Design and Simulation of Wide-band Planar Inverted-F Antenna for Wireless Communication Applications

A DISSERTATION

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Submitted by:

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CANDIDATE'S DECLARATION

I, Chhavi Kaushik, Roll No. 2k16/MOC/02 student of M.tech (Microwave and Optical Communication), hereby declare that the project Dissertation titled **"Design and Simulation of Wide-band Planar Inverted-F Antenna for Wireless Communication"** which is submitted by me to the Department of Electronics Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation titled **"Design and Simulation of Wide-band Planar Inverted-F Antenna for Wireless Communication Application"** which is submitted by CHHAVI KAUSHIK, Roll No. 2k16/MOC/02, Department of Electronics Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi **PROF. N.S. RAGHAVA**

Date: **SUPERVISOR**

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Abstract

There has been a significant growth in the demand for portable, compact and easy to handle and use hand-held wireless communication devices over the years since their introduction in the commercial space. Devices with embedded internal antennas have fulfilled the need for portability.

Device miniaturization can be achieved by reducing the size of the antennas used. Designers all across the world are continuously working on creating new designs mostly with micro-strip patch antennas and planar inverted-F for use in wireless communication applications as these type of antennas are known for their low prolife structure and can be easily embedded in the instruments.

Likewise, the project also attempts to design, implement, simulate, and measure the relevant parameters and understand the performance of planar inverted-F antenna (PIFA). Determination of the resonating frequencies of the antenna is done and respective gains and directivity obtained at those frequencies. FR4 substrate with relative permittivity or dielectric constant of 4.3 but the radiating strip is elevated in a PIFA with the help of a shorting pin or strip so the effective relative permittivity changes.

Two slots in the ground or defected ground structure are cut-out to improve the bandwidth of the model. Modifications and changes might be done to make the results better as the work progresses.

The parameters like return loss, radiation pattern and directivity of the PIFA have been extensively investigated and carried out. All the designing, simulations are done and results are obtained using CST Studio Suite 2014, also all the obtained results satisfy the performance under - 10dB point in the bandwidth of 20.13%.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form
IEEE	Institute of Electrical and Electronics Engineers
BW	Bandwidth
FBW	Fractional Bandwidth
ISM	Industrial, Scientific and Medical
WLAN	Wireless Local Area Network
GSM	Global System for Mobile Communications
GPS	Global Positioning System
VSWR	Voltage Standing Wave Ratio
dB	Decibel
mm	Millimeter
%	Percentage
GHz	Giga Hertz
S/m	Siemens per meter
F/m	Farads per meter
SAR	Specific Absorption Rate
CST	Computer Simulation Technology
SMA	SubMiniature version A
PIFA	Planar Inverted-F Antenna

MSA	Microstrip Antennas
LTE	Long Term Evolution
LAN	Local area network
UMTS	Universal mobile telecommunication system.
DECT	Digital enhanced cordless tele communication.
PDC	Personal digital cellular.
HPBW	Half – power beam width.
FNBW	First null beam width.
RF	Radio frequency.
PMA	Planar monopole antenna.
ESA	Electrically small antenna.
Wi-Fi	Wireless fidelity
IFA	Inverted F-antenna
PTFE	Polytetrafluoroethylene
PEC	Perfect electrically conductor

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CHAPTER 1
INTRODUCTION

1.1 Background

A significant increase in the demand for employing and using compact, easy to handle and portable communication devices has been evident since their introduction in the commercial and personal space. Devices which employ internal antennas have fulfilled this need. One of the major reasons that can put limitations on the miniaturization of a wireless device is the size of the antenna used in them. Antenna Designers all across the globe have been working since their introduction on this critical issue of miniaturization, new designs have been proposed ever since which are mostly based on the micro-strip antennas (MSA) technology and the quite popular from quite some time now, the planar inverted-F antennas (PIFA), have been deployed for portable wireless devices owing to the properties these antennas possess which are: low-profile geometry and can be easily embedded in very small space in the devices.[1]

New wireless applications that can operate in more than one frequency band are also in the making. As multiple frequency bands are used for establishing wireless communication links, dual-band (using two frequency bands) and tri-band (using three frequency bands) phones have gained prominence. One prominent application for short-range wireless link is Bluetooth which operates at 2.4 GHz band.

One industrial market that is growing at a very fast pace in recent times is the Mobile communication and cellular phone technologies and also the one which is engaged in making interconnects which are wireless, wireless local area networks (WLANs) etc. and all these applications have antennas as important requisites.

Hence, taking the evolution and importance of wireless communication links in day to day lives into consideration; antenna technology with portability as a crucial characteristic has also flourished alongside mobile and cellular technologies.

Antennas are designed as per the specifications and the prerequisites given for any particular application or device. The antenna designed accordingly will improve and optimise the transmission and reception of the information signal between two end users or base station whatever may be the scenario, reduction in power consumption will attempted, and the suitable antenna will have longevity and hence improved marketability of the communication device.

From various accounts giving the information about antennas used in earlier times for portable or hand-held devices for wireless communication applications were known as whip antennas. A quarter-wavelength whip antenna owing to its simple structure and convenience to use, it had gained much popularity. Omni-directional pattern in the plane of the earth when it was held straight in vertical direction was one of its prominent features because of which it was in vogue that time and gave optimum gain value as per the device's specifications. New antenna designs have been proposed by scholars working in this field which have lower profile compared to a whip antenna and also without much compromise in the antennas' performance.

Devices which smaller than palm size are available in the market as there as an exponential rise in the demand for these for their ease to use, light-weighted-ness and small power consumption. .

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Conventional PIFAs and MSAs have compact structure, having length that is approximately equal to one-eighth of the wavelength. The major shortcoming of many low-profile antennas is their narrow bandwidth. Impedance matching puts an adverse effect on the bandwidth and limits it. Bandwidth as low as 5% has been accounted for conventional PIFA's, but there is plethora of techniques that can be brought into use for achieving enhanced bandwidth. Few examples of techniques which are used for broadening of bandwidth which have been reported are the addition of a parasitic structure having resonant frequency very near to that of the driving antenna structure.

Fig. 1.1 (a) The Motorola DynaTAC with a monopole antenna.(b) The Nokia 5510 with a helical antenna (c) The Sony Ericsson Xperia with the patch antennas visible at the top

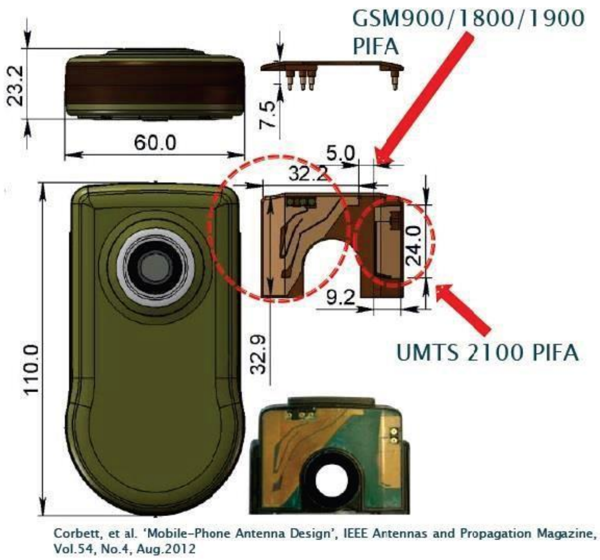

Fig1.2 Internal Antennas of Nokia 6630

1.2 Objective

The thesis is focused on the development and designing a planar inverted-F antenna for wireless communication applications. The proposed antenna should have good performances like wideband upto 1 GHz or more and directivity in the range of 5-8 dBi as this the desirable directivity range for PIFA. The antennas should be capable of maintaining robust and reliable communication links.

The problem of low bandwidth and low gain could be overcome by changing the structure of the patch, increasing the thickness of the substrate, changing the air gap between the patch and the substrate, width of the short plate, optimising the position of the feed from the shorting plate. Good Impedance matching is achieved by connecting a pin diode in on state between the patch and the ground.

Simpler methods have been employed to achieve reasonably good gain and bandwidth so that it is easy to construct and is cost effective. As PIFA is a mostly used as a mobile phone antenna, there are reservations regarding its size so that it can be easily embedded in the mobile phones and other handheld devices.

1.3 Literature review

Of late, the exponential rise in the use of mobile communications systems has created such a scenario that it is now utmost important to have antennas with optimum properties the likes of which are high speed, moderate gain and small size as the space to embed these antennas in the devices which should be light in weight and compact in size, is very limited, and for the sake of manufacturing such devices, it is imperative to request for the design of small size antennas having low cost. Nowadays, there is an ever increasing necessity to integrate all the available wireless services in one single device.

Also in particular, for high-speed and high quality transmission of information and data, in some handheld devices technologies like Bluetooth, LTE and Wi-Fi are integrated in one unit. Many antennas are needed to cover each service in a single unit, and it over-crowds a small device if so many antennas are embedded for every wireless service.

“So now to fulfil the need for a sorted device configuration, such antennas are designed that can operate in multiple bands and can support multiple standards. All in all, the fundamental idea is to always strive to augment and improve the functionality and performance of the wireless communication devices and to cover all the possible frequency bands available for wireless communication. The planar inverted-F antennas (PIFAs) are particularly important owing to their compactness in size and optimum performance. PIFA antennas’ have been adopted for portable wireless device units owing to their low profile geometry, light weightedness and conformal structure (Balanis, 1982). In [4], Dual-feed PIFA with a height h = 10 mm and a minimum bandwidth of the two ports is 200 MHz has been presented.”

In [5], a dual feed PIFA has been presented with height h = 5 mm and a minimum bandwidth 50 MHz by the two ports.

In [6], a compact dual-port antenna for Long-Term Evolution with a height h = 7.5 mm and minimum bandwidth by the two ports is 200 MHz has been presented.

1.4 Thesis Outline

This chapter started with a preliminary discussion about the advent of mobile phone antennas. Later the issues have been discussed which derive the inspiration and need of the research in this thesis. A literature survey has been presented to give an overview of the past work done and the developments in this field until now and the need to start this project came into existence.

The 2nd chapter will present the basics of antenna, its definition and the definition of its parameters, the detailed discussion on micro-strip antenna, its merits, its applications and the design procedure. It forms the foundation of the terms used later in this thesis. It also gives an overview of different substrate materials used by the designers as per their requirement and their comparison table for better selection of the substrate for the fabrication purpose and performance of the antenna.

The 3rd chapter starts with the introduction of planar inverted-F antennas and its evolution in the past years. Then it focuses on the fundamental design aspects of the pifa and formulae required for its designing have been developed.

The 4th chapter presents the methodology adopted to design the proposed work, its designing and simulation. The design of the antenna is explained in detail.

The 5th chapter focuses on the results obtained after simulation on CST Studio Suite 2014. The chapter ends with the conclusions and future scope.

CHAPTER 2
ANTENNA THEORY

2.1 Introduction- Antenna Definition

Antennas play a crucial part in any wireless system and are used send and receive information in the form of electromagnetic waves. According to the IEEE definition [15], an antenna is “a means for radiating or receiving radio waves”. Alternatively, “a transmitting antenna is one which accepts signals from a transmission line, changes those signals into electromagnetic waves and then broadcasts them into free space, and the antenna on the receiving end does the vice-versa i.e. it gathers the electromagnetic waves falling on it and again changes them into signals”.

2.2 Parameters

A number of different parameters are defined and these are helpful in understanding the performance of any given antenna. Some of the important ones are defined below:

2.2.1 Bandwidth

“Frequency bandwidth is the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard. The bandwidth is considered to be the range of frequencies, on either sides of the centre frequency, where the antenna characteristics within an acceptable value range are achieved as those at the centre frequency. In wireless communications, the antenna should provide a return loss less than -10dB over its frequency bandwidth”.

"The frequency bandwidth of an antenna is expressed as either an absolute bandwidth (ABW) or fractional bandwidth (FBW). The *f*H and *f*L are the denotations for the upper edge frequency and the lower edge frequency of the antenna bandwidth, respectively. The ABW is usually defined as the difference of the two frequency edges and the FBW is designated as the percentage of the frequency difference over the center frequency", and is expressed by equation 1.2.1.1 and 1.2.1.2, respectively.

$$ABW = \frac{fH - fL}{fH + fL} \qquad \text{........(eq. 2.2.1.1)}$$

Where,

*f*H = higher frequency, *f*L = lower frequency

$$FBW = 2 * \frac{fH - fL}{fH + fL} \qquad \text{........(eq.2.2.1.2)}$$

"The bandwidth, for broadband antenna, is also expressed as the ratio of the upper edge frequency to the lower edge frequency, where acceptable antenna performance is achieved", as shown in equation 1.2.1.3

$$BW = \frac{fH}{fL} \qquad \text{......(eq. 2.2.1.3)}$$

2.2.2 Return Loss

"Return loss is considered a measure of the effectiveness of the power delivered from a transmission line to a load such as an antenna. If the power incident on the antenna (under test) is taken as Pin and the power reflected back to the source is taken Pref, the amount of mismatch between the incident and reflected power flowing in the travelling waves is given by the ratio of Pin and Pref. The higher this power ratio is, the better the matching of the load and the line. In dB, the return loss is the negative of the reflection coefficient's magnitude." [16,17] Since the power is direct proportion of the square of the voltage, return loss can be expressed as:

$$RL = 10 * \log_{10} \frac{Pin}{Pref} dB \qquad (2.2.2.1)$$

which is a positive quantity if Pref < Pin.

