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on

Design and Analysis of Planer Inverted-F antenna (PIFA) with Electromagnetic Bandgap structures

Submitted in partial fulfillment of
the requirements for the award of the degree of

Master of Technology
in
Microwave and Optical Communication Engineering

Submitted by
Abhishek Sharma
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Under the guidance of
Dr. N.S.Raghava
Professor
Electronics and Communication Department

Department of Electronics and Communication

Delhi Technological University
Delhi, India -110042

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CERTIFICATE

Certified that the thesis entitled "Design and Analysis of Planer Inverted-F antennas(PIFA) with Electromagnetic Band gap structures " submitted by **Abhishek Sharma (2K15/MOC/01)** in the partial fulfillment of the requirements for the award of the degree of Master of Engineering (Electronics and Communication Engineering) of Delhi Technological university, is a record of student's own work carried under my supervision and guidance. To the best of our knowledge, this thesis has not been submitted to DTU or to any other University or institute for award of any degree. It is further understood that by this certificate the undersigned do not endorse or approve any statement made, opinion expressed or conclusion drawn herein, but approve the thesis only for the purpose for which it is submitted.

Supervisor
Dr. N.S.Raghava
Professor
ECE Department
DTU, Delhi

Head of Department
Dr. S. Indu
Professor & HOD
ECE Department
DTU, Delhi

DECLARATION

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(Abhishek Sharma)

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ABSTRACT

In mobile phones and several other wireless communication devices, antenna is an important element which decides the quality & performance of the device over various communication standards. In last few years mobile phones has evolved rapidly and they are required to give various services like data, voice, Internet & multimedia content without compromising on their weight, volume and performance. Latest communication standards such as GPS, Wi-Fi, 3G, WiMAX, 4G LTE, GLONASS etc are needed to be supported by the handsets. The recent growth and rapid development of mobile communication and devices operating at multiple frequency bands has lead to the requirement of antennas which supports multiband or wideband operation.

With Fourth Generation (4G) wireless communication systems evolution worldwide, the demand for handsets to operate on both old & new standards with minimum number of antennas becomes important. Therefore, the most important task for the new antennas is to work on both new 4G LTE, WiMAX frequency bands and already established frequency bands also. However, there is also a requirement in handheld devices to support both cellular and non-cellular technologies such as GPS, WLAN & Bluetooth etc.

In this thesis, a small and compact multiband internal antenna that operates in several bands including GPS, GLONASS, GSM 1800, GSM 1900, UMTS (3G), 4G LTE, WLAN, Bluetooth frequency bands has been designed. The antenna is a single feed and low profile Planar Inverted-F Antenna (PIFA). It has two rectangular slots on the ground plane which improves operating bandwidth & resonance of the antenna. Using High Frequency Structure Simulator (HFSS) software, simulation has been carried out to analyze and optimize the antenna's characteristics and performance. From the simulation results, it has been observed that the antenna is able to operate at desired resonant frequencies and have good operating bandwidth supporting multiple bands.

LIST OF ABBREVIATIONS

DCS	Digital Communication System
FDTD	Finite-Difference Time Domain
GSM	Global System For Mobile Communications
IFA	Inverted-F Antenna
ILA	Inverted L Antenna
IMTS	International Mobile Telecommunication
MSA	Microstrip Antenna
EBG	Electromagnetic band gap structure
PIFA	Planar Inverted-F Antenna
VSWR	Voltage Standing Wave Ratio
WLAN	Wireless Local Area Networks
UMTS	Universal Mobile Telecommunications System
Wi MAX	World Interoperability for Microwave Access
SAR	Specific Absorption Rate
LTE	Long Term Evolution
FEM	Finite Element Method
RF	Radio Frequency
HFSS	High Frequency Structure Simulator

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CHAPTER 1

INTRODUCTION

1.1 History of Mobile Communication

From the beginning of the evolution of mankind, communication plays a crucial role in establishing the exchange of information among the people. Over the last century, several advancements have been done in the area of mobile communication. Heinrich Hertz confirmed the existence of EM waves which lead the new development era in the fields of mobile, aerospace communication, and television.In this row, Guglielmo Marconi in 1897 first ever used the electromagnetic wave for communication for long distance. In the twentieth century, strong progress and evolution is set in the field of antenna and EM waves. The technology have covered a long path to the miniaturization of antenna upto a millimeter scale. Now, in 21^{st}-century wireless communication is progressing very rapidly and mobile units are becoming smaller and smaller incorporating several services.

The antenna is one of the most important hardware for transmitting as well as receiving side of wireless communication. Generally, an antenna act as a transducer device between the free space and guided waveguide. According to the IEEE, the antenna can be defined as the device for radiating or receiving radio waves. Maxwell gave the EM theory on which the working of all the antenna rely on. Modern wireless communication antennas require careful design and thorough understanding of the concepts involved. In the past, lots of type of antennas have been introduced like monopole, dipole, parabolic, helical, horn. These antennae are very much efficient despite their bulky size In the last few decades the scholars like Tatsuo Itoh and many other have done a lot of work on miniaturization of the antenna. Some of them introduce a new terminology called EBG structures which are derived from PBG structures in the optical domain. These are the periodically repeated structures which are generally used to suppress the surface structures. This structure plays a very crucial role in incrementing the bandwidth of microstrip antenna. They also prevent a particular band of frequency from propagating in the frequency band.

During last few years, the mobile radio communication industry both the manufacturers and service providers have started to grow rapidly. All these advancements in wireless technologies resulted in increasing mobile communication users and compact handheld devices. With increasing number of services provided and evolving trend of miniaturization, the need for multi-band compact antennas is on a rise. To the fulfillment of the requirement of a small size fit for the size of mobile phones, the compactness of antenna is to be optimized according to our need. While choosing an antenna for a mobile phone the dimension and specific absorption rate (SAR) are taken into consideration.SAR is the maximum amount of energy which is dissipated per unit volume toward the user body while using the mobile phone is in use. This energy dissipation occurs close to the antenna terminal.

Up the to mid-1990s, almost all GSM mobile handsets had an external antenna that was one of the following three types: a helix, a monopole (whip), or a helix-plus-whip combination. Internal antennas were gradually introduced into mobile phones to facilitate more flexibility in the industrial design and SAR reduction. As we are proceeding in the 21st century, the growth of mobile communication industry continues to rise throughout the world and many new standards and technologies have been introduced in wireless devices such as 3G, 4G LTE, GLONASS, WLAN, Wi-MAX and so on. Frequency bands allocated for modern wireless communication standards are summarized in Table 1.1. Due to this widespread growth of mobile phone subscribers, handset market has also increased tremendously and this means that more antenna designs have to be developed and introduced to cope up with the demand

Table 1.1 Various Communication Frequency Bands

Wireless Communication Service		**Allocated Frequency Band**
GPS 1400 GPS 1575	Global Positioning System	1227-1575 MHz 1565-1585 MHz
WiMAX	Worldwide Interoperability for Microwave Access	3400-3600 MHz
UMTS 2000	Universal Mobile Telecommunications Systems	1920-2170 MHz
4G LTE 700	Fourth Generation Long Term Evolution	704-716 MHz, 734-746 MHz
GSM 900	Global System for Mobile Communication	890-960 MHz
ISM 2.4 ISM 5.2 ISM 5.8	Industrial, Scientific, Medical	2400-2484 MHz 5150-5350 MHz 5725-5825 MHz
DCS 1800	Digital Communication System	1710-1880 MHz
UWB	Ultra Wide Band	3.1 – 10.6 GHz

1.2 Antenna Design Challenges in Mobile Communication Systems

In last few years an exponential growth is observed in demand for small size, compact, flexible, ease of bulk production and robustness for mobile communication applications. The main challenges that designers faced while designing the antenna are trade off among bandwidth, gain, dimensional limitation, polarization diversity and radiation efficiency.To deal with these challenges several miniaturization techniques like metamaterials. Defective ground structure, Electromagnetic Band gap structure etc. are introduced by many of researchers.

1.3 Organization of the Thesis

In this thesis, the implementation of Electromagnetic band gap structures is being done on Planer inverted F antenna. The designing is emphasized on small electrical length, band width, and multi band structure. Despite the structure of conventional PIFA antenna is a complex and very minute change in its structure leads to drastic variation in its characteristics. The main objectives of the thesis are explained with the steps shown below:

a) In Chapter 2 study of various single and multiband antenna designs are discussed and understand its characteristics. Theory and fundamentals behind PIFA are discussed. Some of the critical Antenna parameters are discussed and at last, the Overview on various type of Electromagnetic band gap structures are being done.

b) Chapter 3 involves the literature review of the papers, letters, and patents. Some description of Planer Inverted F antenna implementation on MIMO is reviewed. Some paper related to the EBG structures and its effect were reviewed.Some inferences from the extensive review are also presented.

c) In chapter 4 research methodology on conventional PIFA and proposed PIFA is performed. It involves the calculation of dimensional parameters. The simulation is performed on HFSS software.

d) In chapter 5, Simulation is being done on proposed antenna and conventional antenna and the antenna parameters are noted and analyzed. The return loss (S_{11})

characteristics, 3D gain plot, 2D plot and E field pattern are presented in this portion of the thesis. All the parameters are also being. A discussion of the results is also performed at the end of this chapter.

e) In Chapter 6, The conclusion of this thesis is concluded by comparison of both proposed antennas and suggestion also presented for future antenna development.

CHAPTER 2

MOBILE ANTENNAS AND ITS TECHNOLOGIES

2.1 Introduction

In the past few decades, there is a rapid growth in the demand for mobile communication. Due to rise in this demand, the research and development of small size and wideband antenna grew to the great extent. As discussed in the previous chapter, many technologies were introduced in the past to improve the various characteristics of antennas. In this thesis work, the main goal is to develop a PIFA antenna with the implementation of EBG structure. This work is done to attain a multi-band compact antenna. So, In this chapter, various compact antenna structures, antenna fundamentals, and various band gap structures are briefly discussed. This discussion will help the reader to recall its basics about the antenna and some miniature techniques.

2.2 Antennas Used for compact handheld devices

Various antennas have been designed worldwide for the handheld devices. The main characteristics considered by the designer while designing this antenna are space constraint (dimension), frequency band, bandwidth and Omni directional gain. The antenna can be characterized into internal and external antennas according to their deploying requirements. These antennae are generally designed for frequency requirements of LTE, UTMS (3G), Wi-Fi, Wi-Max, DCS, GSM etc. The antennas are also focused on not cellular applications like GPS, GLONASS, Bluetooth, and WLAN.

Some of the antennas used in mobile communication:

External Antennas

- Monopole antennas
- Helical antennas

Internal antennas

- Microstrip antennas
- Planar Inverted F antennas

2.2.1 Monopole antenna

Monopole antennas represent Fig.2.1 the simplest and earliest generation of mobile antennas. It consists of a straight conductor rod connected to the ground plane on the lower side. They were used for GSM technologies as a quarter wavelength monopole antenna. When these antennae are connected to the PCB circuit of mobile phone then the whole structure act as an unbalanced Half wavelength dipole[2]. The main advantages of this antenna are having high bandwidth, Omni directional radiation pattern and high efficiency, but they protrude out of the handheld devices and have very high specific absorption ratio (SAR).

By implementing some planer modification to this antenna which results in an increase in impedance bandwidth. Planer monopole antenna can be integrated with Mobile phone specifications.

