

**INVESTIGATIONS ON FRACTAL ANTENNAS FOR WLAN,
WIMAX, UWB AND MOBILE APPLICATIONS**

A Thesis Submitted in Partial Fulfillment of Requirements for the Award of Degree of

**MASTER OF ENGINEERING
IN
WIRELESS COMMUNICATIONS**

Submitted by

KAMALJIT KAUR

Roll No. 801363016

Under guidance of

Mrs. AMANPREET KAUR

Assistant Professor, ECED

T.U,Patiala



Electronics and Communication Engineering Department

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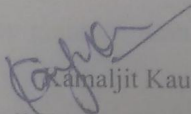
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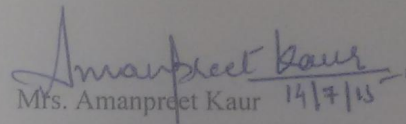
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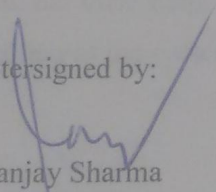

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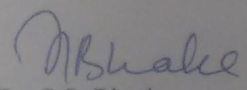
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Mrs. Amanpreet Kaur 14/7/15
Assistant Professor, ECED,
Thapar University,
Patiala-147004(Punjab)

Countersigned by:


Dr. Sanjay Sharma
Head of Department
ECED, Thapar University, Patiala

Date: 14/07/2015


Dr. S.S. Bhatia
Dean of Academic Affairs
Thapar University, Patiala
Date: 14/07/2015

ACKNOWLEDGEMENT

To discover, analyze and to present something new is to venture on an untrodden path towards and unexplained destination is an arduous adventure unless one gets a true torchbearer to show the way. I would have never succeeded in completing my task without the cooperation, encouragement and help provided to me by various people. Words are often too less to reveal one's deep regards. I take this opportunity to express my profound sense of gratitude and humility, my indebtedness to **Mrs. Amanpreet Kaur**, Assistant Professor, Electronics and Communication Engineering Department, Thapar University, Patiala, under whose guidance I had the privilege to complete this thesis. I wish to express my deep gratitude towards her for providing guidance and support throughout the thesis work.

I convey my sincere thanks to Head of the Department, **Dr. Sanjay Sharma** as well as PG Coordinator, **Dr. Amit Kumar Kohli**, Electronics and Communication Engineering Department, entire faculty and staff of Electronics and Communication Engineering Department for their encouragement and cooperation.

My greatest thanks to all who wish me success especially my parents. Above all I render my gratitude to the Almighty who bestowed self-confidence, ability and strength in me to complete this work and showing me the silver lining in the dark clouds. I do not find enough words with which I can express my feelings of thanks to my dear brother **Mehak** and my friends **Jasjeet** and **Yogesh** for their help, inspiration and moral support which went a long way in successful competition of the present study.

Kamaljit Kaur

ABSTRACT

Wireless communications have been developed widely and rapidly in the modern world especially during the last two decades. The future development of the personal communication devices will aim to provide image, speech and data communications at anytime and anywhere around the world. This indicates that the future communication terminal antennas must meet the requirements of multi-band or wideband to sufficiently cover the possible operating bands. However, the difficulty of antenna design increases when the number of operating frequency bands increases. In addition, for miniaturizing the wireless communication system, the antenna must also be small enough to be placed inside the system. However, in order to transmit and receive more information large bandwidths are required and bandwidth enhancement is currently a popular research area. Typical wireless application use devices which are smaller in size and require the use of small sized antennas with increased bandwidths.

In the current research work, Microstrip antennas for UWB applications have been presented. Four fractal antennas are designed and simulated for UWB and mobile applications using CST Microwave Studio V10. These are optimized to improve the performance of each of the antennas by applying suitable performance enhancement techniques. For example a Hexagonal Sierpinski Gasket Antenna is presented with stub and reduced ground which provides an achievable bandwidth of 1.86 GHz and is capable of covering the band for UWB applications.

The second design is Pythagorean Fractal Tree Antenna which is fed using CPW feeding technique and is a wideband antenna with a bandwidth of 2.04 GHz with an average return loss of -35dB and an average gain of 4.5dB. The next design presented is Fractal Flower Antenna which is also a CPW fed Antenna which is also a UWB antenna with 4.2 GHz of bandwidth and also a size reduction by an amount of 50% has been achieved with this antenna.

In the next design Sierpinski Gasket Bow-Tie Antenna is presented in which the conventional Bow-Tie is combined with Sierpinski which covers GSM, ISM, Bluetooth and mobile applications. In order to validate the results two simulated antenna designs, Pythagorean Fractal Tree antenna and Fractal Flower antenna have been fabricated and tested to validate the results. The simulation and measured results of both the antennas have been compared and studied and

they were found in good agreement with each other and hence making them suitable for proposed practical applications.

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ABBREVIATIONS

Wi-Fi	Wireless Fidelity
AMPS	Advanced Mobile Phone Systems
GSM	Global System for Mobile
CDMA	Code Division Multiple Access
IMT	International Mobile Telecommunication
UWB	Ultra Wide Band
MSA	Micro Strip Antenna
CPW	Coplanar Waveguide
ISM	Industrial, Scientific, Medical
CDM	Circular Disc Monopole

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CHAPTER-1

INTRODUCTION

1.1 Wireless Communication:

The growth in the wireless communication industry over the last decade has been tremendous. Technologies like cellular phones, Wi-Fi, WLAN and web browsing have become an inseparable part of business and personal life. Life now a day has become unimaginable without the cellular phones, laptops, and Wi-Fi and broadcasting applications. Two persons or devices can exchange information anytime no matter how far they are from each other; this has become possible due to the advancements in the wireless technology [1].

There are a lot of fields in which a revolutionary change has been made due to wireless technologies. Connectivity on move, connectivity of computers in an office, college or corner café and smart home appliances have become possible due to the wireless technology. Application of the wireless technology in the military field helps in detecting targets, enemies and also robot vehicles. Use of wireless sensor networks has made it possible to determine the status of remote locations in terms of weather [1].

Wireless cellular technology has emerged as one of the major technology booster. The first generation cellular system was released in 1983 also known as AMPS (Advanced Mobile Phone Systems). AMPS operates between 800-900 MHz and uses Frequency Division Multiple Access but carries only voice and also lacks in security. In the second generation (2G) uses Global System for Mobile communication also known as GSM which provides data rate upto 100Kbps along with voice applications. GSM operates at 900 MHz and 1900 MHz and uses Time Division Multiple Access (TDMA) technique [2].

The 3G technology also known as IS-95 Code Division Multiple Access(CDMA) and is based on wideband CDMA and offers high capacity and high data rate than above mentioned technologies. It is also known as International Mobile Telecommunication (IMT-2000) and can provide data rates up to 2Mbps [2].

WLAN, Wi-Fi has become popular due to their high data rates and connectivity to internet in colleges, offices. But UWB technology has become immensely popular due to high data rates as compared to other technologies. High security, non line of sight communication capability, high bandwidth, low cost and non interference to other systems has made this technology so useful for wireless applications. UWB technology has many applications which include RF tagging and identification, radar, collision or obstacle avoidance, precision geo-location, high speed WLAN etc. So the major interest is focused upon the design of antennas for UWB applications, WLAN and mobile applications [1, 3].

So there is a need for the antennas to operate on more than one frequency so that they can operate on both the WLAN bands be it 2.4 GHz or 5 GHz. The antennas for modern systems are required to operate on more than one band so that they can operate on both the GSM bands. The antennas for UWB applications should be operating on more than one band so that single device can be used for more than one application and size of the antenna should also be small which will help to reduce the size of the device also [4].

