DESIGN AND CONSTRUCTION OF A RECTANGULAR MICROSTRIP PATCH ANTENNA

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JUNE, 2015

CERTIFICATION

a. By Student

I certify that this work has not been presented elsewhere for the award of a degree, or any other purpose.

Candidate's Name: **OGADI, PRECIOUS ONOCHIE**

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

b. By Supervisor

I certify that this work carried out by **Mr. OGADI, PRECIOUS ONOCHIE** in the Department of Electrical/Electronics and Computer Engineering of Afe Babalola University; Ado-Ekiti.

Supervisor's Name: **PROFESSOR. J.O. OLOWOLAFE**

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Supervisor's Name: **MR. O. O. ADARAMOLA**

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

DEDICATION

This report is dedicated to the Almighty God, the giver of life, the beautifier of destiny and the dispenser of knowledge for His loving kindness, tender mercies, daily blessing, protection and journey mercies since the commencement of my program in this University. I also dedicate it to my parents through whom God gave my life a shape.

ACKNOWLEDGEMENT

Firstly, I want to appreciate God, for the gift of life and the ability to type and present this project. He has been faithful in every aspect of my life.

Also, I would also say many thanks to my parents for the opportunity and the resources to perform this exercise.

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ABSTRACT

Microstrip antenna is one of the newest developments in the area of electromagnetic antenna design. The desire for a low profile and conformity to planar and non-planar surfaces has made it versatile in communication application. In this research, the rectangular Microstrip patch antenna was designed at a frequency between 1.8GHz and 3.0GHz. The design of the antenna was performed using the cavity model; this model was implemented using MATLAB script according to the antenna design specifications and interfaces to an electromagnetic machine, SonnetLite, for the analysis of the antenna. The simulated antenna produced from SonnetLite consisting of its physical dimensions is then transferred to the platform where fabrication is performed. The characteristic performance of the designed antenna were produced and analyzed using a spectrum analyzer. The obtained results shows that the designed antenna is suitable for use in the resonating frequency of 2.4GHz which is center frequency if the antenna.

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BW: Bandwidth

CAD: Computer Aided Design

GUI: Graphical User Interface

ICT: Information Communication Technology

PCB: Printed Circuit Board

VSWR: Voltage Standing Wave Ratio.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Communication system have been said to have a rapid growth and has been attracting interest for the last few years. Communication among humans occurred first by sound through voice. This process later led to the urge for new mediums for higher distance communication systems such as smoke and flag signals.

The electromagnetic spectrum is regarded as a reference tool for communication as it involves the use of the non-visible region of the electromagnetic spectrum used for communication through the use of radio (Radio waves). This leads to an increasing use of the capabilities of the Electromagnetic Spectrum leading to the advent of different avenues where it can be utilized in area's such as; automotive communications, smart antennas, indoor communications, sensors etc.

Antennas, traditionally the last part of a conventional front end and completely separated from the circuit part, have been transformed to a variety of low profile and low weight structures following developments in planar Microstrip antennas (James and Hall 1989). The demand of wireless technologies is increasing rapidly day by day, with time and requirements. These devices are increasingly getting smaller in size and hence the antennas required for transmit and receive signals also have to be smaller and lightweight. This leads to a process where small size, light weight, case of installation are regarded as advantages in relation to the construction of a low profile Microstrip antenna. This leads to an increasing demand for the compactness property of the Microstrip antenna leading to the initiation of the integration of circuits and antennas on the same substrate resulting in antenna-circuit modules, which can also be met under the term active integrated antennas (Lin and Itoh 1994).

Due to the lightweight, telecommunication systems can be structured to be mounted when required or necessary. Moreover, they are easily fabricated, due to low cost and are easy integrated into arrays or into microwave printed circuits.

1.2 Statement of the Problem

The increasing number of slow, large and heavy communication mechanism has posed a big problem in terms of communication between lecturers and staffs within and outside the offices.

There is need for improved communication equipment such as the Microstrip Antenna to help provide better communication between the lecturers, administrative staff and students.

1.3 Aim and Objectives

Microstrip patch antenna are used to send on-board parameters of article to the ground while under operating conditions. The aim and objective of the thesis is to design and fabricate a probe-fed Rectangular Microstrip Patch Antenna and study the effect of antenna dimensions Length (L), substrate parameters relative Dielectric constant (E_r), and substrate thickness (h) on the Radiation parameters, the Return loss and the Voltage standing wave ratio.

1.4 Significance of Study

This project is essential because it is needed by the Nigerian Communication Commission (NCC) whose task is to deploy and regularize telecommunication systems in Nigeria. Microstrip Antenna are part of the components required in the design of telecommunication systems. Thus, in order to promote partnership between the university system of Afe Babalola University (ABUAD) and Nigerian Communication Commission (NCC) in terms of research and infrastructure, this research consist of the design and construction of a patch antenna that meets the requirements of the Nigerian Telecommunication system.

1.5 Scope of Study

The scope of this work involves the design of Microstrip antenna using mathematical methods and the construction of the antenna in accordance to the requirements of the Nigerian Communication Commission (NCC).

This involves the use of the copper tape as both the ground plate and the radiating patch placed respectively in a dielectric (FR 4) substrate and also the use of the coaxial probe feed technique which consist of the use of a coaxial cable connector to a connector.

1.6 Overview of Microstrip Antenna

The Microstrip antenna is made up of a conducting patch on a ground plane separated by the dielectric substrate. This concept was undeveloped until the revolution in large-scale integration of electronic circuit in 1970.

This led to the early work by Munson on Microstrip antennas for use as a low profile flush mounted antennas on rockets and missiles showed that this was a practical concept for use to solve many antenna system problems. This provided a platform for various mathematical models to be developed for this antenna and its applications were also extended to many other fields. This is represented through the number of journals and articles over the last ten years. The Microstrip antennas are regarded as the present day antennas designers' choice; this is due to the fact that Low dielectric constant substrates are preferably used for maximum radiation, the conducting patch can take any shape but rectangular and circular configurations are the most are the most widely used configuration. A Microstrip antenna is characterized by its length, width, input impedance and gain and radiation patterns. These various parameters of the Microstrip antenna are discussed in subsequent chapters.

Note: The length of the antenna is nearly half wavelength in the dielectric (this governs the resonant frequency of the antenna).

1.7 Categories of Waves on Microstrip

The method involving the transmission and radiation in a Microstrip can be understood considering a point current source (Hertz dipole) located on top of the grounded dielectric substrate (fig 1.1).This source radiates electromagnetic waves depending on the direction where the waves are transmitted; they consist of two distinct categories with different behavior.

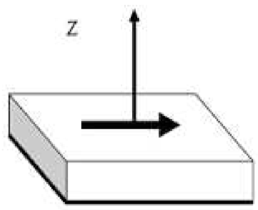

Figure 1.1: Hertz dipole on a substrate

1.7.1 Surface Waves:

This involves the waves are transmitted slightly downward, having elevation angle Ө between $\frac{\pi}{2}$ and π – arcsin ($1/\sqrt{E_r}$) meet the ground plate, which in turn reflects them, towards the dielectric-to-air boundary, which in turn reflects them (total reflection condition). The magnitude of the field amplitude increases for some particular incidence angles leading to an excitation of a discrete set of surface wave modes. This occurs to the rapid decay of the dielectric above the surface due to the field mostly trapped within it. The wave is a non-uniform plane wave.

The direction of largest attenuation (the vector α) pointing upwards; the wave propagates horizontally across β with little absorption in good dielectric. The surface waves take up some part of the signals energy, which does not reach the intended user. This leads to a reduction in the impedance, contributing to the decrease in the efficiency of the antenna.

Also, surface waves introduce spurious coupling between different circuit or antenna elements. This effect drastically reduces the performance of the Microstrip filters because the parasitic interaction reduces the isolation in the stop bands.

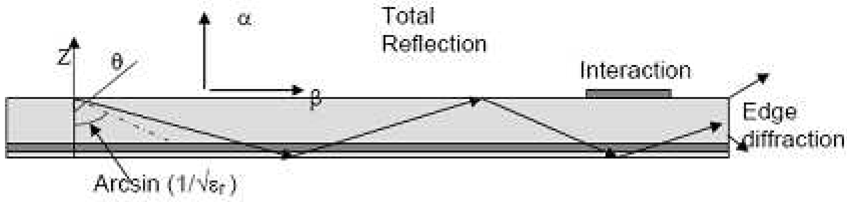

Fig 1.2 : Surface Wave

1.7.2 Leaky Waves:

The waves are directed sharply downwards, with angles Θ between π – arcsin (1/$\sqrt{E_r}$), which in turn is also reflected by a ground plane but only partially by the dielectric-to-air boundary. This leads to a leak from the substrate into the air, hence the name leaky waves.

The leaky wave are non-uniform plane where the attenuation direction α points downwards, leading to an increase in amplitude as the waves moves from the dielectric substrate because the wave radiates from a point where the amplitude of the signal is higher (fig 1.3). Leaky-wave antennas can be divided into two important categories, uniform and periodic, depending on the type of guiding structure.(Onofrio Losito and Vincenzo Dimiccoli, 1997) A uniform structure has a cross section that is uniform (constant) along the length of the structure, usually in the form of a waveguide that has been partially opened to allow radiation to occur.

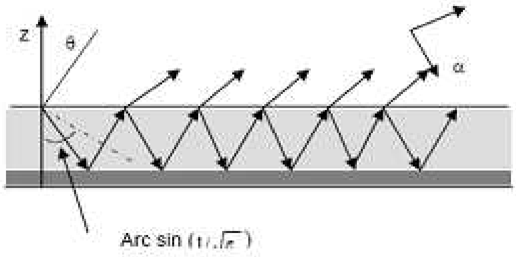

Fig 1.3 : Leaky Waves.

1.8 Directional Antenna:

Directional antennas are antennas used to radiate power in a focused and specific direction. These antennas are fixed in a specific location and directed towards the receiver (or transmitter).

The ability of an antenna of focus in one direction more than other directions is the measure of the quality of the antenna and is often expressed in terms of Power Gain, front to back ratio and other factors of the antenna.

1.9 Radiation Pattern:

Radiation pattern of an antenna is described as an electromagnetic wave, for the course of this research the concentration point is the measuring and calculating the strength of this electromagnetic wave at a point where the wave is in plane wave and normal to the direction of the antenna.

Radiation pattern is the difference of the electric field as a function of angle and has two field components namely the E and H field vectors.

The radiation pattern can be represented using the Cartesian or polar coordinates (fig1.4).

