupled feed [21]

2.6.3.2. Aperture coupled feeds

Similar to the proximity coupled technique, the aperture method also uses electro-magnetic coupling technology. This technique involves having a common aperture that is utilized in coupling the RF energy that is radiated from the microstrip patch antenna [20]. The common aperture is placed on the ground plane whereby there may be one or more conducting patches according to the desired performance expected. A layer of dielectric carrier supports the patches on the ground plane. To increase the efficiency of the microstrip patch antenna, the coupling aperture is situated at the central part of the patch. Variations in a number of factors dictate the magnitude of coupling that is derived from the feed line. The factors are such as; location, shape and size of the aperture that is placed in the central part of the microstrip patch antenna. The location of the radiating patch element is at the top of the feed substrate, and the ground plane is placed between the two substrates. The ground plane between the two substrates has the coupling slot. This design where the ground plane is placed between the substrates enables minimizing the spurious radiation. Aperture-Coupled feeding has a number of other advantages. The other benefits include; ease of integration and the amount of space available becomes increased.

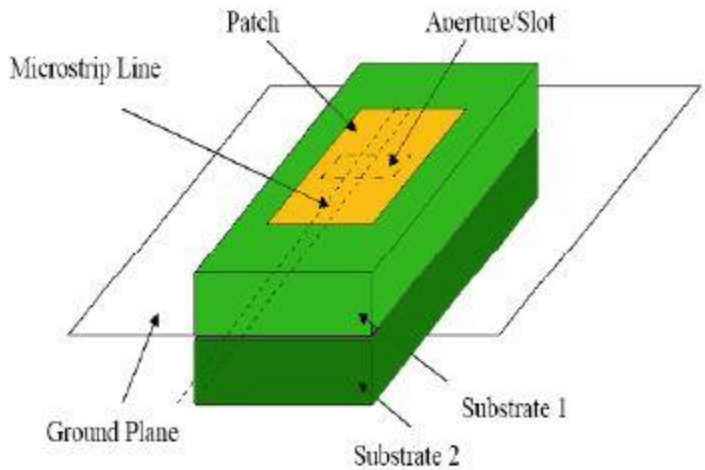

Figure 2.15: Aperture feed technique [20]

Optimal antenna performance can be achieved because it is possible to do an independent selection of the feed substrates and the radiator. A higher dielectric constant can be chosen to ensure that the electrical size of the circuit is reduced. To ensure that the dielectric constants of the two substrates have an effect on each other, the ground plane is introduced. The aperture feed technique is advantageous in the following way; it leads to an increased degree of freedom which allows for optimization of the design. The process of matching the impedance becomes easy for designers because there is an additional degree of freedom [20]. For matching purposes, adjusting the length of the open-circuit stub adjusts the antenna's locus which enables compensation of the reactance.

3. LITERATURE REVIEW

Recently, researchers show a big interest in reducing the size of antennas. This is because technology is going toward creating small devices. According to that, it is important to ensure that the size of the microstrip patch antenna remains minimal at a fixed operating frequency. Therefore a lot of techniques are used for miniaturizing the overall size of the patch antenna at the same concept; they are mentioned in section 3.1. Aside from reducing the element size, some of these techniques have also been employed to produce patch antennas with dual frequency response. These designs operate using a similar principle of operation. Hence reviews of such designs are incorporated within this discussion. The focus of this chapter is to give a review of such techniques and the ultimate aim of producing planar fed reduced size patch antennas. It is predicted that the usage of such techniques will have an adverse circa on patch performance like the bad effect on the gain. Following this brief introduction, section 3.1 will give a brief overview of some methods that used to miniaturize the size of the patch antenna. In subsection 3.1.5 will focus and give a brief explanation on inserting slots in the patch and the previous works that have the same principle of this thesis.

3.1. MINIATURIZATION TECHNIQUES

3.1.1. Use of High-Permittivity Material

The easiest way to miniaturize the size of microstrip patch antenna is to use a material that has high-permittivity as a substrate. Patch antenna dimensions such as width and length are inversely proportional to the square root of εr of the dielectric. By using dielectric that has high-permittivity, the wave propagation will increase within the substrate and this will cause a reduction in both radiation efficiency and the bandwidth, this is because of increased losses. The result of reducing the ground plane will be poor polarization and also changes in the performance characteristics of microstrip patch antenna [22]. A lot of researches have investigated in different configurations and materials to use this technique in an effective way to miniaturize the size of a patch antenna, where a dielectric constant of 10 to 13 and thicker substrate was analyzed [23]. Different radiation performances from that of patch antennas where is the result of this approach [23]. Also, another approach is used in some researches, where a Ceramic is used as a substrate to miniaturize the size of the patch antenna. There are different types of ceramic. In [24], a square ring microstrip patch antenna is designed, where the ceramic is used as a substrate, in which its dielectric constant of this substrate is 5.8. In this design, by using ceramic as a substrate, miniaturization of 50% could be achieved as compared to a antenna with FR-4 as a substrate. In [25], where a Magneto-dielectric substrate is used to get a miniaturized patch antenna. 65% of the size of the patch antenna is reduced by using this material with respect of using FR-4.

3.1.2. Use of Sierpinski Carpet Fractal Method

The property of space filling of the fractal causes an increment in the electrical length that is used to miniaturize the size of the patch antenna. A method of using Sierpinski carpet fractal is used with various iterations to miniaturize the size of the patch of the microstrip patch antenna [26]. At the second iteration, miniaturization of 32% was achieved by using this technique. In this design, initially, the patch was divided into 9 identical rectangles and removed the central rectangle. In the additional iterations, 8 rectangles were remained and again divide them into other 9 identical rectangles and remove the central rectangle from these rectangles. This procedure was followed for other iterations similarly. By using this approach, miniaturization of 32% is achieved at the second iteration with the same performance at 2.45 GHz. In [26] antenna gain and S11 results were compared with patch antenna at the same frequency.

3.1.3. Use of Shorting Pins Between Ground Plane And Patch

The patch antenna could be electrically small by using shorting-pins between the ground plane and the patch, where miniaturization of patch antenna can be achieved according to this reason. For half-wavelength λ microstrip patch antenna, with respect to transmission line model; at the radiation edge, the electrical field distribution is the greatest, and it is zero at the middle of the patch. By putting shorting-pins between ground plane and the patch, half of the electrical distribution is removed and got the same Q-performance at the same resonant frequency; this is called quarter wavelength antenna. By using this approach, high miniaturization could achieve, but it found that antenna gain was reduced; hence the directivity would also reduce. Multiple, double, and single shorting-pins were used in [27] — the results presented by using a parametric sweep. A comparison was made between the miniaturized antenna and the one and found that miniaturization of 66% was achieved.