Microstrip patch antennas are the only antenna which irrespective of the small size can operate on lower frequencies. Small size of these antennas has helped to make modern devices compact. Further the use of fractals in Microstrip antennas helped to operate on more than one frequency band and led to multiband operation of a single antenna and resonance at lower frequencies even with smaller size. Thus Microstrip patch antennas are perfect candidates for modern application [5].

1.2 Microstrip Patch Antenna:-

Microstrip patch antenna consists of a thin metallic film of a conducting material such as copper above a ground plane but separated by small fraction of wavelength. The figure 1.1 shows the geometric configuration of the patch antenna which shows how a conducting patch is separated from the conducting plane by a substrate which is usually a non conducting material [5].

The patch made over the substrate is connected to the power using a feed line of the same conducting material as that of the patch. The figure also shows how the radiation occurs at the edges in such a manner that it results in broadside radiation [5].

There are a lot of substrates available with dielectric constant (ϵ_r) between 2.2 and 12 can be used to design these antennas. FR-4 epoxy resin substrate is the mostly used substrate [5].

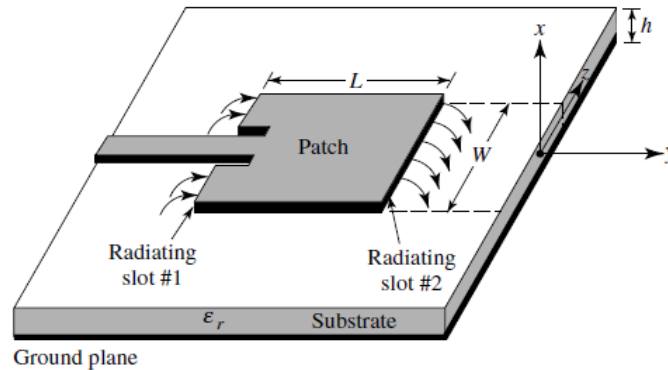


Fig 1.1 Microstrip patch antenna [5]

Choice of the dielectric constant plays a very important role. If the large bandwidth and high efficiency are required then dielectric constant should be small. If compact size and less undesired radiations are required the dielectric constant can be high. These antennas are designed in such a way that the radiation pattern's main lobe is normal to the patch i.e. broadside patterns [5].

1.3 Advantages of Microstrip Patch Antennas:-

The main features of the Microstrip patch antennas which have made them so popular in the field of wireless and personal communication applications are listed below [5]:-

- These antennas are small in size and help to achieve lower frequencies with small dimensions which have made them suitable for modern application.
- The MSA's are easy to design, model and fabricate. Fabrication cost is easy. Easy installation is another remarkable feature.
- These antennas can be made very small in terms of thickness which makes them a perfect candidate for the radar, aircraft, and satellite and missile applications.
- These antennas can be made to operate at more than one frequency which leads to multiband property.

- Circular polarization can be easily achieved by mere variation in the feeding technique.
- These antennas offer a fair degree of robustness and heat resistance.
- These antennas can be designed with variable frequency and other characteristics using some adaptive elements [5].

1.4 Disadvantages of Microstrip Patch Antennas:-

Along with some advantages Microstrip patch antennas also have some shortcomings which are listed below:-

- Efficiency of these antennas is very poor.
- Poor isolation between the patch and the feed line.
- The average gain obtained from these antennas is also very less.
- Power handling capacity of these antennas is quite poor
- These antennas have very narrow bandwidth around the resonance frequency which is the major limiting factor of MSA's
- Surface wave excitation due to bends and discontinuities cause a major loss [5].

1.5 Methods of Analysis of Microstrip Patch Antenna:-

There are many methods such as transmission-line, cavity model, integral equations and moment methods available for the analysis of the Microstrip patch antenna. Among these entire listed methods transmission-line model is most commonly used method.

1.5.1 Transmission Line Model:-

Transmission line model considers the antenna as a combination of two slots but assures least accuracy and takes into consideration the fringing effect.

1.5.1.a Fringing Effect:-

Fringing is excited along the edges of the Microstrip patch antenna due to its finite dimension along its length and width. The extent of this effect depends on the patch dimensions and

substrate height. If L and w are the length and width of the patch and h and ϵ_r are the height and dielectric constant of the substrate.

If $\frac{W}{h} \gg 1$ and $\epsilon_r \gg 1$ field lines most are bounded to the substrate but some part of these lines is in the air which makes it appear longer than its physical dimension. Due to the propagation of the some waves inside the substrate and the air ϵ_{eff} is introduced which is also a function of frequency. The design procedure after the determination of f_r , ϵ_r and h following steps are followed [5].

The determination of the width of the antenna can be done as follows:-

$$W = \left(\frac{v_0}{2f_r}\right) ((\epsilon_r + 1)/2)^{-1/2} \dots\dots\dots (1)$$

After the determination of the width effective dielectric constant is calculated as:-

$$\epsilon_{eff} = \frac{(\epsilon_r + 1)}{2} + \left(\frac{\epsilon_r - 1}{2}\right) \left(1 + 12 * \frac{h}{W}\right)^{-\frac{1}{2}} \dots\dots\dots (2)$$

Due to fringing the patch seems electrically longer at edges so the increase in length is

$$\frac{\Delta L}{h} = 0.412((\epsilon_{reff} + 03)\left(\frac{W}{h} + 0264\right)) / ((\epsilon_{reff} - 0258)\left(\frac{W}{h} + .8\right)) \dots\dots\dots (3)$$

After the increase in is calculated actual length can be calculated as follows:-

$$L = 1/(2f_r \sqrt{\epsilon_{reff}} \sqrt{\mu * \epsilon}) - 2\Delta L \dots\dots\dots (4)$$

Thus using above equations an antenna with the required operating frequency and given specifications can be designed.

1.6 Feeding Techniques:-

Feed line in Micro strip patch antenna is used to excite the patch to radiate. The design of the feed line is very important and tedious task. Feed line should be properly matched so that the matching losses are minimized and antenna efficiency is good.

Polarization of the antenna can also be changed by the properly designing the feed of the antenna. At high frequencies design of the feed is even more difficult due to losses [6].

The antenna can be fed directly or indirectly by a feed line depending upon the type of feed used. There are a lot of feeding techniques. Some of them are explained below:-

- Microstrip Feed Line
- Coaxial Feed Line
- Aperture Coupled Feed
- Proximity Coupled Feed
- Coplanar Waveguide feed

1.6.1 Microstrip Feed Line:-

This is the simplest of all the feeding techniques. In this feeding method a simple feed line is added to the patch which can also be considered as a patch extension. The matching can be done by changing the dimensions of the feed line and the inset position [5].

The figure 1.2 shows the structure of the patch antenna fed using Microstrip feed line where the feed line is shown with the same colour as that of the patch, width and position of the feed line can be varied in order to get better result [6].

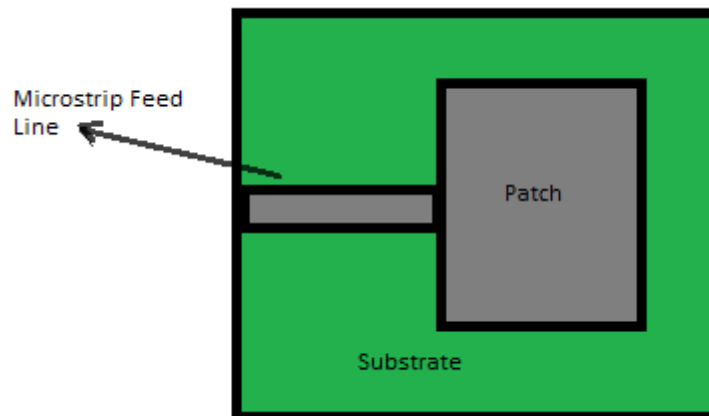


Fig 1.2 Microstrip Feed Line

The main advantage of this feed line is its ease of fabrication and simple modelling. The major disadvantage of the Micro strip feed line is less radiation bandwidth. When designing it for the high thickness of the substrate surface wave propagation increases. Due

to some asymmetries some higher order modes are generated which further cause cross-polarization [6].

