Design and characterisation of a microstrip patch antenna for Wi-Fi

By

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Abstract

In recent years, the inventions in communication systems require the development of low cost, minimal weight, compact and low profile antennas that are capable of maintaining high performance over a wide spectrum of frequencies. This technological trend has focused much effort in the design of micro strip patch antennas because of its inherent characteristics that fits the requirements of modern communication devices. This dissertation presents the design and simulation of a compact rectangular slot patch antenna for dual frequency operation at 2.45GHz and 5 GHz using the inset feed technique. The simulation of the designed antenna was done with the aid of computer simulation technology (CST) microwave studio version 16 and MATLAB which will be used to calculate the parameters. The substrate used for the proposed antenna is the flame resistant four (FR-4) with a dielectric constant of 4.3 and a loss tangent of 0.023. The proposed antenna may find applications in wireless local area network (Wi-Fi) and Bluetooth technology.

Keywords: Antenna, Slot Patch, Dual Frequency, Inset.

Declaration

I, **Shumba Prosper** hereby declare that I am the sole author of this dissertation entitled "Design and characterisation of a micro strip patch antenna for Wi-Fi". I authorize Midlands State University to this dissertation only for purposes of scholarly research.

Signature…………………………………………... Date…………………………………………

Approval

This dissertation/thesis entitled "Design and characterisation of a micro strip patch antenna for Wi-Fi" by **Shumba Prosper** meets the regulations governing the award of the degree of *BSc Telecommunications Honours* of the Midlands State University, and is approved for its contribution to knowledge and literal presentation.

Supervisor………………………….............Date…………………………………….....

Dedication

To my parents Mr D Shumba and Mrs E Shumba, who instilled me a fascination with electronics and Telecommunications. To my loving and supportive family, classmates and friends. Also to my brother who is my role model Dr Shumba for moral support since the day I began this degree programme.

Acknowledgements

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ABBRIVIATIONS

VSWR ………Voltage standing wave ratio

RL……………Return loss

CST …………..Computer simulation technology

WLAN …………Wireless local area network

FR4……………..Flame resistant four

Chapter 1

1.1 Background and motivation

Antennas play a totally critical position inside the field of Wi-Fi communications .As nanotechnology is in the process of being introduced in all sectors of technology, then the wireless communication (Wi-Fi) takes interest, and this phase off the wires because they are cumbersome .Nowadays Wi-Fi widely used in many electronic gadgets. As of today technology antennas have shown that they are the most important things in all wireless communication. It is used in industry, academic institutes and even at home. Wi-Fi can be used to link gadgets hence removing the running cables everywhere. In all modes of communication whether civilian or military there is need of an antenna which is ease to manufacture and also with compatibility in such a way that it can fit in anything, and that antenna is the patch antenna. It is very popular due to its distinguishing feature or characteristics. In terms of weight it have low weight thus why in military it is used in missiles and it is one of its characteristics [1].The patch can be made of different configurations but the most best ones are the rectangular and the circular one [2].When comparing with other antennas patch antennas have many benefits such that it saves costs like the same antenna can be used indoor and outdoor also hence we can say it function in any type of environment. The antenna will be simulated using mat lab and the purpose of the antenna is to receive Wi-Fi and also to broadcast Wi-Fi and it should have constant polarization. Proper cutting and shaping the patch is realized so as to improve the gain of the antenna .The other thing to be put into consideration the antenna size also matters because these days in technology size is an issue therefore the patch should have a smaller size. The antenna can provide dual band operation and there is feed line flexibility [3].In this project, they might be a new technique that can be introduced to reduce the antenna size and this will provided not much an antenna which is not complicated to manufacture

1.1.1 Problem definition

Due to advancement in technology there is introduction of wireless communication everywhere, Wi-Fi is being installed in many places such at school, homes, market center e.g. Tel-one Wi-Fi at Bahudur Centre, Gweru[8] .All this is happening because of increase in demand of the Wi-Fi

hence 2there is need for greater improvement in that sector of wireless communication. There is need for an antenna that have high gain and if the antenna have high gain it reduces power consumption in devices [4].In laptops which are used in day to day life they are patch antennas therefore if that antenna have high gain the laptop will reduce power loss on when trying to connect to an access point which might be far away. Antennas which can be utilized in those programs must be low profile, mild weight, low quantity and large bandwidth [6]. To satisfy these necessities, micro strip antenna is favored. Even though micro strip have many advantage it also have some demerits   such as it has short bandwidth and sometime occasional efficiency.

1.2 Title overview

When designing a patch antenna they are factors which are supposed to be taken into consideration but in this project there will be much about the rectangular microstrip patch antenna. Looking at the micro strip antenna given below on figure 1.0 it is fed by the way using transmission line [5]. Usually the patch antenna is made up of material that is good conductor like copper .Copper is used to make   ground plane and the transmission feed line. The diagrams shown below show how the prototype of the patch antenna will be looking like, where L represents the length of the patch, W is the width of the patch and h is the thickness of the substrate where the patch will be sitting and h will be having permittivity. The size or the thickness of the floor plane or ground plane does not matter because it does not affect anything. The size of the substrate matters, h matter because it have an effect on the wavelength and it should not be zero and this may affect the antenna performance, like   degrading it. For the diagram shown in figure 1.0 the operating frequency is given by the length of the patch of the design. Also the ratio of voltage to current (impedance) is controlled by the width of the patch antenna .However increase in the width increase the   bandwidth of the patch antenna , so in short patch width varies directly as the bandwidth[7].Another factor to be consider when increasing the patch width the impedance should be also be decreased but this can be done by have an extended patch antenna width in short ,a very wide patch even though it is going to take a lot of space.
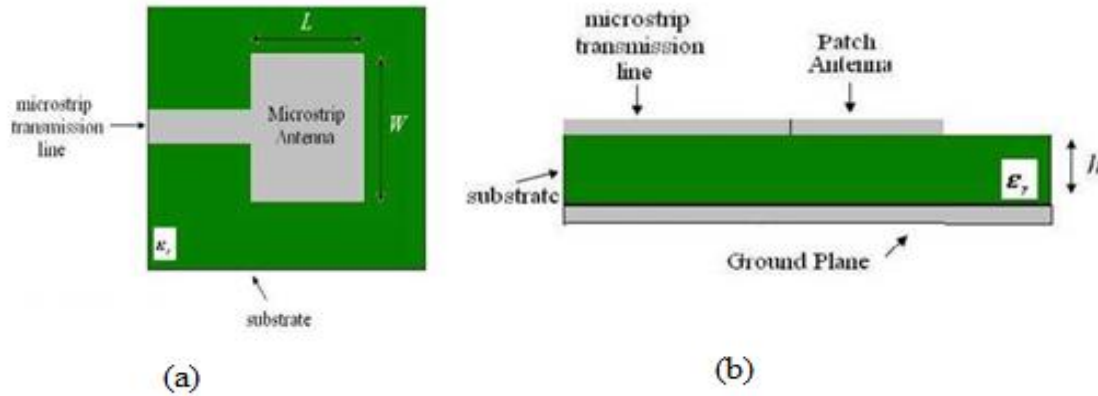
Figure 1.0: Top view and side view of the patch[7]

1.3 Aim of this examine are stated as follow:

- To design and Simulate rectangular micro strip patch antenna arrays
- To develop the antenna that may provide high gain, directivity, wide bandwidth and higher efficiency
- To look at the characteristics of the patch antenna, the input impedance, radiation pattern, beam width, gain , radiation efficiency, side lobe level and radiation efficiency

1.3.2 Scope of examine

This examine has two levels, phase one is about designing and simulating square micro strip single patch .The simulation of the designs has been executed by using computer as a simulation device that will be having CST Studio microwave software and using the Mat lab software.

1.4 Dissertation Overview

Dissertation overview gives an insight of what is going to be in the whole document and in each individual chapter.

Chapter 2–literature review: In this chapter they will be a theoretical aspect about antennas. This the things that are expected to be the outcomes of the project .This when the antenna is made in only calculations and the simulation of the antenna is done theoretically doing the mathematics of the simulation.

Chapter 3– research methodology: This chapter will give detail how the project is it going to be done both the design and simulation of the patch antenna .In this part of the project they highlights of how the project was modified to achieve the expected results.

Chapter 4–results and analysis: This is where the results are presented and they are compare to the theoretical part of the project and thus where challenges faced are address during the project. The solution to challenges faced are mentioned in this chapter.

Chapter 5– conclusion: This is the last chapter of the dissertation and aims on the project objectives and the areas which requires modification and also mentions limitations within the project.

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Chapter 2

Theoretical Aspect

2.1 Introduction

In this chapter the microstrip patch antenna is going to be discussed in detail but I will be narrated on it theoretical characteristics. In the designing process of the microstrip patch antenna there factor that are supposed to be taken into consideration, but firstly what is an antenna? An antenna or some might say a radio wire, which is a device, which comprises   of conductors, which are electrical .An antenna, can act as a transmitter or receiver. The point when it demonstrations Likewise a transmitter, it radiates electromagnetic wave under the space. Also when it goes about Likewise receiver, it takes electromagnetic waves from space [2]. Practically a number of antennas have the taking after parameters. The general characteristics of antennas are height above the ground, gain, tower loading and interference rejection. The parameters are discussed below.

2.2 Antenna Gain

 This is the direction in which there is more   radiation or this is a measure of the ability of an antenna to direct the input power into radiation in a particular direction and also measured at the peak radiation intensity.

$$G(\theta, \emptyset) = \frac{U(\theta, \emptyset)}{P_{in}/_{4\pi}} \qquad\qquad 2.1$$

Where

$P_{in} = Input\ power$

$U(\theta, \emptyset) = Radiation\ density$

Gain is attained by administering the radiation far from different parts of the radiation surface

2.3 Directivity

Directivity is a measure of the focus of radiation in the bearing of the most extreme. This is also measure that describes only the directional properties of the antenna, and it is therefore controlled only by the pattern.

$$\text{Directivity} = \frac{maximum\ radiation\ intensity}{average\ radiation\ intensity} = \frac{U_{max}}{U_0} \qquad 2.2$$

Directivity can be seen from the radiation pattern and gain shows the efficiency of an antenna

$$U_0 = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}[U_C(\theta,\emptyset)]\sin\theta\ d\theta\ d\emptyset \qquad 2.3$$

The co- and cross-polarization directivities are defined using the following equation

$$directivity_c = \frac{U_{c,max}}{U_0} \qquad 2.4$$

Figure 2. 1 radiation intensity [2]
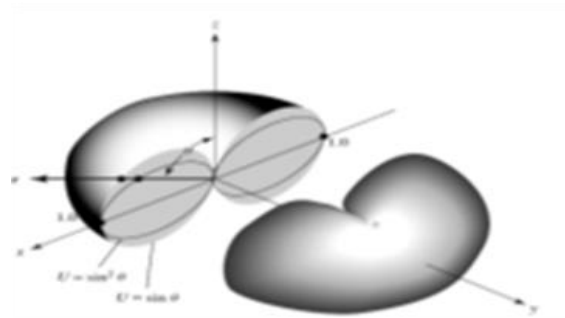
2.4 Antenna Efficiency

Usually this is associated with many efficiencies .The total efficiency is used to cater for the losses at the input terminals and also within the structure of the micro strip patch antenna. The

Loss are due to:
- Conduction and dielectric ,this is called the I^2 R losses
- Reflection which is caused by the mismatch between the antenna and the transmission line

Overall efficiency can be written as

$$e_0 = e_r e_c e_d \qquad\qquad 2.5$$

Where

e_0=total efficiency (dimensionless)
e_r=reflection (mismatch)
e_c=conduction efficiency (dimensionless)
e_d=dielectric efficiency (dimensionless)

2.5 Effective Area

This defined as the ratio of the power at the terminals of the receiving antenna as to the power density of the wave incident on the antenna. The effective area is used to determine the power delivered to the load, which under conjugate matching is only one-half of that intercepted; the other half is scattered and dissipated as heat.

$$A_e = \frac{P_T}{W_i} \qquad\qquad 2.6$$

Where

A_e=effective area (m^2)

P_T=power delivered to the load (W)

W_i=power density of incident wave (W/m^2)

2.6 Side lobes

Usually microwave antennas seem to be directional for example the patch antenna seem to be directional. When an antenna radiates some of the energy spills and hence causing what we call side lobes .The side lobes are the ones which are seen with lower amplitude where as the main lobe have higher amplitude all this is demonstrated in Figure 2.2a.

2.7 Front-to-Back Ratio

Usually when an antenna radiates energy practically not all energy is radiated from the front of the antenna. The front to back ratio is the gain in the required forward direction to the gain in the opposite direction out of the back of the antenna.

