Sudan University of Science and Technology

College of Graduate Studies

Study of the effect of using different substrates on the performance of the batch antenna.

دراسة أثر استخدام مواد مختلفة على أداء الهوائي الرقعي

A thesis submitted for partial fulfillments of the requirement of the degree of master in physics

Submitted by

Marwa Osman Alrofai Omer

Supervisor

D. AmelAbdellah Ahmed Elfaki

feb.2017

الآيـة

قال تعالى:

﴿ كَلَّا إِنَّ مَعِيَ رَبِّي سَيَهْدِينِ ﴾

صدق الله العظيم

سورة الشعراء الآية ﴿ 62 ﴾

Dedication

Thanks GOD Almighty, Who illuminated the path for me, opened for me the doors of knowledge and provided me with patience and will.

Then to who consecrated me by education at a young age, and they were the shines light that enlighten my thoughts by advice and guidance in old age. Mom and Dad, May Allah protect them.

To who had made a head start to the furtherance of science and education that have been made and did not wait for a giving hope. Dr. Amel Abdellah Ahmad Elfaki.

To my brothers and sisters and my friend nisreen alfadel.

And thanks and gratitude to alsammani Mustafa who stood beside me.

My thanks to all who contributed in the output of this research to come into its final version .

Acknowledgement

To the first guided and cresset that illuminates the path for me, to whom he gave me and still gives me Without Borders, to whom I raised my head high with pride .... Abe Alaziz

God perpetuate a wealth me

To whom her heart saw me before her eyes and her womb embraced me before her hands, to my tree that wither not , to shadow that accommodated to him at all a while .... my beloved mother

may God save her

To the spirit of my grandfather God rest his soul and May He bestow His mercy and His soul rest in peace Who loved science and was in love with our ideal of science

May God have mercy on him

To the candles that illuminate the path for me, my brothers who encouraged me and continued without charge

To the bright jewel and protected ivory and the pearl

Dear sisters

To my fellow path and colleagues ....to the engineer Akram osman and who assistant me through my career and preleased me for practical work

Allah keep them save

All of them dedicate the fruit of my best ...

Researcher

Marwa osman alrofai

ABSTRACT

Design microstrip antenna by Simulation in ADS (Advance Design System) Momentum and to Studying the effect of using different substrates material on the performance of the batch antenna by using(FV $\varepsilon_r = 4.3$,QUARTZ $\varepsilon_r = 3.8$,ALUMINA$\varepsilon_r = 9.7$) in same frequency(2.4 GH).

The performance of micro strip Antenna is effected by its structure and dimensions but the substrate material has also significant role in analyzing antenna performance. When dielectric constant increases then the gain as well as the bandwidth also decreases. The efficiency of the antenna also improves with low dielectric constant. The overall performance of the antenna is influenced by substrate material at great extent.

مستخلص البحث

تم تصميم هوائي رقعي عن طريق المحاكاة باستخدام نظام التصميم المتقدم لدراسة اثر استخدام مواد مختلفة على أداء الهوائي الرقعي (microstrip antenna) باستخدام تردد واحد 2.4 جيجا هرتز ومواد ذات ثابت عزل كهربي مختلف (الفايبر 4.3، الكوارتز 3.8، الألمنيوم 9.4).

يعتمد أداء الهوائي على تركيبه وأبعاده والمادة المصنع منها التي تلعب دوراً مهماً في تحليل أدائه ،حيث وجد انه كلما زاد ثابت العزل الكهربي كلما قل الكسب وعرض النطاق للهوائي ،وان كفاءة الهوائي تزداد عند انخفاض ثابت العزل الكهربي .

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Chapter one

Introduction

1.1 Antenna Modeling:

microstrip patch antenna using rectangular patches. This antenna will have the main beam in the broadside direction with a specified beam width. The designed antenna consists of an single antenna with one rectangular patch. This one rectangular patch are connected to the transmission line with specified length and width depending on the impedance of the rectangular patch. A coaxial probe is connected to the transmission line which will excite the system i.e. the antenna. The design is implemented and analyzed in ADS Momentum. ADS Momentum is a 2.5D simulator which is used to solve complex electromagnetic circuits. It can build passive electromagnetic circuits and the simulation shows the S-parameters of the designed system. ADS Momentum takes care of the electromagnetic coupling effect. It also provides 2D and 3D visuals of output parameters, for example the radiation pattern and the directivity of the Antenna.

1.2 Objectives of The Research :

Review the antenna design techniques based on planer microstrip line, and calculate the dimension of the patch antenna using closed formulas.

Design and simulate a microstrip patch antenna using ADS Momentum simulator, the antenna will consist of one rectangular patch in a linear fashion, having this design specifications: height of the patch is 17.4 µm, the impedance of the patch is 10 Ω, electrical length of the patch is 180º , and thickness of the substrate is 1.5 mm (FV substrate). The antenna will operates at Resonant Frequency 2.4 GHz.

Studying the effect of using different substrates on the performance of the batch antenna.

1.3 Literature Review:

Deschamps: first proposed the concept of the MSA in 1953. However, practical antennas were developed by Munson and Howell in the 1970. The numerous advantages of MSA, such as its low weight, small volume and ease of fabrication using printed-circuit technology, led to the design of several configurations for various applications. With increasing requirements for personal and mobile communications, the demand for smaller and low- antennas has brought the MSA to the forefront

D.Pavithra and K.R.Dharani 2013: studied that substrate material affect the performance parameters such as Return Loss (S11). The patch antenna is designed for 4 different frequencies with FR4 and DUROID-6006. The results represent that for frequencies up to 4GHz FR4 material is convenient.

1.4 Statement of the Problem:

The rising importance of wireless communication and multimedia services increasing the efforts to the design and implementation of microstrip patch structures. A patch antenna is advantageous because of its low cost, small size, ease of fabrication, and can easily be integrated into many commercial transceiver systems. Microstrip antenna elements radiate efficiently as devices on microstip printed circuit boards. The microstrip patch antenna is an excellent candidate for portable wireless devices.

1.5 Research Layout:

The thesis consists of four Chapters, Chapter one consists of an introduction. Chapter two represents antenna fundamental. Chapter three the microstrip patch antenna .Chapter four result and discussion

Chapter two

Antenna Fundamentals

2.1 Introduction

Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. waveguide, transmission line) and the free space. The official IEEE definition of an antenna as given by

Stutzman and Thiele [4] follows the concept: “That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves”.

2.2 Antenna radiates

In order to know how an antenna radiates, let us first consider how radiation occurs. A conducting wire radiates mainly because of time-varying current or an acceleration (or deceleration) of charge. If there is no motion of charges in a wire, no radiation takes place, since no flow of current occurs. Radiation will not occur even if charges are moving with uniform velocity along a straight wire. However, charges moving with uniform velocity along a curved or bent wire will produce radiation. If the charge is oscillating with time, then radiation occurs even along a straight wire as explained by Balanis [5].

The radiation from an antenna can be explained with the help of Figure 2.1 which shows a voltage source connected to a two conductor transmission line. When a sinusoidal voltage is applied across the transmission line, an electric field is created which is sinusoidal in nature and this results in the creation of electric lines of force which are tangential to the electric field. The magnitude of the electric field is indicated by the bunching of the electric lines of force. The free electrons on the conductors are forcibly displaced by the electric lines of force and the movement of these charges causes the flow of current which in turn leads to the creation of a magnetic field.

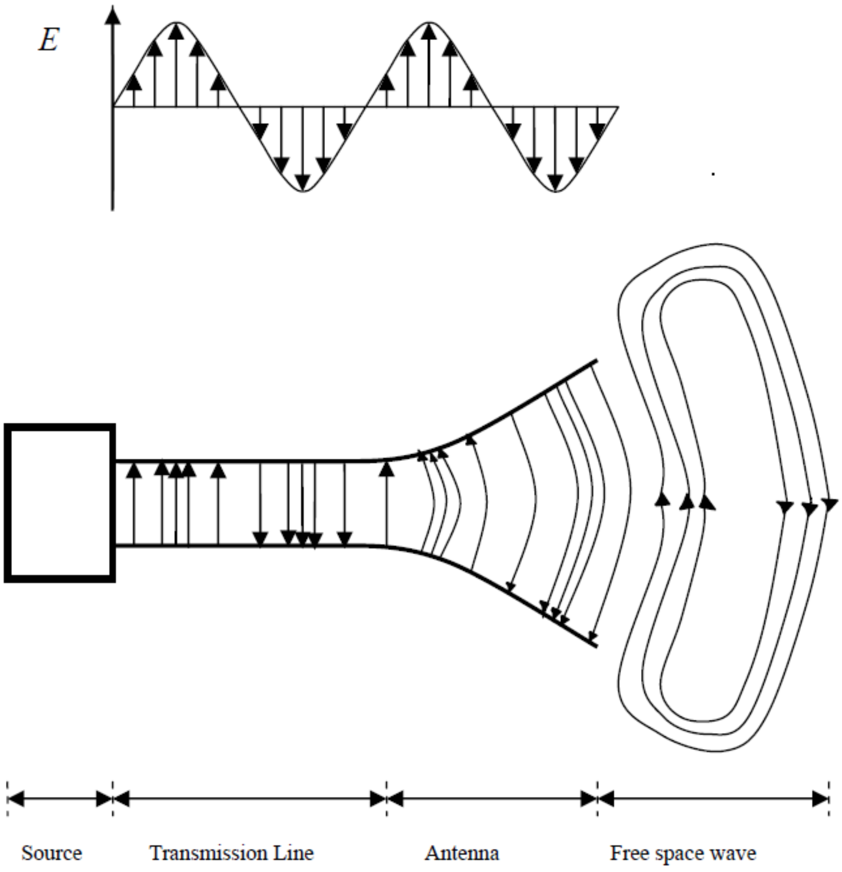


Figure 2.1 Radiation from an antenna

Due to the time varying electric and magnetic fields, electromagnetic waves are created and these travel between the conductors. As these waves approach open space, free space waves are formed by connecting the open ends of the electric lines. Since the sinusoidal source continuously creates the electric disturbance, electromagnetic waves are created continuously and these travel through the transmission line, through the antenna and are radiated into the free space. Inside the transmission line and the antenna, the electromagnetic waves are sustained due to the charges, but as soon as they enter the free space, they form closed loops and are radiated [5].

2.3 Antenna Performance Parameters

The performance of an antenna can be gauged from a number of parameters. Certain critical parameters are discussed below.