3.1.4. Use of Meta-Materials

In order to get materials that have properties in which are not found naturally, some materials are engineered artificially. These materials are called meta-materials. Meta-materials are having negative permittivity ε and permeability μ. Materials with only negative permittivity are called as negative-index permittivity materials and materials with only negative permeability is called as negative-index permeability materials. Materials with both permeability and permittivity negative are called as negative-index materials (NIM). This type of structure is used to get high performance of the patch antenna and enhance the gain and the radiation efficiency. These types of structures can be used to miniaturize the patch antenna. In [28], a rectangular patch antenna radiating was investigated. Here circular-shaped ring resonators or square-shaped ring resonators were used as meta-materials to obtain miniaturization. In this work, miniaturization up to 44.5 % of patch antenna was obtained. In [29] left-handed meta-material with negative-index is used to obtain the miniaturization in patch antenna. In this work, 8 shaped meta-material is designed with the ϵr=-2 and μr=-4 at 1.8 GHz frequency. At 1.8 GHz frequency, the designes designs achieved -34 dB return loss and the size of the rectangular microstrip patch antenna was miniaturized by 71 %.

3.1.5. Inserting Slots in the Patch Method

Introducing the slots on the patch is a technique commonly used to reduce the microstrip patch antenna. When the slots are cut from the patch, the path of the current is changed. Current travels extra path as compared to the without slot of microstrip antenna [30]. The following are previous works related to this research. [31] Makes meanders in the patch and indicates that, by combining short-circuiting and meandering of the patch, the antenna size can be reduced to be less than 10% that of a conventional microstrip antenna operated at the same frequency. [32] Makes ten rectangular slots in the patch, by doing that, 50% of the initial size can be reduced. In [33], a novel, compact, probe-fed microstrip patch antenna for operation in dual-polarization mode is designes. The novel design isachieved by etching out asymmetric pattern of crossed slots from the surface of a square probe-fed patch. Reduction in a patch size of up to 51% with respect to a traditional dual-polarized square patch operating at the same frequency is obtained. In [34], a broadband asymmetric U-slot patch antenna with a narrow probe is presented. It can be indicated that the designes antenna has reduced size of 33% compared to the conventional antenna.

4. DESIGN CONSIDERATIONS

There are 3 steps to obtain the final design of the desired miniaturized saw teeth antenna. These steps are performed in Figure 4.1, Figure 4.2, and Figure 4.3. The procedure of designing the conventional patch antenna (without applying the saw teeth slots) is shown in Figure 4.1, while the procedure of designing the miniaturized patch antenna (with applying the saw teeth slots) is shown in the Figure 4.2, and finally the procedure of improving the gain of the miniaturized patch antenna is shown in Figure 4.3.

The designing of the desired microstrip patch antenna is performed by the first step within the usage of the elemental Equations that will mention in the next subsection. After finishing the design of the microstrip patch antenna, the second step is started. In this step, eight slots would be made in the rectangular patch to obtain the desired saw teeth patch antenna (four slots in the left side and four slots in the right side). After finishing the design of the desired saw teeth antenna, apply defected ground structure (DGS) in the form of T-shape to improve the gain.

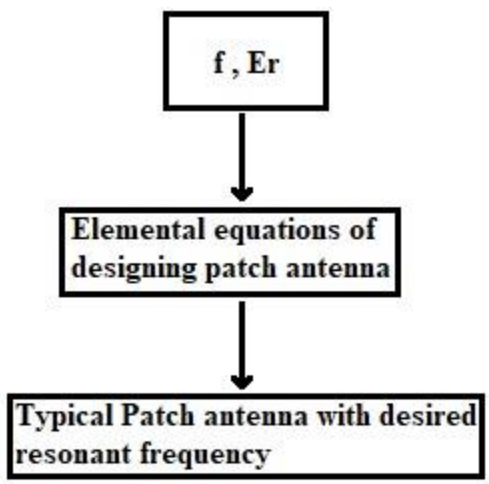

Figure 4.1 Steps of designing patch antenna

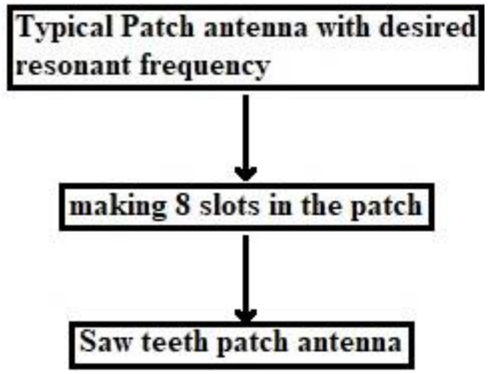

Figure 4.2: Steps of designing saw teeth patch antenna

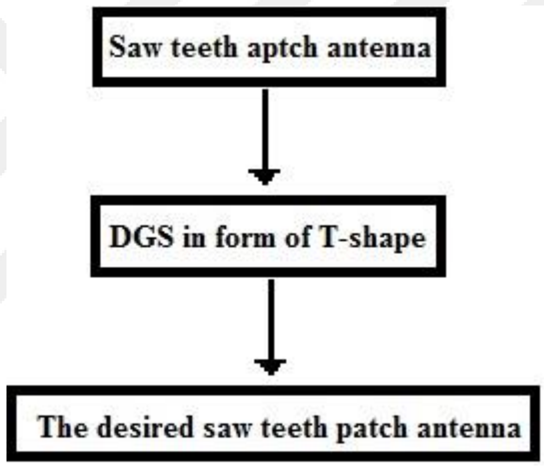

Figure 4.3: Steps of improving the gain

The additional details for designing the standard patch antenna within the usage of the elemental Equations and additionally the designing of the miniaturized patch antenna are given in following subsections.

4.1. DESIGN OF THE PATCH ANTENNA

Figure 4.4 shows the front view of the designes microstrip patch antenna (MSPA). The rectangular patch with the length (Lp) and the width (Wp) is located on the FR-4 substrate that its dielectric constant is (ε_r=4.4) and also its loss tangent is 0.002, where its length is (Ls) and also its width (Ws). The required resonant frequency are often obtained by adjusting the length of the substrate (Ls) and its width (Ws), the patch's length (Lp), its width (Wp), the dimensions of the feed line (width (wf) and also the length (Lf)) in a proper way. The material that is chosen for the substrate is FR-4 with a loss tangent equal to 0.002 because it is the best choice to design a patch antenna with lower frequencies. The dimensions (the length (Ls) and the width (Ws)) are the same in both substrate and the ground plane layers.

