DESIGN AND IMPLEMENTATION OF MULTIBAND AND BROADBAND MICROSTRIP ANTENNAS FOR WIRELESS SYSTEMS

A thesis submitted
for the award of degree of
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by
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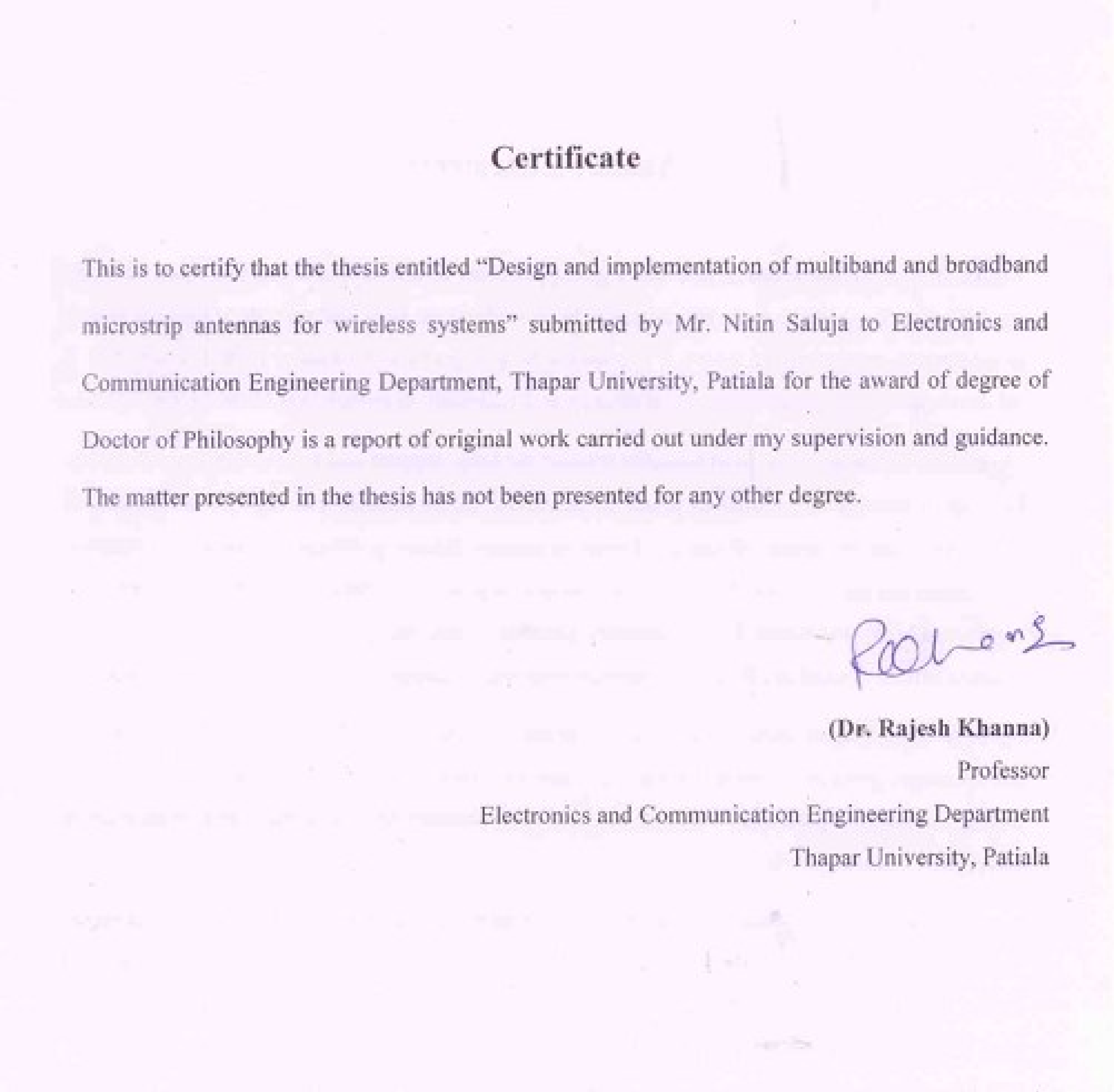

Certificate

This is to certify that the thesis entitled "Design and implementation of multiband and broadband microstrip antennas for wireless systems" submitted by Mr. Nitin Saluja to Electronics and Communication Engineering Department, Thapar University, Patiala for the award of degree of Doctor of Philosophy is a report of original work carried out under my supervision and guidance. The matter presented in the thesis has not been presented for any other degree.

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Abstract

With advancement in wireless systems, the device size is shrinking. The modern day wireless systems are termed as next generation wireless systems. The modern day, small size wireless devices are not just limited to voice conversation but also support high data rate multimedia applications like VoIP, video conferencing, wireless broadband and online gaming etc. The high data rate can be achieved by increasing the bandwidth support of the system. Antenna being important integral part of wireless system requires to support broad bandwidth. The heterogeneous technology support to wireless system is other advancement in next generation wireless systems. So the antenna for next generation wireless devices require support to larger bandwidth and support to multiple technology. This motivation leads to research presented in the thesis.

The thesis is organized with four objectives. The first objective is devoted to the study of different type of techniques for multiband and broadband operation. In process for achievement of first objective, the historical development in wireless systems are considered for insight to different technology and application support. The planar antenna has advantages of being conformal, low profile, small size and ease of integration with device PCB. So the challenge is to design multiband and broadband planar antennas. The length of antenna is frequency dependent so specific techniques can achieve multiband and broadband operation. In this thesis, the different techniques which are already presented in literature for achieving multiband and broadband support to microstrip antennas are surveyed.

In the next chapters, the different designs to achieve multiband operation are discussed. This is second objective of the thesis. The planar multiband antenna is designed and termed as multiband microstrip patch antennas. To start with, the planar antennas with different type of feeds are compared. The slot in patch of MPA is one method to achieve multiband operation of planar antenna. The different type of fractal shape patches are considered for multiband operation. The sierpinski carpet and sierpinski gasket shapes are discussed with limitation of each. The analysis reveals that the sierpinski carpet suffers with problem of impedance matching at the edge of the patch and sierpinski gasket suffers with the problem of non-uniform conduction at the nodes of triangles. Further the modified CPW feed with sierpinski gasket shape is considered for multiband operation of antenna.

The second types of design discuss the planar broadband antennas. The Rumsey’s principle term the broadband antenna as frequency independent antennas. It is analyzed that, the bandwidth can be enhanced by increasing the substrate height and decreasing the substrate dielectric constant. The effect of different type of feeds on bandwidth of antenna is considered. The defected ground structure is another method to achieve broadband operation of planar antennas. The hybrid fractal is proposed as ultra-wideband planar antennas. The hybrid fractal comprises of sierpinski gasket and sierpinski carpet shape. The sierpinski gasket shape is performing two operations, one is to resonate at multiple frequencies and to act as impedance transformer for sierpinski carpet antenna. The different resonances are merged to obtain broadband response of antenna. The hybrid fractal so proposed offers high gain along with the wide impedance bandwidth.

The planar inverted F antenna because of its inherited small size is used for modern day mobile handsets. The PIFA support to multiband and broadband operation is discussed in the thesis. The folded edge, Fractal PIFA is proposed as small size antenna for 3G mobile handsets. Further F-PIFA are made resonant at multiple band of frequencies. The MIMO concept further enhance the data rate for wireless systems without need of increasing the bandwidth. The MIMO PIFA with patches at different heights can be used to reduce correlation between two antennas. The ECC value of proposed antenna is analyzed and concluded as MIMO PIFA antenna for LTE applications.

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Acronyms and Abbreviations

3G	Third Generation
4G	Fourth Generation
BW	Bandwidth
CPS	Coplanar strip
CPW	Coplanar waveguide feed
CRLH	Composite right left handed
dB	Decibel
DCS	Digital Communication Systems
DCS	Digital communication standard
DGS	Defected ground structure
DRA	Dielectric resonator antenna
EBG	Electromagnetic band-gap structure
ECC	Envelope correlation coefficient
EHF	Extremely high frequency
EM	Electromagnetic
EM	Electromagnetic
F-PIFA	Fractal planar inverted F antenna
GHz	Gigahertz
GPS	Global positioning system
GSM	Global system for mobile communications
HD	High definition
HDRA	Hemisphere dielectric resonator antenna
ISM	Industry specific and medicals
LTE	Long term evolution
MEMS	Microelectronics mechanical switches
MHz	Megahertz

MIMO	Multiple input multiple output
MPA	Microstrip patch antenna
PCB	Printed circuit board
PCS	Personal Communication System
PIFA	Planar Inverted F antenna
SFM	Sleeve Feeding Method
SLL	Side lobe level
SP	Square pulse
TEM	Transverse electromagnetic
TM	Transverse magnetic
UHF	Ultrahigh frequency
UMTS	Universal mobile telecommunication system
UWB	Ultra wideband
VLSI	Very large scale integration
VNA	Vector network analyzer
VoIP	Voice over internet protocol
WBAN	Wireless body area network
WiFi	Wireless Fidelity
WiMAX	Worldwide interoperability for microwave access
WLAN	Wireless local area network
WPAN	Wireless personal area network

Chapter 1

Introduction

Modern day's advancement in technology is dominated by achievements in the field of wireless technology. The prime objective in this era of technology is derived by need of small and high speed devices. The miniaturization of devices is well supported by the shift in operating frequency band of wireless technology to higher range. Also, the high data rate requires the operating frequency band to be on higher side. The dimensions of the component in device is inversely proportional to the frequency. The increase in operating frequency of technology results in reduction in component size so that objective of miniaturization of devices is well achieved. This era sets a trend of everyday change in technology. The speed of advancement is so high that the device introduced today gets outdated the next day. The technology change in wireless has well achieved the objective of miniaturization as well as the speed has increased considerably in last decade. The decade proved phase of improvements in wireless technology after its implementation phase in last decade. So, the research has played crucial role in advancement of wireless devices. The revolutionary change in wireless technology in this decade is caused by advancements in microwave devices. The shift of operating band from radio frequency to microwave frequency achieved objectives of miniaturization and high data rate. Free optics [1] can be used with high speed switching to achieve high data rate but need for wireless communication is desirable.

1.1Wireless Communication

From the beginning of communication with symbol and sign, the communication has gone through tremendous growth. The human communication started with introduction to speech around 100,000 years back and then symbols were invented 30,000 years back. The written communication was developed later around 5000 years back in the form of scripts. The most common type of symbols used in traditional time for the communication are cave paintings, petroglyphs etc. The communication over distance was carried out by using smoke and drum sound as carrier of the information. The semaphore which is system of communication using visual signal was introduced in 1792 by Claude Chappe, but got popular in late 18th century and early 19th century. In 1837 the electrical communication started its existence with introduction of Morse telegraph. Later after introduction of telephone in 1876, wireless telegraphy was introduced in 1893. The first wireless telephone conversation was made in 1880 by Graham Bell and Charles Sumner Tainter introduced photophone. In photophone, audio was transmitted wirelessly using modulated light beams. The Hertz experiment to prove existence of electromagnetic wave in 1888 was the beginning of wireless communication using electromagnetics and till then the technological era is all devoted to development of wireless communication. The electromagnetic wave emerged as the carrier which can penetrate physical material as well. It was major breakthrough in communication lead to development of wireless communication. Electromagnetic theory was later predicted by James Clarke Maxwell and Michael Faraday. In 1885 scientists claimed the invention of radio but the communication was made using electromagnetic induction rather radio waves. The demand in that phase was to develop wireless communication over larger distance. The Indian scientist Sir Jagadish Chandra Bose was first to use semiconductor junction for detection of radio signals. Sir Bose used millimeter waves for the communication over large distance. The long wave exhibiting properties like light encouraged him to use millimeter or microwave for communication. In 1894, Sir Bose demonstrated publically the use of radio waves in Calcutta. In 1927, the first commercial radio telephone service was established. Earlier wireless communication was using different carriers for communication and aimed the transmission of information in form of voice only. The electromagnetic wave proved carrier for longer distance communication and frequency of operation shifted to higher side in recent technologies.

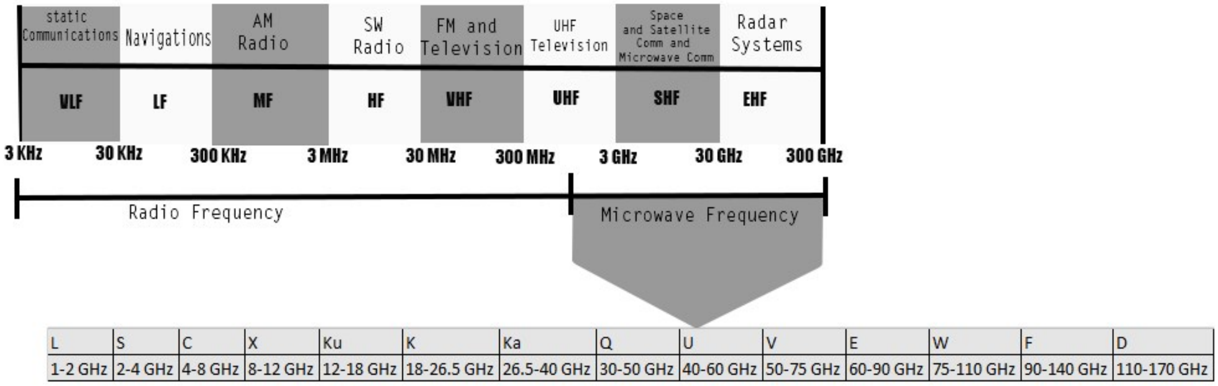
Further, the frequency is important factor in wireless communication as the wave property is dependent on frequency. Based on the frequency of operation the different modes of wireless communication are

1. Electromagnetic induction
2. Radio wave
3. Sound wave
4. Optical wave

Due to peneteration power of Electromagnetic waves, it is used for wireless communication. The different frequency desgingation according to the frequency is given in figure 1.1.

1.2 Microwave Communication

Microwave is electromagnetic wave with frequency in range of GHz. The wavelength for microwave is in range of millimeter. The microwave frequency range is assigned letter specification given in figure 1.1. The waves at microwave frequency have smaller wavelength than radio waves and include UHF and EHF frequency band.



L	S	C	X	Ku	K	Ka	Q	U	V	E	W	F	D
1-2 GHz	2-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	18-26.5 GHz	26.5-40 GHz	30-50 GHz	40-60 GHz	50-75 GHz	60-90 GHz	75-110 GHz	90-140 GHz	110-170 GHz

Figure 1.1: Electromagnetic and Microwave frequency spectrum

As discussed in section 1.1, the experiment carried out by Hertz for existence of Electromagnetic wave, Hertz used microwave at frequency of 450 MHz for communication. In the demonstration by Sir J.C. Bose discussed in section 1.1, the door bell with radio control was demonstrated. The radio control used millimeter wavelength for transmission of information from control to bell. Since the size of component is dependent on the frequency of operation and size is inversely proportional to the frequency. The use of higher frequency band results in reduction of size. The data rate at the same time increased at microwave frequencies. Also The microwave can penetrate ionosphere which is not possible in case of radio waves. The wave at microwave frequency is used in point to point communication. The next generation wireless communication technology is shifting to higher operating frequency bands due to their advantages. The microwaves are extensively used in Wireless communication, Radar and Satellite communication. So, different wireless standards are using microwave frequency for communication. The different wireless standards and their frequency of operation are given in table 1.1. At microwave frequencies the components behave like distributed elements rather than lumped elements. These days, the different components like resistors, capacitance and inductance are fabricated on stripline for microwave frequenceis.

Table 1.1: Different wirleess communication standard

Wireless Standard	Operating Frequency
Global system for mobile communication (GSM)	900 MHz and 1800 MHz
Digital Communication System (DCS)	1800 MHz
Universal Mobile Telecommunication System (UMTS 3G)	2.1 GHz
Personal Communication Systems (PCS)	1900 MHz
Bluetooth	2.4 GHz
WiFi	2.4 GHz and 5.1 GHz
WiMAX	
4G (Long Term Evolution)	699 MHz – 960 MHz, 1710 MHz – 2690 MHz
Industrial Specific and Medical (ISM)	2.4 GHz, 5.1 GHz, 5.7 GHz
Worldwide Interoperability for Microwave access (WiMAX)	2.5 GHz, 3.2 GHz, 5.2 GHz

1.3 Antenna

Antenna word is taken from segment on head of insect ants. Antenna in context of radio is a conductor which can transmit and receive electromagnetic waves. Antenna is a type of transducer which converts electromagnetic energy to electrical signal at receiving end and electrical signal to electromagnetic energy at transmitter end.

1.3.1 Radiation from Antenna

The antenna radiates mainly due to change of current density in conductor with respect to its dimensions. The current is flow of charge. The charge flowing with uniform speed through conducting wire produces uniform current and wire does not radiate. If current flowing through conducting wire is varied, the wire will radiate. In wireless communication the energy is to be radiated in free space. So uniform current distribution can be disturbed with abrupt change and it will result in change in current density and radiation will occur. There are many other ways to generate time varying current in conductor. The conducting wire can be curved and bent to generate time varying current and radiation will occur. In [2] radiation mechanism of antenna is discussed. Two parallel transmission lines produce electric line of forces from one wire to another if the dimension of conductor is λ. The electric lines of forces cancel each other and no radiation occurs. If parallel transmission lines are flared at one end it will disturb electric lines of force. The disturbance in electric lines at one ends loosen up the electric lines of forces and time varying current allows it to radiate.

1.3.2 Historical Developments in Antenna

As explained in section 1.1, the Hertz experiment proved existence of EM waves in 1888. The antenna used in the experiment was λ/2 dipole. It was followed by the use of horn antenna in 1897 by scientist J.C. Bose. In 1901, G. Marconi sent signal transalantic from England to Newfoundland. The antenna used in the transmission consisted of 50 vertical wires in form of a fan at transmitter end and 200 m wire supported by flying kite. In early days the antenna technology was limited to wire antennas. In world war – II, the invention of microwave component lead introduction to advancment in antenna beyond wire antnenas. The antenna introduced in this era was mainly aperture antennas. The different type of antennas evolved during world war – II are waveguide horn, slot, reflector, open ended waveguide and lense antenna [2]. The antenna intorduction enabled wireless communication in applications like radar and remote sensing in era of world war – II.

1.3.3 Different types of antenna

The antenna can be classified into different categories depending on their characteristic parameters like shape, material used and radiating structure. Depending on characteristics directivity, the antenna can be classified as Isotropic antenna and Directive antenna. On the basis of shape, the atnenna is classified as wire antenna, planar antenna, fractal antenna, horn antenna, reflector and dielectric lense etc. The dielectric antenna and metallic radiating antenna are two type of antennas classified on basis of material used. The radiating structure may work on the principle of resonance or it may be leaky wave antenna.

Isotropic and directive antnenas

Isotropic antenna is hypotheticaly ideal antenna. It is considered as lossless antenna. This type of antenna radiates equally in all directions. While directional antennas radiate and receive more or less energy from a particular direction.

Wire Antennas

Wire antenna consist of metallic wires of definite length capable of radiating electromagnetic waves at specific frequency. The different examples of wire antennas are short dipoles, halfwave dipoles, folded dipole, monopole and loop antenna. The short dipole is the simplest type of antennas with length quite smaller than wavelength of the wave. The current distribution of this type of antenna is considered to be triangular distributed. This type of antenna antenna is usually considered as narrowband antenna. If the length of antenna is $\lambda/2$, it is said to be half wave dipole. The half wave dipoles are more directional than short dipole. The half wave dipole is ominidirectional type of antenna. The monopole antenna length is considered half of $\lambda/2$ dipole. The antnena is placed vertically above the large ground plane. For monopole, one end of feed is connected to radiator and other is connected to ground.

Planar Antennas

Planar antenna is one of the recent trends in antenna design. The conductor when sticked to planar surface is called planar antnenas. The most popular planar type of antenna is Microstrip antennas. The microstrip antennas consist of substrate, patch and ground. The patch can assume any shape like rectangular, triangular and circular etc. based on their desired specifications. The patch can also have fractal shape, which enable multiband and broadband operation of antenna. Due to low profile and ease of integration with feed network makes planar antenna popular in this era.

Horn Antenna

Horn antenna is flared out waveguide structure with flaring in different axis. Horn antenna can further be classified as E-plane horn, H-plane horn and pyramidal horn. Horn antennas are quite popular high directive gain antennas. Horn antennas are fed by section of waveguides. The Horn antennas are most commonly used in measurement of gain of any test antenna.

Reflectors and Dielectric lenses

Reflectors are further differentiated according to their geometerical configuration. The most popular configuration of reflectors are plane, corner and parabloic (Curved) Reflectors. The reflectors are large in size and used to enhance gain of antenna. Lens antennas are used to collimate diversified waves. It is used to prevent spread of the wave in undesired directions. Dielectric lenses are most commonly used in modern day applications.

Modern day antennas

The example of modern day antennas are Planar inverted F antenna (PIFA) which is used for mobile applications. The other examples are Near field communication antennas and Dielectric resonators.

1.4 Microwave antenna

The microwave communication refers to the transmission of radio waves at higher frequencies in range of around 1 GHz to 30GHz. The advantages of Microwave communication encouraged the next generation technologies shift to higher frequency. The advantages of microwave communication can be summarized as

- The bandwidth availablity is more. Microwave communication has large capacity to carry information because the operating frequency is quite high.
- Microwave communication has high penetration power.
- Since size of the antenna is directly proportional to wavelength. The wavelegth of microwave is quite less, so the size of antenna is quite less.
- It enables line of sight communication over large distances. The satellite communication is one of the application at microwave frequency.

The advantage of microwave communications is inherited due to its small wavelength. Since size of the dipole is considered to be $\lambda/2$. The antenna size is in range of milimeters. Microwave antenna is quite important component in microwave communication. The communication at longer wavelength is affected by objects of comparitive size. In short wavelength like in case of microwave communication the interference from objects are quite less.

The commonly used antenna at microwave frequency is microstrip antenna and dielectric resonator. Both are explained as under.

1.4.1 Microstrip Antenna

The microstrip atnenna was evolved in early 1950s as planar antnenna. The microstrip antenna got popular in 1970s. it consists of substrate, patch and ground plane. The substrate is dielectric material while patch and ground plane are electric conductors. These type of antennas are narrowband antennas in their quite basic form. These types of antenna enjoy advantages in terms of low cost for manufacturing, ease of integration, planar and conformal to the base. Microstrip antennas are used at higher frquency band and most commonly used for microwave communication. The disadvatages are stated as low bandwidth and low power handling capacity. The surface wave excitaiton is common problem in microstrip patch antenna. These antennas are quite popular candidate for next generation wireless devices for its advantages. Different type of patch shapes can be used in microstrip patch antenna. The common shapes used as microstrip patch are rectangular, circular, elliptical and other continous shapes. The most common form of microstrip patch in use for modern day device are planar inverted F antenna (PIFA). The PIFA are used in mobile devices these days. The PIFA are low profile antennas and omnidirectional in nature.

1.4.2 Dielectric resonator

The dielectric resonator antenna is dielectric mounted on metal and the ground plane. The dielectric resonator radiates when wave enter in dielectric and bounce back and forth inside it. It produces standing waves and the walls of dielectric material is transparent to radio wave and it radiates. The dielectric resonator does not have metallic part which dissipate energy at higher frequencies. The dielectric resonator antenna is commonly used at microwave frequency. The advantages of dielectric resonator can be summarized as

- Higher Bandwidth
- Ease of Coupling
- Size of the dielectric resonator antenna is said to be $\approx \frac{\lambda}{\sqrt{\varepsilon_r}}$, so by increasing the dielectric constant the size can be reduced.
- The example of dielectric material is ceramic.

1.5 Need of next generation generation wireless systems

As the mobile communication has become essential part of everyone's life. The wireless industry has experienced lots of rapid changes in the era. The major changes in the wireless device are reduction in size with development of technology and enhancement in multimedia service experience to users. As the consequence of the reduction in size, the frequency of technology has been shifted on higher sides. This is the reason that these days wireless communication system is dominated by communication at microwave frequency. The antenna being important part of any wireless devices has gone through various changes in recent past. The demand of multimedia application has ignited high data rate aplication support to mobile antenna. The communication at higher data rates has bottleneck of length dependent behavior of antenna. Further wirelss device these days is embed with support to multiple technology in single device. The mobile phone is the best example of multi technology device. The mobile phone these days are enabled with GSM (2G), UMTS (3G), Bluetooth, WiFi etc. The different technologies discussed here operate at different frequency bands. The different frequency bands support to device require multiple antennas. The alternate for use of multiple antenna is multiband antenna.

The needs for next generation wireless devices can be summarized as small size, higher data rate, support to multiple technology and low cost. So the need of next generation wireless devices has driven the need for broadband and multiband antenna while keeping the size of antenna small and cost effective. In this thesis new techniques to achieve the broadband and multiband operation of antenna are presented.

Since antenna has proved to be bottleneck in achieving next generation wireless system goal. The antenna desired characteristics required are small size, high gain, low side lobe level, high directivity, broadband and multiband operation.

1.5.1 Multiband Antennas

As discussed in previous sections, the multiple technology support in a device requires multiband support of antenna. Since frequency of operation for antenna depends on length of the antenna, it is difficult to obtain multiband operation from single antenna. The antenna has impedance match at specific frequency only. So, special antenna structures are needed to support multiband operation. As discussed in previous section at microwave frequency the planar antenna is used in modern day wireless device. The fractal shape patch is commonly used for multiband operation of planar antenna. The fractal is a self similar scaled repeating structure. The common examples of fractal shapes are sierpinski carpet, sierpinski gasket and koch monopole etc. The fractal antennas exhibits multiband operation because of self similar structure at different scale. The different length of antenna resonate at different frequency and offers multiband operation of antenna.

1.5.2 Broadband Antenna

The bandwidth dependency of antenna is bottleneck in achieving high data rate for multimedia applications in modern day wireless device. The need of high bandwidth is driven from recent trend of high data rate multimedia support in wireless device. Generally, the antenna is considered frequency dependent structure resonating at specific frquency for given length. So the broad bandwidth of antenna is needed for modern day wireless device. The broadband antenna was referred by Rumsey as frequency inependent antenna. The Rumsey in [3] discuss principle for frequency independent antennas also named as rumsey's principle. According to Rumsey broad bandwidth can be achieved if gemoetry of antenna is defined in terms of angles, so that frequency of operation for antenna no longer depends on length but depend on angles only. In case of planar antenna such as microstrip antennas broad bandwidth can be achieved by numerous ways discussed later in chapter 4.

1.6 Objectives of the thesis

Based on study of preceeding sections, the following objectives are laid for the thesis research

i) To study different broad banding and multi banding techniques used with Microstrip Antenna.

ii) To design and simulate a new optimized Microstrip Patch antenna for different access technologies.
   i. Parametric study of proposed antenna.
   ii. Fabrication and testing of the proposed antenna.

iii) To design and simulate a new optimized Microstrip Antenna supporting multiple technologies in single antenna i.e. Multiband support.
   i. Parametric study of proposed antenna.
   ii. Fabrication and testing of the proposed antenna.

iv) Comparison of simulated and measured results.

1.7 Organization of the thesis

The thesis is organized in six chapters.

In Chapter 2 '**Literature survey**' of different type of antennas including multiband and broadband antennas has been included. The literature survey covers basic microstrip antennas, the different types of performance criteria of antennas, fractal antennas, hybrid fractal antennas, UWB antennas, PIFA antennas, F-PIFA antennas and their performance analysis. It also includes the details of requirement of antenna for modern day wireless devices and different methodology to implement requirements. It also covers the detail of the effect of varying different antenna dimensions on its design. The different shapes of antenna are studied and it motivates the new shapes for efficient radiation from antenna. The literature survey for different types of feed for microstrip patch antenna has also been included.

Chapter 3 is devoted to the description of **'multiband antennas'** particularly multiband microstrip antenna. The multiband antenna requires the multiple resonance from given antenna. The analysis of different antennas are carried out using EM simulation software and the comparison of various multiband techniques have been discussed. The chapter also includes the effect of multiband operation on gain of different type of antennas. The multiband operation of antennas for various access technologies has been presented in detail. The main objective of the research is to propose multiband antenna having small size and optimum gain at desired frequency bands. The chapter details the different type of fractal shape to achieve broadband and multiband operation of antenna. The sierpinski Carpet and sierpinski gasket are the most commonly used shapes for fractal antennas. The fractals with different type of feeds are simulated and fabricated. The sierpinski carpet antenna is presented with CPW feed for multiband operations. The current distribution problem for sierpinski gasket has been discussed in the chapter. The current distribution in sierpinski gasket type of fractal is not uniform because of its shape of triangle. Due to non-uniform current distribution in sierpinski gasket type of antenna, the current is unable to reach apex of the antenna. Different techniques have been proposed to deal with this problem. The use of modified coplanar waveguide feed for uniformity in current density for sierpinski gasket type of antenna have been proposed. The comparison of the sierpinski gasket antenna with and without modified CPW feed is given in the chapter. The current distribution of proposed antenna with modified CPW feed and without modified CPW feed is given. The multiband antenna with modified CPW feed for sierpinski gasket type is presented in the chapter along with radiation characteristics of antenna. The proposed antenna is fabricated and measured results are compared with simulated results.

In chapter 4 the details of designing **‘broadband antennas’** is presented. The high data rate need of modern day wireless applications require broad bandwidth of the antenna. So, the broadband antenna is need of modern day wireless devices. In this chapter, the different techniques to achieve broad bandwidth have been discussed. This chapter includes the effect of dimensions of ground plane on wideband behavior of antenna. The aim of the research is the study of broadband antenna while maintaining the gain so that gain bandwidth product is maximized. The chapter also includes the study of **‘fractal and hybrid fractal shape of antennas’**. The chapter also includes the design of hybrid fractal antennas for modern day wireless devices. The hybrid fractal of sierpinski gasket and sierpinski carpet antennas is given in this chapter. The hybrid fractal with defected ground structure is proposed for dual wideband operation of antenna. The two fractals have different frequencies of resonance so multiband operation can be achieved using hybrid fractal. The hybrid fractals are also presented with CPW feed for frequency bands 2-5 GHz and 7-9 GHz. The current distribution is given as proof of concept and radiation properties are given in terms of gain of the antenna. The proposed antenna has multiple wide bands which is objective of the study. The novelty in design is evitable in terms of gain bandwidth product offered by the antenna. The hybrid fractal with CPW feed is also advantageous for its ease of integration with next generation wireless devices. The parametric studies are described in the chapter for the proposed design and optimum parameters are chosen. The size reduction is evitable by using fractal shaped patch of the antenna. The hybrid fractal shape antennas help achieving multiband and broadband operation of antennas. The proposed antennas are best suited for modern day wireless devices.

Chapter 5 considers small size **‘antennas for modern day wireless devices’**. The PIFA is used as small size antenna in modern mobile handsets. In this chapter the main focus is design of planar inverted F antennas. The PIFA antennas are $\lambda/4$ dimension shorted pin antennas. The PIFA with fractal shaped patch is proposed in the thesis. The antenna for mobile 3G application is given in this chapter. In literature F-PIFA for multiband resonances of antenna and size reduction is proposed. But in the design presented in thesis, the edges are folded for further reduction of antenna size. In literature the folded edge is used for size reduction but in the proposed design two edges are folded with F- PIFA so results in ultra-small size antenna for mobile applications. The parametric analysis of folded edge F-PIFA is carried out and the parameters are optimized for antenna at UMTS frequency band. The antenna is ultra-small size antenna with overall dimension of 14.94 mm X 16 mm. The disadvantage of folding the edges is also characterized in the chapter. It is clarified that folded edge decreases bandwidth of the antenna so compromise is made between bandwidth and size of the antenna. The size reduction is up to 21.61 % in comparison to conventional antenna (calculated with formulation of conventional antennas) is reported in the chapter. The multiband and broadband operation of folded edge F-PIFA is presented. In the proposed design small size F-PIFA for two bands operating at 2.25 GHz- 2.863 (613 MHz bandwidth) GHz and 4.81 GHz-6.21 GHz (1400 MHz bandwidth) is proposed. Both of the bands are wide enough to support high data rate applications. The antenna is fabricated in lab and shown in the chapter. The Multiple Input Multiple Output (MIMO) technique recently introduced in modern day wireless devices require the MIMO antenna to be incorporated in these devices. MIMO-PIFA antenna is given in this chapter. The Envelope correlation coefficient (ECC) parameter is studied for the proposed design. The methods to decrease correlation between antenna elements to increase the data rate, are introduced in chapter. The different heights PIFA are proposed for decreasing correlation between the antennas. The MIMO PIFA antenna for LTE/WiFI/4G/3G/WiMAX application is introduced. The ECC parameter is given for the desired frequency band. The ECC value for the proposed design is satisfactory for the given design and can be used as MIMO antenna in the modern day wireless devices. The comparison between measured and simulated results is given and it shows good agreement. The PIFA antenna is the best candidate for small size antennas to be used in modern day mobile handsets. As proposed designs fulfil the criteria of performance for the next generation mobile handsets so best suited for its use in the devices.

Finally the chapter 6, gives the summary of **‘conclusions’** drawn in all the objectives. In thesis work has been concluded that multiband and broadband operation can be observed from various antennas. Fractal shape is important to achieve multiband operation of antenna. The different type of fractals are studied in the thesis. The type of feed and its effect on bandwidth of the antenna is presented in the thesis. The broad bandwidth is achieved using various methods like modified feed, modified ground planes and by using fractal shapes with overlapping resonances. The hybrid fractal shape is introduced for multiband and broadband operation of antenna. The antennas are fabricated and comparison between simulated and measured results is given. The solution to the problem of non-uniform current density in sierpinski gasket fractal is proposed. Further small size of antenna is obtained by using planar inverted F antennas. The PIFA antennas are introduced with Fractal shapes patches. Further edges are folded for further reduction in size of the antenna. The MIMO PIFA is introduced in thesis for different applications in modern day wireless devices. In the end the scope of future work has been presented.