(a)   (b)
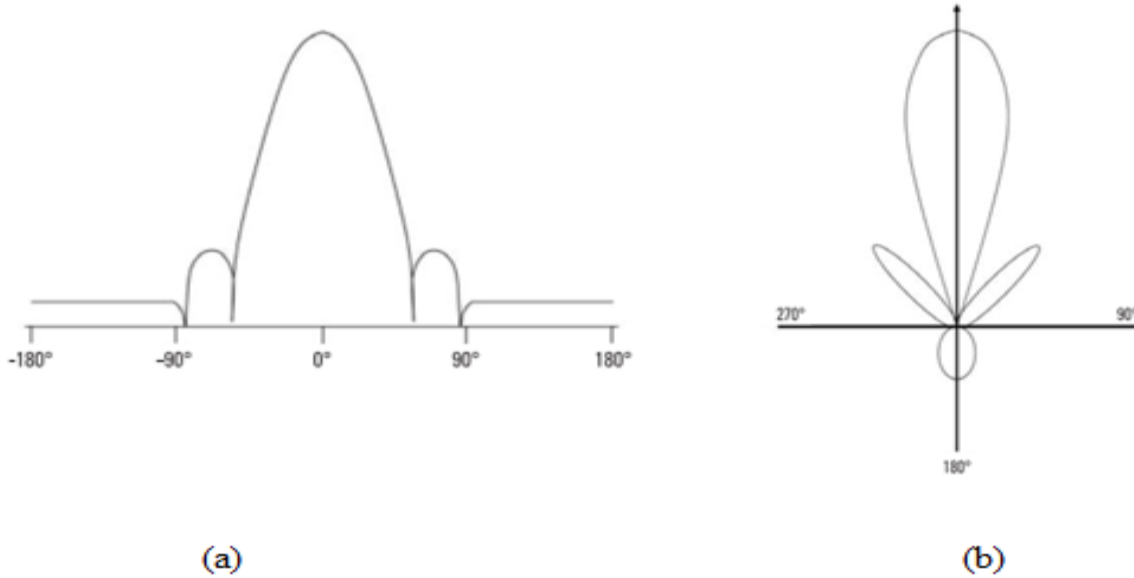
Figure 2. 2: (a) show side how side lobes (b) show the antenna pattern with main, back, and side lobes [3]

2.8 Path Loss

Path loss and power is found by combination of the gain of the transmitting antenna with the effective area of the receiving antenna. In short it is summarized by

$$\frac{P_d}{P_t} = \frac{A_2 G_1 (\theta,\emptyset)}{4\pi R^2} \qquad\qquad 2.7$$

The equation below is mostly used when two antennas are involved.

$$\frac{P_d}{P_t} = \frac{A_1 G_2 (\theta,\emptyset)}{4\pi R^2} \qquad\qquad 2.8$$

A quick evaluations of path loss is given by the equation bellows where R is the distance and f is the frequency in megahertz.

$$path\ loss(dB) = K_u + 20\log(fR) - G_1(dB) - G_2(dB) \qquad\qquad 2.9$$

2.9 Input Impedance

 This is characterized as, "the impedance exhibited toward an antenna, at its terminals alternately the proportion of the voltage of the present during those combine from claiming terminals or the proportion of the suitable parts of the electric to attractive fields toward a point (magnetic field)". Henceforth those impedance of the antenna might a chance to be composed as provided below.

$$Z_{in} = R_{in} + jX_{in}$$
2.10

Where Z_{in} is the antenna impedance, X_{in} is the antenna reactance, which impedance is the coefficient of the power stored in the near field of the antenna and R_{in} is the antenna resistance about two components, those radiation resistance Rr and the loss resistance RL in. All is found at the terminals of the antenna. 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.

2.10 Antenna Factor

This is defined by the following equation. Antenna factor can be said it is inversely proportional to the height of the antenna.

$$AF = \frac{E_i}{V_{rec}} = \frac{2}{h}$$
2.11

Where
E is the electric field is the height and V_{rec} is the voltage received by the antenna .AF is often given as dB (m^{-1}).

2.11 Return Loss

It is a parameter, which demonstrates the measure of energy that is "lost" to the load and does not come back as a reflection. Hence, the RL is a parameter to show how great the matching

between the transmitter and antenna has occurred. Simply put it is the S11 of an antenna and the graph is shown below.
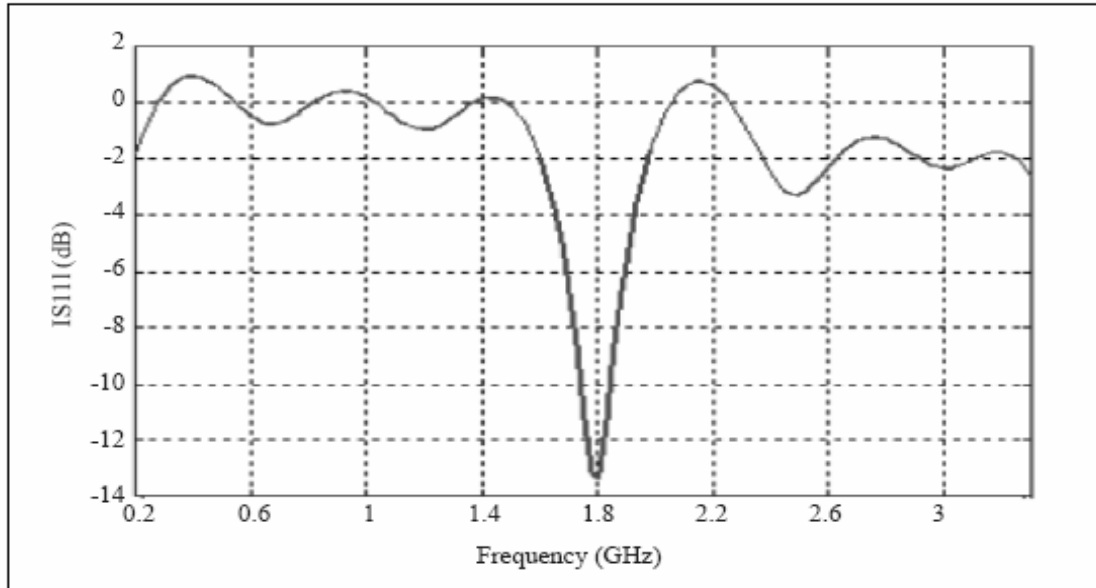
Figure 2. 3: RL curve of an antenna [3]

The return loss of an antenna is linked to the VSWR and they are linked with the reflection coefficient (p) and it defines the ratio between the reflected and the incident waves. This is shown by the following equation.

$$\rho = (VSWR - 1)/(VSWR + R) \qquad\qquad 2.12$$

Return loss (RL) is used to express the mismatch, which is the decibel difference between the power incident on the mismatch and the power reflected from the mismatch. RL can be expressed in decibels as in terms of the reflection coefficient.

$$RL_{dB} = 20 \log(^1\!/_\rho) \qquad\qquad 2.13$$

Where p is the reflection coefficient

2.12 Radiation Pattern/Antenna pattern

Radiation pattern could be characterized in distinctive routes like it can be a mathematical, procedure, alternately it might make a graphical representational of the antenna as a function of space coordinates [1]. 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). Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." The radiation property of most concern is the two- or three-dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. More specifically it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. It can be plotted as a 3D graph or as a 2D polar or Cartesian slice of this 3D graph, all is summarized by the following diagram below.
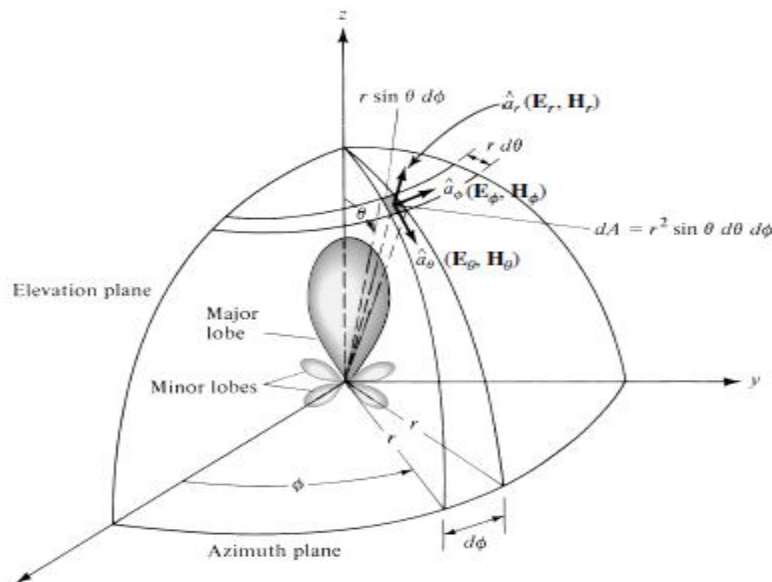

Figure 2. 4: Coordinate system for antenna analysis [1]

2.13 Beamwidth

This is the precise detachment of the h lf-power focuses of the r di ted pattern. The Beamwidth of pattern is defined as the angular separation between two identical points on opposite side of the

pattern maximum. In an antenna pattern, there are   number of beamwidths. One of the most widely used beamwidths is the Half-Power Beamwidth (HPBW),.which is defined as the angle cross the m in lobe of antenna between the direction at which the antenna's sensitivity is half maximum value at the center of the lobe.
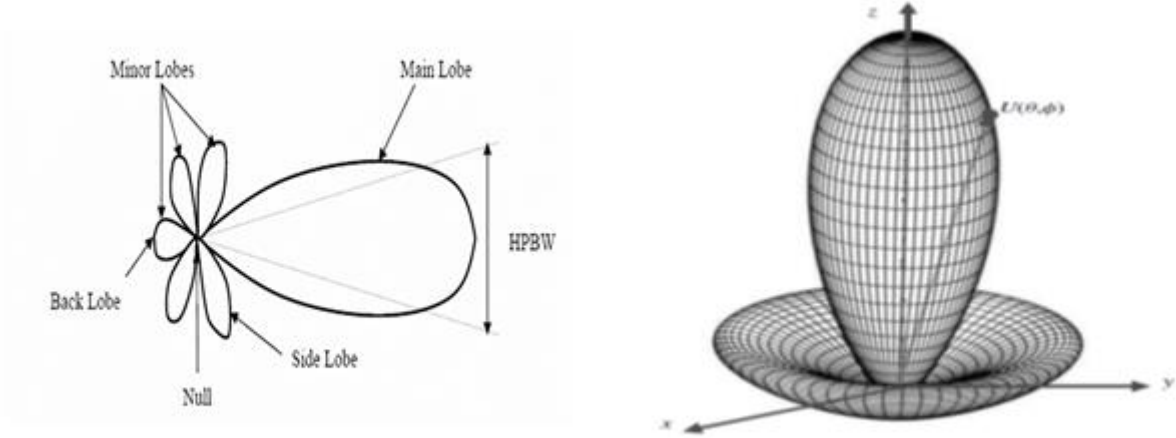

Figure 2. 5: Determination of HPBW from radiation pattern [2]

2.14 Basic characteristics of a Patch Antennas

 Patch antennas are planar resonant cavities that spill from their edges and emanate. Printed circuit techniques can to be used to etch antennas looking into delicate substrates to produce minimal and repeatable antennas in a low profile. Makers to portable correspondence base stations regularly manufacture these antennas specifically done sheet metal and mount them on dielectric Entries alternately froth in an assortment about approaches will dispose of those expense from claiming substrates and etching [1]. This additionally dispenses those issue about radiation starting with surface waves energized previously, a thick dielectric substrate used to expand data transfer capacity (bandwidth).

A patch antenna of a radiating patch on particular case side of a dielectric substrate which need a ground plane on the different side in its basic form likewise demonstrated in figure 2.5. The patch is generally made of conducting material and large such that copper alternately gold and can take any shape. Those transmitting or receiving patch and the feed lines are as a rule photo

etched on the dielectric substrate. Arrays about antennas could make be photo etched on the substrate, alongside their bolstering networks [5].The photo etching techniques could be used to make a variety of antennas with the use of microstrip circuits.
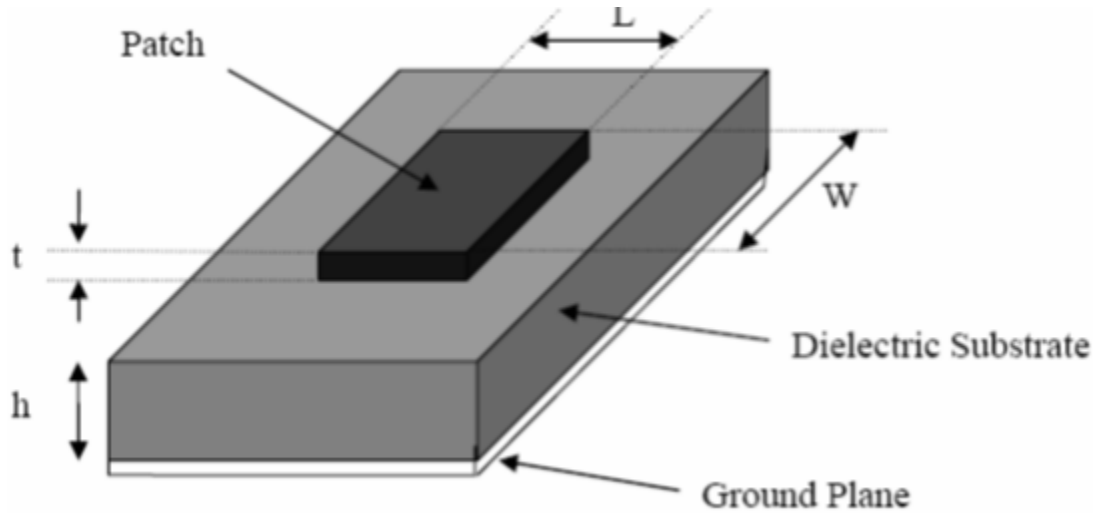

Figure 2. 6: A Typical Microstrip Patch Antenna [3]

 In order to simplify dissection and execution prediction, the patch is generally circular, square, rectangular, and triangular. When designing a rectangular patch, the length L of the patch is usually $0.3\lambda_o < L < 0.5\lambda_o$, where λ_o is the free-space wavelength. The patch is selected to be very thin such that $t << \lambda_o$ (where t is the patch thickness). The height, h of the dielectric substrate should be in the range $0.003\,\lambda_o \le h \le 0.05\,\lambda_{o.}$ The range of the value of the d dielectric of the substrate (ε_r) is normally in the range $2.2 \le \varepsilon_r \le 12$.Factors to be considered when designing a patch antenna are like what might be required for antenna great performance and this may be the thickness of the dielectric substrate with low dielectric constant and this provides exceptional efficiency, bigger data transfer capacity and also superior radiation.