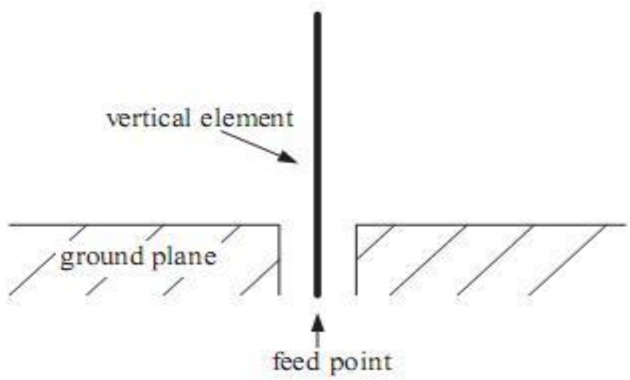

Fig 2.1 Basic monopole antenna structure [3]

2.2.2 Helical antenna

This antenna Fig.2.2 had wide applications in the last decade of 19th century. This demand arose due to its compact size with comparison with the monopole antenna with is been discussed in the previous topic. The characteristic of helical structure is a tradeoff between its size and performance as its performance is inferior to the monopole structure. To achieve the multi-band frequency in helix antenna variable pitch radiator is joint with monopole strip radiator. The pitch stages are generally used to control the resonant frequencies. Due to a helical structure, an inductance is introduced then it can also call an inductance loaded monopole antenna.

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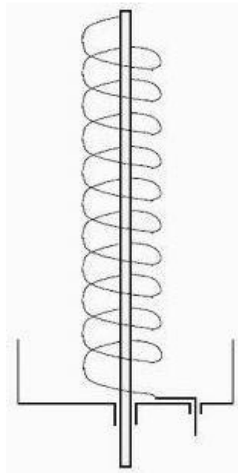

Fig. 2.2 Helical Antenna

2.2.3 Microstrip antenna

Microstrip antennas in Fig 2.3 are also called as printed or patch antennas. They got their name as these are fabricated on planar plastic circuit boards. This antenna consists of low loss substrate which is covered with copper on one side or both sides. The lower side is called is called ground plane, however, the upper patch is radiating plane. The main radiation of this antenna is through the fringing fields which are perpendicularly radiate from the edges of the radiating patch. The microstrip patch supports the Quasi TEM mode which is due to it's not homogeneous structure as air on one side and substrate on another side of the radiating patch. It's planar and compact size makes it suitable for wide applications monolithic integrated circuits and active antennas despite it's some disadvantages as low gain, narrow bandwidth, low ohmic losses etc

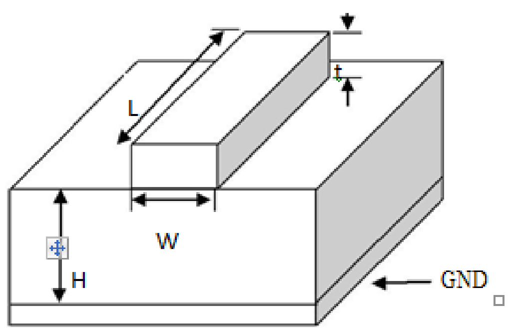

Fig. 2.3 Basic Microstrip Antenna

2.2.4 Planar Inverted F Antennas

Planar Inverted F antenna has introduced as one of the most capable and suitable structures in this class of patch antennas in last few years. PIFA has much variety of applications like mobile communication, Ultra wide band antennas, RFID, and MIMO antennas which cover the frequency band of WLAN (5.16 - 5.5 GHz), GSM 850 (824-890 MHz), Bluetooth (2.4-2.48 GHz), GSM 900 (.890-.960 GHz), 4G LTE(700 MHz-3.8GHz),WiBro (2.3-2.4 GHz), PCS/GSM 1900 (1.850-1.990 GHz), 802.11 (2.4-2.485 GHz), and UMTS(2.1 GHz),[4], DCS/GSM 1800 (1.710-1.880 GHz),

Inverted L antenna Fig. 2.4 is the folded version of traditional monopole antenna which makes it simple due to its planar transformation. This has high reactance and low resistance just like the monopole antennas. It's folded L structure make it suitable for easy frequency tuning.

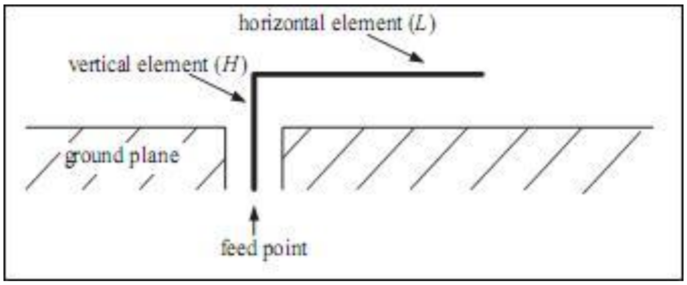

Fig. 2.4 Typical Inverted L-antenna (ILA) antenna structure [2]

The above inverted L antenna has a resistive load with making it difficult for impedance matching. So, the modification has done by introducing a second conductor shorting pin with the ground which results in an Inverted F antenna Fig. 2.5 This modification gives it a better tuning option.

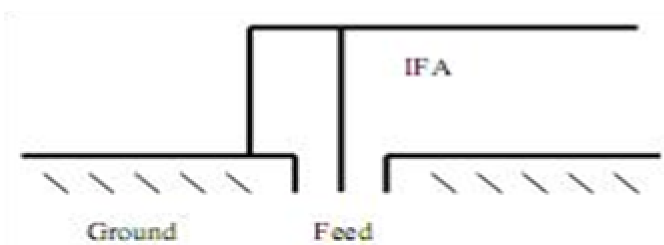

Fig. 2.5 Typical Inverted-F antenna (IFA) antenna structure [2]

In spite of the modification made on ILA antenna to convert it to IFA antenna. These antennas have inherently very narrow band width. So, To increase the antenna bandwidth the wire type structure is modified into planar sheet form with results a PIFA. It has a purely real impedance at the resonating frequency. The width of shorting pin, the relative position of the feeding point and shorting pin, the dimension of radiating patch and the air gap between radiating patch and substrate characterize the electric performance of PIFA Fig 2.6.

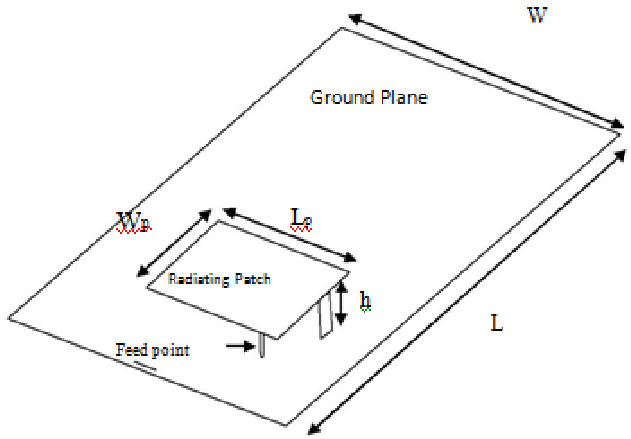

Fig. 2.6 Typical PIFA [3]

Table 2.1 Comparative analysis between above mobile phone antennas

Parameters	**PIFA**	**Microstrip**	**Monopole**
Gain	Moderate to high	High	High
Radiation Pattern	Omnidirectional	Directional	Omnidirectional
Applications	Internal antenna in mobile phones	Satellite communication and spacecraft	Radio broadcasting and vehicular antenna
Merits	Small size, low cost, reduced backward radiation	Low cost, low weight, easy to integrate	Compact size, cheap fabrication process
Demerits	Narrow bandwidth characteristics	No bandpass filtering effect	Difficult fabrication at frequency greater than 3GHz

2.3 Planar Inverted F Antenna Theory

Various researchers have made improvements on previously discussed antennas and the results of different antennas were discussed. PIFA due to its compact size and planer dimension has become most used internal antenna in the field of Mobile communication. This section represents the several aspects of PIFA to understand its functioning.

2.3.1 Introduction

Planar Inverted F antenna also called as the Shorted Microstrip antenna. This antenna is called so due to the shorting post between radiation patch and ground. The shorting post near the coaxial feed reduces the electrical length of PIFA. This method is responsible for the narrowband structure. Narrow band is one of the major drawbacks of this antenna. Some of the advantages and disadvantages are:

Advantages

- Having very compact size and light weight.
- High efficiency at the resonant frequency.
- PIFA can be modified into quadrature polarization radiation which has major application in antenna transceivers.
- Can be modified into multi band antenna which has almost same dimensions as single band antenna

Disadvantages

- Have moderate gain.
- Narrow bandwidth.
- Fabrication is complicated as compared to other microstrip antennas.

As PIFA has a major drawback of having a narrow bandwidth, several techniques are implemented to increase its bandwidth:

- By adjusting the relative coordinates of coaxial feed and shorting post.
- Varying the thickness of substrate be used to increase bandwidth and lower the Q factor.
- Implementing the several types of EBG structures, which suppress the surface waves and bandwidth can be incremented.
- The dimension of ground plane plays a major role in bandwidth. Bandwidth can be incremented by optimizing the dimension of the ground plane.
- Bandwidth can also be affected by using stacked elements

Compactness is the great concern while designing a PIFA due to its limited space availability. Some of the miniaturization to lower the size is:

- Introducing a capacitive loading increment the bandwidth and also decrease the dimension of the antenna from $\lambda/4$ to $\lambda/8$. The capacitive loading can be produced by introducing a parallel strip to the lower ground plane which acts as a capacitance.

- Sorting pin can also reduce the electrical dimension of the antenna. This method changes the radiation resistance into a reactive component which can be compensated by introducing capacitive effect.

The dimensions of a PIFA antenna are calculated from the frequency[5] of operation as follow:

$L_p + W_p = \lambda/4$

$L_p + h = \lambda/4$ when $W/L_p=1$

$L_p + W_p + h = \lambda/4$ when $W=0$

It is clear from the above expressions that the quarter of the wavelength is approximately the sum of dimension of the radiating patch and the dimension of shorting pin. The resonating frequency mainly depends on the dimension of the shorting pin.

Table 2.2 PIFA parameter and its effect on its performance

Parameters	Effects
Length	Increase inductance of the antenna and determine resonance Frequency
Width	Control impedance matching
Height	Control Bandwidth
Width of shorting plate	Effect on the anti-resonance and increase bandwidth
Feed position from shorting plate	Effect on resonance frequency and bandwidth

2.4 Feeding Techniques

The antenna (PIFA) can be excited by various topologies. Some of them are through direct contact however other is through indirect contact. In direct contact feeding, the feeding strip is directly attached to the radiation patch. In indirect contact feeding, the microstrip feed and radiating patch are coupled through an electromagnetic coupling to transfer power. Some of the popular feeding techniques are as follow:

2.4.1 Coaxial feeding technique

This feeding technique as shown in the figure is most frequently used feeding technique. This Fig2.7 is generally drilled from ground through the substrate and soldered to the radiating patch. It consists of a simple coaxial cable and the external conductor is connected to the ground plane.

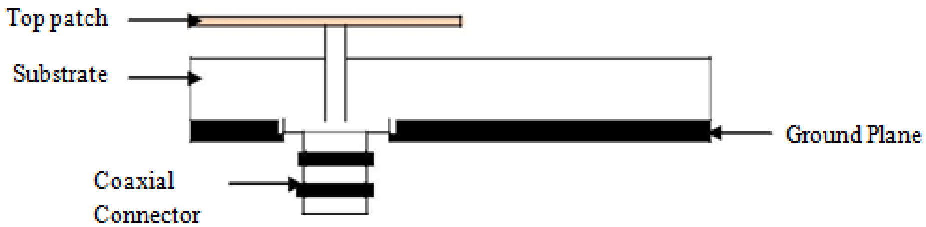

Fig. 2.7 Coaxial feed Technique for Antenna Structure

The impedance matching is very easy to achieve due to its flexibility of choosing the feeding coordinates. This feeding technique has several disadvantages of having narrow bandwidth and fabrication is quite tricky due to the drilling mechanism through the substrate.

2.4.2 Microstrip feeding Technique

In this feeding technique, the feeding strip is directly connected to the radiation patch. The strip dimension is narrower than the patch dimension which is joined to the edge of the substrate. It provides design flexibility and proper impedance matching. It has the disadvantages of spurious surface losses while increasing the substrate width.