2.3.1 Radiation Pattern

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle θ and the azimuth angle ϕ . More specifically it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity [5]. Let us consider the case of an isotropic antenna. An isotropic antenna is one which radiates equally in all directions. If the total power radiated by the isotropic antenna is P , then the power is spread over a sphere of radius r ,so that the power density S at this distance in any direction is given as:

$$\mathrm{S} = \frac{P}{area} = \frac{P}{4\pi r^2} \tag{2.1}$$

Then the radiation intensity for this isotropic antenna U_i can be written as:

$$U_i = r^2\mathrm{s} = \frac{P}{4\pi} \tag{2.2}$$

An isotropic antenna is not possible to realize in practice and is useful only for comparison purposes. A more practical type is the directional antenna which radiates more power in some directions and less power in other directions. A special case of the directional antenna is the omnidirectional antenna whose radiation pattern may be constant in one plane (e.g. E-plane) and varies in an orthogonal plane (e.g. H-plane).

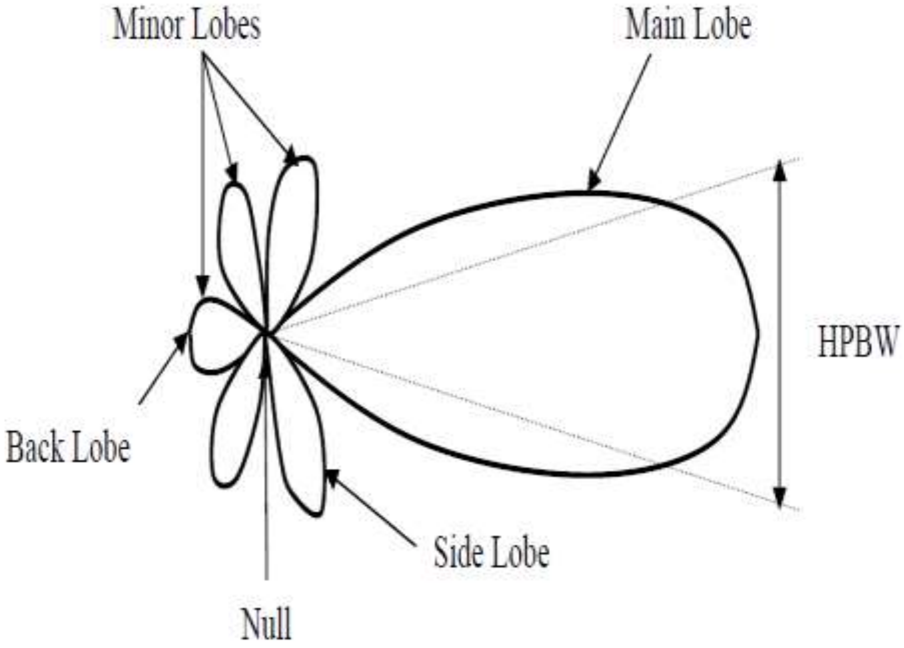


Figure 2.2 Radiation pattern of a generic directional antenna

Figure 2.2 shows the following*:*

- HPBW: The half power beam width (HPBW) can be defined as the angle subtended by the half power points of the main lobe.

- Main Lobe: This is the radiation lobe containing the direction of maximum radiation.

- Minor Lobe: All the lobes other then the main lobe are called the minor lobes. These lobes represent the radiation in undesired directions. The level of minor lobes is usually expressed as a ratio of the power density in the lobe in question to that of the major lobe. This ratio is called as the side lobe level (expressed in decibels).

- Back Lobe: This is the minor lobe diametrically opposite the main lobe.

- Side Lobes: These are the minor lobes adjacent to the main lobe and are separated by various nulls. Side lobes are generally the largest among the minor lobes. In most wireless systems, minor lobes are undesired. Hence a good antenna design should minimize the minor lobes[5].

2.3.2 Directivity

The directivity of an antenna has been defined by [5] as “the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions”. In other words, the directivity of a non isotropic source is equal to the ratio of its radiation intensity in a given direction, over that of an isotropic source.

$$D = \frac{U}{U_i} = \frac{4\pi U}{P} \tag{2.3}$$

Where

D is the directivity of the antenna

U is the radiation intensity of the antenna

U_i is the radiation intensity of an isotropic source

P is the total power radiated

Sometimes, the direction of the directivity is not specified. In this case, the direction of the maximum radiation intensity is implied and the maximum directivity is:

$$D_{max} = \frac{U_{max}}{U_i} = \frac{4\pi U_{max}}{P} \tag{2.4}$$

Directivity is a dimensionless quantity, since it is the ratio of two radiation intensities. Hence, it is generally expressed in dBi. The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity, then the one which has a broad main lobe, hence it is more directive.

2.3.3 Antenna Gain

Antenna gain is a parameter which is closely related to the directivity of the antenna. We know that the directivity is how much an antenna concentrates energy in one direction in preference to radiation in other directions. Hence, if the antenna is 100% efficient, then the directivity would be equal to the antenna gain and the antenna would be an isotropic radiator. Since all antennas will radiate more in some direction that in others, therefore the gain is the amount of power that can be achieved in one direction at the expense of the power lost in the others as explained by Makarov [6]. The gain is always related to the main lobe and is specified in the direction of maximum radiation unless indicated. It is given as:

$$G(\theta,\varnothing) = e_{cd} D(\theta,\varnothing) \text{ (dBi)} \tag{2.5}$$

2.3.4 Input Impedance

The input impedance of an antenna is defined by [5] as “the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point”. Hence the impedance of the antenna can be written as:

$$Z_{in} = R_{in} + jX_{in} \tag{2.6}$$

where

Z_{in} is the antenna impedance at the terminals

R_{in} is the antenna resistance at the terminals

X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components, the radiation resistance R_r and the loss resistance R_l . The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

2.3.5 Voltage Standing Wave Ratio (VSWR)

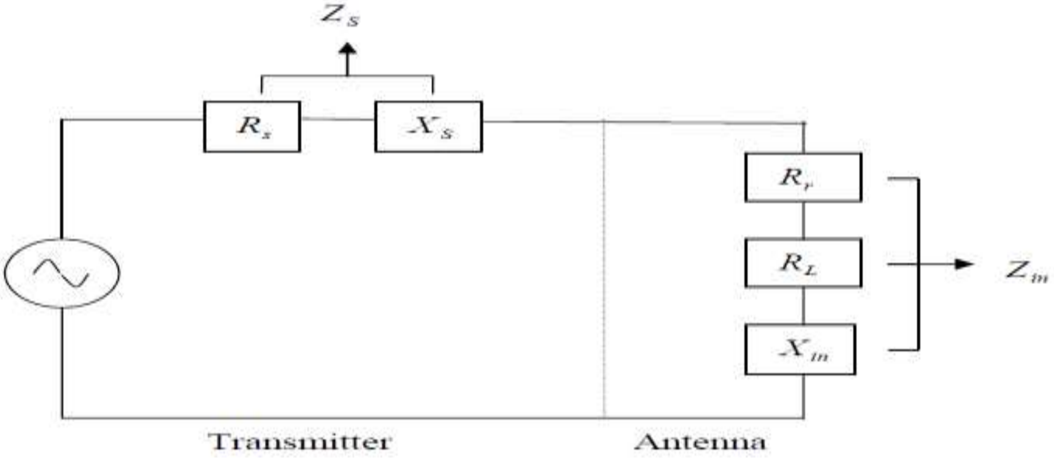


Figure 2.3 Equivalent circuit of transmitting antenna

In order for the antenna to operate efficiently, maximum transfer of power must take place between the transmitter and the antenna. Maximum power transfer can take place only when the impedance of the antenna (Z_{in}) is matched to that of the transmitter (Z_s). According to the maximum power transfer theorem, maximum power can be transferred only if the impedance of the transmitter is a complex conjugate of the impedance of the antenna under consideration and vice-versa. Thus, the condition for matching is:

$$Z_{in} = Z^{*}s \tag{2.7}$$

Where

$$Z_{in} = R_{in} + j\,X_{in}$$

$Z_s = R_s + j\ X_s$ as shown in Figure 2.3

If the condition for matching is not satisfied, then some of the power maybe reflected back and this leads to the creation of standing waves, which can be characterized by a parameter called as the Voltage Standing Wave Ratio (VSWR).

The VSWR is given by [6] as:

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{2.8}$$

$$\Gamma = \frac{V_r}{V_i} = \frac{Z_{in}-Z_s}{Z_{in}+Z_s} \tag{2.9}$$

where

Γ is called the reflection coefficient

V_r is the amplitude of the reflected wave

V_i is the amplitude of the incident wave

The VSWR is basically a measure of the impedance mismatch between the transmitter and the antenna. The higher the VSWR, the greater is the mismatch. The minimum VSWR which corresponds to a perfect match is unity. A practical antenna design should have an input impedance of either 50 Ω or 75 Ω since most radio equipment is built for this impedance.

2.3.6 Return Loss (RL)

The Return Loss (RL) is a parameter which indicates the amount of power that is "lost" to the load and does not return as a reflection. As explained in the preceding section, waves are reflected leading to the formation of standing waves, when the transmitter and antenna impedance do not match. Hence the RL is a parameter similar to the VSWR to indicate how well the matching between the transmitter and antenna has taken place. The RL is given as by [5] as:

$$\text{RL} = -20log_{10}\,|\Gamma| \ \text{(dB)} \tag{2.10}$$

For perfect matching between the transmitter and the antenna, $\Gamma = 0$ and $RL = \infty$ which means no power would be reflected back, whereas a $\Gamma=1$ has a $RL = 0$ dB, which implies that all incident power is reflected. For practical applications, a VSWR of 2 is acceptable, since this corresponds to a RL of -9.54 dB.

2.3.7 Antenna Efficiency

The antenna efficiency is a parameter which takes into account the amount of losses at the terminals of the antenna and within the structure of the antenna. These losses are given by [5] as:

- Reflections because of mismatch between the transmitter and the antenna.
- I^2R losses (conduction and dielectric).

Hence the total antenna efficiency can be written as:

$$e_t = e_r e_c e_d \qquad (2.11)$$

Where

e_t : total antenna efficiency

$e_r = (1-\Gamma^2)$: reflection (mismatch) efficiency

e_c : conduction efficiency

e_d: dielectric efficiency

Since e_c and e_d are difficult to separate, they are lumped together to form the e_{cd} efficiency which is given as:

$$e_{cd} = e_c e_d = \frac{R_r}{R_r + R_L} \qquad (2.12)$$

e_{cd} is called as the antenna radiation efficiency and is defined as the ratio of the power delivered to the radiation resistance Rr , to the power delivered to Rr and RL .