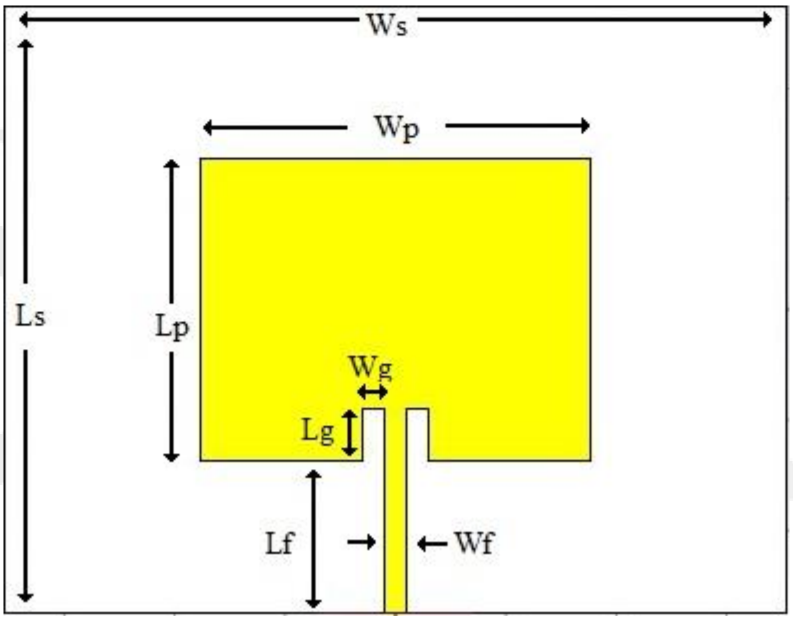

Figure 4.4: Top view of the MSPA

The ground plane layer is made of a lossy copper annealed material that has a 5.8x10S/m as the conductivity with a thickness (t) equal to 0.016 mm. The patch is made of the same material of the ground plane layer (a lossy copper annealed) with the same thickness ((t) equal to 0.016 mm) but different dimensions (the patch length is (Lp) and the patch width is (Wp)). The entire dimensions of the microstrip patch antenna (MSPA) that labeled in the Figure 4.4 are mentioned in the Table 4.1. For simulating the structure, the Transient domain solver of CST MWStudio is used.

The Designing of the microstrip patch antenna (MSPA) is done by using the following elementary formulas.

1. Width of the patch: [14]

$$\mathrm{Wp} \; = \frac{C}{2f}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{4.1}$$

Where c is the speed of light and ε_r is dielectric constant of the substrate

2. Effective permittivity of the microstrip antenna: [14]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + \frac{12h_s}{w_s}}}\right) \tag{4.2}$$

3. Fringing field factor: [14]

$$\Delta L = 0.412h \; \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{w_s}{h_s} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{w_s}{h_s} + 0.8\right)} \tag{4.3}$$

4. Effective length of the patch: [14]

$$L_{eff} = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4.4}$$

5. The actual length of the patch: [14]

$$L_p = L_{eff} - 2\Delta L \tag{4.5}$$

6. Approximation of substrate/ground dimensions:[14]

$$L_s = 2\times \mathrm{L_p} \tag{4.6}$$

$$W_s = 2\times \mathrm{W_p} \tag{4.7}$$

7. Characteristic impedance: [35]

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_r}\left[\frac{w_s}{h_s} + 1.393 + 0.677\ln\left(\frac{w_s}{h_s} + 1.444\right)\right]} \tag{4.8}$$

8. Width of inset-fed: [36]

$$Wg = \frac{C}{\sqrt{2\epsilon_{reff}}}\frac{4.65 \times 10^{-12}}{f} \tag{4.9}$$

9. Length of inset-fed: [36]

$$Lg = \frac{L}{\pi}\cos^{-1}\left(\sqrt{\frac{Z_{in}}{R_{in}}}\right) \tag{4.10}$$

Table 4.1: Dimensions of patch antenna

Variables	Dimensions in mm
Ws	70.84
Ls	54.84
Wp	35.42
Lp	27.42
Lf	13.71
Wf	2.88
Lg	5
Wg	4
Hs	1.6
Ht	0.035

4.2. SAW TEETH ANTENNA

By making a symmetrical number of triangular slots on both side of MSPA, a shape of saw teeth patch antenna (STPA) can be obtained. Four slots are been made in the both side of the patch. Figure 4.5 shows the top view of the STPA. Figure 4.6 shows the top view of the triangular slot. The dimensions of the triangular slots that labeled in Figure 4.6 are the same for all the slots. The best dimensions of the four slots are obtained by using the parametrical sweep tool in CST studio with certain iterations. The dimensions of the triangular slots are shown in Table 4.2.

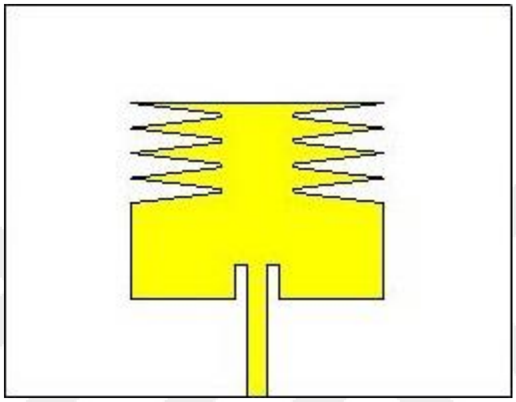

Figure 4.5: Saw teeth patch antenna

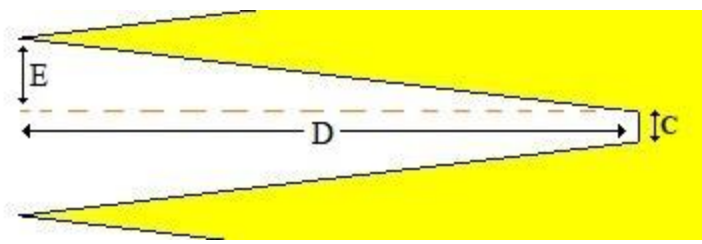

Figure 4.6: Top view of the slot

Table 4.2: Dimensions of any single slot

Variables	Dimensions in mm
C	0.5
D	12.6
E	1.5

5. RESULTS AND DISCUTIONS

After completing the design as is shown in the previous chapter and finishing the simulations of all designs by using CST studio program and its tools (like parametrical sweep tool). Radiation pattern, surface current, gain, return loss (S_{11}), Voltage Standing Wave Ratio (VSWR) are shown in this chapter for all designs.

5.1. MICROSTRIP PATCH ANTENNA

For proceeding with a similar goal of a lot of studies have been made to investigate, test, and develop the antenna, a RMSPA is designed in this work. It is obvious from the Figure 4.5 and Table 4.1 that the overall dimensions of the rectangular microstrip patch antenna are (70.84 x 54.84) that placed over FR-4 with relative permittivity (εr) of 4.4.

The designes rectangular microstrip patch antenna that shown in the Figure 4.5, has a return loss equal to -24.06 dB at the frequency 2.624 GHz as shown in the Figure 5.1. Where return loss (RL) is known as the losses in power in which for the wave or signal that reflected or returned as a result of the mismatch with a device inserted in the line terminating load [14]. The return loss usually expressed in decibels (dB).