1.6.2 Coaxial Feed Line:-

This method of feeding is much widely used in the design of Microstrip patch antenna. Figure 1.3 shows that coaxial feed line consists of two cylinders of conducting material, inner conductor is attached to the patch and the outer conductor is attached to the ground plane. Thus energy is provided to the patch with the help of conducting cylinders [5].

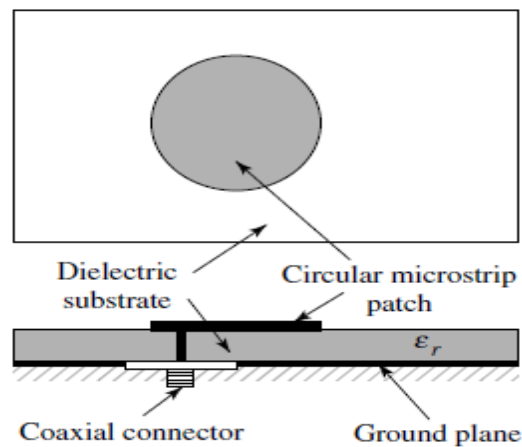


Fig 1.3 Coaxial Probe Feed [5]

It's easy modelling and fabrication are its major plus points. Matching is also quite easy in case of the coaxial probe. But lesser bandwidth and surface waves for high thickness substrates are some of its disadvantages [5].

1.6.3 Aperture Coupled Feed:-

In this type of feed there are two feed substrates, the lower substrate is the feed substrate which is on the top of this feed line and after that there is ground plane and then the upper substrate on the top of which patch is designed the coupling of the electromagnetic energy is done through a slot in the ground plane or an aperture. For the matching and better performance slot position and dimensions can be optimized. That why it is called aperture coupled feed. The matching can be done by varying the dimensions of the aperture and the feed line [7].

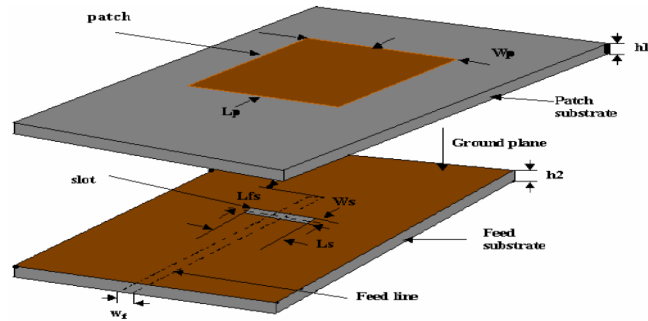


Fig 1.4 Aperture Coupled Feed [7]

Modelling and fabrication of this feed is much more difficult than the above mentioned methods. But it has so many advantages like higher bandwidth and shielding from spurious radiations because of the isolation provided by the ground plane between the feed and the radiating element. This method allows the selection of the feed and the patch separately. Cross polarization is almost equal to zero theoretically [7].

1.6.4 Proximity Coupled Feed:-

In this method of feeding the ground plane is at the lowermost position on the top of there is substrate with high dielectric constant on which feed line is designed above which there is upper substrate with lower dielectric constant on the top of which patch is designed as shown in figure 1.5.

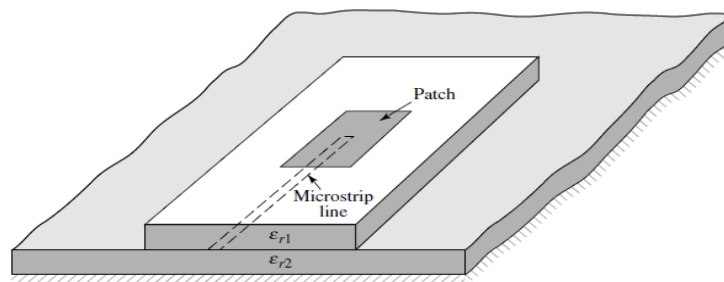


Fig 1.5 Proximity Coupled Feed [5]

Amongst all the feeding methods this feeding technique has the highest bandwidth and spurious radiations are also very less. The matching is done by varying the length of the feed and length to width ration of the patch. But this feeding technique is most difficult to design, model and fabricate [6].

1.6.5 Coplanar Waveguide Feed:-

It is also called CPW feed. In this feeding method entire conducting metal is on the same side of the substrate so it is a uniplanar. Figure 1.6 shows that in this feeding technique the metallic strip is deposited on one side of the substrate separated by two slits from ground electrodes running parallel to the strip [8].

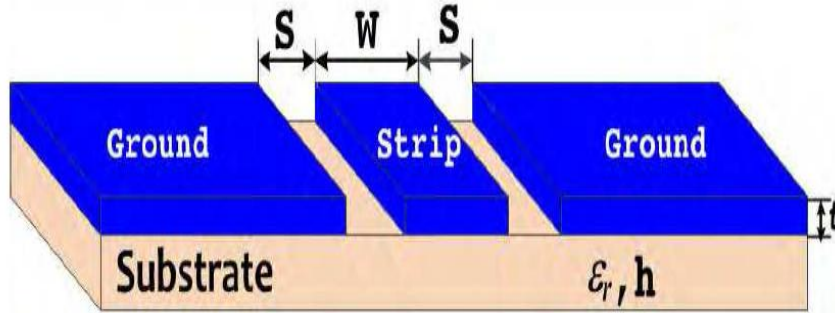


Fig 1.6 Coplanar Waveguide Feed [8]

Due to higher bandwidth, easy fabrication, low radiation losses and less dispersion losses this method of feeding has become very popular. This feeding technique provides design flexibility, easy fabrication along with better antenna performance in terms of matching, bandwidth, and gain as compared to other techniques. That is why this technique of feeding is used in some of the proposed antenna designs presented in this thesis [8].

1.6.6 Comparison of All feeding Techniques:-

The following table compares the features of the above mentioned feeding techniques:-

Table 1.1 Comparison of all Feeding Techniques

Parameter	Microstrip Feed Line	Coaxial Feed Line	Aperture Coupled Feed	Proximity Coupled Feed	Coplanar Waveguide
Modeling	Easy	Easy	Difficult	Difficult	Easy
Bandwidth	Narrow	Narrow	Large	Large	Large

Fabrication	Easy	Easy	Difficult	Difficult	Easy
Isolation between Feed and Patch	Low	Low	Good	Good	Low
Matching	Easy	Easy	Difficult	Difficult	Easy
Spurious Radiation	High	High	Low	Low	Low

Thus it can be concluded from the above table that CPW feed is easy to fabricate and less complex as compared to other techniques and gives much better results and this gives a reason why CPW feeding technique is preferred in the current research work which focuses on multiband and wideband fractal antennas.

1.7 Fractals:-

Fractals were first introduced by B.B.Mandelbrot in 1977 and this term was taken from a Latin word fractus which actually means broken. Fractals are the structures which appear same at every scale that is why they are also called self similar. Antennas designed using Fractals possess some unique properties which have made them very popular in the fields of wireless communication, medicine and defence [9].

Mandelbrot was the one who studied the relationship between fractals and natural object. Figure 1.7(a)-1.7(d) shows that many natural objects have been made successfully using fractals i.e. clouds, coastlines, tress, thunderbolt, snowflakes and mountain ranges. It is believed that human heart beat also follows fractal patterns [9].