2.15 Feeding methods

Microstrip patch antennas can be fed with many methods but the most common methods which are easy are the following four feeding technique which are the microstrip line, coaxial probe , aperture coupling and proximity coupling .They are categorized into two contacting and non-

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contacting. What happens in the contacting method is that the RF power is fed directly to the radiating patch and in the non-contacting method is that the electromagnetic field coupling is done to transfer power between the radiating patch and microstrip line. The most important thing to take note of   is the maximum transfer of power that is to say the feed line should match with the input impedance of the antenna.

(a) Microstrip line feed

(b) Probe feed

(c) Aperture-coupled feed

(d) Proximity-coupled feed
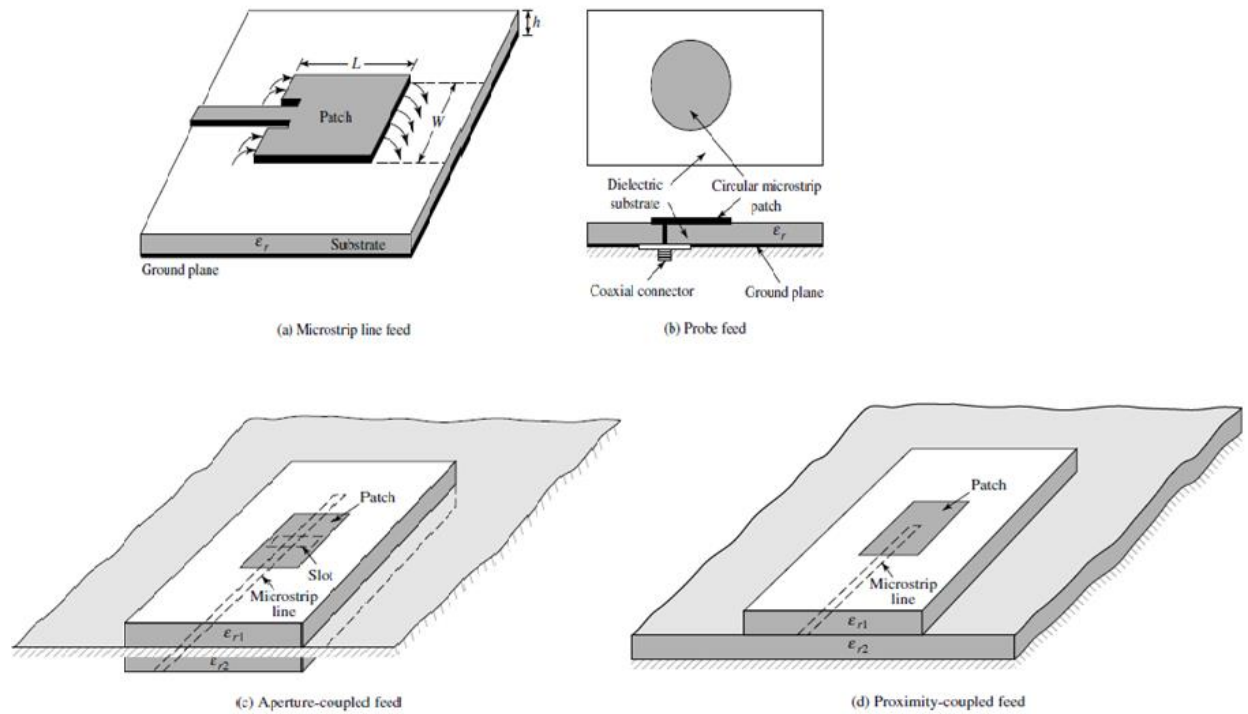
Figure 2. 7: show the typical feeding method of a patch antenna[3]

(a) Microstrip line

(b) Probe

(c) Aperture-coupled
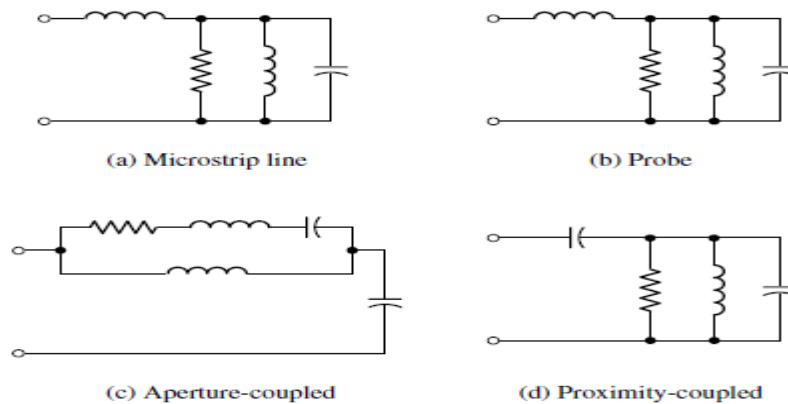
(d) Proximity-coupled

Figure 2. 8: The equivalent circuit for the feeding technique [2]

2.15.1 Microstrip Line Feed

The microstrip feed is linked to the patch and the microstrip feed have smaller width comparing with the width of the patch and this feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

Figure 2. 9: Microstrip Line Feed[4]
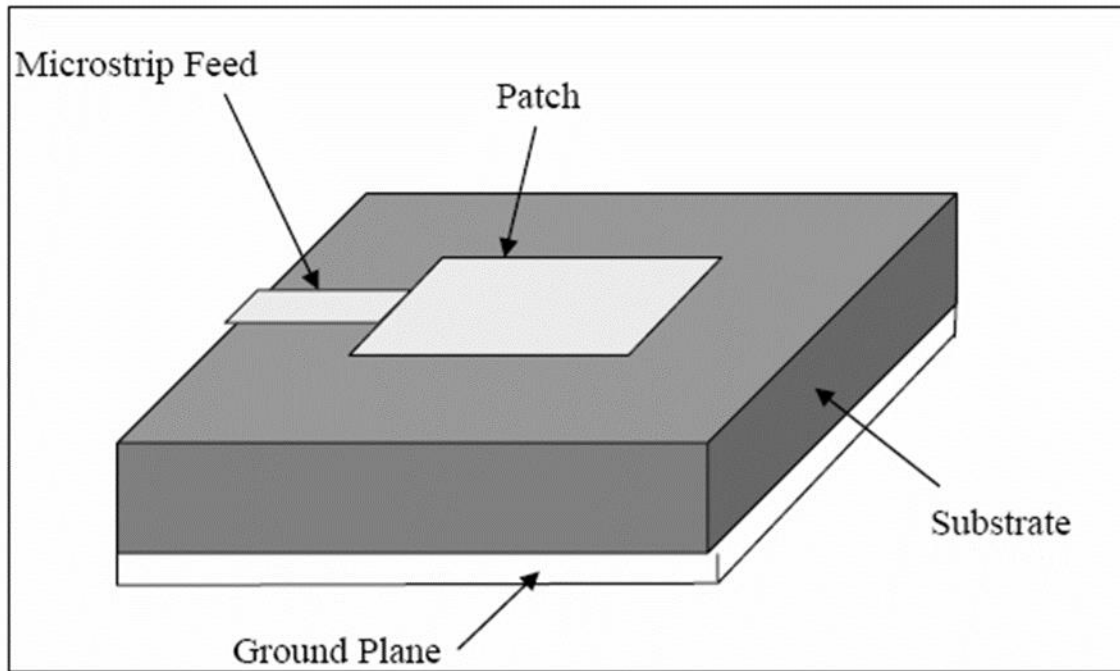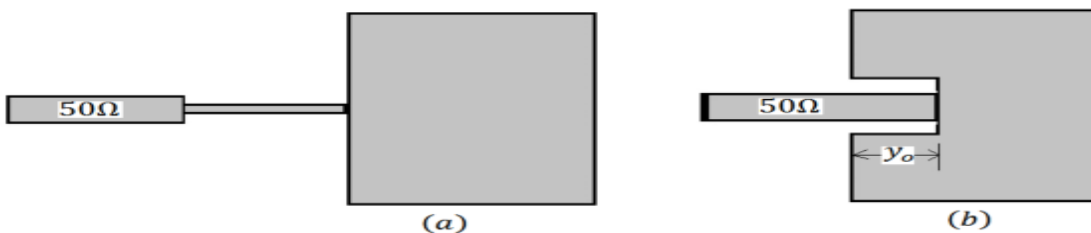
The inset cut in the patch done   to match the impedance of the microstrip feed line to the patch without the use any additional matching element. All of this is done by properly controlling the inset position. Therefore this is an easy feeding technique, hence it is easier in modelling and asimpedance matching.

Figure 2. 10: Microstrip patch antenna with feed from side [3]

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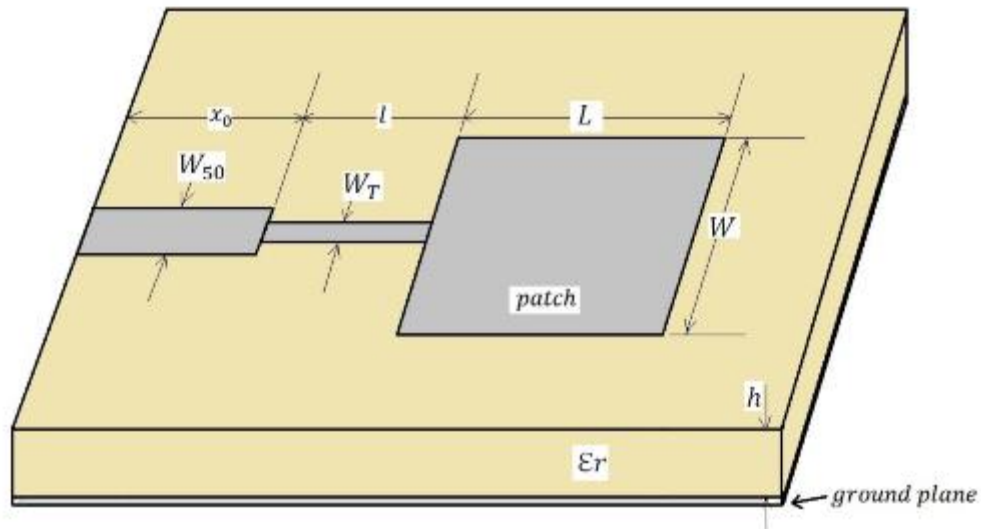
Figure 2. 11: Microstrip patch antenna showing all dimensions [4]

2.15.2 Coaxial Feed

A hole is drilled through the substrate where the inner conductor of the coaxial connector is soldered to the radiating patch, whereas outer core is connected to the ground plane. The main advantage of this type of feeding technique is that the feed can be placed at any desired location within the patch in order to match with its input impedance. The coaxial feed method is easy to fabricate and has low spurious radiation.

Figure 2. 12: Coaxial Feed [2]

2.15.3 Aperture Coupled Feed

There is coupling between the patch and the feed line is done through an aperture in the ground plane as shown in the diagram below. 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 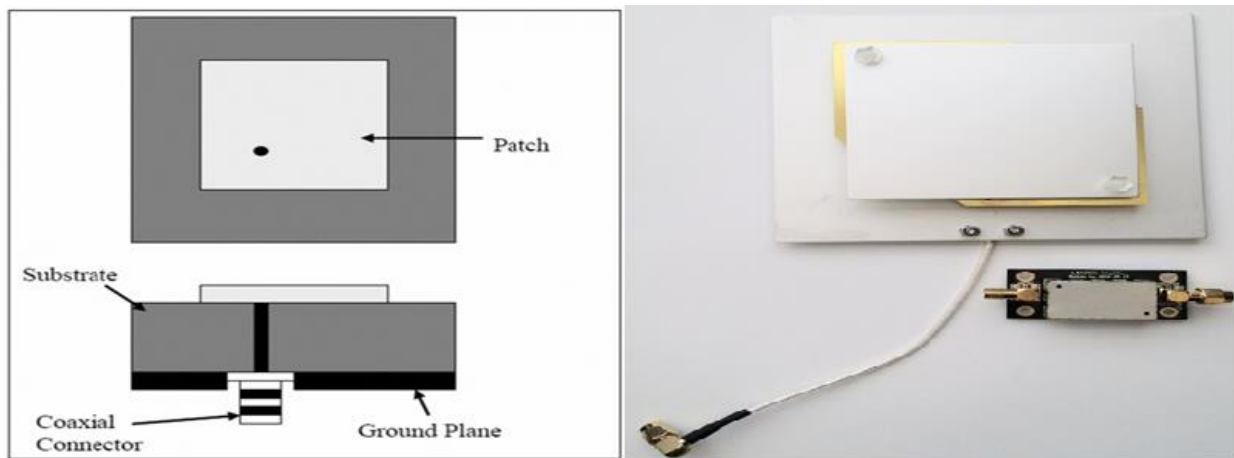to the patch is determined by the shape, size and location of the aperture. When considering that the ground plane separates the patch and the feed line, spurious radiation is reduced. This feeding technique is not going to be discussed because it was not used in designing of the patch antenna because this increases the patch antenna thickness.