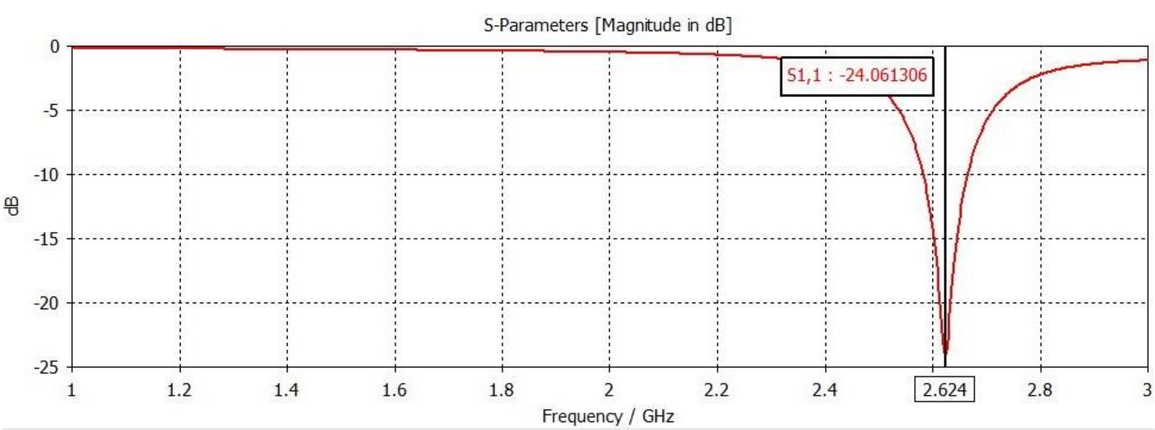

Figure 5.1: The return loss of designes MSPA

The 2D graphical representation of the radiation pattern of the MSPA is shown in Figure 5.2. Where radiation pattern represents as the energy that received by the antenna or sends into space by the antenna and it also describes the radiation properties of the antenna.

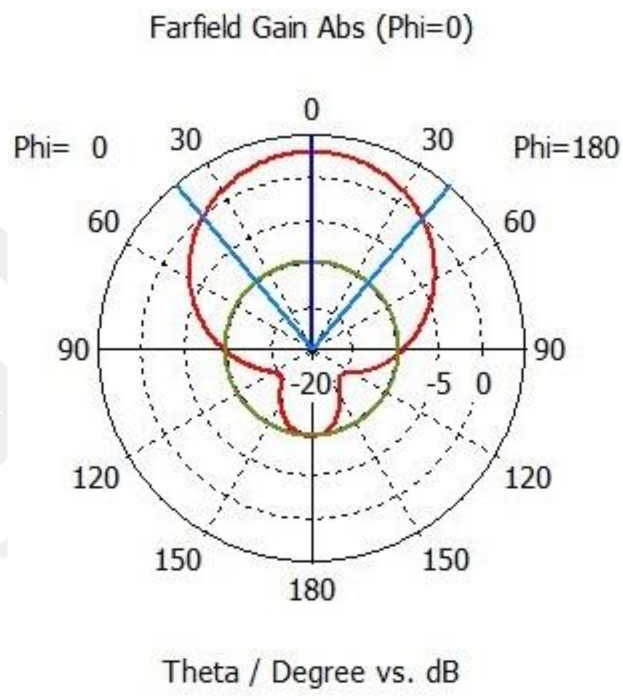

Figure 5.2: Radiation pattern of MSPA

MSPA has a gain of 3.21 dB at 2.562 GHz, which indicates that at this frequency, the antenna is more efficient. The gain describes the power which is received or sent by the antenna in a certain direction.

The value of VSWR is 1.1336 as shown in Figure 5.3 at the frequency 2.624 GHz. VSWR value indicates how much the impedance is matched between the feed and the source, which is one of the essential requirements for designing the antenna.

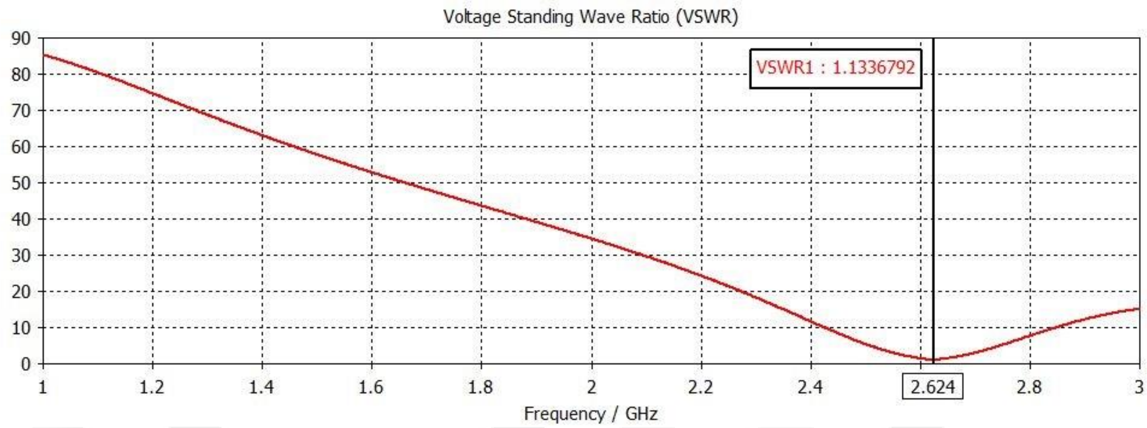

Figure 5.3: VSWR of designes MSPA

The surface current of the MSPA are shown in Figure 5.4. The surface current is the current that induced in a surface when an electromagnetic field is applied to that surface.

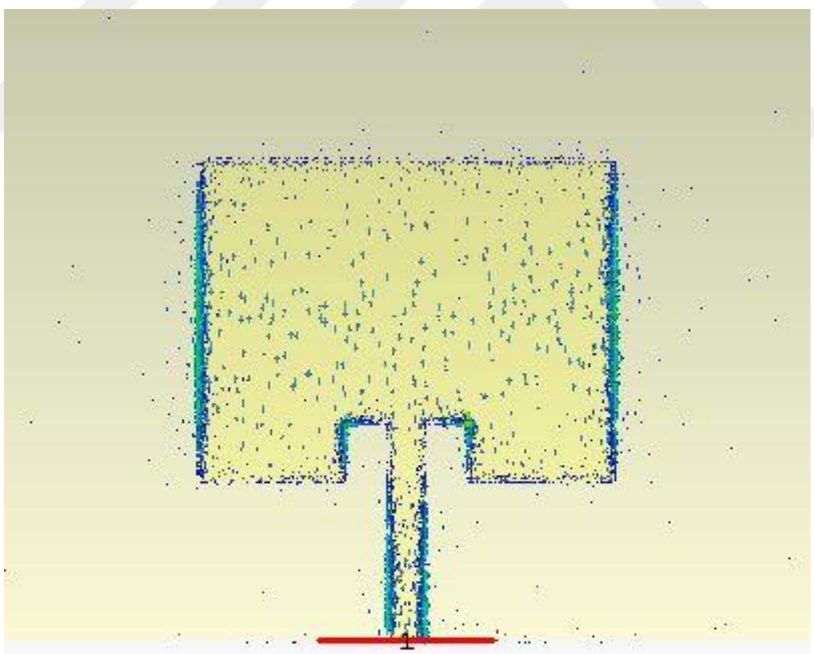

Figure 5.4: Surface current of the designes MSPA

5.2. SAW TEETH PATCH ANTENNA

A unique operating frequency can be obtained by cutting eight slots from the patch. By using this method “making a number of slots in the patch”, the operational frequency of the MSPA will minimize. The major purpose of this method is to minimize the overall dimensions of the MSPA, and not to change the operating frequency. To get the best dimensions of the slots, a parametric analysis is done on a number of slots, depth of the slots (d), (c) and on (e) dimensions. Figures 5.5, 5.6, and 5.7 and the Table 5.1 show the results of the parametric analysis.