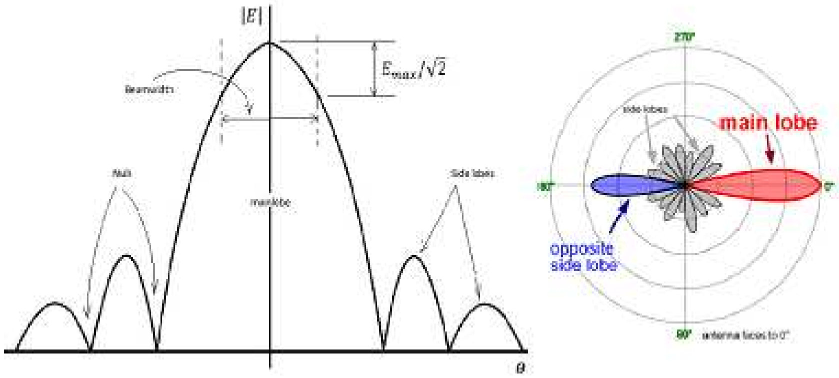

Fig 1.4 : Radiation Pattern consisting of the Cartesian and Polar diagram.

1.10 Organization of this Thesis

Chapter 2 includes the introduction to Microstrip antenna consisting of the advantages and disadvantages, feeding methods, method of analysis been researched.

Chapter 3 involves the design of the antenna; including the use of specialised software and the construction of the antenna.

Chapter 4 consist of the antenna parameters and the analysis of the Antenna in terms of Radiation Pattern.

Chapter 5 includes conclusions and future scope of this project work

CHAPTER 2

LITERATURE REVIEW

MICROSTRIP ANTENNA

2.1 Introduction

The Microstrip Patch Antenna consist of a single-layer design which includes four parts (Patch, ground plane, substrate, and the feeding part). These antennas are integrated with printed strip-line feed networks and active devices. This is a relatively new area of antenna engineering. Patch antennas are classified as single – element resonant antennas. Once the frequency is obtained, everything (such as radiation pattern input impedance, etc.) remains constant. The patch is a very slim ($t \ll \lambda_0$, where λ_0 = the wavelength of free space), radiating metal strip (or array of strips) located on one side of a thin no conducting substrate, the ground plane is the same metal located on the other side of the substrate.

The patch is usually 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.

The substrate layer thickness is 0.01–0.05 of free-space wavelength (λ_0). This is used primarily to provide proper spacing and mechanical support between the patch and its ground plane. It is also often used with high dielectric-constant material to load the patch and reduce its size.

The advantages of the Microstrip antennas includes:

i. They are compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc.
ii. Low profile planar configuration which can be easily made conformal to host surface.
iii. Can be easily integrated with microwave integrated circuits (MICs).
iv. Capable of dual and triple frequency operations.

v. Low fabrication cost, hence can be manufactured in large quantities.
vi. Mechanically robust when mounted on rigid surfaces.

However, Microstrip antenna also consist of some disadvantages, namely:

i. Low efficiency.
ii. Narrow bandwidth of less than 5%
iii. Low RF power due to the small separation between the radiation patch and the ground plane (not suitable for high-power applications)

Microstrip patch antennas consist of a very high antenna quality factor (Q). It shows the losses associated with the antenna where 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.

2.2 Types of Patch Antenna

There are numerous shapes of Microstrip patch antennas; they have been designed to match specific characteristics.

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 2.2. For a rectangular patch, the length L of the patch is usually 0.3333λo< L < $0.5\lambda_0$, where λo is the free-space wavelength. The patch is selected to be very thin such that t << λ_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 $2.2 \leq \varepsilon_r \leq 12$.

The most common types of patches are shown below:

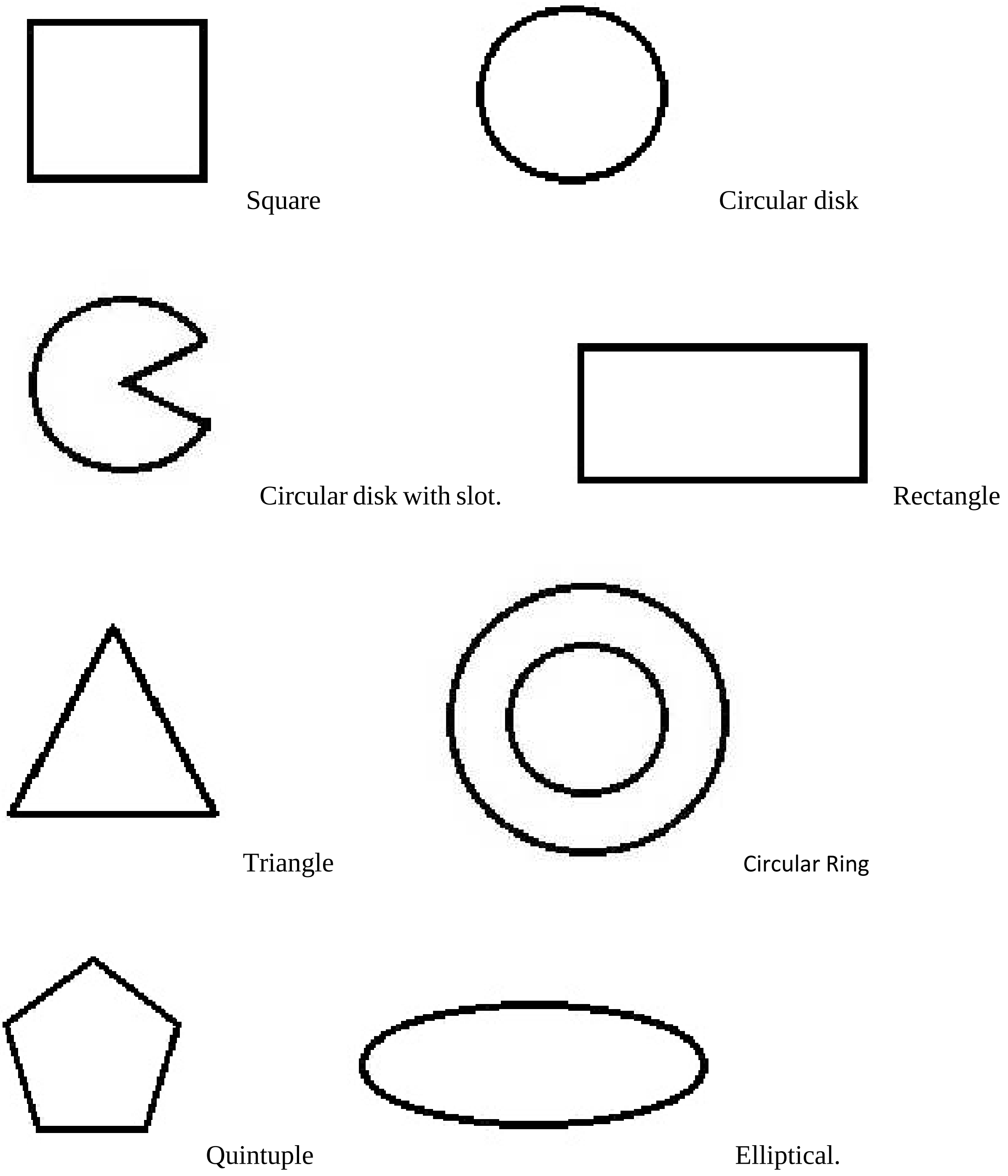

Fig 2.1: The Common Shapes of Patch Antennas.

Microstrip patch antennas radiate mainly due to the fringing fields between the patch edge and the ground plane. The selecting of a substrate is very important, considerations are made depending on the temperature, humanity, and other environmental ranges of operating. The Thickness of the substrate h has a big effect on the resonant frequency f_r and bandwidth $B_W$of the antenna. The bandwidth of the Microstrip antenna will increase with an increase in substrate thickness h but with limits, otherwise the antenna will stop resonating.

2.3 Related Works

The recent developments in the area of the design of rectangular patch antenna includes the paper and work of Li et al (2008). This paper involves a Microstrip patch antenna designed using planar metamaterial patterned substrate. It was developed using an ordinary patch antenna, and isolated triangle gaps and crossed strip-line gaps were etched on the metal patch and ground plane.

This patterned substrate is demonstrated in literature to consist of left-handed characteristics. This involves the wave propagating along the patch strongly enhanced, and the working band is also broadened significantly form Megahertz to Gigahertz. Simulations performed based on full wave FEM simulator was employed and results shows that the patch possess necessary and desirable characteristics (high efficiency , low loss, low VSWR).

Microstrip patch antenna with fractal boundary defined by Koch curve was introduced by Hazdra and Maz'anek (2004). The properties of the koch3 (third iteration) fractal-boundary microstrip patch antenna was studied. The aim was to find and identify the localized modes which increase the antenna directivity (antenna's behavior can be understood as array). They successfully employed the cavity model based on FEM to solve the antenna as planar resonator (Hazdra, 2003) and (Garg and Bharita, 2000).

These results in the set of Eigen modes and Eigen numbers. This was the first and fast approximation approach of the fields inside the resonator which also helped to find appropriate feeding point because it must be located in the maximum of the electric field.

According to Kumar and Srivastava (2010), millimeter wave technology is and emerging aera that is still much undeveloped and therefore, requires substantial research efforts since its applications are numerous. In their work, a rectangular patch was designed on thick substrate and simulated using SONNET software; they also reported the development of a novel analysis technique for circular patch antenna for millimeter wave frequency.

The antenna was designed at 39GHz on thick substrate and was analyzed and simulated. The results of the theoretical analysis obtained were in good relationship with the simulated results derived.

2.4 Feeding Techniques

Microstrip patch antennas can be fed using different methods. These methods are classified into two categories;

- Contacting and
- Non-contacting.

The contacting method involves the process where the RF power is fed directly to the radiating patch using a connecting element such as a MicroStrip line. In the non-contacting method, this consist of an electromagnetic field coupling done to transfer power between the Microstrip line and the radiating patch.

There are many methods of feeding a Microstrip antenna. Although, the popular four method includes:

a. Microstrip Line
b. Coaxial Probe (Coplanar feed)
c. Proximity Coupling
d. Aperture Coupling

The architecture of the antenna is radiating from one side of the substrate, so it is easy to feed it from the other side (the ground plane), or from the side of the element.

2.4.1 Microstrip Line:

This is the widely used method of feeding because it is very simple to design and analyse, and very easy to manufacture. This involves a conducting strip connected directly to the edge of the Microstrip patch.

The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage where the feed is etched on the same substrate to provide a planar structure.

However, an increase in the thickness of the dielectric substrate used leads to an increase in the surface waves and spurious feed radiation, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

The impedance of the patch is given by:

$$Z_{\propto} = 90 \ \frac{\varepsilon_r^2}{\varepsilon_r - 1}\left(\frac{L}{W}\right)^2 \qquad 2.1$$

The characteristic impedance of the transition section should be:

$$Z_T = \sqrt{50 + Z_{\propto}} \qquad 2.2$$

The width of the transition element is derived from:

$$Z_T = \frac{60}{\sqrt{\varepsilon_r}} ln\left(\frac{8d}{W_T} + \frac{W_T}{4d}\right) \qquad 2.3$$

The impedance of the Microstrip feed is determined using the equation below:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}\left(1.393 + \frac{W}{h} + \frac{2}{3} ln\left(\frac{W}{h} + 1.444\right)\right)}} \qquad 2.4$$

The length of the strip can be found using:

$$R_{ln(x=0)} = cos^2\left(\frac{\pi}{L} x_0\right) \qquad 2.5$$

The length of the transition line is quarter the wavelength.