1.8 Summary of the chapter

The chapter briefs the motivation for the thesis. The chapter covers historical development of wireless communication, historical prospective of antenna designs etc. In this chapter the technical aspect of antenna is also presented. The radiation characteristics of antenna is described. The chapter also briefs different type of antennas. The design and fabrication of broadband antenna, Multiband Antenna and small size antennas are proposed as objectives of the thesis. In the end of the chapter the thesis organization is detailed.

Chapter 2

Study of multiband and broadband techniques

The last decade was devoted to the growth of telecommunication in different parts of the world. After the growth witnessed by telecommunication in recent past, not only the number of users have increased termandously but services and facilities offered by recent technologies have gone through extensive changes as well. The modern day demand of multimedia appilcations support shifted technology support to higher data rates. The need of higher data rate has further driven the requirement of broad bandwidth of the antenna. The data rates can further be increased with use of Multiple input multiple output (MIMO) system. The antenna is an important integral part of mobile and wireless devices. So, the higher data rate support calls for broadband antenna. Further need of different applications derives support of different technologies in a single device. It can be achieved using multiband antenna. From inception of radio communication in early 1910s, lots of papers have got published on amature bulky radio transmitter and receiver [4-8]. In [8] author discussed significance of antenna impedance on transmission of electormagnetic waves. During these early days of wireless communication, the use of dipole and coil antennas was quite common. Dellinger in [9] discussed the advantage of coil aerials and it was early development in antenna design. In that decade, also the size reduction was also emphasized. Further Miller and Hund formulated the inductance, capacitance and resistance of coil antenna in [10]. As coventional designs of antennas were high profile and antennas were extended at large height from the base. The high profile antennas were less reliable, costly, difficult to integrate with transmitter and receivers and were large in size. The planar antenna was introduced in 1960s but got popular in 1980s. The research work reported in domain of microstrip patch in early 1980s. Inspite of advantages of low profile microstrip antennas, it suffered from low bandwidth and surface wave excitation problem. The need of higher data rate applications and support to multiple technologies in next generation wireless devices drived researchers to look after broadband and multiband antenna.

In 1969 Gallegro A [11] printed dipole on high dielectric constrant substrate. In the era of 1970-1980 microstrip antennas got popular. In this decade antenna design has gone through transition from wire antenna to planar antennas in form of microstrip patch antenna. Microstrip patch antenna fits well because of its specific advantages. Various papers discuss advatnages of microstrip antenna as small size, conformal nature, ease of integration with transmitter and receiver and ease of fabrication [12]. Different models are proposed for analysis of microstrip patch antenna. . Neural analysis is used in [13] to analyze multiband antennas. The advancement leads to enormous research in relevant domain such as in [14] the microwave and optical properties of nano material is considered. Authors in [15] describes advancement in wireless technology and next generation networks. MPA is the most popular antenna at microwave frequencies used in wide range of applications like satellite applications, mobile communication, aircraft antenna and antennas in near field communication. The last decade research has come up with some issues in microstrip antenna given as

(i) Limited Bandwidth
(ii) Resonance at single frequency (Lack of multiband support)
(iii) Size of antenna
(iv) Ease of integration.

2.1 Techniques to implement wideband antenna

The conventional microstrip antenna suffers with problem of less bandwidth and surface wave excitation [16]. In literature various methods are discussed to achieve wide bandwidth with microstrip patch antenna. The bandwidth enhancement of microstrip patch antenna can be achieved by increasing the height of susbtrate or by decreasing the dielectric constant. The increase in height of the susbtrate will lead to poor gain of the antenna and decreasing the dielectric constant will have surface wave excitation problem [2]. The most common techniques used in enhancing bandwidth of microstrip patch antenna can be slot cut in micostrip patch antenna [17-21], multi layer structure [22-24], Aperture coupled feed [25-29], Fractal shaped patch [30] etc.

The enhancement of bandwidth using inductive coupling is also reported in the numerous papers. In [31], inductively coupled branch strip is used for bandwidth enhancement. Author claims that inductively coupled branch causes an additional resonance near lower frequency band of printed antenna. So enhancement of bandwidth is achieved. The proposed antenna covers LTE and Wireless wide area network bands (WWAN) (704–960 MHz and 1710–2690 MHz). Khoondzadeh-Asl et. al. in [32] proposes low profile wideband antenna for avionic applications.

Author uses the inductive loading to reduce height of the antenna. The added inductive structure also contributes in radiation. Inductance is realized using circular groove on the ground plane. Further length reduction is achieved using shorting pin concept. Authors state that the shorting pin reduces the bandwidth and claims that if shortening pins are incorporated in the antenna structure, it can change the non radiating series resonance to radiating parallel resonance. The height of the proposed antenna is 0.03λ and proposed antenna has impedance bandwidth of 17 %. The impedance matching is achieved at 1.16 GHz to 1.38 GHz.

Further the use of dielectric resonators to achieve wide bandwidth is also reported by authors. In [33] inverted hemisphere dielectric resonator antenna (HDRA) is proposed. Author termed it a cup shaped inverted HDRA. The proposed antenna resonates at 2.04 GHz and support band of 1.8 GHz – 3.7 GHz. The proposed antenna has gain of 4.5 dBi at 2.3 GHz. Proposed DRA supports two modes i.e. TM_{101} and $TM_{01\delta}$. Further coupling of different operating modes at differnet frequencies can achieve wide bandwidth. Pan et. al. in [34] proposed wideband slot loop hybrid antenna. In this paper author claims coupling of three different modes to achieve wide bandwidth. The overall dimension of proposed antenna is 45 X 57.4 X 1.6 mm^3. Three different resonant modes are given viz; a loop mode for the lower band, slot mode for the middle band and the monopole mode for the higher band. The impedance bandwidth of proposed design is 102.9 %. The impedance bandwidth of proposed antenna is 1.82 GHz to 5.68 GHz. The FR4 with thickness of 1.6 mm is used as substrate. The peak gain of proposed antenna is 5.3 dBi. He et. al. in [35], discuss achievement of wide bandwidth with circular polarization across entire bandwidth. In this paper cross dipole with open end is used as radiating element. To enhance imepdance bandwidth and polarization bandwidth, cross dipole is used with wide open ends. The overall dimension of proposed antenna is 0.45λ X 0.45λ X 0.24λ. The peak gain of the proposed antenna is 6.8 dBi. Author claims impedance bandwidth of antenna to be 50.2 % and cutting-quarter printed ring provides higher impedance and axial ratio bandwidth. In [36] broadband balun is used to enhance both impedance bandwidth and circular polarization bandwidth of antenna. In this paper circular shape of patch is used. The 90^o broadband balun is used in the proopsed design in place of 90^o hybrid coupler. The proposed antenna offers impedance bandwidth of 59.52 % from 1.18 GHz to 2.18 GHz. In [37] the electromagnetic shielding properties of textile fabric is discussed which can be considered to study effect of materials of electromagnetic property. Koohestani et. al. in [38] proposed antenna for wireless body area network applications. The proposed antenna exhibit vertical polarization, so reduce radiation on body. UWB technology is used for WBAN application. The antenna is proposed with UWB support. The author discuss the requirement of WBAN antenna as low profile with low backward radiation antenna. The proposed antenna is low profile monocone structure with cylndrical structure on top covered by top cross plate. The structure on top of monocone is added to enhance impedance bandwidth of the antenna. The overall height of antenna is 8.5 mm. The antenna has impedance matching from 3.06 GHz to 12 GHz. Authors claims the omnidirectional pattern from proposed antenna.

The vaivaldi shape is also suitable for wideband operation of antenna. In [39] vivaldi antenna with stepped connection between slot line and taperd patch is introduced. The vivaldi antenna offers high bandwidth and compactness in design is achieved with stepped connection. The antenna is proposed for UWB application in frequency band 3-15.1 GHz. In proposed design Microstrip to slotline transition structure is used as feed. The author claims flat group delay response of proposed antenna.

The fractal is a famous way to achieve wide bandwidth. The wide bandwidth of antenna achieved by fractal is because it has self similar structure. According to Rumsey’s principle if all dimensions of antenna can be defined in terms of angle, the antenna will be frequency indpendent antenna. The fractals are supposed to follow Rumsey’s Principle. The various fractals are discussed in literature to achieve wide bandwidth of antenna. In [40] Azari A. discussed a fractal shaped antenna for super wideband applications. The proposed Fractal antenna geometry is based on an iterative octagon. Proposed antenna is applicable in 10 GHz–50 GHz frequency range and author claims that gain of this fractal microstrip antenna is reasonable in entire bandwidth. In proposed antenna substrate used is Rogers TMM with relative permittivity (ε_r) 4.5 and thickness 1.524 mm. The overall ground plane dimensions are 6X6 cm^2. Coaxial probe is used to feed antenna. Antenna is simulated for frequency range from 10 GHz to 50 GHz range. This wideband behavior is due to the fact that the currents along the edges introduce additional resonances, which produce an overall broadband frequency response characteristic. Levy et. al. in [41] proposes antenna array for UWB technology to be used in intra-chip communication and medical imaging applications. The circular monopole is used and ground is utilized to match impedance so as to improve the bandwidth of the antenna array. The antenna array utilized circular elements with increasing size. The antenna array is claimed to work in frequency range of UWB applications. In [42] Azari and Rowhani proposed hexagon fractal antenna for broadband application. In the paper up to two iterations are applied on initial hexagonal shape. The dimension of proposed antenna is 7 X 7 cm^2. The author claims resonance of the proposed antenna to be 0.1 GHz to 24 GHz. In [43] Naghshvarian-Jahromi introduces Penta Gasket Koch monopole fractal antenna. The author considers -5 dB bandwidth as performance criteria. The substrate used for the proposed antenna is Roger RO4003. By changing the ground plane length impedance bandwidth is improved. The ground length for proposed antenna is 18 mm. The author claims -5 dB bandwidth from 1 GHz to 20 GHz. The proposed antenna exhibit semilog periodic behavior. Butterfly type of fractal shape is proposed in [44]. Author used butterfly fractal for the purpose of achieving wide bandwidth and size reduction. The size reduction is achieved using butterfly fractal and wide bandwidth is achieved using T probe feed. Author claims improvement of bandwidth from 0.17 % to 13 %. The sleeve feeding method which is modified T probe feed is used in paper to achieve even higher bandwidth. In sleeve feeding method (SFM), the coaxial probe used to be extended in air gap. So, using Sleeve feeding method the overall bandwidth achieved by proposed design is 27 %. The antenna achieves overall gain of 5.7 dB. Mirazpour et al. in [45] proposes snowflake fractal antenna for wideband applications. The capacitive coupled feed is used and discussed in the paper. The size reduction is achieved using slot loading technique. The author describes snowflake fractal as modified Koch fractal antenna. Author describes that Koch shape is obtained by two united solid equilateral triangle and higher iterations are obtained by adding smaller triangles to the base structure. The proposed snowflake shape is obtained by subtracting and not adding the smaller triangles in above discussed step of constructing Koch fractal antenna. The proposed antenna has impedance bandwidth from 4 GHz to 6 GHz. Author claims 70 % reduction in size of antenna using proposed configuration than counterpart Koch fractal antenna. In [46] the circular fractal antennas are used to achieve wideband and multiband operation of antenna. The Descartes theorem is used in the paper to construct fractal for frequency independence of antenna. The coplanar waveguide feed is used in proposed design and RT Duroid substrate is used under two circle configuration fractal antennas. The antenna has matched impedance from 1 GHz to 10 GHz. The proposed antenna gain is 5.91 dBi in E plane and 3.63 dBi in H-plane. The high data rate applications are well supported by UWB technology. The UWB response can also be achieved by fractal antennas. In [47] UWB response is achieved using fractal tuning stub. The UWB response with frequency notch in frequency range 4.95 to 5.85 GHz is proposed in the paper. The total volume of proposed antenna is 48 X 41 X 1 mm^3. Krishna et. al. in [48] proposed dual wideband antenna operating in frequency ranges 2.38 GHz to 3.95 GHz and 4.95 GHz to 6.05 GHz. In the proposed design Koch fractal slot with CPW feed is used to achieve wide bandwidth. Author claims that dual wideband operation is cost effective solution than ultra-wideband antennas. Since the entire frequency bandwidth of ultra-wideband technology is not needed so requires filtration of undesired frequencies to avoid interference. The extra circuitry to implement filter is not needed in case of dual wideband operation. The gain of the proposed design is approx. 2 dBi throughout the band. The overall dimension of antenna is calculated for different substrates. The overall dimension of proposed antenna for FR4 epoxy is 33.5 X 28.5 mm^2. Fractal can also be used as stacked monopole to achieve wider bandwidth. Song et. al. in [49] proposed ultrawideband antenna with fractal stacked monopole. All the stacked patches are fed with parallel feed. The patch shape used in proposed design is sierpinski carpet and diamond sierpinski carpet. The gain upto 9 dBi is achieved by proposed design in frequency range of 1.8-2.2 GHz.

There are various other methods to achieve wider bandwidth. In [50], Sadeghzadeh-Sheikhan R.A. et al. proposed a monopole planar antenna which incorporates ladder structure etched at back plane. Though patch used in proposed design is rectangular shaped patch, resonant structure at backplane make this as ultra-wideband antenna. The overall size of proposed antenna is 22 X 22 mm^2. Proposed antenna resonates at 2.7 GHz to 20 GHz. Author defines radiation efficiency of antenna to be greater than 80 percent. Microstrip feed line is used to feed the patch in proposed design. The rectangular monopole is coupled to ladder shaped structure in the conductor backed-plane. Antenna is fabricated on a FR4 substrate having dielectric constant $\varepsilon_r = 4.4$ and thickness $h = 1.6$ mm. The over-all dimension of rectangular shaped patch is 13 X 10 mm^2.

The lumped circuit elements can be utilized to increase bandwidth of planar antenna. In [51] Mumcu et al. introduces double-loop antennas, the antenna is loaded with lumped inductors and coupling capacitors to enhance bandwidth of the antenna. In this paper author has used printed unit cells that is composed of partially coupled microstrip line pairs. The purpose of coupling microstrip line pair is to control the frequency separation between two radiating modes. If two radiating modes get merged it will result in wideband antennas. Lumped reactive loads are used in proposed antenna, so that size of the antenna can be reduced. Further different shape properties can be utilized to achieve wide bandwidth of antenna. In [52] Yu et. al. discuss the half oval shape wideband antenna for breast imaging application. The patch is designed with half oval shape and trapezium. The total length of the patch is 15.1 mm. Coaxial feed is used in the proposed design. The proposed antenna is having impedance matching from 2.7 GHz to 5 GHz. Since author claims that broadband antennas are preferred to detect breast tumor because wide bandwidth increase the possibility of diagnosis of breast tumor. In the paper antenna array is used as sensor for detection of breast tumor. The FR4 with dimension 100 X 100 mm^2 is used as substrate in the propose design. The circular slot antenna is designed and fabricated in [53]. In this paper the antenna is proposed for impedance bandwidth of 3.1 GHz – 10.6 GHz. To avoid interference with WLAN the band notch filter at frequency 5GHz is achieved by insertion of two L shaped branches with ground. The substrate used in the design is FR4 with height of 1.4 mm. The impedance bandwidth gain varies from 3.16 dBi to peak 6.91 dBi. The antenna gain at the notched frequencies is less. Chen and Cheng in [54] proposed a UWB antenna. The ground is cut with trapezoidal shaped slot and the shape of the radiating patch is rectangular. The patch and microstrip feed line is connected by three via holes. The overall dimension of proposed design is 27 mm X 29 mm X 1.0 mm. Author emphasizes that the UWB antenna must have good performance in time domain as well as in frequency domain. The substrate used is having a dielectric constant of 2.65. Antenna has impedance matching in frequency range 3 to 10.6 GHz. Yin at al. in [55] proposes circular monopole with reduced ground plane to achieve wide bandwidth. The multiple notches are introduced to avoid undesired interference with different technologies in the desired frequency range. The notches are achieved using L-type band stop filter and by using split ring resonator. The four sharp notches are introduced at frequencies of 2.4 GHz, 3.5 GHz, 5.5 GHz and 7.6 GHz. The overall substrate dimensions are 48.7 mm X 42 mm. The antenna resonates at ultra wide bandwidth of 2.2 GHz to 10.8 GHz.

2.2 Techniques to implement multiband antenna

The support of multiple technologies in a device is desirable in this era of wireless communication. This feature in next generation wireless system requires multiple antennas to be embed in the device. If each technology support require seprate antenna, it will increase overall size of the device. The other alternate for the multiple technology support in a device is the use of multiband antenna. Since the modern era is devoted to planar antennas in wireless devices. The multiband support in planar antennas can be achieved by numerous techniques. The multiband can be achieved by cutting slot in the patch or by using fractal techniques. In literature the multiband operations are discussed as given next.

In [56] quasi-yagi antenna is proposed for 700 MHz band, GSM 900, DCS1800, GPS and Bluetooth. The antenan is designed to provide gain upto 4.4 dBi. The proposed antenna is fed by microstrip to CPS transition. The multiband operation is achieved by the interaction between the section extended ground plane and the branch of driver dipole element. Yagi antennas have three elements termed as driver, direction and reflector. Author in this paper uses dipole as driver element, parasitic as director element and truncated ground as reflector element. The overall dimension of the substrate is 130 mm X 95 mm. In [57] Mousavi P. achieves multiband operation using dual feed monopole slots antennas. The proposed design supports GPS, irdium and quad GSM bands. The author achieves multiband operation alongwith multiple polarization. The antenna for the generation of multibands consist of two parts; first part is L shaped monopole slot fed by C shaped feed covering GPS and irdium bands and second part consist of differnet integrated monopole slots to achieve quad GSM bands. The Substrate used for antenna design is FR4 with thickness 0.8 mm. Chen et. al. in [58] proposes modified T shaped antenna for multiband operation. The multiband is achieved using two horizontal asymmetric horizontal strips. The proposed antenna has overall dimensions of 10 mm X 26 mm. The substrate used in proposed design is FR4. The propsoed antenna resonates at two bands inclding band at 2.4 GHz and 5 GHz.

Fractal antennas can be utilized to generate mutliband antennas. The self repetition with scaling property of fractals enable its use as multiband antenna. Different type of fractals are proposed in literature to achieve multiband performance of antenna. The multiband behavior of sierpinski gasket is given in [59-60]. Further the investigation resulted in modification of the fractal shapes to achieve improved bandwidth or gain in multibands. The variants of fractal are available to achieve multiband operation of antenna. In [61] fractal antennas are said to be advantageous in term of smaller size and support to multiband and broadband properties. Different type of fractal shape antennas are introduced in literature. The antenna with a superior characteristic of compact size by using the fractal technique has been known as Koch monopole antenna proposed in [62]. Next, a miniaturization of loop antenna can be achieved using the fractal technique such as Minkowski square loop antenna [63]. The fractal Antenna can also be created by using the initial square pulse (SP) to iterate at each side of the loop. Other antennas, which have the characteristics of multiband created by fractal geometries, are following: multiple ring monopole antennas [64], coplanar waveguide (CPW) fed circular fractal slot antenna [65], and a tri-band printed antenna based on a Sierpinski gasket [66]. Yoshioka et. al. in [67] discuss the method to design compact dual band antenna. Since size is prime factor multiband operation with size reduction is important factor.

In [68] Conical monopole antenna is proposed. The shape is derived from modified sierpinski gasket. The author claims that sierpinski gasket suffers with narrow bandwidth in their multibands. Author proposed conical monopole antenna as modified sierpinski gasket. The multiband operation achieved by the proposed shape has wider multibands. The propsoed antenna has overall size of 15.24 cm. The monopole is mounted over 120 cm X 120 cm ground plane. The five operating bands are achieved due to fractal iterations and basic structure of monopole itself.

In [69] circular disc monopole patch as a mulitband antenna is proposed. In the ground plane L shaped slot is cut. The slot in ground plane can be considered as the defected ground plane. Author claims proposed antenna to be efficient in the frequency range from 2.68 GHz – 3.28 GHz and 4.74 GHz to 9.58 GHz. The overall dimensions of antenna are 24 mm X 28.3 mm. In the proposed antenna FR4 substrate with height 1.59 mm is used. The multiband operation of proposed antenna is due to L slot in the ground plane generating two resonating modes at lower band of frequencies. The parameters are selected such that both the lower frequency bands merge up and widers lower frequency band is obtained. The higher band is achieved because of circular disc monopole. While in [70] the E shaped slot is cut in the ground plane to achieve multiband operation. Abutarboush et. al. propsoed multiband and wideband monopole antnena. The antenna resonates at three frequency bands i.e. 0.94 GHz, 2.7 GHz and 4.75 GHz. The overall dimensions of antnena are 30 X 40 X 1.57 mm^3. The rectangular shaped patch is used in the proposed design. The bands can be controlled by structural parameters of the E slot in ground plane. The proposed antenna offers gain of -3.67, 1.34 and 4.94 dBi. In [71] chen et. al. achieved multiband operation using parasitic slots and stepped impedance resonators. The proposed antenna is fed by coplanar waveguide feed. The three resonances are obtained at 1.5 GHz, 3.5 GHz and 5.5 GHz. The gain of proposed antenna at band of resonance are 5.34 dBi for 1.5 GHz band, 4.02 dBi for 3.5 GHz band and 4.72 dBi for 5.5 GHz band. In the proposed design multiple mode resonance of step impedance resonator is utilized. The parasitics are used to make radiation pattern ominidirectional at the higher order band of frequencies. Eshtiaghi et. al. in [72] proposed multicircular antenna for multiband operation.

The multiple circular segment of different radius are combined to achieve multiband operation of antenna. The overall dimension of FR4 substrate used in proposed design is 47 mm X 67 mm. IFS scaling and rotation is used to design the proposed shape. The antenna resonates at multiple band of frequencies. Author claims that the proposed shape covers DCS, PCS, UMTS, WLAN and WiMAX applicataions. The maximum gain of proposed design is 5 dB. Ding et. al. in [73] proposed quasi-yagi-type antenna. The multiband operation is achieved by concept of yagi uda antenna in planar form and the coplanar waveguide feed transition to coplanar strip (CPS). The proposed antenna has three arms and one parasitic driver dipole elements. The antenna operates in three frequency bands i.e. 1.8 – 2.0 GHz, 2.25 – 3.05 GHz and 3.35 – 3.8 GHz. The overall dimension of antenna is 50 mm X 60 mm. The bands can be varied by dimensions of three arms or by changing the CPS transition properties. The antenna offers directive radiation pattern in entire bandwidth. In [74] open end U shaped slot is proposed. In the presented design Hsu and Chang claims excitement of two modes including slot mode and monopole mode to achieve multiband operation of antenna.

Lee et. al. in [75] proposed multiband planar antenna for multiple technology wireless systems. The wideband planar dipole is considered in the paper and band notch filters are proposed in wideband to achieve multiband operation of antenna. The band notch filters are U shaped slots. The U Shaped slots introduce notches at 3.03 GHz and 4.78 GHz. The antenna is proposed to provide the peak gain of 6.5 dBi in the desired frequency range. In [76] composite right/left handed unit cells are proposed to achieve multiband operation of antenna. The conventional type of dipole is used as radiating element. The ‘via’ less Composite Right left handed (CRLH) is used in the paper to load dipole. Author discusses in the paper that CRLH is combination of Complementary split ring resonator and capacitive gap in the dipole arm. The proposed antenna offers omnidirectional pattern in entire frequency range. The antenna is proposed for two frequency ranges i.e. 1.68 GHz and 2.41 GHz. In the other variant of design provided in the paper, triple band generation is discussed.

Moosazadeh in [77] used U-shaped and L-shaped slot to achieve multiband operation of antenna. In the paper, the antenna is proposed for WLAN and WiMAX application. Author claims antenna to be smaller in size as compare to conventional antennas in literature. The reduced ground plane allowed the wideband antennas and band rejection property is introduced by U-shaped and L-shaped slots. The dimensions of ground plane are 3 mm X 15 mm. The proposed antenna radiates at 2.25-2.85 GHz, 3.4-4.15 GHz and 4.45-8 GHz. The proposed antenna has overall dimension of 15 X 15 X 1.6 mm3 FR4 substrate. The gain of proposed antenna varies from 2.5 dBi – 3.8 dBi. In [78] inverted U slot and coupled C slot is used to achieve pentaband operation of antenna. The multiband operation is achieved for navigation and communication in vehicular application. The effect of slots on resonance frequency is also discussed in the paper. Three bands are achieved by inverted U-shaped slot and two additional bands are achieved by breaking fundamental resonant modes of square patch radiator. The coaxial type of feed is used in the proposed design. The frequencies of resonance are achieved at 1.176 GHz, 1.381 GHz and 1.575 GHz for navigation application and 1.472 GHz and 1.675 GHz for communication appliation. The proposed antenna offers moderate gain in the frequency ranges. Hsu and Chung in [79] discussed open end U-shaped slot antenna for multiband operation. The proposed antenna is fabricated on FR4 substrate. The overall dimension of the proposed antenna is 65 mm X 120 mm. The open ended U shaped slot responsible for multiband operation of antenna. The four resonant modes at frequencies 720 MHz, 1.76 GHz, 2.4 GHz and 3.5 GHz are achieved in the given design. The tapered structure is used at end of open end U-shaped slot. The two resonance modes are obtained from monopole section and two resonances are obtained because of slot section. Reddy and Sarma in [80] discussed koch fractal boundary antenna for multiband operation of antenna. The proposed antenna resonates at three frequency bands i.e. 2.32-2.52 GHz, 3.37-3.45 GHz and 5.6-5.9 GHz. Author claims antenna to be good candidate for WLAN/WiMAX applications. The Koch fractal slot is embed in the radiating structure for multiband radiation. The indentation factor for the propsoed fractal shape is indentation angle. The three resonances are obtained with three differnet current distributions. The first resonance at 2.4 GHz is obtained by the current distribution at boundary of koch fractal and fractal slot. The resonance of 3.4 GHz is obtained by current distribution at boundary of koch fractal shape and the third resonance of 5.8 GHz is obtained by current distribution across the slot only. The substrate used is having dielectric constant 2.2 with thickness 3.2 mm. The overall dimension of antenna is 36 mm X 36 mm. Ilvonen et. al. in [81] proposed multiband antenna with practical size constraint for mobile terminals. Author discusses three different reasons for three frequency of resonances in given deisgn. The complete volume as non-self resonant type structure is used for resonance at lower band of frequency. The matching circuit is propsoed in the paper to adjust the lower band of frequency. The wing in vertical direction is proposed by author to utilize volume size efficiently. The lower frequency resonance is obtained at 830 MHz with 31.6 % bandwidth. The middle band resonance is obtained with right angle triangle type feed design. The middle band resonance is obtained at a frequency of 2200 MHz with bandwidth of 16 %. The higher band resonance is obtained by the stub antenna along feed. The higher band resonance is aimed at 3.5 GHz with 6 % bandwidth. Author claims good efficiency and radiation gain at given three resonance bands. In [82], Cheong et. al. proposed Yagi Uda antenna for three band operations in radar applications. The Yagi Uda antenna consists of driver, director and reflector. The planar Yagi Uda antenna is discussed in the paper. The given yagi-uda antenna design operates at 1.9 GHz, 2.5 GHz and 3.5 GHz with fractional bandwidth of 3.51 %, 2.25 % and 1.58 % respectively. The driver element of proposed antenna is designed with embedded L shaped slot lines dipole. The dipole exhibits impedance matchig at multiple bands. The directors elements are used to improve gain in desired frequency bands. The gain of propsoed design in three bands are 6.29, 4.63, and 6.77 dBi respectively. Author claims that the directors for lower frequency behaves like reflectors for higher frequency bands. This is the basis for multiband operation of antenna. Further Li and Mao in [83] proposed Koch like sided hexagonal sierpinski carpet antnena for multiband operation. The antenna is designed to support WLAN, WPAN, WiMAX and WiFi. The given antenna is fed with coplanar waveguide feed. The substrate is FR4 with height 1 mm. The overall dimensions of antenna are 45 mm X 40 mm. Author claims that the proposed antenna is better in comparison to conventional antennas in literature in terms of gain, efficiency, bandwidth and overall size. The antenna resonates from 2 GHz to 6 GHz. Mopidevi et. al. in [84] porposed quad band antenna for public safety applications in US. The antenna is designed to work in two modes. The first mode supports 220 MHz, 470 MHz and 4960 MHz and the second mode supports 800 Mhz and 4960 MHz. The Microelectronics Mechanical switches (MEMS) are used to reconfigure the frequency of operation in antenna. The mode 1 resonances are achieved using meander, assymetric arm and pole structure metallization. The small antenna is designed on RO4003 substrate to achieve resonance at 4960 MHz. The proposed antenna has 3 %, 4 %, 21 % and 17 % fractional bandwidth at 220 MHz, 470 MHz, 800 MHz and 4960 MHz respectively. Valkonen et. al. in [85] proposed capactively coupled element for multiband operation. The proposed antenna is non resonant type and matching circuit for multiband is proposed in the paper. The proposed antenna shows good impedance matching at frequency range 690–960 MHz and 1650-2850 MHz. The antenna is fabricated on RO4003C substrate. The trapezoidal shape is fed through the feed and resonance is obtained at 2.7 GHz.

2.3 Mobile Antennas

The broadband and multiband support of antenna while the size of antenna to be smaller is exactly what the need of modern day compact mobile devices. The planar inverted F antenna (PIFA) is most commonly used antenna in mobile devices due its small size. In literature, the numerous articles discuss about broadband and multiband support to mobile antennas.

The analysis of PIFA was started in decade of 1980-1990. It was early time for portable mobiles. The size of mobile handsets were larger and it was phase of initial resaerch in analysis of PIFA. Taga and Tsunekawa in 1987 proposed PIFA [86] at 800 MHz and analysis of the proposed antenna is performed using wire-grid model. In the paper authors found out optimum size of radio casing used in analysis of antenna. In the paper, the radiation parameters of proposed PIFA is analyzed. The PIFA is analyzed at different positions of radio casing. The PIFA element in direction of lateral side of radio casing is proposed to be optimum configuration of antenna. It is claimed that for achievement of 10 % bandwidth in proposed design, the height should be more than 0.08λ. The paper highlights the challenges of PIFA in early days of portable mobile handsets.

Wong and Yang in [87] proposed modified PIFA with compact size and larger bandwidth. The compactness in design achieved by meandering of PIFA and the larger bandwidth is achieved by using chip resistor load in the place of short. The overall dimension of proposed antenna radiating patch is 40 mm X 25 mm. The design is proposed for center frequency 800 MHz and 11.2 % bandwidth is obtained using load resistor of 6.8 ohm. Author claims that the feed position shifts away from resistor load as the resistance of the load increased. The proposed antenna is claimed as compact and high bandwidth antenna. The proposed antenna has loss of 6 dB gain with use of resistor. The enhancement of bandwidth is achieved at cost of gain because of increasing ohmic loss at the resistor load.

Colburn et. al. in [88] discuss the diversity performance of dual antenna hansets. In this paper, the three configuration are analyzed for diversity performance in moving transmitter environment. The first configuration is top mounted helix and the other antenna as PIFA at the back of handset. In second configuration the two PIFAs are side mounted. In third configuration the PIFA is mounted at the top and Flip monopole is used as the second antenna. The paper claims that the three of the configuration achieve decorrelation equal to the decorrelation in vertical dipoles seprated by distance of 0.4 λ.

In [89] Rowell and Murch claimed that the capacitive load can lead to size compacts of PIFA. The propsoed design achieve capacitive loading by speration of feeding plate and the radiating patch. The proposed antenna resonates at center frequency 1.8 GHz with 178 MHz bandwidth. While in [90] same authors proposed PIFA for dual band operation. The PIFA is designed for 900/1800 MHz band operation. In the proposed design the capacitive feed and capacitive load is used. The slot is introduced to patch for reducing the frequency of resonance. The overall dimensions of PIFA is 25 mm X 26 mm. The feed is offset by 5 mm to further reduce the frequency of operation. The proposed anntenna resonate at the frequencies 910 and 1790 MHz with 5 % and 8 % impedance bandwidth.

Virga and Samii in [91] proposed low profile antennas for mobile handsets. In this paper the effects of different parameters of PIFA on the input impedance is discussed. The PIFA parameters like the length and height of radiating plate, shorting plate, Feed and space between feed and shorting plate is considered. It is concluded that the feed is capacitive impedance and after adding the radiating plate the capacitive nature of impedance is decreased. The shorting plate further adds up the capacitive effect. The compact antenna is designed with adding capacitive plate below radiating plate to feed the patch. In the paper the antennas with dual L elements for different frequency are discussed.

Salonen et. al. in [92], the U-shaped slot PIFA is proposed. The antenna operates at dual band of frequency i.e. 2.4 GHz and 5.2 GHz. Author claims that the overall dimensions of proposed PIFA has effect on lower frequency band and the dimensions of U shaped slot affects the higher frequency band. The dimensions of radiating patch is 40 mm X 25 mm. The patch is kept at height 10 mm and the width of shorting plate is 9 mm. The dimensions of U-shaped slot are 27 mm length wise and 2 mm is the width of slot.

In [93] Ogawa et. al. proposed curved PIFA antenna for use on a shoulder. The antenna works in 350 MHz band. Author claims that the proposed antenna achieves gain of -5.5 dBd which is 3.5 dB higher that whip antenna of that era. The bandwidth of the proposed antenna is 12 MHz. The overall dimensions of propsoed antenna are 60 mm X 60 mm X 20 mm. The antenna was proposed to embed in jacket for communicaton between police and fire services. The proposed antenna is verified in different environments for performance.

Song et. al. in [94] proposed triple band PIFA for mobile handhelds. The three radiating plates operating at different frequencies are used. The loaded feed is used for the plate operating at lower frquency and the two different plates are embed on patch. The isolation between two feeds are claimed to be better than -15 dB. The dimensions of three plates are 55 mm X 38 mm, 21 mm X 11.5 mm and 12 mm X 8.5 mm. The height of propsoed antenna is 10 mm. The triple band resonance is obtained by the proposed antenna at 0.942 GHz with 4.03 %, at 1.74 GHz with 3.1 % bandwidth and at 2.82 GHz with 4.12 % bandwidth.