2.2.3 Radiation Pattern

"Radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from it[16]. It is usually a graphical representation of the antenna's radiation properties as a function of space coordinates. The antenna's radiation pattern can also be considered as a measure of its power or radiation distribution with respect to a particular type of coordinates. Generally spherical coordinates are considered because the ideal antenna is supposed to radiate in a pattern that is spherically symmetrical. Almost all the time, the radiation pattern is determined in the far field."

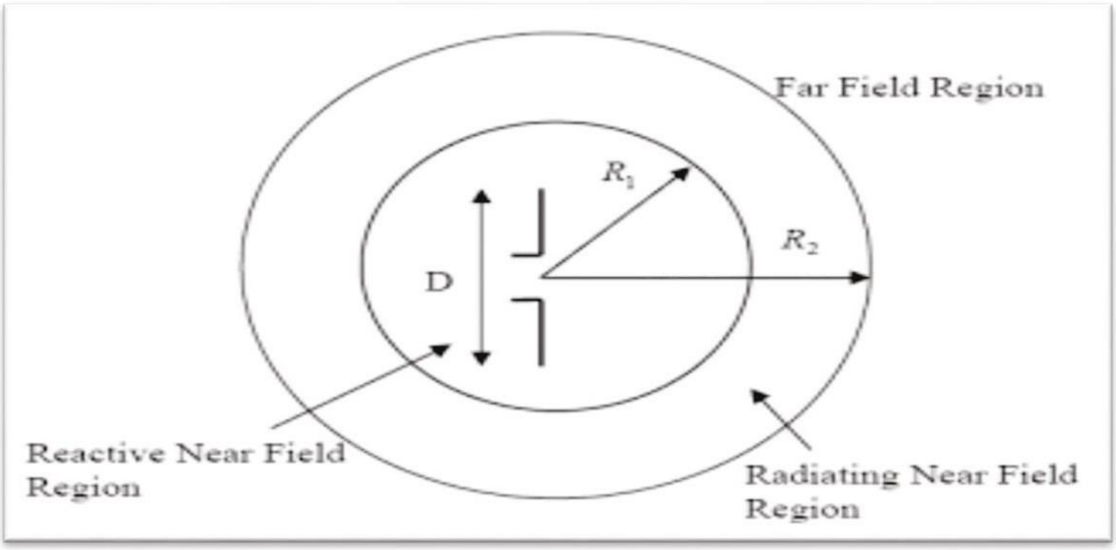

Fig 2.2.1 The Radiation Pattern and the field regions

2.2.4 Gain

"Gain is the most important figure of merit that is helpful in describing the performance of an antenna radiator. The term antenna gain describes about the amount of power that is transmitted in the direction of peak radiation to that of an isotropic source."

OR

"The relative gain is given by the ratio of the power gain in a particular direction to the power gain of a reference antenna in its referenced direction. In almost all cases a lossless isotropic source is considered the reference antenna. In the case when the direction is not specified, the power gain is usually taken in the maximum radiation's direction. 3 dB gain of a transmitting antenna means that the power, that is received far from the antenna, will be 3 dB higher than what one expects to receive from a lossless isotropic antenna that has the same input power. Likewise, a receiving antenna that has a gain of 3 dB in a given direction would receive power which is 3 dB more than the power that is expected to be received from a lossless isotropic antenna."

2.2.5 Group Delay

"Another important parameter which is to be taken into consideration while discussing the wideband microstrip antenna is group delay. It provides the pulse-handling capability. It also gives the amount of distortion in the pulse signal. It is quite a useful measure of time distortion which is generally calculated as the differentiation of phase with respect to frequency. Using this one can also evaluate the non dispersive behaviour of antenna as a derivative of far field response with respect to frequency. If group delay variation exceeds more than 1 nsec, phases are said to be non-linear in the far field region and phase distortion also occurs which can be a serious problem for wideband applications."

2.2.6 Efficiency

"Antenna radiation efficiency's definition can be given as the ratio of power radiated from the antenna to the input power. It also gives the relation between the gain and directivity. Conduction and dielectric losses are also taken into account for calculating the radiation efficiency."

2.2.7 Polarization

"Polarization of any given antenna in a particular direction is defined as the polarization of the wave transmitted or radiated by the antenna". "Polarization is observed in the direction of maximum gain, when the direction is not defined explicitly. The polarization changes with the direction from the centre of the antenna of the energy waves which have been radiated, so that varied polarizations are obtained on varied parts of the radiation pattern".

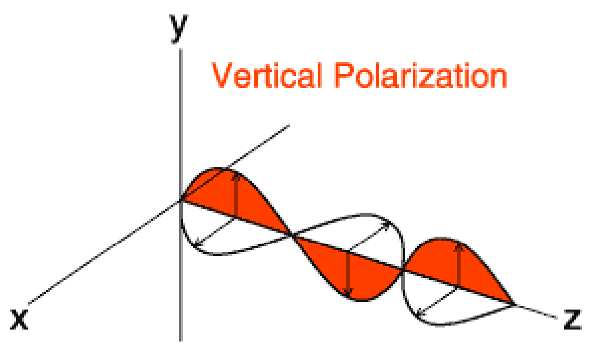

Fig.2.2.2 Vertical Polarization

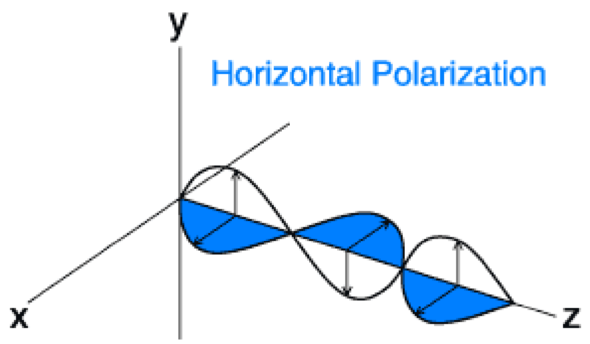

Fig.2.2.3 Horizontal Polarization

2.3 Introduction to Micro-strip Patch Antennas

A type of antennas that has gained considerable popularity in terms of its most frequent use in wireless communication systems in recent times is the micro-strip antenna. "A typical micro-strip antenna geometry is illustrated in Fig.2.1. There are numerous types of micro-strip antennas, but their common feature is, they consist of the following four parts:

- a very thin flat metallic region known as the *patch*;
- a *dielectric substrate*;
- a *ground plane*, and it is usually quite larger than the patch; and
- a *feed*, which is used to supply the RF power."

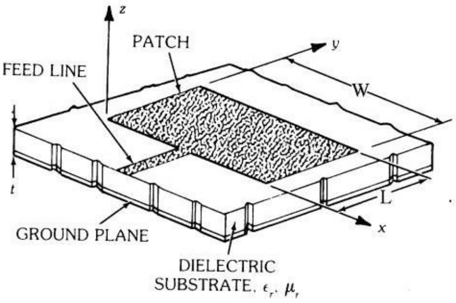

Fig 2.1 Geometry for a typical rectangular micro-strip element

Often the micro-strip elements are constructed by photo-etching the patch (and sometimes the feeding circuitry also) from a single printed-circuit board (PCB) cladded with conductor on both the sides. The patch conductors usually are made up of copper or gold and are often virtually assumed to be of any possible shape. The most frequently used are the square, rectangle, circular shape, ring shape, and elliptical too or any other possible polygon configuration". "Conventional shapes are generally used to simplify the analysis and performance prediction. Square, rectangular and circular shapes are the most commonly employed because of their ease of analysis and fabrication." Some of the merits of the microstrip antennas over the conventional microwave antennas are following:

- Low in volume, light weight,
- Low cost of fabrication,
- Easy mass production,
- Linear and circular polarization possible using simple feed,
- Can be easily integrated with MIC,
- Feed lines and matching networks can be simultaneously fabricated with antenna structures.

Many researchers have been driven by the ever increasing demand for modern mobile, wireless communication and satellite communication systems and so working to improve the performance and developing different applications of patch antennas.

Micro-strip antennas have a myriad of applications ranging from personal to commercial use (in mobiles, GPS) to military deployment (GPS and missile etc), as they are easily designed and fabricated.

"One of the first tasks in the designing of printed antenna is making the choice of a suitable substrate or dielectric material. The major electrical parameters which are considered are the relative dielectric constant and the loss tangent. A higher dielectric constant means smaller patch antenna but often reduces bandwidth and hence results in tighter fabrication tolerances. A high loss tangent causes reduction in the antenna efficiency and increment in feed losses. As a rule of thumb, one should select a substrate with lowest possible dielectric constant. Substrate thickness should be chosen as large as possible so as to maximize bandwidth and efficiency but not so large that it allows surface-wave excitation."

2.4 Different Dielectrics Substrates used and their properties

2.4.1 Bakelite

"Bakelite or polyoxybenzylmethylenglycolanhydride is an early plastic. It is a thermosetting phenol formaldehyde resin which is formed from an elimination reaction of phenol with formaldehyde. Its most common uses are: it is used as an electrical insulator which possesses considerable mechanical strength."

2.4.2 FR-4 or (FR4) Gloss Epoxy

"FR-4 or (FR4) is a kind of grade designation assigned to glass-reinforced epoxy laminate sheets, rods, tubes and printed circuit boards (PCB). FR-4 is a composite material which is composed of a woven fiber-glass cloth with an epoxy resin binder that is flame resistant (*self-extinguishing*). FR-4 glass epoxy is a known and quite versatile high-pressure thermo set plastic laminate grade with considerably good strength to weight ratios. With negligible water absorption property, FR-4 finds its use as an electrical insulator which possesses considerable mechanical strength."

2.4.3 RO4003

"RO4003® Series High Frequency Circuit Materials are glass reinforced hydrocarbon/ceramic laminates (Not PTFE) which are usually designed for high volume commercial applications which are performance sensitive. RO4000 laminates are designed such that they offer superior performance at high frequency and considerably low cost circuit fabrication. It is a low loss material which can be fabricated by employing standard epoxy/glass (FR4) processes and is made available at competitive prices".

2.4.4 Taconic TLC

"Taconic TLC substrates are particularly designed to satisfy the low cost need of the newly emerging commercial RF/microwave applications. Taconic TLC substrates are generally manufactured with thickness 0.0145" (0.37 mm) having ε_r=2.70, and 0.020" (0.50 mm) having ε_r=3.0 and 0.031" (0.80 mm) and thicker having ε_r=3.30 and 3.20. Both these materials have superior mechanical and thermal stability and cost is much less than the traditional PTFE substrates".

2.4.5 RT Duroid

"RT Duroid is composite of Glass Microfiber Reinforced PTFE (polytetrafluoroethylene) produced by Roger Corporation. RT Duroid 5870 substrate has loss tangent quite low. They show supreme chemical resistance which includes solvent and reagents which are used in printing and plating, ease of fabrication – cutting, shearing, machining, environment friendly".

Dielectric constant of substrates plays a crucial role in determining the antenna performance. The substrate whose dielectric constant is low usually gives comparatively better performance to the substrate having high dielectric constant. Loss tangent or dissipation factor also have an effect on the antenna performance. Dielectric losses usually are dependent on the configuration of the circuit, frequency, dielectric constant of the substrate and loss tangent.

Table 2.4.1 Different substrates and their properties

Parameters	**Bakelite**	**FR4 Glass Epoxy**	**RO4003**	**Taconic TLC**	**RT Duroid**
Dielectric constant	4.78	4.36	3.4	3.2	2.2
Loss Tangent	0.03045	0.013	0.002	0.002	0.0004
Water Absorption	0.5-1.3%	<0.25%	0.06%	<0.02%	0.02%
Tensile Strength	60 Mpa	<310 Mpa	141 Mpa	-	450 Mpa
Volume Resistivity	3*10^15 Mohm.cm	8*10^7 Mohm.cm	1700*10^7 Mohm.cm	1*10^7 Mohm.cm	2* 10^7 Mohm.cm
Surface Resistivity	5*10^7 Mohm	2*10^5 Mohm	4.2*10^9Mohm	1*10^7 Mohm	3*10^7 Mohm
Breakdown Voltage	20-28 kV	55 kV	-	-	>60kV
Peel Strength	-	9 N/mm	1.05 N/mm	12 N/mm	5.5 N/mm
Density	1810 kg/m^3	1850 kg/m^3	1790 kg/m^3	-	2200 kg/m^3

2.5 Steps to design a Rectangular Micro-strip Patch Antenna

A rectangular patch antenna is the simplest among all the patch antennas and it is always designed in such manner that it operates near the resonance. Now to satisfy the resonance condition, the length 'L' of the patch radiator is chosen accordingly. 'L' close to the half of the wavelength is opted so that at the desired, the input impedance is purely real.. "Since both the ends of the patch are open, an open-end correction is to be taken into account while calculating the physical length 'L' of the patch".