Fig 1.7 (a)

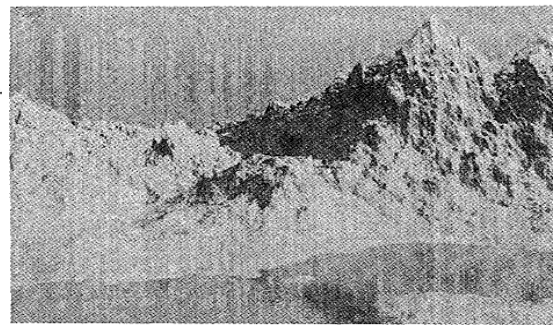


Fig 1.7 (b)

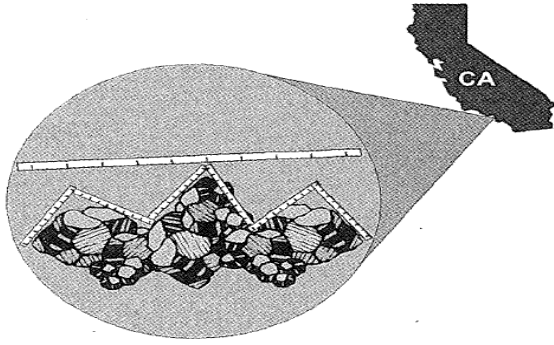


Fig 1.7(c)

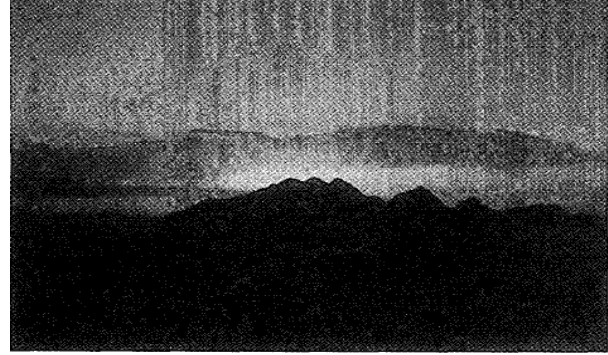


Fig 1.7 (d)

Fig 1.7 The Tree Patterns, Landscape, Coastline and Mountain Ranges Developed using Fractals [9]

1.7.1 Fractal Antennas:-

The property of self similarity in fractals can be used with MSAs to provide new fields of antenna design called Fractal antenna. Fractal antennas are self similar structures and an iterative method is used to generate them. While designing these antennas the basic structure is scaled down in such a manner that the whole structure seems similar irrespective of the scale factor used. Multiband behaviour of these antennas is the most unique and useful feature. The self similarity at different scales leads to the surface current distribution which is also scalable at different operating bands which leads to multiband and log periodic behaviour [4].

Due to increase in the path for threading current the resonant frequency is lowered. The space-filling property of these antennas helps to minimize the size; such antennas may also be of infinite length and can be packed in a finite volume. These two properties lead to small size of the antenna which will further be useful for size miniaturization of the modern devices and is very useful for wireless communication applications [10].

1.7.2 Properties of Microstrip Fractal Antennas:-

The following table throws some light on some unique properties of the fractal antennas which have made the immensely popular.

- 1) Fractals are self-similar structures. They are created by using copies of it but at different scales. The entire geometry is similar to the initiator and is easy to design.
- 2) Fractal antennas have the property of space-filling. This property leads to the packing of more and more antennas in small volumes i.e. Hilbert Curve.
- 3) Fractal antennas are designed using an iterative process. These antennas show multiband behaviour corresponding to each iteration. Thus single antenna can radiate at more than one frequency.
- 4) These antennas help in size miniaturization. These antennas resonate at lower frequencies with smaller physical size as compared to the ordinary antennas.
- 5) These antennas are low profile, easy to model and fabricate and their cost of fabrication is also very less. It's just etching of copper over some epoxy material.
- 6) These antennas have sharp edges and discontinuities which help to increase the electrical length of the antenna and make it radiate efficiently.
- 7) These antennas are robust. They show much prevention against heat or mechanical strain.
- 8) These antennas are easy to feed and provide much flexibility to design and fabricate.
- 9) These antennas lead to packing of more energy in smaller volume which results in high quality factor [10].

1.7.3 Types of Fractals:-

Mainly fractals are divided into two categories i.e. deterministic and random. Deterministic fractals are those which are generated using much iteration at different scale factors repeated copies using recursive algorithms. Random fractals make it possible to simulate natural phenomena because they show certain degree of randomness. Algorithms and mathematical functions can be found or developed for both [5]. Fractals are small, self similar, low profile and conformal geometries. There are many fractal geometries which have been widely used as an antenna shape [4]. Some of them are explained below:-

1.7.3.1 Sierpinski Fractal Antennas:-

These are the most popular geometries amongst all the fractals. These include Sierpinski Gasket, Carpet, Hexagon and Pentagon. Sierpinski Gasket antenna is the most popular

geometry. Figure 1.8 shows the various design steps of the design procedure of the Gasket. An equilateral triangle is taken as the generator in the zero iteration [4].

In the next iteration another triangle scaled down by a factor of two is subtracted from the generator such that vertices of the smaller triangle coincident with the mid points of the generator. This process can be repeated to a lot of iterations [4].

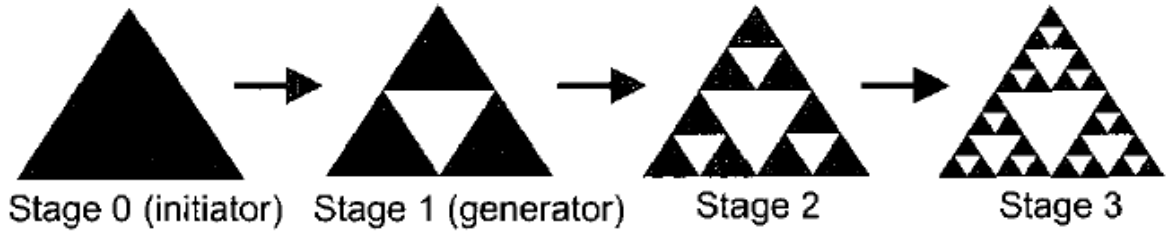


Fig 1.8 Design steps of the Sierpinski Gasket Fractal antenna [11]

These antennas show the multiband behaviour and log periodic spacing between the resonant frequencies [12]. Many other variations such that making a perturbed geometry and varying the flare angle are done and important conclusions were drawn from the results [13]. The design formula for the design of Gasket is suggested in [14]. This formula includes the effective side length and other effects such as effective length of the patch [14].

$$f_r = \begin{cases} (.15345 + .34\rho x) \left(\frac{c}{h_e}\right) (\xi^{-1}) & \text{for } n = 0 \\ .26 \left(\frac{c}{h_e}\right) \delta^n & \text{for } n > 0 \end{cases} \dots\dots\dots (5)$$

Where $\xi = \frac{h_k}{h_{k+1}}$ is the ratio of height of the triangle at the kth iteration and k+1 th iteration and $\delta = 1/\xi$ is the scale factor . If the scale factor is 2 the ξ is .5 . and $\rho = \xi - .260735$ and

$$x = \begin{cases} 0, & k = 0 \\ 1, & k = 1 \end{cases} \dots\dots\dots (6)$$

Another important Sierpinski geometry is Carpet which is very important in case size reduction is required. Carpet geometry can either be a square or rectangle. As shown in figure 1.9, to create the square carpet antenna initiator square is reduced by some scale factor and is cut from the centre of the bigger square and in the next iteration the remaining area is divided into nine equal squares and in the next iteration same steps are repeated [4]. The

Sierpinski Carpet antenna can be designed by using equations 1-4 which are design equations of transmission line model for a rectangular patch antenna design.