In [95] Lui and Murch proposed dual frequency PIFA using LC-resonators. The chip inductance and chip capacitance is added in the PIFA. The three methods are discuss in the paper to incorporate LC resonating structure in the design. In first technique the lumped inductors and capacitors are incorporated in the design. In second technique the lumped inductor and capacitor are fabricated on antenna structure. The inductor is made by the loop and the capacitance is formed with metal on insulator approach. In third technique the meander type of strucutre is proposed for inductor design and metal on insulator approach is implemented for capacitor. The proposed antenna operates at 900 MHz and 1800 MHz with bandwidth 35 MHz and 140 MHz and gain -0.8 dBi and 2 dBi respectively.

Yang et. al. in [96] proposed U-shaped PIFA with U-shaped slot for dual frequency band operation. The overall dimensions of patch is 48 mm X 35 mm. The slot of dimension 23 mm X 12 mm is cut to make the shape look like the letter U. The proposed shape is considered as combination of L-shaped patch and rectangular patch responsible for operation at 1.8 GHz and 0.9 GHz respectively. The air gap of 5 mm and U-shaped slot is proposed in the design for bandwidth enhancement. Aurthor termed the proposed antenna as UU-PIFA. The proposed antenna offers bandwidth of 27 MHz at 0.9 GHz center frequency and 85 MHz and 1.8 GHz center frequency.

In [97] Chen et. al. proposed PIFA with meandered patch with folded edges is discussed. The meandered patch results in size reduction of antenna. The patch is folded to achieve size reduction further but the effect of folded patch reduced when used with meandered patch. In the paper, the design is proposed for GSM 900 and DCS 1800 mobile phone systems. The overall dimensions of proposed antenna are 24 X 10 X 7.2 mm^3. The antenna operates in frequency band 930 MHz – 950

MHz and 1706 MHz – 1865 MHz with maximum gain 2.5 dBi. The effect of folded edge can further be extended for different type of patch shapes. It can be proved as method to reduce size of PIFA.

In [98] Chiu and Lin simulated the compact PIFA with multi frequency resonators. The overall dimension of proposed design is 32.2 mm X 24.6 mm. The patch is kept at height of 7.5 mm from the ground plane. The open end slot is cut to make antenna resonant at multiple frequency. In the proposed PIFA patch, L-shaped slot is cut. It divides the antenna into two parts, one is larger part and other is smaller part. The third resonance is obtained by cutting smaller parts results in another resonance at higher frequency band. The proposed PIFA achieves 160 MHz at the DCS-1800 MHz band. Thus antenna resonates at GSM 900 band and DCS-1800 band with 8 % and 16 % bandwidth respectively.

In [99] the effect of ground plane on performance of PIFA is analyzed. The PIFA is studied with different groudn sizes. It is concluded in the paper that the ground plane has little effect on resonance frequency but there is certain limit on ground plane size below which it will start affecting frequency of resonance. Bandwidth though depends on the ground size. If size of patch is less than 0.8 λ, the bandwidth is low if patch is square. If size of patch is less than 0.4 λ, the bandwidth is low if ground plane is rectangular. The ground plane size effects the gain pattern. The radiation pattern of proposed design is very much dependent on ground plane size.

After introduction of LTE as 4th generation technology in mobile system. The PIFA with support to MIMO technology is getting popular. The correlation between antenna elements in MIMO system is important parameter. The literature review of the latest trend in PIFA reveals the research in field of multiple input multiple output system incorporated in PIFA structures. In [100] Lim et. al. proposed MIMO PIFA with reconfigurable bands. The correlation between the antenan elements is also claimed to be reconfigurable at the same time. In the proposed design the decorrelation between the two antenan elements is achieved by band notched quarter wave slot in the ground plane. The two PIN diode between the band notched slot in ground plane makes it reconfigurable in terms of correlation. The reconfigurablity in terms of frequency is achieved by introduction two PIN dioides, one in the slot line on patch of PIFA element and the other is connected to capacitive load from ground. The antenna can be switched to any of the three modes of WiMAX. The overall dimension of patch is 11 mm X 9.6 mm. The antenna can be configured to 3.5, 2.6, 2.35 GHz bands of WiMAX. The both antenna elements are seprated by 26 mm. Mun et. al. in [101] proposed LTE MIMO antenna for laptop applications. The design is proposed for multiple frequency bands. The design is considered reconfigurable in two frequency bands. The frequency bands supported by the proposed design is 704-787 MHz in state 1 and it operates at 791-862 MHz and 2500 – 2690 MHz in state II. The overall dimensions of antenna are 5 mm X 125 mm X 1 mm. The gap between two antenna element is kept 0.5 λ which enables decorrelation between two radiator elements below specified value. The PIN diode switches are used to achieve reconfigurablity of antenna. In [102] Addaci et. al. proposed multiband diversity PIFA for wireless terminals. The proposed antenna operates in frequency band 2.4-2.48 GHz and 5.15-5.725 GHz. The antenna elements in proposed design are claimed to be closely spaced. The two slots are introduced on PCB to reduce the correlation between the two antenna elements. The dimension of PIFA is 14.25 mm X 10 mm and are kept at 7.7 mm height from the PCB. The overall dimenison of the PCB is 100 mm X 50 mm.

2.4 Summary of the chapter

In the chapter, literature study of different techniques to achieve broadband and multiband operation of antenna is discussed. The literature is reviewed for conventional type of antennas and the evolution of antenna deign with development of technologies are correlated. The literature review of antenna reveals that in last decade the antenna size has reduced considerably. Further different techniques are evolved to achieve wider bandwidth and multiband support. The PIFA is emerged as small size antenna to be used in mobile phones. The recent advancement in planar antnenas are evident of introduction to MIMO PIFA which resulted in more efficient use of spectrum. The PIFA and MIMO PIFA are discussed in the section 2.3 of the chapter.

Chapter 3

Modified CPW fed Multiband Fractal Antennas

The microstrip patch antenna growth has been tremendous since its introduction. The need of multiband antennas and various techniques to achieve multiband operation of antenna have been emphasized in literature review in chapter 2. Further planar antennas support to multiband operation is quite important these days. The most commonly used methods to achieve multiband operation of antenna can be summarized as slot antennas, U shaped, L-shaped, C- shaped and E-shaped slot antennas, fractal patch antennas, multi-polygonal shape antennas, multimode resonance of antennas, Hybrid fractal shape of antennas, Quasi Yagi Uda shape of antenna, Band notch filter antennas, Lumped resonator feed antennas etc. The fractal shaped patch is most commonly used method to achieve multiband operation of antenna. In this chapter a novel modified CPW fed fractal shape patch antenna is proposed to achieve multiband operation. The Sierpinski carpet patch antenna is also proposed for multiband support. In the next section a brief introduction to microstrip patch antenna is given. The microstrip patch antenna is studied for its S11 parameter and its radiation mechanism.

3.1 Resonance modes and radiation pattern study of conventional Microstrip patch antennas

In this section microstrip patch antenna is studied for effect of parametric variations of dimensions on frequency of resonance at different resonant modes and radiation pattern. The analysis of resonance mode and radiation pattern is important to understand concept of multiband antenna design. The microstrip patch antennas consist of metallic patch, dielectric substrate, feed line and metallic ground plane. The different patch shapes can be used according to need of the antenna. The commonly used patch shapes are rectangular, circular, polygon, slot monopole, fractal shape, modified fractal and hybrid fractal. In Microstrip patch antenna, the substrate is commonly made up of FR4, RO4002 etc. Since FR4 substrate is cost effective and easily available substrate, it is preferably used in the designs proposed in this chapter. The metallic ground plane is responsible for fringing fields and the feeds carry signal from RF connector to patch. The design flow of generic rectangular patch microstrip antenna is shown in figure 3.1. In the flowchart, the impedance matching using the different type of feed is discussed. The dimensions of rectangular patch can be calculated using flowchart shown in figure 3.1.

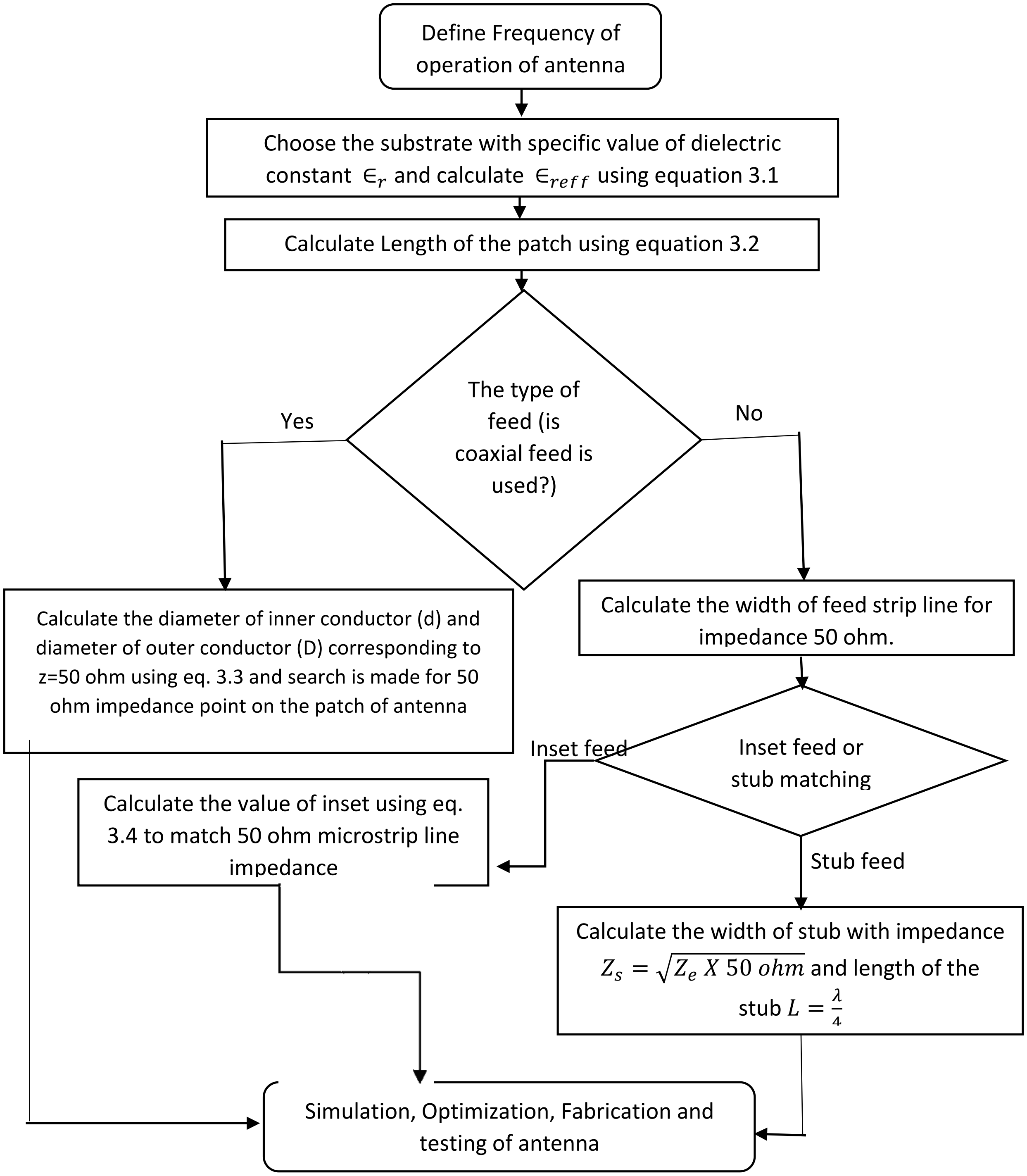


Figure 3.1: Flow chart for design of rectangular microstrip antenna with different type of feeds

3.1.1 Design of the square patch antenna

The antenna is designed on FR4 substrate and the dimensions of microstrip patch are 30 mm X 30 mm for frequency of resonance at 2.4 GHz. As an example, the simple rectangular patch antennas with different type of microstrip line feeds are shown in figure 3.2. The microstrip line of width 3.04 mm can provide desired 50 ohm impedance for matching with 50 ohm connector. The edge impedance of patch is found to be 384.92 ohm using equation 3.2. The comparison of rectangular microstrip patch with different feeds are given in figure 3.2.

The different equations in computation of parameters for rectangular microstrip antenna are given as

Effective dielectric constant

The dielectric constant offered by the substrate changes due to existence of Quasi TEM mode. The effective dielectric constant of the substrate after considering Quasi TEM mode of operation is given as

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad , \qquad (3.1)$$

here ϵ_r is dielectric constant of the substrate, h is height of the substrate, w is width of the substrate.

Length of the Rectangular Patch

Antenna resonance depends on length of antenna. For dominant mode resonance the length of the antenna is given as

$$L = \frac{c}{2f_r\sqrt{\epsilon_r}} \quad , \qquad (3.2)$$

where c is speed of light and f_r is frequency of resonance of antenna.

The Impedance of coaxial feed can be given as

$$Z_o = \frac{138}{\sqrt{\epsilon_r}} log_{10}\left(\frac{D}{d}\right) \quad , \qquad (3.3)$$

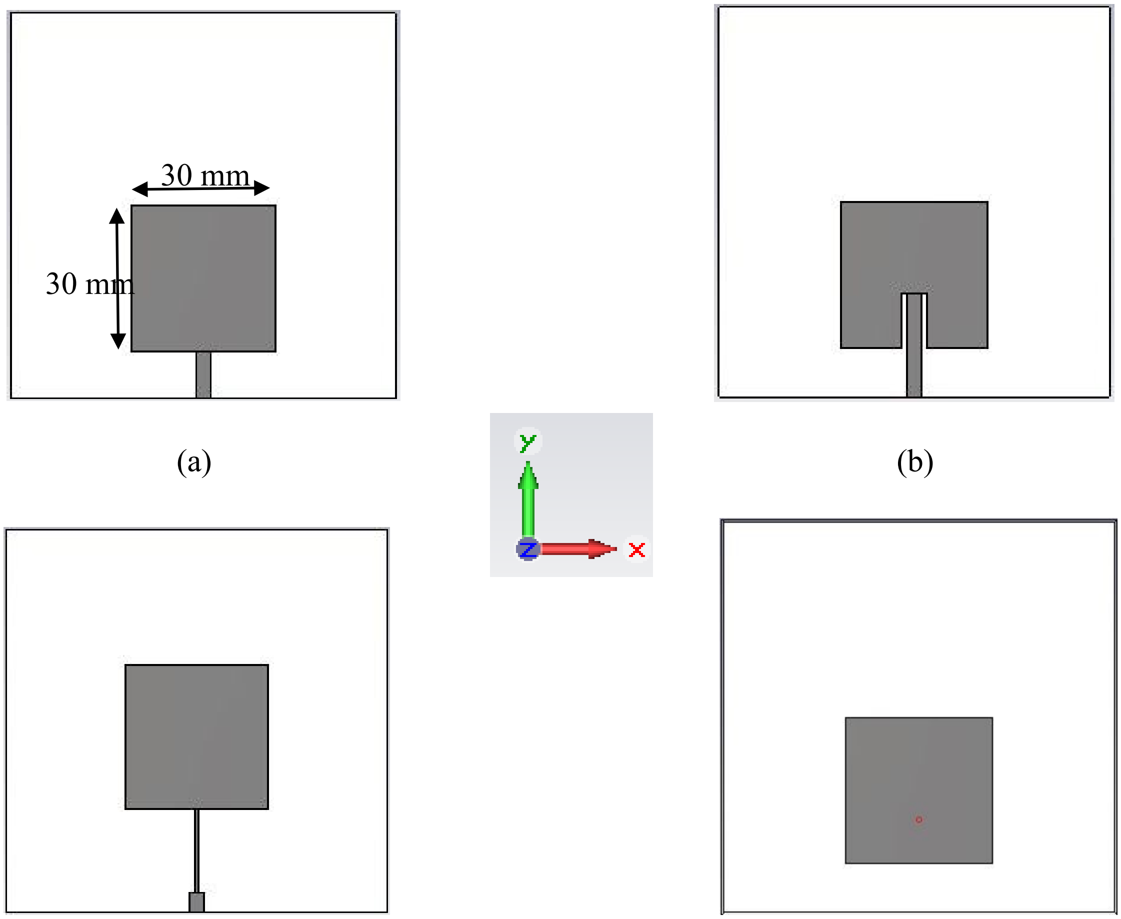
where, D is diameter of outer conductor in coaxial feed and d is inner diameter of inner conductor.

Position of Inset Feed

$$Z_{in}(y = y_o) = Z_{in}(y = 0)\, cos^2\left(\frac{\pi}{l} y_o\right) \qquad , \qquad (3.4)$$

where *l* is length of the patch.

In figure 3.2 (a) the simple stripline feed is fed to edge of square patch. The mismatch between the 50 ohm impedance of stripline and 398.9 ohm edge impedance of square patch results in decerased performance in terms of s11. The four different type of feeds are shown in figure 3.2. The inset feed, stub matching feed and coaxial feed is used with square patch to match 50 ohm impedance of stripline. The antenna resonates at 2.375 GHz. The inset feed is used in figure 3.2 (b), the stripline of 50 ohm feeds the patch at inset position where the impedance offered is 50 ohm.



(a)

(b)

(c)

(d)

Figure 3.2: Microstrip patch antenna with (a) microstrip line feed, (b)Inset feed Microstrip patch antenna , (c) stub matched microstrip line feed, (d) Coaxial fed Microstrip patch antenna

In figure 3.2 (c) the λ/4 stub matching is shown. The matching of 50 ohm feedline impedance with edge impedance of 398.9 ohm is achieved by using 17.745 mm length of the stub. The width of the stub is 1.1 mm. In figure 3.2 (d) the coaxial feed is used with same square patch. The coaxial probe feeds the patch at 50 ohm position on the patch. The inner and outer diameter of the coaxial probe is achieved using eq. 3.3.

3.1.2 Reflection coefficient analysis

The return loss graph for different type of feeds is given in figure 3.3. The square patch resonates at a frequency of 2.4 GHz in TM_{010} mode and 4.43 GHz. in TM_{020} mode in case of inset feed. The graph indicates that there is an impedance mismatch between stripline and square patch in figure 3.2 (a). Since the edge impedance of patch does not match with impedance of microstrip line, the inset feed, stub matching and coaxial feed can be used. The three other feeds viz. inset feed, stub matching feed and coaxial feed offers better impedance match so better return loss. There is small shift in resonance for different feeds as shown in figure 3.3. The shift is observed for the change in input reactance for different type of feeds.

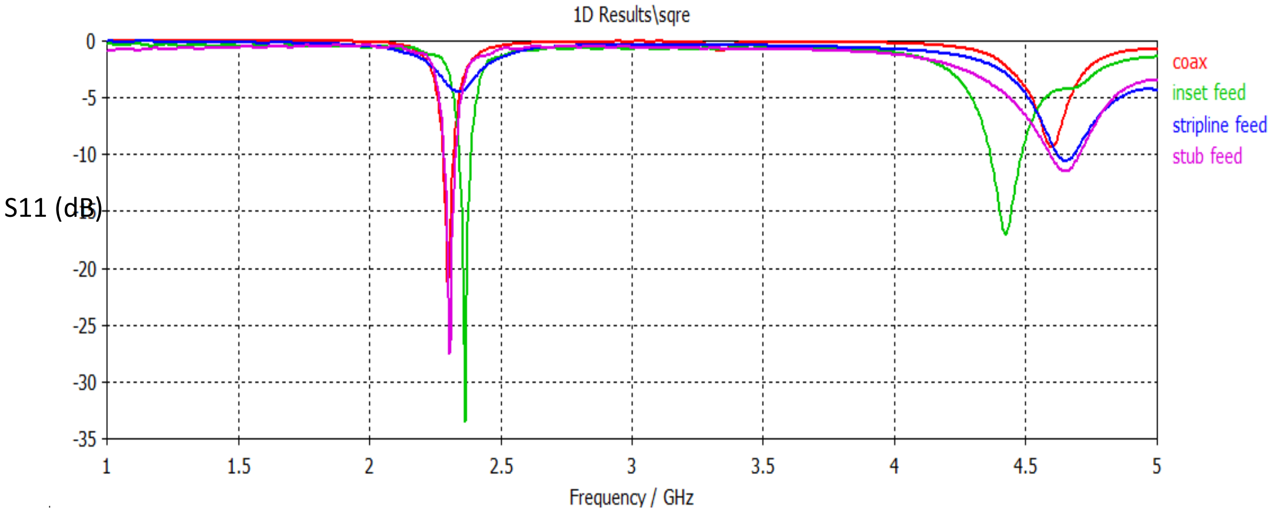
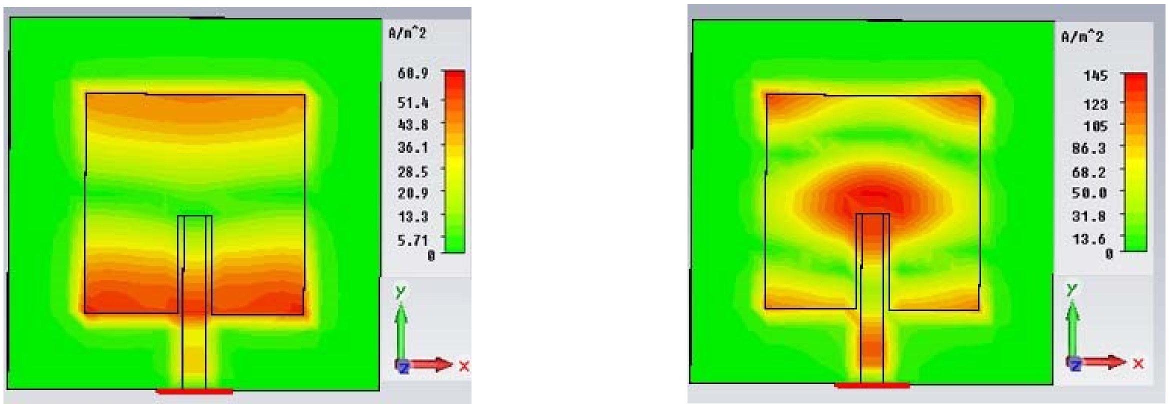


Figure 3.3: S11 (dB) versus frequency (GHz) for different feeds

3.1.3 Current distribution analysis

In figure 3.4, the current density for inset fed square microstrip patch antenna is shown at 2.4 GHz and 4.64 GHz. The current density at 2.4 GHz reveals the existence of TM01 mode at the frequency, while the TM02 mode exist at 4.64 GHz.

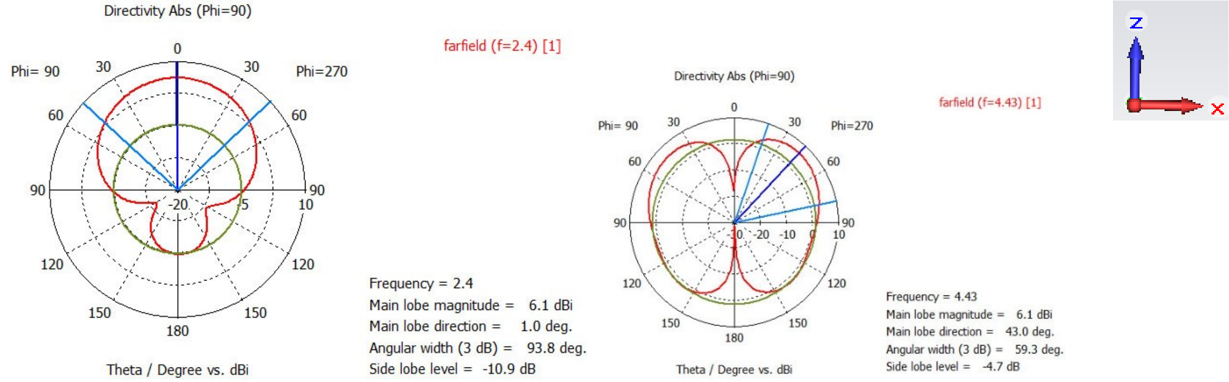


(a) (b)

Figure 3.4: Current density of inset fed square patch antenna at frequencies (a) 2.4 GHz. (b) 4.43 GHz.

3.1.4 Radiation pattern analysis

The radiation pattern for stub fed square shaped patch is shown in figure 3.5. It is clear from the figure 3.5 that, the radiation pattern at frequency 2.303 GHz has less side lobes than the radiation pattern at frequency of 4.6413 GHz and less directive. The radiation pattern at higher mode resonance i.e. at 4.6413 GHz has more side lobe level than at dominant mode resonance. So the antenna does not radiate in desired manner for higher modes resonance. Hence the presented antenna is not considered for higher mode resonance. The antenna can only be used at frequency 2.303 GHz. The multiband resonance can be achieved by various other methods given in next sections.



Frequency = 2.4
Main lobe magnitude = 6.1 dBi
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 93.8 deg.
Side lobe level = -10.9 dB

Frequency = 4.43
Main lobe magnitude = 6.1 dBi
Main lobe direction = 43.0 deg.
Angular width (3 dB) = 59.3 deg.
Side lobe level = -4.7 dB

(a) (b)

Figure 3.5: Radiation pattern of stub match antenna at frequencies (a) f=2.4 GHz. (b) 4.43 GHz.

3.2 Introduction to Multiband Microstrip Patch antenna techniques

The multiband operation is quite desirable in next generation wireless systems as discussed in previous sections. The multiband operation can also be achieved in microstrip patch antenna. In microstrip patch antenna, the single patch radiating efficiently at multiple band of frequency is desirable. The patch is resonating structure in its inherited form, so usually radiate at single frequency only. The radiation in antenna is caused by the change of current density in radiating structure and the current density can be disturbed by various methods for multiple frequencies. The most common methods are cutting the non-uniform slot or using the fractal shape of antenna. So these methods can be utilized to achieve multiband operation in microstrip patch antenna. The radiation at different modes can also be utilized to achieve multiband operation of antenna in microstrip patch antenna. But the performance of microstrip patch at higher frequencies is not satisfactory. Different types of multiband microstrip patch antennas are discussed in next sections.

3.3 Study of slotted monopole square patch antenna

The slot in the patch of microstrip antenna disturbs the current density of antenna and it results in additional resonance at slot mode. The slot dimensions and position can be optimized to achieve resonance at desired frequency. The various slot shapes can be cut in microstrip patch according to the desired specifications. The most common slot shapes are horizontal slots, U-shaped slot and C-shaped slots etc. The vast literature is given in context of slot monopole antenna to achieve multiband operation of antenna. The slot cut in microstrip patch antenna for achieving multiband operation of antenna has advantages and disadvantages as compare to other methods. The slot method in context of microstrip patch antenna is efficient method to achieve multiband operation of antenna. The ease of computation and fabrication of slot monopole antenna makes it proper choice for multiband antenna. The disadvantage of slot antenna for multiband operation antenna is the difficulty in optimizing impedance matching at desired frequencies. Also the size requirement for the slot monopole multiband antenna is more than multiband achieved using fractal shape of antenna.

3.3.1: Design consideration of rectangular microstrip antenna with horizontal slot

The horizontal slot can be cut in microstrip square patch to achieve additional resonance. The slot cut rectangular patch antenna can be used as multiband antenna. The example of slot cut in square patch is shown in figure 3.6. It is clear from the figure 3.6 that the horizontal slot is symmetrical in x axis. The dimensions of square patch are 30 mm X 30 mm. The inset feed for matching at 2.4 GHz is used in the given design. The size of the slot is 4 mm X 22 mm.

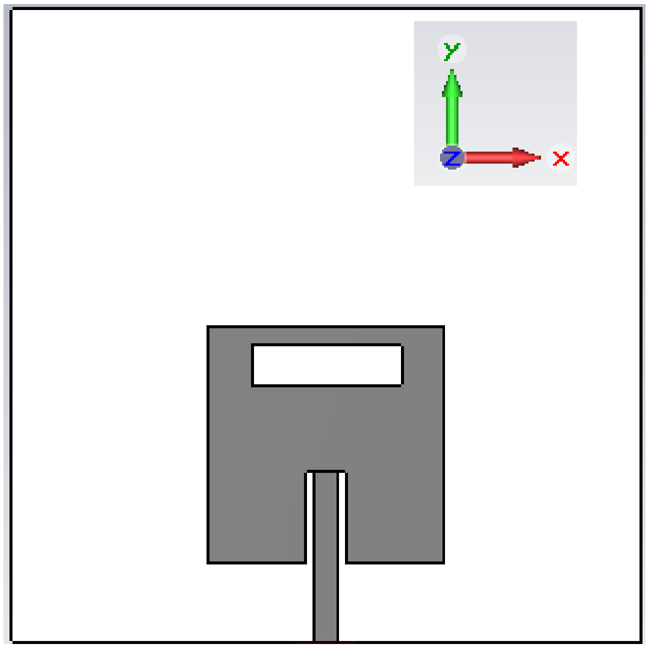


Figure 3 .6: The square microstrip patch antenna with horizontal rectangular slot

3.3.2: Reflection coefficient analysis of design

In figure 3.7, the comparison of reflection coefficient for square patch antenna without slot and with slot is shown. It is clear from the figure that the square patch without slot resonates at 2.37 GHz for dominant mode and at 4.64 GHz for higher mode. The introduction of slot in the square patch design results in extra resonance at 3.5 GHz. The slot mode can be adjusted with dimensions and position of horizontal slot. The return loss graph in figure 3.7 describes the impedance matching of given design at different frequency. It is clear from the figure 3.7 that introduction of slot slightly shifts the frequency of resonance at fundamental modes and introduces additional resonance at 3.5 GHz. Hence the antenna operates at multiple bands of frequencies. This is the basis of square microstrip patch antenna with slot and having characteristics of multiband antenna. Further in the next sections the radiation pattern for different resonances is shown.

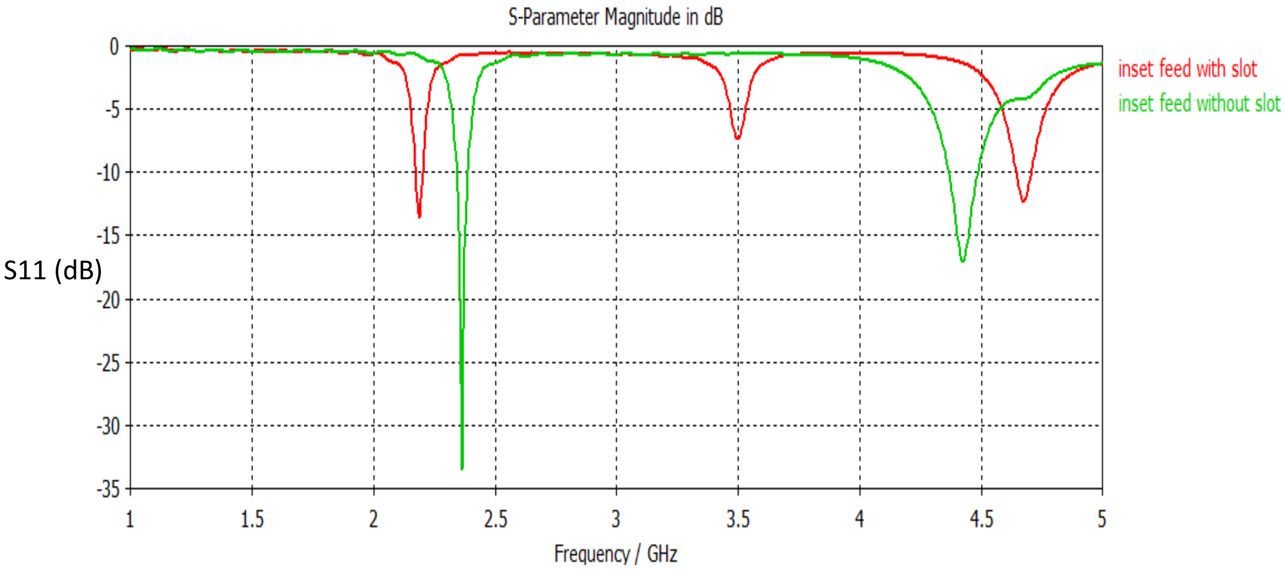
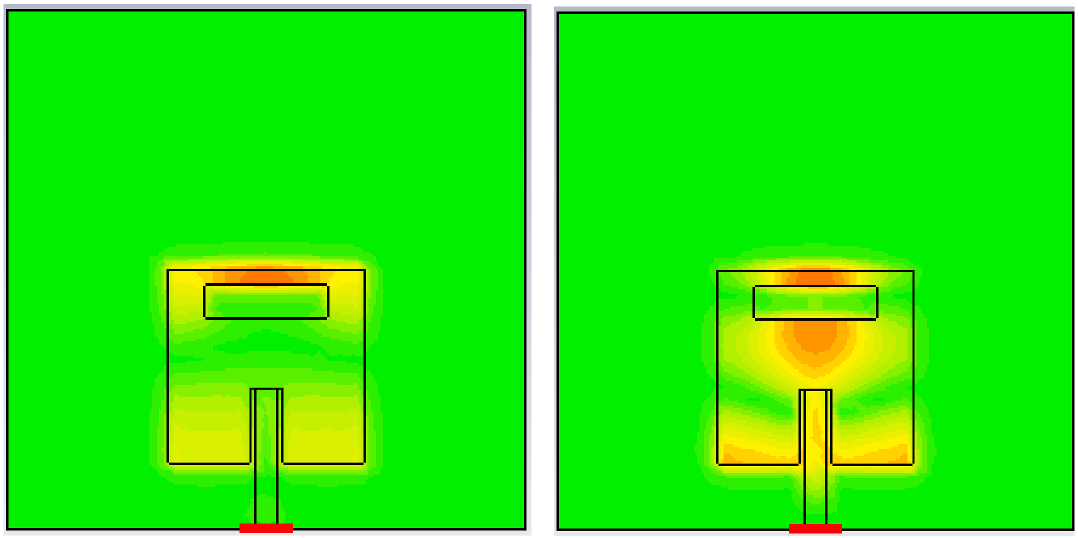


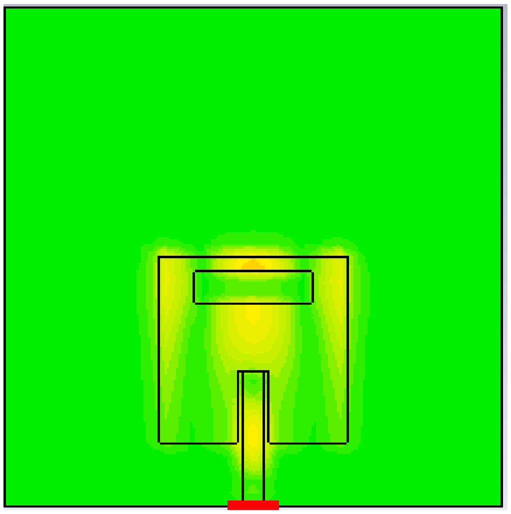
Figure 3.7: S11 (dB) versus frequency (GHz) for slot monopole antennas

3.3.3 Current density analysis of design

The concept of multiband resonance by introducing slot in microstrip patch antenna can be proved by current density at multiple frequencies given in figure 3.8. The current density at 2.2 GHz, 3.5 GHz and 4.7 GHz is shown in figure 3.8 (a), 3.8 (b) and 3.8 (c) respectively. The current density at frequency of 2.2 GHz proves existence of TM01 mode at the frequency. The current density at 3.5 GHz is due to slot mode and the higher mode exists at 4.7 GHz.