Therefore:

$$l = \frac{\lambda}{4} = \frac{\lambda_0}{4\sqrt{\varepsilon_{reff}}} \qquad 2.6$$

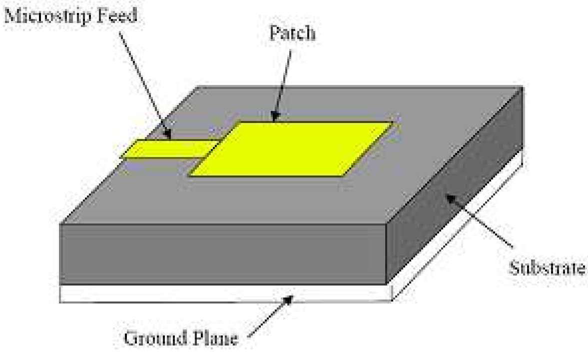

Fig 2.2a: Microstrip line feed Technique

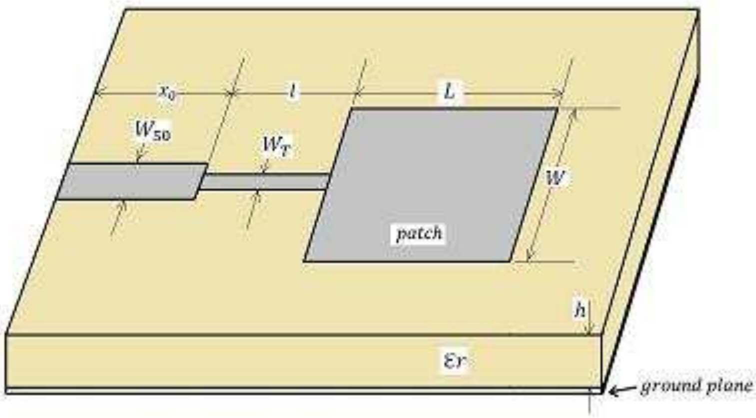

Fig 2.2b: Rectangular patch Microstrip Antenna with the line feed

2.4.2 Coaxial Probe (Coplanar Feed):

The Coaxial probe or feed is a very common technique used for feeding Microstrip patch antennas. The coupling of power to the patch antenna through a probe is very simple, cheap, and effective way. If the feed point is adjusted to 50Ω, the use a 50Ω coaxial cable with N-type coaxial connector.

The N-coaxial connector is coupled to the ground plane of the Microstrip antenna and the center connector of the coaxial will be passed through the substrate and soldered to the patch.

The advantage of this feeding scheme is 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, the main disadvantage is that it provides narrow bandwidth and the modelling is difficult, since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, making it not completely planar for thick substrates ($h > 0.02\lambda_0$).

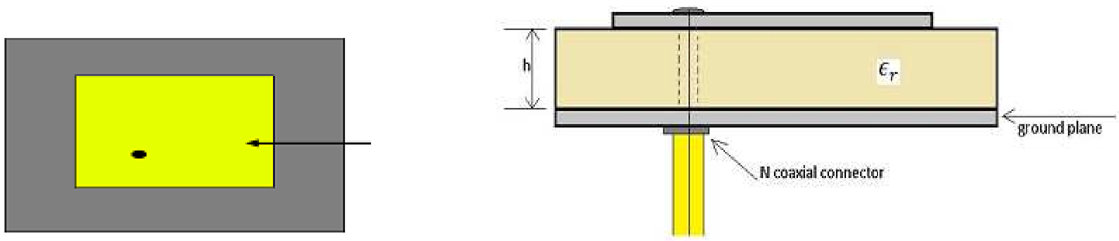

Fig 2.3: Coaxial Probe feed Technique

2.4.3 Proximity Coupling:

This type of feed technique is known as the electromagnetic coupling scheme. This involves the use of two substrate ε_{r_1} and ε_{r_2} consisting of the patch at the top, and the ground plane in the bottom. A Microstrip line is connected to the power source and lying between the two substrates.

The principle involves the capacitive behavior between the patch and the feed strip line. Analysis and design of such an antenna is complicated than the other ones discussed in the previous sections because it takes into account the effect of the coupling capacitor between the strip feed line and the patch as well as the equivalent R-L-C resonant circuit representing the patch and the calculating of two substrates (ε_{r_1} and ε_{r_2})

The advantage of this feed technique is the elimination of spurious feed radiation and provision of very high bandwidth (as high as 13%), due to overall increase in the thickness of the Microstrip patch antenna.

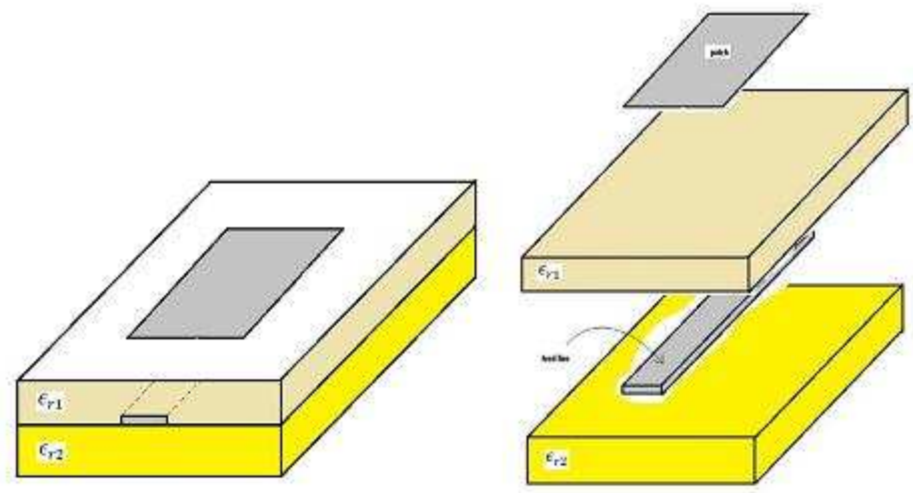

Fig 2.4: Proximity Coupling feed Technique

2.4.4 Aperture Coupling:

This technique involves the use of the aperture mechanism, where the radiating patch and the Microstrip feed line are separated by the ground plane.

The ground plane consist of an aperture usually centered under the patch, in the shape of a circle or rectangular, and separates two substrates: the upper substrate ε_{r_1} with the patch on it, and the lower substrate ε_{r_2} with the Microstrip feed line under it, spurious radiation is minimized.

This involves the use of a high dielectric material as the bottom substrate and a thick, low dielectric constant material is used as the top substrate to optimize radiation from the patch. This type of coupling gives wider bandwidth.

The disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which leads to an increase in the antenna thickness.

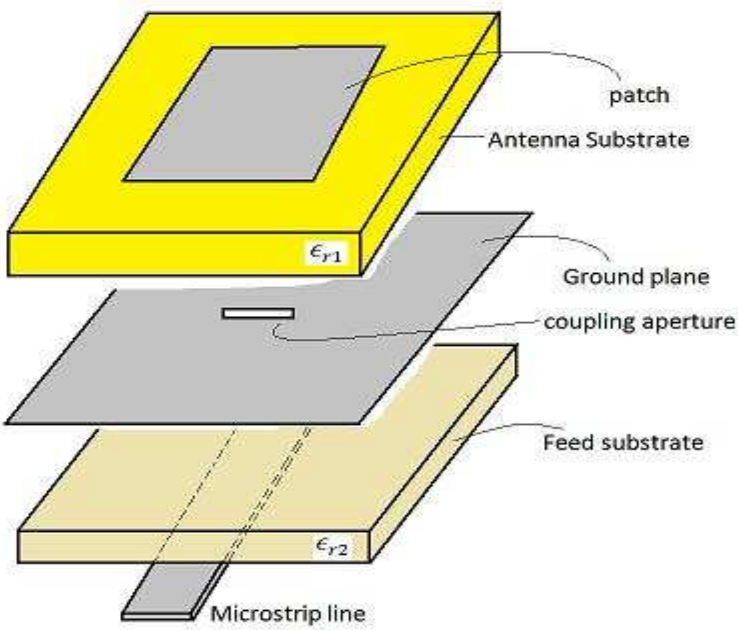

Fig 2.5: Aperture coupling feed Technique

2.5 Method of Analysis:

There are many methods of Microstrip antenna analysis; the preferred models for the analysis of Microstrip patch antennas are the transmission line model and the cavity model.

The transmission line model involves where we assume that the patch is a transmission line or part of a transmission line. The transmission line model is very simple to study but it is less accurate.

The cavity model is accurate and provides good physical insight but is complex in nature, it involves the assumption that the patch is a dielectric-loaded cavity.

2.5.1 Transmission Line Model:

The transmission line method is an easy way of studying the Microstrip antenna. This involves the representation of the Microstrip antenna using two slots of width W and height h, separated by a low-impedance transmission line of length L. The Microstrip is a non-homogeneous line of two dielectrics, typically the substrate and air.

The study of the Microstrip line involves a wider transmission line (w/h >>1 and $\varepsilon_r > 1$) using the figure (2.6) below to build a good picture of the study of the antenna.

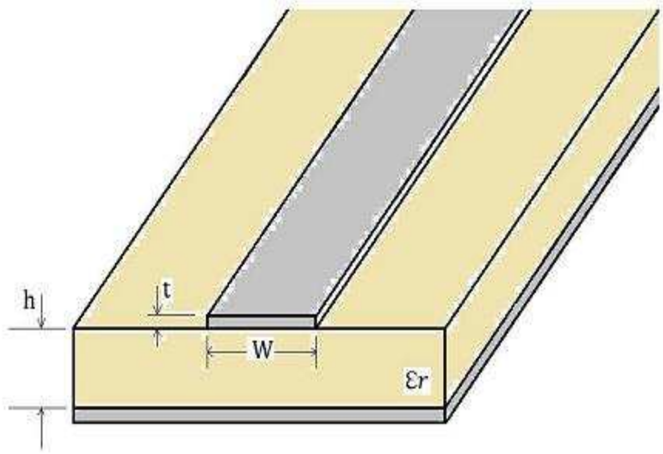

Fig 2.6: Microstrip Line

The approximation occurs initially to assume the thickness of the conductor t that forms the line has no effect on our calculations, because it is very thin comparing with the substrate h, (h >> t); therefore empirical formulas are used depending only on the line dimensions: The width W, the length L, the height h, and the dielectric constant ε_r of the substrate.

The impedance of the Microstrip is determined using:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{reff}\left(1.393+\frac{W}{h}+\frac{2}{3}ln\left(\frac{W}{h}+1.444\right)\right)}} \qquad 2.7$$

The width of the Microstrip line is derived using the equation below:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \qquad 2.8$$

Fig 2.7: Electric field lines.

From Figure 2.7, it is seen that 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 there is different phase velocities in air and the substrate. Therefore, the dominant mode of propagation would be the quasi-TEM mode. Hence, an effective dielectric constant (ε_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line, leading to the value of ε_{reff} slightly less than ε_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.