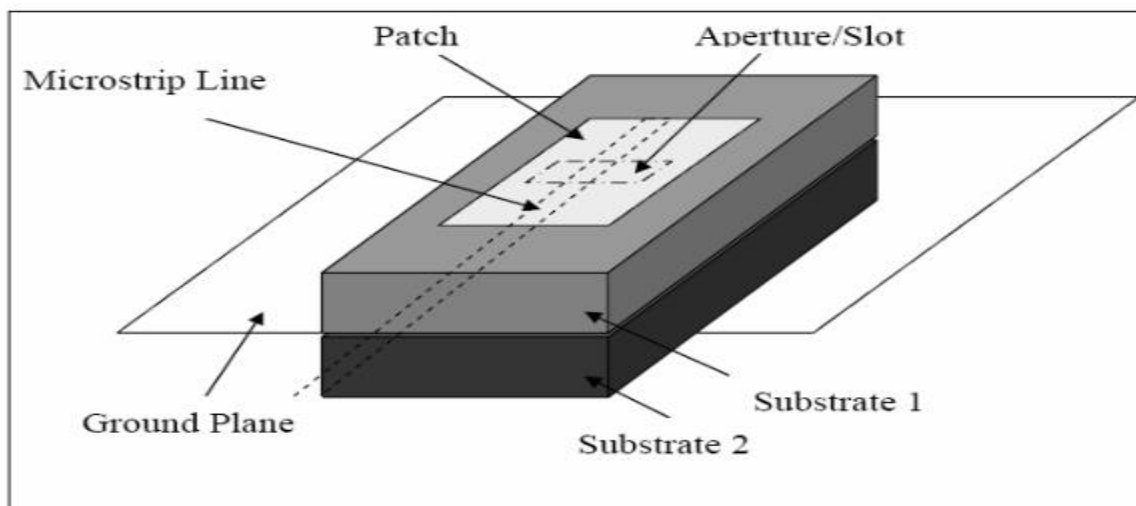Figure 2. 13: Aperture coupled Feed [2]

2.15.4 Proximity Coupled Feed

It is also called as the electromagnetic coupling scheme. As shown, 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. This feeding technique gives a higher bandwidth of about 13 % and also increase the size of the patch antenna.
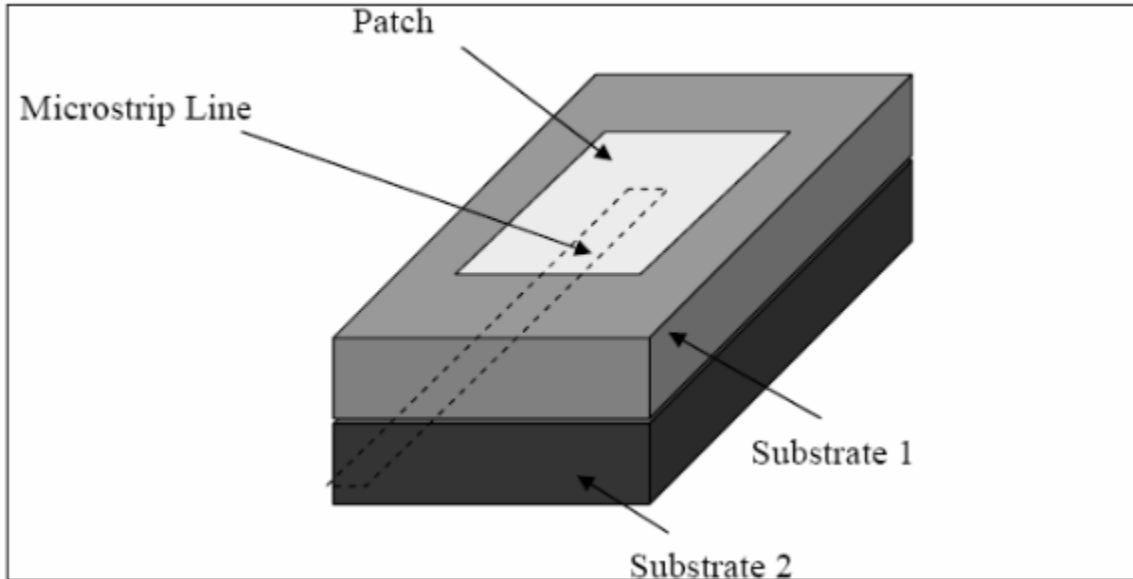
Figure 2. 5: Proximity coupled feeder [3]

2.16 Methods of Analysis in Rectangular patch

The most popular models for the analysis of Microstrip patch antennas are the transmission line model, cavity model, and full wave model .In this project the most method of analysis which is going to be more discussed is the transmission line model and this is easier to be used because the antenna was simulated even it is less accurate than the cavity model. It is explained in detail as it is used by a number solvers for example such as CST studio for simulations.

2.16.1 Transmission Line Model

Even although the transmission line model gives less accurate results it, does give some physical insight. So to cut the story short the transmission line model show a   microstrip patch antenna consisting of two slots, separated by a low-impedance Z_c transmission line of length L.

2.16.1.1 Fringing Effects

The patch edges undergo fringing because the dimensions which are length and width of the patch are finite. The amount of fringing is a function of the height of the substrate and the dimensions of the patch. The fringing effect also influences the resonant frequency. Fringing makes the microstrip line look like it have increased in size electrically compared to its physical dimensions. Hence it is discovered that some of the waves travel in the substrate and little in air, the effective dielectric constant is introduced to cater for fringing effect and also the wave propagation in the line. So have the effective dielectric constant introduced, let us assume that the center conductor of the microstrip line with its original dimensions and height above the ground plane as show in the figure below.

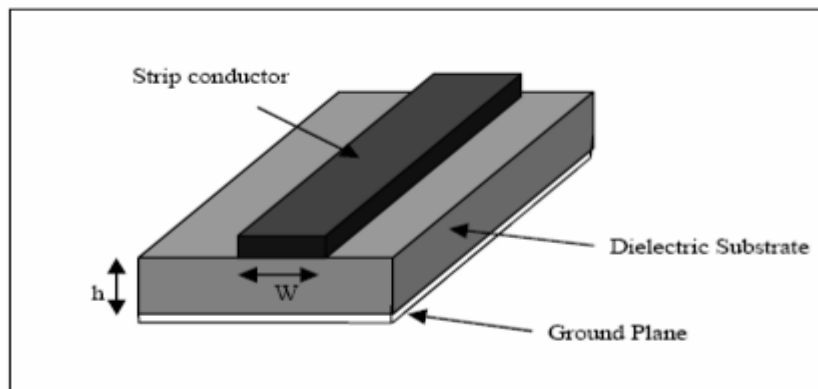Figure 2. 6: Microstrip Line [5]

The microstrip line shown above is a typical electric field lines are shown below. This is a nonhomogeneous line of two dielectrics which is typically the substrate and air. As seen almost all of the electric field lines reside in the substrate and less lines exist in air. The field lines are mostly seen in the dielectric.
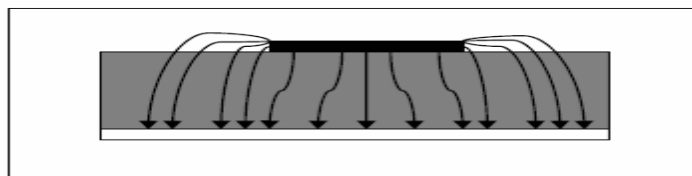
Figure 2. 7: Electric Field Lines [3]
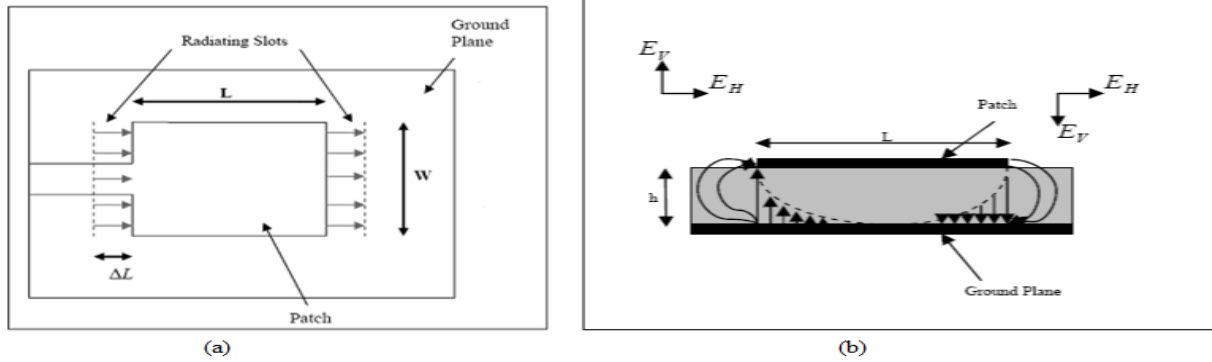
Figure 2. 8: Top View of antenna (a), side view of antenna (b) [3]

The equation for calculating the effective dielectric constant is given in chapter three where it was used in the calculation of the of the patch parameters. The fringe factor is calculated using the following equations.

$$(f_r)_{010} = \frac{1}{2L\sqrt{\mu_0\epsilon_0}\sqrt{\epsilon_r}} = \frac{v_0}{2L\sqrt{\epsilon_r}} \qquad 2.14$$

Where

q = fringe factor,

f_r = resonant frequency and

v_o = velocity of light

2.17 Design

Based on the simplified formulation that has been described, a design procedure is outlined which leads to practical designs of rectangular microstrip antennas. The procedure assumes that the specified information includes the dielectric constant of the substrate (Er), the resonant frequency (fr), and the height of the substrate h.

$$h \leq 0.3 \times \frac{\lambda_{air}}{2\pi\sqrt{\varepsilon_r}} \qquad 2.15$$

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$$\lambda_{air} = \frac{c}{f_r} \qquad\qquad 2.16$$

Where λ_{air} = wavelength in free space (air),

    c = speed of light = $3 \times 10^{\,8}$ m/s,

    f_r = the selected resonant frequency =2.45GHz,

    Loss tangent (tan #) = 0.023.

    $h = height$

The practical width of the patch is   which is used in designing is calculated using the following equation.

$$W = \frac{1}{2f_r\sqrt{\mu_0 \epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{2}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \qquad\qquad 2.17$$

Where υ_0 is the free-space velocity of light.

The equation below is used to determine the effective dielectric constant of the microstrip patch antenna.

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2}+\frac{\epsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-\frac{1}{2}}$$

$$2.18$$

Once W is found using equation 3.3 and then determine the extension of the length

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \qquad\qquad 2.19$$

The equation below shows the how the real length of the patch antenna is determined.

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\epsilon_0\mu_0}} - 2\Delta L \qquad\qquad 2.20$$

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}} - 2\Delta L_p \qquad\qquad 2.21$$

When the calculation of the length and the width of the patch is done there's need for calculation of the feed point which is may be calculated using the following equation and the main goal is to match the antenna to 50Ω.Hence now the feed point is now determined using the following equations.

$$Rin = \frac{1}{2(G1+G12)} \qquad\qquad 2.22$$

$$Rin = \frac{1}{2(G1+G12)}\cos^2\left(\frac{\pi}{L}y_0\right) \qquad\qquad 2.23$$

$$G1 = \frac{I1}{120\pi^2} \qquad\qquad 2.24$$

$$I1 = \int \left[\sin\left(\frac{WK_0}{2}\cos\theta\right)\right]^2 \sin^3\theta d\theta \qquad\qquad 2.25$$

$$G12 = \frac{1}{120\pi^2}\int \left[\sin\left(\frac{WK_0}{2}\cos\theta\right)\right]^2 J_0(k_0Lsin\theta)sin^3\theta d\theta \qquad\qquad 2.26$$

Calculating the dimensions of the ground plane.

$$\lambda_{eff} = \frac{v_0}{f_r}\sqrt{\varepsilon_{reff}} \qquad\qquad 2.27$$

Equations (2.28)and equation (2.29) is used to determine the dimension of the ground plane ,there's no need for the calculation of the dimension of the substrate because their dimension are similar.

$$L_g = 6h + L \qquad\qquad 2.28$$

$$W_g = 6h + W \qquad\qquad 2.29$$

If the feeding method is via a microstrip feed line and hence the characteristic impedance is calculated using the following equation.

$$Za = 90\frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2$$ 2.30

Width of transmission feed line (W_T):

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}}\ln\left(\frac{8d}{W_T} + \frac{W_T}{4d}\right)$$ 2.31

Length of transmission feed line :

$$l = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}}$$ 2.32

2.18 Conclusion

The things which are discussed in this chapter they are characteristics of the patch antenna which are supposed to be calculated in the following chapter .The values or the parameters that are in this chapter they are only theoretical .On practical they are supposed to similar to that of theory ,theory in terms of designing it is the measuring instrument.

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Chapter 3

Methodology

3.1 Introduction

In this chapter there will be some discussion of how the micro strip patch antenna can be design .The design procedure will be based on what was done in theory, in this case it will be referenced from the previous chapter .The antenna structure that is supposed to be made is shown below .This antenna structure is going to be made in CST studio and the parameters are going to be calculated using mat lab. In mat lab thus were the equation used are going to be written and then patch antenna parameter calculator is then created.