(a) (b)



(c)

Figure 3.8: The current density on slot monopole antnena at frequencies (a) f=2.2 GHz. (b) f=3.5 GHz. (c) f=4.7 GHz.

3.3.4 Radiation pattern analysis of design

The radiation pattern of slot monopole design is given in figure 3.9. The radiation pattern at 2.2 GHz is shown in figure 3.9 (a). The radiation pattern consist of main lobe and -15.3 dB back lobes. The radiation pattern is considered satisfactory for the next generation wireless systems.. as the pattern has back lobes below acceptable range. The radiation pattern at frequency 3.5 GHz is given in figure 3.9 (b). It is clear from the figure that the main lobe in radiation pattern at frequency 3.5 GHz is less symmeterical in x-axis than main lobe at 2.2 GHz but it can also be considered accetable for next generation wireless devices. The radiation pattern for higher modes at frequency of 4.7 GHz is given in figure 3.9 (c) depicts that the side lobe level at a frequency of 4.7 GHz is higher than acceptable limit. The presented design offers 6.9 dBi, 7.7 dBi and -11.4 dBi gain at 2.2 GHz, 3.5 GHz and 4.7 GHz respectively.

The performance characteristics of slot monopole antenna design proves that the antenna can be utilized at frequencies 2.2 GHz and 3.5 GHz. The given design can be termed as dual band slot square patch antenna. The slot can be optimized for varying frequency resonances by adjusting dimensions of square patch and slot. In comparison to conventional square patch microstirp antenna, the slotted monopole antnena results in additional resonance at 3.5 GHz. But in some cases the multiband operation is not just limited to only dual band but it is required to extend it for three, four or more operating bands. In the next section novel fractal designs are introduced to achieve multiband operation of antenna.

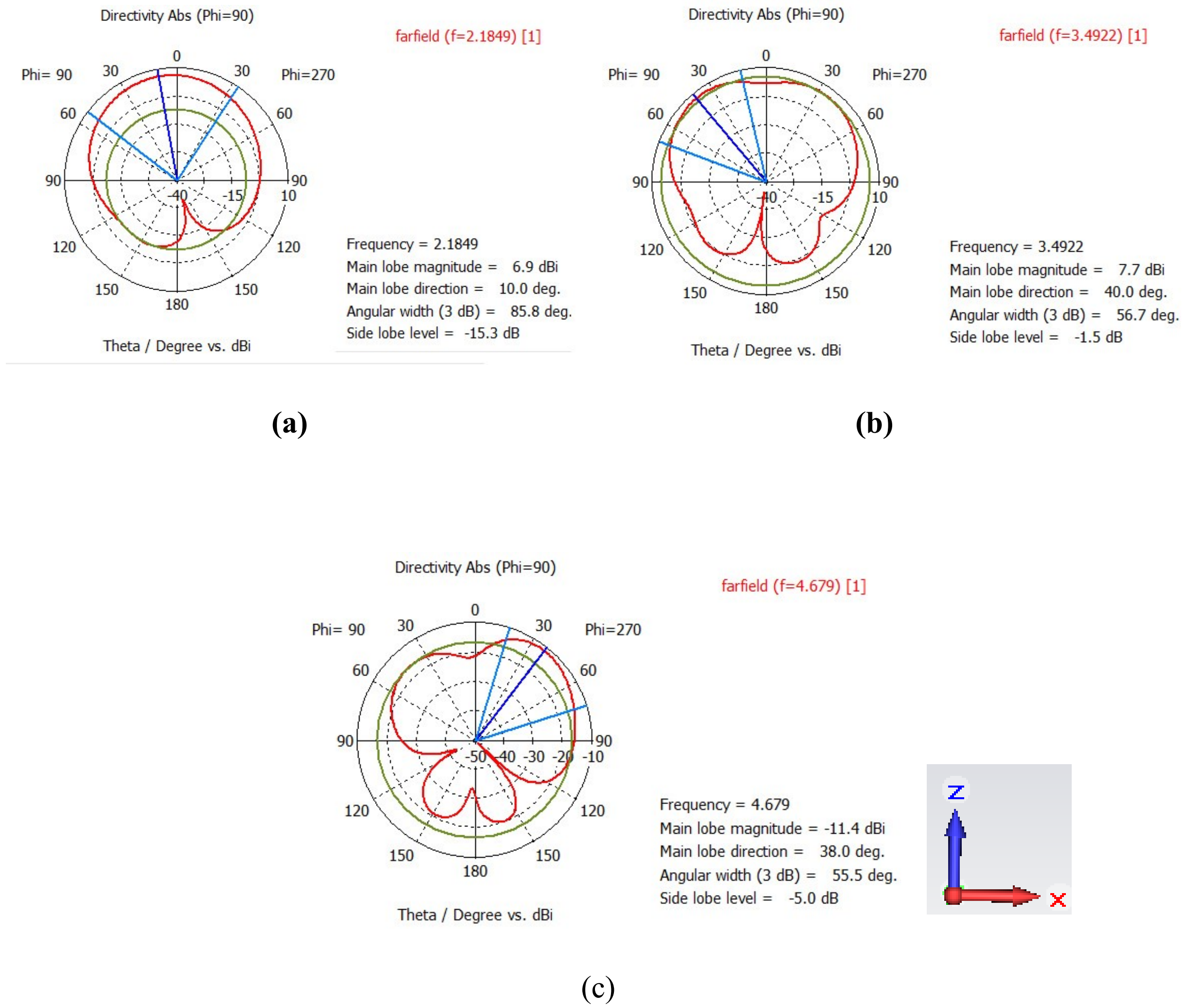


Figure 3.9: Radiation pattern of antenna at frequencies (a) f=2.1849 GHz (b) f=3.4922 GHz and (c) f= 4.679 GHz.

3.4 Fractal Multiband Antennas

It is clear from the figure 3.3 that the simple rectangular antenna radiates efficiently only at single dominant resonant frequency. The slot monopole discussed in section 3.3 can be used for dual band resonance. The slot optimization for resonances at dual frequency is more tedious task and increased size of slot antenna demands for alternate solution of multiband antenna. Further it is clear from the figure 3.9 that the design does not result in equal efficiency at multiple resonant frequencies. The antenna size is always a bottleneck in size reduction of wireless devices. The demand for small size antennas in wireless systems is desirable since introduction of VLSI chips. The fractal is self-repeating iterative structure and can be utilized in design of patch for microstrip antenna. The fractal shapes are known to be space filling structure. The fractal shapes can be used to design small size multiband antenna. The fractal shapes with their virtue of space filling property are more space efficient. The fractal shapes have inherited multiband log periodic behavior. The different type of fractal shapes are presented in the literature. The fractal shape antennas are widely adopted as multiband antennas.

3.4.1 Design consideration of CPW fed Sierpinski Carpet Multiband Antennas

The different iterations of sierpinski carpet shaped fractal patch are shown in figure 3.10. In this section the multiband behavior of sierpinski carpet shape with CPW feed is discussed. The coplanar waveguide feed is used because it eases the antenna to embed on device PCB. The proposed design is shown in figure 3.11. The strip-line feed to sierpinski carpet shaped fractal results in impedance mismatch at edge of the patch same as evident from conventional square patch design in section 3.1. The λ/4 stub with dimensions calculated from flowchart given in figure 3.1, is used in the proposed design to achieve impedance matching.

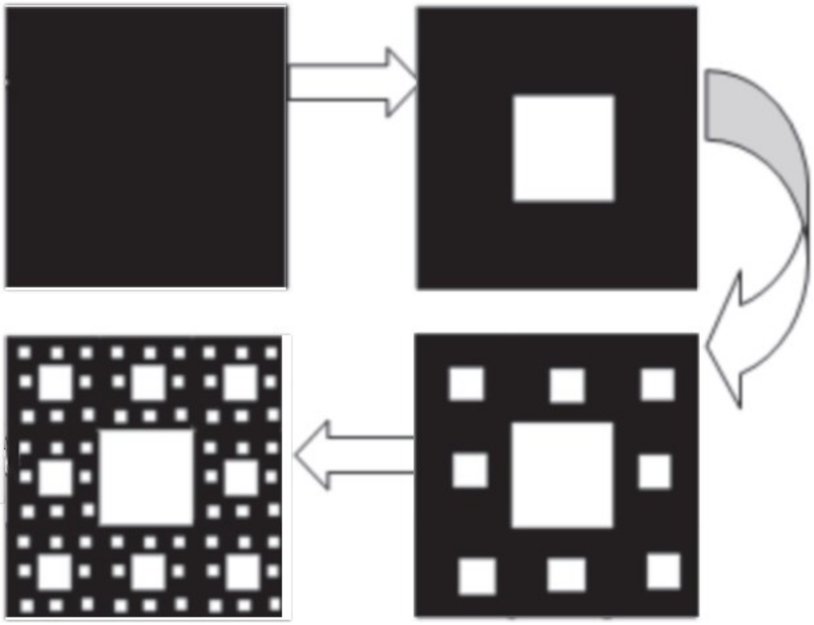


Figure 3.10: Design of sierpinski carpet fractal patch

The design parameters for the CPW fed sierpinski carpet fractal shape are listed in table 3.1. The spacing between the feed and the ground plane is 2 mm. It is clear from the design parameters that the size of sierpinski carpet antenna is less that its counterpart slot monopole antenna design.

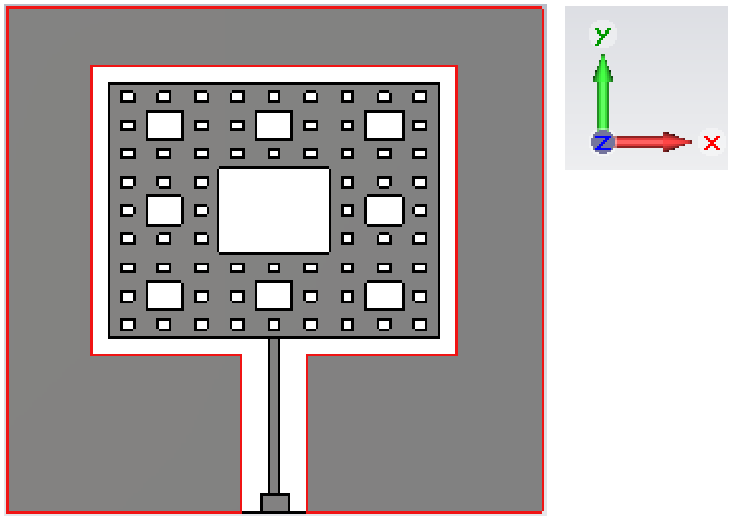


Figure 3.11: Coplanar waveguide fed sierpinski carpet antenna

Table 3.1: Design parameters of CPW fed sierpinski carpet antenna

Parameter	**Value**
Dimensions of the patch	28.7 mm X 37 mm
Feed dimension	2 mm X 3.174 mm
Stub size	1.1 mm X 17.45 mm
Substrate Size	57 mm X 60 mm
Substrate Material	FR4

3.4.2 Return loss analysis of proposed design

The return loss performance for sierpinski carpet antenna with coplanar waveguide feed is shown in figure 3.12. It is clear from the graph that the third iteration of sierpinski carpet resonates at four bands of frequencies at 1.77 GHz, 3.3 GHz, 5.34 GHz and 6.66 GHz defined for -10 dB reflection coefficient. The table 3.2 shows frequency of resonance and corresponding bandwidth for proposed design.

Table 3.2: Frequency of resonance and corresponding bandwidth

Resonant Frequency	1.77 GHz	3.3 GHz	5.34 GHz	6.66 GHz
Bandwidth	310 MHz	205 MHz	583 MHz	352 MHz

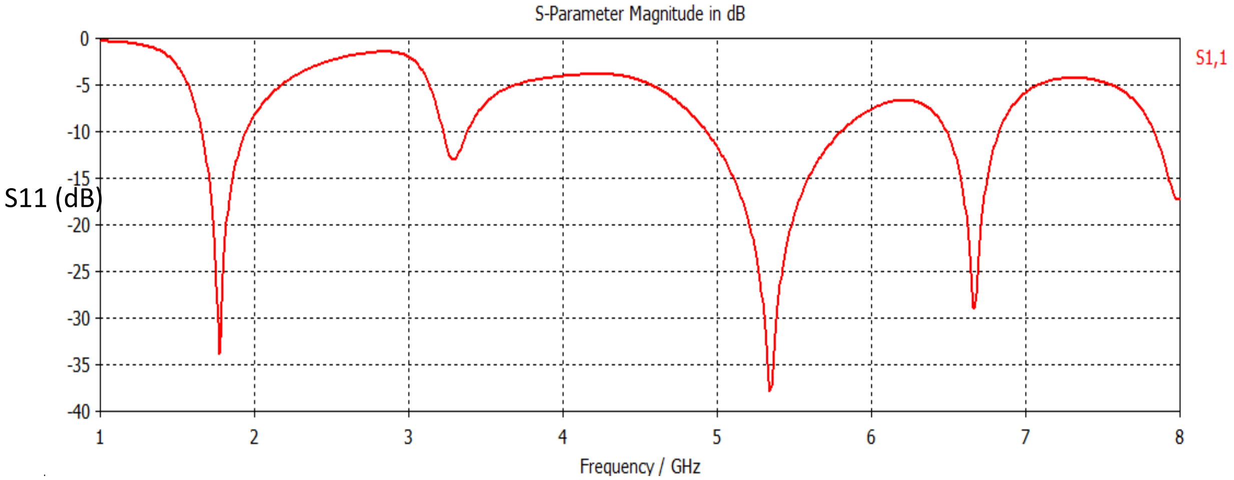
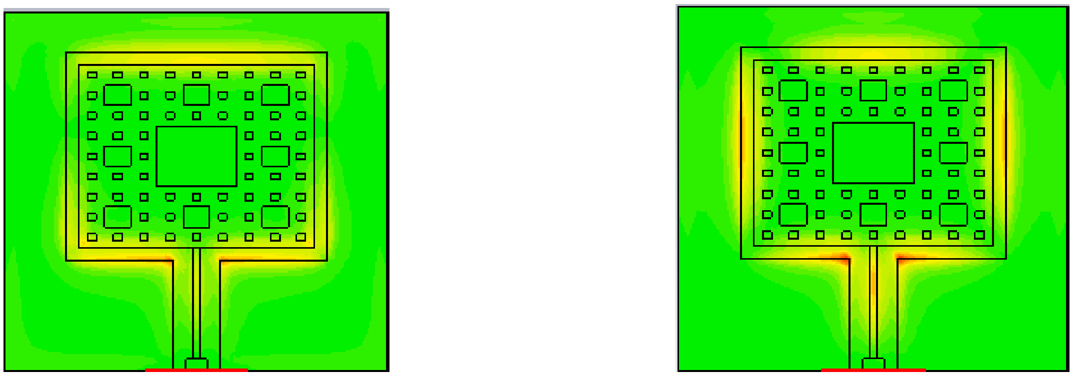


Figure 3.12: S11 (dB) versus frequency graph for CPW fed sierpinski carpet antenna

3.4.3 Current density of proposed design

The current density at various frequencies for CPW fed sierpinski carpet antenna is shown in figure 3.13. The current densities at various frequencies describe the resonance of various size rectangles in the fractal antenna. The multiple resonance of sierpinski carpet fractal is due to resonance of different sized rectangles in the fractal. In comparison to two resonances of slot antenna, the proposed fractal antenna exhibits four resonances. The size reduction and multiple resonances can be listed as advantages of sierpinski fractal antenna. The frequency of resonance can be changed by altering dimensions of fractal patch.



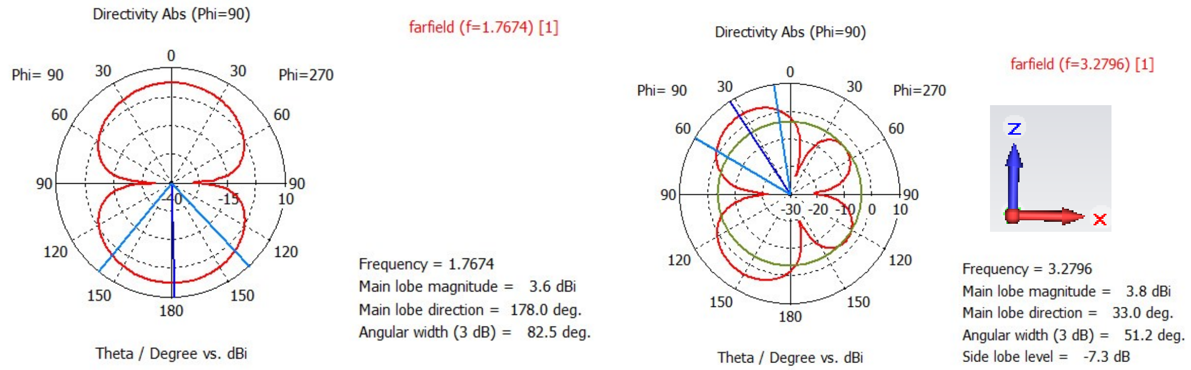
(a) (b)

(c) (d)

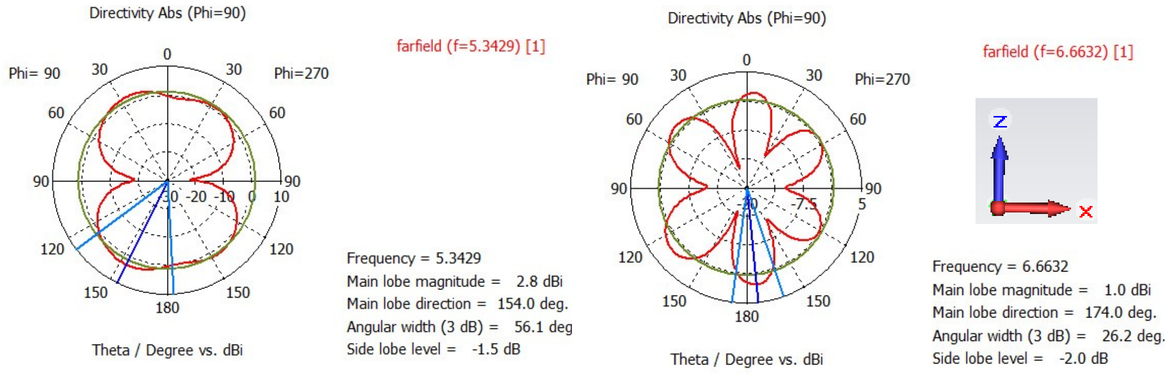
Figure 3.13: The current density of CPW fed sierpinski carpet antenna at frequencies (a) 1.7674 GHz. (b) 3.2796 GHz. (c) 5.3429 GHz. (d) 6.6632 GHz.

3.4.4 Radiation pattern of proposed design

The radiation patterns of sierpinski carpet antenna at different frequencies are shown in figure 3.14. The radiation pattern of proposed design at frequency of 1.7674 GHz resembles radiation pattern of dipole. The radiation pattern at frequency of 3.2796 GHz is having main lobe with low level side lobes. The radiation pattern at frequency of 5.3429 GHz is having dipole like radiation pattern but lacks with symmetry in x-axis. While the radiation pattern at frequency of 6.6632 GHz is having main lobe with higher levels of side lobes. Therefore it can be concluded from the return loss graph and radiation pattern that the CPW fed sierpinski carpet design proposed in the section can be used at three frequencies viz: 1.7674 GHz, 3.2796 GHz and 5.3429 GHz. It is also clear from the results that the frequencies of resonance for the proposed fractal shaped patch are essentially log periodic in nature.



(a) (b)



(c) (d)

Figure 3.14: The radiation pattern of CPW fed sierpinski carpet antenna at frequency (a) f = 1.7674 GHz (b) f = 3.2796 GHz (c) f= 5.3429 GHz (d) f = 6.6632 GHz.

3.5 Design of Modified Sierpinski Gasket antenna with tapered CPW feed

In this section the design of multiband antenna using Sierpinski gasket antenna is presented. Sierpinski gasket fractal is exactly equilateral shape fractal generated by recursively adding small equilateral triangles. The sierpinski gasket shape is generated by Boolean addition of two equilateral triangle shapes in horizontal and adjusting the third equilateral triangle vertically on the top of two triangles as shown in figure 3.15.

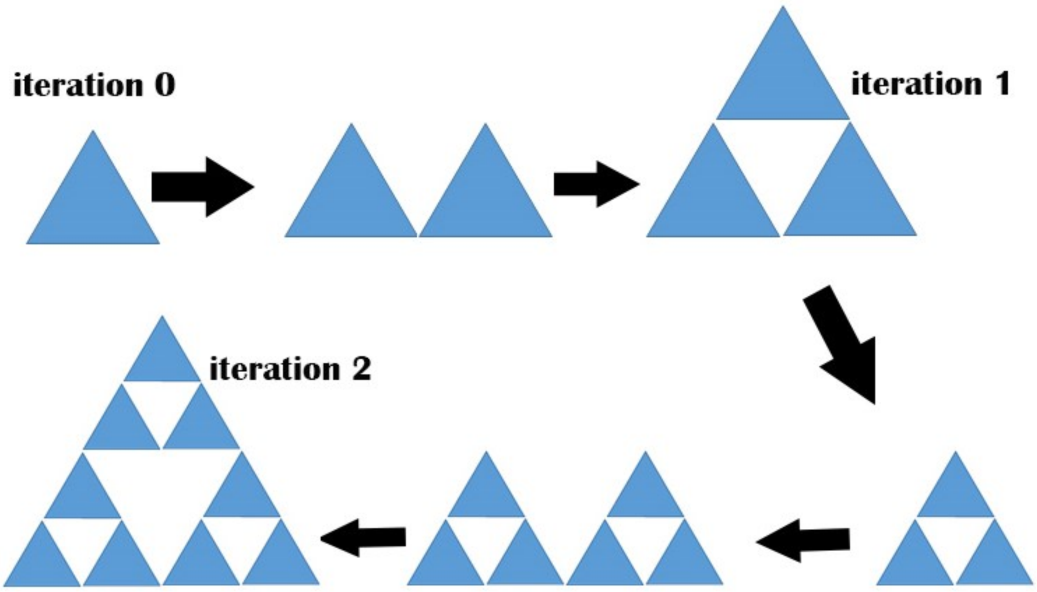


Figure 3.15: Generation of Sierpinski Gasket shape by equilateral triangle

The sierpinski gasket shape has inherited property that the dimensions of the sierpinski gasket can be defined in terms of angle. According to Rumsey's principle, the angle dependency of dimensions make antenna frequency independent. Hence sierpinski gasket can be used as multiband antennas. Further sierpinski gasket suffers with problem of diminishing current density from apex to the other end of triangle as it has abrupt points which results in discontinuity of conduction. The figure 3.16 defines node A, node B and node C points on the sierpinski gasket antenna. The current density will be low at node B and almost zero at node C because the nodes B and C present discontinuity to flow of conduction current. The problem so discussed can affect the performance of sierpinski gasket antennas. So, the discussed problem is termed as discontinuous conduction at abrupt nodes of sierpinski gasket antenna.

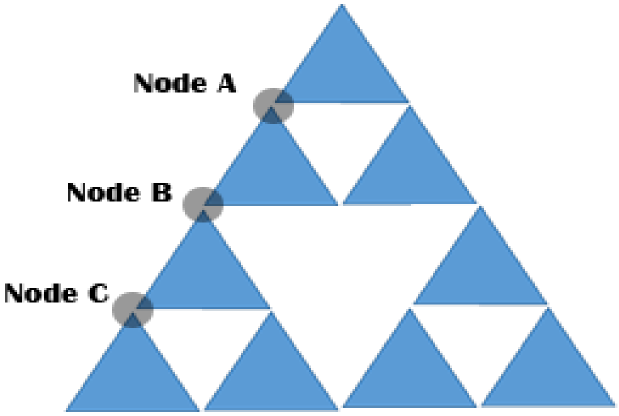


Figure 3.16: Sierpinski gasket with non-conductive nodes due to sharp transitions

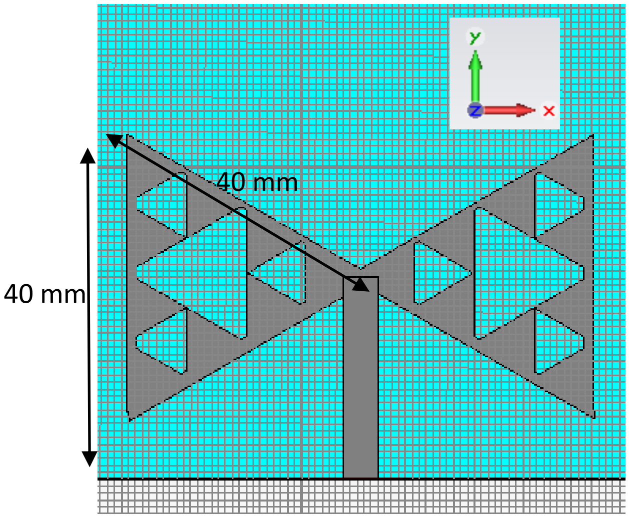


Figure 3.17: Microstrip line fed Sierpinski gasket dipole antenna (Ground plane is having same dimensions as substrate)

Table 3.3: Design parameters of Sierpinski gasket fractal dipole

Parameter	Substrate Length	Substrate Width	Patch overall length	Patch overall width	Feed line width	Substrate Height
Value	80 mm	80 mm	40 mm	69.28 mm	4.5 mm	1.59 mm.

The problem of discontinuos conduction is solved by lessen the sharpness of nodes as shown in figure 3.17. The sierpinski gasket dipole with microstrip line feed is shown in figure 3.17. The return loss graph for the siepensiki gasket antenna is shown in figure 3.21.

3.5.1 Design of tapered CPW fed sierpinski gasket antenna

As discussed in the previous section that the sierpinski gasket fractal design suffers with discontinuous conduction at the nodes of triangles. In this section tapered CPW fed sierpinski gasket antenna is proposed. The duroid substrate with dielectric constant 2.5 and 1.59 mm height is used for proposed antenna with overall dimension 80 mm X 80 mm. The overall dimension of conducting patch is same as in figure 3.17 i.e. 40 mm X 69.28 mm. In figure 3.18 the ground planes are tapered along edge of microstrip patch and fed with coplanar waveguide. The second iteration of sierpinski gasket is proposed in the design.

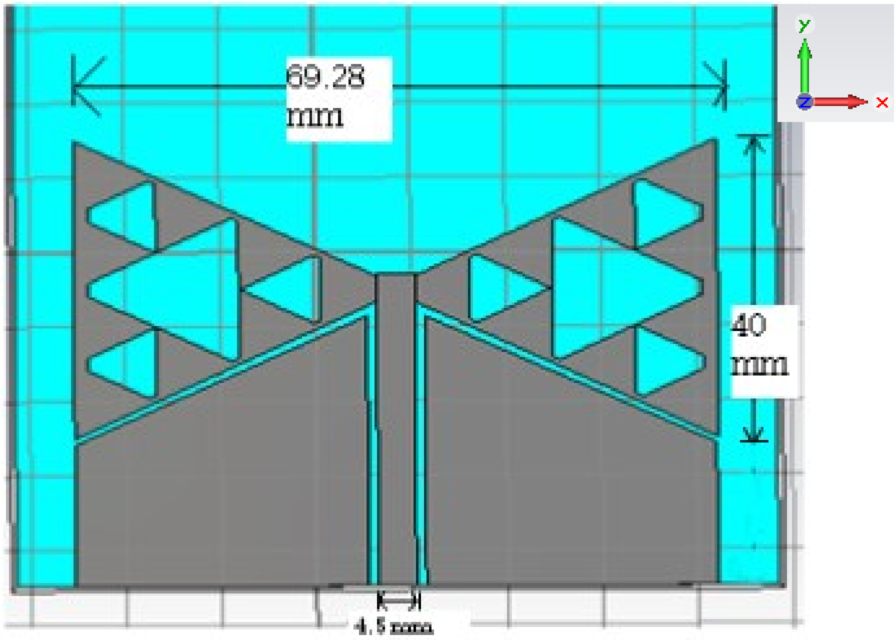


Figure 3.18: Modified Sierpinski Gasket antenna with CPW feed

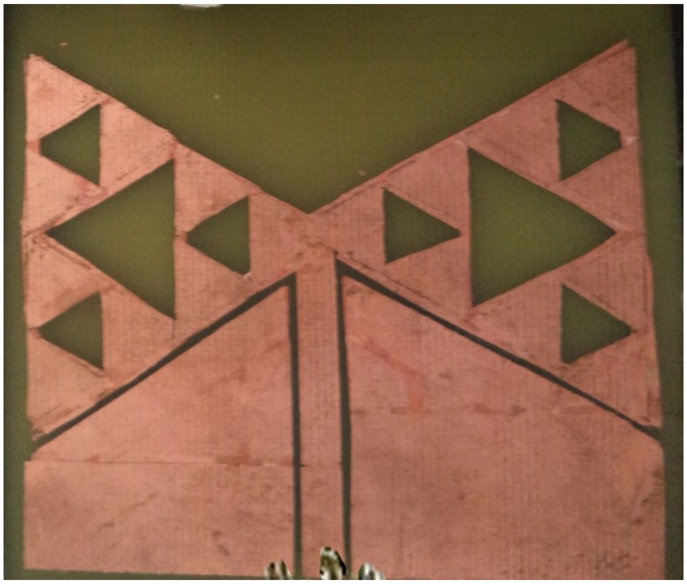


Figure 3.19: Fabrication of proposed Modified Sierpinski Gasket antenna

The fabrication of prospoed antenna is shown in figure 3.19. The antenna is fabricated on Duroid substrate with tapered CPW feed. The antenna is fabricated with photolithiography and wet etching method. The fabricated antenna is measured with VNA and simulated results are compared with measured results.

3.5.2 Reflection coefficient of proposed design

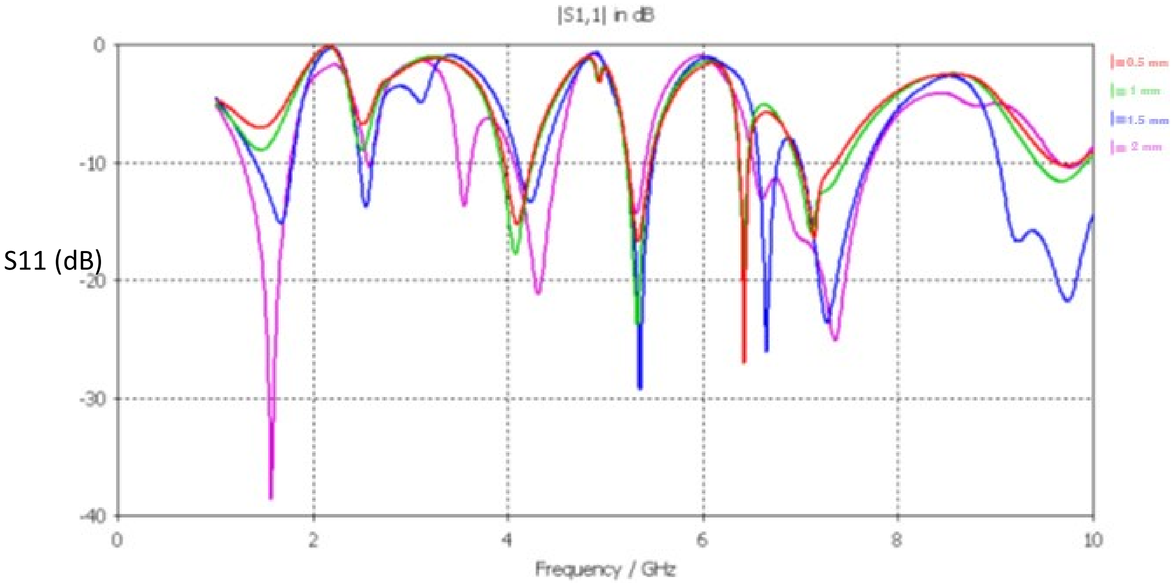


Figure 3.20: S11 (dB) versus frequency for different spcing between ground plane and the feed line

In figure 3.20, the return loss graph are compared for different values of spacing between ground plane and center feedline. The spacing of 0.5 mm is considered and the return loss graph is shown in figure 3.21. It is clear from the figure that the -10dB return loss is obtained for for frequencies 1.57 GHz., 4.31 GHz., 5.31 GHz., 7.37 GHz. The frequency of resonance and corresponding bandwidth at resonant frequency is given in table 3.4. The measured and simulated results are compared in figure 3.22. The simulated and measured results shows good agreement. It proves the proof of concept for proposed design. The tapered ground plane CPW fed antenna in figure 3.19 has novelty in the design as compare to planar rectangular ground plane CPW fed sierpinski gasket antenna.