2.4.3 Aperture couple feeding Technique

This Fig. 2.8 feeding technique is a popular example of indirect contact feeding. Here the feeding strip establishes an electromagnetic coupling with the radiation patch through an aperture slot made on the ground plane. This technique has application is phase array antenna. There is an increment of 12% in bandwidth in using this feed. The fabrication process of this feeding is difficult.

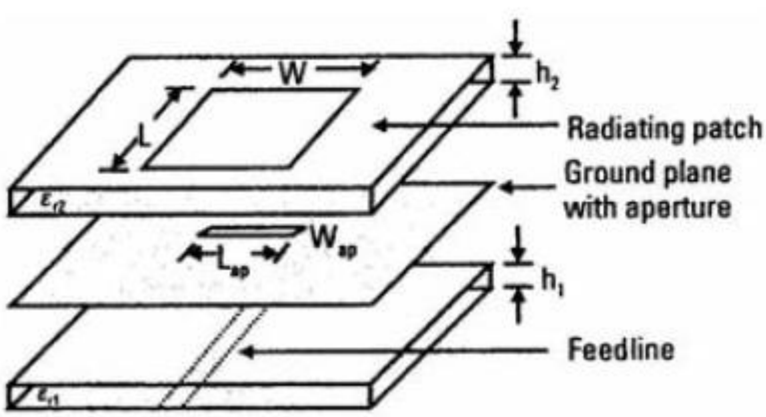

Fig. 2.8 Aperture feed technique for Antenna Structure

2.5 Antenna Parameters

The performance of the antenna is being measured by several numbers of parameters. In this portion of the thesis, critical ones from them will be discussed. Regardless to the type antenna, measurement parameters are same for all type:

- Directivity
- Impedance matching and VSWR
- Radiation pattern

2.5.1 Directivity

The directivity of antenna measured as the ratio of radiation intensity in a particular direction to the average radiation intensity in all direction.

$$D = \frac{U}{Ui} = \frac{4\pi U}{P}$$

Where,

D=Directivity of antenna

U_i = Radiation intensity of isotropic antenna

U = Radiation intensity in particular direction

P = Total power radiated

The gain and directivity of the antenna are related as per the equation:

D = ɳ G, where ɳ is the efficiency of the antenna.

2.5.2 Impedance matching and VSWR

Antenna act as a transducer with also act as an impedance matching network between the internal radio circuit network (50-ohm line) and the external space. It is very critical to perfectly match the both network for optimum transfer of power over a frequency band.

The impedance matching of the antenna is characterized by Voltage standing wave ratio (VSWR) and Reflection loss which is symbolized by the S_{11} scattering parameters. In this paper, these three terms can be used interchangeably. Return loss represents the fraction of power which is being reflected from the internal terminal of the antenna. VSWR is dimensionless quantity, however, return loss is measured in dB. Ideally, return loss should be zero that meant no reflected power but in practical designing, it is acceptable up to a certain limit.

It is significant to note the reciprocal nature of antenna due to which the return loss will have a different role for transmitting and receiving sides. In transmitting mode, the reflected power will be towards the output amplifier while for receiving mode the reflected power will be toward antenna itself. The acceptable VSWR and Return Loss relations are:

Table 2.3 VSWR and Return Loss (S_{11}) relationship

VSWR	**S_{11} (dB)**	**Reflection Loss (dB)**	**Comment**
-20.0	1.2:1	0.04	Very Good
-15.0	1.4:1	0.15	Good
-9.5	2:1	0.5	Acceptable
-6.0	3:1	1.2	Marginal

2.5.3 Radiation Pattern

The radiation pattern represents the three-dimensional representation of radiation intensity with respect to all directions. Radiation intensity is the power radiated per unit solid angle. The patent is radiated with respect to the $\theta\ and\ \varphi$ coordinate of spherical coordinate system.

Although omnidirectional radiation pattern is not realizable, it can be used as a comparison for the measured radiation pattern. Radiation pattern generally gives the information of directivity, side lobes, back lobes, HPBW, FNBW, and resolution.

E field pattern is the representation as a function of vector R containing antenna at the center with respect to electric field vector.

2.6 Electromagnetic Bandgap Structure

Prior to the introduction of EBG structures, there were PBG structures in an optical domain which were used prevent the Light waves from propagating in a particular frequency band[10] Fig 2.9.PBG was artificially designed structures which were in two or three-dimensional geometry[11]. Due to its vast advantages in the optical domain, this concept was implemented in microwave field and millimeter wave region [12].Here the term regarded as EBG structures. EBG is periodically repeated structures of dielectric material or the structure in metal strips which are used for suppression of electromagnetic waves in a particular frequency band.

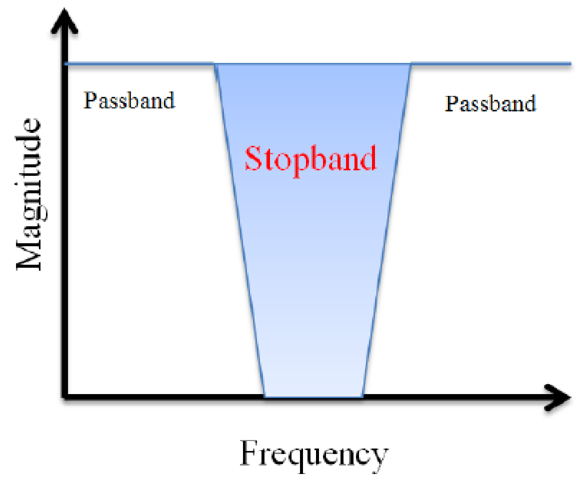

Fig. 2.9 Characteristic of EBG structure

- On the basis of geometry, the EBG structures are further divided into a one-dimensional structure.
- two dimensional or Planar structure.
- three dimensional or volumetric structure.

Some of the microwave structures have application in microwave circuits as demonstrated below. The 1D periodic holes below a microstrip line are presented in Fig. 2.10(a). The mushroom type in Fig 2.10(b) is an example of planar EBG. Woodpile shaped EBG is an example of 3-dimensional EBG as in Fig.2.10(c).

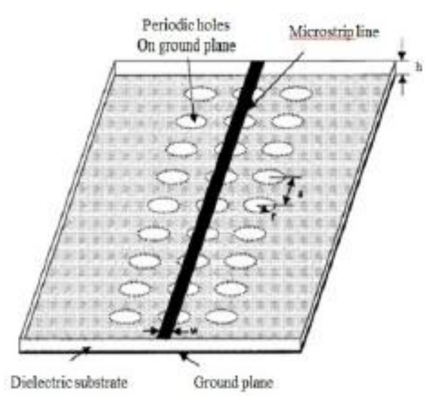

Fig. 2.10(a) 1-D DGS type EBG structure

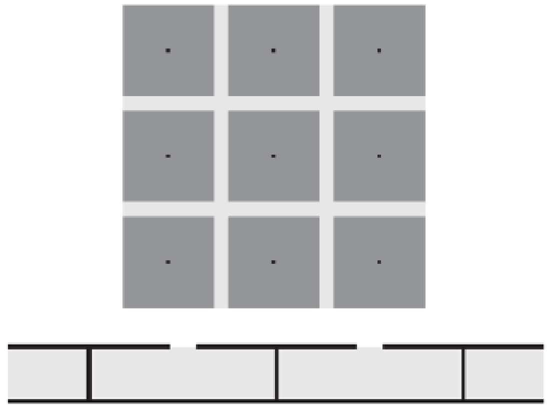

Fig. 2.10(b) Planer EBG structure

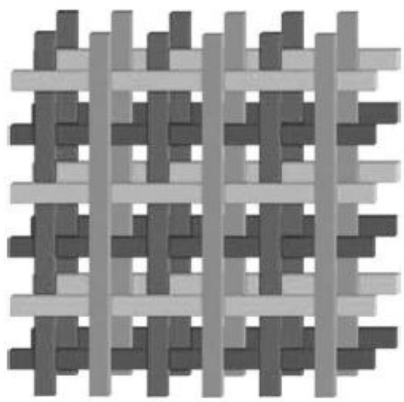

Fig. 2.10(c) Woodpile type EBG structure

Apart from the subdivision on the basis of dimension, there is various type of planer EBG structures like cross slot shape EBG, swastika shaped EBG, Hexagonal shaped and much more. The periodic spacing among the structures is minutely calculated and optimized to achieve optimum suppression of electromagnetic waves. Due to very limited space constraint, the implementation of EBG structure is very difficult. These structures lower down the mutual coupling between the different layers of the antenna.

CHAPTER 3
LITERATURE SURVEY

3.1 Literature Review

In the world of cellular mobile communications, the increase in requirement of light weight, compact and antenna having low power consumption. With the rapid development in the mobile phone market, reduction in the size of mobile handsets and need of wide and multi-band antenna has been seen recently. Earlier the mobile communication was limited to voice call and messages only, but gradually the is need of multi-band antenna for Bluetooth, 3G, LTE, Wi-Fi, Wi-Max etc. has increased. So trade off should be done with gain, radiation pattern and band width to make small compact wideband that can still work for a given application and frequency bands.

Rashid Ahmad Bhatti et al.[14] has designed a antenna for the mobile phone applicatons.the main motive of the observation is to attain low height and multi band frequency. this antenna is designed for the frequency band of ISM frequency, Bluetooth,UMTS,PCS,WLAN. The dimension of antenna is 1.5 cm^3 which make it working for mobile applications. The results are simulated and compared with measured testing. Good gain is observed on desired frequency.

Fabien Ferraro. [15] designed PIFA array consist of two elements with phase shift in polarizing planes of radiation of both antennas. The proposed structure consists of a ground plane having a dimension of 100mmx40mm. There are two PIFA radiating PIFA patches on two opposite sides of the upper plane. Both the antennas are excited through a Quasi lumped coupler which can provide 360^0 phase shift between both antenna output. The simulated, as well as measured results, are compared and it is observed that one antenna radiate in the vertically polarized plane and other antenna radiated in the horizontal polarized plane.

J. Cho et al. [16] designed a compact antenna whose resonant frequency are reconfigurable. Being its small size it is applicable for mobile phones. The designed PIFA can be embedded inside the mobile phone in the required space. The designed antenna is simulated and the result is compared with measured results.

Narendra Kushwaha[17] studied the different types of EBG structures for a single band

and double band frequencies. An EBG structure is proposed to achieve the multi-band and wide bandwidth. The Proposed structure is simulated and fabricated. Its results are compared with Mushroom type EBG. The comparison is done on the ground of -20dB cutoff frequency and Bandwidth. The effect of a change in radius of the unit cell and the gap between two consecutive unit cells is also studied. It is observed from the discussion that swastika type EBG is compact and having wider bandwidth, the square shaped EBG has single band frequency and Fractal type EBG has a wider bandwidth. It also observed that EBG structures shift the resonant frequency to the lower frequency, Hence compactness is achieved

Ki-Jin Kim[18] proposed a dual band PIFA having high isolation between both the bands of the antenna. The both the bands of the antenna are at ISM band(2.4GHz) and C-band(5.2GHz). To maintain the isolation between both the band an N-shaped slot is being made on the ground plane. The dimension of the ground plane is taken 500 mm on RT duroid substrate. The dimension of the N-shaped slot is optimized to achieve high efficiency of the antenna and maintaining isolation. This proposed antenna is also used for designing of multiple element MIMO arrays. The scattering matrix and Total active reflection coefficient (TARC) of all the antennas are simulated and compared. After the comparison, it is observed that the TARC in 4 element Array is below -3 Db so the proper impedance matching is required.

Manoj K. Meshram[19] proposed a quad band PIFA antenna consist of two unit cells. The designing is done for long term evolution(LTE) and Wireless Fidelity(Wi-Fi) application for mobile phones. The isolation is established between two radiating patches by employing the defective ground structure of slot shape of a rectangular ring and inverted shape. By implementing DGS structure high isolation which is about -26dBi is attained. The radiation pattern of this MIMO is calculated as well as simulated on HFSS software. An omnidirectional radiation pattern is observed in both the radiation patches. Both the unit antenna output have quadrature phase difference to achieve its characteristic of diversity.