The Effective dielectric constant(ε_{reff}) is given by Balanis as:

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\ \frac{h}{W}\right]^{\frac{1}{2}} \qquad 2.9$$

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of the dielectric substrate.

W = Width of the patch

The Microstrip patch antenna in figure (2.6 and 2.7) is longer than its physical dimensions because of the effect of fringing. The effective length is therefore different from the physical length by ΔL. The fringing fields along the width is modelled as the radiating slots.

The extension of the length of patch is determined using the equation by Hammerstad as:

$$\Delta L = 0.412h\ \frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad 2.10$$

This extension of length ΔL expresses it as a function of the ratio $\frac{W}{h}$ and ε_{reff} .

To calculate the effective length of the patch L_{eff}:

$$L_{eff} = L + 2\Delta L \qquad 2.11$$

Therefore the Actual length of the patch L is:

$$L = L_{eff} - 2\Delta L \qquad 2.12$$

For a given resonance frequency f_0 , the effective length given as:

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \qquad 2.13$$

For a rectangular Microstrip patch antenna, the resonance frequency of TM_{010} is determined by James and Hall as:

$$(f_r)_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_0\varepsilon_0}} = \frac{C}{2L\sqrt{\varepsilon_r}} \qquad 2.14$$

For effective radiation, the width W is given by Bahl and Bhartia as:

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad 2.15$$

2.5.2 Cavity method:

The cavity model used in analyzing the Microstrip antennas is based on the assumption that the region between the Microstrip patch and ground plane has a resonance cavity bounded by ceiling and floor of electric conductors and magnetic walls along the edge of the conductor.

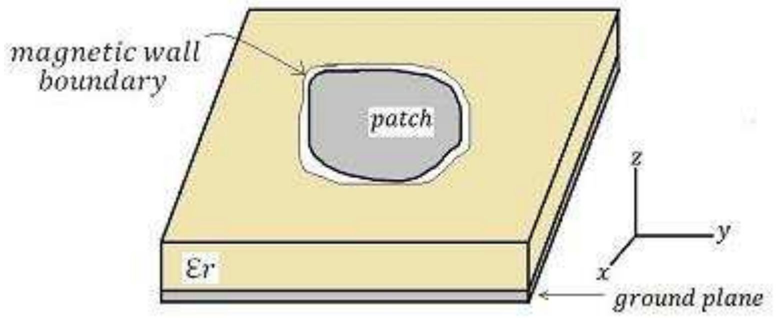

Fig 2.8: Magnetic wall model of a Microstrip antenna.

Although the transmission line model discussed in the previous section is easier to use, it consist of some inherent disadvantages especially when used in rectangular patches, it ignores field variations along the radiating edges. These disadvantages can be overcome by using the cavity model.

The assumption of the cavity method is based on the following observations for thin substrates ($h << \lambda$):

- The region enclosed by the cavity consist of only three field components: E component in the z axis (E_z) and two components of ؛ along the x and y axis (H_x , H_y).
- Since the h (height of the substrate) is very thin (h << λ), the fields in the interior region do not vary much with z-coordinates for all frequencies i.e. normal to patch.
- The electric current in the Microstrip patch has no component normal to the edge of the patch at any point.

This model is good for the study of Microstrip resonators with the edge extending slightly to account for the fringing field.

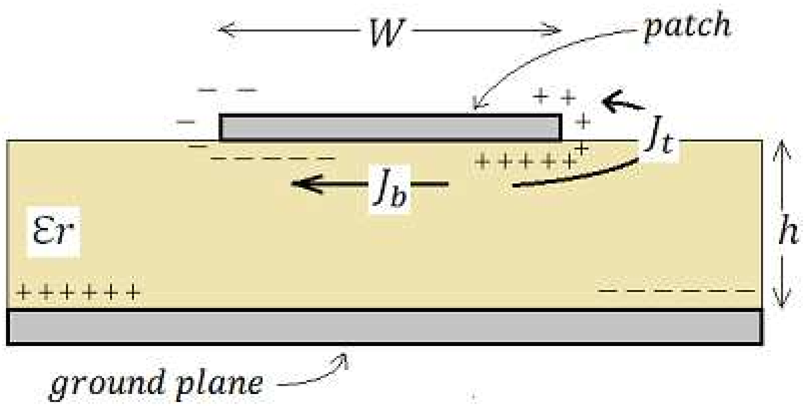

Fig 2.9: Charge distribution and current density creation on the Microstrip patch.

This is used to study the mechanism of the cavity. This involves the process where the Microstrip patch is provided power when connected to a microwave source, charge distribution is created and seen on the upper and lower planes (surface of the patch and the bottom of the ground plane) of the antenna. The charge distribution is controlled by two mechanism; an attractive and repulsive mechanism.

The attractive mechanism consist of a force between the opposite charges on the patch and on the ground plane, it creates a current density inside the dielectric J_b at the bottom of the patch, which helps in keeping the charge concentration intact at the bottom of the patch.

The repulsive mechanism is between the like charges on the bottom surface of the patch, which tend to push the charges from the bottom of the patch around the edge of the patch to the top of the patch, this will create the current density J_T. As a result of this charge movement, currents flow at the top and bottom surface of the patch.

In the case of Microstrip antennas W >> h the attractive mechanism dominates and at charges concentration will within the dielectric under the patch, and the current flow around the edge can be neglected, because it decreases with corresponding decrease in the ratio of the height to width. “This would allow the walls to be modelled as a perfect magnetic conducting surfaces which would not disturb the magnetic field and in turns the electric field distribution beneath the patch in an ideal environment”. This good approximation to the cavity model leads us to deal with the side walls as perfect magnetic conducting walls.

The field inside the cavity consist of three components E_z , H_x , H_y ; this leads to the wave equation written as:

$$\nabla \times \nabla \times \vec{E} - k^2\vec{E} = -j\omega\mu_0\vec{J} \qquad 2.16$$

$$\nabla^2 E_z + k^2 E_z = j\omega\mu_0\hat{z} \cdot \vec{J} \qquad 2.17$$

In addition, we have on the top and the bottom conductors:

$$\hat{n} \times \vec{E} = 0 \qquad 2.18$$

Add on the walls:

$$\hat{n} \times \vec{H} = 0 \qquad 2.19$$

Where $k^2 = \omega^2\mu_0\varepsilon_0\varepsilon_r$ is also known as the wave number.

$\vec{J} =$ Electric current density fed by the feed line to the patch.

$\hat{z} =$ The unit vector normal to the plane of the patch

Since the walls of the cavity, as well as the material within it are lossless, the cavity would not radiate and its input impedance would be purely reactive. Hence, in order to account for radiation and a loss mechanism, one must introduce a radiation resistance RR and a loss resistance RL.

A loss cavity would now represent an antenna and the loss is taken into account by the effective loss tangent δ_{eff} which is given as:

$$\delta_{eff} = \frac{1}{Q_T} \qquad 2.20$$

Q_T is the total antenna quality factor and is expressed by:

$$\frac{1}{Q_T} = \frac{1}{Q_d} + \frac{1}{Q_c} + \frac{1}{Q_r} \qquad 2.21$$

Q_d Represents the quality factor of the dielectric and is given as:

$$Q_d = \frac{\omega_r W_T}{P_d} = \frac{1}{\tan\delta} \qquad 2.22$$

Where ω_r is the angular resonant frequency.

W_T is the total energy stored in the patch at resonance.

P_d is the dielectric loss.

$\tan\delta$ is the loss tangent of the dielectric.

Q_c Represents the quality factor of the conductor and is given as:

$$Q_c = \frac{\omega_r W_T}{P_c} = \frac{h}{\Delta} \qquad 2.23$$

Where ω_r is the angular resonant frequency.

W_T is the total energy stored in the patch at resonance.

P_c is the conductor loss.

Δ is the skin depth of the conductor.

h is height of the substrate

Q_r Represents the quality factor for the radiation and is given as:

$$Q_r = \frac{\omega_r W_T}{P_r} \qquad 2.24$$

Where ω_r is the angular resonant frequency.

W_T is the total energy stored in the patch at resonance.

P_r is the power radiated from the patch

Substituting the equations above into δ_{eff}

$$\delta_{eff} = \tan\delta + \frac{\Delta}{h} + \frac{P_r}{\omega_r W_T} \qquad 2.25$$

The above equation describes the total effective loss tangent for the Microstrip patch antenna.

2.5.3 The Ground Plane:

The ground plane is infinite in size as for a monopole antenna, but in reality this is not applied easily, besides a small size of ground plane is required. The length of the ground plane should be at least one wavelength (i.e. the length of the patch is equal or less than half wavelength $\left(L \leq \frac{\lambda_0}{2}\right)$). Therefore the ground plane will extend $\frac{\lambda}{4}$ from edge of the patch.

$$\lambda_0 = \frac{C}{f_r} \qquad 2.26$$

Where λ_0 is the wavelength in free space.

C is the speed of light in free space (29979248 m/s)

f_r is resonance frequency.

The effective wavelength of a substrate λ_{eff} is determined using the equation below:

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

Where ε_{reff} is the dielectric constant in the substrate.

The width if the patch W must be less than the wavelength in the dielectric substrate in order for the higher-order modes not to be excited.

CHAPTER THREE:

METHODOLOGY

3.1 Introduction

For the design of Microstrip patch antenna, several software's are employed which include; COSMOL, IE3D, CST Microwave studio etc.

The design of a square Microstrip antenna using appropriate equations and simulation using written Matlab codes according to the design procedure. This is achieved via a graphical user interface (GUI) generated by the MATLAB that allows users to modify, visualize and compare the whole process of the design whenever there is a need to fabricate the antenna (odeyemi et al 2011).

3.2 Design Method

The simplified formulation discussed in the previous sections above involves the procedure for designing a rectangular Microstrip antenna.

This procedure involves the specification of the substrate that will be used, the resonant frequency and the thickness of the substrate. Once these parameters are derived the width and the length of the patch is determined using the relationship.

The design of the rectangular patch antenna, these essential are required:

i. Frequency of operation (f_o) : This is also known as the Resonant Frequency; it is essential to select an appropriate resonant frequency of the antenna. Communication systems make use of frequency ranging from 1800 – 5600 MHz, therefore the antenna must be designed to operate in this frequency range. The frequency selected for my design is between 1.8GHz – 3.0GHz. Therefore, the resonant frequency employed for this work is 2.4 GHz.

ii. Dielectric constant of the substrate (ε_r) : This is referred to as the Effective Permittivity of the substrate. The dielectric material used for my design is FR4 epoxy Polycarbonate consisting of a dielectric constant of 4.4.

iii. Height of the Dielectric Substrate (h) : The height of the dielectric substrate for this design is selected as 1.5mm as it is the standard height of the FR4 epoxy substrate.

3.3 Antenna Design Template

The design of a rectangular patch antenna was developed using essential equations required to perform this process. The rectangular patch design parameters were obtained using equations (3.1), (3.2), (3.3), (3.4) and (3.5).