3.2 The Design

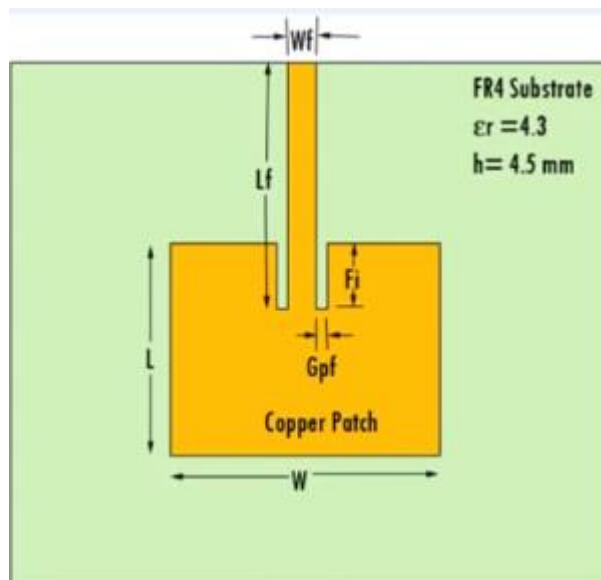The antenna which is going to be designed is a rectangular patch antenna is got a microstrip feed line.

Figure 3. 1: shows the type of antenna that is going to be designed[2]

When designing a micro strip patch antenna there are parameters to be requires calculated first which are like the length and the width of the patch. In this case the minimum targeted frequency will be 2.45GHz.The first design step is to choose a suitable dielectric substrate of appropriate thickness (h). A flame resistant substrate (FR4) with dielectric constant Ɛr =4.3 having thickness (h) =1.6mm is chosen as the substrate material for the patch antenna.

3.2.1 Calculations in Matlab

Firstly the code was written was on based on calculation so the function which is being used is calculate .The mat lab software was used to calculate the parameters of the patch antenna so in other words the mat lab was just used as a calculator. The antenna which is being design should have the parameters of that are equivalent to the circuit which is being shown in figure 2.8a.The antenna in patch form should be like the one which is being demonstrated in figure 2.9 , the ground and the patch are separated by the substrate which had a height h ,hence the height of the substrate it is a fixed parameter and also the height of the of the patch and of the ground are the fixed parameter hence it was not necessary for the mat lab to calculate that[3] . All the parameters that were required for the patch antenna design are shown in figure 2.11. When writing the mat lab code the first thing was for it to first ask the user the fixed values that like the height of the substrate, dielectric constant and the resonant frequency, therefore a mat lab code was written in a way that the user is able to understand .The first thing to be calculated using mat lab was the width of the patch because almost all the parameters of the patch are derived from the width of the patch, the equation is in chapter 2 which is equation (2.17). After calculating the width the next parameter was the effective dielectric constant which is calculated using 2.18 and then the extension of the length using (2.19) [4].The patch length can be calculated using (2.20) or (2.21) and the input impedance is calculated using (2.22) .In mat lab the most import thing when doing calculation with fixed or constant values it is good to input them first. Therefore it is now easy to calculate the dimensions of the ground and these are calculated using (2.28) and (2.29) which are the length and the width of the ground plane respectively .The length and the width of the ground of the patch are similar except for the height only[5] .Impedance of the transition section is calculated using (2.31) and the width of the

transition line and the length of the transition line is calculated using 2.32 and 2.33 respectively .After writing all this the in mat lab it the start to call for the output value which are then used in CST studio in the designing of a three dimensional patch antenna .
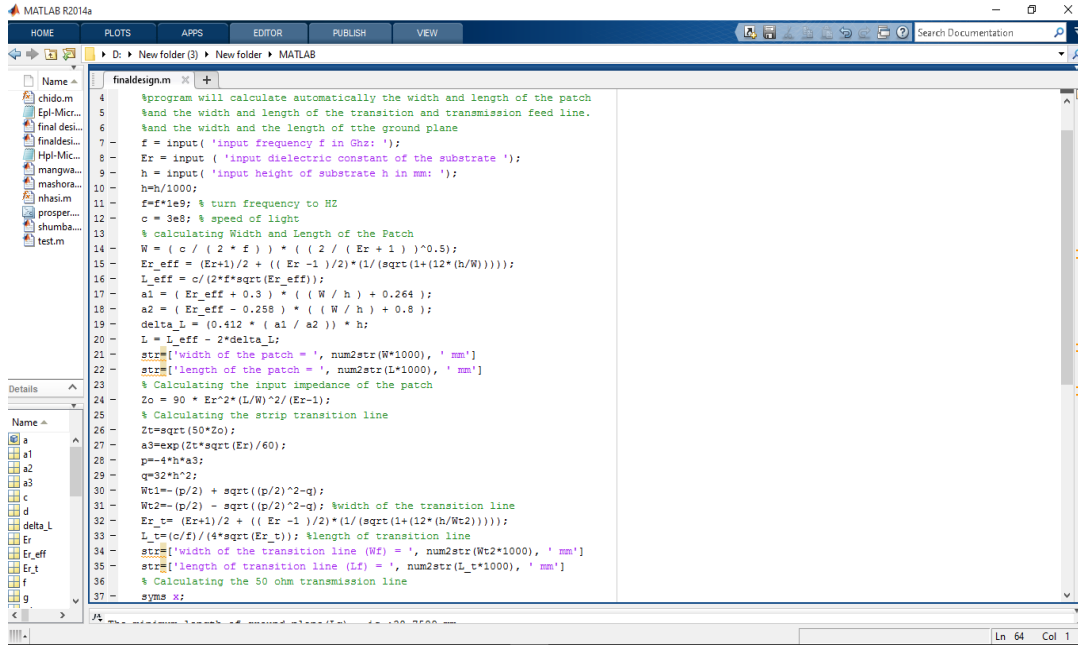

Figure 3. 2: matlab environment used for the calculation

The whole code for the mat lab is in the appendix A and the code consist of the equations but they are written in the form that the mat lab environment understood it therefore the result obtained in matlab are then used in modeling the patch antenna in CST studio 2016

3.2.2 Modelling and simulating in CST studio 2016

In CST studio, the type of antenna to be modeled is selected and the frequency range to be monitored is entered. The first thing to be modeled was ground plane , in CST studio one has to select the block and give it parameters .In this case the ground plane which is used is the copper plate which have a thickness of 0.1mm ,other parameters are calculated using matlab .Then the

next component which comes on top of the dielectric substance is the Fr4 substrate which have the dielectric constant of 4.3 .The height of the substrate is 1.6 mm ,so this is the distance between the radiating patch and the substrate. Then the block of radiating patch is then placed on top of the substrate and the radiating patch consist of height of 0.1mm which is similar to that of the ground plane .After all this there is need for creation of the insertion gap where the microstrip transmission feed line to be insert .Last there is need for the creation of the port which is fed by waveguide port so values of the coordinates of the port are then entered the simulation begins and the results are obtained as shown in in chapter 4 .

Name	Value(mm)	Description
L	29.1589	Length
W	37.6099	Length
Lg	38.7589	Length
Wg	47.2099	Length
Lf	18.2624	Length
Fi	14.5795	Length
Gpf	2.015	Length
Wf	0.1818	Length
H	1.6	Length
T	0.1	Length

Table 4. 1: values used create a patch antenna

After inserting the substrate then the patch antenna is then placed on top of the substrate and using the parameters calculated in matlab the following model came out.
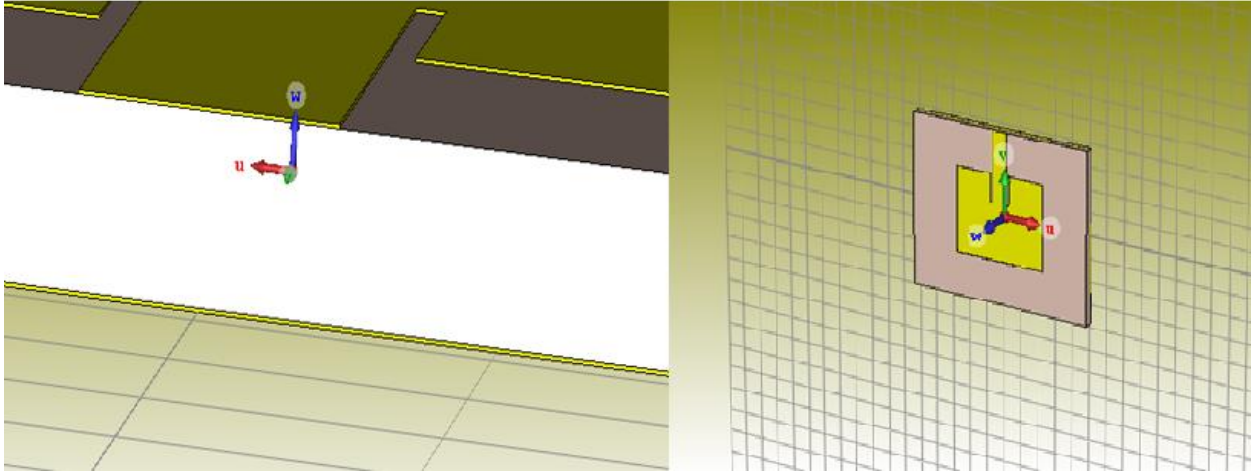
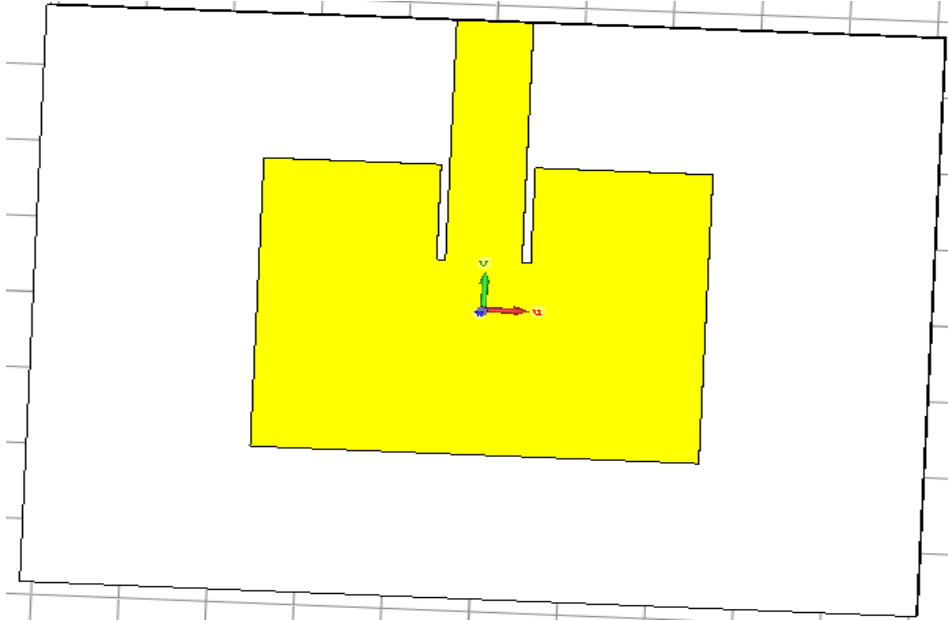Figure 3. 3: side view of the patch antenna and showing the patch antenna

Figure 3. 4: patch antenna in CST studio

The above table 3.1 shows the parameters that were used in CST Studio when designing the patch antenna   where w is the width of the patch is the length of the patch, Lf is the length of the feed line and h is the height of the substrate and the other parameter is the height of the patch but in this case the height of the patch was take to be (t).

3.3 Conclusion

In short the values obtained in this chapter are going to be discussed in the next chapter and the next chapter marks if the results are in line with the theory. The accuracy of this chapter is determined in the following chapter.

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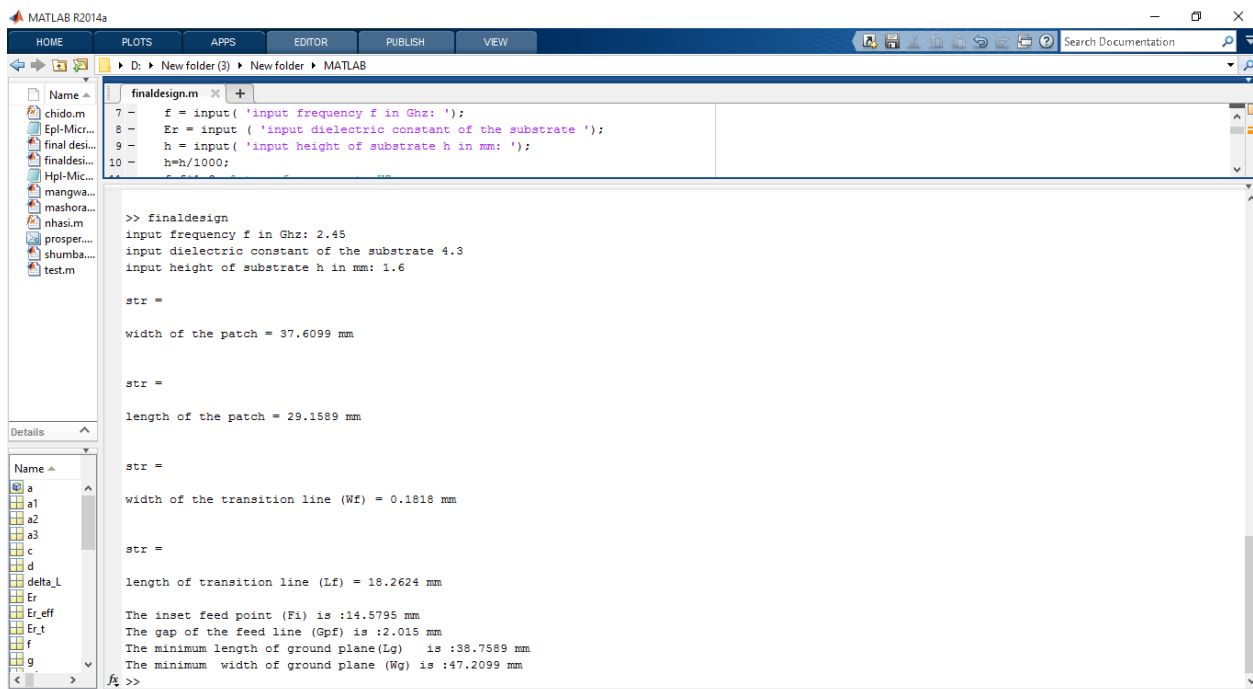
Chapter 4

Results and analysis

4.1 Introduction

In this chapter thus where the results obtain from doing the project are compare to the theoretical value or parameters and this will give a view if there are modification that have been done or there is failure of the project hence in short it's a comparison and theory is the measuring instrument .