Amol Choudhary[20] proposed a microstrip antenna consist of hexagonal Electromagnetic band gap structures. The software used for designing and simulation is IE3d. The proposed structure is compared with simple microstrip antenna. The ground plane optimized in both the antennas is of 56mmx100mm with is stacked at the air gap of 10.5mm. It is been observed that EBG can stop a particular frequency in the frequency band. By implementing EBG the efficiency is increased by 74% and gain of 10dBi is achieved.

N S Raghava[21] proposed a stacked microstrip antenna in his paper. The design comprises of two rectangular patches and a shorting post is stacked on the dielectric substrate. The holes are etched on the lower patch whose periodic layout act as Electromagnetic Band gap structure. EBG structure is used for suppression of surface waves. The whole structure is supported by a patch at an air gap of 8.5mm. The notable increment in efficiency is observed in proposed design and also increase in gain, directivity. The antenna has application in road automobile communication. Same author[22] proposed an another antenna which same basic dimensions. But in this paper author designed a new cross shaped slot type EBG. The position of the coaxial feeding point and shorting pin are being optimized on several coordinates and its results are compared with each position. The antenna efficiency of 99.06% is achieved in best-optimized coordinates. The radiation pattern is observed at a 2.54GHz frequency, so this antenna can be used for wireless communication.

Rashed H. Bhuiyan[23] designed a double meander PIFA with is attached with a parasitic metal box. The design got its name due to its double meandering on both sides of the parasitic box. The dimension of the ground plane is 50mmx108mm. The basic antenna is designed for 600MHz-900MHz. So it can be used for 4G voice applications. The role of the metallic parasitic box is to improve the bandwidth as well as shift the resonating frequency at the lower frequency. The cross polarization of the antenna is below -16dB. The antenna shows the omnidirectional radiation pattern all over the frequency band.

Sonali Kushwah[24] has proposed a triangular shape meandered antenna. It is designed for the frequency of fixed and mobile Wi-Max, DCS 1800 applications. The proposed structure is the combination of triangular meandered shape and a simple PIFA. The main motive of this designing to improve single band antenna into multi-band as well as increasing its bandwidth.The overall size of the antenna is 50mmx36mm.The proposed design shows the gain of 3.028dBi.

Darko Kirovski[25] from Microsoft corporation published a patent consist of a design of multi element PIFA array. It comprises a four element PIFA. the main motive of this design was to manipulate various radiation pattern by trading off the relative phase shift as well as spacing among them.In this patent same PIFA antenna can be utilized for directional radiation pattern as well as omnidirectional radiation pattern. This PIFA system has the applications in smart computing devices and mobile phones.The system involves the signal manipulation mechanism of splitting the signal components before feeding a single PIFA unit cell.

Hassan Tariq Chattha[26] studied the effect of the width of shorting pin and coaxial feed ina PIFA antenna in his letter. There is a need for wideband antennas in the Ultra wide band systems(UWB) as per the need of multi applications of wireless communication.But the PIFA antennas have a demerit of having Narrow bandwidth.so this investigating is done to overcome these disadvantages. Several optimizations are being done to get the desired results.The simulated and measured results are designed and compared.The increment of 65% in bandwidth is achieved in the finally optimized result.

Akhilesh Verma[27] proposed a design having meandered slots on a radiating patch. Several strips meander on the radiating patch.It is done to minimize the electrical dimension of the antenna as well as improve its characteristics. Its parameters are compared with the conventional antenna. Proposed design is designed using an FR4 substrate of height 1.56mm.The dimension of the ground plane is 70mmx40mm. a conducting patch is fixed at the air gap of 4mm. This antenna is designed for the frequency range of mobile/fixed application, x band and Wi-Max which is appropriate for satellite communication and weather radars.

3.2 Inferences Drawn

After an extensive literature review on the Planer inverted F antenna for mobile communication application, it is clear that the lot of research work can be done to convert single band antenna into a multiband antenna. The frequency of PIFA can be shifted to desirable frequency by using several switching operations. The switching operation involves the use of PIN diode, varactor diode, using DGS. It also observed that the PIFA antenna can be extended into a MIMO array for multiple user applications.

As new communication applications are introducing frequently, designers have to incorporate the need of applications in their designs without increasing the cost, complexity etc. PIFA antenna can be implemented for the technologies like , WLAN 4G LTE. So for smaller and lighter mobile handsets, there is a need of low profile antenna structure which supports multiple frequency bands.

CHAPTER 4

DESIGN METHODOLOGY

4.1 Introduction

The designing and simulations of the antennas are carried out using High-Frequency Structure Simulator (HFSS).PIFA designing is a tough and mind-numbing task. It may be observed in the last part of this thesis that on a slight change of few millimeter in the antenna physical dimensions, coaxial feed position, shorting plate dimensions and in many parameters shifts the resonant frequency or affects the return loss or change the gain of the antenna in the very drastic way. This is due to the properties of PIFA structure which is very sensitive to changes in size and effect of the ground plane.

The design is simulated and optimized numerous times as designing of a PIFA for practical applications is through trial and error process. Thus trials which include changing the dimensions of the top patch, ground plane, introducing slots on the ground plane, position of the coaxial feed source, the antenna is optimized to work on desired frequency bands.

In the previous chapter, the design theory of PIFA antenna and the different types of electromagnetic band gap structures (EBG) is been described. The effects of electromagnetic band gap structure on microstrip antenna are also discussed. So, In this chapter, First a design of simple Planer Inverted F antenna will be optimized and analyzed and finally, a PIFA containing EBG structure will be proposed.

4.2 Selected Geometry

The geometry selected for the Planar Inverted F antenna is adaptable to small and slim cell phone geometry. The antenna dimension is 31x20x3.6 mm^3. FR4 Substrate is used which have dielectric constant ε_r = 4.4 and the loss tangent is 0.02.Substrate height is 1.6 mm. Copper is used as a metal part of the antenna having a conductivity of 5.8e7 S/m and thickness 0.2mm. PCB is taken of length 70 mm. A coaxial cable is used to feed the antenna from the backside of PCB.

4.3 Design of PIFA Antennas

In this section, several PIFA designs will be discussed along with the proposed PIFA antenna with Electromagnetic band gap structures on the upper surface of the substrate. To understand the effect of EBG structure on PIFA antenna a basic PIFA design is designed analyzed initially. Then further EBG modification is implemented on the simple antenna and analyzed.

4.3.1 A Simple Planer Inverted F Antenna

Before starting with the designing of the PIFA antenna with EBG structures, we will go through with the designing process of a simple PIFA and its characteristics will be analyzed. Designing of this antenna structure helped the author to understand the basic concepts, characteristics and various factors that determine the performance of the PIFA. Using the design parameters given in chapter 2, the basic dimensions of the PIFA is derived using the following equation.

$$L_p + W_p + W_S = \lambda/4 \quad (5.1)$$

The optimized dimensions for the PIFA are:

$L_p = 20$ mm

$W_p = 10$ mm

$W_S = 5$ mm

After calculating the dimensions of the top radiating patch, an optimizing process commences developing new dimensions for the Fig 4.1(a), (b) PIFA to obtain desired results. With the use of HFSS, several simulation attempts were made to obtain the desired resonant frequency and bandwidth by varying L_p, W_p, the width of short circuit plate, feed source location and ground plane and height of the air gap. Finally, all the aspects of simple PIFA antenna are analyzed Fig. 4.2 (a),(b) and final dimension is extracted as follow:

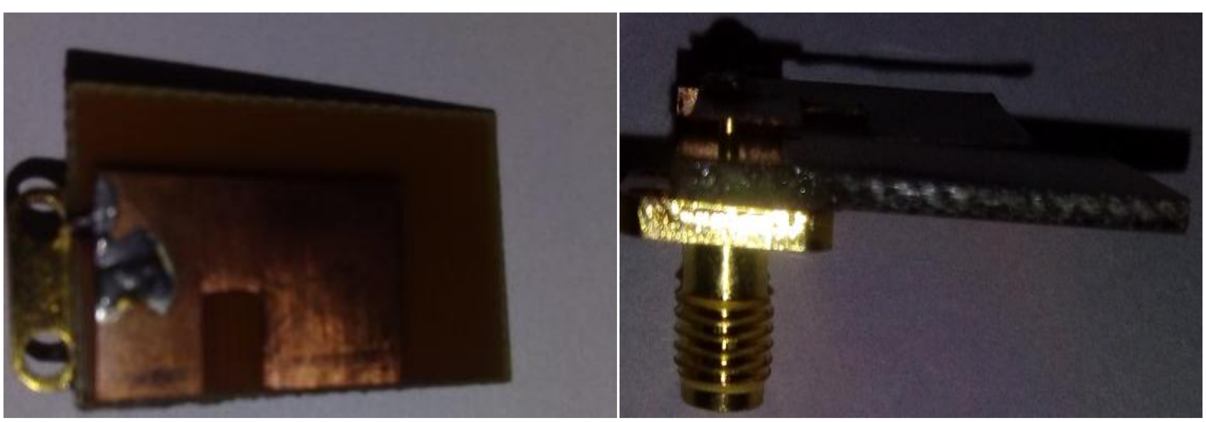

Fig. 4.1 Simple PIFA (a) Top View (b) Side View of fabrication

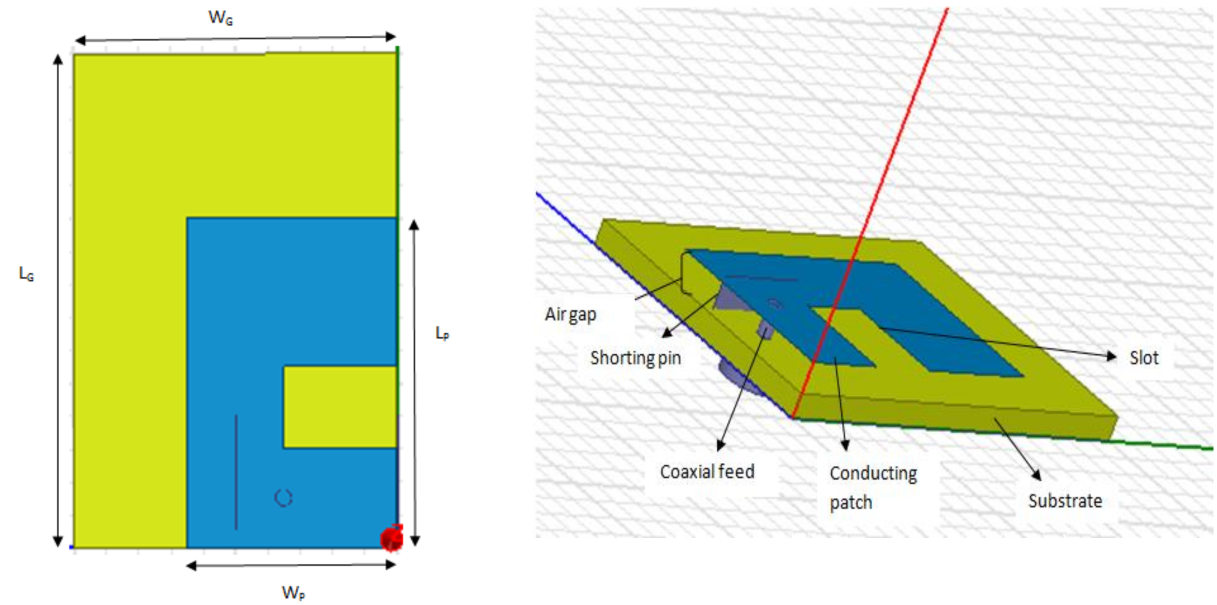

Fig. 4.2 Simple PIFA (a) Top View (b) 3D View in HFSS

TABLE 4.1 Detailed Dimensions of Proposed Single Band simple Antenna

Parameter	**Value (mm)**
L_g	31
W_g	20
L_p	20
W_p	13
L_S	6
W_S	3
H	1.6

4.3.2 A Wideband PIFA with electromagnetic band gap structure

The structure of proposed PIFA antenna with EBG structure is shown in Fig.4.3. The proposed PIFA antenna Fig 4.4 consists of a slotted radiating patch, shorting pin, EBG structure on the upper surface of the substrate, coaxial feed, and a ground plane. The air gap between radiating patch and EBG plane is optimized to reduce the overall thickness of antenna. It is done to meet the compact requirement of mobile phones. The antenna is also been fabricated on optimized dimensions.