In figure 3.21 the return loss graph for differnet types of feeds are compared. It is clear from the figure that the use of tapered ground plane CPW fed sierpesniki gasket antenna resonates at four bands in comparison to microstrip line feed resonate strongly at only one band. So the improvement of resonance is obtained using the tapered ground plane CPW feed. The bandwidth offered at four resonances are considered to be good performance. So the proposed design can be considered as novel optimum design to achieve multiband operation of antenna.

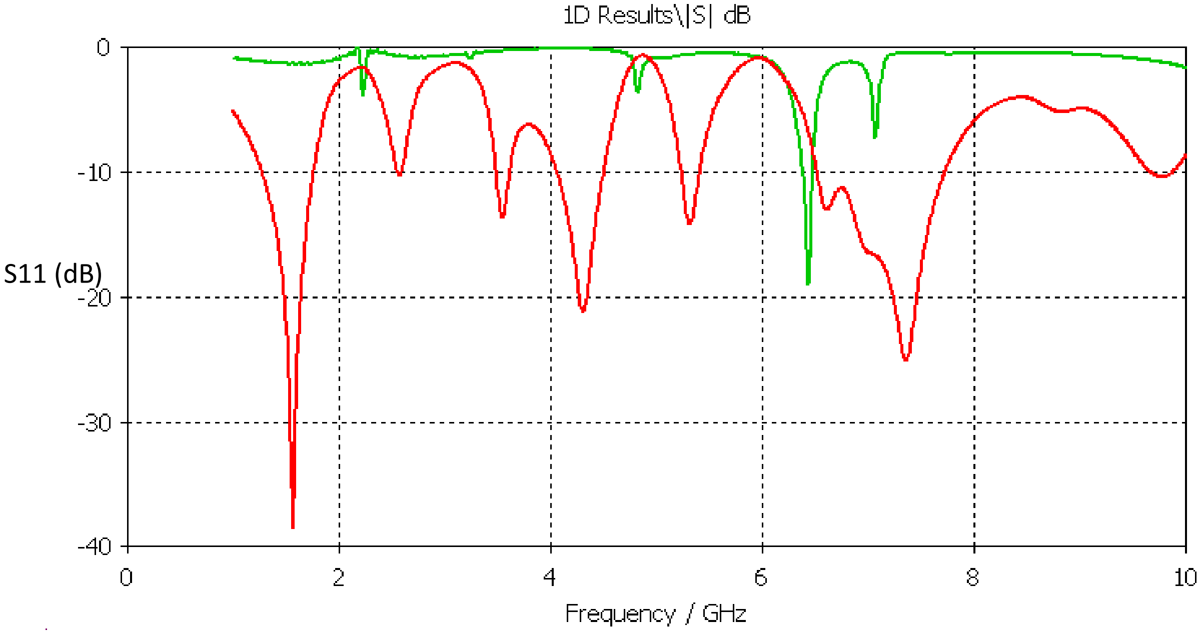


Figure 3.21: The comparison of return loss for microstrip line feed sierpinski gasket structure and proposed tapered ground plane CPW fed antnena (Green plot corresponds to design in figure 3.17 and Red plot corresponds to design in figure 3.18).

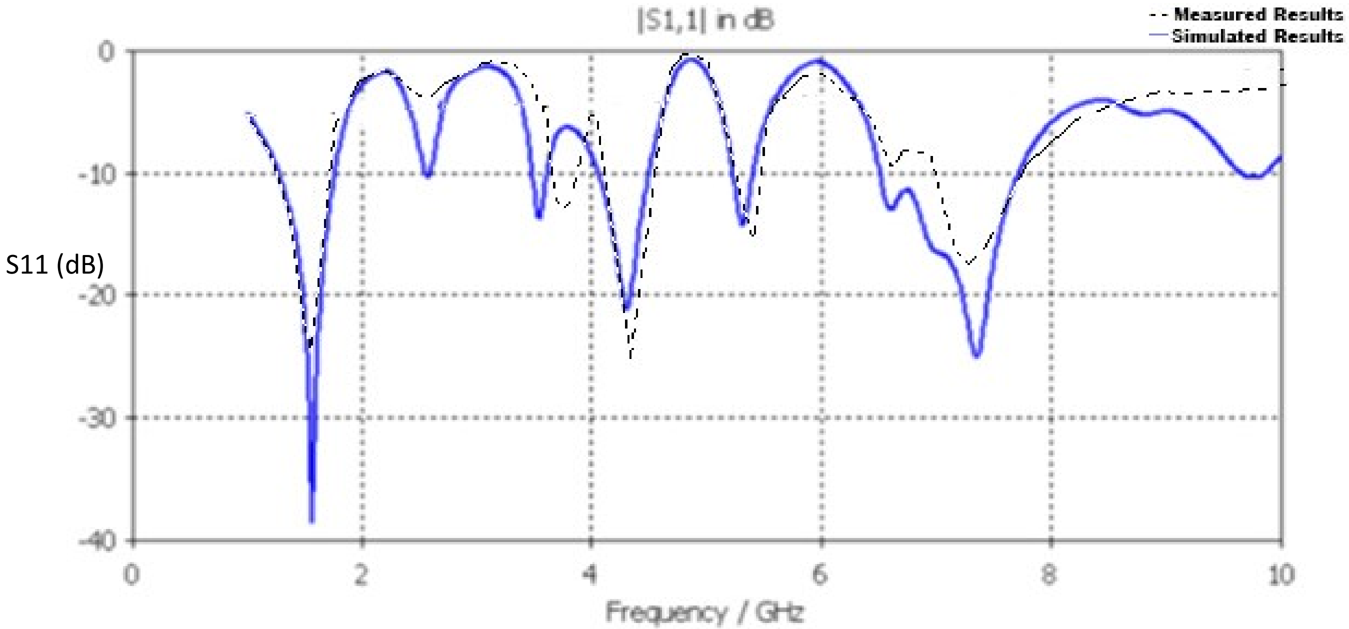


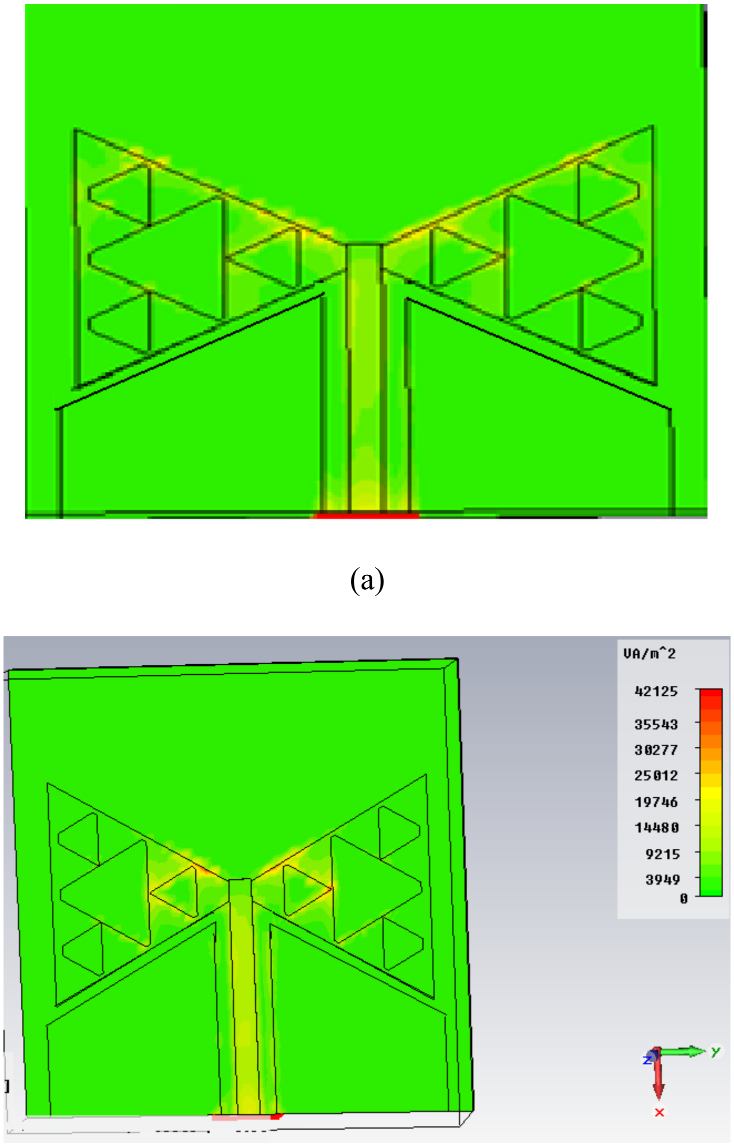
Figure 3.22: Comparison of measured and simlulated results for proposed design at optimum spacing

Table 3.4: Frequency of resonance for tapered cpw fed sierpesniki gasket and corresponding bandwidth

Frequency of Resonance	1.57 GHz.	4.31 GHz.	5.31 GHz.	7.37 GHz.
Bandwidth	451 MHz	460 MHz.	170 MHz.	670 MHz.

3.5.3 Current density analysis of proposed design

The current density for proposed antenna at 4.31 GHz and 7.37 GHz is shown in figure 3.23 to study the radiation mechanism of proposed antnena. It is clear from the current density on proposed antenna that the current density distribution of larger triangles are responsible for resonance at frequency 4.31 GHz and the current density distribution of smaller triangles are responsible for resonance at higher frequency 7.37 GHz. The problem of discontinuous conduction at abrupt nodes of triangle is solved by using tapered CPW feed.



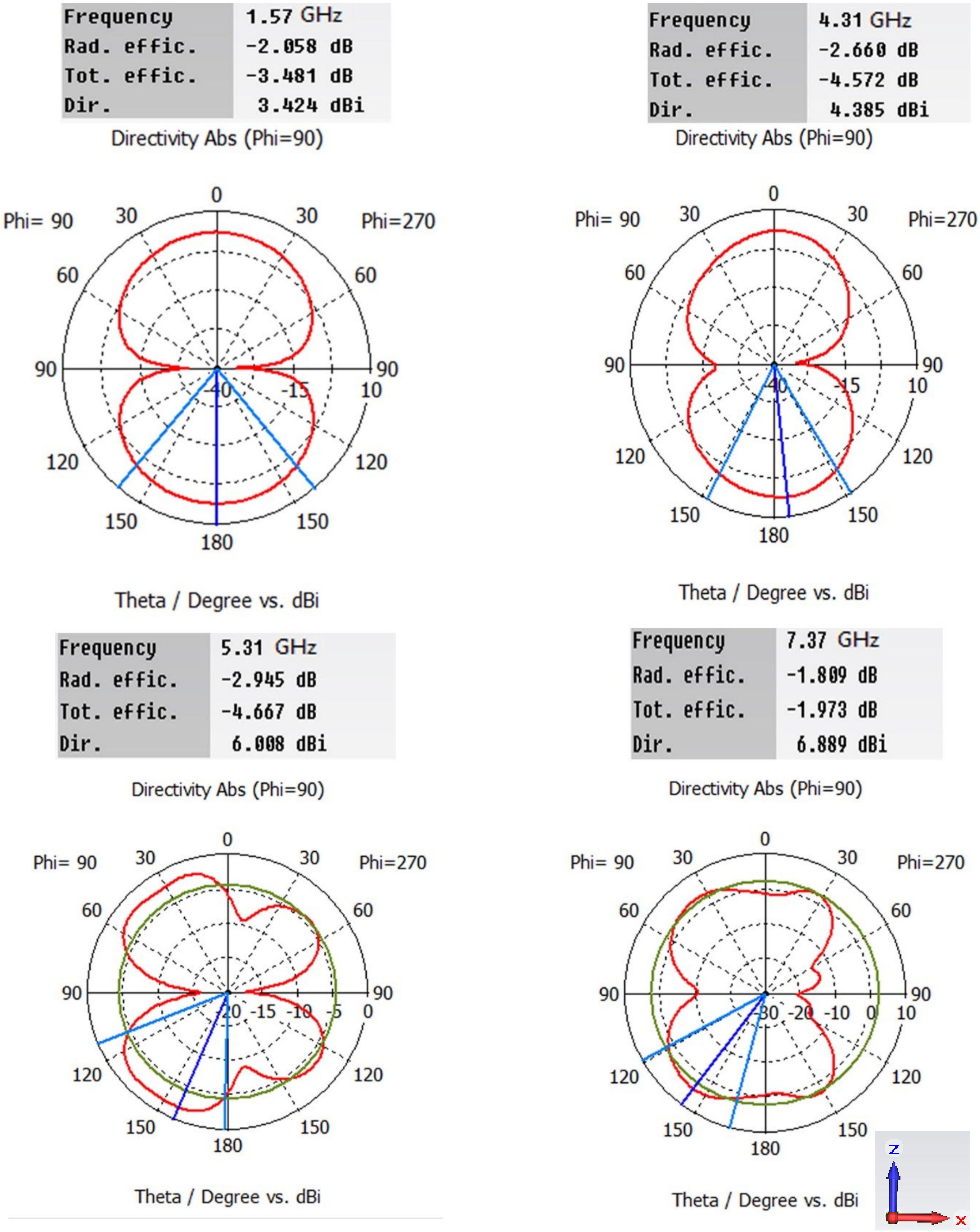
(a)

(b)

Figure 3.23: Current density of proposed antenna at frequency (a) f=4.31 GHz and (b) f=7.37 GHz.

3.5.4 Radiation pattern of proposed antenna

The radiation pattern of propsoed antenna is shown in figure 3.24. It is clear from the figure that the radiation pattern is essentialy resembles dipole like radiation pattern for 1.57 GHz and 4.31 GHz with low side lobe level. The radiation pattern for frequency band 5.31 GHz and 7.37 GHz has more side lobes but provides sufficient gain. In term of multiband support and radiation pattern with gain offered at specific frequency make the proposed design attrative to be used as multiband antenna.



Frequency	1.57 GHz
Rad. effic.	-2.058 dB
Tot. effic.	-3.481 dB
Dir.	3.424 dBi

Frequency	4.31 GHz
Rad. effic.	-2.660 dB
Tot. effic.	-4.572 dB
Dir.	4.385 dBi

Frequency	5.31 GHz
Rad. effic.	-2.945 dB
Tot. effic.	-4.667 dB
Dir.	6.008 dBi

Frequency	7.37 GHz
Rad. effic.	-1.809 dB
Tot. effic.	-1.973 dB
Dir.	6.889 dBi

Figure 3.24: The radiation pattern of proposed antenna at 1.57 GHz, 4.31 GHz, 5.31 GHz and 7.37 GHz.

3.6 Summary of the chapter

In this chapter, the different techniques are presented to achieve multiband operation of antenna. The design of square patch MPA with size 30 mm X 30 mm is studied and considered as basis of multiband antenna. The Current density and radiation pattern of different type of feeds are presented in the chapter. The study presented gives insight to different feed mechanism of microstrip patch antennas. Further the slots can be introduced to achieve multiband operation of antenna. The slot monopole resonate at 2.2 GHz, 3.5 GHz and 4.7 GHz. The current density proves that the resonance at 2.2 GHz is fundamental resonance, 3.5 GHz is slot mode resonance and 4.7 GHz resonance is higher mode resonance. The radiation pattern depicts that antenna can be utilized at frequency 2.2 GHz and 3.5 GHz. The radiation pattern for 6.66 GHz proves that the antenna is not suitable to use at this frequency. Further the sierpinski carpet fractal is considered for multiband operation. The proposed antenna is CPW fed and resonate at 1.57 GHz, 4.31 GHz, 5.31 GHz and 7.37 GHz. The antenna can be utilized for DCS, UMTS, LTE, WLAN and PCS applications. Further the sierpinski gasket antennas are considered for multiband operation of antenna. The problem of sierpinski gasket antenna is discussed in the chapter. The modified CPW fed for sierpinski gasket is proposed for multiband operation of antenna. The antenna resonates at 1.77 GHz, 3.3 GHz, 5.34 GHz and 6.66 GHz. The radiation pattern of proposed antenna depicts that antenna can proved efficient at four band of frequency.

Chapter 4

Design and fabrication of improved bandwidth gain product antennas

The recent trend in wireless communication requires multimedia communication through wireless channel. The other aspect of wireless communication is wide bandwidth of antenna. The antenna is a quite important component of wireless system. The multimedia support require high data rate consequently require larger bandwidth. So, it is important to have broadband antenna in next generation wireless systems. The broadband antennas are discussed extensively in literature given in chapter 2. But the improvement of gain bandwidth product is considered as gap in the research work. The antenna is frequency dependent component of wireless system and antenna operates in a limited band of frequency only. So, the methods to achieve broadband operation may prove complex. In the era of planar antennas, in this chapter different methods to achieve broadband operation with planar shapes will be discussed. To begin with, the effect of different microstrip patch antenna parameters on bandwidth is presented. The increase in bandwidth usually results in decrease of gain. Moreover it can be said that the bandwidth gain product is constant. The aim is to increase impedance matching of antenna so as to enhance bandwidth gain product of antenna. In the last section the hybrid fractal is used as broadband antenna. The two variants of hybrid fractal i.e. dual wideband defected ground plane hybrid fractal antenna and CPW fed hybrid fractal to improve bandwidth gain product is discussed.

4.1 Effect of different MPA parameters on antenna bandwidth

In this section effect of different MPA parameters on antenna bandwidth is discussed. It is important to carry this study in design concept of broadband antenna. The impedance bandwidth of antenna termed simply as bandwidth of antenna can be defined as the range of frequency for which return loss is below -10 dB. The microstrip patch antenna is fed by 50 ohm connector and impedance of antenna is frequency dependent parameter. The impedance matches to the impedance of connector at limited specific frequency only. The various parameters of MPA can be summarized as patch length, patch width, substrate height, substrate dielectric constant, substrate dielectric tangent loss, ground plane length, ground plane width and type of feed etc. In this section the effect of the substrate parameters and type of feeds on bandwidth of microstrip patch antenna is discussed.

4.1.1 Effect of substrate thickness and dielectric constant on bandwidth

In this section, the effect of substrate thickness on bandwidth of antenna is discussed. To study the effect of height on bandwidth, the square patch with inset feed antenna is made resonant at 2.4 GHz for different heights of the substrate. The inset feed microstrip patch antenna with resonance frequency 2.4 GHz is designed in accordance with flowchart given in figure 3.1. The detail of the presented design is listed in table 4.1.

Table 4.1: Design parameters of inset feed square patch antenna for 2.4 GHz.

Parameters	**Values (mm)**
Length and width of the patch	29.54 mm
value of inset through patch	13.265 mm
Width of the feed	3.074 mm
Height of the substrate	1.59 mm
Substrate Dielectric constant	4.3

The different designs of inset feed are optimized for 2.4 GHz resonant frequency. The design parameters of designs with different substrate heights and frequency of resonance 2.4 GHz are tabulated in table 4.2. In table 4.3, the bandwidth and gain corresponding to different substrate heights at frequency of resonance 2.4 GHz is listed. In figure 4.1, the bandwidth comparison of different substrate height designs are shown. In figure 4.2, the graph between gain (dBi) and bandwidth (MHz) correspond to different substrate height is shown. It is clear from the figures that as the substrate height is increased, the bandwidth increases and gain decreases. So, increasing the substrate height can increase the bandwidth of the antenna but compromise is made with gain (dBi). It is concluded from the section that the bandwidth gain product of the designs are constant if bandwidth enhancement is achieved by varying parameters of MPA. The different methods are needed to be proposed for improving bandwidth gain product.

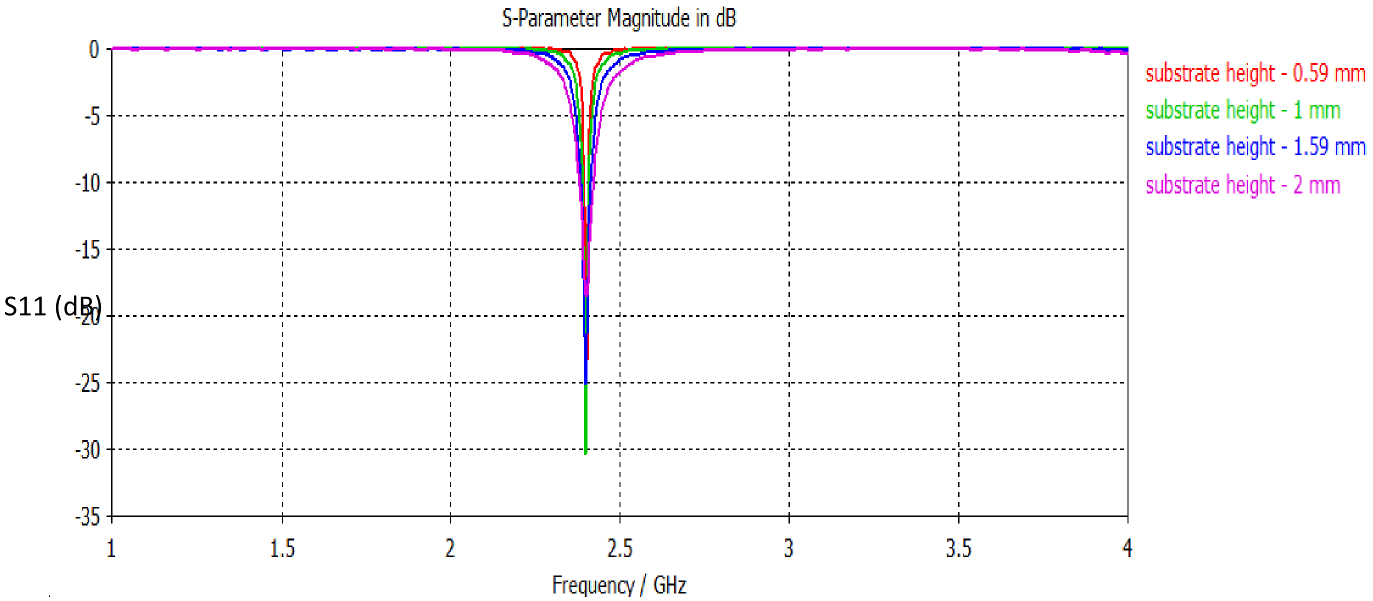


Figure 4.1: The bandwidth comparison of different designs with varying substrate thickness

Table 4.2: Design parameters for different substrate height MPA for resonance of 2.4 GHz.

	Substrate height – 0.59 mm	Substrate height – 1.0 mm	Substrate Height – 1.59 mm	Substrate height – 2.0 mm
Patch dimension	29.8 mm	29.75 mm	29.54 mm	29.6 mm
Feed width	1.1 mm	1.96 mm	3.074 mm	3.85 mm
Inset Length	14.2 mm	14 mm	13.265 mm	12.125 mm

Table 4.3: The bandwidth gain comparison table for different substrate heights

	Substrate height – 0.59 mm	Substrate height – 1.0 mm	Substrate Height – 1.59 mm	Substrate height – 2.0 mm
Bandwidth (MHz)	12.5	19.6	30.2	41.4
Gain (dBi)	6.23	6.2090	6.197	6.187

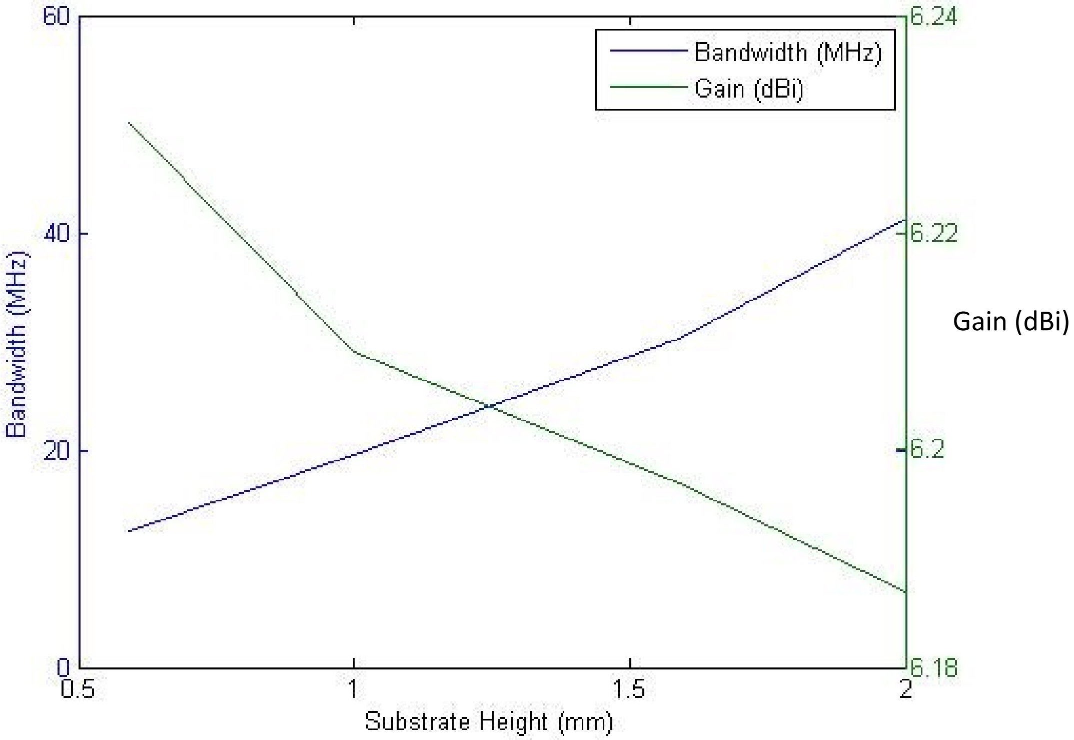


Figure 4.2: The graph between bandwidth and gain against substrate height

To find dependency of bandwidth on dielectric constant of the substrate, the 2.4 GHz designs with different dielectric substrate are used.

Table 4.4: The bandwidth and gain of 2.4 GHz designs with different substrate

Substrate	Bandwidth (MHz)	Radiation Pattern
FR4 ($\varepsilon r=4.4$)	30.2	More Directive
Rogers RT5880 ($\varepsilon r=2.2$)	31.3	Less Directive

The FR4 with dielectric constant 4.4 and Rogers RT5880 with dielectric constant 2.2 are compared. The bandwidth gain table for the different substrates is given in table 4.4.

As discussed in [103], the reason for increase in bandwidth with increase in substrate height can be described as the stored energy decreases with increase in thickness of the substrate. Though bandwidth can be increased by either increasing the substrate thickness or by decreasing the substrate dielectric constant, but the increase in substrate thickness may result in following disadvantages

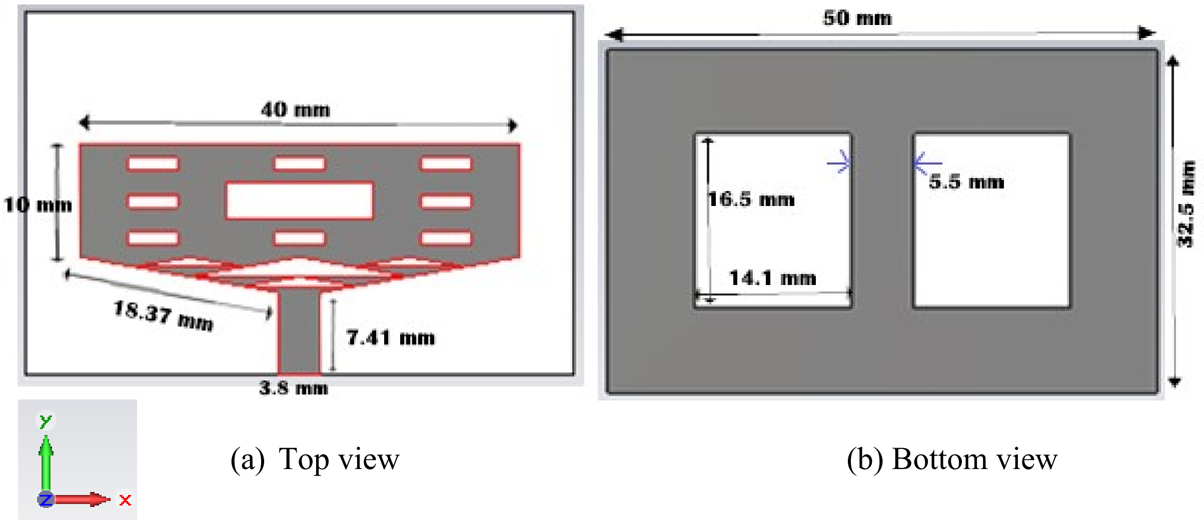
i. The increase in substrate thickness decreases the gain of the antenna.
ii. The increase in substrate thickness results in radiation from feed as well.
iii. The increase in substrate thickness may result in impedance matching problem because of increased inductive impedance.
iv. Higher order of excitation may exist.

4.2: Hybrid fractal broadband antenna

In context of broadband antennas, Fractal antennas may result in broad bandwidth support to antenna. The most commonly used fractal shapes are sierpinski carpet and sierpinski gasket etc. The both type of the fractals suffer with different type of problems. The sierpinski gasket suffers with discontinuous conducting path at the nodes of triangles as discussed in the section 3.4.2. The sierpinski gasket suffers with problem of impedance matching at the edge. The broadband operation achieved by the fractals have advantage of compactness in size. The hybrid fractal can be combination of two or more different type of fractals. In this section the hybrid fractal which is combination of sierpinski gasket and sierpinski carpet is considered for the wideband operation of antenna.

4.2.1 Design of defected ground structure hybrid fractal broadband antenna

As discussed in previous section that the parameter variation to improve bandwidth of antenna results in decrease of gain. In this section defected ground structure hybrid fractal antenna is proposed to improve bandwidth gain product. The MPA suffers with limited bandwidth for because of surface wave excitation. The defected ground structure can be proposed to decrease surface wave excitation. Further the hybrid fractal results in wideband operation of antenna. The MPA with hybrid fractal shape patch and ground structure with slotted defects results in good bandwidth gain produce. The prototype of defected ground structure hybrid fractal broadband antenna is proposed here. The top view and bottom view of proposed antenna is shown in figure 4.3. The radiating patch for proposed antenna is merger of sierpinski carpet and sierpinski gasket. The overall dimension of sierpinski carpet structure is 40 mm X 10 mm and sierpinski gasket has sides of length 40 mm and 18.37 mm. The overall dimensions of ground plane are 50 mm X 32.5 mm. The two slots of size 16.5 mm X 14.1 mm is cut in the ground for creating defect ground plane structure.



(a) Top view (b) Bottom view

Figure 4.3: Defected ground structure hybrid fractal antenna

4.2.2 Return loss performance for proposed antenna

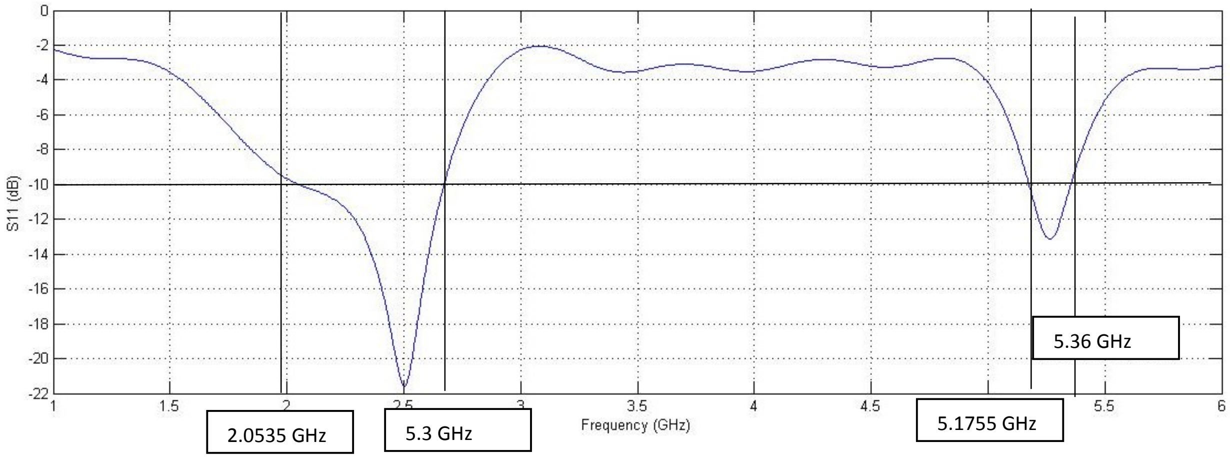


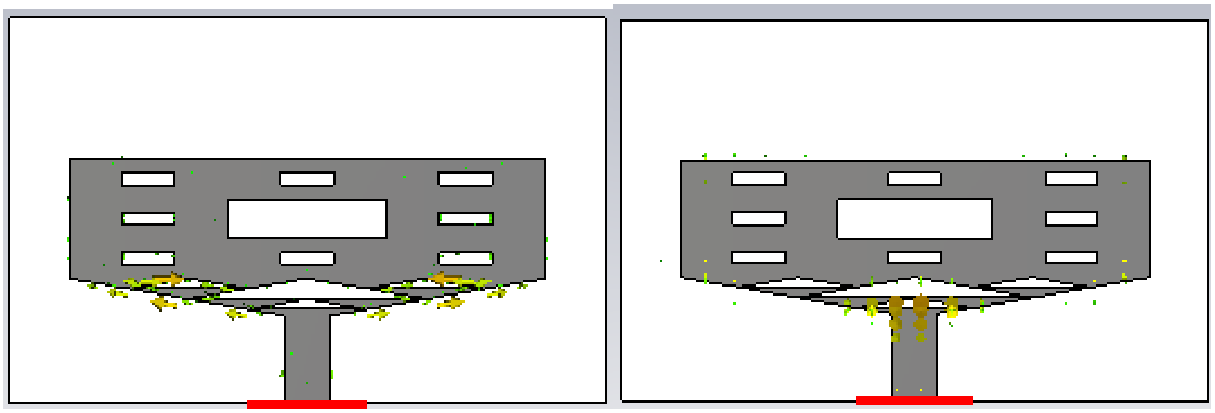
Figure 4.4 The S11 versus frequency graph for defected ground strucure hybrid fractal antenna

The return loss graph for proposed antenna is shown in figure 4.4. The proposed antenna resonate at frequency 2.5 GHz and 5.3 GHz with impedance bandwidth of 616.5 MHz (2.0535 – 2.67 GHz) and 184.5 MHz (5.1755 –5.36 GHz) respectively. The antenna is designed for operating bands of WLAN application. The broad bandwidth enables high data rate application support of next generation wireless device. The largest dimension of antenna is responsible for resonance at lower frequency band at 2.5 GHz. The DGS enhance the bandwidth at the higher frequency resonance. The wideband is obtained by merging of two resonance frequency from hybrid fractal antenna.