4.2 Matlab parameter results

These results were obtained after entering the resonant frequency, dielectric constant, substrate height and the impedance of the antenna which was 50 ohms.

Figure 4. 1: shows the results obtained from the matlab

The components are the created basing on the parameters created by matlab code and the patch antenna will be formed as that in figure 3.1.

The following graph shows the return loss of the patch antenna for the frequency range from 2.45 GHz to 5 GHz .This range was chosen because it is within the range of Wi-Fi and it follows the regulation of the country and also Wi-Fi ranges from 2.45GHz to 5GHz.

4.3 CST STUDIO RESULTS

4.3.1 Return loss

It is a parameter that is used to measure the power reflected by the antenna due to the mismatch of the antenna. Let us consider an example, if the return loss is 0dB there is nothing to radiate by the antenna because the power provided to the antenna is completely reflects by the antenna or this means that the power input equal to the power reflected. The return loss of the antenna performed is shown in the figure 4.2:
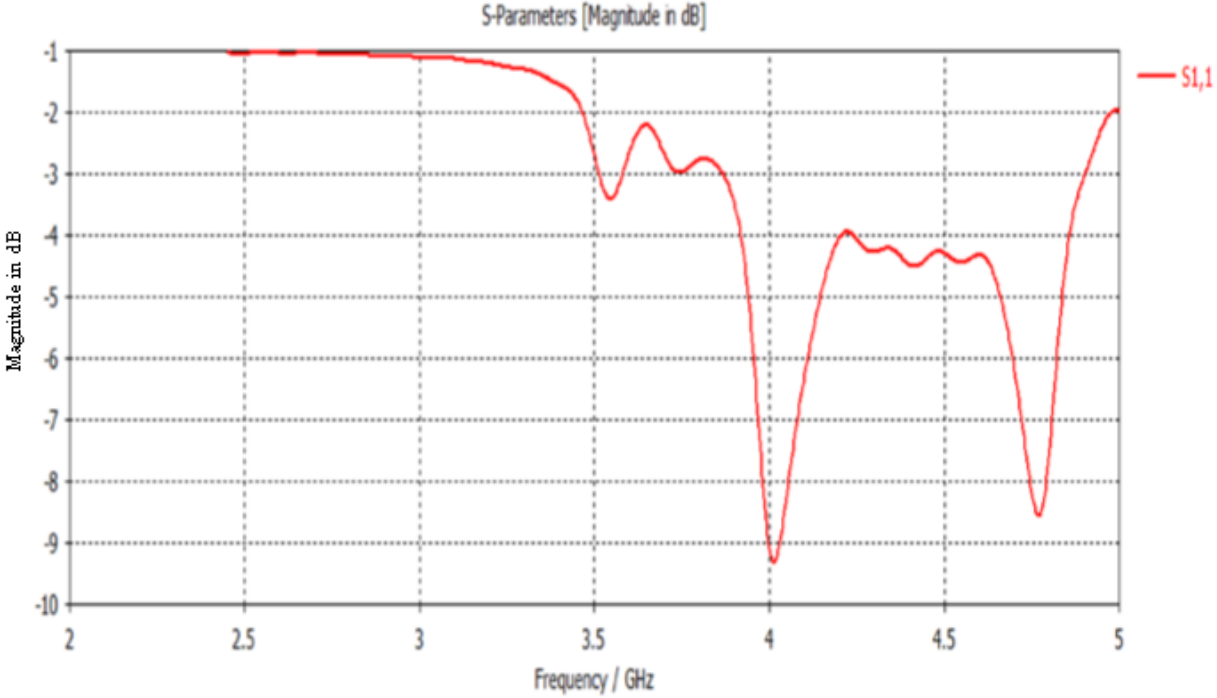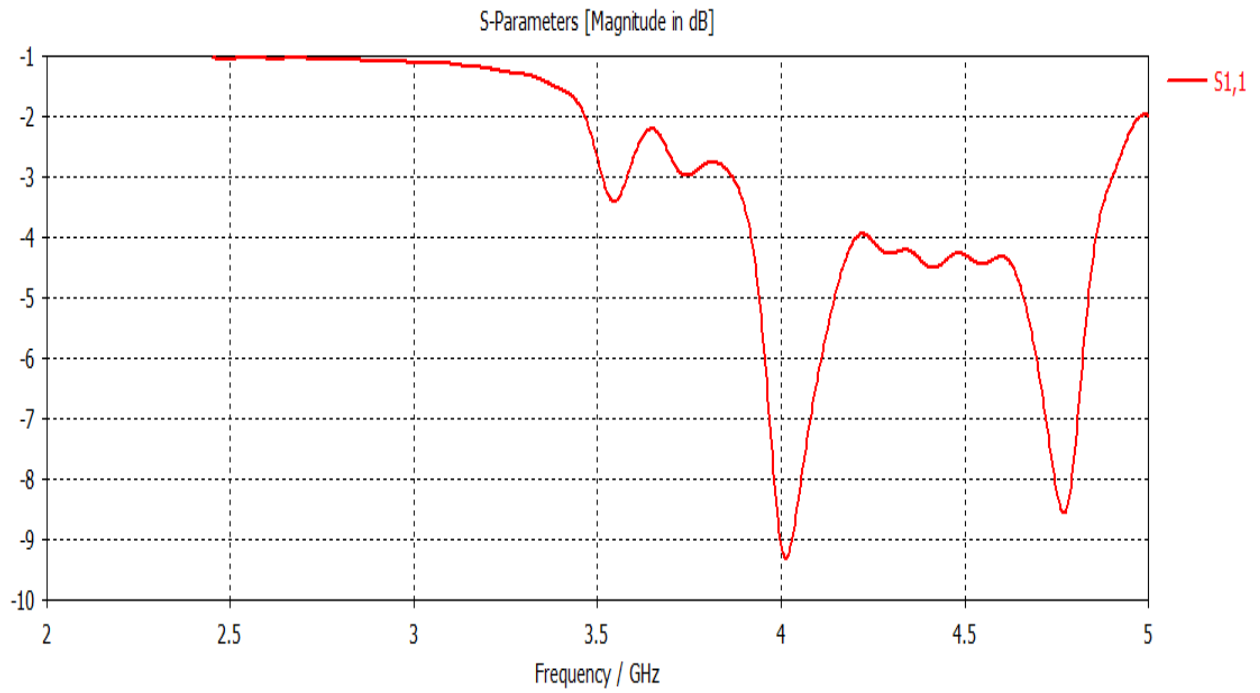

Figure 4.2: return loss

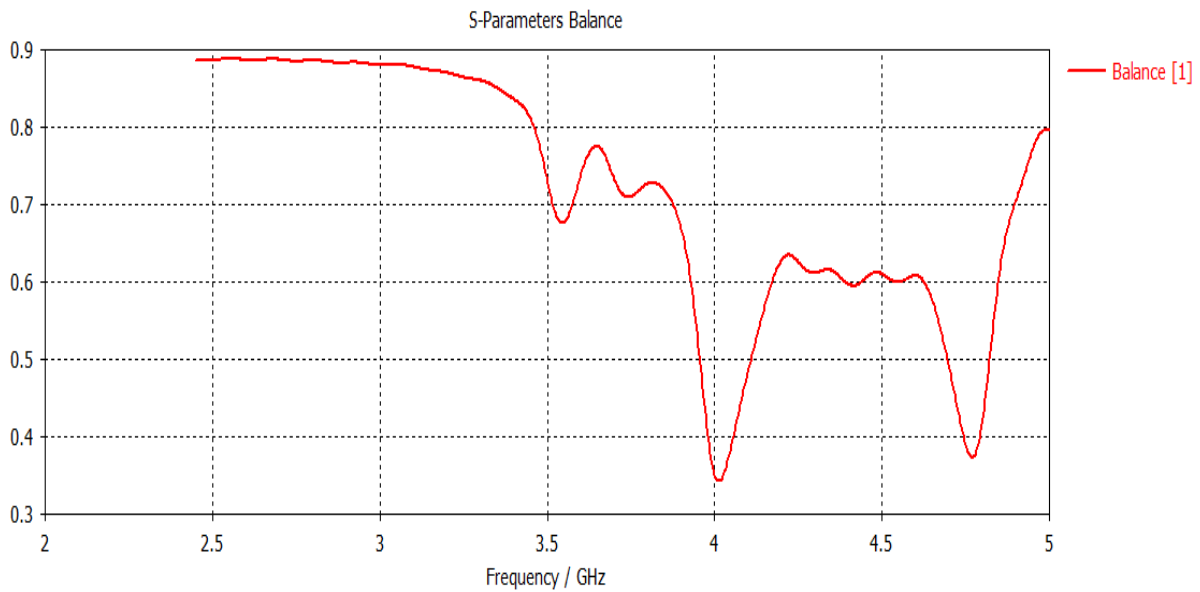Figure 4.3: Return losses for rectangular antenna

Figure 4.4: S-parameter balance

Therefore the characteristics of the antenna shows that the it has low return loss at 4.1GHz and this show that the antenna works more effectively at lower frequencies .As the frequency increases the return loss begin to increase which mean as the frequency increases without changing the dimensions and the properties of the antenna the return loss begins to increase .Looking at the graph it shows that   at the 4.75GHz frequency the return loss decreases this is due to the fact that the patch antenna have a wideband hence the antenna should perform in good manner in the frequency range of 2.45GHz to 5GHz. Looking at the graphs of the return loss given above shows that the return loss was high which mean all the power was entering into the antenna because smaller return loss is bad which means less power is entering into the antenna. In conclusion the patch antenna which is a dual band does not receive power continuously so looking at the above results than antenna have two points where the return loss decreases   to a minimum and also the return loss never reached 0 dB so there no hundred percent   reflection.

4.3.2 VSWR

 This is the ratio of maximum value of standing wave voltage to its minimum value. The minimum VSWR for an antenna would be 1. The antenna with less VSWR has the better return loss compared to the other antenna. The VSWR of the microstrip patch antenna is shown in the figure 4.3
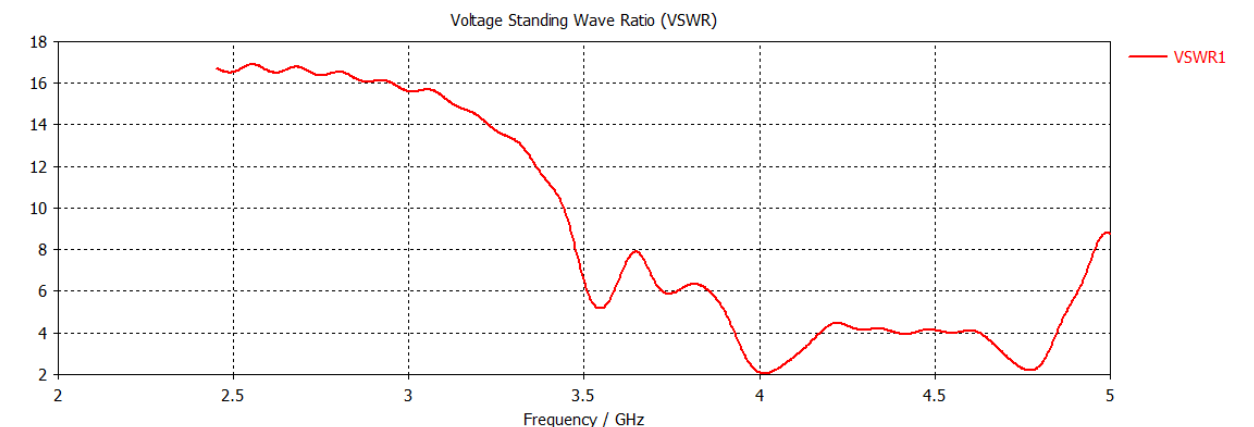

Figure4.5: VSWR for rectangular antenna

As shown in the graph at a frequency of 2.75GHz the VSWR is at almost 1 which show that the antenna is performing very well according to theory .According to the graph as the frequency increases the VSWR also increases but this is seen between 4.75 GHz and 5 GHz and in terms of the patch antenna the VSWR seems to vary with the return loss .The characteristics of the return loss graph   in terms of the shape are almost similar to that of the VSWR.