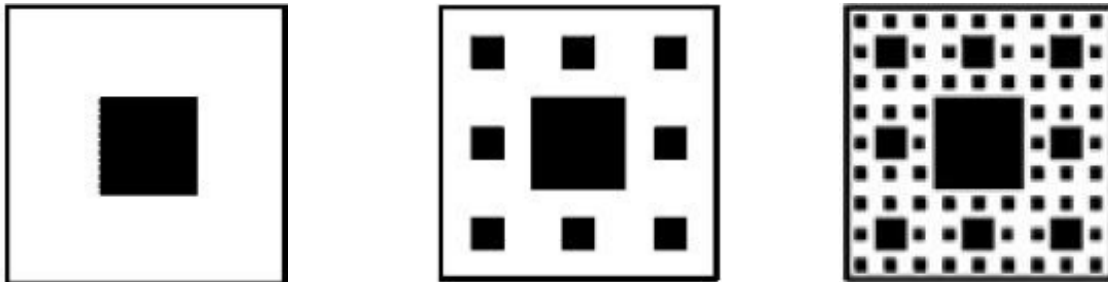


Fig 1.9 Design steps of the Sierpinski Carpet [4]

The main advantage of the Sierpinski Fractal antennas is multiband behaviour due to self similar behaviour at all the bands around resonant frequencies. The smaller resonant frequencies are easy to get if the antenna is designed using more number of iterations [4].

1.7.3.2 Koch Island:-

In Koch Island an equilateral triangle is taken as the generator as shown in figure 1.10, the side of the triangle is divided into three equal segments and the central segment is removed and two segments are added to make an equilateral triangle.

The equations 5 and 6 are used to design the Koch Island Fractal antenna. If this process is repeated several times the periphery of the island becomes infinite bounded in small space and the current travels longer distances to resonate at lower frequencies and also high quality factor [5].



Fig 1.10 the design Stages of the Koch Island [15]

Koch curve is popular due to its small size, wide bandwidth and directive properties due to higher modes propagation. If the iterative process explained above is applied for several times the Koch Island becomes an antenna with infinite boundary resulting in the packing of more antenna length into a limited area and antenna with smaller size is obtained with resonant at lower frequencies [4].

1.7.3.3 Hilbert Curve:-

Hilbert curve is another candidate of the fractal family. Hilbert curve is developed by four smaller copies of the generator but these copies are joined by additional line segments. Due to packing of the more antennas in small volumes this geometry appears to be space-filling. This geometry is self-avoiding no two segments intersect each other. If more and more number of iterations are performed are performed than the antenna can resonate at lower frequencies because of the larger electrical length as compared to the physical length [16].

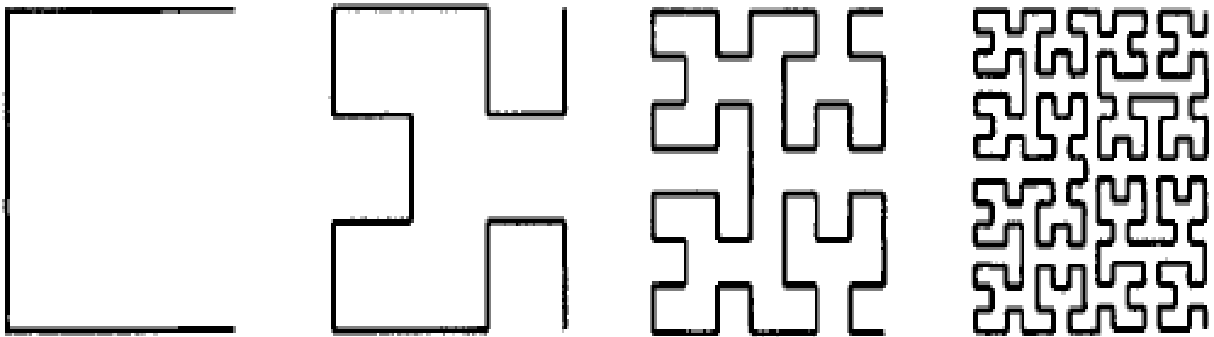


Fig 1.11 Four iterations of the Hilbert fractal antenna [16]

The length of each segment and the total length of the segment and the resonant frequency is given by the formulae given below [16]:-

$$d = L/(2^n - 1) \dots\dots\dots (7)$$

$$s(n) = (L^{2^n} - 1) * L/(2^n - 1) \dots\dots\dots (8)$$

$$(\mu_o/\pi) * k * \lambda/4 \left[\log \left(\frac{8k\lambda}{b^4} \right) - 1 \right] = m * 120/w * \log \frac{2d}{b} \tan \beta d + (\mu_o/\pi) [\log 8s/b - 1] .. (9)$$

Where L is the outer dimension, n is the fractal iteration, where $m = 4^{n-1}$, d is the length of parallel wire connection, diameter is represented by b and k is an odd integer. Such geometry helps to put longer antennas in a limited volume. This property leads to miniaturization which is the major need of modern applications. This antenna has made it possible to achieve lower resonant frequency with a very small size [4].

1.7.3.4 Hexagonal Sierpinski Fractal:-

Hex flake or Hexagonal Sierpinski has become so popular because of its multiband and wideband properties. In the design of Hexagonal Sierpinski antenna the original hexagon it replaced by seven hexagons whose side length is reduced by a factor of three [17]. This antenna shows the multiband behaviour and log periodic with the scale factor of three while the Sierpinski Gasket shows the same with the scale factor of two [4]. These antennas are useful where larger gap is required between the operating bands. The design formula for the hexagonal Sierpinski is given below [17]:-

$$f_n = .468 * c / [l * \delta^{n-2}], 2 \leq n \leq k + 1 \dots\dots\dots(10)$$

Where n is the resonance number and k is he iteration number and c is the speed of light and δ is the scale factor.

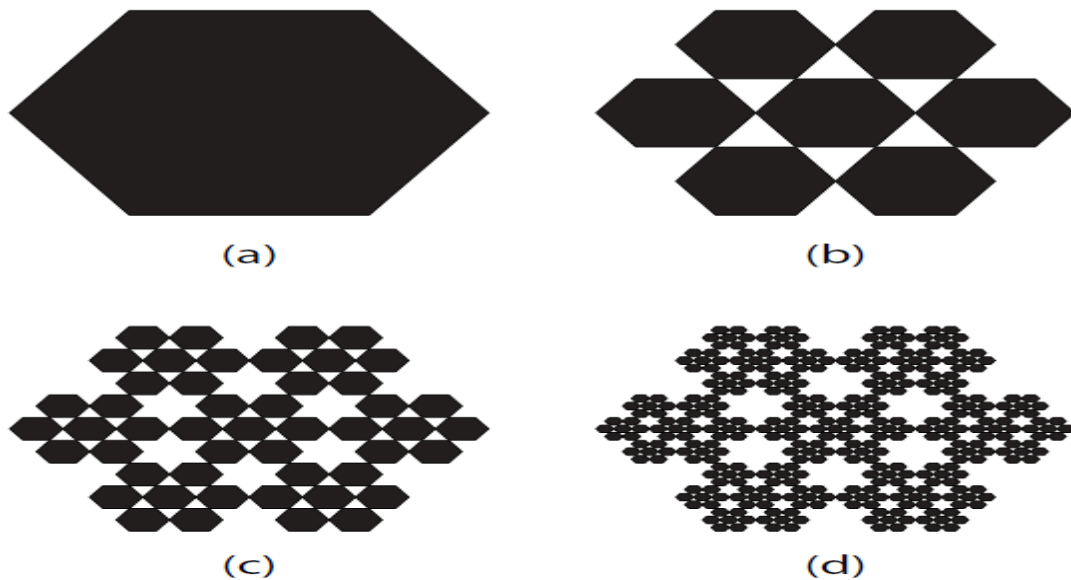


Fig 1.12 Various Stages of the Design of Sierpinski Hexagonal Fractal [17]

1.7.3.5 Pythagorean Tree:-

Fractal patch antenna using Pythagorean tree is novel design. This geometry has multiband and wide band properties. This design is created using the Pythagoras theorem that three squares when combined in a proper manner they enclose a right angle triangle as shown in figure 1.13.