2.3.8 Polarization

Polarization of a radiated wave is defined by [5] as “that property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector”. The polarization of an antenna refers to the polarization of the electric field vector of the radiated wave. In other words, the position and direction of the electric field with reference to the earth’s surface or ground determines the wave polarization. The most common types of polarization include the linear (horizontal or vertical) and circular (right hand polarization or the left hand polarization).

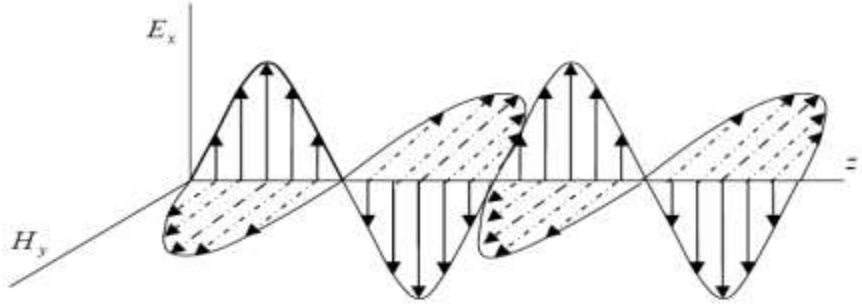
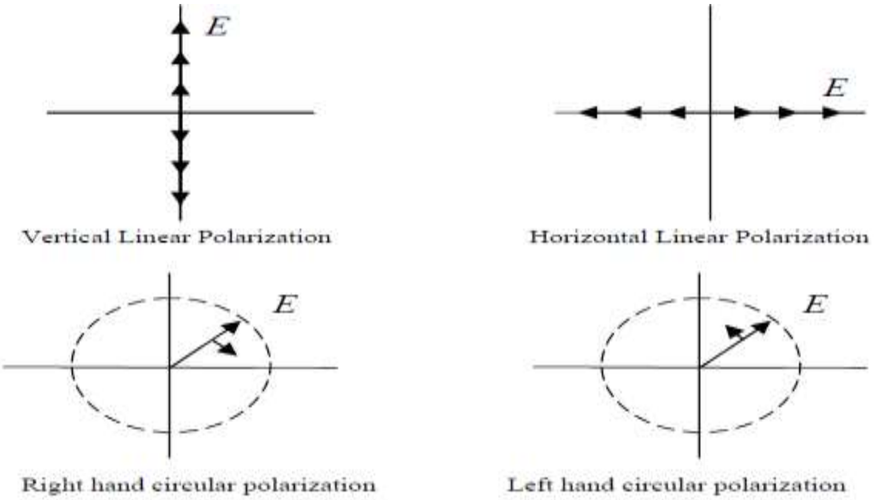


Figure 2.4 A linearly (vertically) polarized wave

If the path of the electric field vector is back and forth along a line, it is said to be linearly polarized. Figure 2.6 shows a linearly polarized wave. In a circularly polarized wave, the electric field vector remains constant in length but rotates around in a circular path. A left hand circular polarized wave is one in which the wave rotates counterclockwise whereas right hand circular polarized wave exhibits clockwise motion as shown in Figure 2.5.



Vertical Linear Polarization

Horizontal Linear Polarization

Right hand circular polarization

Left hand circular polarization

Figure 2.5 Commonly used polarization schemes

2.3.9 Bandwidth

The bandwidth of an antenna is defined by [5] as "the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard." The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency. The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation. The bandwidth of a narrowband antenna can be defined as the percentage of the frequency difference over the center frequency [5]. According to [4] these definitions can be written in terms of equations as follows:

$$BW_{broadband} = \frac{f_H}{f_l} \tag{2.13}$$

$$BW_{narrowband}(\%) = [\frac{f_H - f_c}{f_c}]100 \tag{2.14}$$

Where

f_H upper frequency

f_l lower frequency

f_c center frequency

An antenna is said to be broadband if $\frac{f_H}{f_l} = 2$. One method of judging how efficiently an antenna is operating over the required range of frequencies is by measuring its VSWR. A $VSWR \leq 2$ ($RL \geq -9.5dB$) ensures good performance.

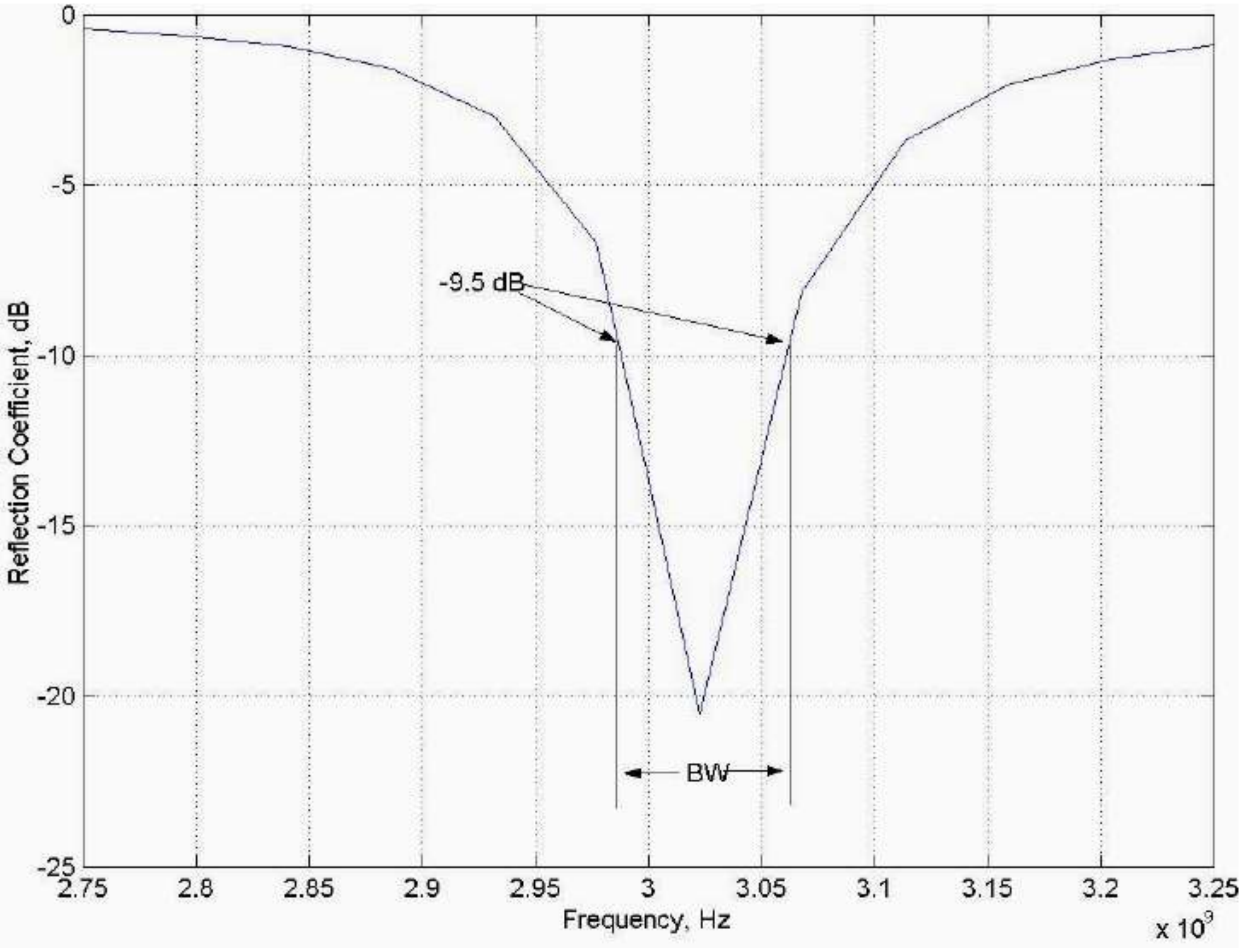


Figure 2.6 Measuring bandwidth from the plot of the reflection coefficient

2.3.10 S-parameters

The S-parameters are very important in microwave design for describing the behavior of electrical devices. Most of the electrical properties i.e. gain, return loss, power, VSWR etc relates to the S-parameters.The S-parameters can be observed by sending a signal through an input port and observing the response on an output port. The term impedance is of great importance while calculating the S-parameters because the system should be matched properly, otherwise reflection which will give rise to standing waves and the system will not produce the desired output. The S-parameters s_{11} and s_{22} represent input and output reflection while s_{21} is the forward transmission coefficient (gain) and s_{12} is the reverse transmission coefficient (isolation)[5].

2.4 Types of Antennas

Antennas come in different shapes and sizes to suit different types of wireless applications. The characteristics of an antenna are very much determined by its shape, size and the type of material that it is made of. Some of the commonly used antennas are briefly described below[7].

2.4.1 Half Wave Dipole

The length of this antenna is equal to half of its wavelength as the name itself suggests. Dipoles can be shorter or longer than half the wavelength, but a tradeoff exists in the performance and hence the half wavelength dipole is widely used.

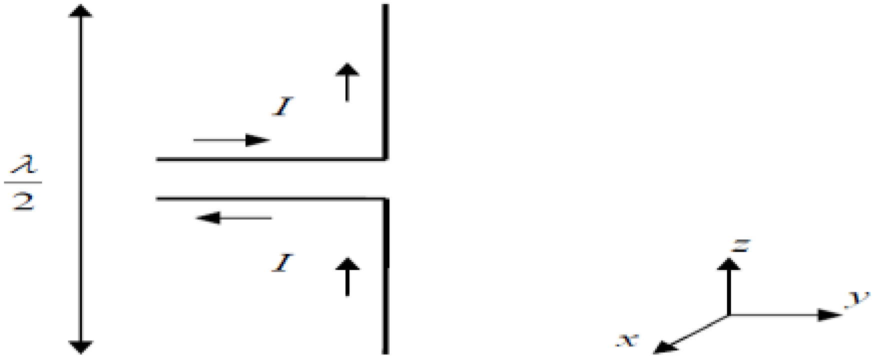


Figure 2.7 Half wave dipole

2.4.2 Monopole Antennas

The monopole antenna, shown in Figure 2.8, results from applying the image theory to the dipole. According to this theory, if a conducting plane is placed below a single element of length $L / 2$ carrying a current, then the combination of the element and its image acts identically to a dipole of length L except that the radiation occurs only in the space above the plane as discussed by Saunders [7].