4.3.3 Far field pattern

Polar plot*:*

Looking at the chart below it shows that the side lobes where almost similar to the main lobe hence the antenna is not that too much directional. This may seem that the antenna at lower frequency may be almost radiating in all direction .As know that directivity is almost related to the gain of the antenna so it may be analyzed that for a lower frequency the gain which is being achieved is much better in terms of a Wi-Fi broadcasting or evening receiving because a patch antenna works as a transceiver. Also another characteristic is that there is larger beam width which is good for the receiving antenna.
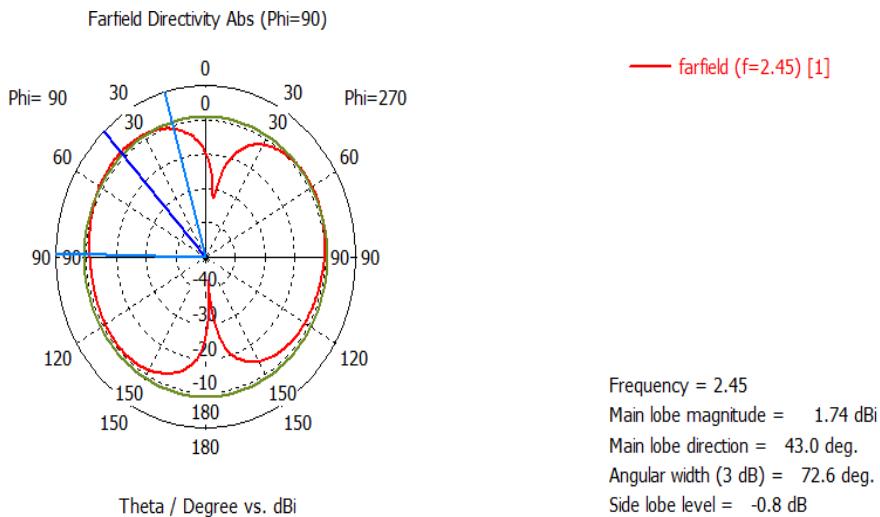

Figure 4.6: show the radiation at frequency of 2.45GHz

This is associated with the antenna gain so the higher the magnitude the more likely to be a higher gain. On figure 4.4 above it seems to be radiating in all direction and this shows that the

37

antenna radiates normal to its patch sources and this is based to the antenna theory. According to the diagram the main lobe is at 43.0 degree but there is little difference with side lobes .It is shown that at 180 degrees the magnitude of the antenna seems to have decreases to almost zero where as the main lobe have a, magnitude of 1.74dBi. From this results for a smaller frequency it seem the performance of the antenna will be not well pleasing because the results for a smaller frequency it seem the performance of the antenna will be not well pleasing because the gain will be poor especial in the far field.

The three dimensional view of the microstrip patch antenna is shown the figure 4.5 .On three dimension it shows that the main lobe is almost similar to one of the side lobe .It clearly shows that at the diagram where there is red color the much more radiation hence the three dimension diagram is self-explanatory.
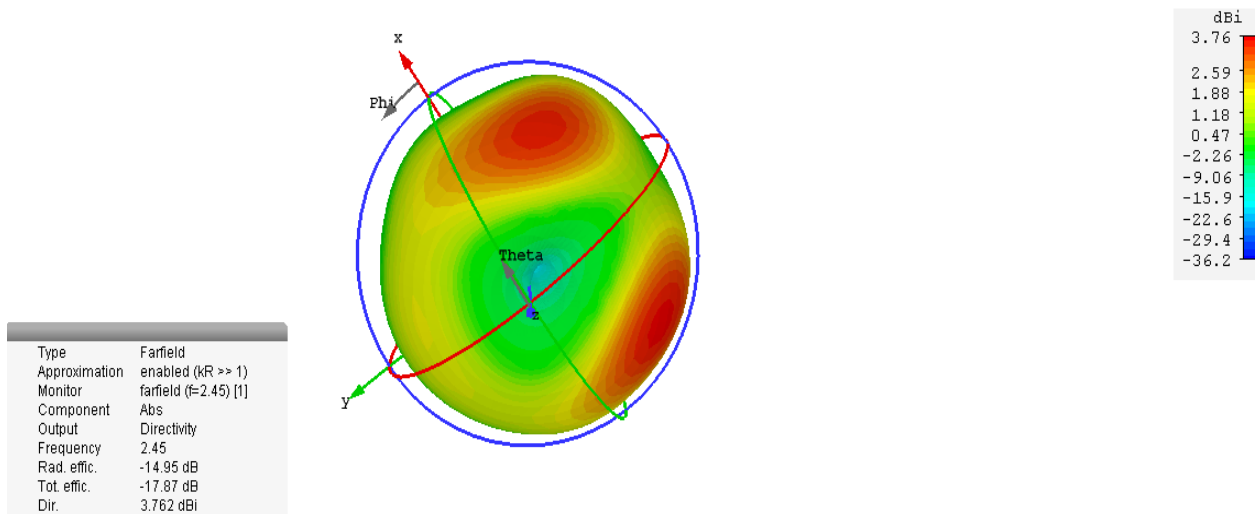

Figure 4.7: Radiation in field at 2.45GHz
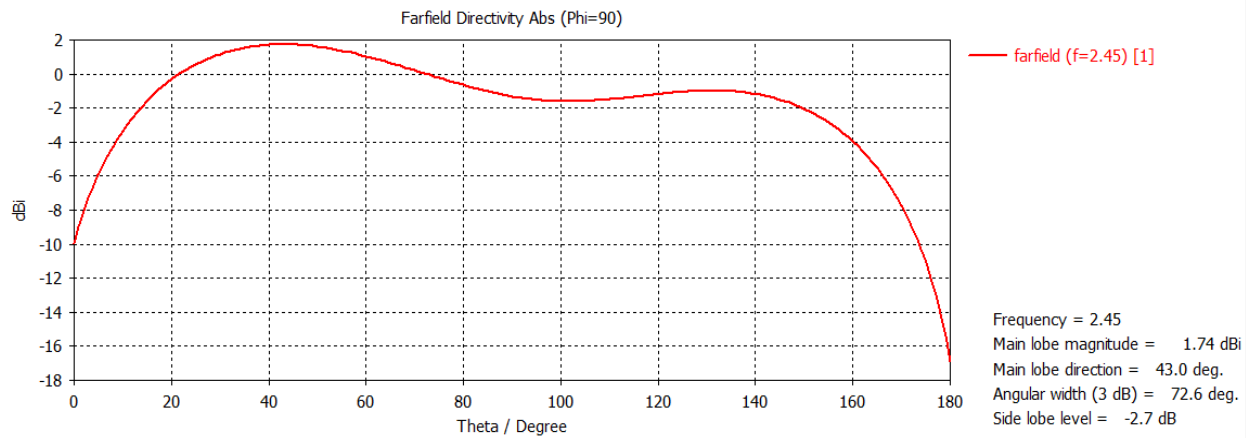
Figure 4.8: Graph of the radiation pattern in far field at 2.45GHz
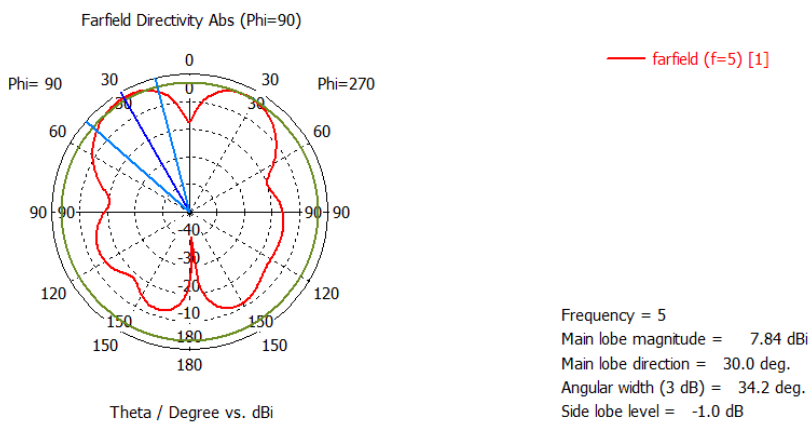
4.3.4 Farfield pattern

Polar plot:

Figure 4.9: Radiation pattern at 5GHz

In figure 4.7 it show that the radiation pattern at 30.0 degree there is much radiation and comparing with the side lobe there is much difference .As shown on the diagram above the as theta decreases the directivity also increase hence we may say the patch antenna have higher directivity at theta is zero .

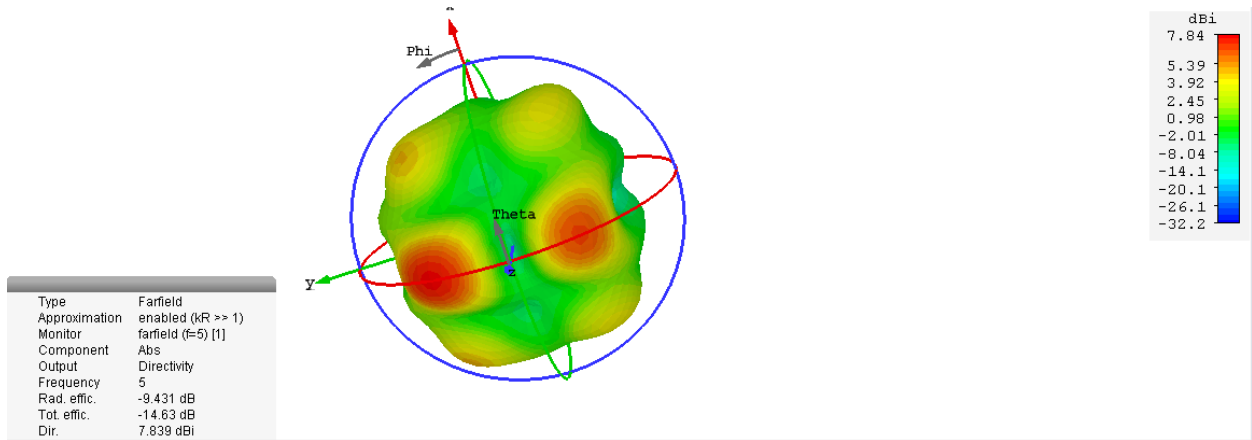| Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5) [1]
Component	Abs
Output	Directivity
Frequency	5
Rad. effic.	-9.431 dB
Tot. effic.	-14.63 dB
Dir.	7.839 dBi

Figure 4.10: Three dimensional view of the microstrip patch antenna

The three dimensional diagram shows that the directivity is almost at all angle unlike at when the patch is operating at lower frequency. The graph below illustrate that as theta increases the directivity of the patch antenna also decrease .The other thing to be noticed is that when the antenna is operating at higher frequency the directivity will be almost fixed ,in this case we may say there will be high directivity at   a point when theta is 30.0 degree .
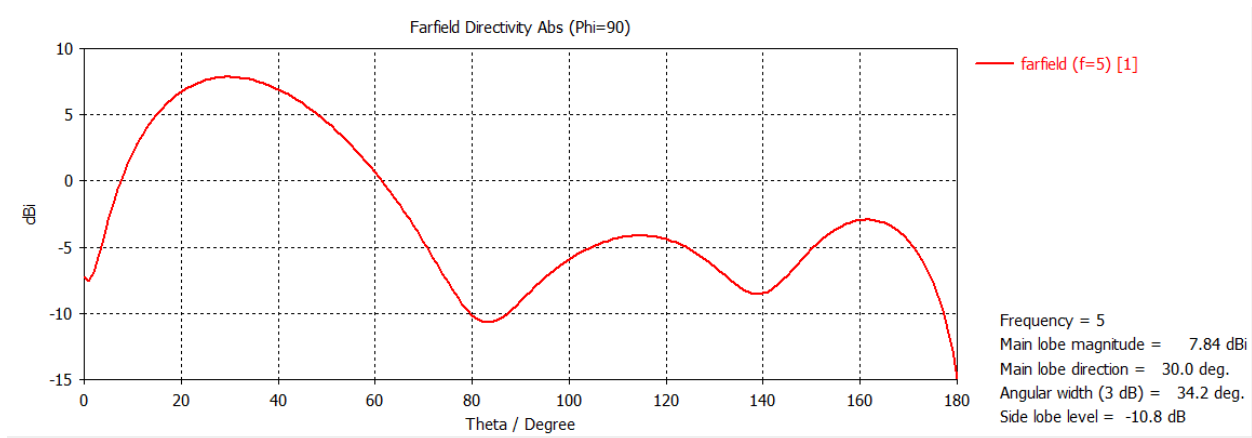
Figure 4. 11: Graph of the radiation pattern of the patch antenna at 5GHz

4.3.5 Power
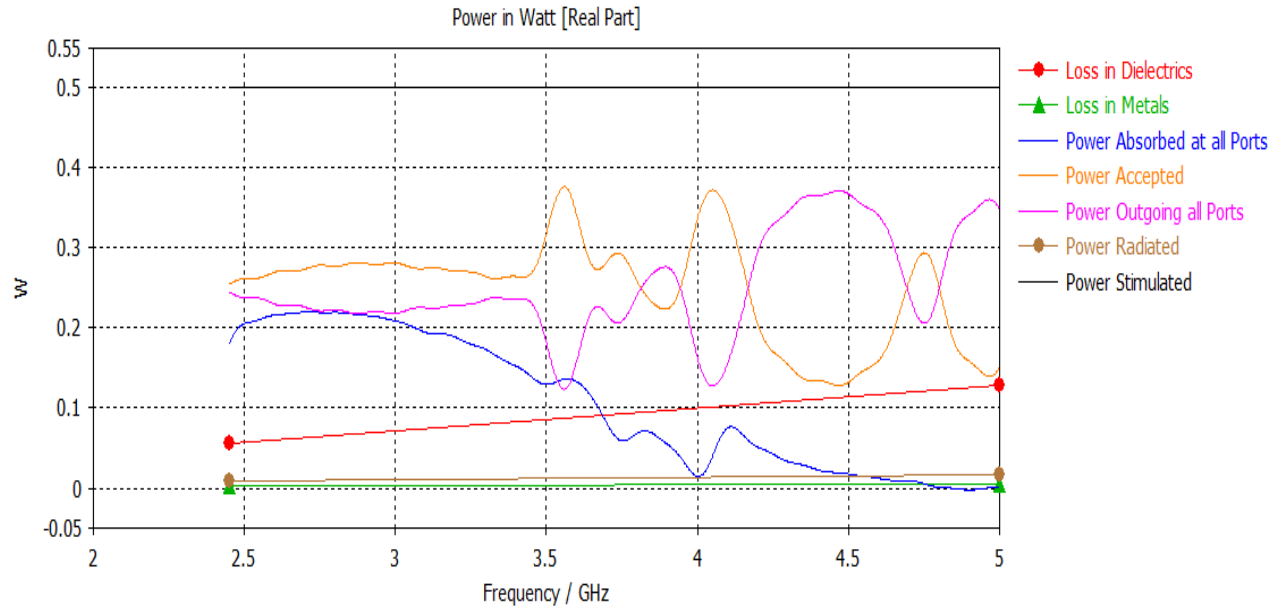
Figure 4.12: Graph of frequency against power

As seen on the graph for a patch antenna the power accepted   is similar to the power which is out going at all the ports in this case there is only one port. On the patch antenna the is no loss in the metals but there is little loss in the dielectric material .Referencing to the return loss the graph proof of what is being shown by the return loss curve is true.