This design is simple to design, mode and fabricate. The use of proper feeding techniques and slots can help to obtain better results. This antenna has proved very useful for those applications which require high gain along with large bandwidth along with small size, small size of this antenna is another very powerful feature of this antenna [18].

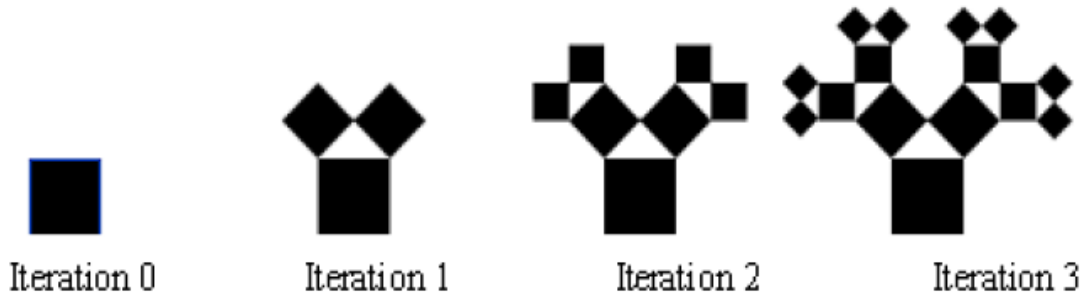


Fig 1.13 Three iterations of Pythagorean Fractal patch antenna [18]

This novel Fractal antenna geometry is very good in terms of some performance parameters such as gain, bandwidth, and directivity and is also very compact. The ultra wide band behaviour of the antenna makes it worthy [18].

1.7.3.6 Fractal Flower:-

This is the new circular disc monopole antenna (CDM) in which a circular disc antenna is designed using Fractal technique. This antenna has the ultra wideband property. If size reduction is required this antenna helps to reduce it. This antenna is designed by modifying the circumference of the circular monopole as shown in figure 1.14 which increases the electrical length and resonance at lower frequency is possible [19]. The design equation of this antenna is given by:

$$f_L = 7.2/(l + a + h) \text{ GHz} \dots\dots\dots (11)$$

Where $l = 2r$ and $a = \pi r^2$ and r is the radius of the monopole antenna and h is the height of the substrate material [19].

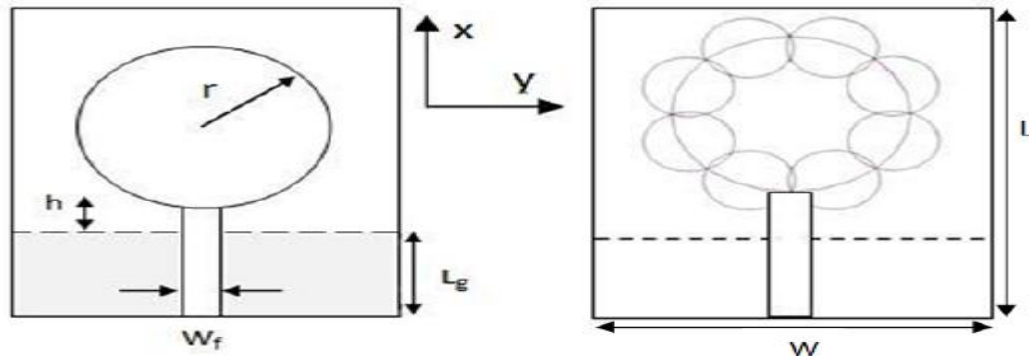


Fig 1.14 Circular Disc Monopole Antenna before and after first Fractal Iteration [19]

The antenna has the major advantage to the wireless applications is its ultra wide band behavior with the very small size. If designed carefully this antenna can operate over the entire UWB band i.e. can have very large bandwidth [19].

The research work presented in this article concentrates on the design and implementation of fractal antennas for WLAN, Wi-MAX, UWB and mobile applications. The organization of the thesis in this regard is presented in the next section.

1.8 Thesis Organization

The entire thesis is divided into eight chapter glimpse of which is given below:

Chapter-1 includes the introduction to wireless communication, Microstrip patch antenna, Fractals and Fractal antennas and their properties.

Chapter-2 is based on all the literature survey done based upon the development of Fractal antennas and the research gaps that have been found and the thesis objectives have been.

Chapter-3 represents the design and simulation of the Sierpinski Gasket Fractal Antenna and the techniques used to enhance the antenna performance.

Chapter-4 include the design and simulation of Pythagorean Fractal Tree antenna with CPW feeding technique

Chapter-5 covers the design and simulation of the Circular Monopole Disc Antenna after applying first Fractal iteration.

Chapter-6 includes the design of the Sierpinski Gasket Bow-Tie antenna which is studied thoroughly after second order Sierpinski iteration.

Chapter-7 has the entire fabricated antennas and the results of the testing of these antennas.

Chapter-8 includes the conclusion and future scope of the work in the field of Fractal antennas.

CHAPTER-2

LITERATURE SURVEY

2.1 Development in the Field of Fractal Microstrip Antennas:

In the year 1996 **C.Puente**, et al. [12] did the first ever experiment to show the multiband behaviour of the fractal antenna geometry. A triangular Sierpinski had been taken as the first candidate due to its similarity with bow-tie triangular antenna. The antenna radiated at more than one frequency band i.e. multiband behaviour and the log periodic behaviour of all the bands with the factor of two. If the structure was closely analyzed then it seemed self similar at all scales. This experiment opened the way to design the new frequency independent antennas.

In the year 1998 **C.Puente**, et al. [20] studied the behaviour of both Sierpinski monopole and dipole antenna. Self similar behaviour's conversion into electro-magnetic behaviour had been studied using current distribution. The bands obtained after simulations were equal to the number of iterations and followed the log periodic behaviour with the factor of two. Radiation patterns also showed good and consistent behaviour over the frequency range. Current distribution at all the bands also seemed to be almost similar.

C.Puente, et al. [13] performed variations on the Sierpinski gasket antenna and studied them extensively. Varying the flare angle of the triangular antenna and its effects were studied thoroughly. A conclusion had been drawn that if the flare angle of the antenna is kept broader then the resonant frequency will shift towards the left which will help to reduce the antenna size. If the flare angle was kept smaller (narrow) this made the antenna to deviate from log periodic behaviour and also from multiband behaviour.

Methods of matching of the perturbed Sierpinski antennas had been presented by **C.T.P. Song**, et al. The antennas with scale factor different from two offer so much difficulty in matching with the 50 ohm line. Two techniques had been suggested to overcome the same. In the first technique effect of having the ground plane on the same side which contained the patch and in the second method an angular feeding technique was suggested which maintained the multiband behaviour but the former decreased the frequency spacing [21].

A novel design Sierpinski hexagonal antenna had been presented by **P.W.Tang** and **P.F.Wahid**. This antenna was designed in dipole configuration and the behaviour of this antenna had been studied up to second iteration. The multiband behaviour of this antenna had been proved and the fact was established that this antenna showed the log periodic behaviour with scale factor of three while the Sierpinski gasket showed the same with the scale factor of two [17].

A novel design of fractal antenna had been presented in which folded slot antenna is combined with Koch curve and up to two iterations of the Koch had been performed over the folded dipole by **A.Sundaram**, et al. This technique moved the resonant frequency to the left end i.e. resonant frequency got lowered and the return loss also got improved after the second iteration [22].