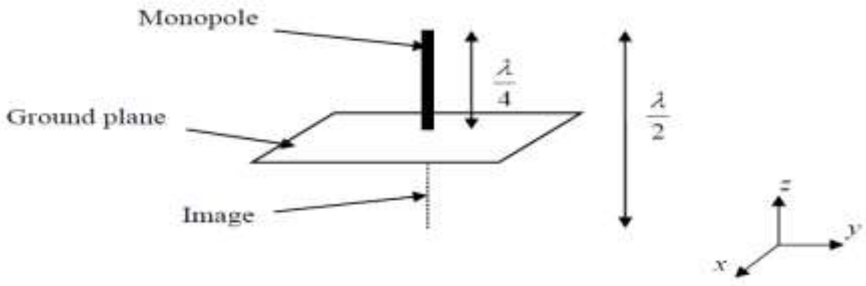
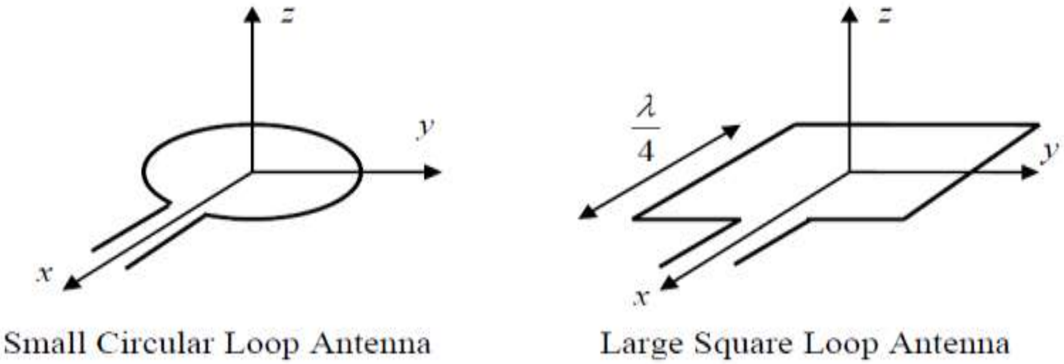


Figure 2.8 Monopole Antenna

For this type of antenna, the directivity is doubled and the radiation resistance is halved when compared to the dipole. Thus, a half wave dipole can be approximated by a quarter wave monopole ($L / 2 = \lambda / 4$). The monopole is very useful in mobile antennas where the conducting
plane can be the car body or the handset case

2.4.3 Loop Antennas

The loop antenna is a conductor bent into the shape of a closed curve such as a circle or a square with a gap in the conductor to form the terminals as shown in Figure 2.9. There are two types of loop antennas-electrically small loop antennas and electrically large loop antennas. If the total loop circumference is very small as compared to the wavelength ($L \lll \lambda$), then the loop antenna is said to be electrically small. An electrically large loop antenna typically has its circumference close to a wavelength. The far-field radiation patterns of the small loop antenna are insensitive to shape [4].



Small Circular Loop Antenna

Large Square Loop Antenna

Figure 2.9 Loop Antenna

2.4.4 Helical Antennas

A helical antenna or helix is one in which a conductor connected to a ground plane, is wound into a helical shape. Figure 2.10 illustrates a helix antenna. The antenna can operate in a number of modes, however the two principal modes are the normal mode (broadside radiation) and the axial mode (endfire radiation). When the helix diameter is very small as compared to the wavelength, then the antenna operates in the normal mode. However, when the circumference of the helix is of the order of a wavelength, then the helical antenna is said to be operating in the
axial mode.

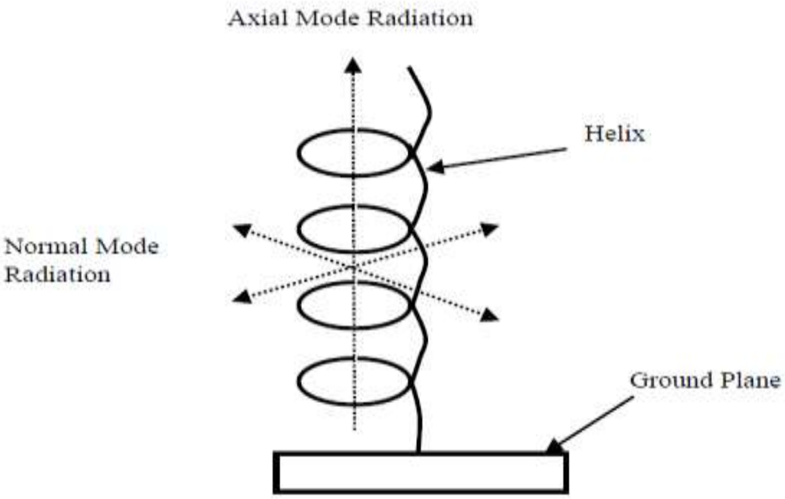


Figure 2.10 Helix Antenna

2.4.5 Horn Antennas

Horn antennas are used typically in the microwave region (gigahertz range) where waveguides are the standard feed method, since horn antennas essentially consist of a waveguide whose end walls are flared outwards to form a megaphone like structure. Horns provide high gain, low VSWR, relatively wide bandwidth, low weight, and are easy to construct. The three basic types of horn antennas that utilize a rectangular geometry are shown in Figure 2.11.

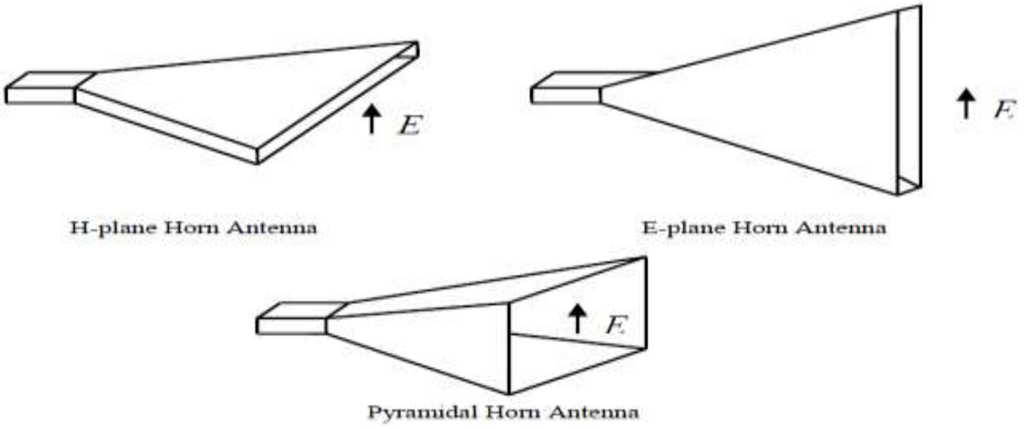


Figure 2.11 Types of Horn Antenna

2.4.6 Microstrip Antennas

A microstrip patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane as shown In the figure 2.12. Low dielectric constant substrates are generally preferred for maximum radiation. We discuse it in the next chapter .

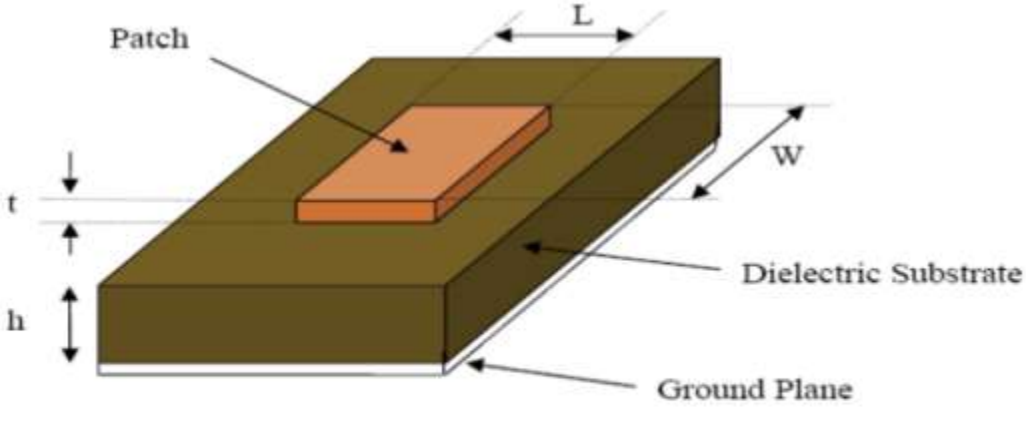


Fig 2.12 microstrip patch antenna

Chapter Three

Microstrip Patch Antenna

3.1 Introduction

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 3.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

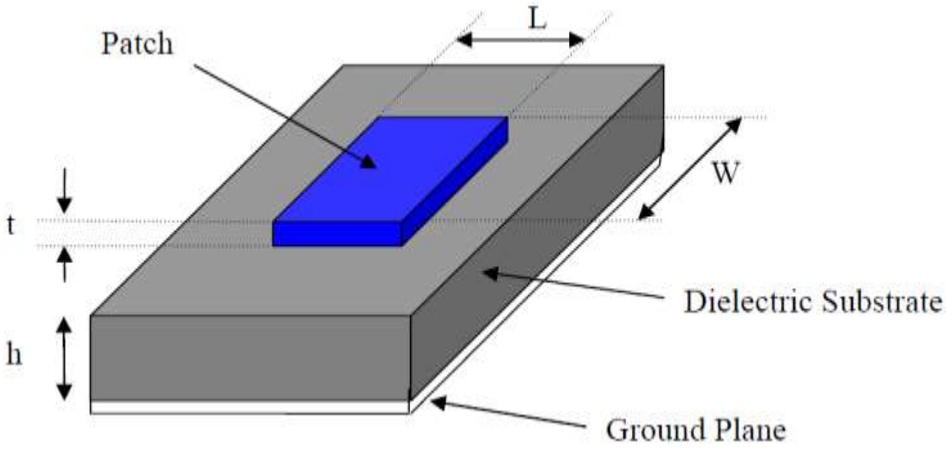


Figure 3.1 Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, elliptical or some other common shape as shown in Figure 3.2. For a rectangular patch, the length L of the patch is usually $0.3333\,\lambda_0 < L < 0.5\,\lambda_0$,where λ_0 is the free-space wavelength. The patch is selected to be very thin such that $t \ll \lambda_0$ (where t is the patch thickness). The height h of the dielectric substrate is usually $0.003\,\lambda_0 \leq h \leq 0.05\lambda_0$ The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

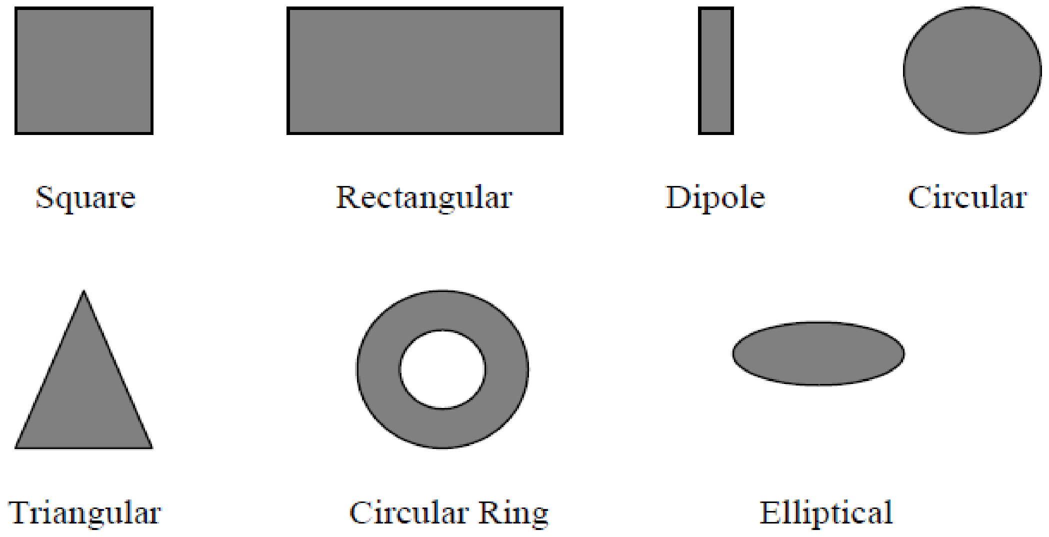


Figure 3.2 Common shapes of microstrip patch elements

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation [5]. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

3.2 Advantages and Disadvantages

Microstrip patch antennas are increasing in popularity for use in extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc... The telemetry and communication antennas on missiles need to be thin and conformal and are often Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication.