The width 'W' of the patch usually has the value between 0.5 to 2 times of the patch length 'L'. Input impedance value of the patch antenna can be altered by varying the width. As the input impedance of the patch should be matched to 50-ohms so by changing the width 'W' of the patch, input impedance can be controlled to some extent. Suppose 'W' is chosen very small then the radiation efficiency of the antenna is reduced. So we need to maintain a trade-off between the input impedance and radiation efficiency of the antenna. Once W and L are chosen, input impedance of the patch can be calculated and then an impedance transformer can be used to match this impedance to the 50-ohm feed line. The design of a rectangular micro-strip patch antenna starts with (a) making a choice of the substrate/dielectric (b) selecting a feed mechanism, (c) determining the width 'w' of the patch and (d) selection of the feed location.

"In the following steps, after choosing the essential parameters such as dielectric constant of the substrate (ε_r), frequency of operation (f_r), height of dielectric substrate (h), the procedure/steps for designing a rectangular patch antenna is given:

1) Calculating the Width of the patch (W**)**:

For an efficient antenna radiator, a practical value of the width that leads to good radiation efficiency can be calculated by using the following formula:

$$W = \left(\frac{c}{2*f_r}\right) * \sqrt{\frac{2}{\varepsilon_r+1}}$$

By substituting the values of c= 3*10^8 m/s, f_r and ε_r in this formula 'W' can be calculated.

2) Calculating Effective dielectric constant of the structure:

The value of the effective dielectric constant due to the interface of air and dielectric substrate can be calculated by using the formula given below:

$$\varepsilon reff = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} * \left(1 + 12 * \left(\frac{h}{W}\right)\right)\hat{}\left(-\frac{1}{2}\right)$$

By putting the values of h,ε_r and W, the effective dielectric constant can be calculated using the above formula.

3) Calculating the length of the patch (L**):**

The length of the patch is calculated by using the below given formula:

$$L = (v_o)/(2*(f_r)*\sqrt{\varepsilon_{reff}}) - 2 * \Delta L$$

Using the values of ε_{reff} and ΔL, 'L' can be calculated using the above formula.

4) Calculating the ground plane dimensions of the patch antenna:

"The transmission line model is applicable to only infinite ground planes. However, it is necessary to have a finite ground plane for practical considerations. It has been demonstrated that similar results can be obtained for infinite and finite ground plane if the ground plane's size is greater than the dimensions of the patch by approximately six times the thickness of the substrate all around the periphery." Hence, the dimension of the ground plane can be calculated as:

$$L_g = 12h + L \text{ and } W_g = 12h + W$$

5) The feed point determination:

"All feed excitation ports are to be matched to 50 ohm. In order to have impedance matching, the connecter should be placed at some distance from the edge which is matched to 50 ohm impedance. Normally, a trial and error method is adopted to check and find the minimum value of the Return loss. The feed point is initially kept at the center of the X-axis and varied in the Y-axis direction to get the optimum value of return loss.""

CHAPTER 3
PLANAR INVERTED-F ANTENNAS (PIFA)

3.1 Introduction

Mobile handsets have evolved to become tools of entertainment as well as necessity since their commercial launch. To improve the functionality of the handsets and other wireless devices and also striving to maintain such a physical form that allows for handheld use, manufacturers have perennially faced the challenge of integrating an increasing number of complex circuits within a set device volume. This applies to the mobile handset antennas also, whose radiating dimensions are in inverse proportion to the operating frequency. As the next generation Long Term Evolution (LTE) that supports lower frequency bands is deployed, the handset designers have to deal with the resulting larger antenna footprint and opt for the radiating topologies that function well in densely packed systems.

PIFA is the abbreviated form of Planar Inverted-F Antennas which are nowadays the most common cellular phone antennas. Planar Inverted F antennas have developed from monopole antennas. Inverted L antennas are realized by folding down the monopole so as to decrease the height of the antenna and at the same time maintains the identical resonating length. When feed is applied to the Inverted L form of the monopole, it looks like an Inverted F. The thin top wire of the Inverted F is replaced by a planar element or a conducting patch to get the Planar Inverted F antenna.

The sequence of evolution of PIFA from a monopole antenna is shown on the next page:

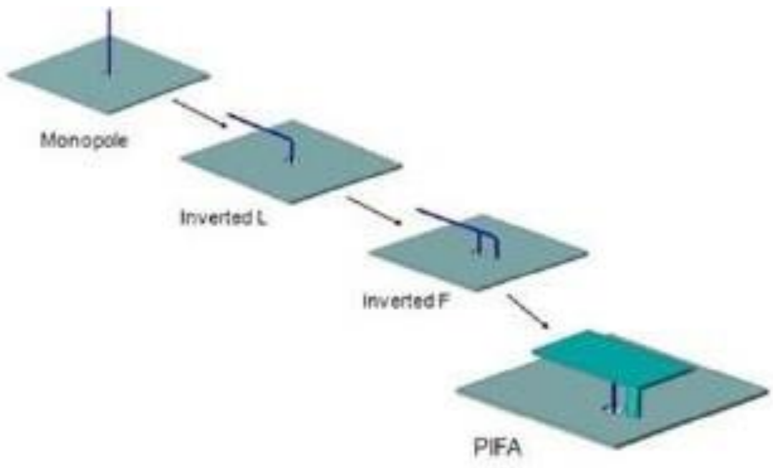

Fig.3.1 PIFA from monopole

3.2 PIFA Design

The Planar Inverted-F antenna (PIFA) is now being frequently used in the mobile phones. This antenna resonates at 1/4th of the wavelength and hence reduces the space that is required on the handheld device/phone to embed it. The resemblance of the antenna geometry with an inverted F justifies the name PIFA. The Planar Inverted-F Antennas owe their popularity to the low profile nature and their Omni-directional pattern. [2]

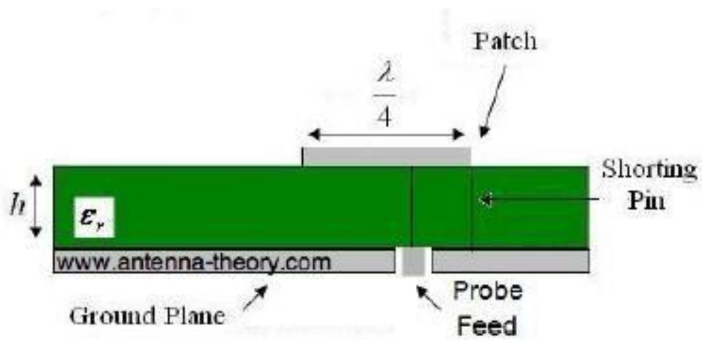

Fig 3.2 Basic Structure of a Planar Inverted-F Antenna

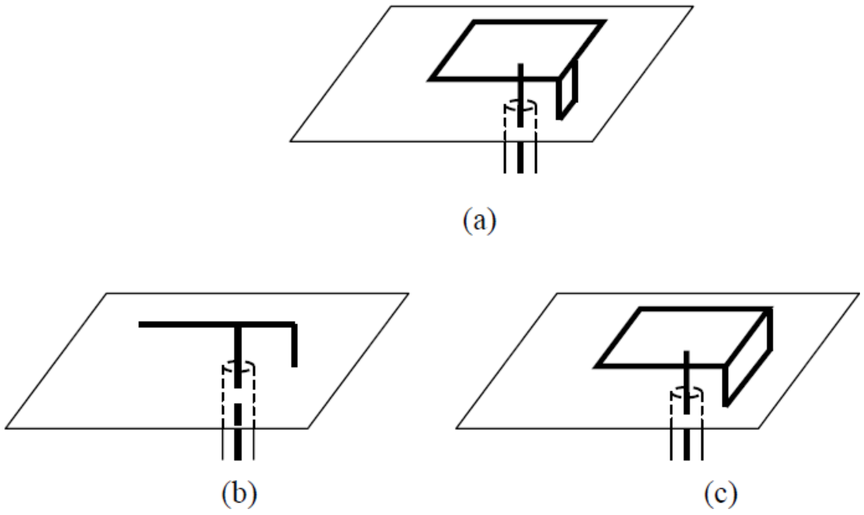

Fig 3.3 PIFA is made by combining (a) IFA(Inverted-F Antenna) with a MSA(Microstrip Antenna) and (c)joining the patch with the ground plane with the help of a shorting pin/plate.

The PIFA is resonant at 1/4th of the wavelength as a shorting pin/plate is connected at its end. The feed is to be positioned between the open and shorted ends of the antenna structure, and the position of the feed also known to control the input impedance.

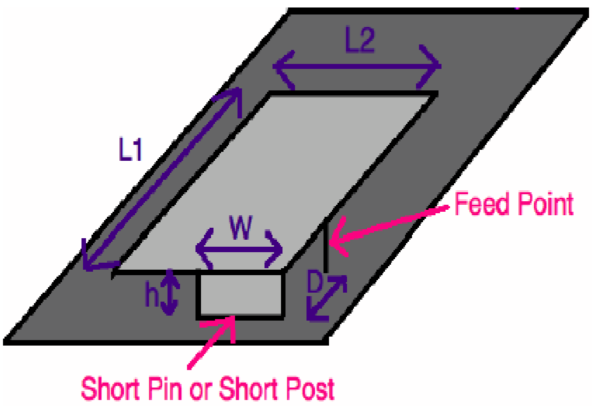

Fig 3.4 PIFA with a shorting plate

In Figure 3.4, a PIFA with length *L1* and width *L2* is considered for understanding its fundamentals. The shorting pin (or shorting plate) has width *W*, and generally kept at one end of the structure. The feed point can be along the same edge or iterations are done to determine its position where good impedance matching results are achieved. The feed is considered at a distance *D* from the shorting pin/plate. The patch is taken at a height *h* above the ground plane. The PIFA is placed on the top of a dielectric substrate with permittivity ε_r, similar to the patch antenna.

"The impedance of the PIFA is generally controlled by changing the distance (D) of the feed from the shorting pin/plate. The closer the feed is positioned to the shorting pin/plate, the impedance will decrease; the impedance is generally increased by moving it away from the shorting edge. The impedance of the PIFA can be tuned with this parameter."

"The resonant frequency has dependence on *W*. Suppose that *W*=*L2*, then the shorting pin has the width same as that of the patch. In this particular case, the PIFA is resonant or we can say has maximum radiation efficiency, when:

$$\text{If} \qquad W = L_2 \;\rightarrow L_1 = \frac{\lambda}{4} \qquad \text{.........(eq.3.2.1)}$$

Now if W=0 or W<<L_2, which means the short is a pin, then the PIFA will be resonant at:

$$\text{If} \qquad W = 0 \rightarrow L_1 + L_2 = \frac{\lambda}{4} \qquad \text{............(eq. 3.2.2)}$$

A space of about 1/4th of the wavelength is needed between the edge and the shorting plate. If we take width of the short, *W*=*L2*, then the distance between one edge and the short is simply L_1 which is given by the equation" [3.2.1].

“Since fringing fields along the edge are the reason for the radiation in micro-strip antennas, we observe that the length from the open-circuited radiating edge which is shown as the far edge in Figure 3.4 to the shorting plate is on an average equals to L1+L2. The clockwise and counter-clockwise paths measured almost always add up to 2*(L1+L2), so on an average, we can safely say that resonance occurs when the path length (L1+L2) for a single path is of quarter-wavelength.”

In general, the resonant length of a PIFA can be approximated as a function of its parameters as:

$$L_1 + L_2 - W = \frac{\lambda}{4} \quad \text{.......(eq. 3.2.3)}$$

And as we know c=λ*f, then substituting for λ in eq.3.2.3,we get:

$$f = c_o/(\lambda * \sqrt{\varepsilon_r}) \text{ ....(eq.3.2.4)}$$

Where c_o is 3*10^8 m/s.

Hence using the above derived equations one can easily design a basic PIFA and further modulations can be done to improve the performance and as per the requirements of the application.

3.3 Applications

Inverted-F antennas find applications mostly in compact wireless hand-held devices, the likes of which are mobile phones and laptop or tablet computers which employ wireless transmissions such as Bluetooth, GSM and Wi-Fi.