Table 5.1: Effect of number of slots

No. of slots	Return loss (dB)	Frequency (GHz)
1	-20.23	2.538
2	-21.44751	2.202
3	-16.71396	1.962
4	-12.34814	1.808
5	-11.5608	1.726

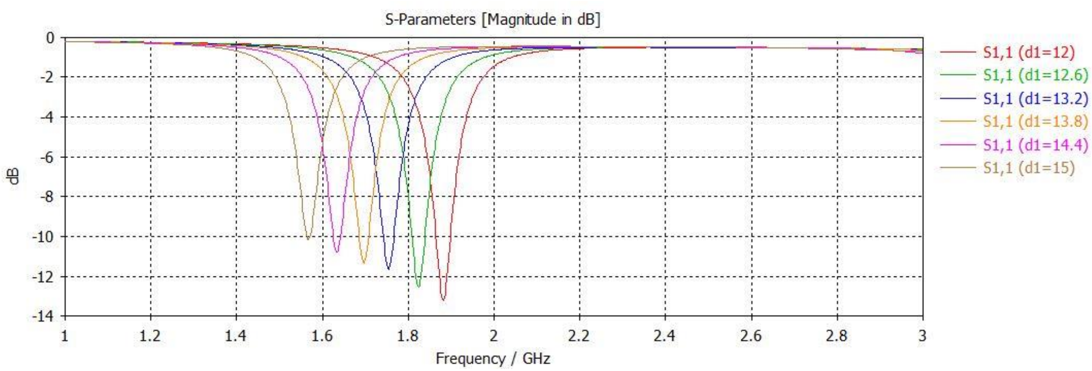

Figure 5.5: Parametric study on "d" dimension

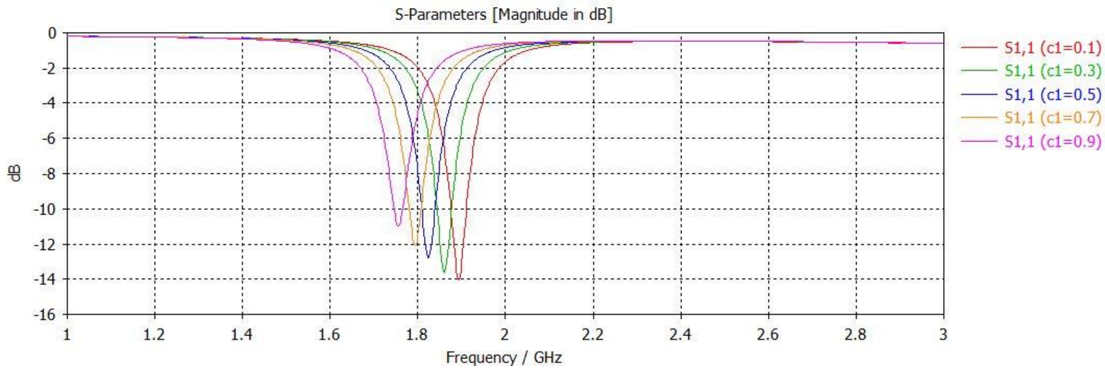

Figure 5.6: Parametric study on "c" dimension

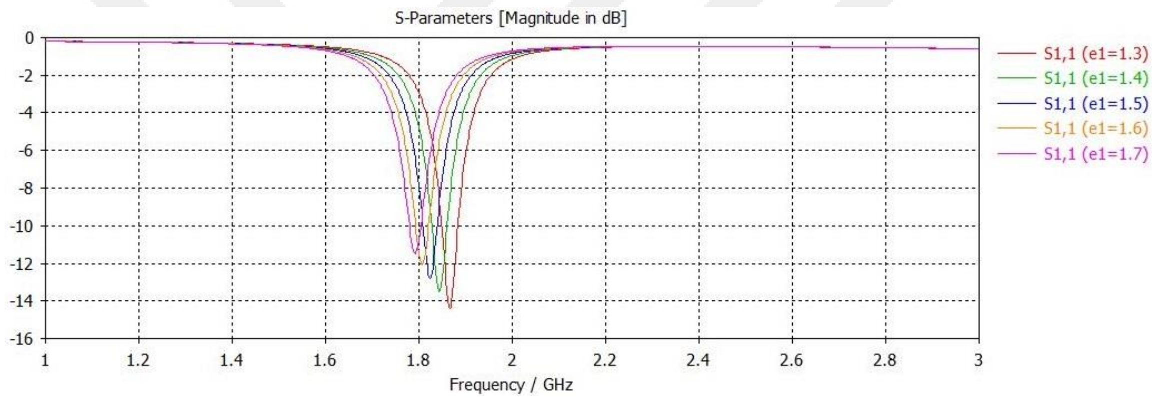

Figure 5.7: Parametric study on "e" dimension

The parametric study shows that as the depth of the slot “d” is increased, the return loss and the frequency decreases. The same effect is occurred when the dimensions “c” and “e” are increased.

According to this parametric study, 4 slots, e = 1.5mm, d = 12.6mm, and c = 0.5mm yield for the best compromise between good performance and good size reduction as -12.7687 dB is obtained as a return loss of the saw teeth patch antenna at 1.824 GHz which is depicted in Figure 5.8.

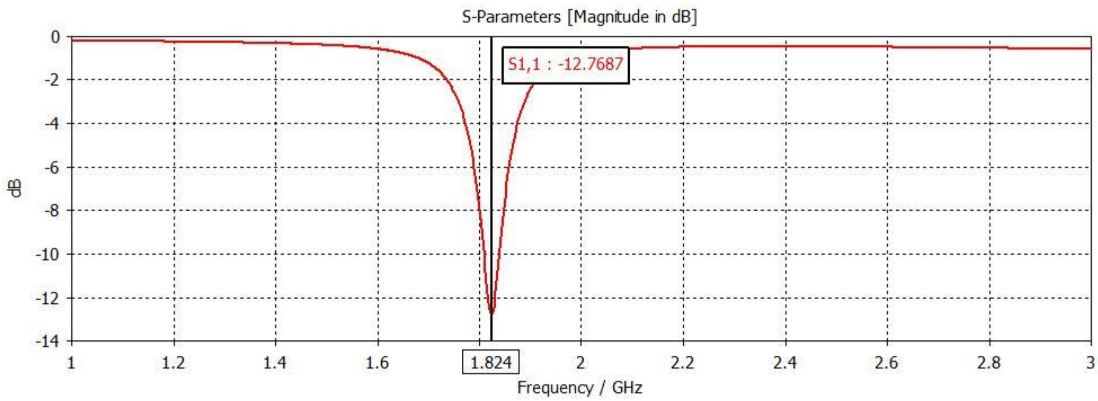

Figure 5.8: The return loss of STPA

The 2D graphical representation of the radiation pattern of the STPA is shown in Figure 5.9.