Some of their principal advantage and disadvantage discussed by [5] and Kumar and Ray [8] are given below.

Advantages

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Disadvantages

- Narrow bandwidth.
- Low efficiency.
- Low Gain.
- Extraneous radiation from feeds and junctions.
- Poor end fire radiator except tapered slot antennas.
- Low power handling capacity.
- Surface wave excitation.

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic bandgap structures as discussed by Qian et al [9]. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

3.3 Feed Techniques

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line.

In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch [5]. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

3.3.1 Microstrip Line Feed

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 3.3. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

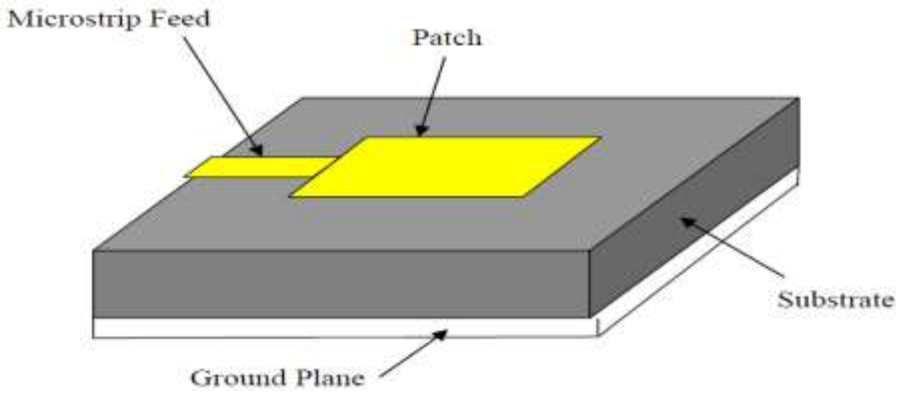


Figure 3.3 Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna [5]. The feed radiation also leads to undesired cross polarized radiation .

3.3.2 Coaxial Feed

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 3.4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

+

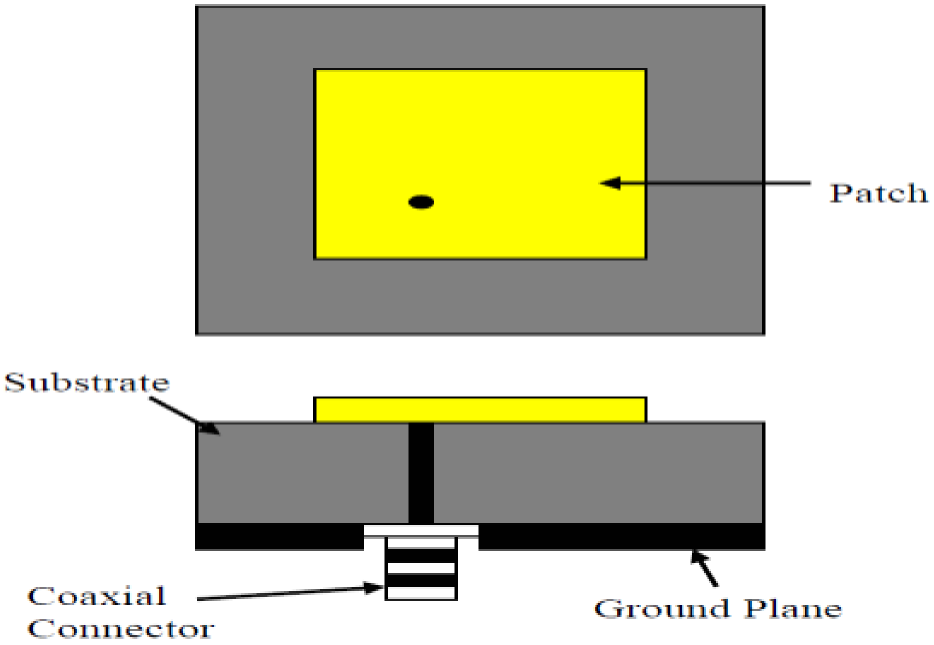


Figure 3.4 Probe fed Rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02 \lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems [8]. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these problems.

3.3.3 Aperture Coupled Feed

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 3.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

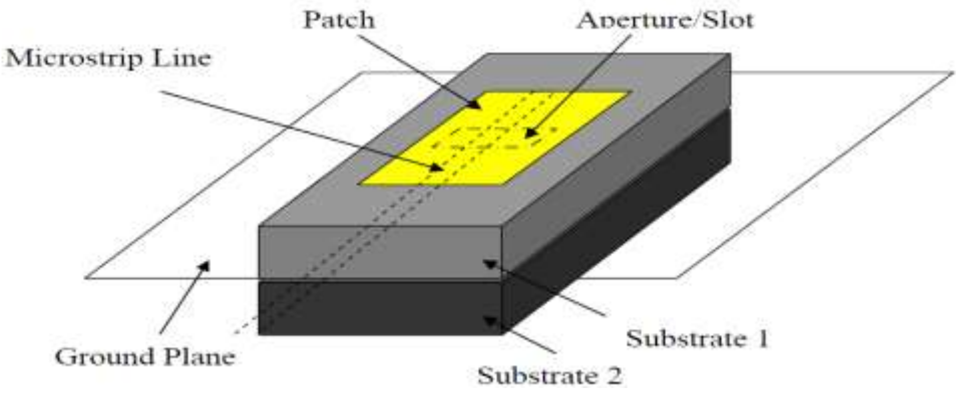


Figure 3.5 Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [5]. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

3.3.4 Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 3.6, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) [5], due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

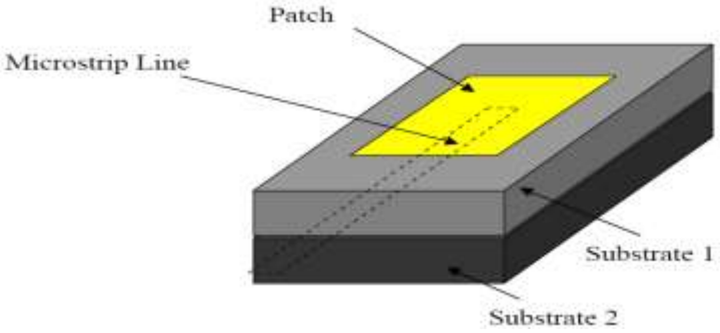
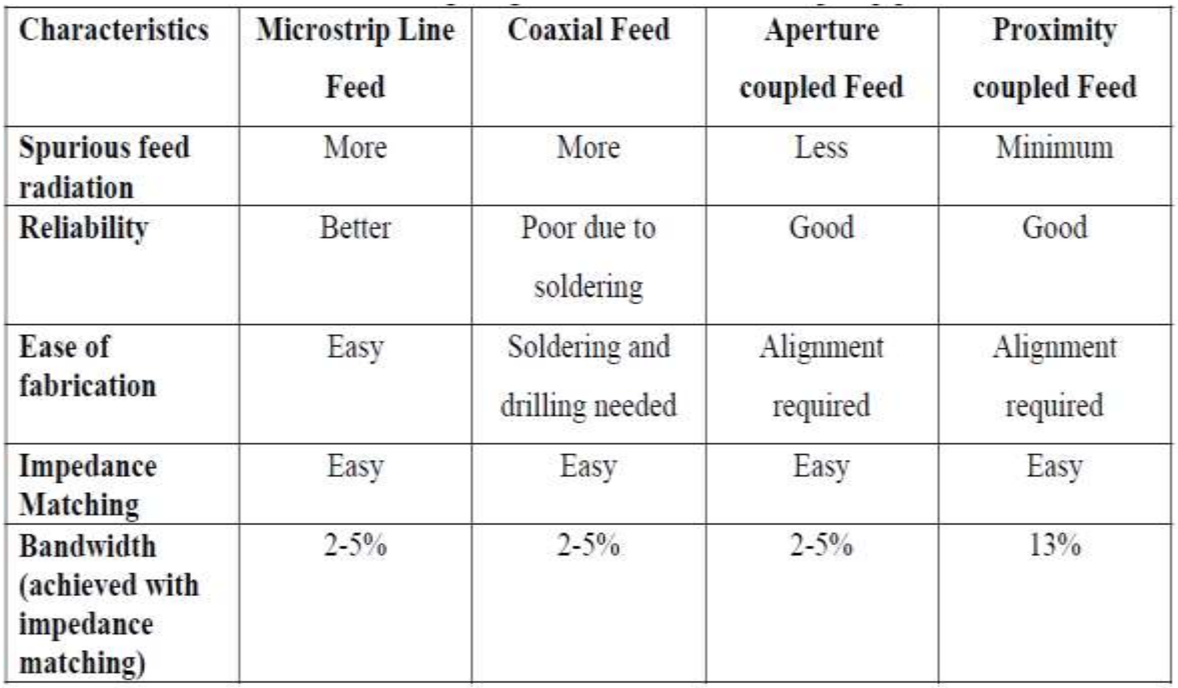


Figure 3.6 Proximity-coupled Feed

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

Table 3.1 Comparing the different feed techniques [4]



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

3.4 Methods of Analysis

The most popular models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model [5] (which include primarily integral equations/Moment Method). The transmission line model is the simplest of all and it gives good physical insight but it is less accurate. The cavity model is more accurate and gives good physical insight but is complex in nature. The full wave models are extremely accurate, versatile and can treat single elements, finite and infinite arrays, stacked elements, arbitrary shaped elements and coupling. These give less insight as compared to the two models mentioned above and are far more complex in nature. In this project transmission line model is used.