By taking into consideration the physical and analytical reasoning the existing formula for the design of Sierpinski gasket antenna had been modified by **R.K.Mishra**, et al. This formula took into account the effective side length, some of the parameters of the substrate. Formula for the effective side length had also been suggested using some algebraic modifications. The simulated and measured results were more close to as that calculated using the new formula. The side length can also be calculated if all other parameters are available [14].

A wideband, compact and microstrip line fed antenna had been presented for the Wi-MAX and WLAN applications by **D.D.Krishna**, et al. Resonance frequency of the antenna was lowered by applying Koch iterations on the sides of it. The effect of the slot in the patch and the stub flaring had also been studied. The use of reduced ground plane had been proved useful for size reduction. Wideband matching had been done by using a tuning stub. The coupling between the slot and the feed had been improved by compact ground plane [23].

A.Aggarwal and **M.V.Kartikeyan** presented an entirely new geometry fractal Pythagorean tree with CPW feed. This antenna had been modelled using the Pythagoras theorem according to which a right angled triangle is enclosed by three touching squares. The antenna radiated over two bands one for 2.4 GHz (WLAN/Wi-MAX) and other for 3.5 GHz (Wi-

MAX). The impedance bandwidth of this antenna was 20% higher than the other multiband antennas. The ultra wideband behaviour of this antenna was without the use of any stubs or slots or any other designing techniques [18].

A Sierpinski Carpet antenna with ground CPW feed is compared with the conventional coaxial fed antenna by **M.N.Jahromi**, **A.Ralahati** and **R.M.Edwards**. The former one increased the dynamic range of the input impedance which helped its behaviour to become wideband from multiband. The radiations patterns showed that gain of the ground coplanar waveguide fed antenna was high as compared to conventional Sierpinski Carpet with coaxial feed line [24].

A.Kaka, et al had proposed a novel approach of combination of two geometries namely, Minkowski and Sierpinski. Sierpinski carpet had been modelled as it led to miniaturization and then first iteration of Minkowski had been applied to the sides of the square carpet that attains wide bandwidth. This antenna possessed Omni-directional patterns and had the bandwidth equals 7.5 GHz which covers almost entire UWB band [25].

N.Bayatmaku, et al presented a novel fractal geometry i.e. an E shape fractal antenna. This antenna had been modelled by cutting two smaller rectangles and then applying this procedure repeatedly to generate the entire structure. Simulated results of all the iterations had been studied carefully. Size reduction and getting more number of bands had been the major advantages of this antenna. This antenna had its applications in GSM, LTE and UMTS bands. As the number of iterations is increased bandwidth also got increased [26].

L.Ghanbari, **S.Nikmehr** and **M.Rezvani** worked on novel ultra wideband fractal geometry. Using this particular geometry size reduction up to 50% had been achieved. Fractal iteration had been done on CDM (circular disc monopole). Applying this technique an increase in the circumference of the disc monopole had been achieved and made it resonate at lower frequencies. Wide bandwidth had been offered by this antenna covering almost entire UWB band along with good radiation properties [19].

D.Li, et al. presented a monopole antenna with its boundary replaced by the Koch curve. Major work had been done on the miniaturization and ultra wideband behaviour of this antenna. The antenna had been fed using coplanar waveguide. The antenna had wide bandwidth covering from 4.3-12 GHz. The simulation results showed that antenna radiations patterns were Omni-directional and had good return loss at operating frequencies [26].

Based on Sierpinski Carpet geometry a diamond shape fractal antenna had been presented by **K.Pahwa**, et al. Two iterations had been done and antenna showed tri-band behavior. Size miniaturization and multiband behaviour had been obtained. Antenna resonance made it applicable for wireless applications. Coaxial feeding technique made the design easy to fabricate [27].

To achieve the size reduction **S.Shreshtha**, et al worked on Sierpinski Carpet antenna incorporating the space-filling property. The antenna was edge-fed and three fractal iterations had been done. Size reduction had been achieved without degrading any other parameter such as return loss, impedance bandwidth and radiation pattern [28].

S.M.Choudhury and **M.A.Matin** used a frequency selective surface (FSS) as the ground plane which allowed passing only certain frequencies and reflected all others. It also improved the antenna performance by acting as a cavity. By varying the width of the FSS its effects on the antenna performance had been studied. The return loss remained unaffected but the bandwidth of the bands increased. Bandwidth had been varied by varying the width of the FSS [29].

A novel CPW fed circular antenna in which a square had been inscribed with various iterations was presented by **K.K.Sawant**, et al. A notch of N-shape had also been presented in the design which helped to avoid interference between WLAN bands. This antenna provided the flexibility to vary notch band characteristics over the entire UWB band. Impedance matching at high frequencies had been achieved by applying two rectangular slots in the middle of the ground plane electrodes [30].

H.Oraizi and **S.Hedayati** proposed novel square slot antenna on which Giuseppe piano fractal iterations had been performed. This antenna was proved to be a good candidate for size reduction, wide bandwidth, and good return loss and radiation properties. Feed line position had also been optimized and concluded that the antenna gave best results if fed along the diagonal of the square slot [31].

B.K.Jeemon et al designed novel triangular patch antenna on the sides of which Koch is fractal iteration had been applied after the Sierpinski fractal iteration. The antenna had been proved to possess ultra-wide bandwidth behaviour. Application of these two geometries improved the return loss and impedance bandwidth over the UWB range. Radiation patterns were stable and Omni-directional in H-plane. Lower cut of frequency had been lowered if more number of iterations is performed [32].

Novel design by modifying the existing Sierpinski Carpet geometry had been presented for the Wi-Fi/WLAN, LTE and Bluetooth applications by **T.Kalaimani**, et al. The geometry had been created by removing the upper square after dividing the generator into four equal squares. Antenna had showed multiband behaviour with pattern having good directivity [33].

Dr.V.R.Anitha and **M.Y.Sindhu** worked on novel fractal geometry with the concept of re-configurability using PIN diode switches. The antenna had been a multiband antenna and covered the WLAN and Wi-MAX band. The antenna with re-configurability activated only required path for certain application while the rest part of the antenna remained inactive. Antenna was designed in such a way that it could be used for a particular type of application by activating only the required branch while the other branch remained ineffective [34].

For the miniaturization a Koch dipole fractal antenna had been presented on which two iterations had been performed by **A.K.Singh**. Flare angle variations had also been done so as to obtain optimum results. The Koch presented here give the optimum results after the first iteration and with the flare angle of 60° . This antenna had seemed promising when compared with the other log periodic antennas in terms of VSWR, directivity and gain etc [35].

In this paper perimeter of the triangular patch antenna had been increased by performing Koch iterations on its sides and the antenna had been presented with reduced ground and stable Omni-directional patterns were obtained. The antenna that worked on Wi-Max and C-band applications with good amount of gain was obtained by **S.Yadav**, et al [36].

By applying the Koch iteration over the Hexagonal patch antenna and the ground plane electrodes which helped to generate some additional resonances that helped to cover the entire UWB Band by **S.Tripathi, Mohan** and **Yadav**. Higher order iterations helped to lower the resonance frequency and applying Koch iteration to the ground plane increased the electrical length and enhanced the bandwidth. The antenna had got the gain between 4-6dBi and bi-directional patterns [37].

A novel design working between 4.12-6.8GHz combining circular and triangular geometries had been proposed for UWB applications by **S.Yadav**, et al. The Omni-directional patterns and the average gain of 2.2dB were obtained. To enhance the gain of the antenna circular shaped slots had been cut. Reduced ground had also been proved effective [15].

C.J.Xi and **G.Y.Lin** worked to reduce the size of low pass filter for which fractal geometry had been combined with defected ground surface. Inverse Koch fractal was applied on the dumbbell shape and this technique improved the frequency selectivity of the filter and reduced the reflection loss of the pass band. The proposed technique had been proved useful for the size reduction of the filter [39].