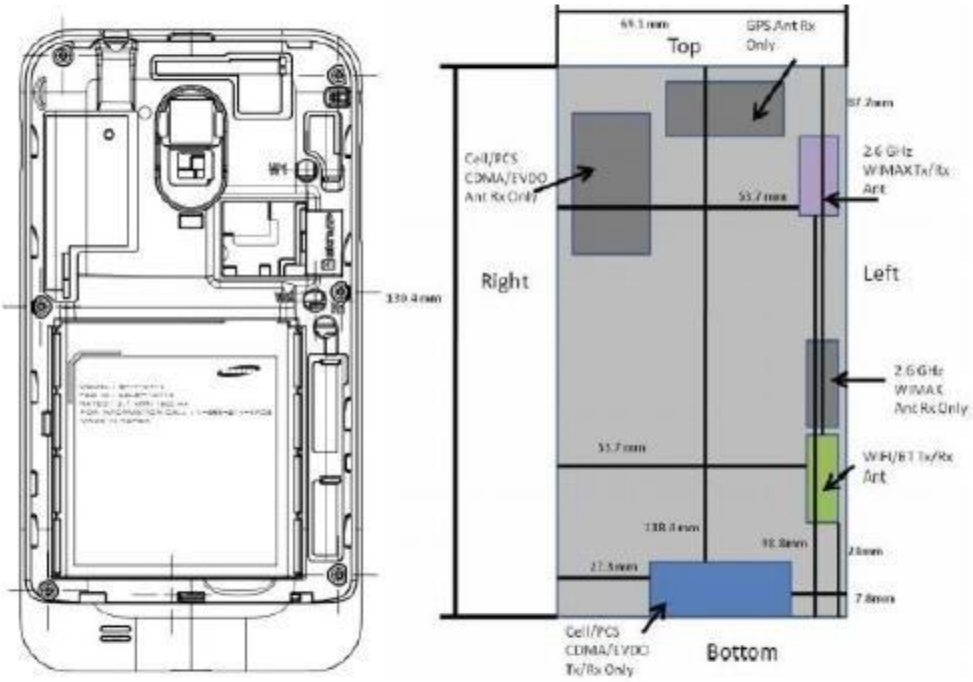

Fig 3.5 The antenna types and location on Samsung Galaxy S

PIFAs can also brought in use for Vehicle Telematics as the follow the contour of the vehicle with which it is connected for style and aerodynamics reasons

- Multiband PIFAs are used to combine the antennae feeds for satellite navigation, car radio and of course for mobile phones.
- A small PIFA can also be designed for wearable applications.
- PIFAs can be designed for military applications too.
- Widely used for LTE,WLAN,GSM-900,DCS-1800,PCS-1900, and so on

CHAPTER 4
DESIGN AND FABRICATION OF PLANAR INVERTED-F ANTENNA

4.1 Methodology

The previous chapters dealt with the following topics: the introduction and overview of the evolution of the antennas which are widely used in wireless devices for different application of wireless communication, the objective and outline of the thesis and the literature review about the previous work done in this field was also presented.

Antenna theory giving the definition of its parameters was developed so that they help in better understanding of the performance of the proposed design and design procedure of Micro-strip patch antennas was understood.

Further, an introduction about the PIFA was given and how it evolved from monopole antenna and patch was added and it became Planar Inverted-F antenna from Inverted-F antenna and some applications were mentioned.

These topics now will be used to design the proposed antenna which is a wideband PIFA having very narrow thickness so that can be efficiently embedded in any wireless device. This wideband compact PIFA has been designed on CST Studio Suite 2014 and simulations are done and its relevant characteristics too have been evaluated and observed.

4.2 Geometry of the proposed antenna

The geometry of the proposed antenna is shown in Fig. 4.1. It is based on the conventional PIFA antenna but uses two additional shorting plates which help in improving the return loss and bandwidth of the antenna structure so that wideband achieved should be below -10dB.

Two slots in the ground are also made or we can say it a defected ground structure (DGS), as shown in fig 4.2, which help in improving the band-width and hence a considerable increase in the band has been achieved without much effect on the gain, directivity and radiation efficiency.

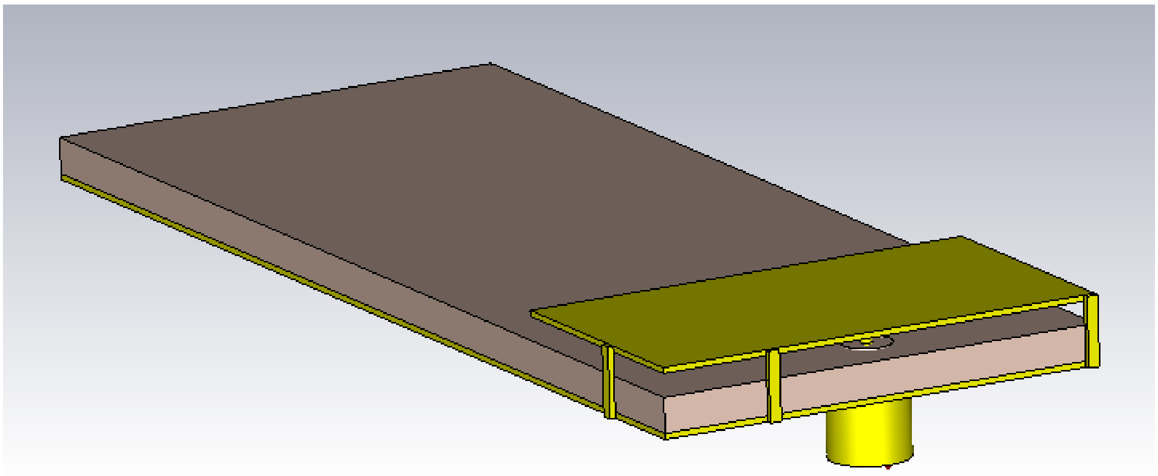

Fig 4.1 Design of the proposed antenna

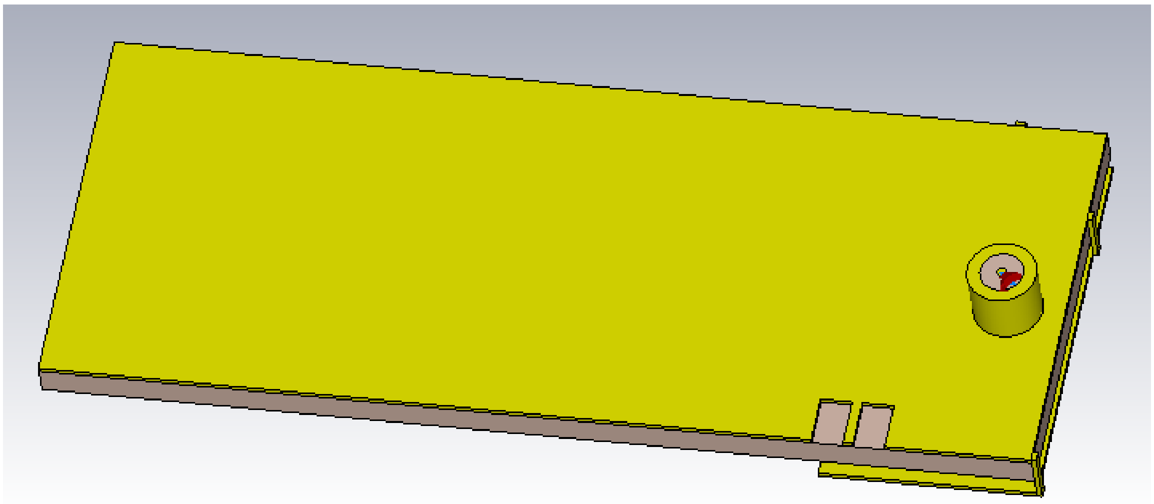

Fig 4.2 Slots made in the ground

Fig 4.1 shows the geometry of the proposed PIFA model. It is designed by using FR-4 (lossy) substrate having dielectric constant, ε_r=4.3 and dielectric loss tangent, tan δ =0.025 and thickness, t=3 mm and having dimensions 100*40mm^2. The ground is of pure copper and is having 0.5 mm thickness, now after maintaining an air-gap of h= 2 mm, a patch, which is also made of pure copper and having dimensions 40*22*0.5mm^3, is connected to the ground plane with help of three shorting plates having width Ws=1 mm and thickness 0.5 mm and the shorts are also made of copper.

For feed, an SM A connector has been used which connects the patch and goes through the substrate and ground, and excitation is given to it operate the antenna. The feed is at a distance, D=17 mm from one shorting plate and 11 mm and 22 mm from the other two shorting plates, and 4.75 mm away from the edge near which it is connected.

4.2.1 Basic PIFA design

This basic PIFA is designed bringing into use the FR-4 (lossy) substrate with the above mentioned dimensions and the copper patch too has the same specifications mentioned in the previous section. The shorting plates also have the same width as that of the final design in the basic model which are Ws=1 mm and are connected between the patch and the ground as shown in the figure 4.3

The distance 'D' between the feed and one of the shorting plates is maintained 17 mm and other two are at 11 mm and 22 mm distance from the feed, and by connecting a discrete port to the feed structure, the simulations are done and the results are presented in the next chapter.

The air-gap between the substrate and patch is 2 mm making the antenna compact but small air-gap has its own limitations on the gain of the antenna but gives good return loss S11(dB).

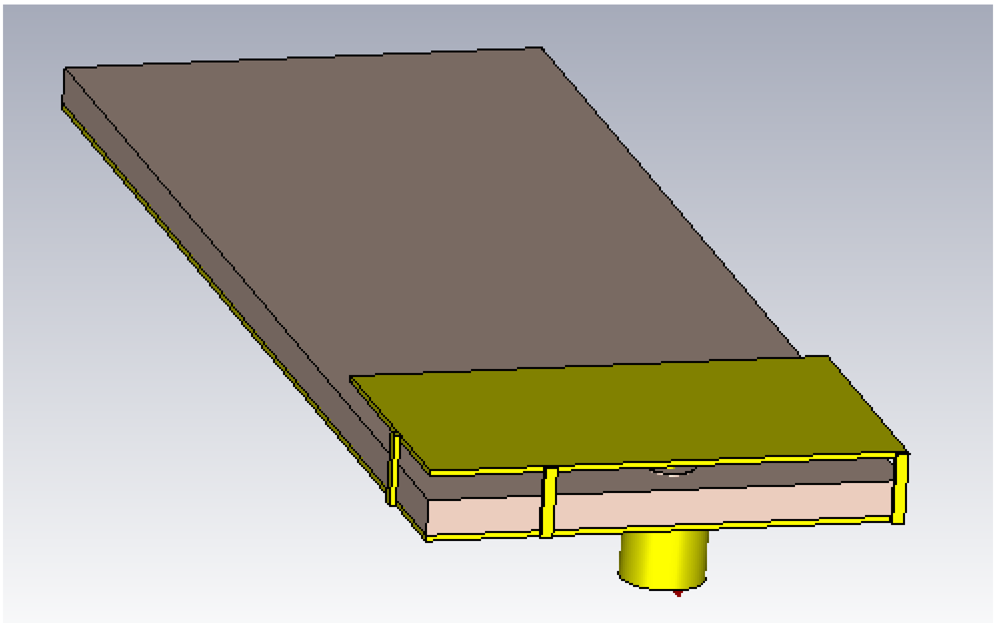

Fig 4.3 Top View of the basic antenna structure

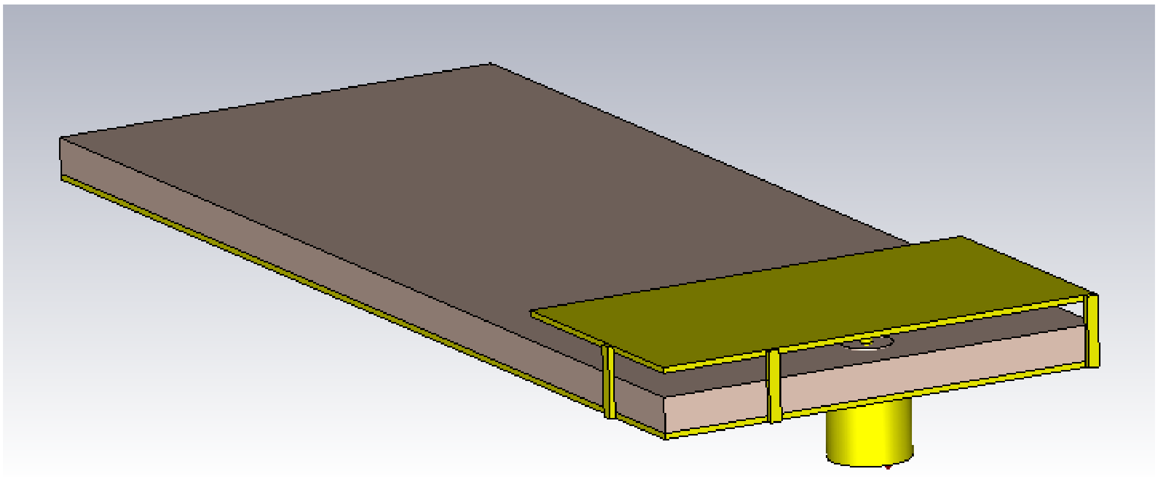

Fig 4.4 Side view of the basic PIFA model

4.2.2 Basic PIFA with two slots etched on the ground

A defected ground structure (DGS) is said to increase the bandwidth but it has its own adverse effects on the gain and the return loss. So two slots are cut-out from the ground with the intention to improve the bandwidth and the desirable result has been obtained.

In this design, the substrate, ground and the patch dimensions and other specifications remain the same, but two slots of 5*3.2*0.5 mm^3 have been removed from the ground plane 14 mm away from the shorting plate and maintaining a gap of 1 mm between both the slots, shown in fig 4.2, which have considerably increased the bandwidth.