The width of the patch is obtained by:

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \tag{3.1}$$

Where c = Speed of light

f_0 = Resonant frequency

ε_r = Effective permittivity

Also the length of the patch were determined using:

The effective constant of the Microstrip antenna is derived using;

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\,\frac{h}{W}\right]^{\frac{1}{2}} \qquad (3.2)$$

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of the dielectric substrate.

W = Width of the patch

The extension length is also achieved using the equation below;

$$\Delta L = 0.412h\,\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (3.3)$$

Where ε_{reff} = Effective dielectric constant

ε_r = Dielectric constant of substrate

h = Height of the dielectric substrate.

W = Width of the patch

While the actual length of the patch is determined by:

$$L = L_{eff} - 2\Delta L \qquad (3.4)$$

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

The ground dimensions of the antenna is essential to have a finite ground plane. The size of the ground plane is greater than the patch dimensions by approximately six times the height of the substrate. This is given as:

$$L_g = 6h + L \quad (3.5)$$

$$W_g = 6h + W$$

3.4 Simulation

The specifications stated above are written in MATLAB script using appropriate equations to derive the parameters of the patch and the Ground Dimensions. This is shown on the Graphical User Interface (GUI) on MATLAB as shown in figure 3.1, which fits the given specifications and interfaced with SonnetLite EM software to perform the electromagnetic simulation. The flowchart describing the simulation process is shown in figure

3.4.1 Use of MATLAB

The MATLAB software was used to code the specification for designing the antenna generating the width and the length of the rectangular patch antenna, the probe feed point and other parameter values.

The algorithm of the rectangular patch length and width is given in equation (2.12) and (2.15).

Table 3.1: Algorithm for the MATLAB Simulation

Algorithm for the MATLAB Simulation
Begin Initialize rectangular patch antenna GUI Input f_o,ε_r,h. Compute the L, W, E- and H- plane HPBW, gain and efficiency. Output the radiation pattern (in polar and rectangular form) of the designed antenna. End

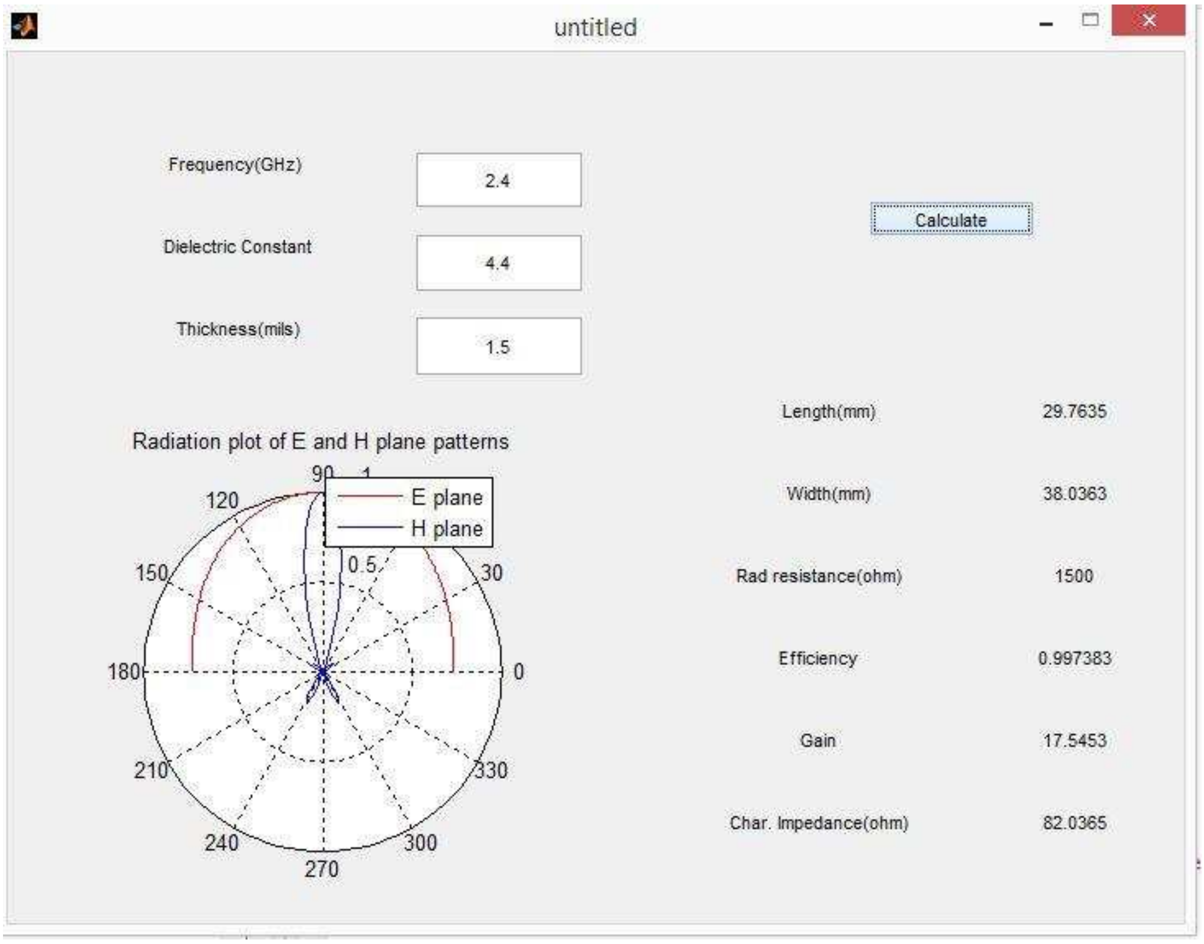

Fig 3.1: Graphical User Interface for the Rectangular Patch Antenna.

3.4.2 Use of Sonnet:

The sonnet software is an electromagnetic analysis engines that provides solutions for high-frequency electromagnetic (EM) analysis, using a modified method of moments analysis based on Maxwell's equation. The SonnetLite software is used to provide solutions to design challenges involving predominantly planar (3D planar) circuit and antennas. Predominantly planar circuits include Microstrip, Stripline, MMIC and PCB. SonnetLite 15.53 is an evaluation version of the Sonnet software, limited to certain processes as it uses a memory of 32MB. The parameters passed to the SonnetLite from MATLAB using SonnetLab toolbox for MATLAB are used as the initial parameters. Then the initial parameters in turn go through an iteration process where the patch parameters and the best position of the probe feed is determined.

Also, the projected bandwidth of the antenna will be obtained by the EM machine and will be used for plots of radiation pattern using an estimated frequency error of 0.001.

Table 3.2: Algorithm for the EM Simulation

Algorithm for the EM simulation
Begin Pass the L, W and Z_{in} to SonnetLite Optimize the L, W and ρ using antenna bandwidth sweep (ABS) If frequency error > 0.01 for L, W , Return to optimize L, W else pass to optimize probe offset end If frequency error > 0.01 for ρ, Return to optimize ρ end output the antenna characteristics (Radiation Pattern) end End