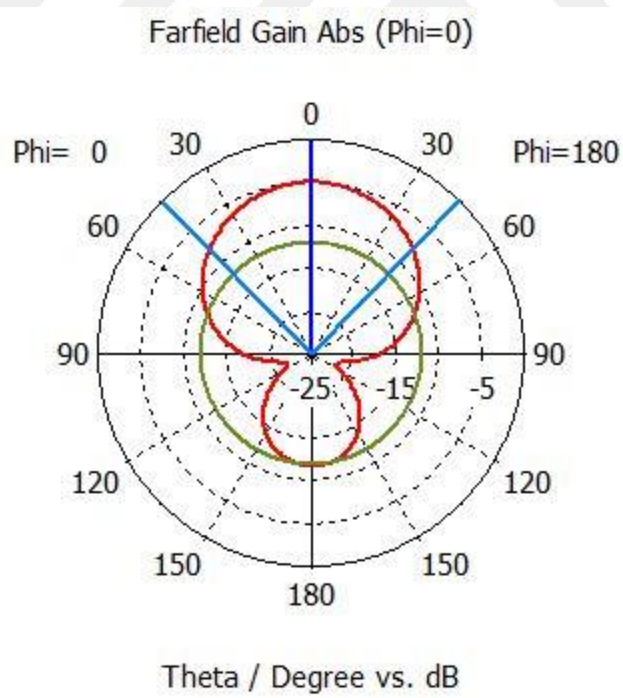

Figure 5.9: Radiation pattern of the STPA

STPA has a gain of -4.97 dB at 1.824 GHz. This gain is bad. The value of VSWR is 1.597; this is shown in Figure 5.10 at the frequency 1.824 GHz.

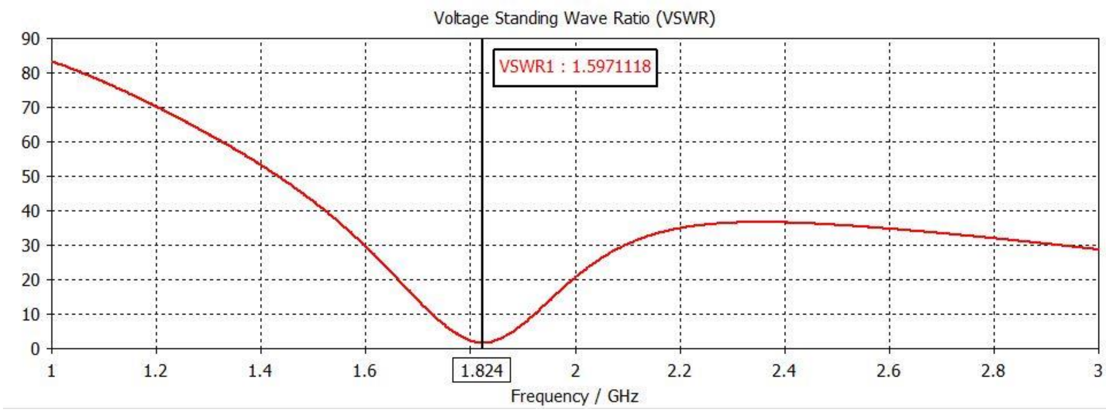

Figure 5.10: VSWR of the STPA

The surface current of the STPA is shown in Figure 5.11.

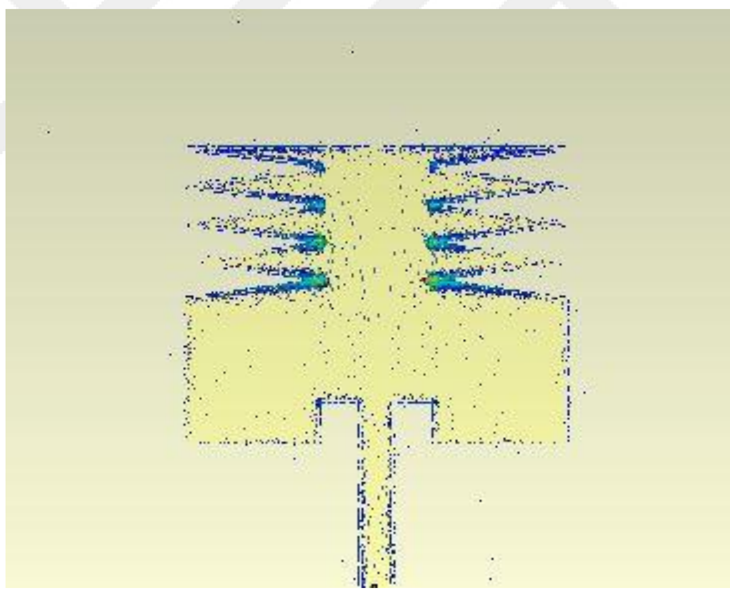

Figure 5.11: Surface current of the STPA

5.3. ENHANCING THE GAIN OF THE SAW TEETH PATCH ANTENNA

By applying the slots to the microstrip patch antenna, which the usage of this technique will have an adverse circa on patch performance like the bad effect on the gain. To improve the gain of the STPA, defected ground structure (DGS) in form of T-shape in the ground plane is used. T-shape defected ground plane will cause a disturbance in the surface current distribution. This will change the characteristics of transmission line in sense of its equivalent capacitance and inductance [37]. Figure 4.8 shows the back view of the enhanced MSPA.

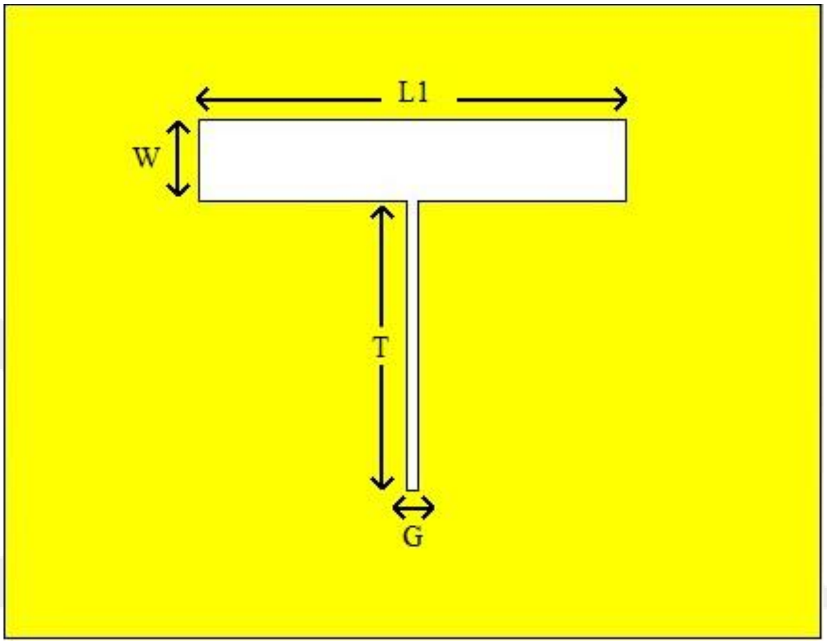

Figure 5.12: Bottom view of saw teeth patch antenna

Table 4.3 shows the dimensions of DGS.