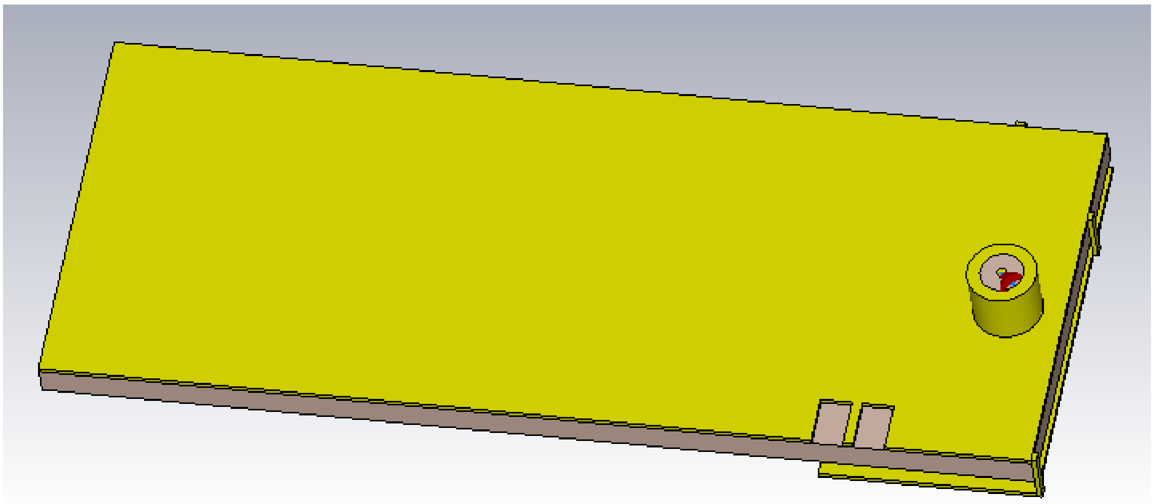

Fig. 4.5 Two slots cut-out from the ground plane

4.3 Fabrication of the designed antenna

The proposed antenna has been fabricated as per the above design specifications.

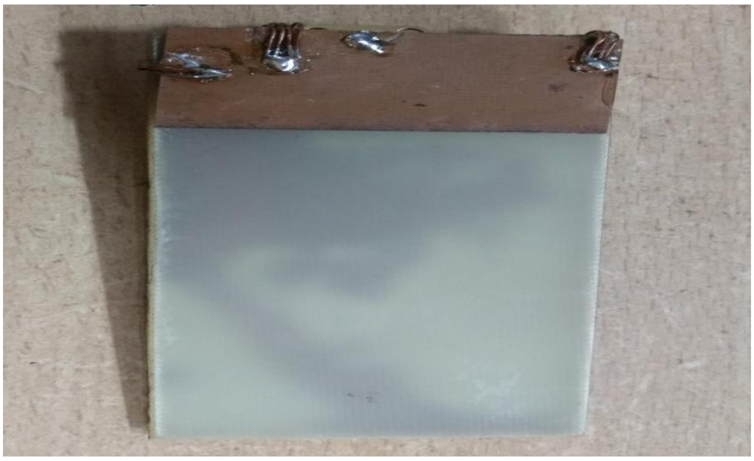

Fig 4.6 Top view of the antenna

Fig 4.7 Rear view of the antenna

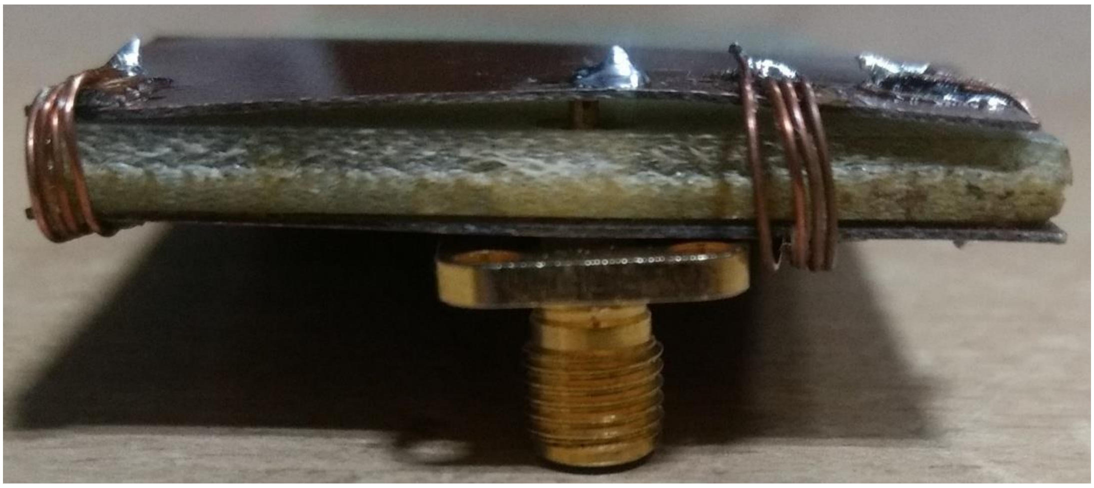

Fig 4.8 Side view of the antenna

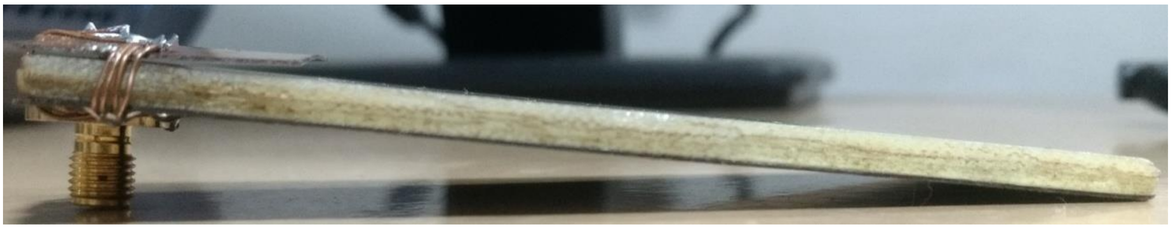

Fig 4.9 Side view of the antenna

CHAPTER 5

RESULTS AND CONCLUSIONS

5.1 Simulation Results

“The proposed antenna has been designed and simulated in Computer Simulation Technology (CST Studio Suite 2014 version) software”. The results have been analyzed in terms of S-parameters and directivity i.e. the far field patterns at the desired frequency. S-parameters describe the electrical behaviour between the ports in an electrical system. S11 denotes the input return loss. Return loss is a proper way to characterize the input and output of signal sources. The return loss must be greater than -10db.