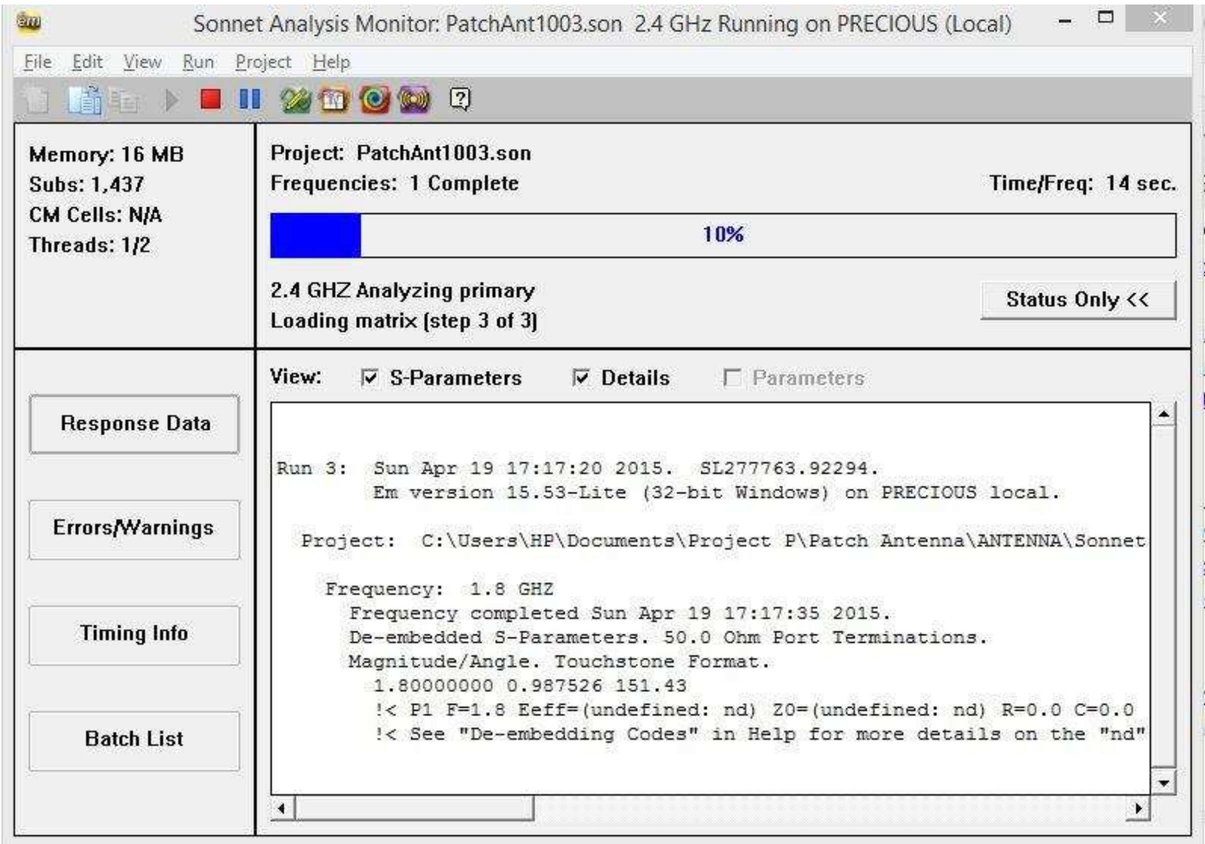

Fig 3.2: SonnetLite EM Simulation Interface

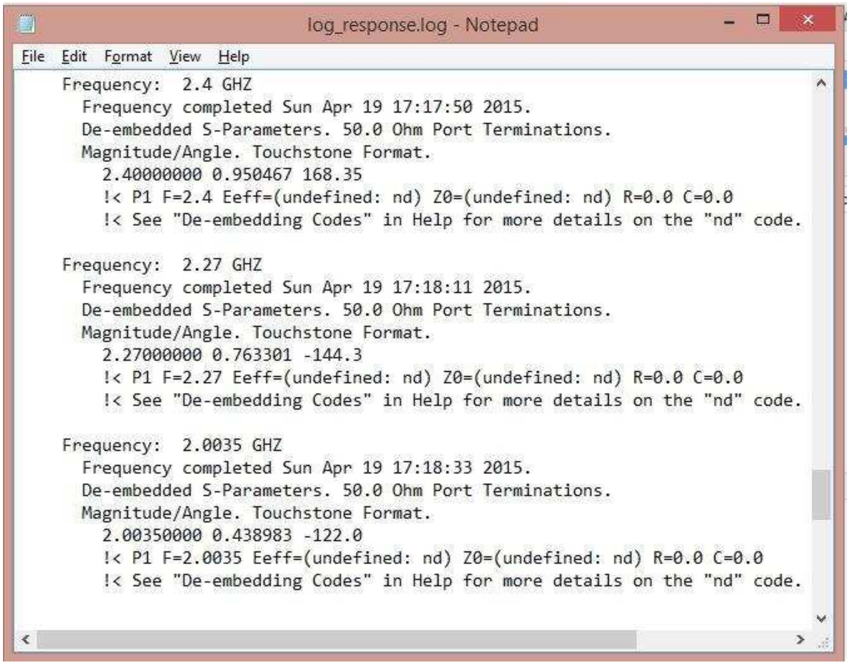

Fig 3.3: Antenna Response Log using SonnetLite

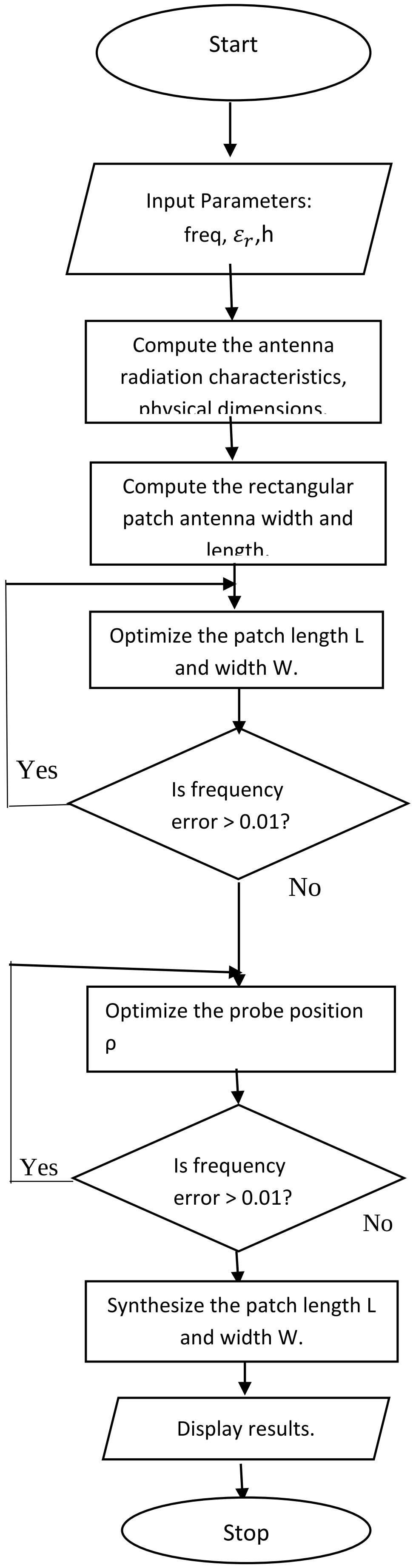

Fig 3.4: Flowchart of the Simulation process.

3.5 Printed Circuit Board Design:

The designed antenna consisting of output parameter value which were used to produce a printed circuit board. The printed circuit board consist of a ground which is copper metal, an FR4 epoxy dielectric substrate and a copper patch. The output parameter values obtained based on the simulation were:

Length of the Patch = 29.3778 mm

Width of the Patch = 37.9095 mm

Substrate thickness = 1.6mm

Probe feed position = 10.4255 mm

Length of the ground substrate = 38.3778mm

Width of the ground substrate = 46.9095 mm

3.6 Antenna Fabrication:

The following steps were taken in the fabrication of the designed antenna:

i. The simulation provided the output parameter value used in cutting the single sided copper-clad FR4 epoxy dielectric substrate to the ground dimension provided by the design.
ii. The rectangular patch and ground template were placed on the single sided copper-clad FR4 epoxy dielectric substrate.
iii. Drill the probe feed point on the patch through to the ground template.
iv. Perform the construction of a 50 ohms coaxial cable consisting of a SMA connector
v. Terminate the coaxial cable to the patch through the probe feed soldering the cable on the patch.

CHAPTER FOUR

RESULTS AND DISCUSSION.

4.1 Radiation Pattern of the Antenna

The result shown in figure 4.1 denotes the polar plot, radiation pattern of the designed antenna at the resonant frequency of $2.4GHz$. The E-plane of the radiation pattern is the plane containing the electric field vector (E_θ) and the direction maximum radiation while the H-plane pattern consist of the magnetic field vector $(E_\emptyset)$ with the direction of maximum radiation and the cross polarization component. The efficiency of 99.7% was obtained for the antenna with a gain of 17.5453dB.

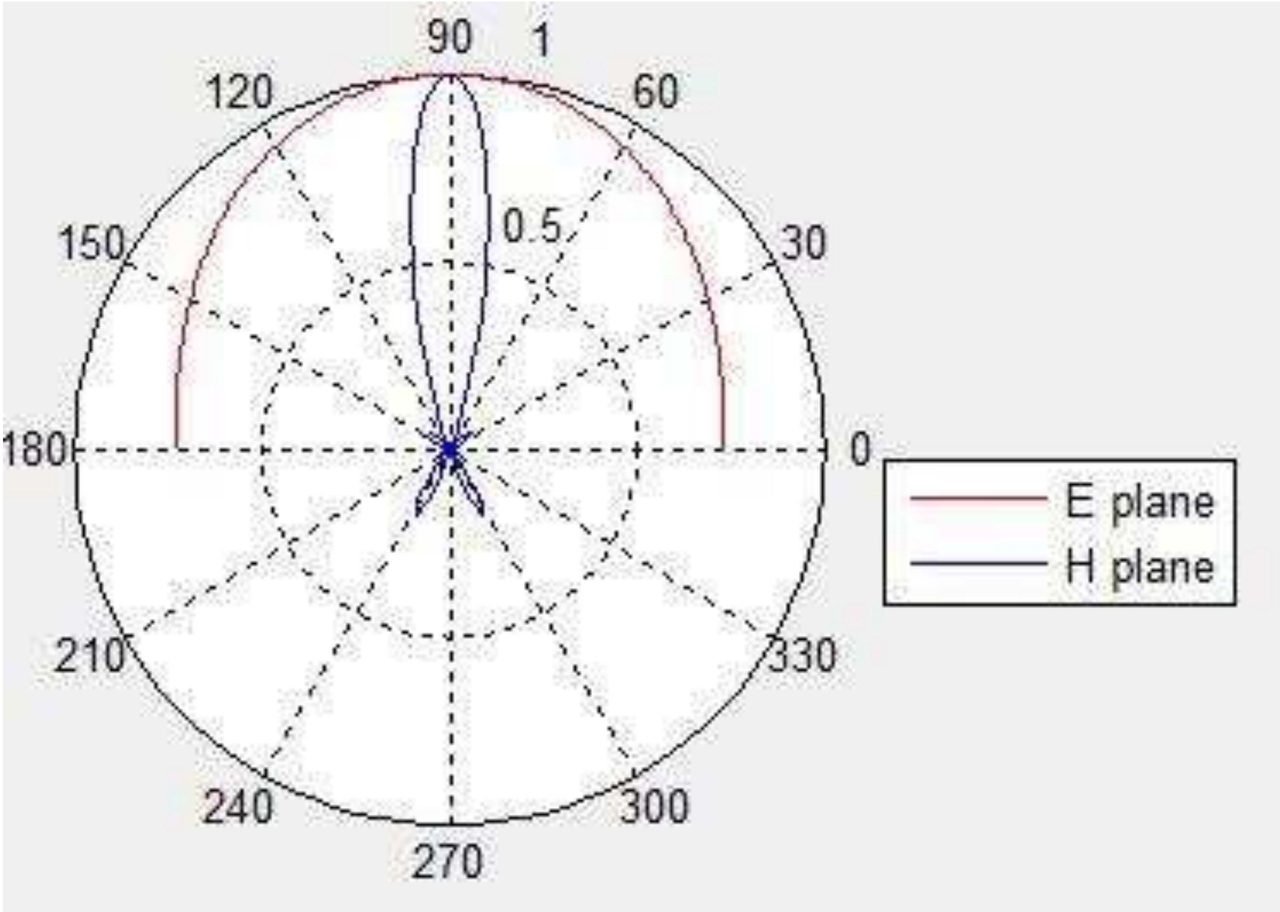

Figure 4.1: The E-plane and H-plane Radiation pattern of the designed antenna.

4.2 Return Loss

The figure 4.2 below shows that the return loss of -22dB was obtained at the resonant frequency of the designed antenna. The higher the return loss, the lower the reflection coefficient to zero, the better the power handling capacity of the antenna with less energy loss.

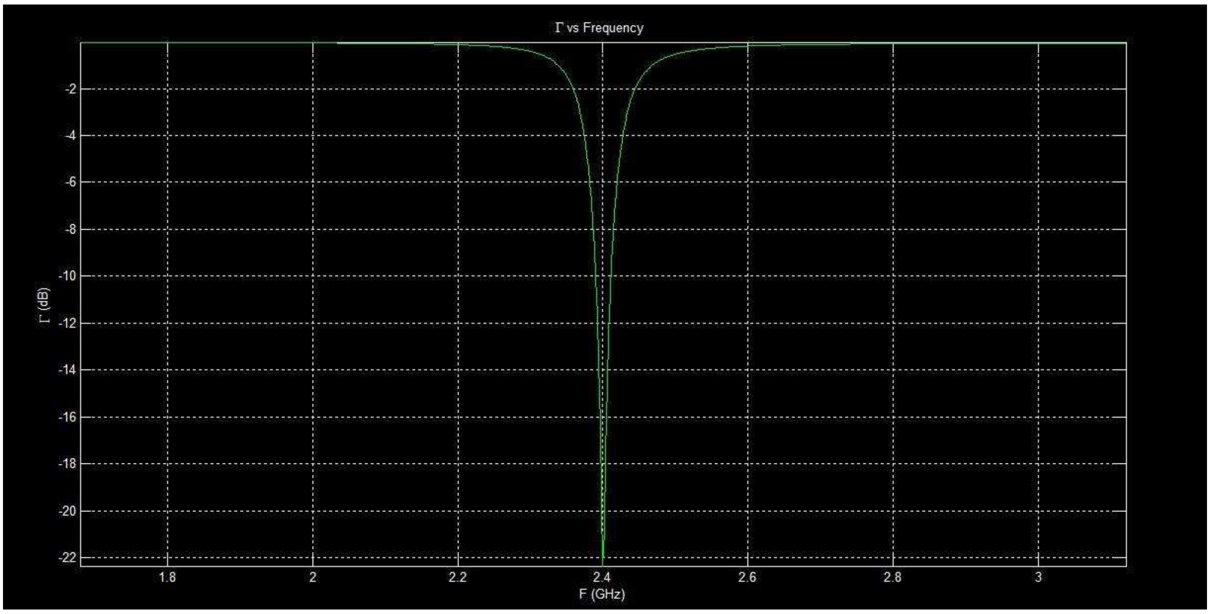

Fig 4.2: Return Loss against Frequency.