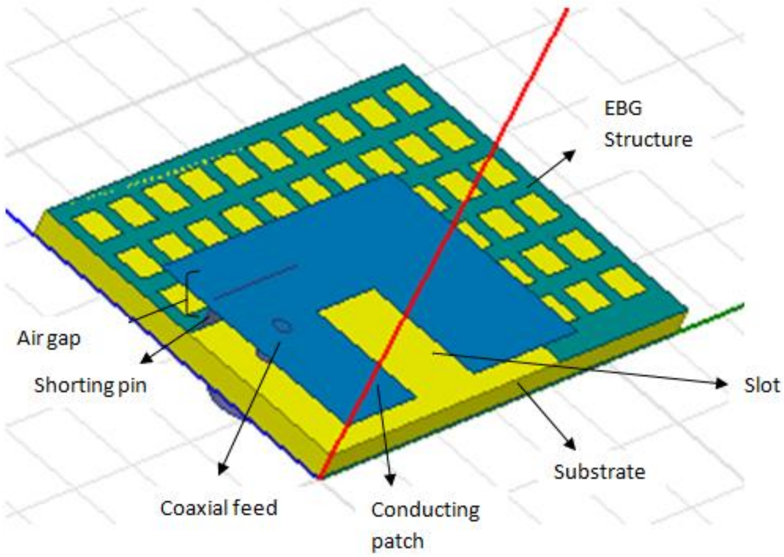

Fig. 4.3 PIFA antenna with EBG in HFSS

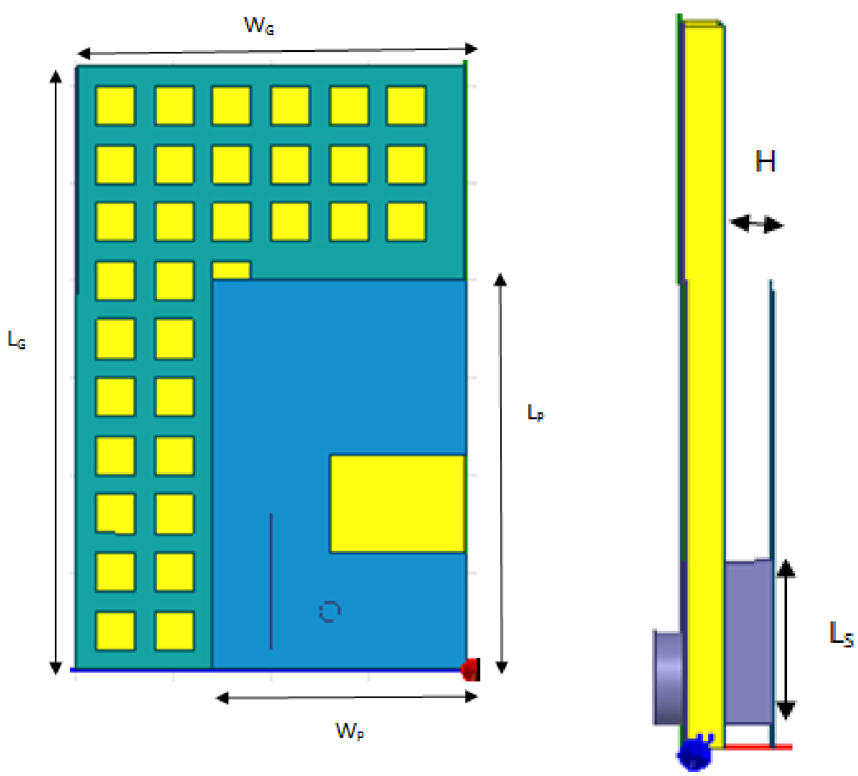

Fig. 4.4PIFA with EBG (a) Top View (b) Side View on HFSS

The dimensions of the radiating patch are 20x13x2 mm^3 while the dimensions of ground plane 31x20x1.57 mm^3

TABLE 4.2 Dimension of Proposed Antenna with EBG structure

Parameter	Value (mm)	Parameter	Value (mm)
L_G	31	H	2
W_G	20	Slot width	3
L_P	20	Slot length	6
W_P	13	permittivity	4.4
L_S	6	Loss tangent	0.002
W_S	3.6	H	1.6

To make the design suitable for real handset applications, the slot on the ground plane is situated under the top patch, which is an area away from other components of the handset such as a battery, RF components, displays, speakers etc.

As the main objective of this thesis work is to propose a small antenna having thin structure, therefore, the height of the PIFA selected is 2.4mm from the FR-4 substrate and 4 mm from the ground plane. With these dimensions selected for the antenna, the structure can operate at UMTS, LTE, Bluetooth, m-WiMAX, WLAN bands with good enough bandwidth to serve for these applications. The proposed antenna is being fabricated Fig 4.5 for the measurement analysis.

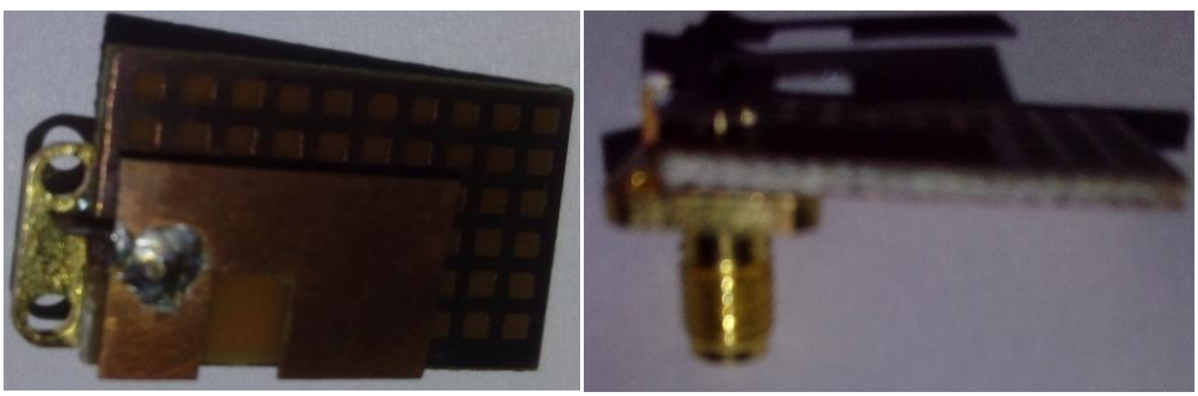

Fig. 4.5 PIFA with EBG (a) Top View (b) Side View of fabrication

CHAPTER 5

EXPERIMENTATION & RESULT COMPARISION

5.1 Introduction

In the initial part of this chapter, the simulation results of both the proposed antenna are presented followed by the real time measured results are also presented. This chapter also comprises the comparative study of both the results. The HFSS simulation software is been used for all the simulation work in this thesis. All the antennas were continuously optimized during simulation. This process was repeated various times to get the final desired results of both the proposed antennas. In this chapter, the characteristics of the result such as return loss (S_{11}), 3-D Gain polar plots, 2D radiation pattern, VSWR graph and E field pattern are to be discussed. In addition to the results, a comprehensive discussion on wide band PIFA is been made.

5.2 Simulation Results of Simple PIFA

In the first step toward proposed structure, the designing and simulation of a simple PIFA antenna are been made. As presented in the previous chapter, after a long and monotonous simulation process, the final structure and dimensions of the antenna were shown in Fig. 4.2

5.2.1 Return loss(S_{11}) parameter characteristics

The following plot in Fig. 5.1 shows the return loss (S_{11}) parameter of the simple PIFA antenna design.

Return Coefficient vs Frequency

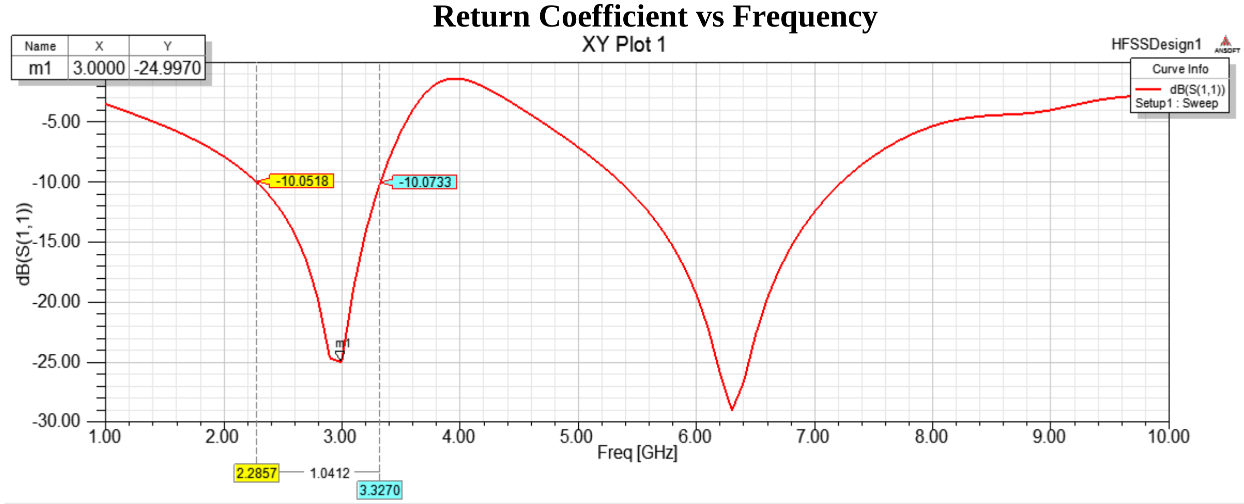

Fig. 5.1 Simulated Return Loss of Simple PIFA

From the graph shown in above Fig. 5.1, it is shown that a resonant frequency of 3000 MHz has been. The return loss obtained was to be -24.99 dB at the resonant frequency with the operating bandwidth for S_{11}<-10dB of 1041.2 MHz starting from 2285.7MHz to 3327MHz. This frequency range covers the applications like Wi-Bro (2300-2400 MHz), Bluetooth (2400-2480 MHz), 802.11 (2400-2485 MHz) etc.

5.2.2 VSWR Plot

The antenna is simulated to observe VSWR for the frequency range 1 to 10000 MHz as shown in Fig. 5.2. The VSWR of 0.9783dB is noticed at the main resonating frequency. The value of VSWR to be less than 3 dB is desirable for mobile applications.