3.4.1 Transmission Line Model

This model represents the microstrip antenna by two slots of width *W* and height h , separated by a transmission line of length L. The microstrip is essentially a nonhomogeneous line of two dielectrics, typically the substrate and air.

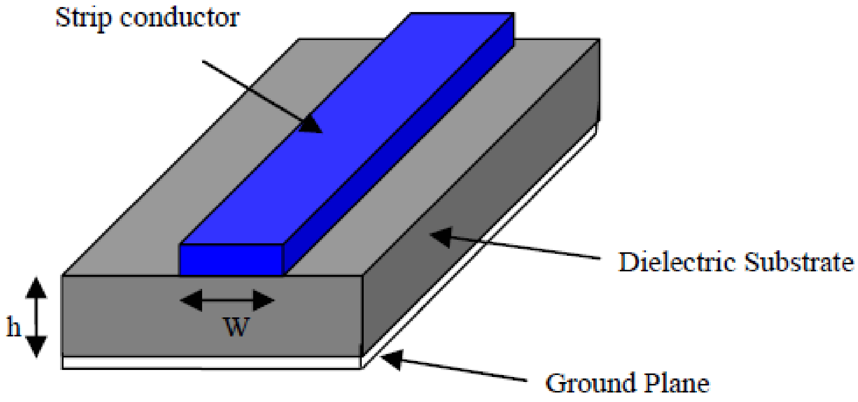


Figure 3.7 Microstrip Line

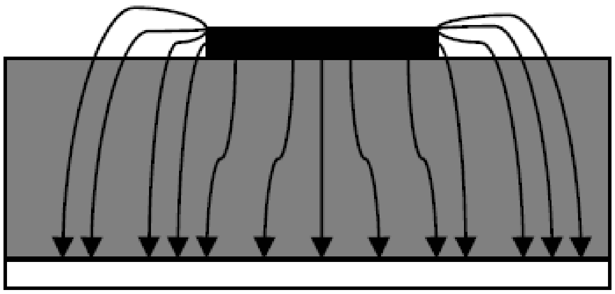


Figure 3.8 Electric Field Lines

Hence, as seen from Figure 3.8, most of the electric field lines reside in the substrate and parts of some lines in air. As a result, this transmission line cannot support pure transverse electric-magnetic (TEM) mode of transmission, since the phase velocities would be different in the air and the substrate. Instead, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant ($\boldsymbol{\varepsilon_{reff}}$) must be obtained in order to account for the fringing and the wave propagation in the line. The value $\boldsymbol{\varepsilon_{reff}}$ of is slightly less then $\boldsymbol{\varepsilon_r}$ because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in the air as shown in Figure 3.8 above. The expression for $\boldsymbol{\varepsilon_{reff}}$ is given by James [10] as:

$$\boldsymbol{\varepsilon}_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \qquad (3.1)$$

Where

$\boldsymbol{\varepsilon_{reff}}$ = Effective dielectric constant

$\boldsymbol{\varepsilon_r}$ = Dielectric constant of substrate

h = Height of dielectric substrate

W = Width of the patch

Consider Figure 3.9 below, which shows a rectangular microstrip patch antenna of length L , width W resting on a substrate of height h . The co-ordinate axis is selected such that the length is along the x direction, width is along the y direction and the height is along the z direction.

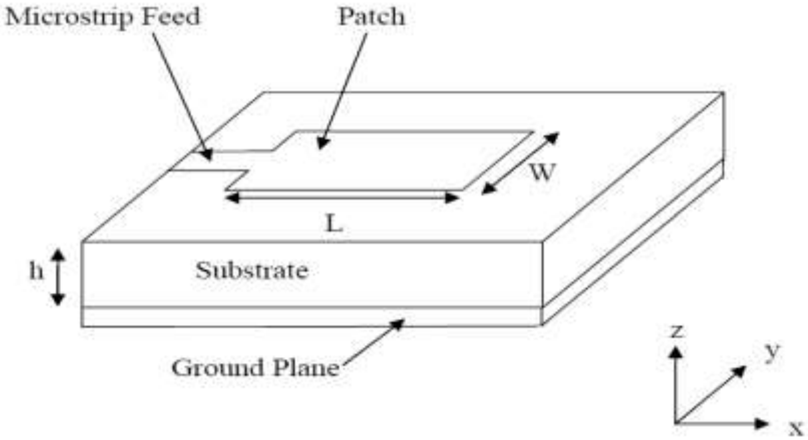
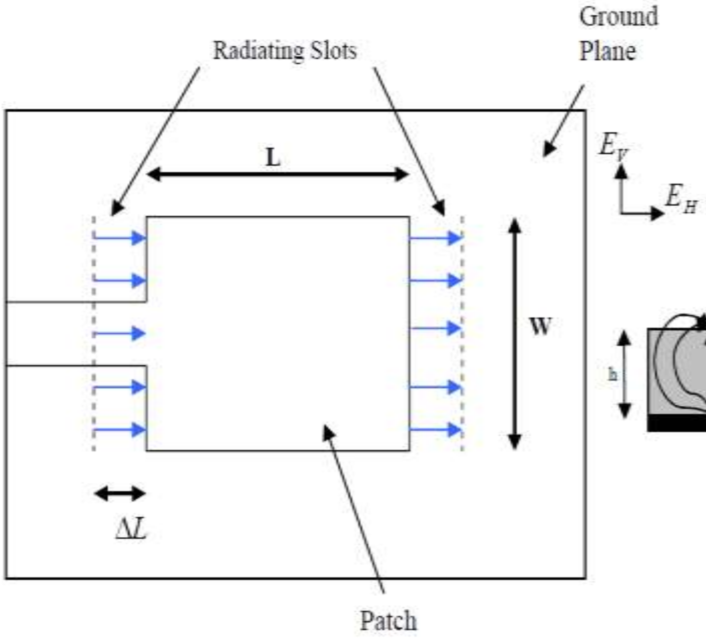


Figure 3.9 Microstrip Patch Antenna

In order to operate in the fundamental TM10 mode, the length of the patch must be slightly less than $\lambda / 2$ where λ is the wavelength in the dielectric medium and is equal to $\lambda_o/\sqrt{\boldsymbol{\varepsilon_{reff}}}$ where λ_o is the free space wavelength. The TM10 mode implies that the field varies one $\lambda / 2$ cycle along the length, and there is no variation along the width of the patch. In the Figure 3.10 shown below, the microstrip patch antenna is represented by two slots, separated by a transmission line of length L and open circuited at both the ends. Along the width of the patch, the voltage is maximum and current is minimum due to the open ends. The fields at the edges can be resolved into normal and tangential components with respect to the ground plane.



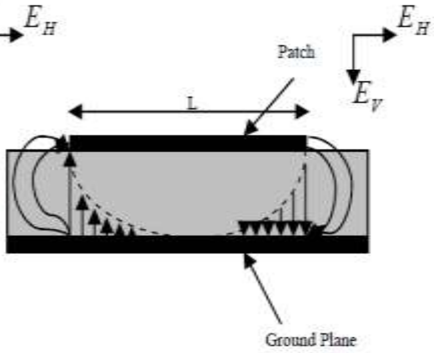


Figure 3.10 Top View of Antenna

Figure 3.11 Side View of Antenna

It is seen from Figure 3.11 that the normal components of the electric field at the two edges along the width are in opposite directions and thus out of phase since the patch is $\lambda / 2$ long and hence they cancel each other in the broadside direction. The tangential components (seen in Figure 3.11), which are in phase, means that the resulting fields combine to give maximum radiated field normal to the surface of the structure. Hence the edges along the width can be represented as two radiating slots, which are $\lambda / 2$ apart and excited in phase and radiating in the half space above the ground plane. The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given by [10] as:

$$\Delta L = 0.412h\frac{\varepsilon_{reff}+0.3(\frac{w}{h}+0.264)}{\varepsilon_{reff}-0.258(\frac{w}{h}+0.8)} \tag{3.2}$$

The effective length of the patch L_{eff} now becomes:

$$L_{eff} = \mathrm{L}+2\,\Delta L \tag{3.3}$$

For a given resonance frequency f_0 , the effective length is given by [10] as:

$$L_{eff}= \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \tag{3.4}$$

For a rectangular Microstrip patch antenna, the resonance frequency for any *TM* ***mn*** mode is given by [10] as:

$$\mathrm{f}_0 = \frac{\mathrm{c}}{2\sqrt{\varepsilon_{\mathrm{reff}}}}\,[\left(\frac{m}{l}\right)^2 + \left(\frac{n}{w}\right)^2]^{\frac{1}{2}} \tag{3.5}$$

For efficient radiation, the width *W* is given by[10] as:

$$\mathrm{W} = \frac{c}{2f_0\sqrt{\frac{\sqrt{\varepsilon_{r+1}}}{2}}} \tag{3.6}$$

Chapter Four

Result & Discussion

4.1 Introductions :

Momentum is a part of Advance Design System and it provides the simulation tools required to evaluate and design products of modern communication systems. Momentum is an electromagnetic solver in the form of a simulator that computes the S-parameters for general planar circuits which includes microstrip, slotline, stripline, coplanar waveguides and many other topologies. Multilayer communication circuits and printed circuit boards can also be simulated in ADS Momentum with accurate results. Momentum is a complete tool for prediction of the performance of high frequency circuit boards, antennas and integrated circuits [11]. The ADS Momentum optimization tool extends Momentum capability to a real design automation tool. The Momentum Optimization process varies geometry parameters automatically to help in achieving the optimal structure that for the circuit or device performance goals. Momentum optimizations can be done by using layout components (parameterized) from the schematic page. One of the great advantages that Momentum possesses is the 3-dimensional interface that it provides for the user during simulations and results. Momentum is a 2.5D solver that can do both 2D and 3D computations. For example while computing the antenna parameters, Momentum provides both 2D and 3D graphs of the directivity and the far-field radiation patterns of the antenna.

4.2 Theory:

The width of the Microstrip patch antenna (W):

$$W = \frac{C}{2f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{4.1}$$

Where

c - free space velocity of light, c = 3*10^8 m/s.

fr - frequency of operation, f_0= 2.4 GHz.