5.1.1 Simulation result of the basic antenna model

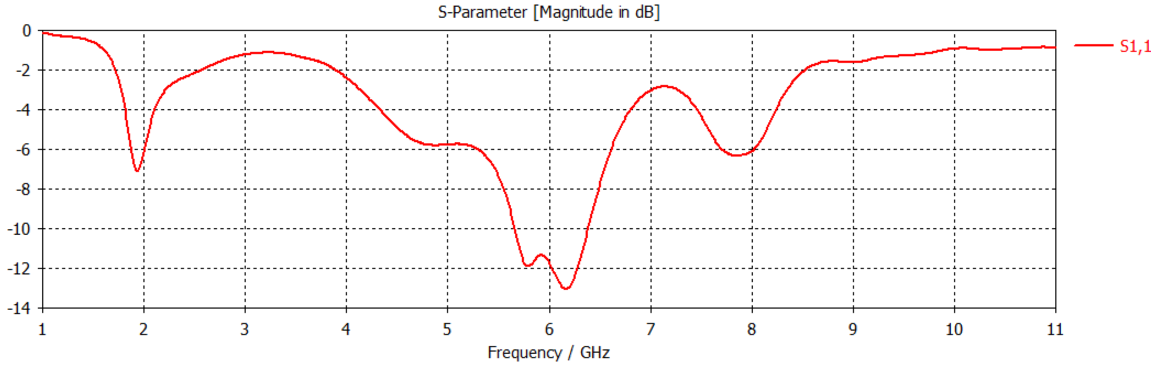

Fig 5.1 S11 plot of the basic model

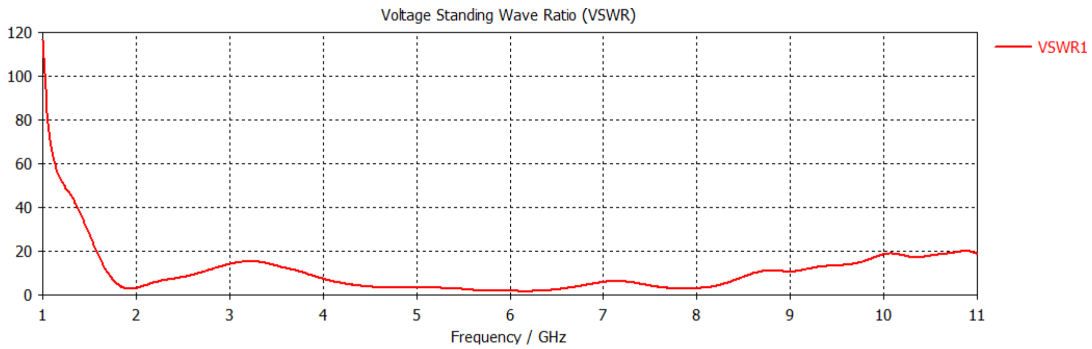

Fig 5.2 VSWR plot of the basic model

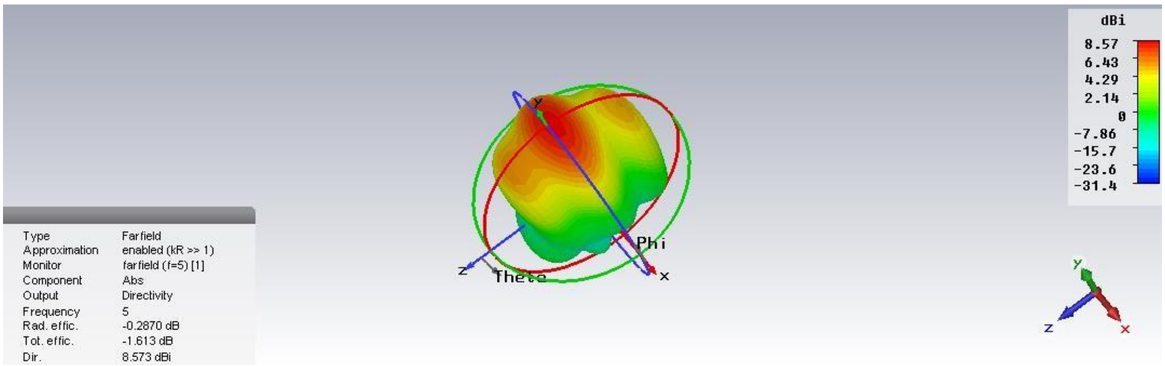

Fig 5.3 3-D Far-field radiation pattern of the basic model

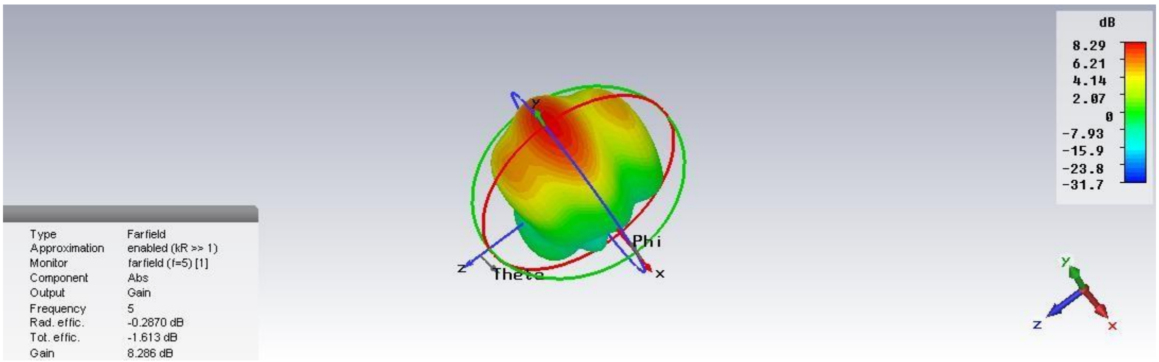

Fig 5.4 3-D Far-field radiation pattern of the basic model

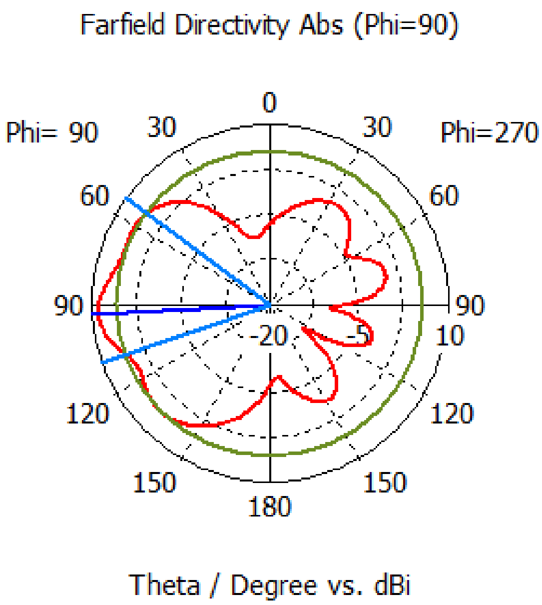

Fig 5.5 Polar plot of the far-field radiation pattern

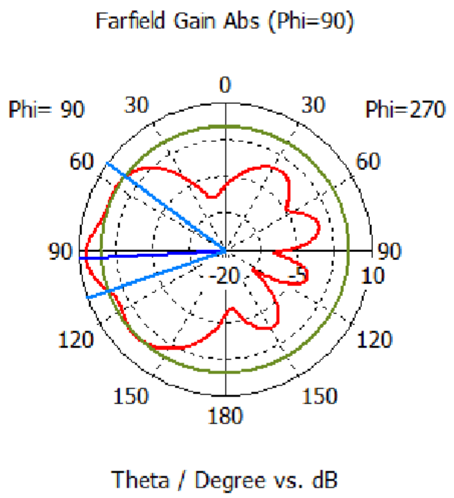

Fig 5.6 Polar plot of the far-field radiation pattern

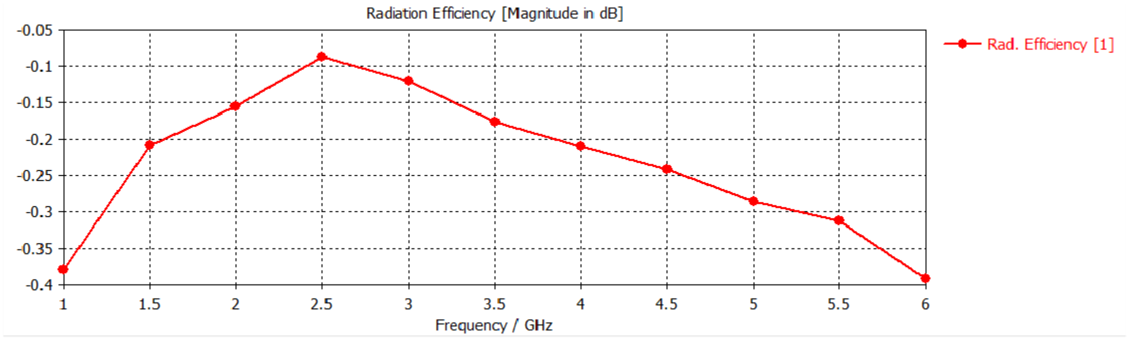

Fig 5.7 Radiation efficiency plot of the antenna model

As a substrate of thickness 3 mm is used, a broad band of frequencies is observed around the resonant frequency as using thick dielectric substrate is a common way to obtain good bandwidth results, but as the air-gap is very small, it has its own effect on the gain and lowers it but small air-gap gives good return loss.

5.1.2 Simulation Results of the basic antenna model with slots etched on the ground

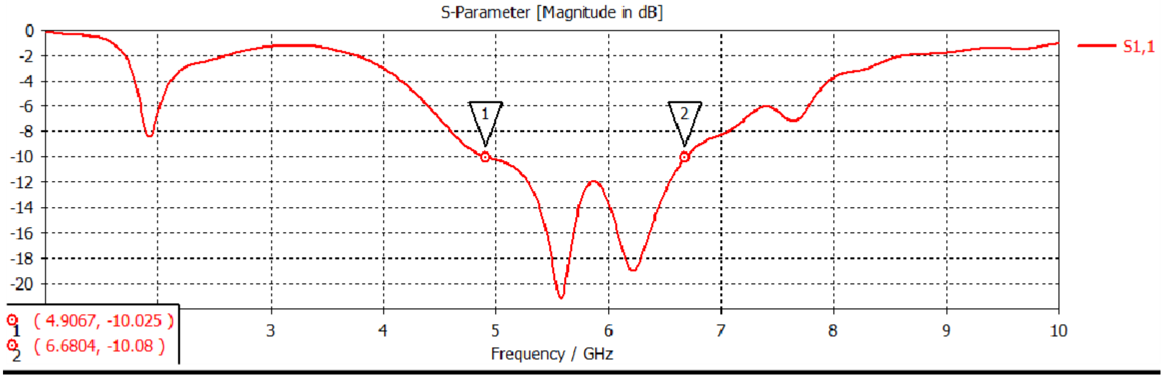

Fig 5.8 S11 plot of the antenna model with slots etched on ground

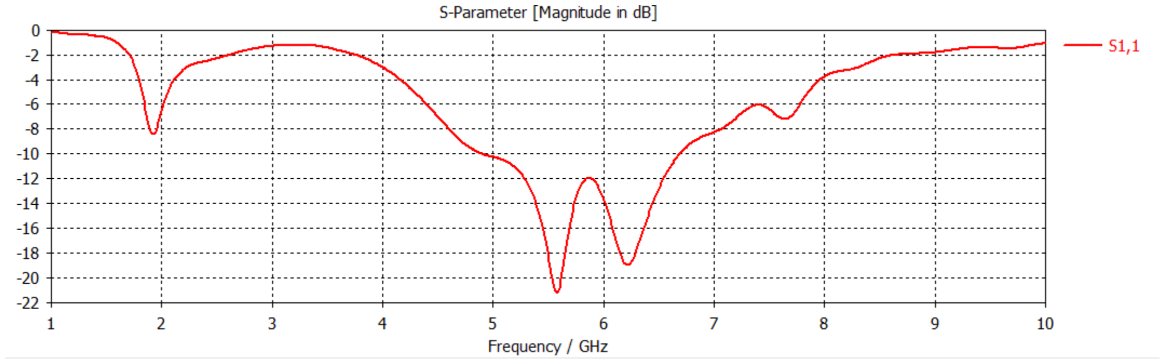

Fig 5.9 S11 plot of the antenna model with slots etched on ground

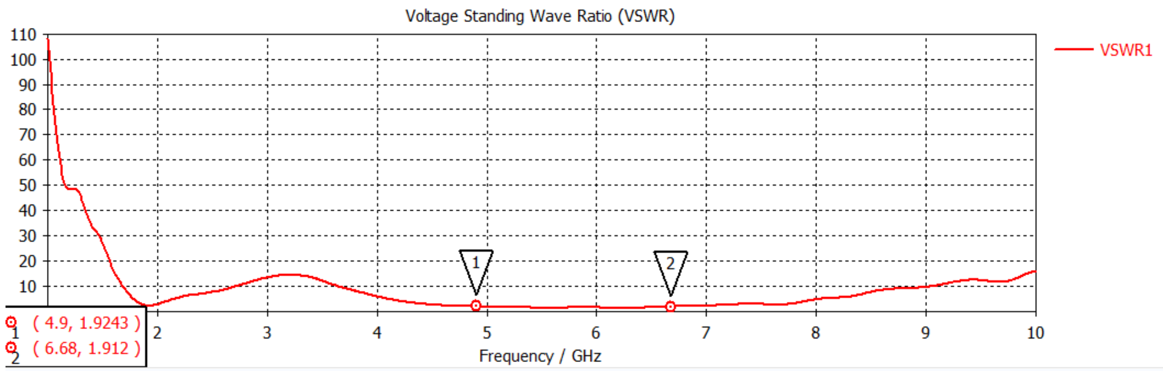

Fig 5.10 VSWR plot

VSWR less than 2 is obtained which is a desirable property of the antennas. VSWR<2 is an important requirement for good performance of the PIFA.

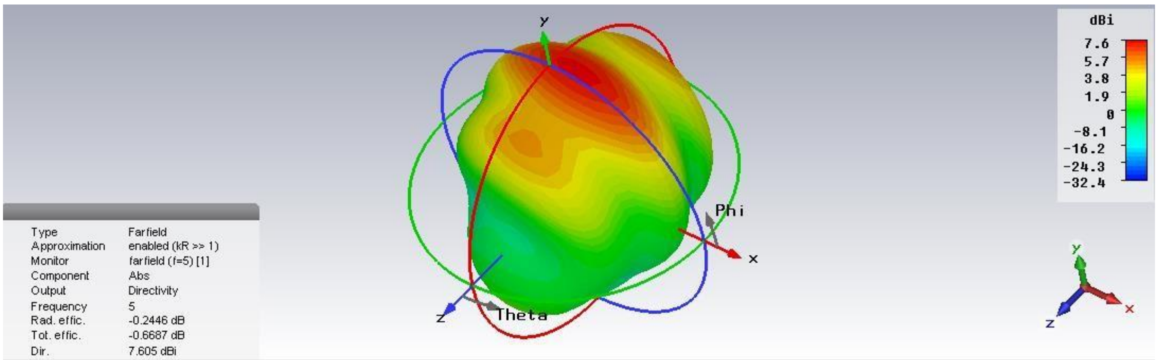

Fig 5.11 3-D Far-Field radiation pattern of the antenna model

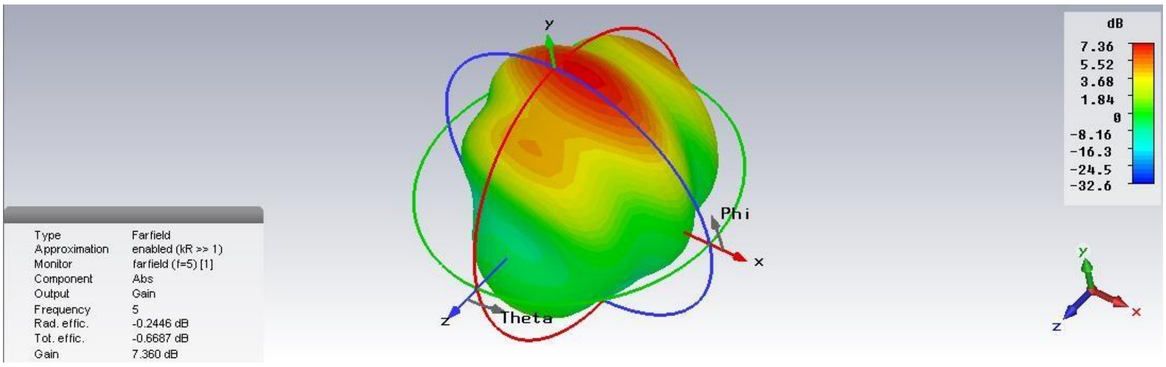

Fig 5.12 3-D Far-Field radiation pattern of the antenna model

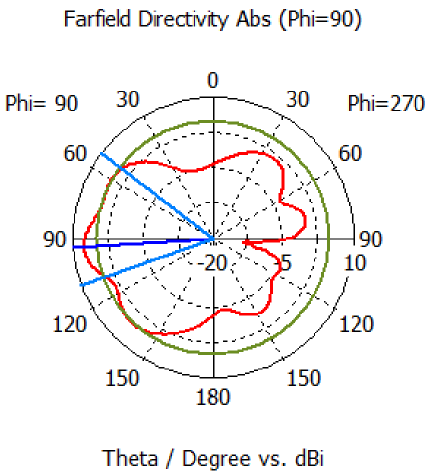

Fig 5.13 Polar plot of the Far-field Radiation pattern

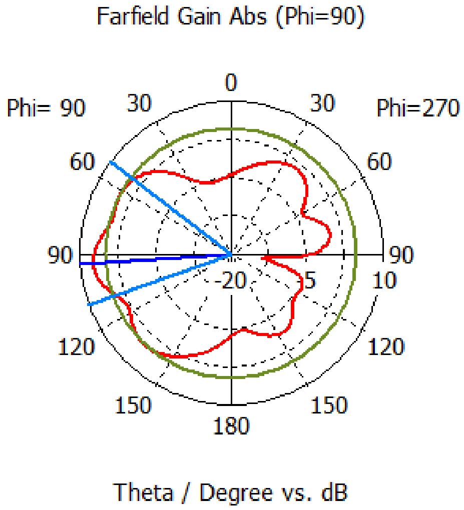

Fig 5.14 Polar plot of the Far-field Radiation pattern

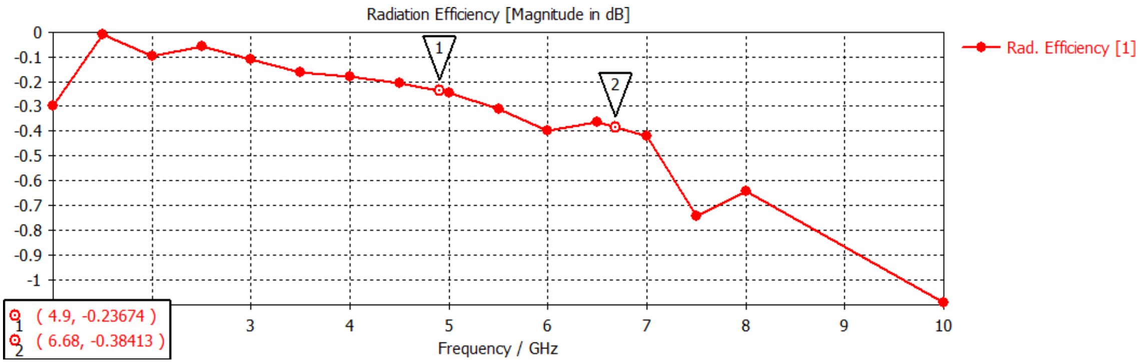

Fig 5.15 Radiation Efficiency plot of the antenna model

Comparing the simulation results of the two models, we observe that the return loss and bandwidth has improved compared to the basic model which is without the slots etched on the ground.