VSWR vs Freq

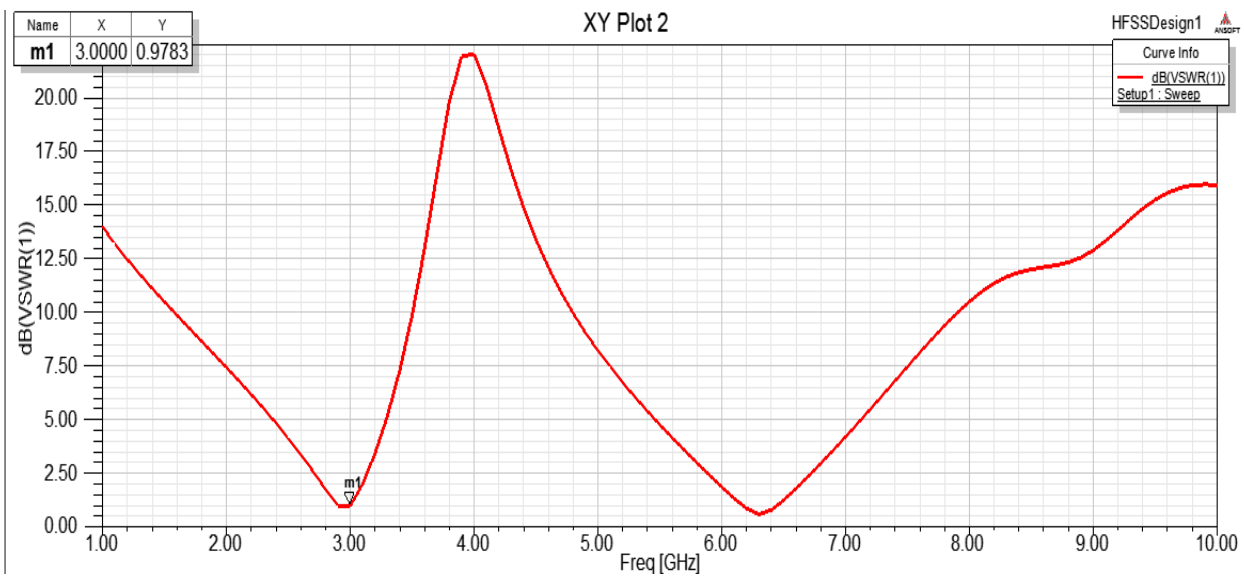

Fig. 5.2 Simulated VSWR plot of Simple PIFA

5.2.3 3D Radiation Pattern

The simulated results of radiation pattern at 3000 MHz is shown from the simulation results of Ansoft HFSS is presented in Fig 5.3. It can be seen from the radiation pattern that the demerit of the PIFA antenna is still visible as the gain is not so good and also radiation pattern is also not omnidirectional.

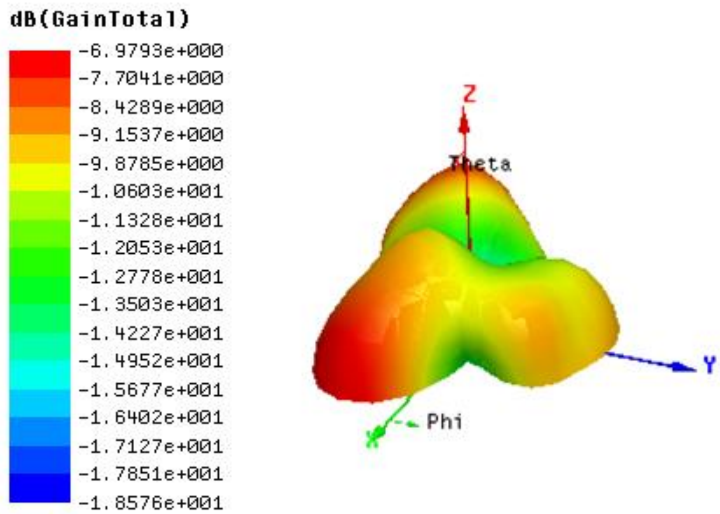

Fig. 5.3 Simulated 3D radiation pattern of Simple PIFA

5.2.4 Gain

. The overall gain of the simple PIFA antenna is shown in Fig. 5.3. The figure also represents the radiation pattern in 2D formof the antenna.

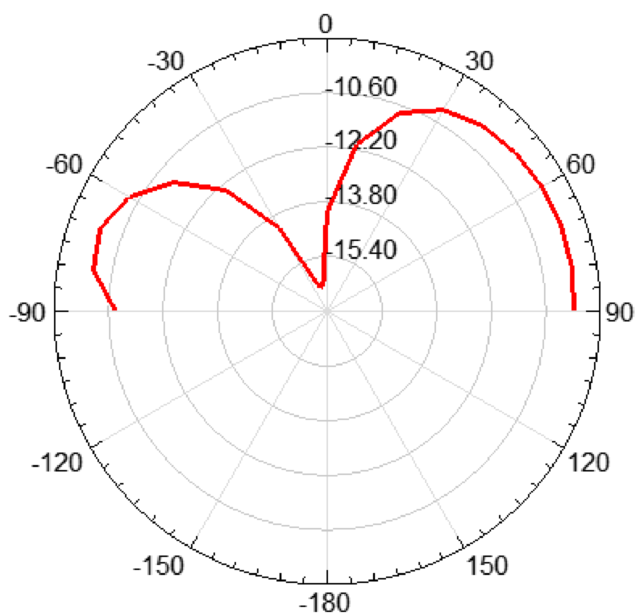

Fig. 5.4 Simulated 2D radiation pattern of Simple PIFA

5.2.5 Electric field pattern

Figure 5.5 shows the Electric field pattern of a radiating patch of simple PIFA. This figure characterized the current distribution of the structure. This pattern mainly represents the E-field orientation throughout the radiating patch.

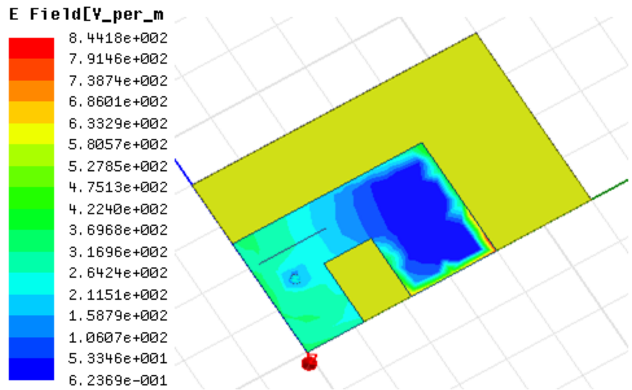

Fig. 5.5 Simulated E-field pattern of Simple PIFA

5.3 Simulation Results of PIFA antenna with EBG structure

On designing and analyzing the simple PIFA antenna, several demerits of low gain, narrow band width were encountered. So, miniaturization is been made on the previous antenna. Electromagnetic bandgap structure is introduced on the antenna. Various optimization is been made on antenna structure to achieve the final results and simulated using Ansoft HFSS software. The characteristics like return loss (S_{11}), gain pattern, E field pattern is observed.

5.3.1 Return loss(S_{11}) characteristics

The return loss characteristics of the proposed PIFA with EBG structures are shown in Fig.5.6.

Return Coefficient vs Frequency

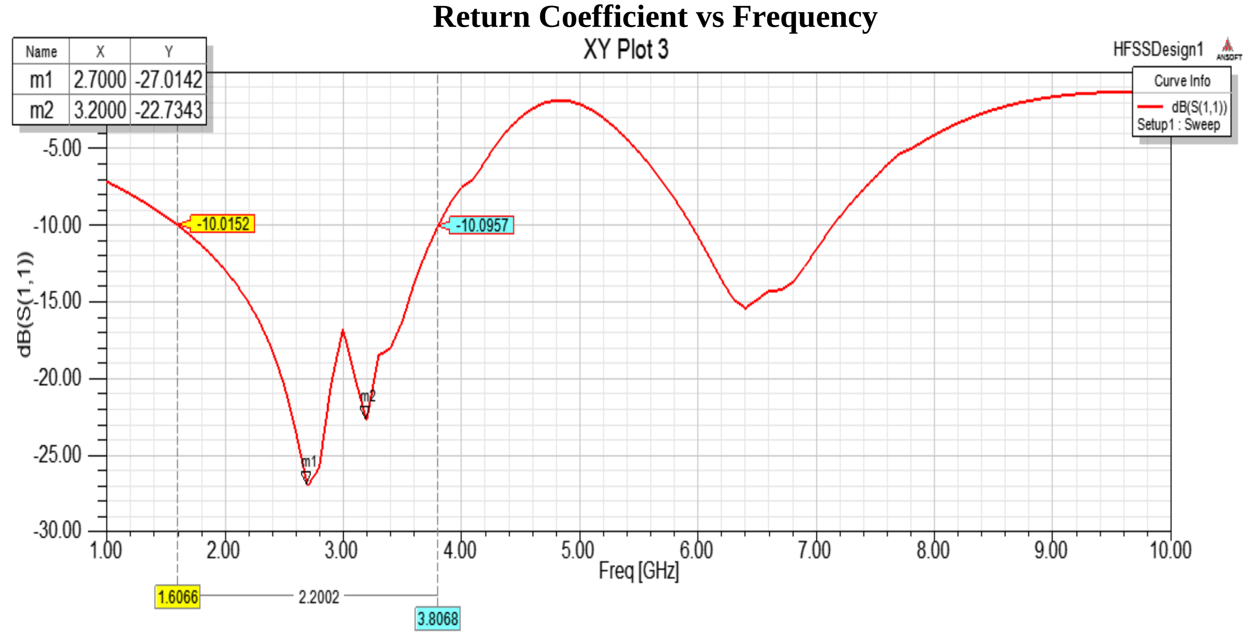

Fig. 5.6 Simulated Return Loss of PIFA with EBG structure

From the plot shown above, It is been observed that the antenna resonate at the frequencies of 2700MHz and 3200MHz having a return loss of -27.0142 and -22.7343 respectively. This plot also symbolizes the frequency range coverage of 2200.2 MHz from 1606.6MHz to 3806.8 MHz It covers the frequency application of DCS 1800(1710-1880 MHz), ISM 2.4(2400-2484 MHz), WiMAX (3400-3600 MHz), 4G LTE 23004G(2300-2400 MHz), LTE 2600(2500-2570MHz, 2620-2690 MHz).

5.3.2 Voltage Standing Wave Ratio Plot

The voltage standing wave ratio of the proposed structure is shown in Fig. 5.7. this plot shows the VSWR value of 0.7752 dB and 1.2701 dB on the 2.7 GHz and 3.2 GHz respectively. These values fall into the category of below 3 dB scale.

VSWR vs Freq.

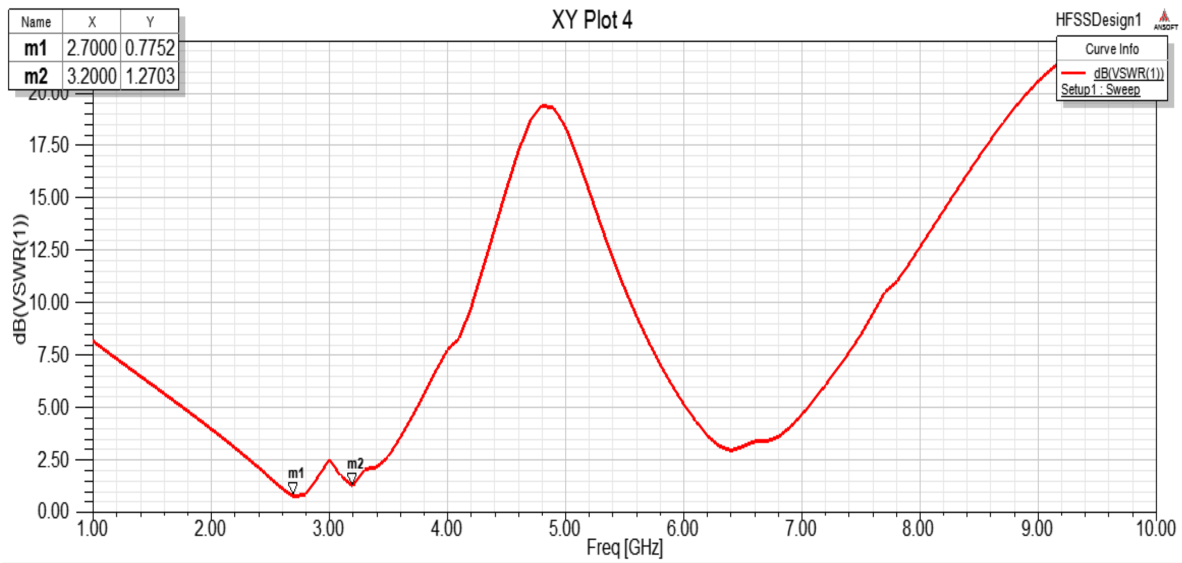

Fig. 5.7 Simulated VSWR plot of PIFA with EBG structure

5.3.3 Radiation Pattern

The simulated 3D radiation pattern resonance obtained from the simulation results of PIFA with EBG structure is shown in Fig 5.8(a) and 5.8(b).It can be observed from the pattern that the antenna is an omnidirectional radiator with a peak gain of 5.554 dB at 2700 MHz and 2.8dB peak gain at 3200 MHz and can be used as the mobile terminals which support multiple wireless standards.