The hybrid shapes of sierpinski gasket and sierpinski carpet are made close resonant and results in merging of two resonance. Hence wideband antnena is evolved with proposed design.

4.2.3 Current density of proposed antenna

In figure 4.5, the current density on hybrid fractal patch at frequency 2.5 GHz and 5.3 GHz is shown. The current denstiy profile reveals that the fundamental mode of larger dimension of sierpinski gasket and sierpinski carpet antenna is responsible for resonance at smaller frequency 2.5 GHz. The smaller triangle componenet of sierpinski gasket is responsible for resonance at higher frequency 5.3 GHz. The current density on DGS is responsible for reduction of surface wave propagation hence improves the bandwidth gain product of antenna.



(a) (b)

Figure 4.5: The current density of hybrid fractal defected ground structure antenna at frequency (a) 2.5 GHz and (b) 5.3 GHz

4.2.4 Radiation pattern of proposed antenna

The radiation pattern of proposed antenna at 2.5 GHz and 5.3 GHz is shown in figure 4.6 (a) and (b) respectively. The gain of proposed antenna at 2.5 GHz is 4 dBi and at 5.3 GHz is 8.8 dBi. The pattern can be considered essentially meeting the criteria of next generation wireless systems. The gain offered by the proposed antenna with achieved bandwidth makes it perfect candidate as improved bandwidth gain product of antenna. The radiation pattern of proposed antenna satisfies the specification of modern day wireless systems. The radiation pattern at both of the frequency can be utilized as wideband moderate gain antennas in next generation wireless systems.

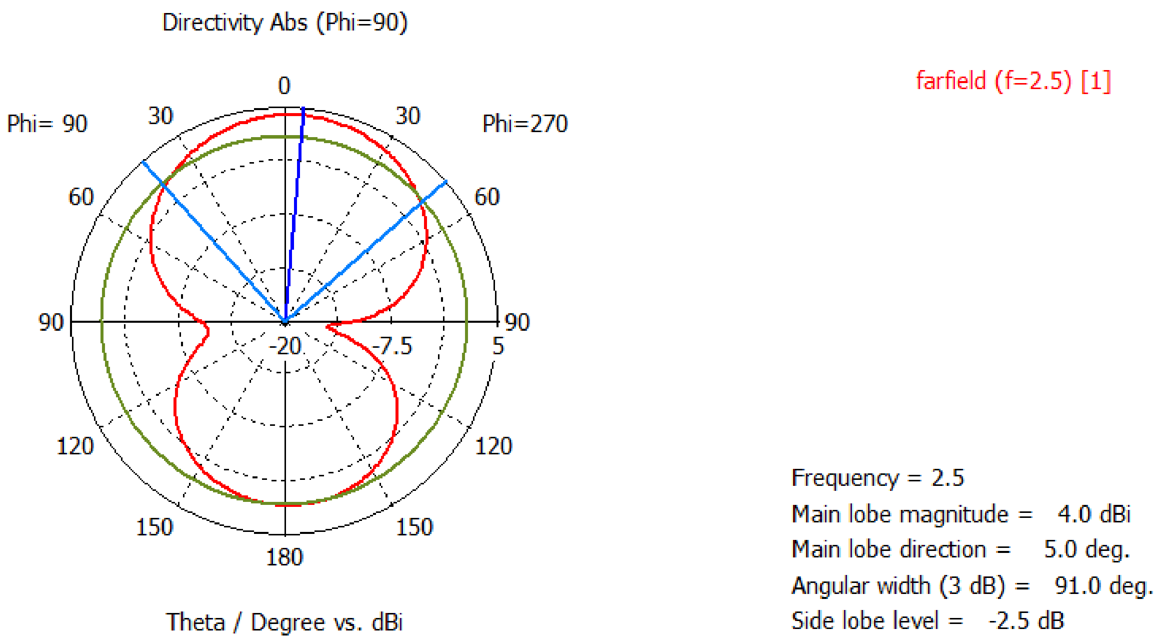


Figure 4.6 (a) The radiation pattern of proposed antenna at 2.5 GHz

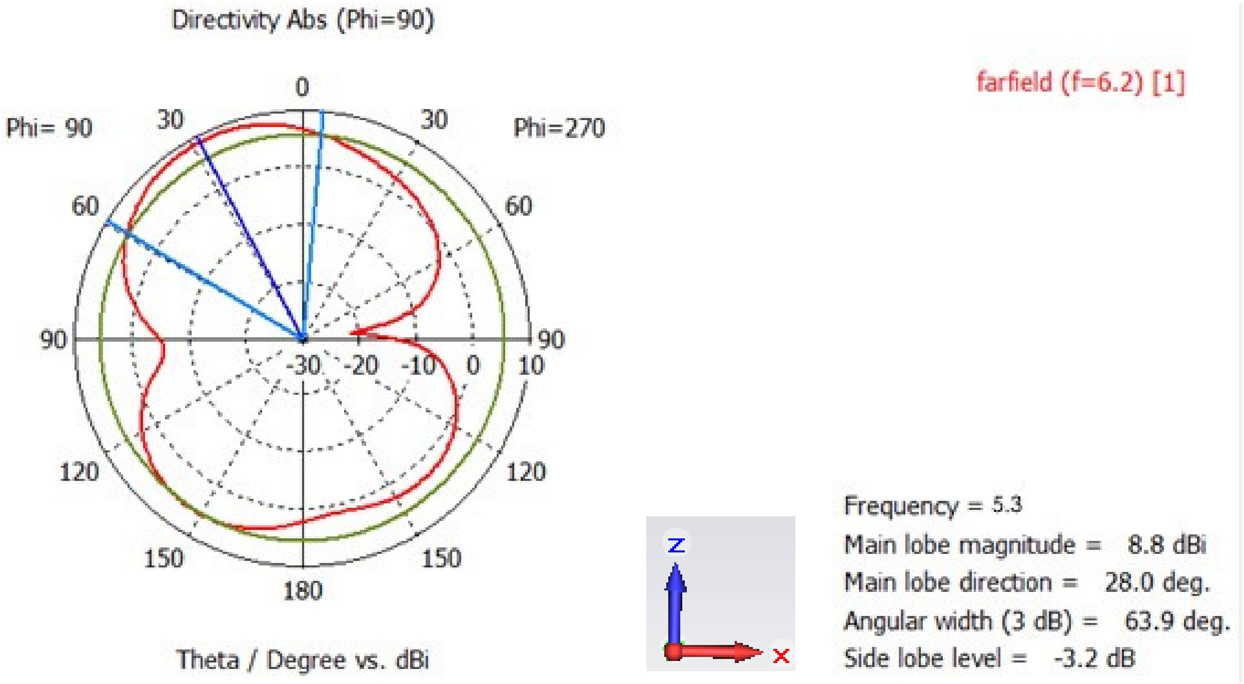


Figure 4.6 (b) The radiation pattern of proposed antenna at 5.3 GHz

4.3 CPW feed hybrid fractal antenna for broadband operation

4.3.1 Design Consideration of proposed antenna

Further to ease the integration of antenna with PCB of the wireless device, the CPW feed is proposed for broadband hybrid fractal antenna. The proposed antenna is fed by CPW feed as shown in figure 4.4. ‘s’ is the gap between feed and the ground plane as shown in figure 4.7 (c). The patch of proposed antenna has hybrid of sierpinski carpet and sierpinski gasket shape. The dimensions of sierpinski carpet antenna in proposed design is 51.75 mm X 7mm. The side lengths of sierpinski gasket is 51.75 mm and 30.55. The dimensions of antenna patch and feed parameters are optimized for the bandwidth of the antenna. The fabricated antenna is shown in figure 4.8.

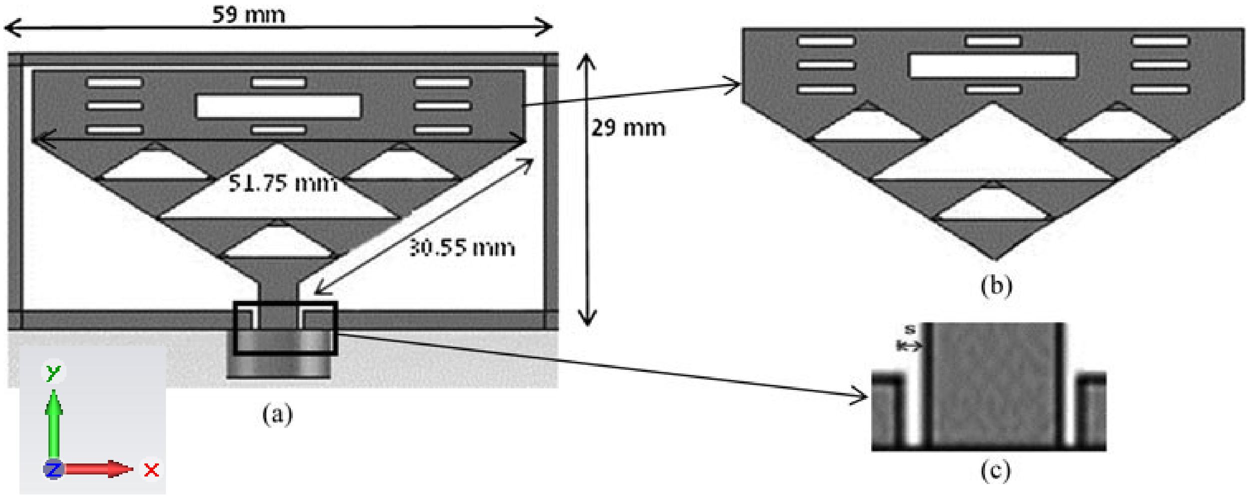


Figure 4.7: The hybrid fractal wideband antenna (a) the proposed design, (b) The patch of the proposed antenna (c) the feed of proposed antenna

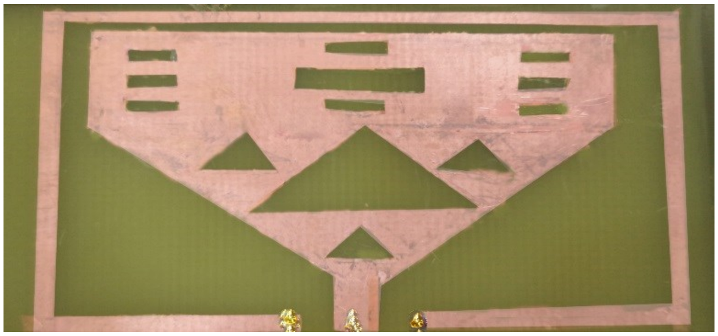


Figure 4.8: The fabrication of proposed antenna

4.3.2 Return loss parameter for proposed antenna

In figure 4.9 the return loss graph for different value of spacing between feed and the ground plane is shown. The optimized value of spacing between feed and the ground plane is 2.75 mm. In figure 4.10, the S11 versus frequency graph is shown for the optimized value of spacing. It is clear from the figure that the antenna has impedance matching in broad frequency range. The antenna has notch at the frequency 2.74 GHz which is introduced to reduce the interference at the specified frequency. The antenna offers impressive bandwidth support hence it can be considered as good antenna for next generation wireless devices. In figure 4.10 the comparison of simulated and measured result is shown. The comparison reveals that the measured results show good agreement with the simulated results.

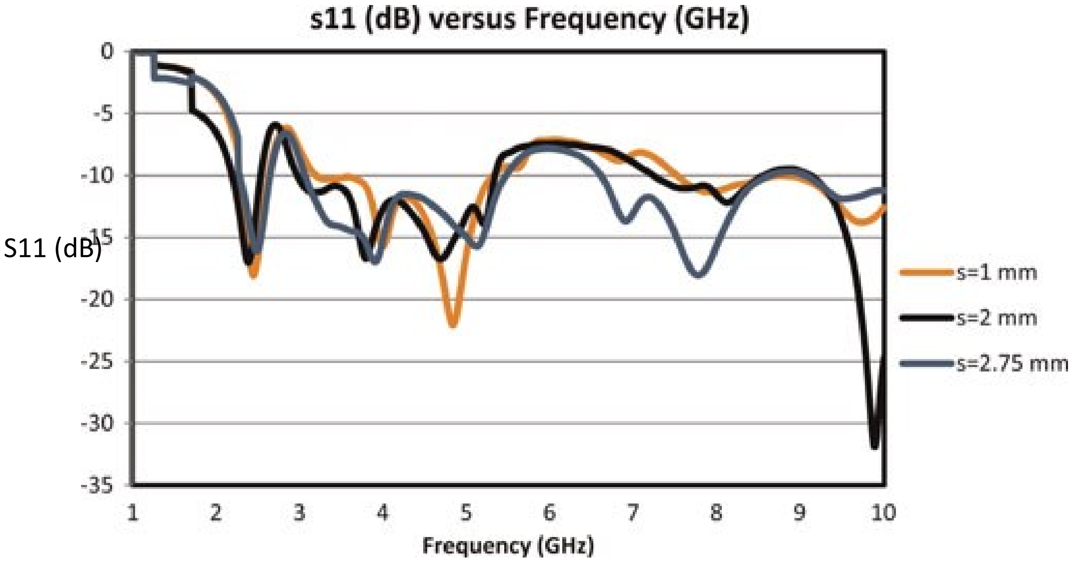


Figure 4.9: The return loss versus frequency graph for different value of spacing between feed and the ground plane

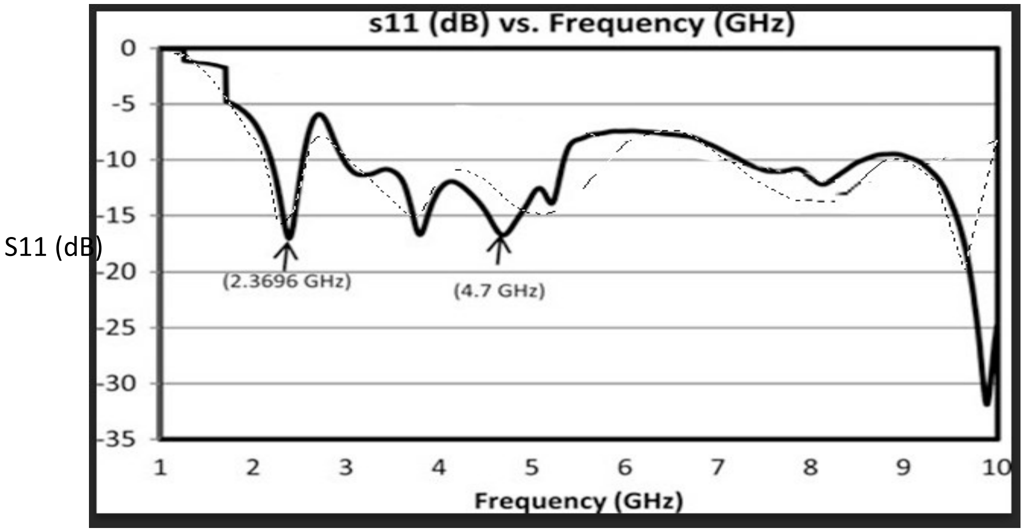
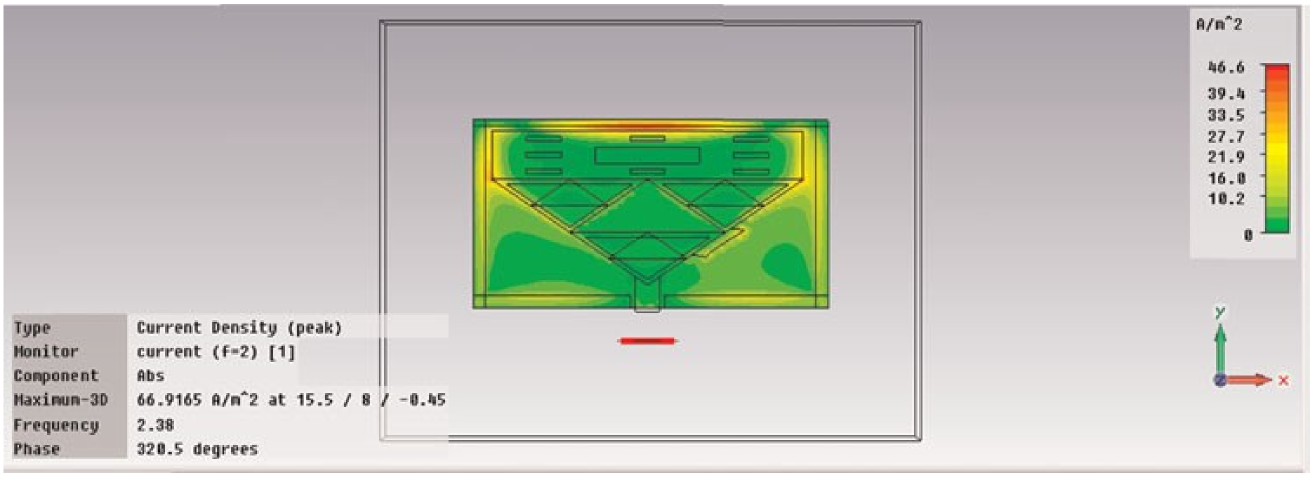


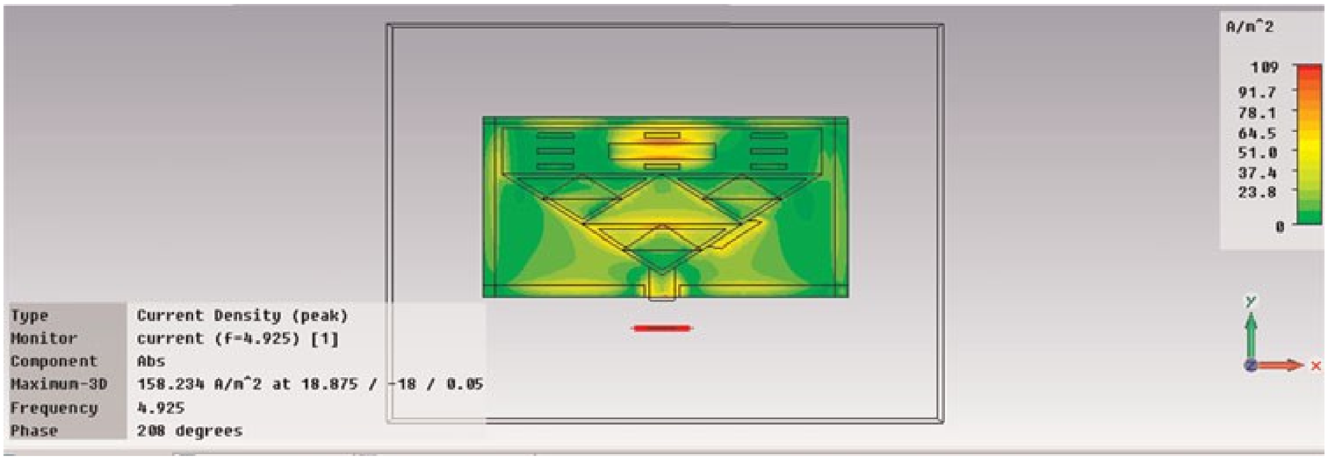
Figure 4.10: The return loss graph for proposed design at the spacing s=2.75 mm

4.3.3 The current density of proposed antenna



Type	Current Density (peak)
Monitor	current (f=2) [1]
Component	Abs
Maximum-3D	66.9165 A/m^2 at 15.5 / 8 / -0.45
Frequency	2.38
Phase	320.5 degrees

Figure 4.11: The current density on proposed antenna at 2.38 GHz.



Type	Current Density (peak)
Monitor	current (f=4.925) [1]
Component	Abs
Maximum-3D	158.234 A/m^2 at 18.875 / -18 / 0.05
Frequency	4.925
Phase	208 degrees

Figure 4.12: The current density on proposed antenna at 4.925 GHz.

In figure 4.11, the current density at frequency 2.38 GHz is shown. It is clear from the figure that the radiation at the frequency of 2.38 GHz is mainly due to current density at the edges. The current density at the frequency 4.925 GHz is shown in figure 4.12. It is clear from the figure that the smaller triangles and the smaller rectangles are responsible for the radiation at the higher frequency. The fractals are made resonant at close frequency so after merging of the resonant frequencies results in broadband response of antenna. The proposed hybrid fractal is efficient radiator. The impedance match through wideband frequency range is achieved as discussed. Further the reason for using hybrid fractal shape is to solve problem of feeding sierpinski carpet antenna at their edges. The sierpinski gasket can be fed at the apex and sierpinski carpet is kept just above the sierpinski gasket antenna. The concept solves the problem of feeding sierpinski carpet antenna. The sierpinski gasket in proposed design performing two operations first it is acting as impedance transformer to feed sierpinski carpet antenna ant otherwise it is acting as the radiating structure itself.

4.3.4 Radiation pattern of proposed antenna

The radiation patterns of proposed antenna at 4.32 GHz and 2.8 GHz are shown in figure 4.9. As shown in the figure that the antenna has gain of 4.1 dBi at the frequency 2.8 GHz and 6.1 dBi at frequency 4.32 GHz. In comparison to simple square patch fed by coplanar waveguide feed, the proposed design performs well in terms of impedance bandwidth and gain. The gain bandwidth product of proposed antenna is much higher than simple fractal antennas even. The hybrid fractal antenna proposed in the section can be used for UWB, Wi-Fi, WiMAX and PCS etc. applications.

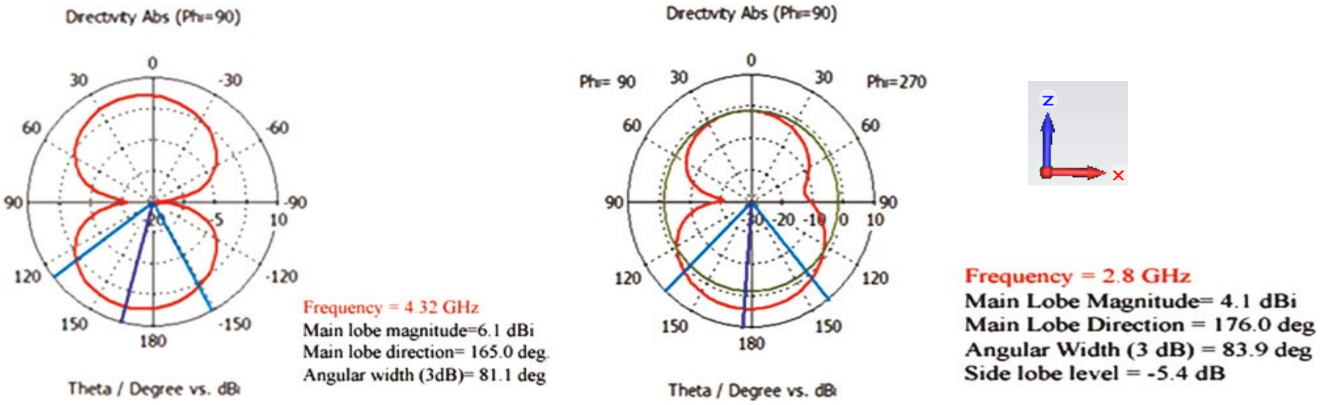


Figure 4.13: The radiation pattern of proposed antenna at 4.32 GHz and 2.8 GHz.

The antenna offers broadband support with moderate gain. The reason for improved bandwidth gain product is the increased efficiency and decreased side lobe levels of proposed antenna.

4.4 Summary of the chapter

The bandwidth can be increased by varying parameters of antenna but results in decreased gain. In this chapter, the methods are proposed to achieve broad bandwidth operation of antenna while gain to be moderate as well. The hybrid fractal shapes are proposed as broadband antenna. The hybrid fractal is combination of sierpinski gasket and sierpinski carpet. The proposed sierpinski gasket and sierpinski carpet resonates at close frequencies results in merging of two bands. Further bandwidth enhancement is achieved by reduction of surface wave propagation using defected ground structure. The proposed defected ground structure hybrid fractal wideband antenna offers bandwidth of bandwidth of 616.5 MHz (2.0535 – 2.67 GHz) and 184.5 MHz (5.1755 –5.36 GHz) with gain 4 dBi and 8.8 dBi at the bands respectively. The result is improved bandwidth gain product of antenna. To ease integration of proposed antenna with PCB of wireless devices, the hybrid shaped fractal is proposed with CPW feed. The proposed antenna supports broadband frequencies with gain of 4.1 dBi and 6.1 dBi at 2.8 GHz and 4.32 GHz respectively. The proposed antenna is fabricated and the measured results are compared with simulated results. The proposed antennas supports the specifications of high data rate next generation wireless systmes.

Chapter 5

Modified Fractal PIFAs for modern day wireless devices

The recent advancements in wireless gadget demand reduction in size and support to high data rate multimedia services like file transfers, VoIP, video conferencing and HD video transfer etc. The needs of modern day wireless devices can be summarized as small size, multiband and broadband antennas. To support multimedia applications in modern day wireless systems, the multiband and broadband antennas are discussed in chapter 3 and chapter 4 respectively. Further the fractal antenna proved to be size efficient multiband and broadband antennas in particular. In [104-106] Fractal is proposed as methods for reduction in size of antenna. The growth of telecommunication in the modern day world resulted in mobile phone to be important ingredient for every individual. In mobile phones planar inverted F antenna is used for its virtue of small size and omnidirectional pattern. The planar inverted F antenna is a type of microstrip patch antenna with feeding mechanism and ground plane and floating metallic patch shorted at one end. It is called inverted F antennas because the cross sectional view of patch, feed and short appears as inverted F. In PIFA the image of current density at patch appears at the ground plane to enable reduction of size. The PIFA is known to be λ/4 antenna. The patch used in PIFA can have various shapes. The rectangular shape is most commonly used for patch of PIFA. The dimensions of rectangular PIFA can be calculated with the formula

$$a + b \approx \frac{c}{4f} \qquad \text{Eq. 5.1}$$

Here ‘a’ and ‘b’ are dimensions of rectangular shape patch and f is frequency of resonance.

In this chapter various designs of PIFA will be discussed. The discussed designs target reduction in size, multiband support and bandwidth enhancement of antenna. Further, in literature Multiple input multiple output (MIMO) antenna system is proposed as technique to achieve high data rate. The MIMO antenna printed on planar surface is desired in modern day wireless devices. In this chapter MIMO planar antennas are proposed and fabricated. The multiband operation is achieved and ECC value in the bands lies in satisfactorily limits. The designs presented in chapter aim at small size MIMO antenna with support to multiband and broadband operation. The antennas are fabricated in the lab. The comparison measured results are compared with simulated results. The radiation pattern for each design is also analyzed. The antennas can directly be put in practical use i.e. can be embed in mobile phones. The standards followed by the mobile phones are achieved and size constraint are also satisfied in the designs.

5.1 Folded edge Fractal PIFA for UMTS (3G) application

5.1.1 Design Considerations of proposed design

In this section antenna for 3G applications in mobile phone is discussed. The proposed antenna is planar inverted F type. The dimensions of proposed antenna are optimized for frequency of operation of UMTS 2100 standard. The dimensions are optimized for frequency of resonance of 1900 MHz. The design steps for proposed antenna are given as

Design Step 1: PIFA with rectangular patch

In planar inverted F antenna designs, the dimensions of metallic patch are considered λ/4. In the presented design, the PIFA with dimensions 14.94 mm X 16 mm is considered as shown in figure 5.1 (a).

Design Step 2: Single iteration of Sierpinski Carpet as patch of PIFA

The fractal antennas are used as small size antenna. So, the single iteration of sierpinski carpet fractal is used as patch of PIFA in design step 2 as shown in figure 5.1 (b).

Design Step 3: Second iteration of Sierpinski Carpet as patch of PIFA

In design step 3, second iteration of sierpinski carpet is used as patch as shown in figure 5.1 (c).

Design Step 4: Vertical folding of broader patch edge given in design step 3

To achieve further reduction in size of antenna, the broader edge of patch is folded in vertical direction as shown in figure 5.1 (d).

Design Step 5: Vertical folding of two patch edges given in design step 3

The small size proposed folded edges F-PIFA is obtained by folding another edge in vertical direction as shown in figure 5.1 (e).

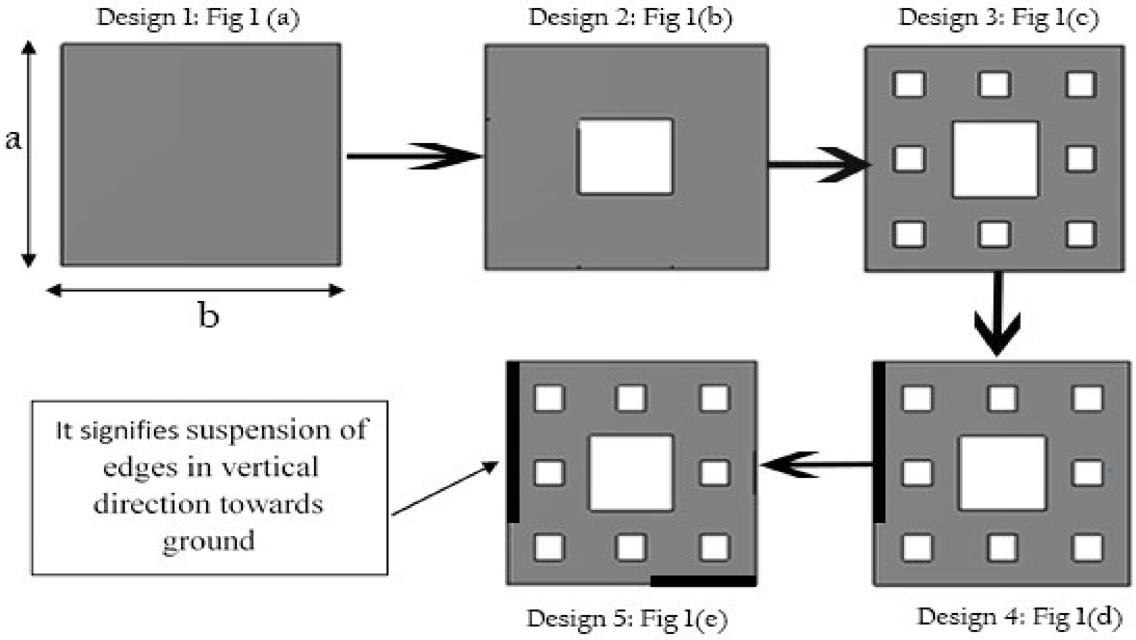


Figure 5.1: Design steps for folded edges F-PIFA

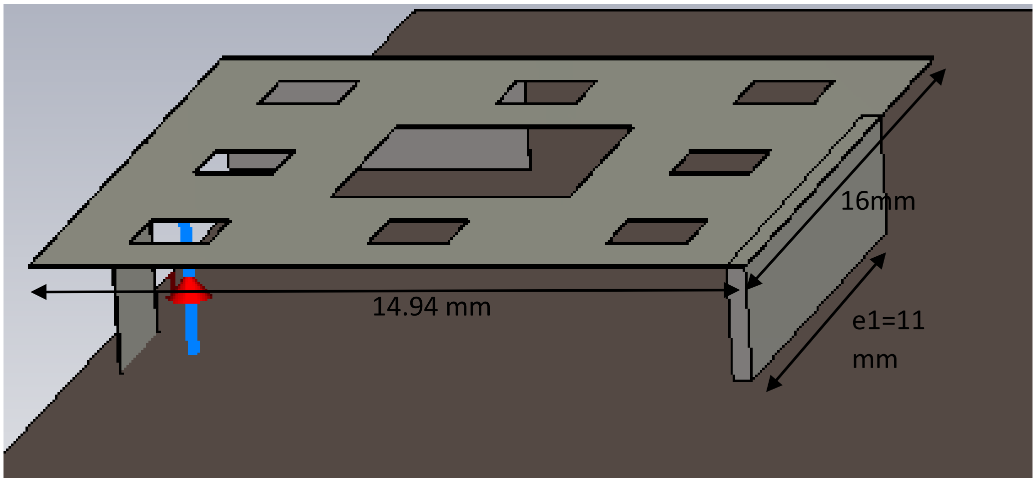


Figure 5.2: Folded edges Fractal PIFA for 3G applications

In figure 5.2, the 3D view of proposed folded edges fractal PIFA is shown. It is clear from the figure that the patch is shorted by metallic plate at one end and fed 2 mm away from the shorted plate. The feed location is optimized for 50 ohm impedance matching and specified gain requirements. The dimensions of folded edges are optimized for required bandwidth and size of the antenna as parameters. In figure 5.3 the vertical view of antenna is shown. The antenna is kept on FR4 substrate of 25 mm X 25 mm. The size of ground plane is 25 mm X 25 mm also. The patch is kept 6.59 mm above the ground plane. The width of shorting plate is 4 mm. The novelty in design is the combination of folded edges and fractal shape for size reduction of antenna.