Table 5.2: Dimensions of DGS structure

Variables	Dimensions in mm
L1	37
W	7
T	25
G	1

As it appears in the results of subsection 5.2, the saw teeth patch antenna has a bad gain. So in order to enhance this problem, a T-shape DGS is applied to the saw teeth patch antenna. This technique also reduces the antenna. By using this approach, the return loss is improved; where the return loss becomes -19.94 dB at 1.778 GHz, this is shown in Figure 5.12.

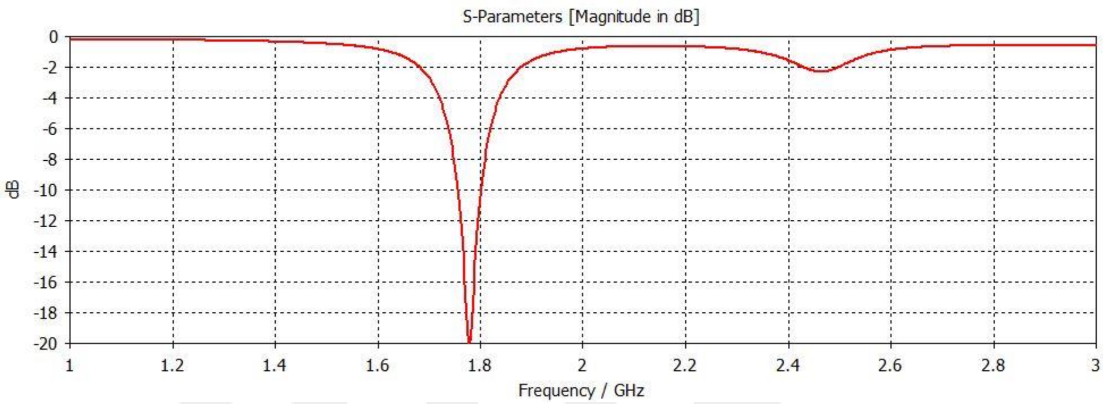

Figure 5.13: Return loss of enhanced STPA

The 2D graphical representation of the radiation pattern of the enhanced STPA after applying DGS is shown in Figure 5.13. The enhanced STPA is 2.14 dB

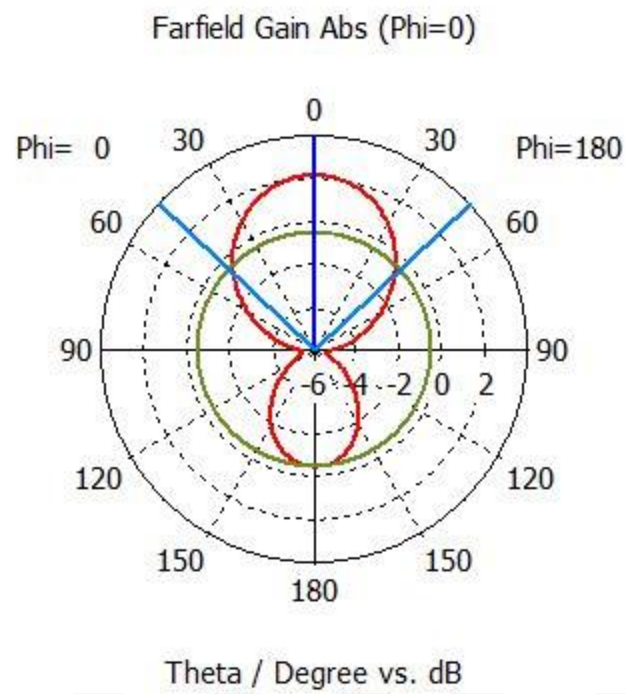

Figure 5.14: Radiation pattern of the enhanced STPA

The value of VSWR is 1.223; this is shown in Figure 5.14 at the frequency 1.788 GHz.

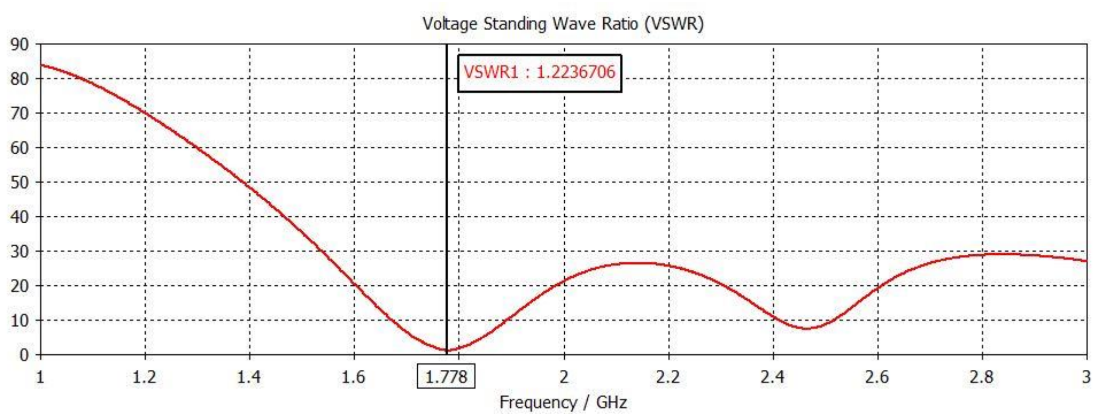

Figure 5.15: VSWR of the enhanced STPA

The surface current of the enhanced STPA is shown in Figure 5.15.