4.3 Voltage Standing Wave Ratio

The figure 4.3a shows VSWR against the frequency. For perfect matching of a coaxial probe to the designed antenna the VSWR ≤ 1. For this design, the desired VSWR = 1.15 indicating that the antenna is well matched over the resonant frequency. This also shows that it consist of its lowest at $2.4GHz$ in accordance to the resonant frequency of the antenna. The closer the VSWR to 1, the better the matching of the antenna to the coaxial probe and figure 4.3b with the thick line indicates that the VSWR in band is 2.

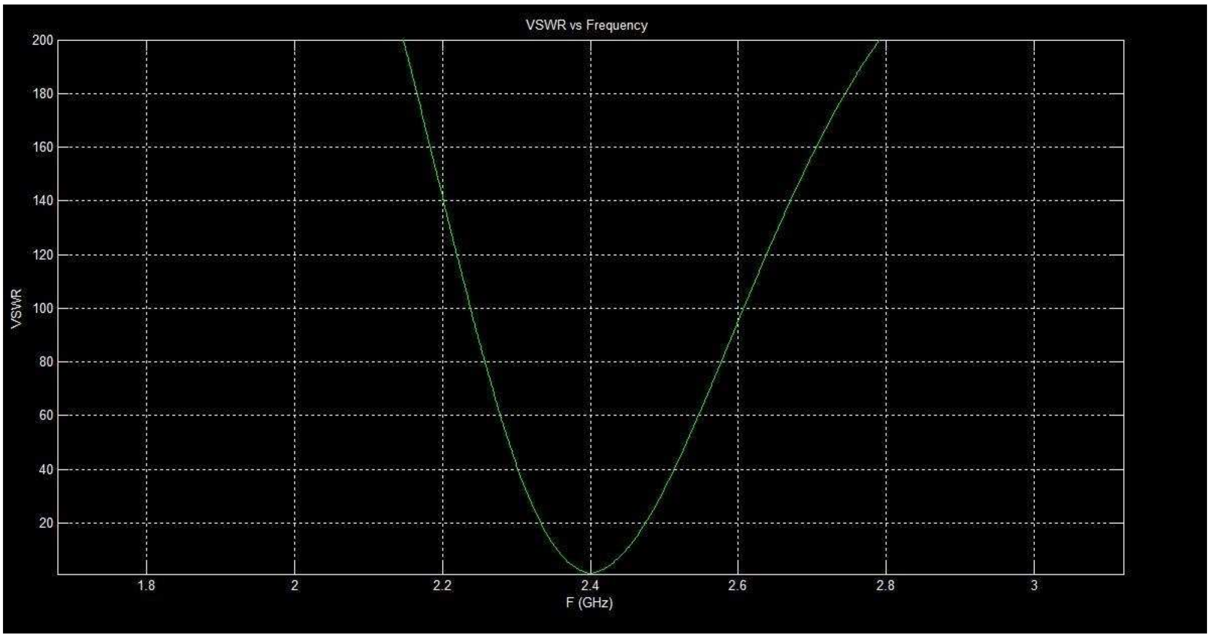

Fig 4.3a: VSWR against Frequency at resonant frequency of $2.4GHz$.

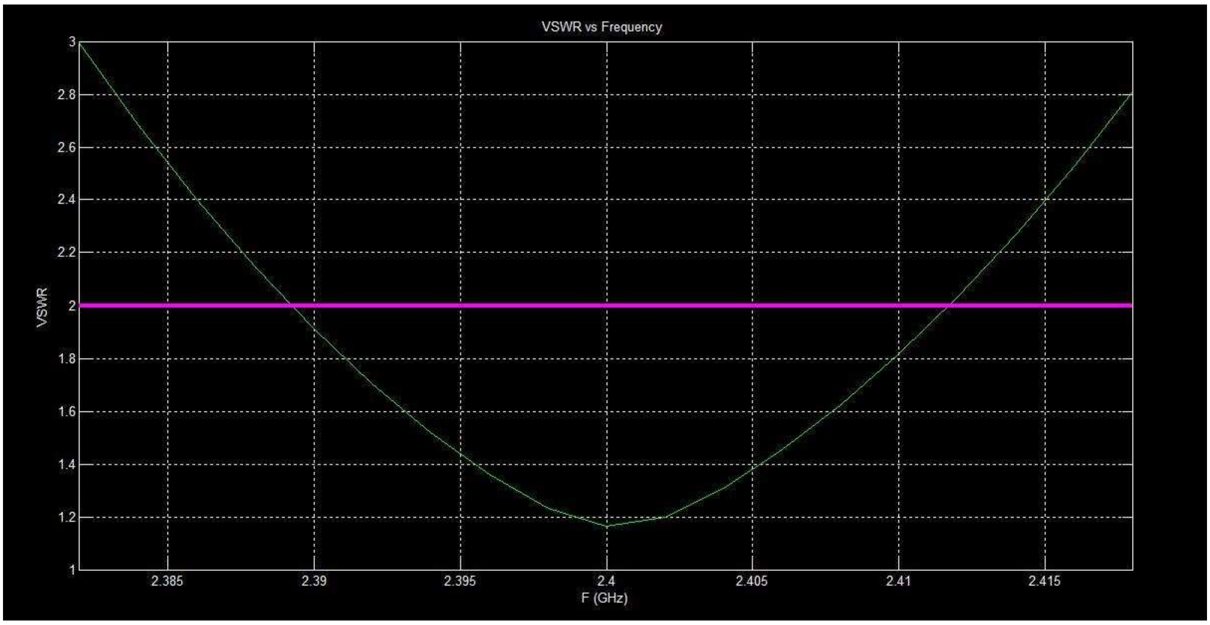

Fig 4.3b: VSWR against Frequency (with band at 2)

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design of a rectangular patch (probe feed) antenna was completed using Matlab/Simulink Software. The simulations provided good results that satisfy the requirements to fabricate the desired antenna used to perform the Bluetooth communication.

The optimization of the antenna was performed using the Simulink software and the Gwinstek Spectrum Analyzer. This led to the major parameter (such as, the radiation pattern, return loss curve, gain and the efficiency of the antenna); that affect the design and applications retrieved and studied where its implications is understood.

5.2 Recommendation:

The following recommendations are proposed and required for immediate and future implementation:

i. Communication systems Engineers are advised to implement the constant phase model (model with optimum better performance in this study) in designing communication equipment's.
ii. The development of Hybrid-model i.e. combination of the Constant-phase random and Random-walk phase models may be considered. The investigation for Carrier-phase estimation should be carried out on the performance of the Hybrid model.

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APPENDIX

APPENDIX A

MATLAB code to generate the physical dimension of the patch antenna

```
% Name: Ogadi Precious Onochie.
% Matric No: 10/ENG 02/018.
% Department of Computer Engineering.
% Project: Design of a Microstrip Antenna using a GUI
% Program to calculate the parameters to design a rectangular patch antenna
% The values of frequency, dielectric constant, and height of the
dielectric.

function varargout = untitled(varargin)
% UNTITLED M-file for untitled.fig
%      UNTITLED, by itself, creates a new UNTITLED or raises the existing
%      singleton*.
%
%      H = UNTITLED returns the handle to a new UNTITLED or the handle to
%      the existing singleton*.
%
%
% The initialization code
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @untitled_OpeningFcn, ...
                   'gui_OutputFcn',  @untitled_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end

% The function executes before untitled is made visible.
function untitled_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output argument.
% hObject    handle to figure
% eventdata  reserved - This is defined in MATLAB
% handles    structure with handles and user data
% varargin   command line arguments to untitled

% Choose default command line output for untitled
handles.output = hObject;

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes untitled wait for user response (see UIRESUME)
% uiwait(handles.figure1);
```

```
% This function provides output that are in turn returned to the command
line.
function varargout = untitled_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - This is defined in MATLAB
% handles    structure with handles and user data

% Get default command line output from handles structure
varargout{1} = handles.output;


% This function executes during object creation, after setting all
properties.
function edit1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit1 (see GCBO)
% eventdata  reserved - This is defined in MATLAB
% handles    empty - handles not created until after all CreateFcns called
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

function edit2_Callback(hObject, eventdata, handles)
% hObject    handle to edit2 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Hints: get(hObject,'String') returns contents of edit2 as text
%        str2double(get(hObject,'String')) returns contents of edit2 as a
double


% This function executes during object creation, after setting all
properties.
function edit2_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit2 (see GCBO)
% eventdata  reserved - This is defined in MATLAB
% handles    empty - handles not created until after all CreateFcns called

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function edit3_Callback(hObject, eventdata, handles)
% hObject    handle to edit3 (see GCBO)
% eventdata  reserved - This is defined in MATLAB
% handles    structure with handles and user data (see GUIDATA)

% get(hObject,'String') returns contents of edit3 as text
% str2double(get(hObject,'String')) returns contents of edit3 as a double


% This function executes during object creation, after setting all
properties.
```

```
function edit3_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit3 (see GCBO)
%reserved - This is defined in MATLAB
% handles    empty - handles not created until after all CreateFcns called

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in pushbutton1.
function pushbutton1_Callback(hObject, eventdata, handles)
freq=str2double(get(handles.edit1,'String'));
er=str2double(get(handles.edit2,'String'));
h=str2double(get(handles.edit3,'String'));
height = h/1000*2.54;
% To calculate the Width of the Patch
Width=30.0/(2.0*freq)*sqrt(2.0/(er+1.0))*10;
% To calculate the Effective Parameters of the Antenna.
ereff=(er+1.0)/2.0+(er-1)/(2.0*sqrt(1.0+12.0*height/Width));
% To calculate the length Extension
dl=0.412*height*((ereff+0.3)*(Width/height+0.264))/((ereff-
0.258)*(Width/...
    height+0.8));
lamda=30.0/(freq*sqrt(ereff));
lamda0=30.0/freq;
% To calculate the effective Length
Leff=lamda/2;
% To calculate the Length of the Patch
L=Leff-2*dl;

Length = L*10;
k0=2*pi*freq/30;
phi1=0:360;
theta1=0:180;
phi=phi1./180.*pi;
theta=theta1./180.*pi;

% To calculate the Radiation Resistance
Rr=120*lamda0/(1-k0^2*height^2/24);
Radiation_resistance = Rr;

set(handles.text4,'String',Length);
set(handles.text5,'String',Width);
set(handles.text11,'String',Radiation_resistance);

% Radiation patterns
% Plotting of radiation patterns on polar and rectangular co-ordinate
system


% To calculate the normalized field values for polar plot
Etheta=sin(k0*height/2.*cos(theta)).*cos(k0*L/2.*cos(theta))/k0/height*...
    2./cos(theta);
Ethetamax=max(Etheta);
Ethetanor=Etheta./Ethetamax;
```

```
Ephi=sin(k0*Width/2.*cos(phi)).*sin(phi)/k0/Width*2./cos(phi);
Ephimax=max(Ephi);
Ephinor=Ephi./Ephimax;
axes(handles.axes1);
cla;

polar(theta,Ethetanor,'-r')
hold on;
polar(phi,Ephinor,'-b')
title('Radiation plot of E and H plane patterns');
% title('E- and H-plane Patterns of Rectangular Microstrip Antenna',...
%     'fontsize',[12]);
legend('E plane','H plane');

% Space wave, surface wave and gain calculations

k0d=k0*height;

%Space wave power
Psp = 377*k0^2*k0d^2/3/pi*(1-1/ereff+2/5/ereff^2);

%Surface wave power
s=sqrt(ereff-1);
k0ds=k0d*s;
alpha0=s*tan(k0ds);
alpha1=-[tan(k0ds)+k0ds/(cos(k0ds))^2];
x0d=ereff^2-alpha1^2;
x0n=-ereff^2+alpha0*alpha1+ereff*sqrt(ereff^2-2*alpha0*alpha1+alpha0^2);
x0 = 1+x0n/x0d;

% To calculate the Efficency
Psur = 377*k0^2/4*ereff*(x0^2-1)/[ereff*[1/sqrt(x0^2-1)+sqrt(x0^2-1)/(...
    ereff-x0^2)]+k0d*[1+ereff^2*(x0^2-1)/(ereff-x0^2)]];

Efficiency=Psp/(Psp+Psur);
%  To calculate the Gain
Gain=10*log10(Efficiency*2*pi*Leff*Width/lamda0);

set(handles.text14,'String',Efficiency);
set(handles.text15,'String',Gain);

% recessed feedline width
% characteristic impedance

x=30*pi/sqrt(er)/50-0.441;

if sqrt(er)*50 <= 120
    W0=height*x;
else
    W0=height*(0.85-sqrt(0.6-x));
end
% Width_of_microstrip_feed=W0;

if W0/height <= 1
    Z0=60/sqrt(ereff)*log(8*height/W0+W0/4/height);
else
    Z0=120*pi/sqrt(ereff)*inv(W0/height+1.393+.667*log(W0/height+1.444));
end
% characteristic_Impedance = Z0
```

```
set(handles.text17,'String',Z0);


% hObject    handle to pushbutton1 (see GCBO)
% eventdata  reserved - This is defined in MATLAB
% handles    structure with handles and user data (see GUIDATA)


% This function executes during object creation, after setting all
properties.
function text1_CreateFcn(hObject, eventdata, handles)
% hObject    handle to text1 (see GCBO)
% eventdata  reserved - This is defined in MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

APPENDIX B

MATLAB code to perform the simulation of the patch antenna using the MATLAB toolbox

for SIMULINK to simulate the antenna in relation to its parameter's and characteristic's.