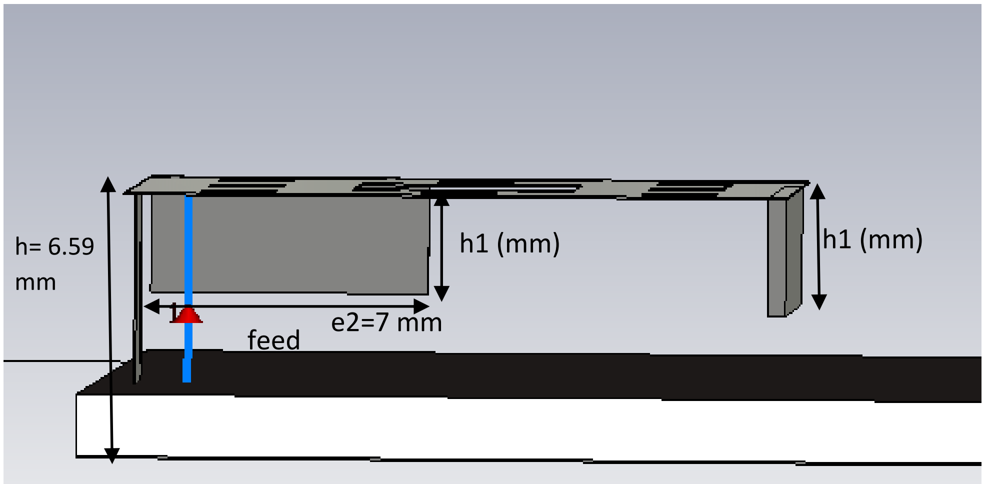


Figure 5.3: Side view of antenna

Figure 5.4 Fabrication of proposed antenna

The proposed antenna is fabricated in the lab and fabricated antenna is shown in figure 5.4. The folding of edges are optimized for compromise of bandwidth and size of antenna. The bandwidth of proposed antenna is function of dimensions of patch and folded sides.

$$BW=f(a+b, e1, e2, h1, h)$$

In figure 5.5, the graph between dimensions of patch (a+b), dimensions of folded edges (e1) and bandwidth is shown. The graph depicts that bandwidth of the antenna is inversely proportional to dimensions of folded edges. The bandwidth is reduced to the fact that the height of radiating extended edges over ground reduces. But, the fold of the edge helps reducing the size. So it is compromise between size and bandwidth. The optimum point is chosen on the graph for specified bandwidth of 270 MHz and dimensions of folded edges are decided. The dimension of broad edge fold is kept 11 mm X 3 mm and smaller edge fold are kept 7 mm X 3 mm. The overall dimension of patch is 14.94 mm X 16 mm.

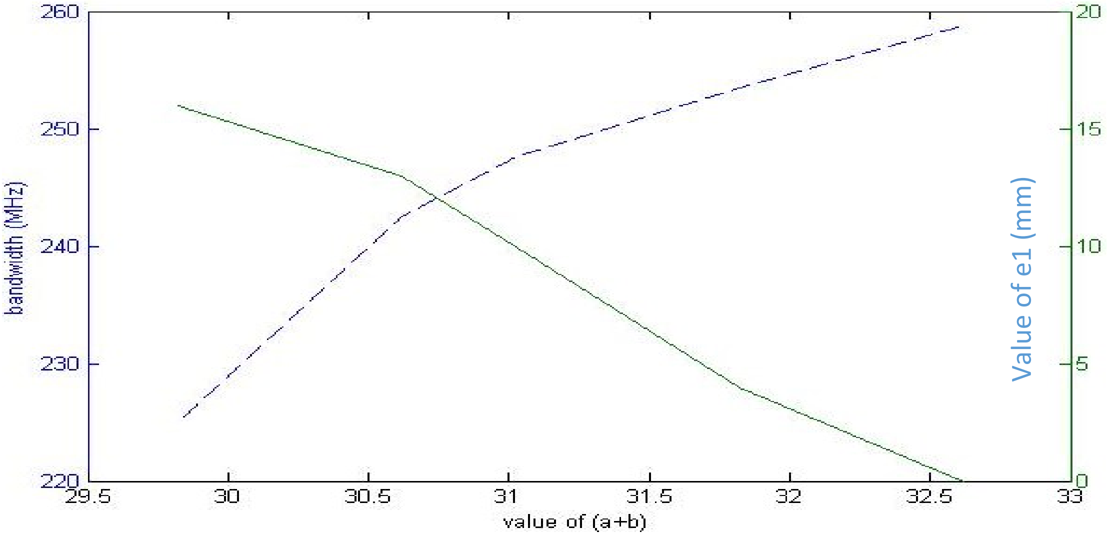


Figure 5.5: Bandwidth and Value of e1 (mm) versus value of (a+b) (dotted line is bandwidth versus value of (a+b) and solid line is value of e1 versus value of a+b)

5.1.2 Reflection Coefficient of proposed design

The return loss graph for different designs given in figure 5.1 is shown in figure 5.6. The resonant frequencies for different designs are listed in table 5.1. It is clear from the figure 5.6 that the use of fractal shape patch shifts the frequency of resonance on lower side. The frequency of resonance for design 3 is further reduced after increasing the iteration of fractal. Further size reduction of antenna is achieved by folding edges of the patch. The two edges are folded in design 5 and the frequency of resonance for design 5 is 1.9547 GHz. antenna resonates at the frequency 1880 MHz – 2150 MHz. It is defined as UMTS 2100 Band. The dimensions required otherwise with conventional design for the specified frequency can be calculated using equation 5.1.

$$a + b = \frac{(3 \text{ X } 108 \text{ m/sec})}{(4 \text{ X } 1.9 \text{ GHz})} = 39.474 \text{ mm}$$

The percentage of size reduction achieved with proposed method is calculated as

$$Size\ Reduction = \frac{39.474 - 30.94}{39.474}\ X\ 100 = 21.61\ \%$$

So as compare to rectangular patch PIFA, size reduction of 21.61 % is achieved with the proposed method.

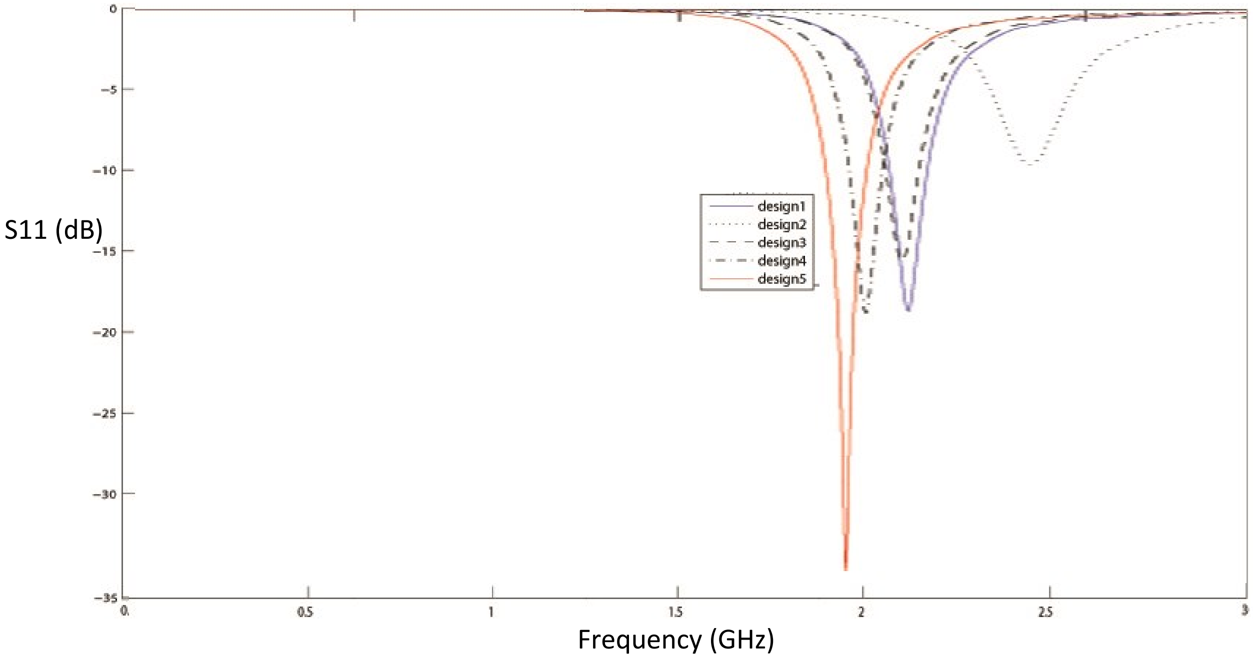


Figure 5.6: Return loss graph for different design steps described above

Table 5.1: Frequency of resonance for different designs described above

Design	**Frequency of Resonance (GHz)**
Design 1	2.4725
Design 2	2.1701
Design 3	2.1614
Design 4	2.0510
Design 5	1.9547

It is clear from the table that the frequency of resonance shifts towards lower frequency with each design step. It can be concluded that the size reduction is achieved with each design step. The overall size reduction of 21.61 % is obtained from final design in comparison to first step of design.

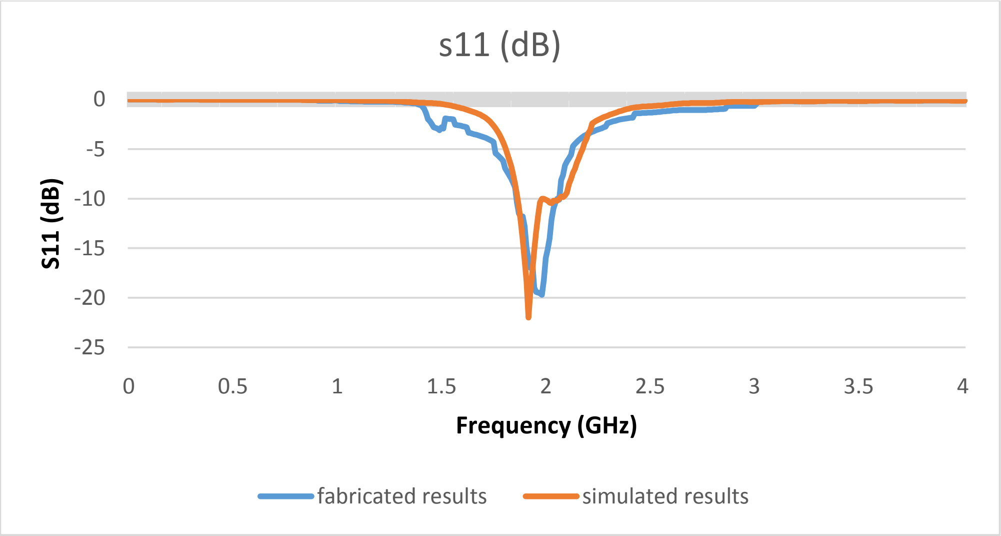


Figure 5.7: Comparison of simulated and measured results

The performance of fabricated antenna is tested and compared with the simulated results. The comparison of measured and fabricated results is shown in figure 5.7. The measured results show good agreement with the simulated results.

5.1.3 Radiation pattern of proposed design

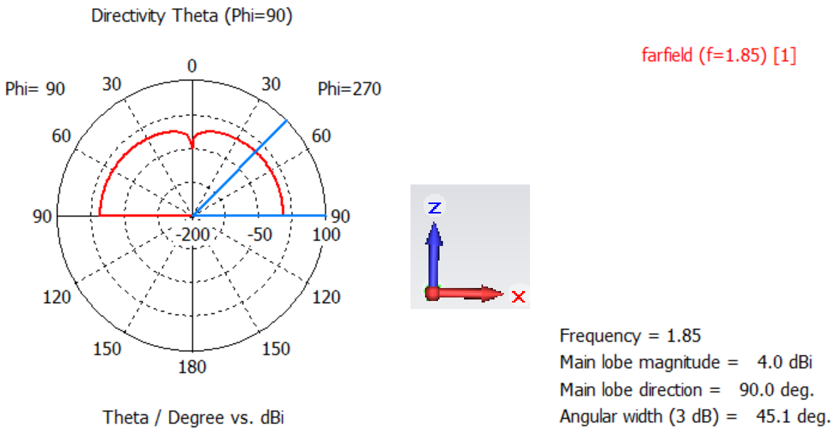


Figure 5.8: The radiation pattern for proposed antenna at 1.85 GHz.

The radiation pattern of proposed design is shown in figure 5.8. The radiation pattern shown in the figure is given for upper half only because the ground plane is considered as perfect electric conductor so inhibit radiation through it. The radiation pattern depicts that the proposed antenna performs good in terms of radiation gain as well. It can be concluded that the proposed folded edges F-PIFA is compact size candidate for 3G technology in mobile phones. The gain offered by the antenna is 4.0 dBI at given frequency which is in accordance to the specification of modern day handsets for 3G phones so can be considered as perfect candidate for third generation mobile phones.

5.2: Small size Folded edge fractal PIFA for WiFi/LTE/WiMAX/ WLAN application

5.2.1: Introduction

In this section, small size multiband folded edge F-PIFA is discussed for WiFi/LTE/WiMAX/WLAN applications in mobile phone. The size reduction is achieved using folded edge concept and using fractal shaped patch same as in section 5.1. In this era or heterogeneous network mobile phones are equipped with multiple technologies. In the section 5.1, the small size antennas for 3G technology is discussed. In this section antenna for WiFi/LTE/WiMAX/WLAN is proposed. Further the antenna resonances are configurable and by changing the parameters of folded edges the operating frequency can be configured.

5.2.2: Design Consideration

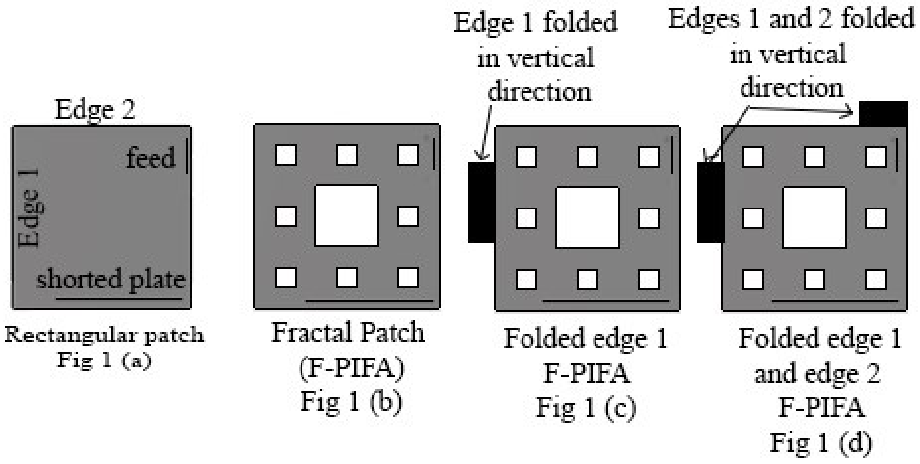


Figure 5.9: Design steps for proposed design

In figure 5.9, the design steps of proposed antenna are shown. In the first step a conventional rectangular patch planar inverted F antenna is designed which is followed by the fractal patch planar inverted F antenna. In third step edge 1 is folded in vertical direction to achieve size reduction of the antenna and finally the fractal PIFA with edge 1 and edge 2 folded in vertical direction are proposed.

The overall dimension of patch for proposed antenna is 19.8 mm X 19.8 mm. The patch shape is having sierpinski carpet fractal. Two of the edges are folded in the vertical direction as shown in figure 5.9. The dimensions of ground plane are 35 mm X 35 mm. The different parameters of proposed design are listed in table 5.2. The dimensions of folded edges are Z1 X H mm^2 and Z2 X H mm^2. The patch is kept at 6.5 mm height from the ground. The shorting plate has 14 mm width. The dimensions of the proposed design are according to standard size of the mobiles these days.

Table 5.2: The parameters of proposed design

Sr No	Parameter	Significance	value
1	L	Length of the substrate and ground plane	35 mm
2	W	Width of the substrate and ground plane	35 mm
3	l	Length of the patch	19.8 mm
4	w	Width of the patch	19.8 mm
5	h	Height of the patch over ground plane	6.5 mm
6	Z1	The width of the folding of side 2	8 mm
7	Z2	The width of the folding of side 1	5 mm
8	H	The height of folded side 1 and side 2 edge	4.5 mm
9	sw	width of the shorting plate	14mm
10	fw	Width of the feed plate	4 mm
11	hw	Height of the feed plate	5.5 mm
12	fl	Frequency of resonance for Lower band	2.25-2.863 GHz
13	fh	Frequency of resonance for higher band	4.81-6.21 GHz

In figure 5.10, differnet views of proposed antenan is shown. The fabrication of the propsoed design is shown in figrue 5.11. The size of fabricated antenna is compared with average size mobile phone these days. The antenna is proposed for WiFi, WiMAX, LTE and WLAN standards.

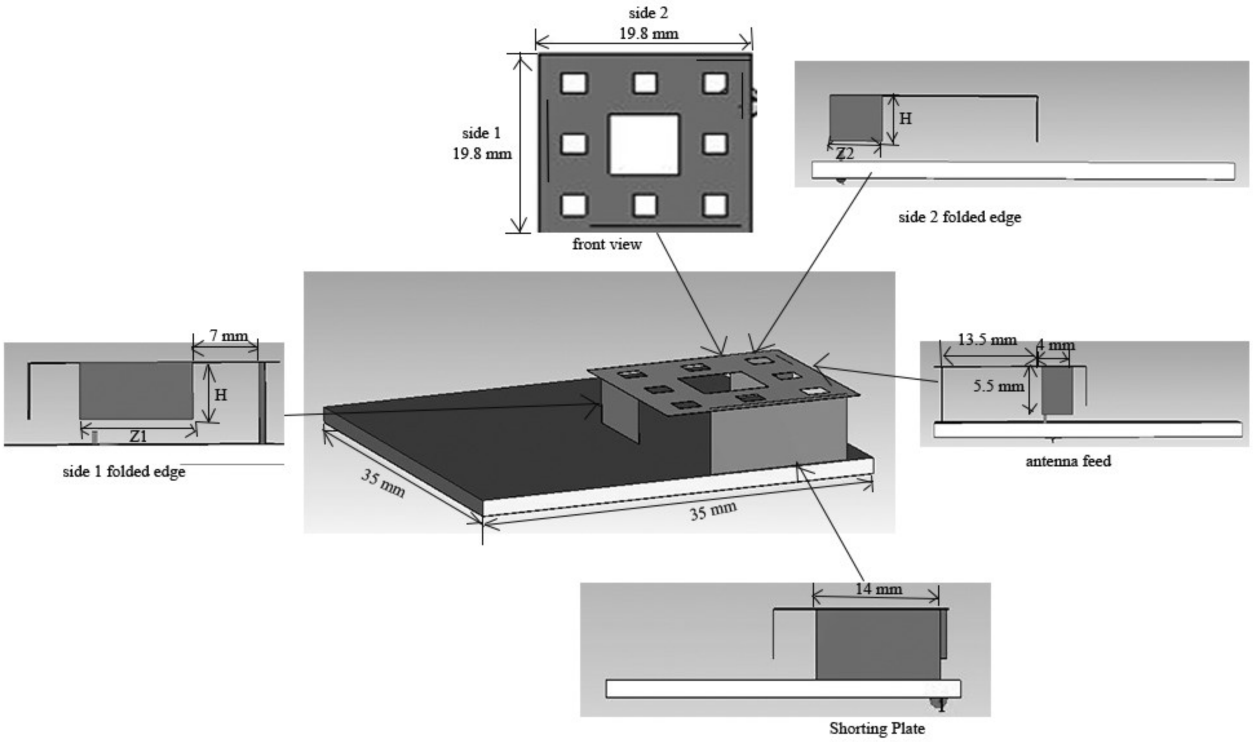


Figure 5.10: Different views of proposed antenna

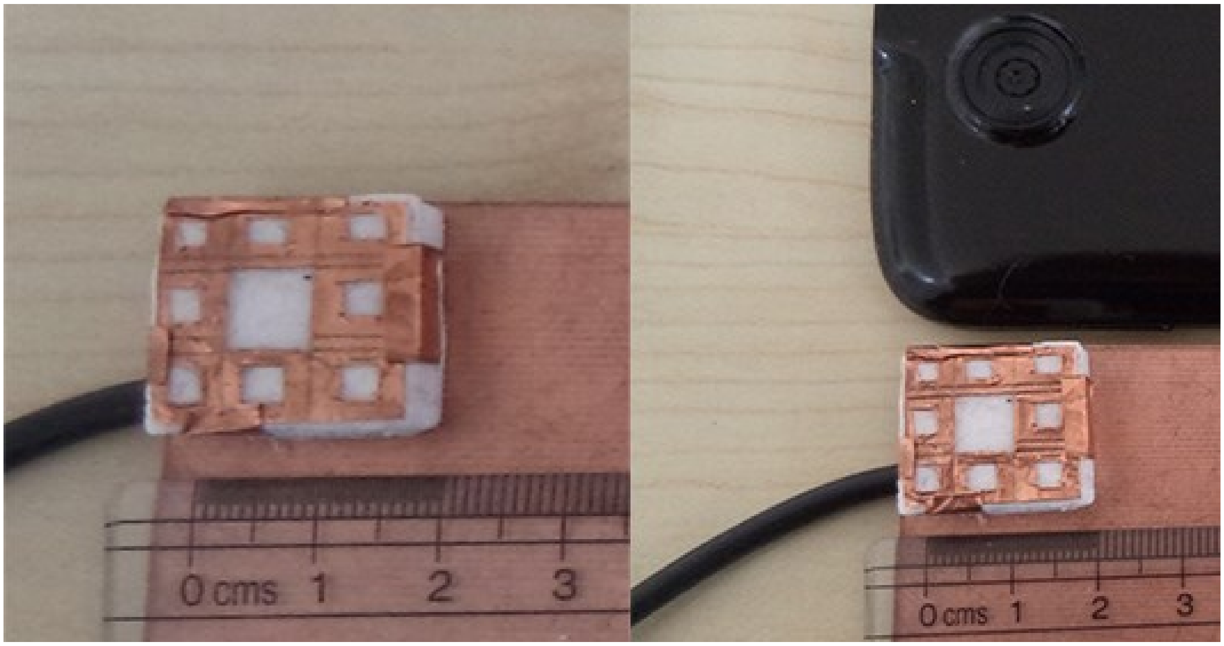


Figure 5.11: The fabrication of proposed multiband folded edge F-PIFA.

5.2.3: Results and discussion

The return losss graph for different designs given in figure 5.9 are given in figure 5.13. It is clear from the graph that the frequency of resonances shifts towards the lower frequencyas the fractal concept is introduced and further when edges are folded.

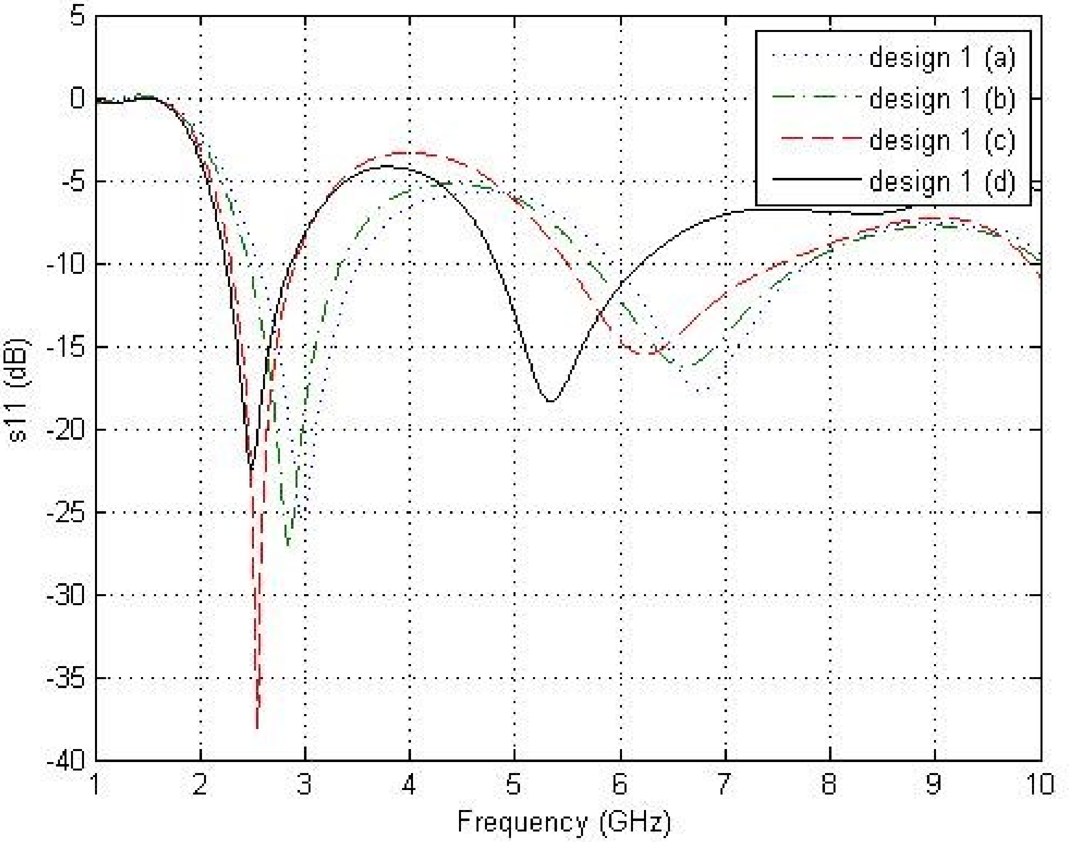


Figure 5.12: S11 (dB) versus frequency graph for different design steps

Parameteric study of variation of side 1 folded edge

In figure 5.13, the parameteric effect of Z1 on return loss is shown. It is clear from the figure that the effect of variation in Z1 has effect at lower frequency band. The increase in Z1 results in shift of frequency graph to left side i.e. the lower frequency of resonance decreases with increase in value of Z1. So, the lower band can be adjusted by change in dimensions of edge 1. The value of Z1 in the proposed design is considered as 8 mm X 4.5 mm.

Parameteric study of variation of side 2 folded edge

In figure 5.14, the parameteric effect of Z2 on return loss is shown. It is clear from the figure that the effect of variation in Z2 has effect at higher frequency band. The increase in Z2 results in shift of frequency graph to left side i.e. the higher frequency of resonance decreases with increase in value of Z2. So, the higher band can be adjusted by change in dimension of edge 2. The final value of Z2 in proposed design is considered as 5 mm X 4.5 mm.

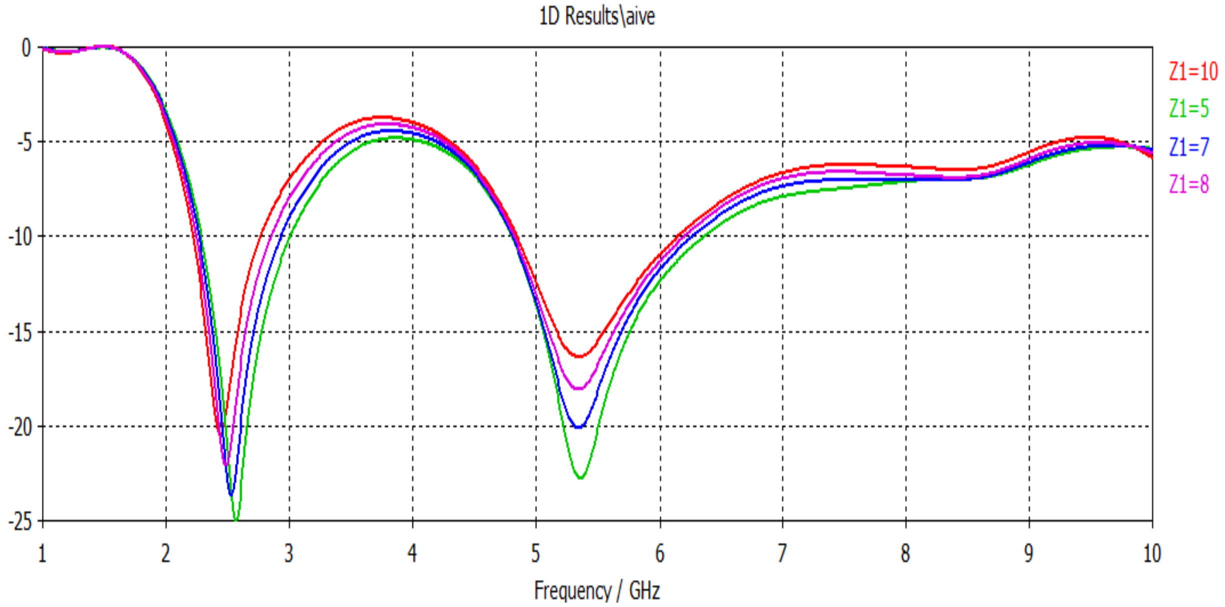


Figure 5.13: The parametric variation of width of side 1 folded edge (Z1)

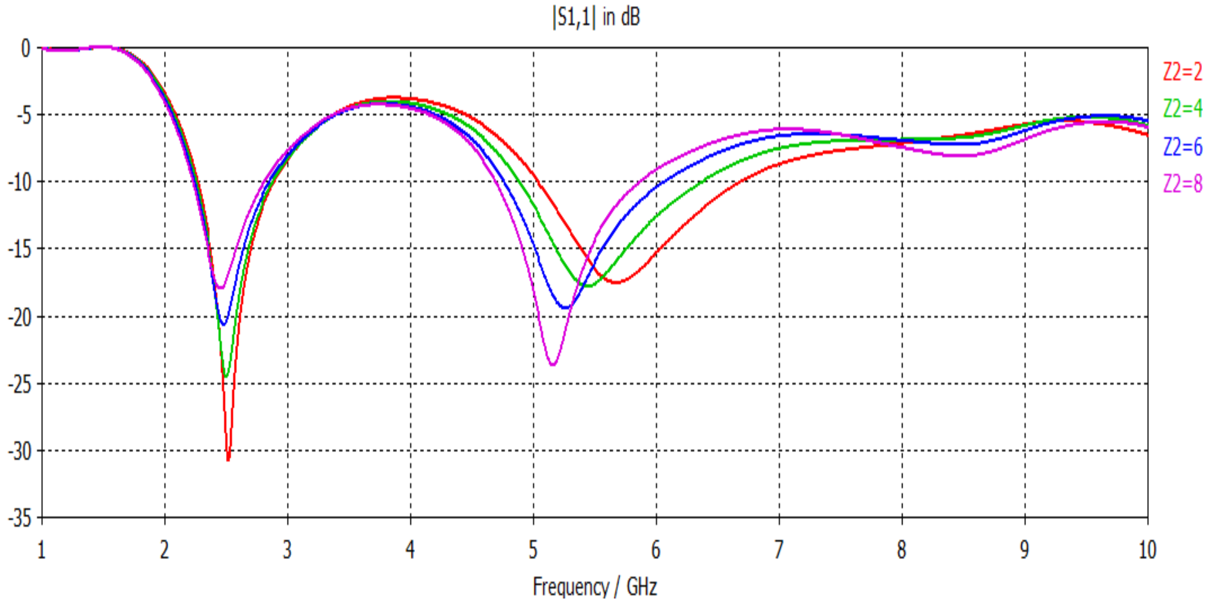


Figure 5.14: The parametric variation of width of side 2 folded edge (Z2)

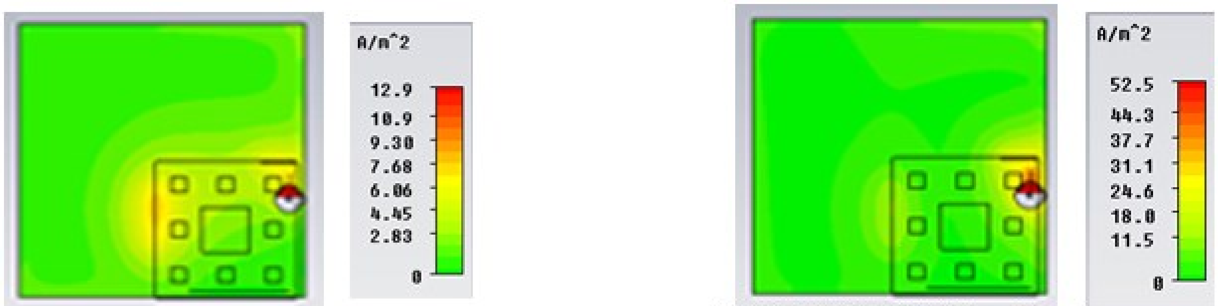
The current density on proposed antenna at 2.5 GHz and 5.3 GHz is shown in figure 5.15. It is sufficient to describe current density for defining reason of reconfigurability of lower and upper frequency band with change in dimensions of folded edges. The proposed antenna can be made reconfigurable as the lower frequency band can be reconfigure by varying value of Z1 and the higher band can be made reconfigured by varying value of Z2.

Current density on proposed antenna

The current density at 2.5 GHz describes that the current path is through the edge 1 for lower frequency band. So changing dimensions of edge 1 changes the length traversed by current at lower frequency of resonance. The concept makes lower frequency band dependent on dimensions of folded edge 1. The current density at 5.3 GHz describes that the current path traversed at the frequency is through edge 2. This is the reason that the frequency of resonance at upper band is dependent on dimensions of edge 2.