Also to calculate the impedance bandwidth, it is necessary that the return loss is more than -10 dB. And on etching the two slots on the ground, the return loss is improved and now an impedance bandwidth of 32.18% is obtained.

Comparing the two models now, the second design gives the optimum impedance bandwidth of 32.18%. 1.77 GHz of band-width is obtained by using a very simple and compact structure and the directivity and gain too conform to the typical directivity value range.

A comparison is tabulated to understand the performance of the three antenna models with regard to bandwidth, return loss, radiation efficiency and directivity.

Table 5.1 Comparisons of parameter values for the two models.

Parameters → Antenna Models ↓	Return loss(dB)	Bandwidth(GHz)	Radiation Efficiency (%)	Directivity (dBi)
Basic PIFA.	-13.12	0.727	93.61	8.573
Basic PIFA with two slots etched on ground.	-21.19	1.77	94.52	7.605

5.2 Measured Results

After the antenna is fabricated, the measurements of the antenna are done using Rohde and Schwarz ZNB-40 Vector Network Analyzer. The S11 of the fabricated antenna is plotted as shown in fig 5.16. On comparing the simulated result previously shown in fig.5.8 with the measured result, we observe that both are almost in agreement and a bandwidth of around 1.4 GHz is obtained in both the cases.

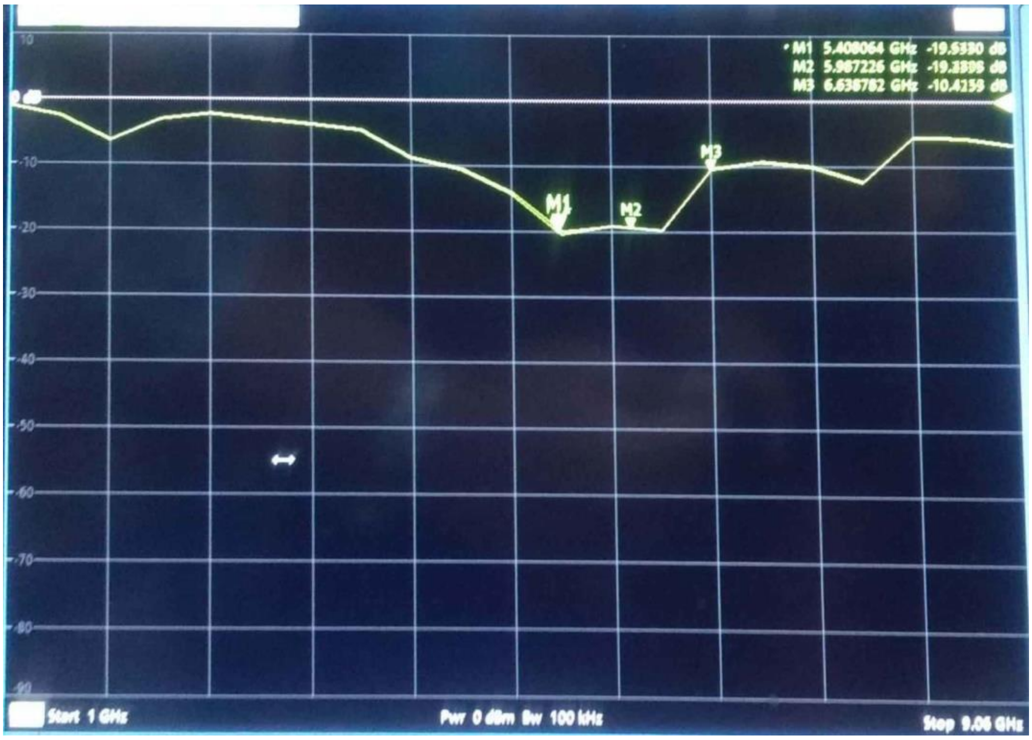

Fig 5.16 S11 plot on the R & S ZNB-40 Vector Network Analyzer

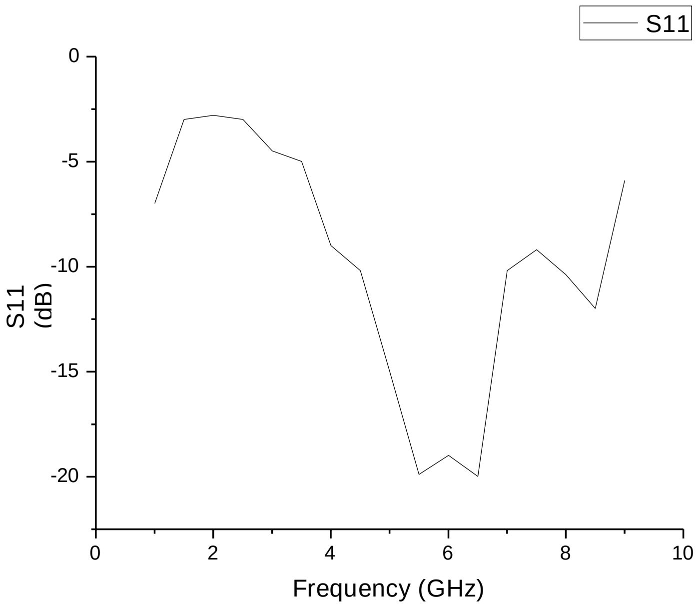

Fig 5.17 S11 (dB) plot obtained from VNA

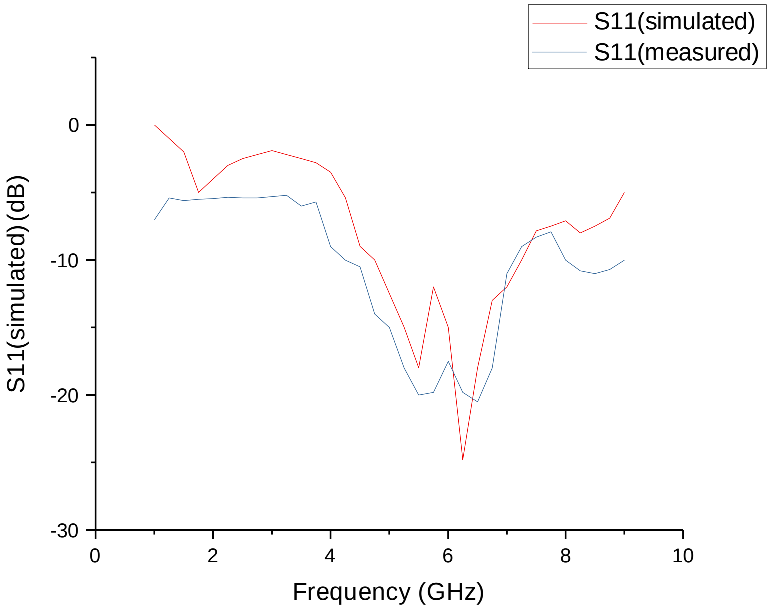

Fig 5.18 Comparison of the simulated result and measured result

A slight improvement in the bandwidth and the return loss is observed in the measured results.

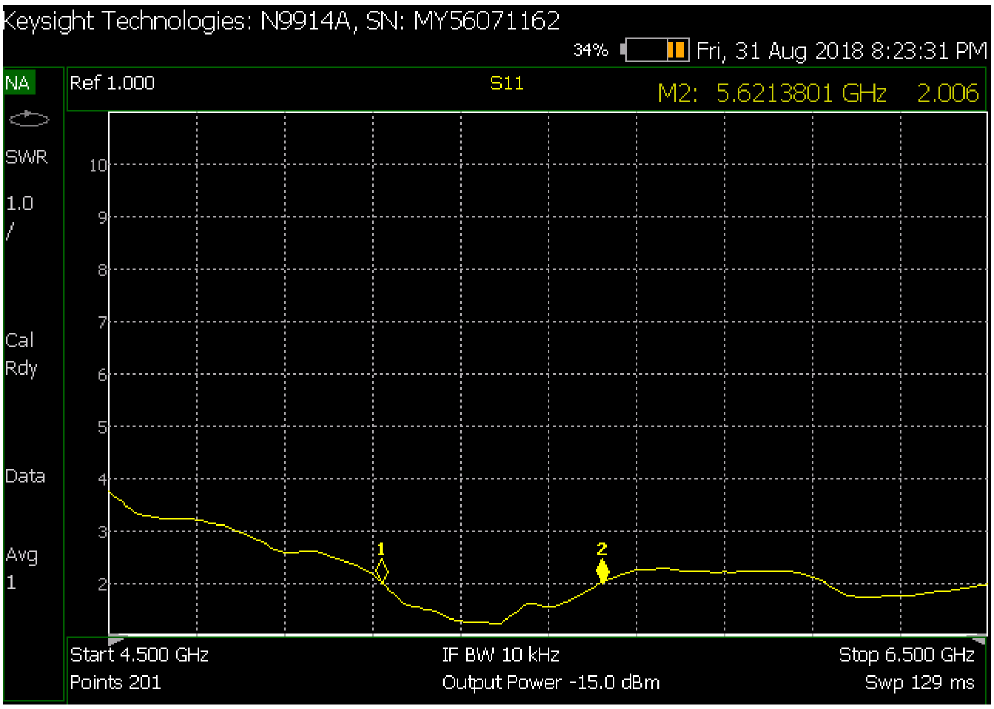

Fig 5.19 Standing wave ratio plot on the VNA

VSWR obtained on the VNA is around 2 and VSWR<5 is an important requisite. Comparing the VSWR plot obtained after simulation with the measured plot obtained on the VNA, both the results are almost in agreement.