εr - dielectric constant

Effective dielectric constant (ε_{reff}):

$$\boldsymbol{\varepsilon}_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{w}]^{-\frac{1}{2}} \quad (4.2)$$

Where;

εr - dielectric constant

h - Height of dielectric substrate

W - Width of the patch

Effective length **(** L_{eff}**):**

$$L_{eff}= \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (4.3)$$

Where;

c - Free space velocity of light,

fr - frequency of operation

ε_{reff}- effective dielectric constant

length extension **(** ΔL **):**

$$\Delta L = 0.412\text{h}\frac{\varepsilon_{reff}+0.3(\frac{w}{h}+0.264)}{\varepsilon_{reff}-0.258(\frac{w}{h}+0.8)} \quad (4.4)$$

The actual length of patch **(** L **):**

$$\text{L}= L_{eff} - 2\Delta L$$

4.3 Methodology:

Calculate width (w) , effective dielectric constant (ε_{reff}) ,effective length (L_{eff}) , actual length of Patch (L) from closed formulas, and run simulator to show the results and the parameters of the antenna, Comparison between different substrate materials of the patch antenna.

4.4 Calculation and Simulation:

Before designing the antenna, the first step is to consider the specification of the antenna base on it application , the various parameters are listed in this Table .

Table 4.1: Single Patch Antenna Design Specifications

Frequency	2.4 GHz
Substrate	FV
Dielectric constant ε_r	4.3
Loss tangent	0.003
Substrate height	1.5 mm
Conductor thickness	20.0 um

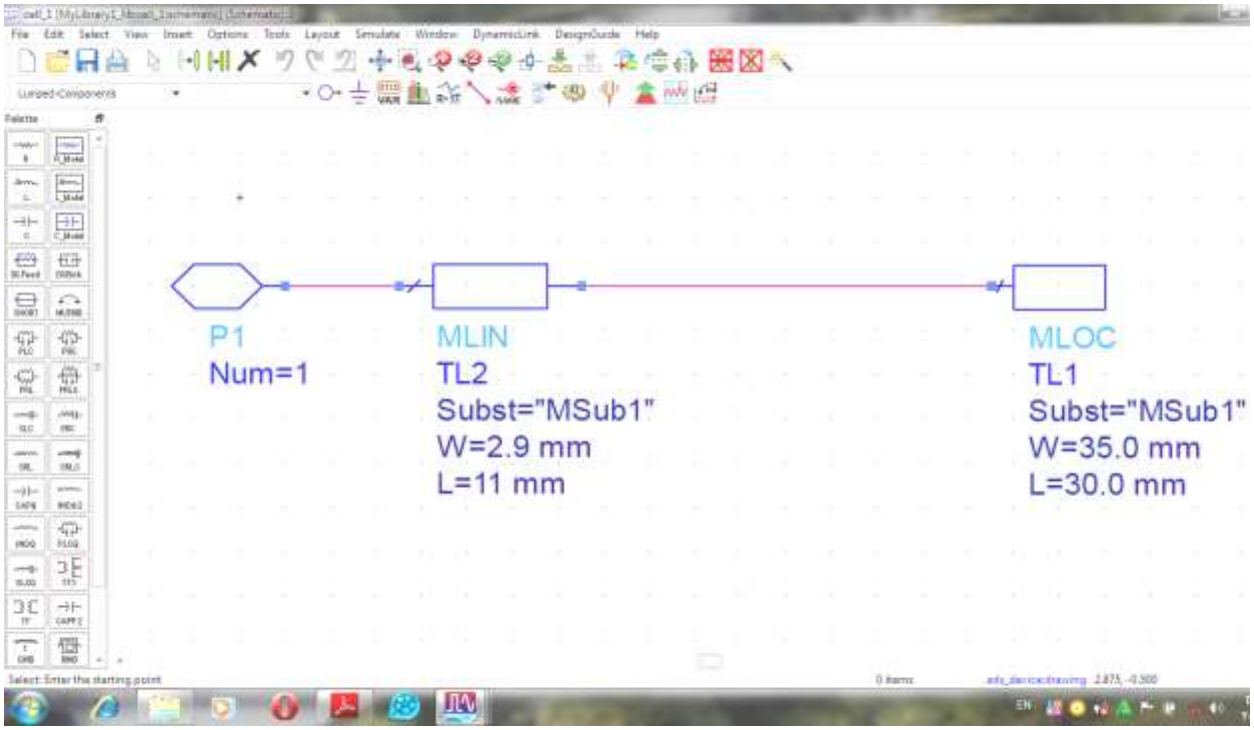
The frequency 2.45 GHz is chosen because the frequency is widely use in a WI-FI application and the antenna can be used as a WI-FI antenna. As for the substrate selection, the major consideration will be the dielectric constant and loss tangent. A high dielectric constant will result in a smaller patch size but this will generally reduces bandwidth efficiency and might have difficulty in fabricating a very small patch size antenna. A high loss tangent will reduce the antenna efficiency.

Results of Rectangular Patch Antenna at 2.4 GHz:

Table 4.2 dimensions of patch & strip line

Patch	
Width	35.0 mm
Length	30.0 mm
Impedance	10 ohm
Stripline	
Width	2.9 mm
Length	11 mm
Impedance	50 ohm

The results of the simulation are shown below- schematic circuit of patch antenna



P1
Num=1

MLIN
TL2
Subst="MSub1"
W=2.9 mm
L=11 mm

MLOC
TL1
Subst="MSub1"
W=35.0 mm
L=30.0 mm

Fig 4.1 schematic circuit

In the figure 4.1 show the dimension of patch & transmission line.