At f=2.5 GHz

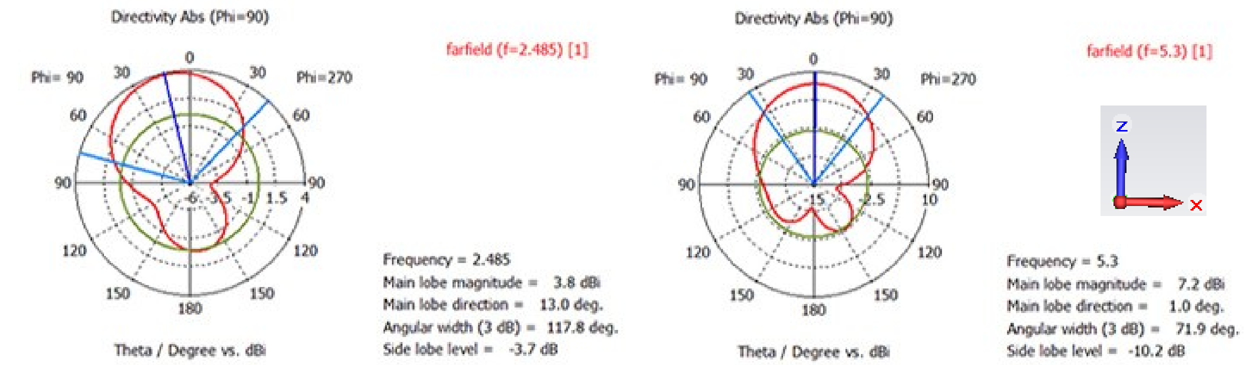
At f= 5.3 GHz



At f=2.5 GHz (CST Simution)

At f=5.3 GHz (CST Simulation)

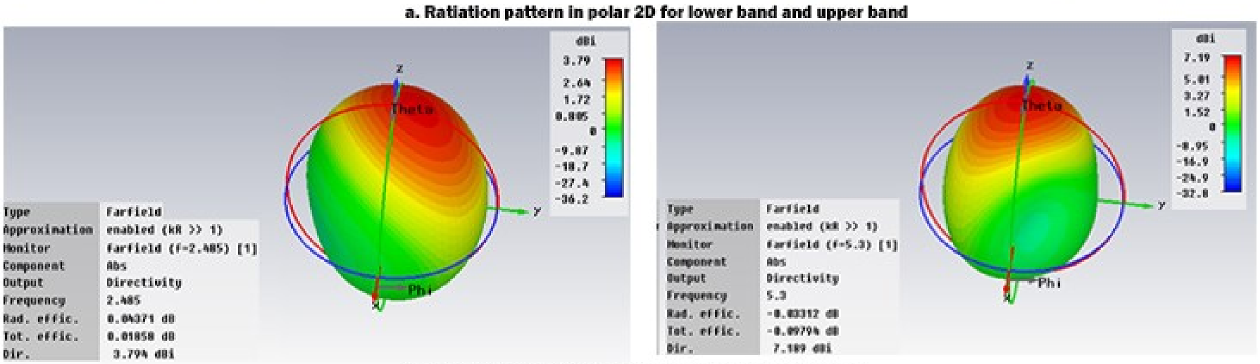
Figure 5.15: The current distribution on proposed antenna at 2.5 GHz and 5.3 GHz.



Frequency = 2.485
Main lobe magnitude = 3.8 dBi
Main lobe direction = 13.0 deg.
Angular width (3 dB) = 117.8 deg.
Side lobe level = -3.7 dB

Frequency = 5.3
Main lobe magnitude = 7.2 dBi
Main lobe direction = 1.0 deg.
Angular width (3 dB) = 71.9 deg.
Side lobe level = -10.2 dB

a. Ratiation pattern in polar 2D for lower band and upper band



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.485) [1]
Component	Abs
Output	Directivity
Frequency	2.485
Rad. effic.	0.04371 dB
Tot. effic.	0.01858 dB
Dir.	3.794 dBi

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.3) [1]
Component	Abs
Output	Directivity
Frequency	5.3
Rad. effic.	-0.03312 dB
Tot. effic.	-0.09794 dB
Dir.	7.189 dBi

b. Radiation pattern in 3D for lower band and upper band

Figure 5.16: The radiation pattern of proposed antenna

In figure 5.16, the radiation pattern for proposed antenna at lower and upper frequency is shown. The proposed antenna has gain of 3.8 dBi at lower frequency band and offers gain of 7.2 dBi at higher frequency band.

Figure 5.17: The measurement of return l\oss for propose design using VNA

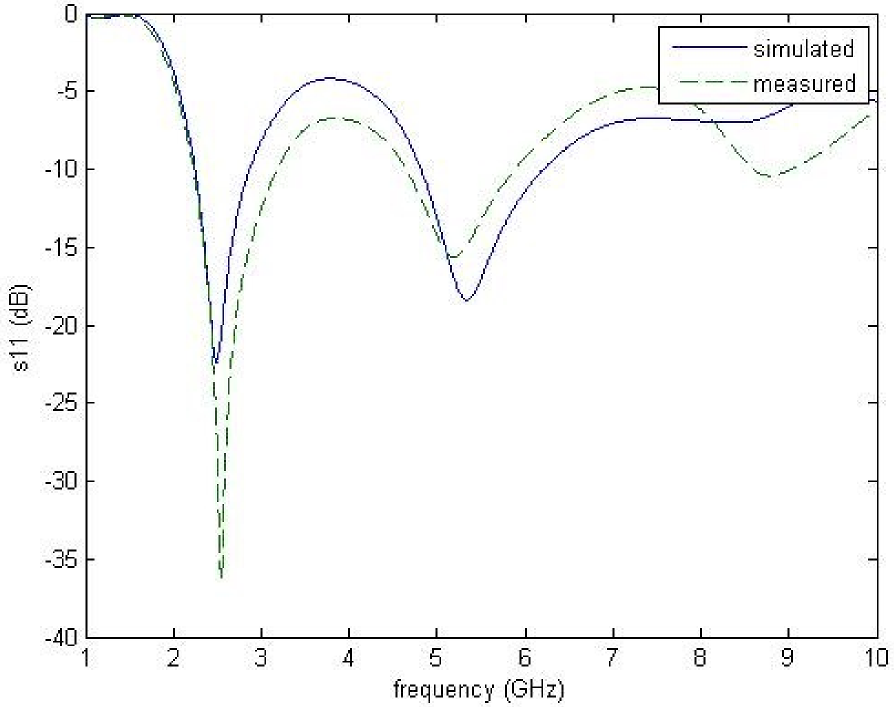


Figure 5.18: The comparison of simulated and measured results

The performance measurement of fabricated antenna is shown in figure 5.17. In figure 5.18, the comparison of simulated and measured result is shown. The proposed antenna covers bands of 2.25 GHz- 2.863 (613 MHz bandwidth) GHz and 4.81 GHz-6.21 GHz (1400 MHz bandwidth) with high gain. So the proposed design is suitable to use in mobile phones for WiFi/WiMAX/LTE/WLAN technologies.

5.3: Small size MIMO-PIFA antenna for LTE/4G/WiFi

5.3.1: Introduction

The 4th generation mobile phones are introduced recently in Asia continent for its advantages of high data rate and QoS support to multimedia services. The 4G technology in Asia operates at frequency range 2.3-2.4 GHz. Since antenna dimensions are frequency dependent and the frequency of operation is defined for 4G. The size reduction of antenna is bottleneck in size reduction of 4G mobile handsets. The MIMO is part of 4G technology which enables achieving high data rates. According to Shanon's capacity theorem, the data rate can be increased by increasing the bandwidth but the bandwidth is limited because of unavailability of spectrum further. So MIMO systems proved to be best choice for increase in data rate of modern day wireless devices. In this section planar MIMO-PIFA antenna is proposed. The challenge in design of planar MIMO antennas is to reduce the correlation between the antennas radiation on planar surface. The planar antenna suffers with surface wave propagation which results in decrease of correlation between two antennas. In the presented design, the MIMO operation is achieved by keeping the two antennas at different heights. So, the effect of surface wave propagation can be minimized. The proposed antenna has two L- shaped conducting patches with square slots as shown in figure 5.19.

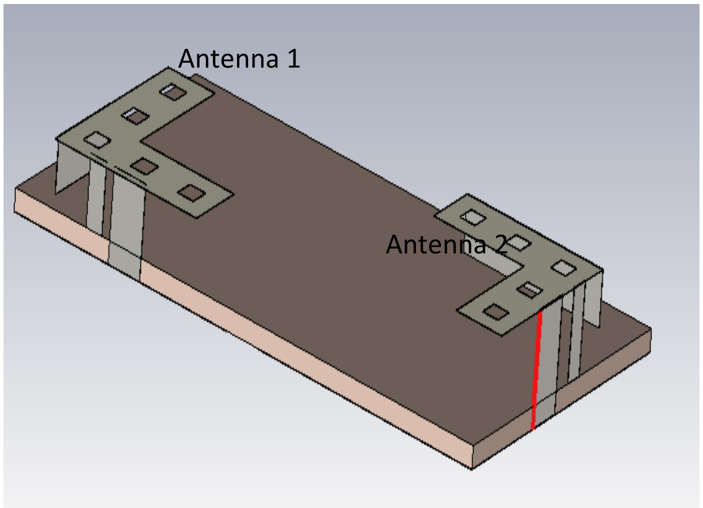


Figure 5.19: Proposed small size MIMO-PIFA antenna for LTE/4G/WiFi applications

5.3.2: Design consideration

The L-shaped patch is used in the antenna element of proposed design. Two such elements are considered for MIMO operation. The channel capacity and correlation between the antenna elements are inversely proportional to each other. To reduce the correlation between antenna elements, L shaped patch is chosen. The correlation due to surface wave propagation is reduced by considering both antenna elements at different heights. The dimensions of the antenna element used in proposed design are shown in figure 5.20. In figure 5.21, the different prospective views are shown. The overall dimension of the proposed antenna element is 18 mm X 19.9 mm. The square slots of 2 mm X 2 mm are cut in L-shaped patch. The overall dimensions of MIMO antenna design is 31 mm X 49 mm.

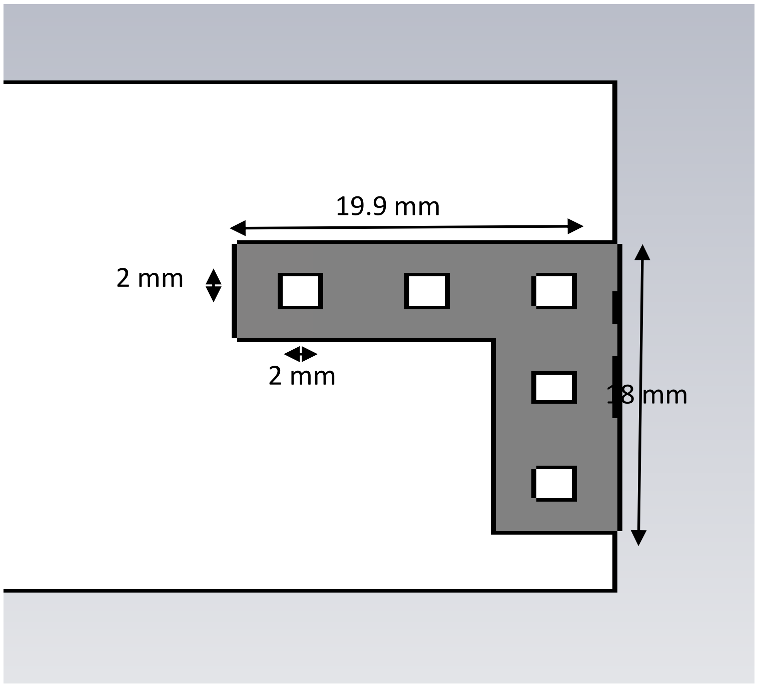


Figure 5.20: Cross sectional view of single antenna element

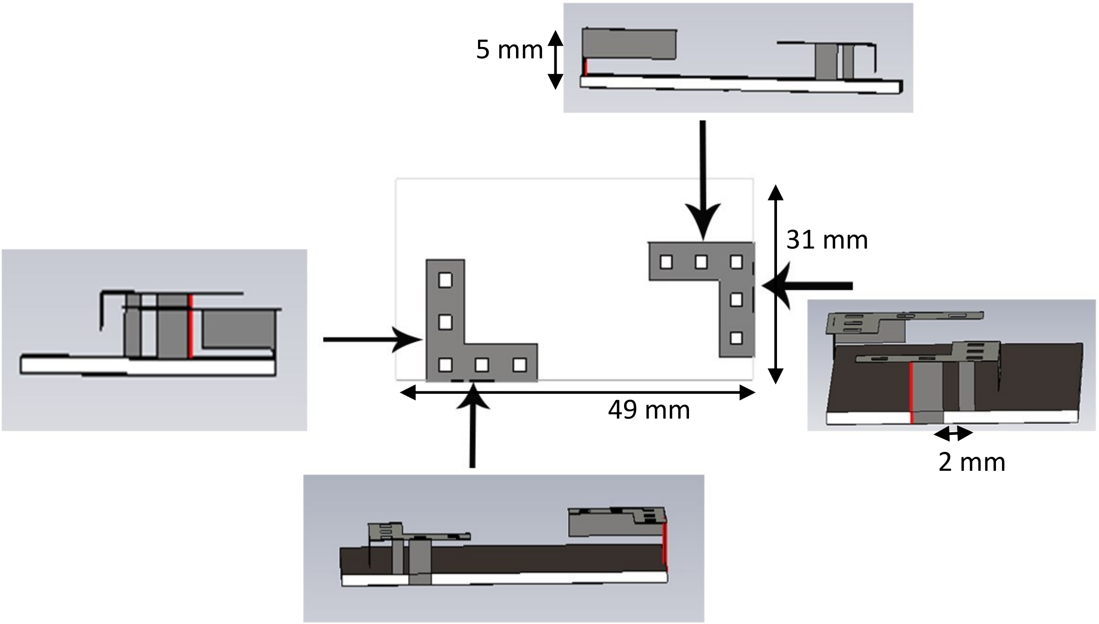


Figure 5.21: Different prospective views of proposed antenna and detailed dimensions of antenna

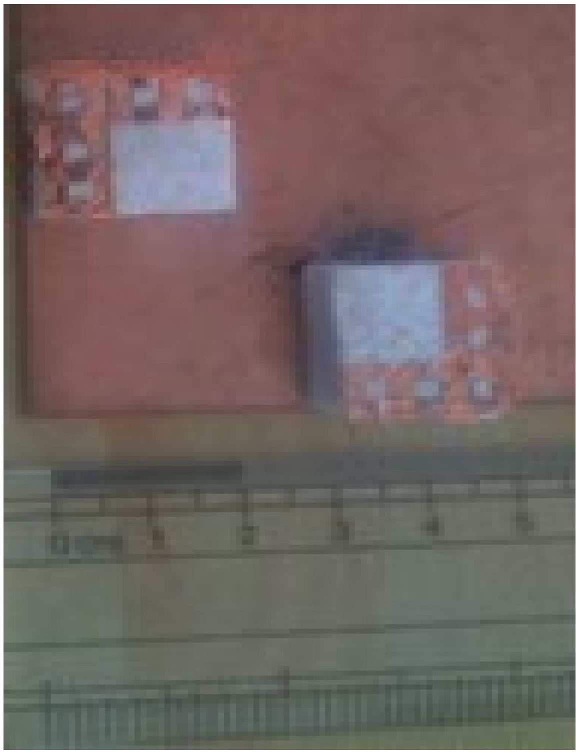


Figure 5.22: Fabrication of proposed antenna

The patch of the antenna is folded in vertical direction to reduce the size of antenna element. The patch is shorted at one end and the feed is kept 2 mm away from the shorted plate. The spacing proposed here are considered as standards for general mobile handsets. The two elements of antenna are kept at different heights. The height of antenna element is kept 5 mm and the height of other antenna element is considered 6.5 mm. The two antenna elements in the proposed design are kept at 46 mm distance from each other. The dimensions of folded edge are 9.05 mm X 4 mm.

5.3.3: Results and Discussion

The fabricated antenna is shown in figure 5.22. The results are measured for fabricated antennas. The measured and simulated S11 and S21 for the proposed antenna design are given in figure 5.23. The impedance bandwidth corresponds to -10 dB reflection coefficient and S21 correlates radiation from two antenna elements. As it can be seen from the figure 5.23 that the proposed antenna impedance matches well in frequency range 2.3 GHz – 2.5 GHz. The LTE operates at frequency 2.3 GHz and MIMO operation is well supported by the proposed antenna. In order to study correlation between the two antenna elements envelope correlation coefficient (ECC) is calculated and presented.

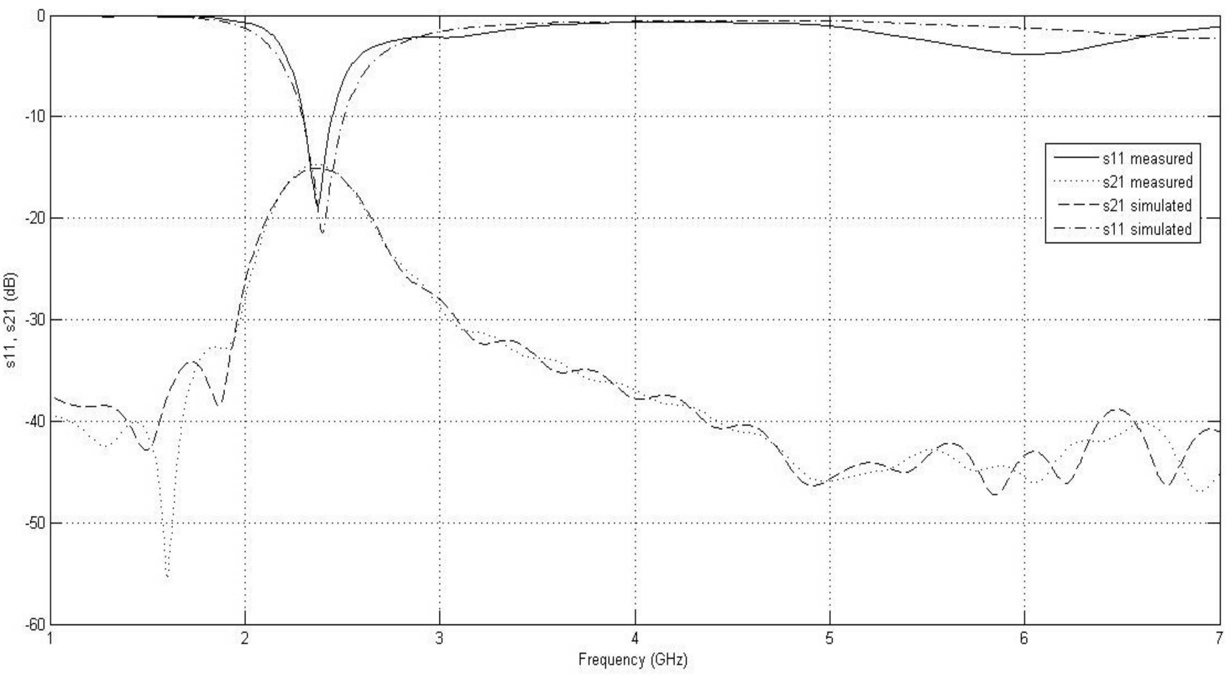


Figure 5.23: The simulated and measured S11 (dB) and S21 (dB) of proposed design

The correlation coefficient can be calculated from the formula of equation 5.2

$$ECC = \frac{|s11^{*}s12+s22^{*}s21|^{2}}{(1-|s11|^{2}-|s21|^{2})(1-|s22|^{2}-|s12|^{2})} \qquad \text{Eq. 5.2}$$

Here S11 is return loss and S21 is known as isolation loss. The ECC is acronym for envelope correlation coefficient. The channel capacity is inversely proportional to the value of ECC. The graph between ECC versus frequency is shown in figure 5.24. The value of ECC lies in acceptable limit for frequency range of LTE standard. The antenna is suitable for 4G mobile handsets as it supports MIMO operation at 2.3-2.5 GHz and offers symmeteric along x-axis radiation pattern at desired frequency range as shown in figure 5.25. The radiation pattern of proposed antenna is shown in figure 5.25. The proposed antenna offers gain of 4.06 dBi at the specified frequency band. The novelty of design is compactness of the design and less correlation. The compactness of the design is due to the fact that the patch is folded and square slot results in increased effective length of the antenna element. The size of the antenna is according to standard sizes of modern day mobile phones. The support to MIMO operation of proposed antenna enables high data rate application support. Hence antenna is best suited for modern day standard of LTE 2300.

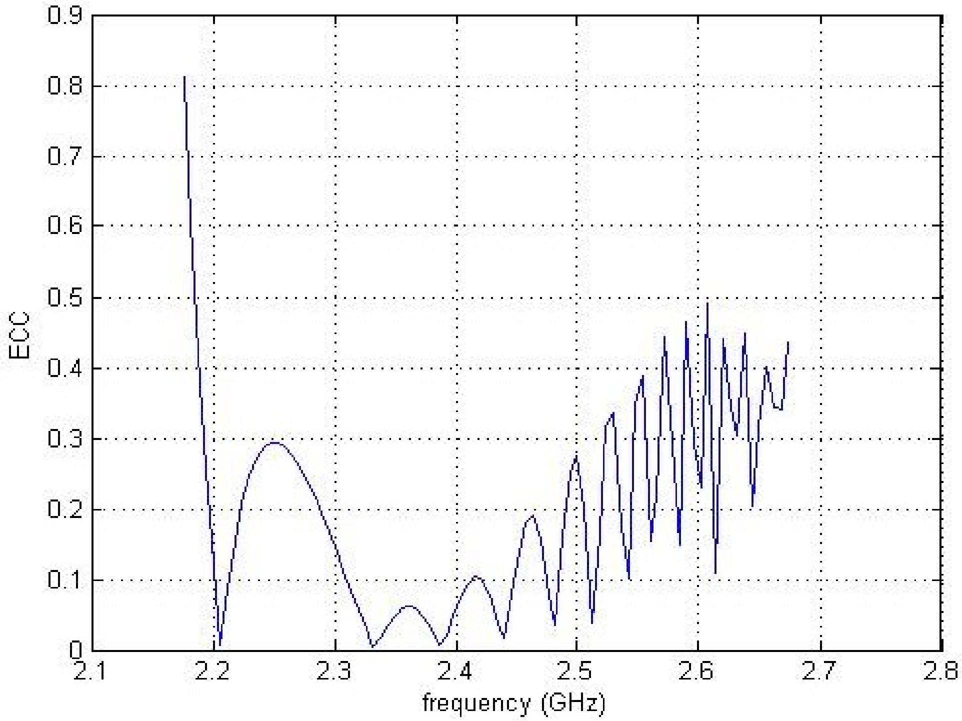


Figure 5.24: The ECC versus frequency graph for proposed design

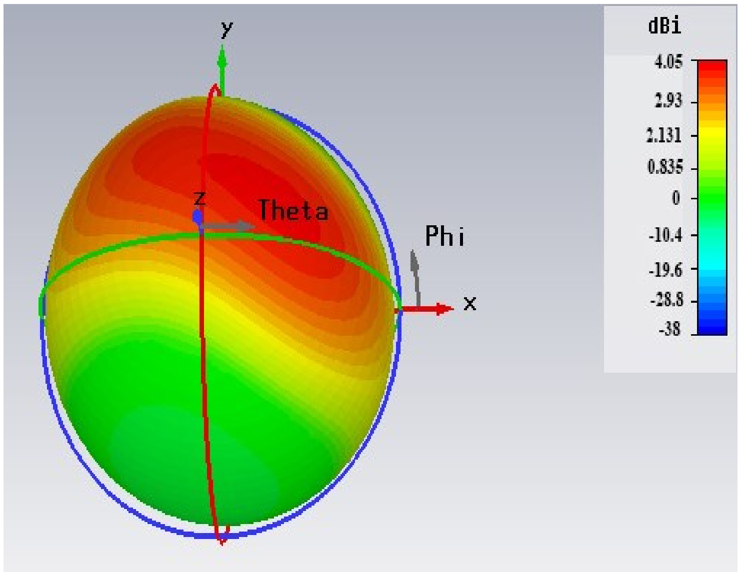


Figure 5.25: The 3D radiation pattern of proposed design

5.4 Summary of the chapter

In this chapter the PIFA antennas for modern day applications are presented. The small size PIFA for 3G mobile phone is proposed. The fractal shaped patch is proposed for size reduction of antenna. Further, the proposed PIFA patch is folded at two edges to achieve size reduction further. In comparison to conventional rectangular PIFA, The size reduction of 21.61 % is achieved with proposed design. The overall dimension of proposed PIFA is 14.94 X 16 X 6.59 mm. The proposed antenna supports frequency band 1880 MHz – 2150 MHz. It is defined as UMTS 2100 Band. Further, the fractal PIFA is proposed to work for dual wide bands. The patch is folded to achieve size reduction. The overall dimension of PIFA is 19.8 mm X 19.8 mm X 6.5 mm. The proposed antenna covers bands of 2.25 GHz- 2.863 (613 MHz bandwidth) GHz and 4.81 GHz-6.21 GHz (1400 MHz bandwidth) with gain of 3.8 and 7.2 dBi respectively. The MIMO concept is introduced to PIFA for high data rate support of antenna. The proposed MIMO antenna has two L-shaped PIFA. The overall dimension of proposed antenna is 49 mm X 31 mm. The antenna can operate at 2.3 GHz – 2.5 GHz. The measured results agree with simulated results, hence can be put in use for practical applications.

Chapter 6

Conclusions and Future Scope

6.1 Conclusions

In this thesis, the requirements of antennas for next generation wireless systems are discussed and achieved. The antenna is considered as important part of wireless systems. The next generation wireless systems require support to multiband operation and wide bandwidth support. With advancements in VLSI the size are scaled to an extent but the antenna size has proved bottleneck to size reduction of wireless devices. In the thesis, designs with desired performance criteria are targeted. The antennas discussed in the thesis are well suited for next generation wireless systems.

In this era the new technology evolves so fast that everyday improved technology is introduced. It is quite impractical to change the wireless devices every-day. So the next generation wireless systems require support to heterogeneous technologies. The WiFi, WiMAX, LTE, UMTS are the major popular technologies of this era. Due to size constraint of next generation wireless systems, it is difficult to embed multiple antennas in single wireless system. The support of wireless systems to multiband operation need single antenna to be resonant at multiple bands.

The next generation wireless systems are known for its support to multimedia applications like video conferencing, VoIP, Video transfer, Broadband internet and high data rate transfer etc. The high data rate applications require antenna to support larger bandwidth. The broadband antennas are also termed as frequency independent antennas. According to Rumsey's principle, if dimensions of antenna are angle dependent, it is considered as frequency independent antennas. The various shapes follow the Rumsey's principle. The fractal shape follows the Rumsey's principle so can be considered as broadband antennas.

So the requirement of antennas for next generation wireless device can be summarized as small size, broadband and multiband support. Like modern day wireless systems antennas has gone through tremendous changes as well. The microstrip patch antennas have completely replaced wire antenna in modern day wireless systems. The microstrip patch antennas are conformal, planar and small size antennas. The MPA has an additional advantages such as ease of integration to device PCBs and ease of fabrication etc.

The thesis begin with discussion about history of wireless communication followed by the explanation of different type of antennas. The need of next generation wireless devices are discussed. The literature review is carried out differently for multiband, broadband and small size antennas. In literature vast number of articles discuss multiband and broadband antennas. In this thesis the constraints are taken care for next generation wireless devices. The specification of next generation wireless systems are met with different designs of microstrip patch antennas. The microstrip patch antenna consist of substrate, patch and ground plane. The patch can have various shapes like circular, rectangular, triangular and polygon etc.

In the first type of design, the simple square patch antenna is analyzed with different type of feeds. It is seen that the simple MPA resonate at the single frequency and TM01 mode resonance is considered as efficient radiation. The second type of designs consider multiband operation of MPA. The multiband is achieve by slot cut in patch of MPA. The slot can result in extra resonance of microstrip patch antenna. The dimensions and position of slot can be adjusted to achieve resonance at the specified frequency. The different type of fractals are also considered as planar antennas to achieve multiband operation of antenna. The sierpinski carpet antenna is discussed as multiband antenna. The problem in sierpinski carpet antenna suffers with problem of impedance match if feed at edge of sierpinski carpet. The return loss graph is discussed for each design because the return loss describes the level of impedance matching at various frequencies. The Sierpinski carpet is proposed for quad band operations. The current density on sierpinski carpet for various frequency is also presented. The gain at various frequency describes the dipole like radiation pattern at 1.76 GHz and 5.3 GHz, while the radiation pattern at 3.27 and 6.66 GHz contains side lobes. Further another type of fractal i.e. sierpinski gasket design is given. The sierpinski carpet antenna suffers with discontinuity in conduction at nodes of different triangles. The solution to this problem of sierpinski gasket is given in the thesis. The CPW feed with slanted ground plane is proposed for uniform conduction at every part of fractal. The CPW fed multiband sierpinski gasket design is presented in thesis for quad band operation. The antenna resonates at 1.57 GHz, 4.31 GHz, 5.31 GHz and 7.37 GHz. The antenna can be utilized for DCS, UMTS, LTE, WLAN and PCS applications. The current density of proposed design at various frequencies proves the multiband nature of fractal shapes. The difference between conventional sierpinski gasket with proposed CPW fed sierpinski gasket is given. . The antenna resonates at 1.77 GHz, 3.3 GHz, 5.34 GHz and 6.66 GHz. The radiation pattern of proposed antenna depicts that antenna can proved efficient at four band of frequency.

The broadband planar antenna is another area of study in the thesis. The effect of MPA parameters on bandwidth of antenna is considered. The gain bandwidth product is additional parameter that is considered for broadband antennas. The increase in bandwidth either increasing the substrate height or by decreasing the dielectric constant of substrate results in decreased gain of antenna. The hybrid fractal shapes are proposed as broadband antenna. The hybrid fractal is combination of sierpinski gasket and sierpinski carpet. The proposed sierpinski gasket and sierpinski carpet resonates at close frequencies results in merging of two bands. Further bandwidth enhancement is achieved by reduction of surface wave propagation using defected ground structure. The proposed defected ground structure hybrid fractal wideband antenna offers bandwidth of bandwidth of 616.5 MHz (2.0535 – 2.67 GHz) and 184.5 MHz (5.1755 –5.36 GHz) with gain 4 dBi and 8.8 dBi at the bands respectively. The sierpinski gasket has two operations in the proposed design. The sierpinski gasket antenna is considered as multiband resonator as well as the impedance transformer for feed at sierpinski carpet shape edge. The proposed design has notch at frequency 2.74 GHz. The antenna is useful for WiFi/WiMAX/LTE/UWB technologies. The antenna offers optimum gain for next generation wireless devices. So the proposed antenna can be considered as best candidate for next generation wireless systems.

Since the next generation wireless system requires small size of the antennas, the size reduction of PIFA is discussed. The fractal shaped PIFA is introduced for 3G application. The size reduction of 21.61 % is obtained by folding patch in vertical direction. The designed antenna is fabricated and tested. The measured and simulated results shows good agreement. The overall dimension of proposed PIFA is 14.94 X 16 X 6.59 mm. The proposed antenna supports frequency band 1880 MHz – 2150 MHz. It is defined as UMTS 2100 Band. Followed by the PIFA for 3G, the folded edge-F-PIFA is proposed for multiband operation. The proposed design has advantages of small size and support to multiband operation. The multiband operations are wide enough to support high data rate multimedia application in next generation wireless systems. The overall dimension of PIFA is 19.8 mm X 19.8 mm X 6.5 mm. The proposed antenna covers bands of 2.25 GHz- 2.863

(613 MHz bandwidth) GHz and 4.81 GHz-6.21 GHz (1400 MHz bandwidth) with gain of 3.8 and 7.2 dBi respectively. The antenna is fabricated in the lab and tested. The proposed design is also the best candidate for the use in modern day wireless systems. The increase in data rate without increase in bandwidth can be obtained by using MIMO technique. The MIMO antenna on PIFA is proposed for use in recently introduce LTE technology. The MIMO is discussed for LTE 2300 standard. The decrease in correlation of antenna elements are obtained by using the antenna patch element at different heights to reduce surface wave excitation leakage. The proposed MIMO antenna has two L-shaped PIFA. The overall dimension of proposed antenna is 49 mm X 31 mm. The antenna can operate at 2.3 GHz – 2.5 GHz. The ECC value is calculated and analyzed for the proposed design. It is concluded that the antenna is best candidate for LTE technology devices. The antenna is fabricated and results from fabrication are compared with measured results. The good agreement between the measured and simulated results proves the concept of designs.

6.2 Future Scope

In the thesis various techniques are discussed to achieve multiband and broadband operation of antenna. In achieving multiband operation of antenna, the circular polarization can be achieved in desired frequency bands. In near future the re-configurable antenna may be put in use. Further the different type of polarization support for different frequency bands can also be targeted. In broadband operation of antenna the Dielectric resonator can also be used for bandwidth enhancement. The dielectric resonator though result in increased size of antenna, it can achieve enormous bandwidth support. Further the polarization bandwidth can also be considered along impedance bandwidth for broadband antennas. The circular polarization is always desirable can be further enhancement of the presented efficient small size antennas.

In design of PIFA type of antennas, active antenna elements can be involved to further enhance the performance of the antenna. The PIFA antennas presented in the thesis can be analyzed for the value of SAR. Although the designs presented in the thesis are sufficient in accordance with need of next generation wireless devices, further the design techniques for multiband MIMO support with high gain can be achieved. Since MIMO is considered as technology to further enhance the data rate, one design is considered in the thesis. The design can be made resonant at multiband along MIMO support. The size reduction can further be achieved and gain enhancement can be obtained by using Electromagnetic band-gap (EBG) structures.

The work can be taken to multiband and broadband planar antenna arrays. The hybrid fractal concept can further be considered for design of PIFA antennas. The work can be considered for the further study of antenna arrays. The travelling wave antenna approach can be utilized for broadband and multiband planar antennas as well.

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List of Publications

SCI Publications

Published and Accepted

- Nitin Saluja, Rajesh Khanna, “Design, analysis and fabrication of a novel multi band folded edge compact size fractal PIFA for WiFi/LTE/WiMAX/ WLAN application” Microwave and optical technology letters, Volume 56, Issue 12, pp: 2836-2841, 2014.
- Nitin Saluja, Rajesh Khanna, “Design analysis and fabrication of novel CPW fed hybrid fractal based Broadband antenna”, International Journal of Microwave and Wireless Technologies, Volume 5, Issue 6, pp:749-752, 2013.
- Nitin Saluja, Rajesh Khanna, “A novel method to improve current density in multiband triangular fractal antenna”, Elektronika ir Elektrotechnika, Volume 10, Issue 126, pp: 41-44, 2012.

Communicated

- Nitin Saluja, Rajesh Khanna, “A novel extended edge based compact PIFA antenna for mobile devices” International journal for light and electron optics.
- Nitin Saluja, Rajesh Khanna, “A novel small size MIMO-PIFA Antenna for LTE/4G/WiFi in mobile phones”, Wireless Personal Communications (springer).