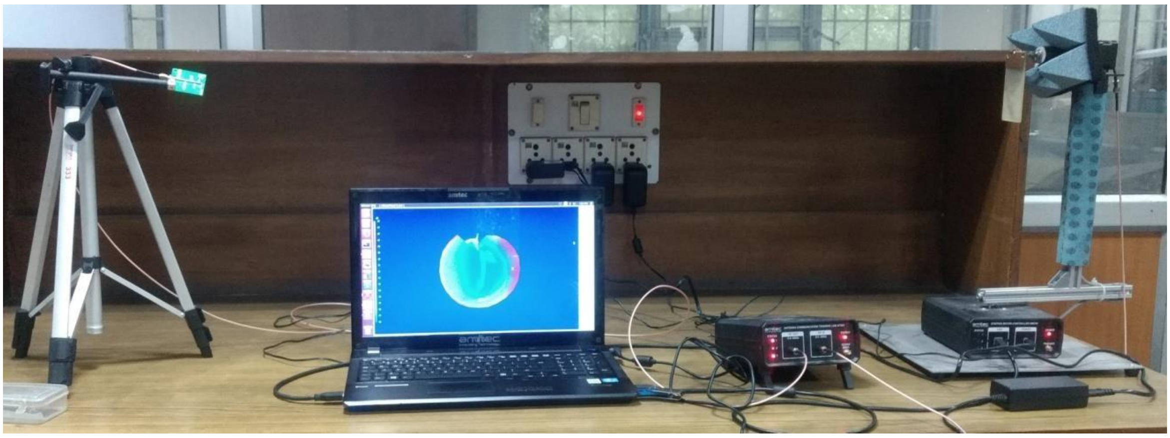

Fig 5.20 Setup to test the 3-D radiation pattern

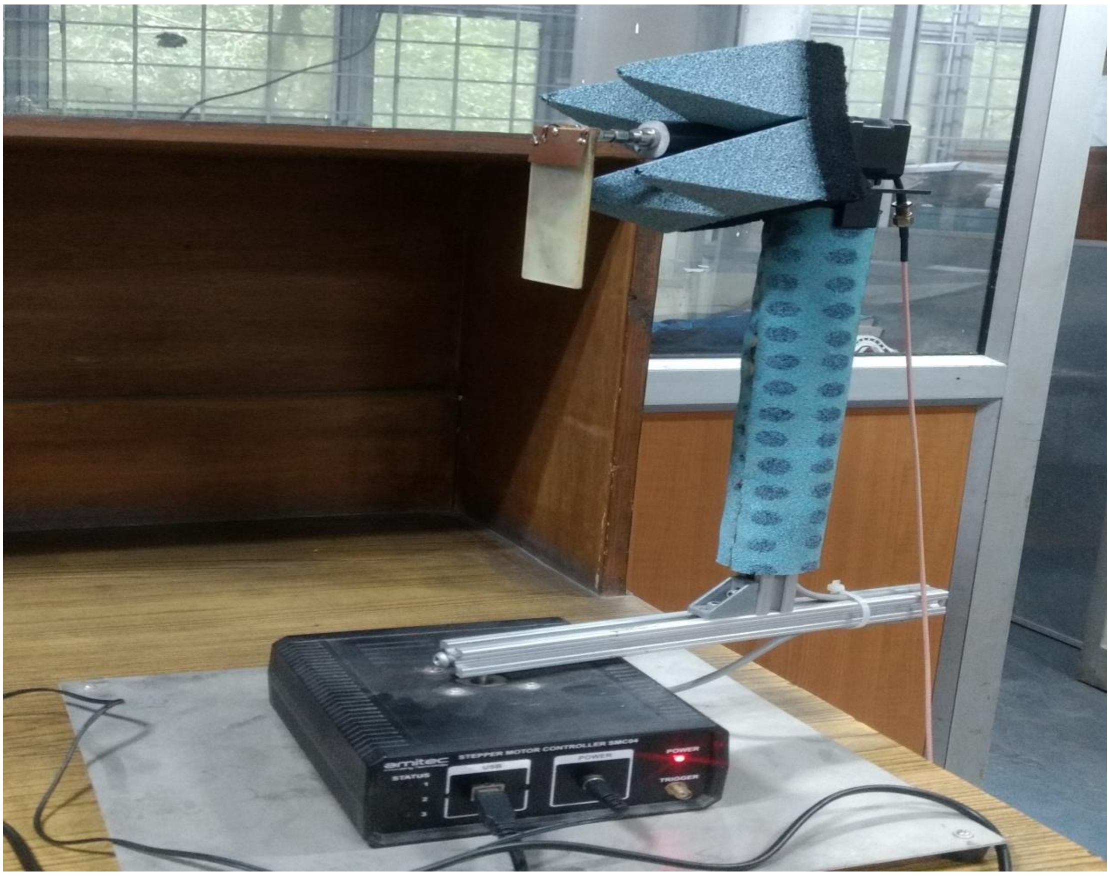

Fig 5.21 Fabricated Antenna under test

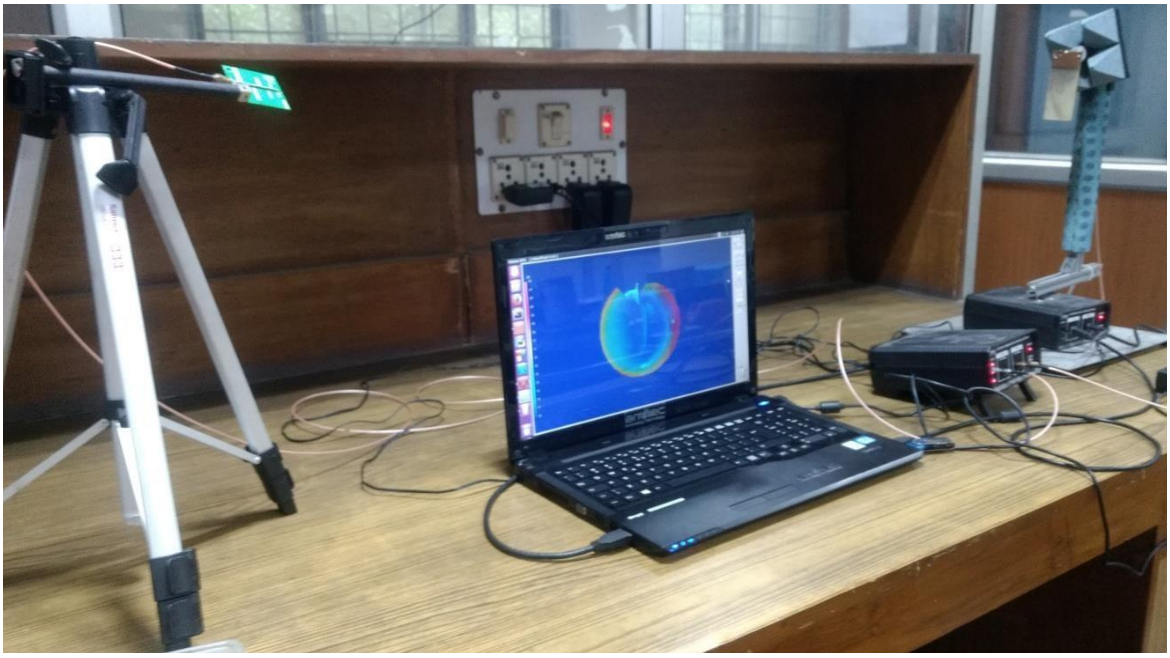

Fig 5.22 Radiation pattern obtained after testing

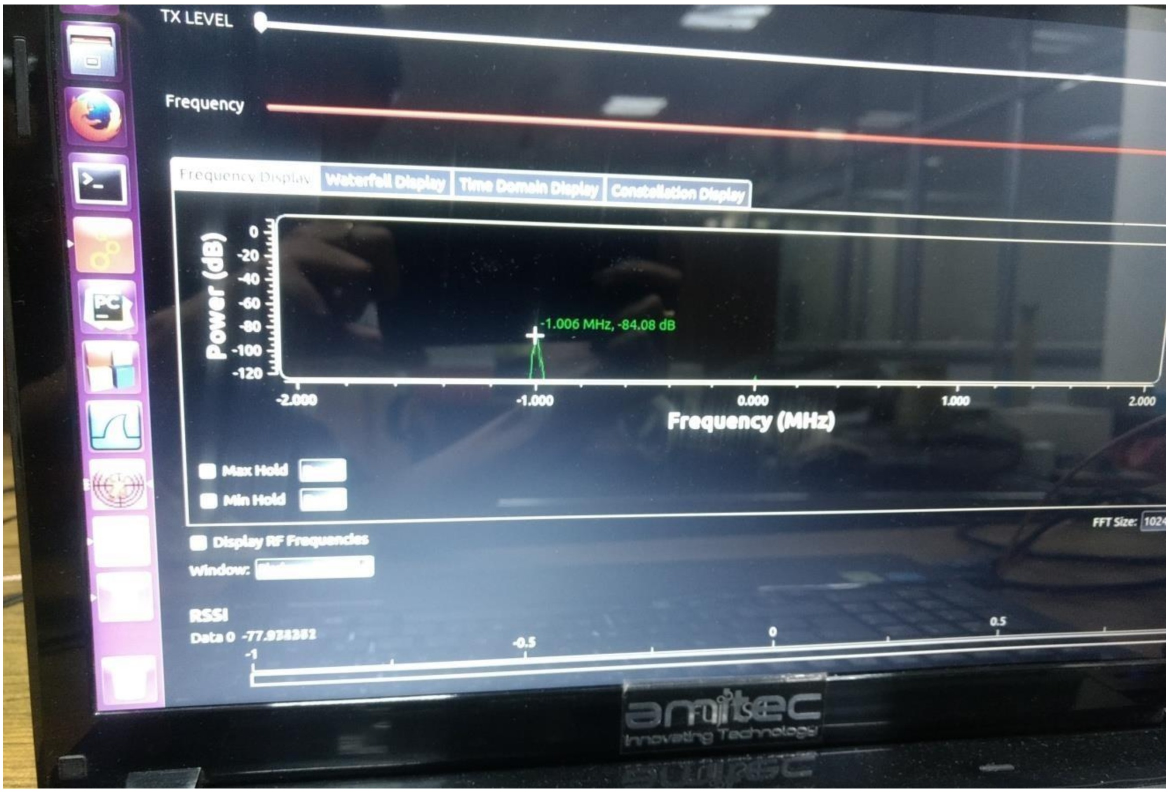

Fig 5.23 Power level

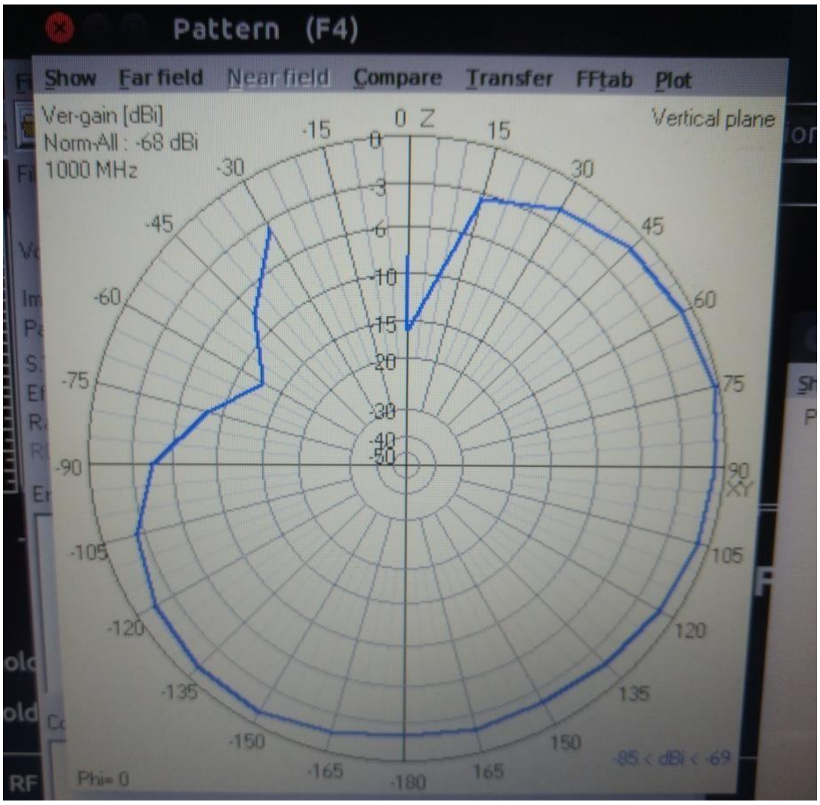

Fig 5.24 2-D Radiation Pattern obtained after testing.

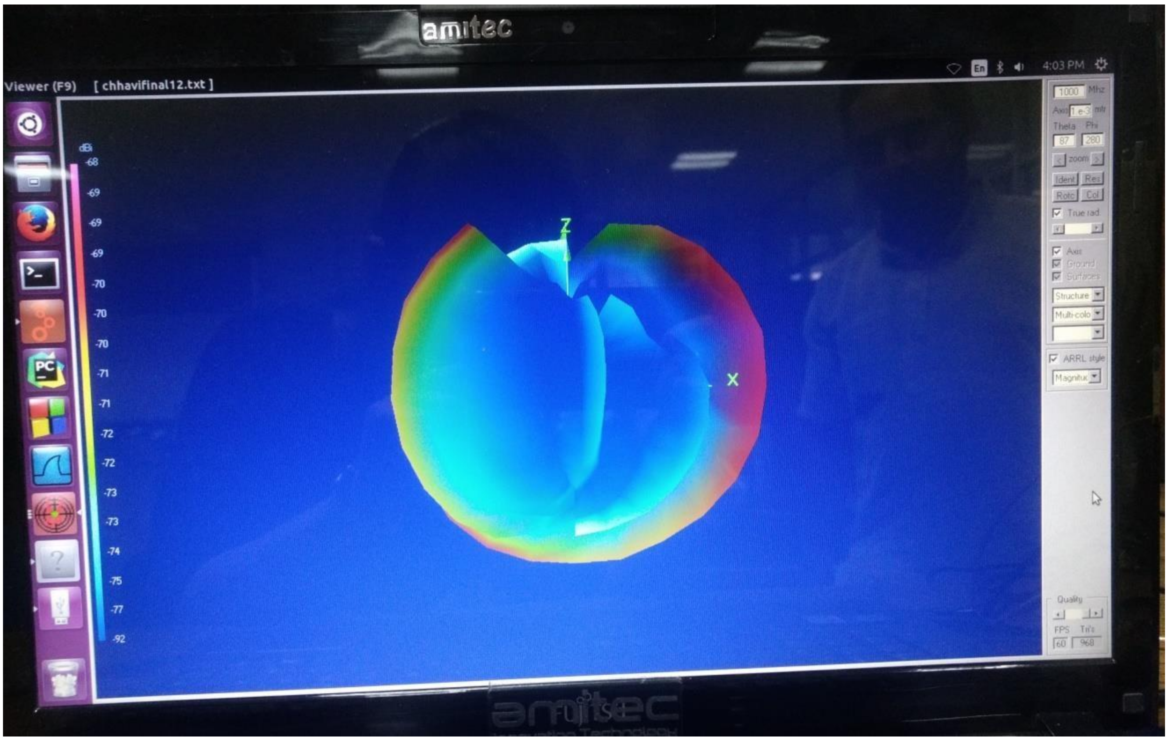

Fig 5.25 3-D Radiation Pattern obtained after testing.

5.3 Conclusions

The essential objective of this project was to design and simulate a wideband planar inverted-f antenna. Many designs were considered before finalizing the design with two slots cut-out from the ground and three shorting plates connected between the radiating patch and the ground plane.

Two slots were formed in the ground forming a kind of DGS which is generally brought in use to augment the bandwidth offered by the antenna. Hence using these, an impedance bandwidth of approximately 32.18% was achieved. As the air-gap is very small, the antenna structure is very compact.

The world of science and technology has always been pushing boundaries and scientists and researchers are continuously working on the betterment of the technology in every field in the interest of the society at large. This project work too is a small attempt in this regard and as every research work has some scope for improvement, further efforts can be made to improve the performance of the antenna model in terms of the gain and radiation efficiency and also further increasing the bandwidth. An attempt to make the antenna reconfigurable and operation in multiple frequency bands with optimum performance in every band can be made without making the antenna bulky and difficult to employ in the devices used for communication on the go.

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