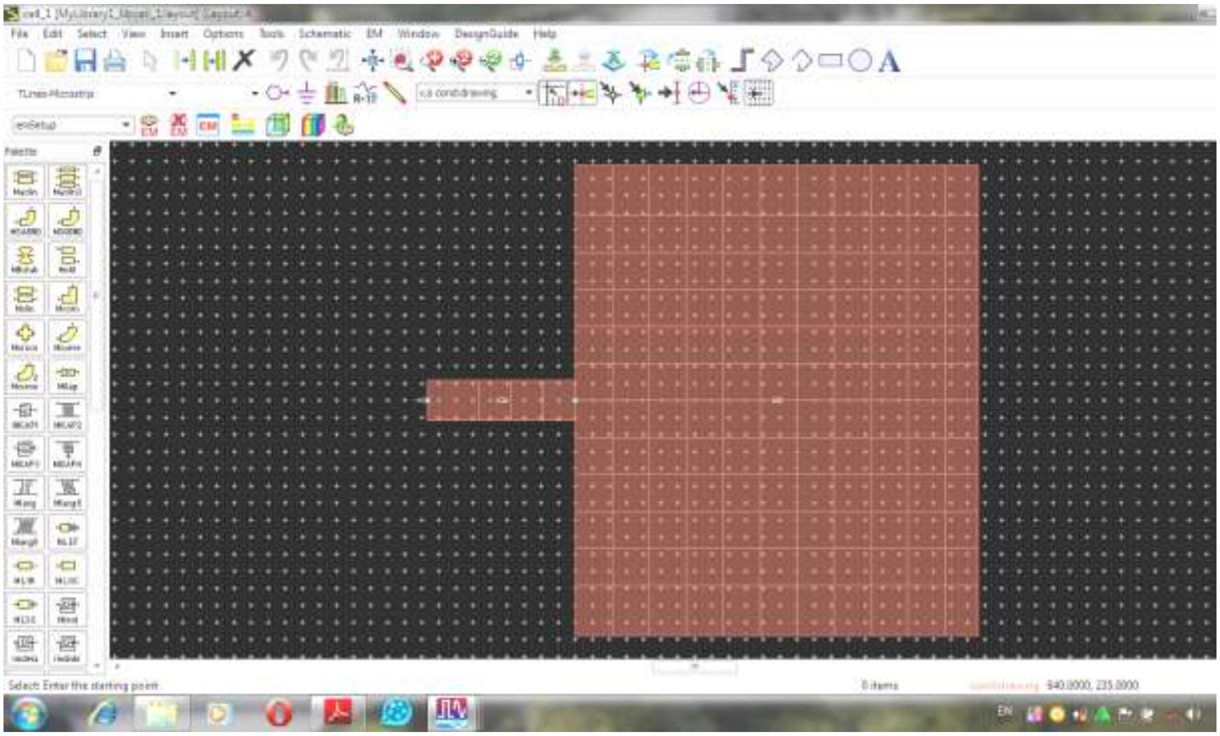


Fig 4.2 Microstrip antenna layout

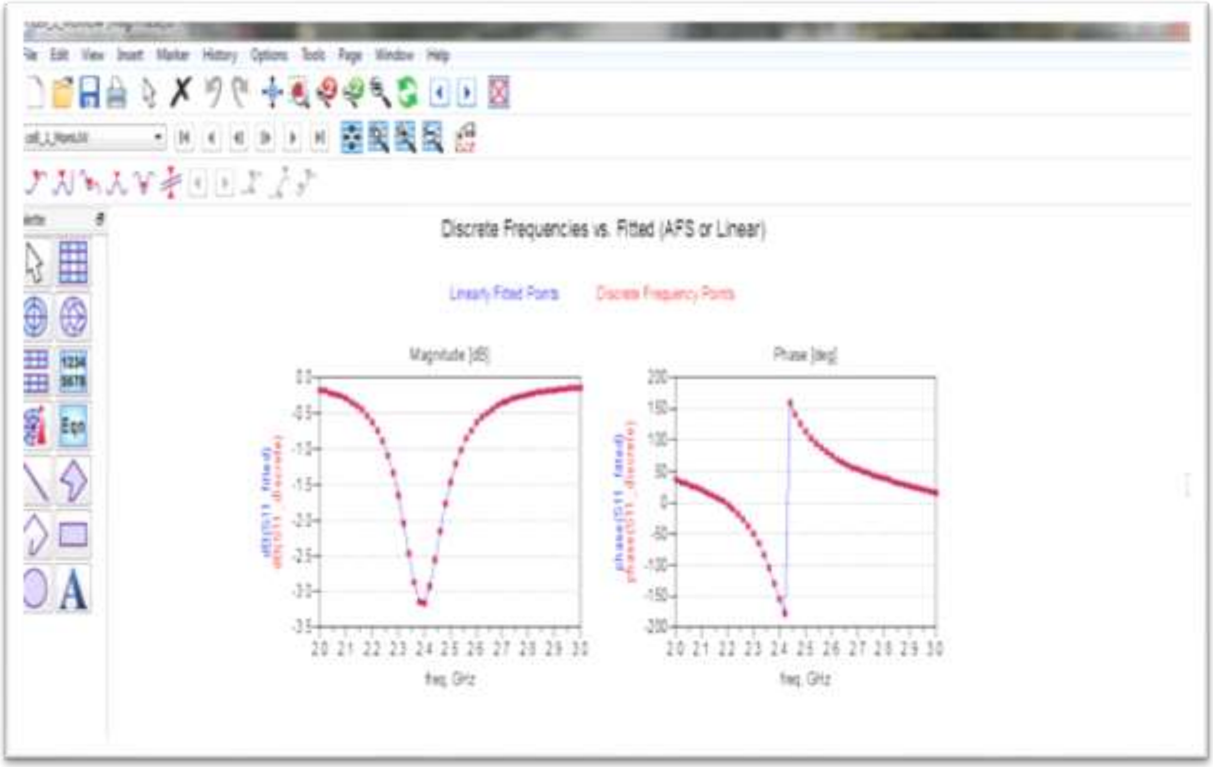
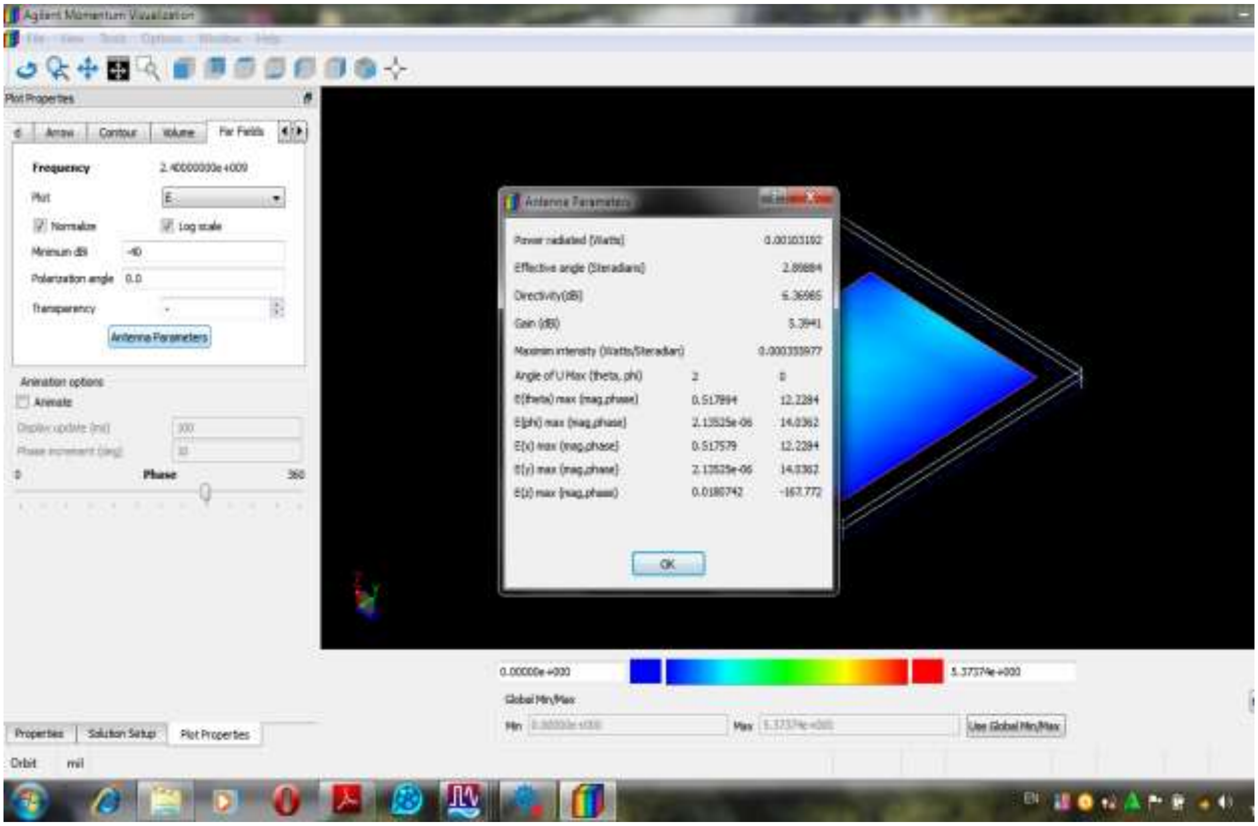


Fig 4.3 S - parameter & phase



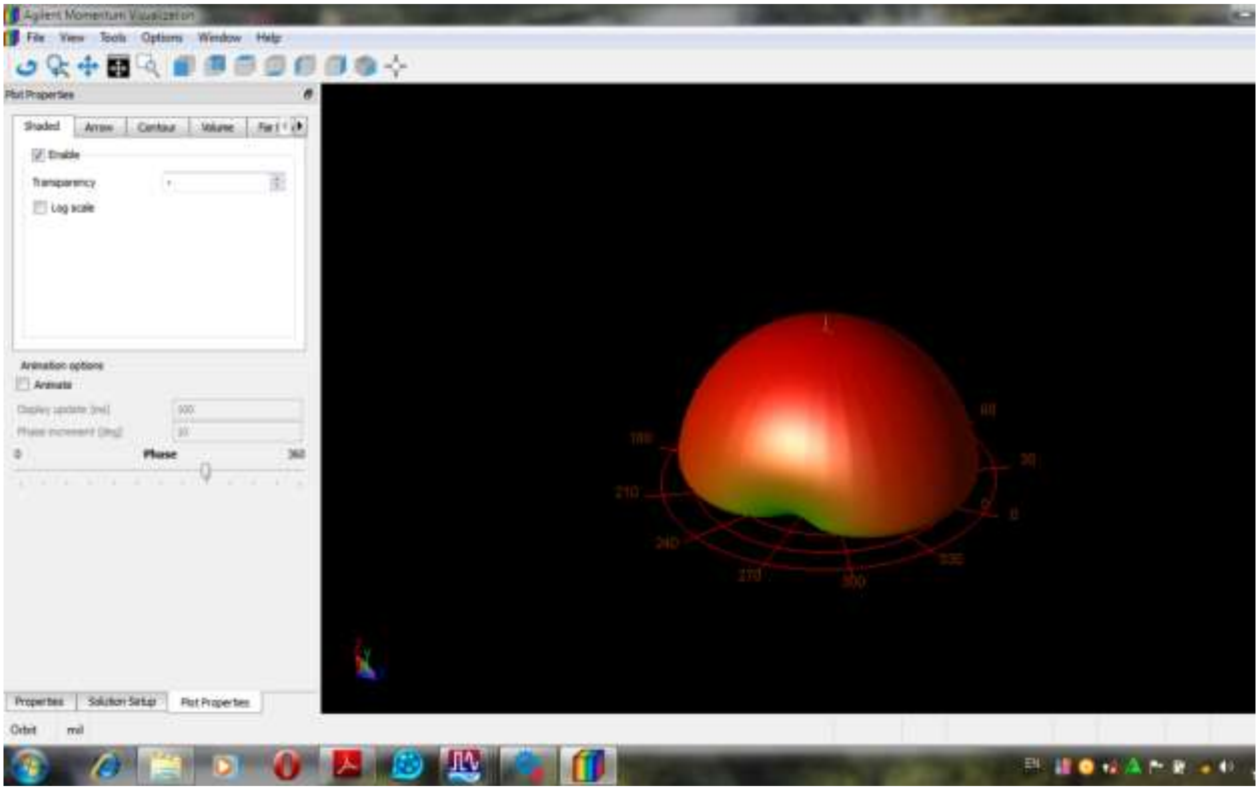
Frequency 2.40000000e+009
Plot E
☑ Normalize ☑ Log scale
Minimum dB -40
Polarization angle 0.0
☐ Animate

Antenna Parameters

Power radiated (Watts)		0.00103192
Effective angle (Steradians)		2.89884
Directivity(dB)		6.36985
Gain (dB)		5.3941
Maximum intensity (Watts/Steradian)		0.000355977
Angle of U Max (theta, phi)	2	0
E(theta) max (mag,phase)	0.517894	12.2284
E(phi) max (mag,phase)	2.13525e-06	14.0362
E(x) max (mag,phase)	0.517579	12.2284
E(y) max (mag,phase)	2.13525e-06	14.0362
E(z) max (mag,phase)	0.0180742	-167.772

0.00000e+000 5.37374e+000

Fig 4.4 Gain and Directivity



☑ Enable
☐ Log scale
☐ Animate

Fig 4.5 3D Radiation pattern

From the simulation for FV substrate using ADS we get that:

The gain = 5.3941 dB , directivity = 6.36985 dB and power radiated = 0.001 W .

Compare between FV, quartz and alumina materials which used as substrate.

Quartz calculation:

It has dielectric constant $\boldsymbol{\varepsilon_r}$ 3.8, Loss tangent 10^{-4} , height 1.5 mm and Conductor thickness 20 um .

From equations in chapter four we get:

W = 40.5 mm, L = 31.6 mm (for patch).

W = 3.20 mm, L = 19.5 mm (for strip line).

Alumina calculation :

It has dielectric constant $\boldsymbol{\varepsilon_r}$ 9.7 , Loss tangent $2*10^{-4}$, height 1.5 mm and Conductor thickness 20 um .

From equations in chapter four we get :

W = 21.5 mm , L = 15.5 mm (for patch).

W = 1.50 mm , L = 10.0 mm (for strip line).

compare between substrates in the table 5.1

All the substrate operate at the same frequency 2.4 GHz

Table 4.3 compare between substrate

Substrate	dielectric constant ε_r	Height	Dimension of patch	Gain(dB)	Directivity(dB)
FV	4.3	1.5 mm	W = 35 mm L = 30 mm	5.4	6.4
Quartz	3.8	1.5 mm	W= 40 mm L = 31.6 mm	6.2	6.4
Alumina	9.7	1.5 mm	W= 21.5 mm L = 15.5 mm	4.1	5.7

According to the table 4.3 we extract that the antenna gain , directivity and dimension is effected by the dielectric constant.

4.5 Conclusion:

design rectangular microstrip antenna and to compare between material substrates and how it effect on the antenna parameters.

The performance of micro strip Antenna is effected by its structure and dimensions but the substrate material has also significant role in analyzing antenna performance. When dielectric constant increases then the resonant frequency as well as the bandwidth also decreases. The efficiency of the antenna also improve with low dielectric constant. The overall performance of the antenna is influenced by substrate material at great extent.

4.6 Recommendations:

Antenna technology is a vast field. Every day new research is published. A few design parameters were taken into consideration while designing this antenna, the following issues will be considering in our future studies:

- Further improvements can be made in The gain, directivity, radiation pattern and efficiency can be improved by using 2n array elements in the microstrip phase array antenna.
- Fabricate the designed antenna and compare it with previously published results.
- Studying the effect of feed line.
- Studying different geometrical shapes of batch antenna.

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