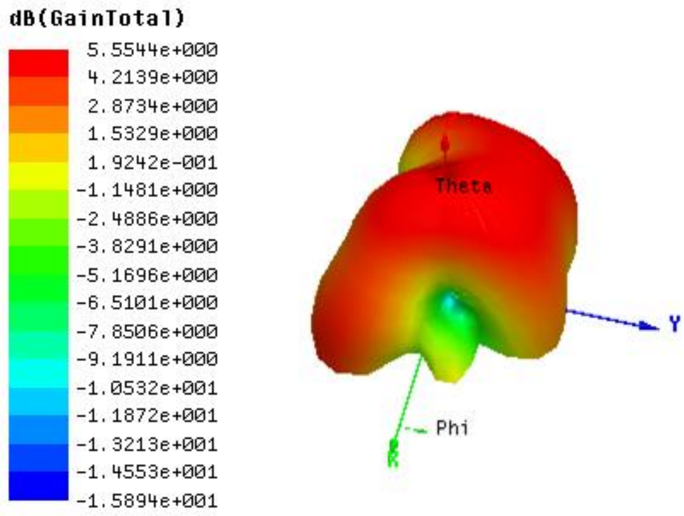

Fig. 5.8(a) Simulated 3D radiation pattern of PIFA with EBG structure

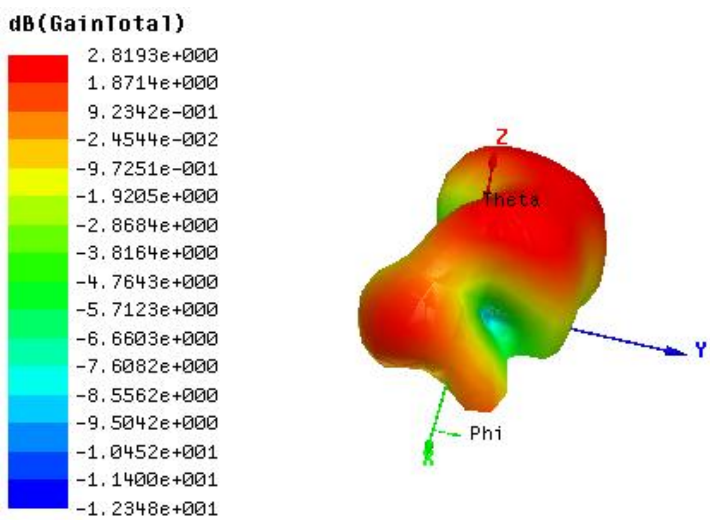

Fig. 5.8(b) Simulated 3D radiation pattern of PIFA with EBG structure

5.3.4 Gain

The gain or the directivity are two of an important parameters of the antenna. The overall gain of the antenna is presented on simulation basis. Fig. 5.9. A peak gain of 5.55 dB is observed at the resonant frequency.

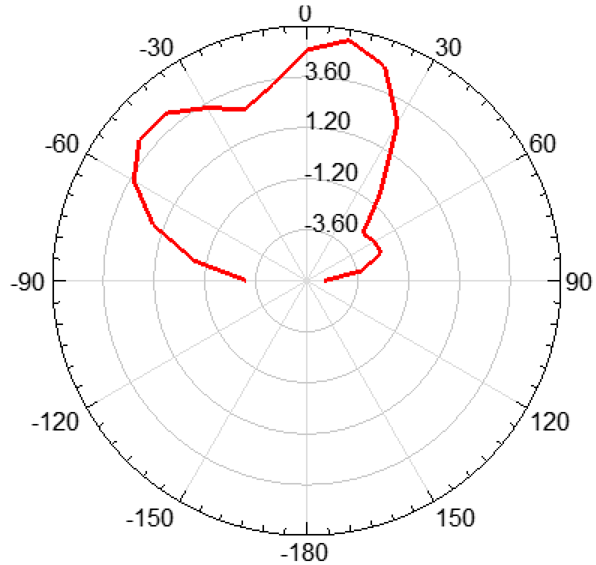

Fig. 5.9 Simulated 2D radiation pattern of PIFA with EBG structure

5.2.4 Electric field pattern

The Fig 5.10 shows the Electric field pattern of conducting patch of PIFA with EBG structure. This figure characterized the current distribution on all conductor surfaces of the structure. It also characterizes the fringing field on the patch.

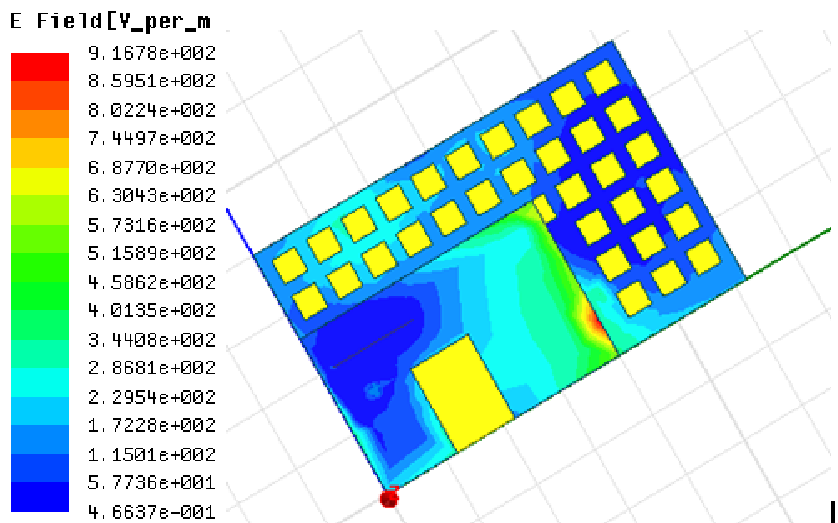

Fig. 5.10 Simulated E-field pattern of PIFA with EBG structure

5.4 Comparative analysis of simulated Return losses

Fig. 5.11 shows the comparative analysis of both the proposed antennas in terms of Return loss. The main motive of this comparison is to analyze the bandwidth comparison. An appreciable increment is observed on the second proposed antenna. It also observed that the S parameter is shifted to the higher frequencies.

Return Coefficient vs Frequency

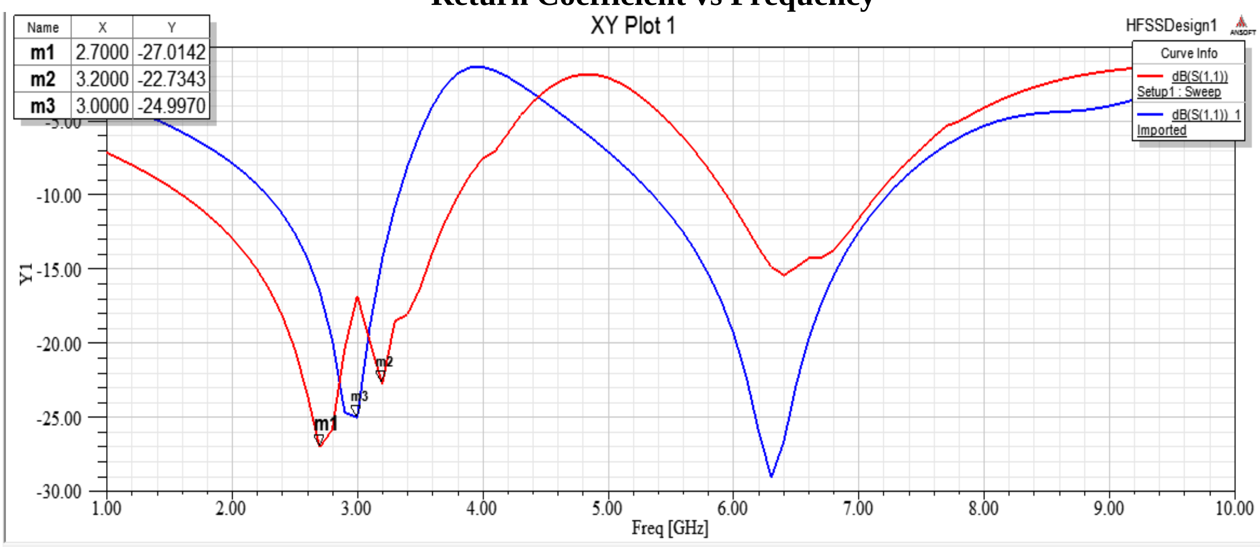

Fig. 5.11 Simulated E-field pattern of PIFA with EBG structure

5.5 Measured Results analysis

In the initial phase both the antennas are simulated on HFSS software. To verify the validity of the simulated results, It is very important to verify those results with the real time measured results. In this process, both the antennas are fabricated and tested as well.


Fig. 5.12 Antenna measurement using VNA

For the measurement of the return loss of both the antenna, Measurement is been observed on Keysight Vector Network analyzer (VNA) Fig 5.12. Before taking the measurement VNA is been calibrated.

Gain and radiation pattern are the key features of any antenna. The radiation pattern measurement setup is shown in Fig.5.13. The set up is a simple prototype of the Anechoic Chamber. This set up comprises of a transmitting antenna, signal generator, power amplifier, test antenna, signal trans receiver, step up the motor and Interfacing module. Yagi Uda standard antenna is used for transmitting side. Step up motor is being set at the step size of the azimuthal angle of 15^o. Power amplifier used on the transmitting side is of the frequency range in 1-6GHz.

Fig. 5.13 Antenna measurement using Anechoic Chamber prototype

5.5.1 Measured results of simple PIFA antenna

Return loss characteristics

Fig. 5.14 shows the return loss measured on the vector network analyzer. It is observed that the resonant frequency is presented at 3.45 GHz with a Reflection coefficient of -19.47 dB. This value falls in the appreciable range of less than -10 dB.

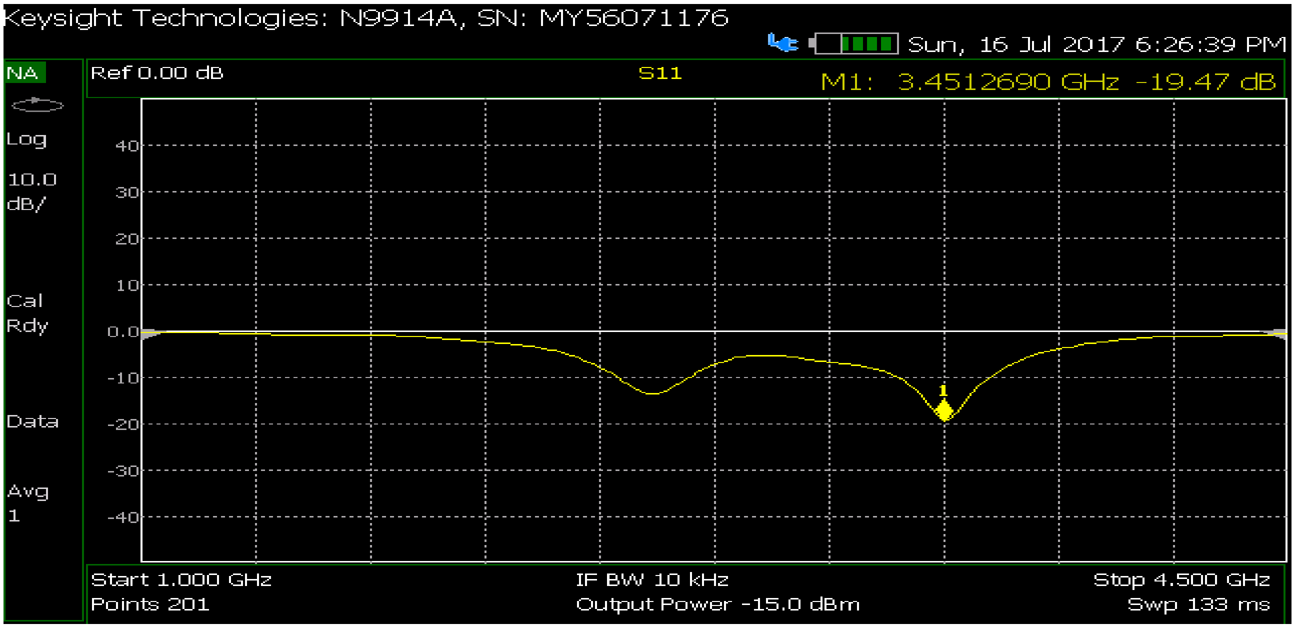

Fig. 5.14. S parameter measured in VNA

Radiation Pattern

The radiation pattern is presented in Fig 5.15. The test antenna is measured at the resonant frequency as shown.