4.3.6 Radiation efficiency
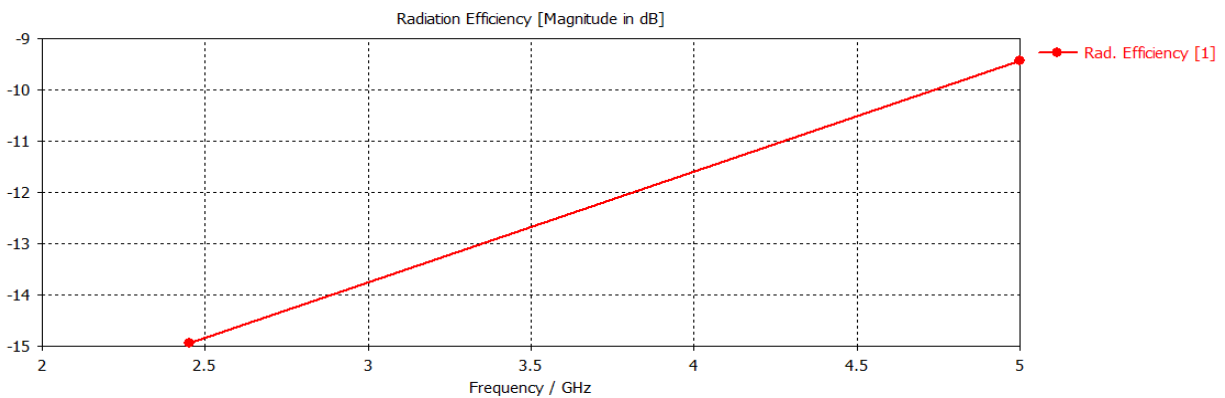
Figure 4.13: radiation efficiency

The above graph show that the radiation efficiency decreases as the frequency increases may be the wavelength was decreasing and then the radiation efficiency was also now decreasing .But looking at the graph below the radiation efficiency seem to have increased because the graph below show the total radiation efficiency .

Figure 4.12: Total radiation efficiency

4.7 Conclusion

This chapter was looking at the results obtained after simulation of the antenna the results were related to the theoretical aspect. The results which were obtained they are comparable to the theoretical values.

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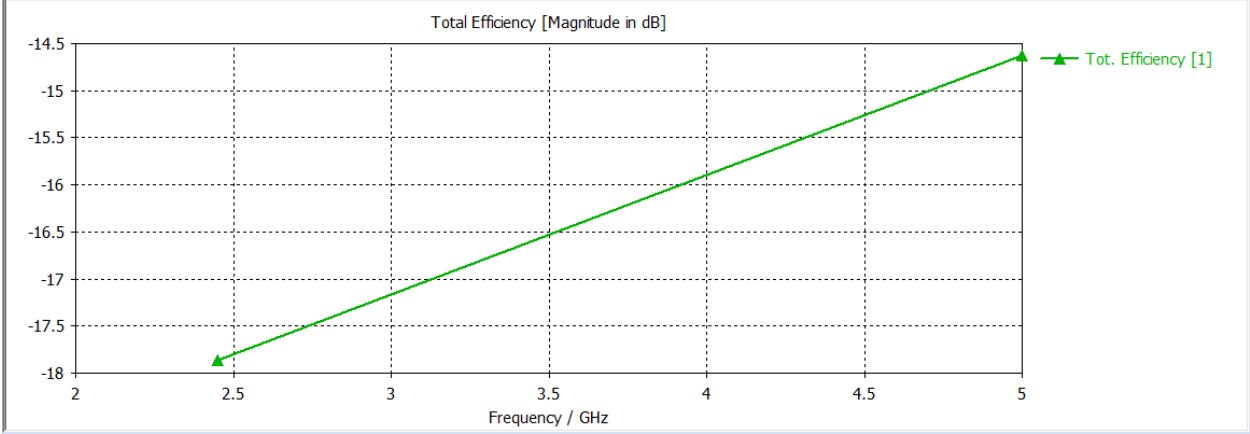
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Chapter 5

Conclusion

5.1 Introduction

Microstrip patch antennas are the recommended antennas because mostly they are easy to fabricate .With the help of CST studio one can fabricate any type of antenna and characterize it. All materials which are necessary in the modelling of an antenna they are found in the   CST Studio. Based on the results obtained the   patch antenna made was working fine and it have not deviated much from the   real antenna. The patch antenna which are shown below are the ones which are similar to the antenna which was designed and characterized .The ones which are shown below are basically used for Wi-Fi, for example the one which is in figur5.1 a have got a symbol which shows that it is for the Wi-Fi and figure 5.1a and figure 5.1b show the internal structure of both of antennas in figure5.1a and figure 5.1b.
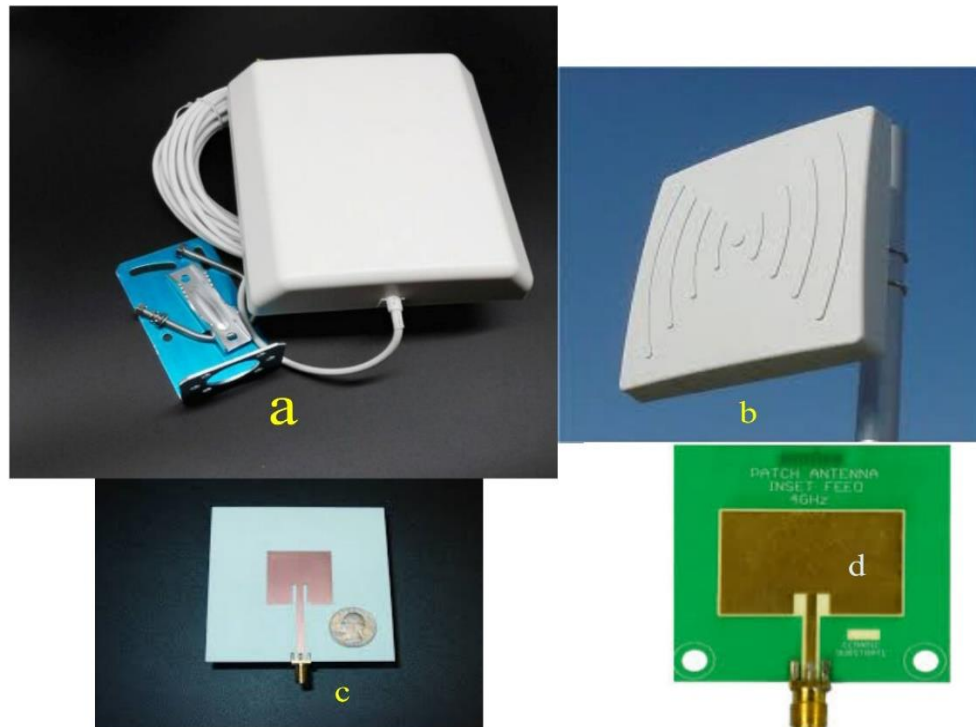

Figure 5. 1: Prototype of patch antenna

5.2 Findings and Recommendations

The objectives presented in chapter 1 have all been achieved, the aim of the study has been reach. When doing simulations it is advisable to use a machine that can handle any parameter .To have a better antenna one has to explore more about the antenna and all about their critics. There are some parameter that cannot be simulated with ordinary computer in shortest possible time hence this may limit the designer in the terms of modifications .So in short for one to do more simulation and see more about the characteristics   of the patch antenna there is need for a better computer and it is good to do simulations of   anything before wasting resources .When it comes to fabrication a better model will be made due to proper simulation results and simulation take care of many things that requires to be analyzed in a very short time . Another thing is that designing a patch antenna using matlab it take time so it is wiser to introduces RF software's such as the CST studio.

5.3 Conclusion

The patch antenna has been successfully designed, and tested .The results were obtained and analyzed and were in agreement with the theory. The characteristics of the patch antenna were found and then discussed in chapter 4 where the results were analyzed. When increasing the frequency of the antenna sometimes it is necessary to change the parameter of the antenna .All the objectives were reached and the aim was achieved. Dual band antenna has been designed and

Simulated, observations have been made on several parameters such as return loss, radiation pattern and VSWR in both cases. From the results of the simulation, it has been observed that the parameters influencing the antenna are the relative permittivity of the dielectric material under the patch, the width (Wf) of the microstrip line, the position of the slot on the patch and the ground plane (in case of the dual band), and the length and width of the patch.

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APPENDIX A

%Program to calculate the parameters to design a rectangular patch antenna

%the user have to feed the values of frequency, dielectric constant, and

%height of the dielectric.

%program will calculate automatically the width and length of the patch

%and the width and length of the transition and transmission feed line.

%and the width and the length of tthe ground plane

f = input('input frequency f in Ghz: ');

Er = input ('input dielectric constant of the substrate ');

h = input('input height of substrate h in mm: ');

h=h/1000;

f=f*1e9; % turn frequency to HZ

c = 3e8; % speed of light

% calculating Width and Length of the Patch

W = (c / (2 * f)) * ((2 / (Er + 1))^0.5);

Er_eff = (Er+1)/2 + ((Er -1)/2)*(1/(sqrt(1+(12*(h/W)))));

L_eff = c/(2*f*sqrt(Er_eff));

a1 = (Er_eff + 0.3) * ((W / h) + 0.264);

a2 = (Er_eff - 0.258) * ((W / h) + 0.8);

delta_L = (0.412 * (a1 / a2)) * h;

L = L_eff - 2*delta_L;

str=['width of the patch = ', num2str(W*1000), ' mm']

str=['length of the patch = ', num2str(L*1000), ' mm']

% Calculating the input impedance of the patch

Zo = 90 * Er^2*(L/W)^2/(Er-1);

% Calculating the strip transition line

Zt=sqrt(50*Zo);

a3=exp(Zt*sqrt(Er)/60);

p=-4*h*a3;

q=32*h^2;

```
Wt1=-(p/2) + sqrt((p/2)^2-q);
Wt2=-(p/2) - sqrt((p/2)^2-q); %width of the transition line
Er_t= (Er+1)/2 + (( Er -1 )/2)*(1/(sqrt(1+(12*(h/Wt2)))));
L_t=(c/f)/(4*sqrt(Er_t)); %length of transition line
str=['width of the transition line (Wf) = ', num2str(Wt2*1000), ' mm']
str=['length of transition line (Lf) = ', num2str(L_t*1000), ' mm']
% Calculating the 50 ohm transmission line
syms x;
Z0=50;
d=h*1000;
a = 1.393-(120*pi/(Z0*sqrt(Er)));
RR1=inline('x/d+0.667*log(x/d+1.44)+a');
la=(3e8/f)*1000;
k=(2*pi)/la;
x=k*(W);
i1=-2+cos(x)+(x*sinint(x))+(sin(x)/x);
g1=i1/(120*pi*pi);        %conductance

a=@(th)((sin((x./2).*cos(th))./cos(th)).^2).*(besselj(0,(k.*L.*sin(th)))).*(sin(th)).^3;
a1=integral(a,0,pi);

g12=a1/(120*pi*pi); %in siemens
r_in=1/(2*(g1+g12));    %in ohms

inset=L/2; %in mm
disp(['The inset feed point (Fi) is :',num2str(inset*1000),' mm'])
g=(3e8*4.65e-9)/(sqrt(2*Er_eff)*f*10^-9);%based on journal by M A Matin (2010)
disp(['The gap of the feed line (Gpf) is :', num2str(g*10),' mm'])
Lg_min=6*h+L;  %
Wg_min=6*h+W;
disp(['The minimum length of ground plane(Lg)   is :', num2str(Lg_min*1000),' mm'])
```

```
disp(['The minimum  width of ground plane (Wg) is :', num2str(Wg_min*1000),' mm'])
```