```
function varargout = OgadiAntenna(varargin)
% OGADIANTENNA MATLAB code for OgadiAntenna.fig
%      OGADIANTENNA, by itself, creates a new OGADIANTENNA or raises the
existing
%      singleton*.
%
%      H = OGADIANTENNA returns the handle to a new OGADIANTENNA or the
handle to
%      the existing singleton*.
%
%      OGADIANTENNA('CALLBACK',hObject,eventData,handles,...) calls the
local
%      function named CALLBACK in OGADIANTENNA.M with the given input
arguments.
%
%      OGADIANTENNA('Property','Value',...) creates a new OGADIANTENNA or
raises the
%      existing singleton*.  Starting from the left, property value pairs
are
%      applied to the GUI before OgadiAntenna_OpeningFcn gets called.  An
%      unrecognized property name or invalid value makes property
application
%      stop.  All inputs are passed to OgadiAntenna_OpeningFcn via
varargin.
%
%      *See GUI Options on GUIDE's Tools menu.  Choose "GUI allows only one
%      instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help OgadiAntenna

% Last Modified by GUIDE v2.5 13-Jun-2015 07:35:12

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',       mfilename, ...
                   'gui_Singleton',  gui_Singleton, ...
                   'gui_OpeningFcn', @OgadiAntenna_OpeningFcn, ...
                   'gui_OutputFcn',  @OgadiAntenna_OutputFcn, ...
                   'gui_LayoutFcn',  [] , ...
                   'gui_Callback',   []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if nargout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
```

```
% --- Executes just before OgadiAntenna is made visible.
function OgadiAntenna_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to OgadiAntenna (see VARARGIN)

% Choose default command line output for OgadiAntenna
handles.output = hObject;

data.Height = 50;
data.Freq = 2.40;
data.Perm = 2;
data.Zin = 50;
data.LossTangentD = 0.0013;
data.MetalCond = inf;
data.MetalThickness = 0.7;
setappdata(hObject, 'metricdata', data);
% handles.data = data;

% Update handles structure
guidata(hObject, handles);
% initialize_gui(gcbf, handles);
% UIWAIT makes OgadiAntenna wait for user response (see UIRESUME)
% uiwait(handles.figure1);


% --- Outputs from this function are returned to the command line.
function varargout = OgadiAntenna_OutputFcn(hObject, eventdata, handles)
% varargout  cell array for returning output args (see VARARGOUT);
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)

% Get default command line output from handles structure
varargout{1} = handles.output;



function editImpedance_Callback(hObject, eventdata, handles)
Zin = str2double(get(hObject, 'String'));
if isnan(Zin)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
data = getappdata(gcbf, 'metricdata');
data.Zin = Zin;
% guidata(hObject, handles);
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function editImpedance_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editImpedance (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
```

```
% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function editFrequency_Callback(hObject, eventdata, handles)
Freq = str2double(get(hObject, 'String'));
if isnan(Freq)
    set(hObject, 'String', '1');
    errordlg('Input must be a number','Error');
end

data = getappdata(gcbf, 'metricdata');
data.Freq = Freq;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function editFrequency_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editFrequency (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function editConductivity_Callback(hObject, eventdata, handles)
MetalCond = str2double(get(hObject, 'String'));
if isnan(MetalCond)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
data = getappdata(gcbf, 'metricdata');
data.MetalCond = MetalCond;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function editConductivity_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editConductivity (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function editThickness_Callback(hObject, eventdata, handles)
MetalThickness = str2double(get(hObject, 'String'));
if isnan(MetalThickness)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
data = getappdata(gcbf, 'metricdata');
data.MetalThickness = MetalThickness;
setappdata(gcbf, 'metricdata', data);


% --- Executes during object creation, after setting all properties.
function editThickness_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editThickness (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function editEr_Callback(hObject, eventdata, handles)
Perm = str2double(get(hObject, 'String'));
if isnan(Perm)
    set(hObject, 'String', 2);
    errordlg('Input must be a number','Error');
end

data = getappdata(gcbf, 'metricdata');
data.Perm = Perm;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function editEr_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editEr (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function editLossTan_Callback(hObject, eventdata, handles)
LossTangentD = str2double(get(hObject, 'String'));
if isnan(LossTangentD)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end
```

```
data = getappdata(gcbf, 'metricdata');
data.LossTangentD = LossTangentD;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function editLossTan_CreateFcn(hObject, eventdata, handles)
% hObject    handle to editLossTan (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end



function edit7_Callback(hObject, eventdata, handles)
Height = str2double(get(hObject, 'String'));
if isnan(Height)
    set(hObject, 'String', 50);
    errordlg('Input must be a number','Error');
end

data = getappdata(gcbf, 'metricdata');
data.Height = Height;
setappdata(gcbf, 'metricdata', data);

% --- Executes during object creation, after setting all properties.
function edit7_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit7 (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called

% Hint: edit controls usually have a white background on Windows.
%       See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end


% --- Executes on button press in pushDesign.
function pushDesign_Callback(hObject, eventdata, handles)
clc
data = getappdata(gcbf, 'metricdata');
GenerateSimulate(data.Freq, data.Zin, data.Height, data.Perm,
data.LossTangentD, data.MetalCond, data.MetalThickness);

% initialize_gui(gcbf, handles);


function initialize_gui(fig_handle, handles)
data.Height = 50;
data.Freq = 1;
data.Perm = 2;
data.Zin = 50;
```

```
data.LossTangentD = 0.0013;
data.MetalCond = inf;
data.MetalThickness = 0.7;
setappdata(fig_handle, 'metricdata', data);

set(handles.Freq, 'String', data.Freq);
set(handles.Perm, 'String', data.Perm);
set(handles.Height, 'String', data.Height);
set(handles.Zin, 'String', data.Zin);
set(handles.MetalCond, 'String', data.MetalCond);
set(handles.MetalThickness, 'String', data.MetalThickness);
set(handles.LossTangentD, 'String', data.LossTangentD);
```

APPENDIX C

Table 4.1: Bill of Engineering Materials and Evaluation

S/No	Materials	Quantity	Unit Cost (₦)	Total Cost(₦)
1	FR4 Epoxy fibre glass one-sided copper clad dielectric substrate	1	4000	4000
2	Copper Foil	1	10000	10000
3	SMA connector	1	200	200
4	RF connector	1	1700	1700
5	Coaxial cable	1	1000	1000
6	Transportation	-	20000	20000
			Total	36900

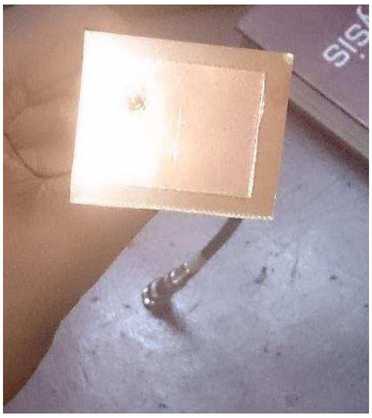

Figure 4.4a: Picture of the Radiating surface of the fabricated antenna

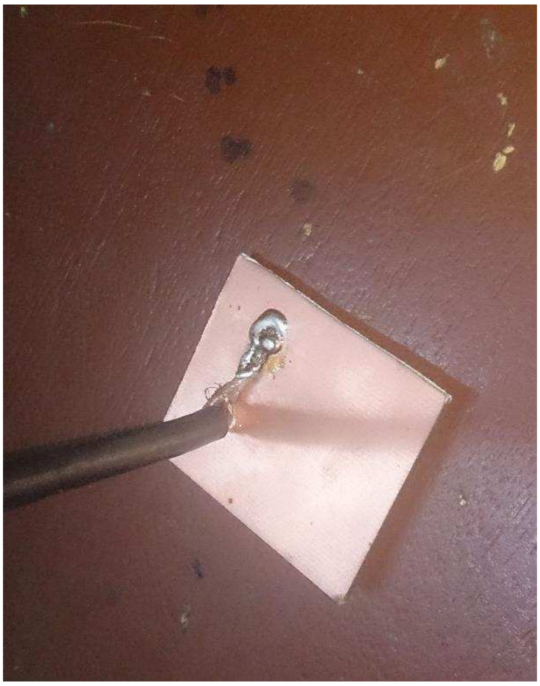

Figure 4.4b: Picture of the Ground surface of the fabricated antenna