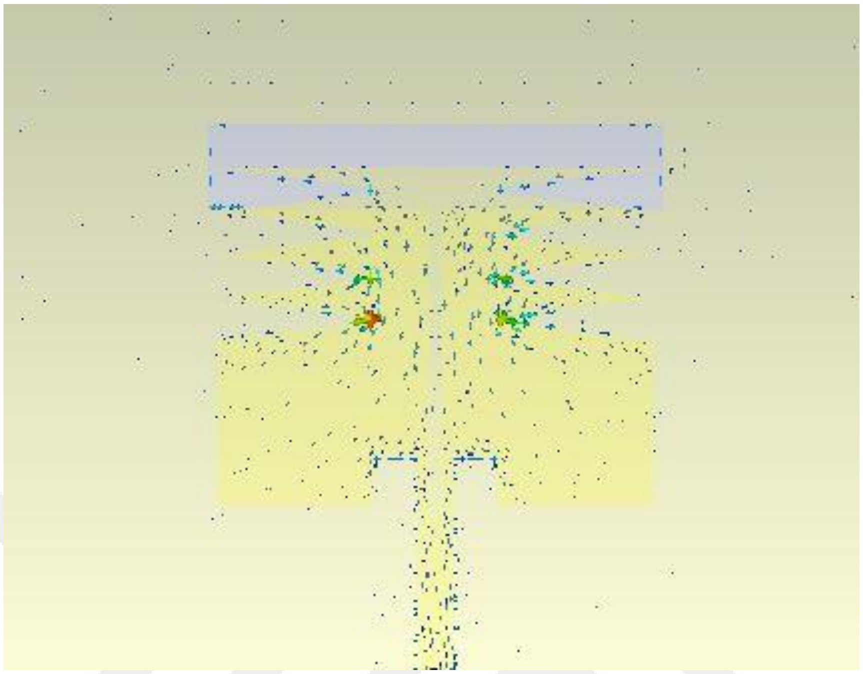

Figure 5.16: Surface current of the enhanced STPA

Figure 5.16 gives the return loss of the three designs

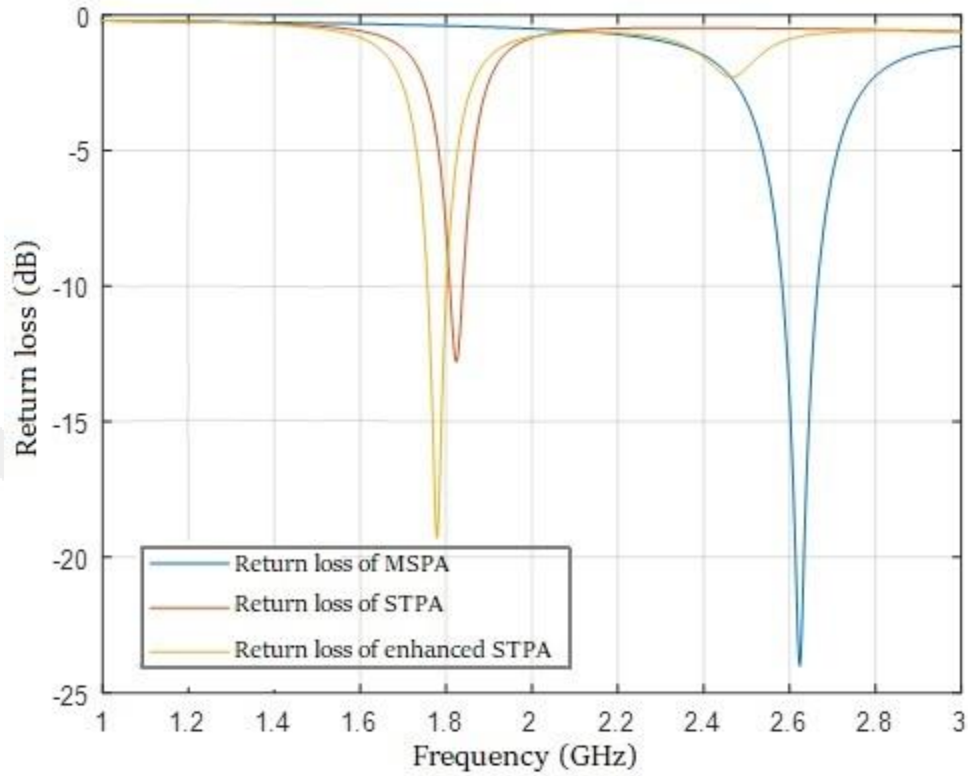

Figure 5.17: Return loss of all designs

Figure 5.17 gives the 2D graphical representation of the radiation pattern of all designs.

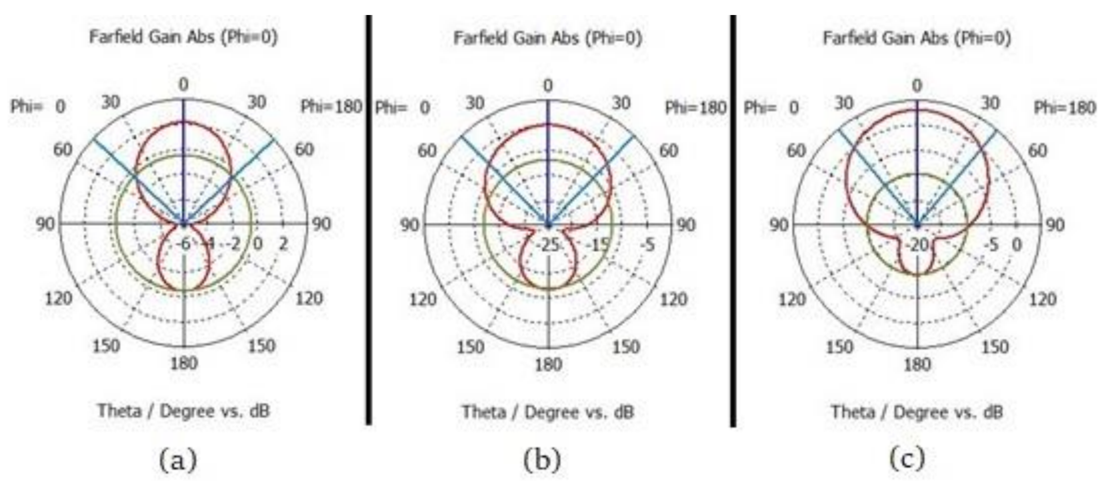

Figure 5.18: Radiation pattern of all designs: (a) Enhanced STPA, (b) STPA, (c) MSPA

5.4. THE PERCENTAGE OF MINIATURIZATION

In order to know how much an antenna will be reduced if this technique is used, a comparison must be made. So first, designing a patch antenna with a frequency equal to the frequency that the improved saw teeth patch antenna is operated with, this is done by using the designing Equations mentioned in subsection 4.1. So the dimensions of this antenna will be (103.3mm X 80.5mm), in another word, its overall area is (8315.65mm).

6. CONCLUSION

The size reduction of wireless devices is recently one of the most common topics that concerned all microwave and telecommunication engineers and researchers since the small size of the wireless, and portable devices are very important. From the results above, it can be concluding that when the method of cutting 4 slots “in both sides” from the patch antenna is used, some parameters get worse and some get better. As this technique is used, the return loss will be worse and increased by 17.12%, while the gain reduced by 33.33%, but the frequency reduced by 32.24%, which implies that the size will minimize. To overcome the problems that appear when applying slots to the patch, a DGS in shape of (T) is used, where the gain will enhanced from -4.97 dB to 2.14 dB. The total size of the conventional patch antenna will reduce by 75%. This percentage of miniaturization is much better than all the techniques that mentioned in the literature review.

There are some additional things that are designes for doing them as a future work:

- Derive some equations that investigate the effected parameters of the slots to get the exact effects of the slots on the performance of the patch antenna.
- Apply this technique to other types of patch antenna geometry.
- Fabricate and measure all the designs.

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