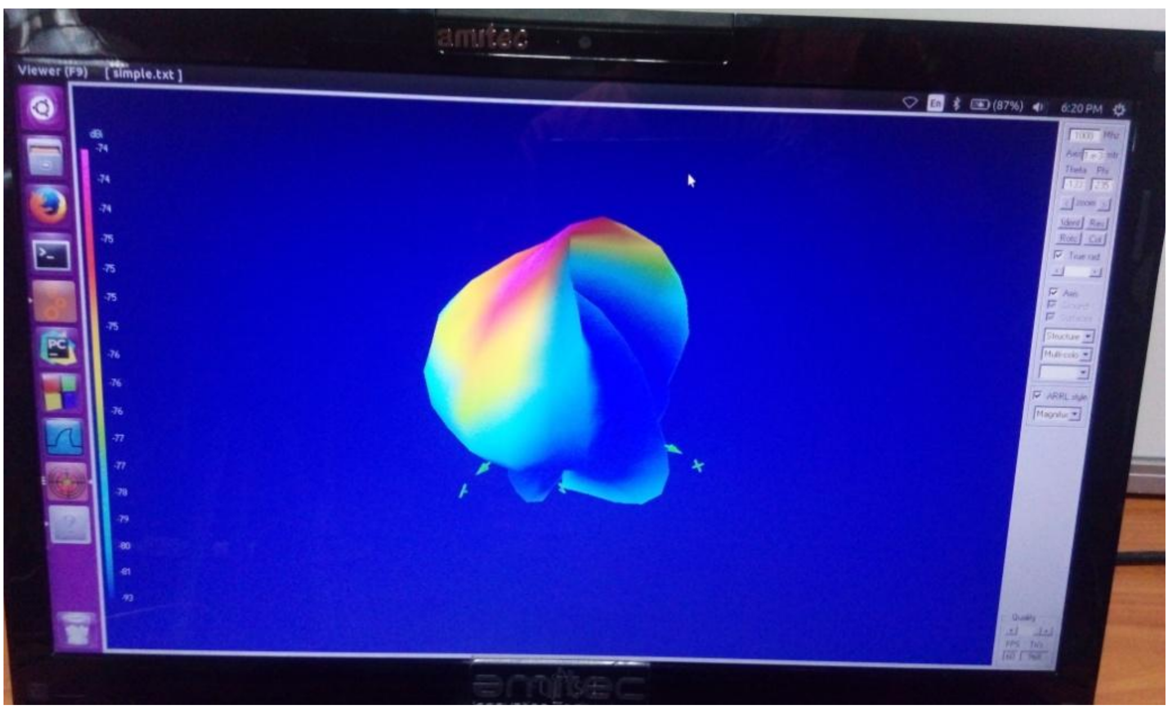

Fig. 5.15. 3-D radiation pattern measured in Anechoic chamber

5.5.2 Measurement Results of Proposed PIFA antenna with EBG structures

Return Loss Characteristics

The Return loss of the proposed antenna with EBG structure is shown in Fig. 5.16. From the figure, it is represented that the antenna has a resonant frequency at two frequencies. The dominant resonant frequency is at 2.15GHz with having a return loss of -33.53 dB. The wide band frequency range is also represented by the measured results.

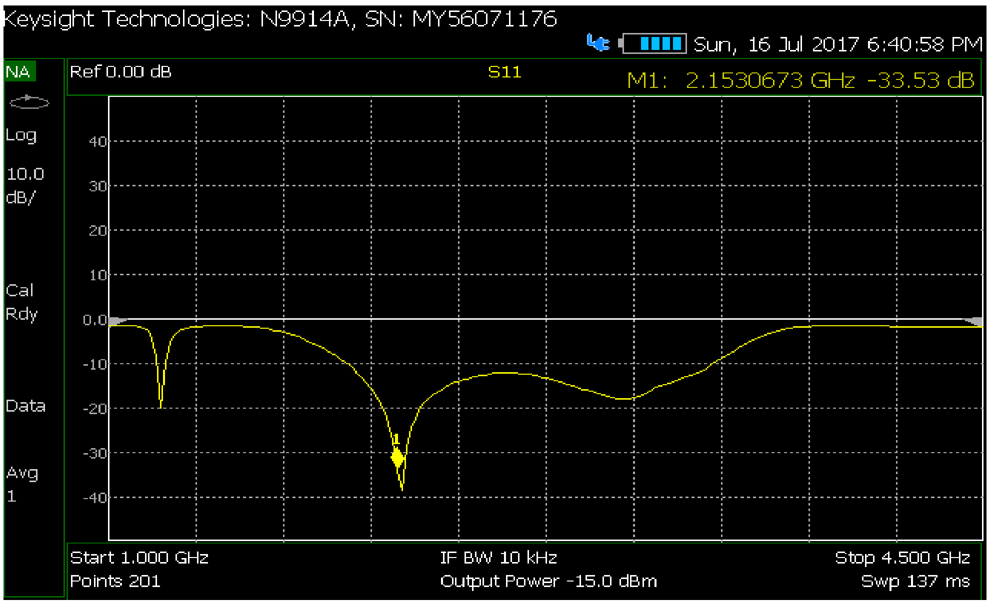

Fig. 5.16. S parameter measured in VNA of PIFA with EBG

Radiation pattern

Fig 5.17 represents the radiation pattern of the Antenna with EBG structure.

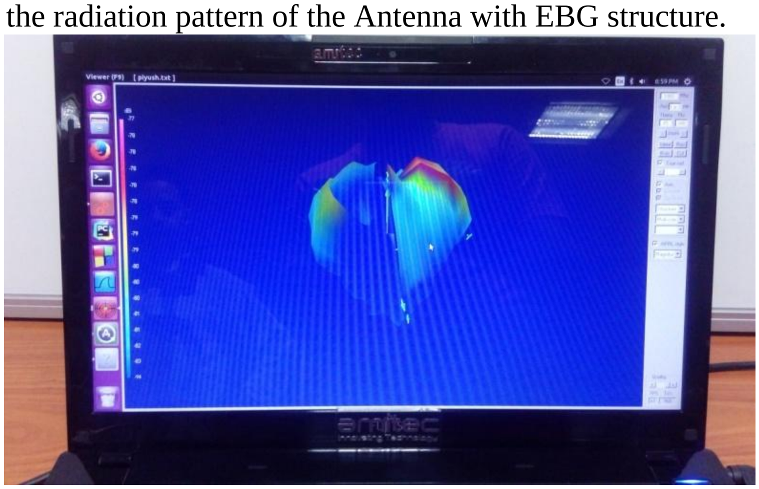

Fig. 5.17. Radiation pattern measured of PIFA with EBG

5.5.3 Comparative analysis of the simulated and measured radiation pattern of Proposed PIFA antenna with EBG structure

Fig. 5.17 represents the comparative polar plot of measured as well simulated results of the proposed PIFA antenna with EBG structure. The text data of HFSS and the Anechoic chamber is obtained. Both the data is imported in D plot software, Here the both plots are merged. The both structure represents the omnidirectional radiation pattern

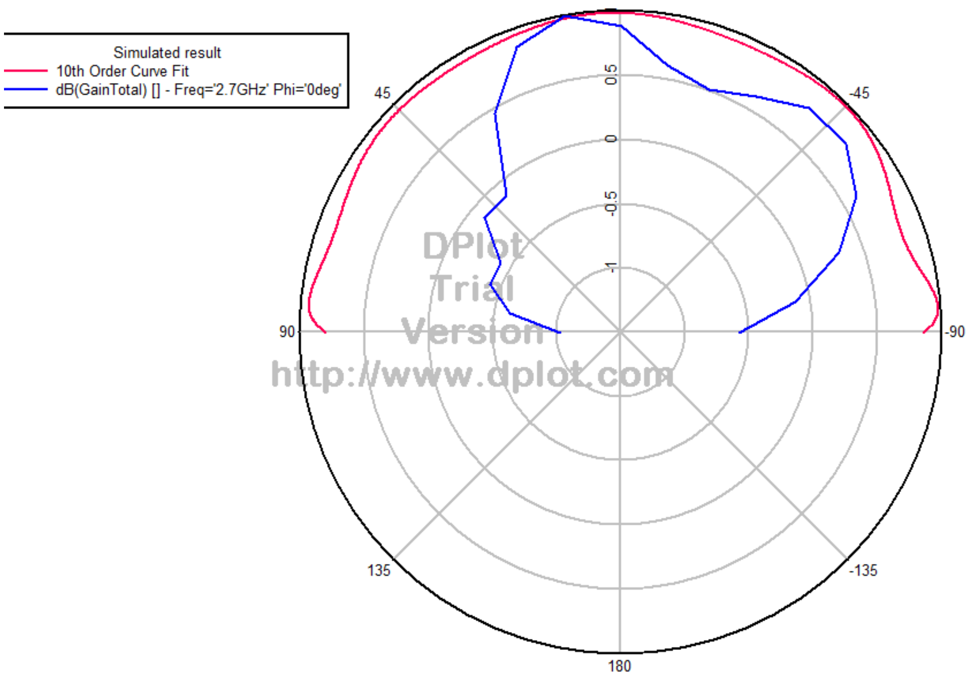

Fig. 5.18. S parameter measured in VNA of PIFA with EBG

CHAPTER 6

CONCLUSIONS & FUTURE SCOPE

6.1 Conclusion

This thesis work is still deemed to be successful as most aspects of the Planar Inverted-F Antenna with Electromagnetic Band gap structures has been studies, designed and simulation results show that the antenna structure is suitable for its use in mobile device. The simulation results are also been verified with measured resuts. All the results of both the proposed antenna are observed and compared.

There are several conclusions which are concluded from the thesis as follow:

I. The designed wide-band antenna which is built on simple PIFA antenna, is very sensitive and shows very abrupt changes in its characteristic on minute variation in its dimensions.

II. PIFA generally have mainly two characteristics, one of them is having compact size and other is having omnidirectional radiation

III. On comparing the S_{11} of both the proposed antennas the PIFA antenna with EBG achieve the improvement in bandwidth with comparison to the simple one.

6.2 Future Scope

Future work can be presented in the below area by observing and analyzing the results and conclusion. The observation also consider the demerit of the design process if proposed antennas.

- The developed hardware can further be used to find Specific Absorption Rate (SAR)by making setup for human model testing and can be used to monitor the effect of antenna on human body.
- Further different shaped EBG structures which include the planar as well as 3-D structures can be implemented and analyzed to improve the antenna performance.
- This design work can be extended for MIMO applications in 5G frequency band.

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