D.Kumar, et al proposed a compact fractal antenna for UWB applications which looked like a key. The antenna was presented with a partial ground and five iterations. The antenna had the operating band from 3-9.1GHz with the average gain of 4.46dB and VSWR<2. The proposed antenna had got the radiation efficiency greater than 90% and the compact size [40].

K.Kharat et al. presented a Koch curve looking like a star having broadband and multiband property. The antenna worked for WiFi, WiMAX and WLAN bands. Koch geometry

introduction reduced the size of the antenna and more number of iterations lowered the frequency of the antenna. To enhance the gain and bandwidth, the antenna was rotated 90^0 in counter clock wise direction [41].

2.2 Research Gaps in the Literature Survey:

During the review of the literature following research gaps have been found:-

- Sometimes the modes other than the fundamental mode (higher modes) degrade the radiation pattern. The reason being the resonant frequencies are similar to the resonant frequencies of the higher mode. To minimize the effect of these higher modes a very less amount of work has been done so work can be done on this problem.
- In the work of antennas usually polarization used is linear. Less work is done on using circular polarization. While circularly polarized antenna gives better results in certain parameters. So there is a scope for improvement using circularly polarized antennas.
- Though fractal antennas have been proved very good in multiband performance. But the return loss performance is not good at all the frequency bands. Achieving matching at all bands opens new door for improvement.
- The designs of Fractal antenna having large operating bandwidth are not many. So there is a scope for designing new antennas having wide operating bandwidth.
- While designing the Fractal antennas feeding technique which is normally used is either microstrip feeding technique or coaxial feeding technique. But only a few are designed using aperture, coplanar waveguide feed. So this is another fact which can be considered for designing new antennas.
- Koch Island, Sierpinski are some geometries which are used while designing the Fractal antennas. New geometries such as hexagonal Sierpinski, Flower, and designs

combining two geometries are not being taken into consideration, so this can be helpful for opening new doors to research scholars.

2.3 Objectives:

Based upon the literature review and the research gaps found following objective are defined:

- 1) To design and simulate Sierpinski Gasket Hexagonal antenna for UWB applications. To improve its performance in terms of impedance bandwidth by applying techniques like stub matching and reduced ground.
- 2) To design and simulate the Pythagorean Fractal Tree antenna for UWB applications.
- 3) To design and simulation of Fractal Flower Antenna for UWB applications and mobile applications.
- 4) Design and simulation of Sierpinski Gasket Bow-Tie antenna for UWB and mobile applications.
- 5) To validate the results of the Pythagorean Tree & Fractal Flower fabrication and testing of the antennas is done using VNA.

CHAPTER-3

DESIGN OF SIERPINSKI GASKET HEXAGONAL ANTENNA FOR UWB APPLICATIONS

3.1 Introduction:

The main aim of this chapter is to design an antenna for UWB applications. The antenna should be of small size with multiband characteristics and fair amount of gain for these applications. Hexagonal Sierpinski gasket antenna satisfies all these requirements, and the same is presented in this chapter. The initial design shows the multiband behaviour but later on by applying some improvement techniques the antenna performance is improved and converted into wideband behaviour.

3.2 Design of Sierpinski Gasket Hexagonal Antenna:

The antenna is designed to resonate at frequency 7.8GHz. The side length of the hexagon is taken as 18mm. The substrate chosen is FR-4 with dielectric constant equal to 4.4 and thickness equal to 1.6mm. The thickness of the conducting material is taken equal to .03mm.

3.2.1 Design Steps of Sierpinski Gasket Hexagonal Antenna:

The antenna is designed using CST Microwave Studio V2010. The results of the antenna are studied after the second iteration. The iterations are done by taking into consideration the fact that a hexagon is a combination of six equilateral triangles as shown in figure 3.1.

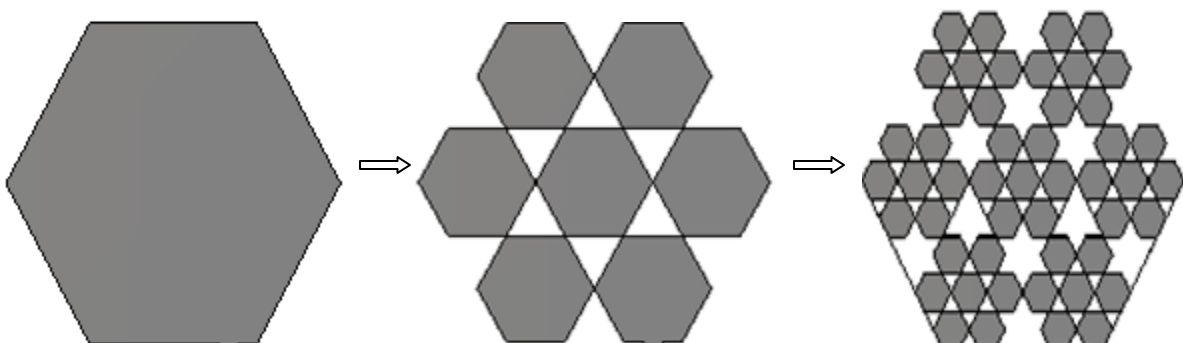


Fig 3.1 Design Steps of Sierpinski Hexagonal Antenna

3.3 Simulation Results of Sierpinski Gasket Hexagonal Antenna:

The antenna design discussed above is simulated using CST Microwave Studio and the simulation results are discussed in this section. Figures 3.2-3.4 show the return loss plots of the Sierpinski hexagonal gasket antenna after each iteration.

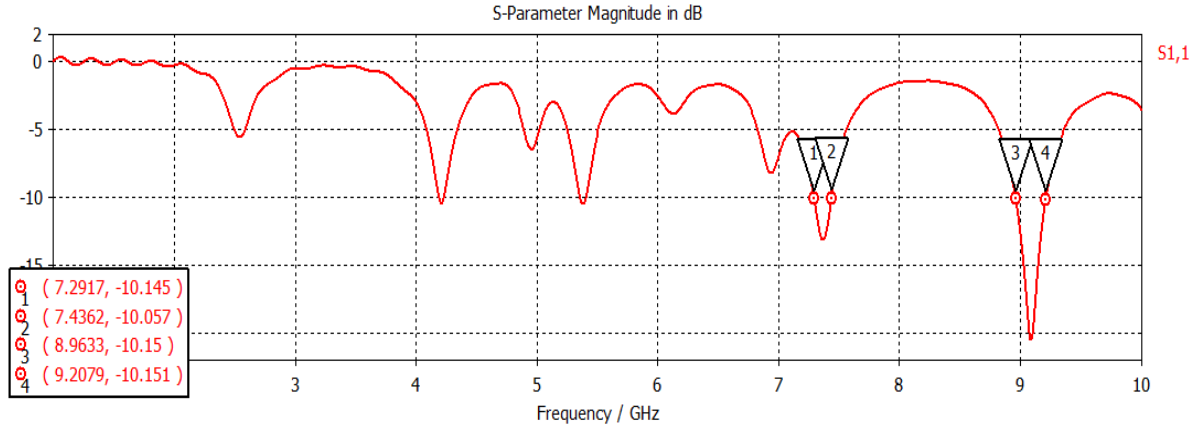


Fig.3.2 Return Loss Plot of the Sierpinski Hexagonal Antenna after Zeroth Iteration

Figure 3.2 shows the return plot of the hexagonal patch antenna in which four bands appear at 4.2 GHz, 5.38 GHz, 7.45 GHz and 9.1 GHz. But the return loss is very poor at these frequencies so the first Sierpinski iteration is applied.

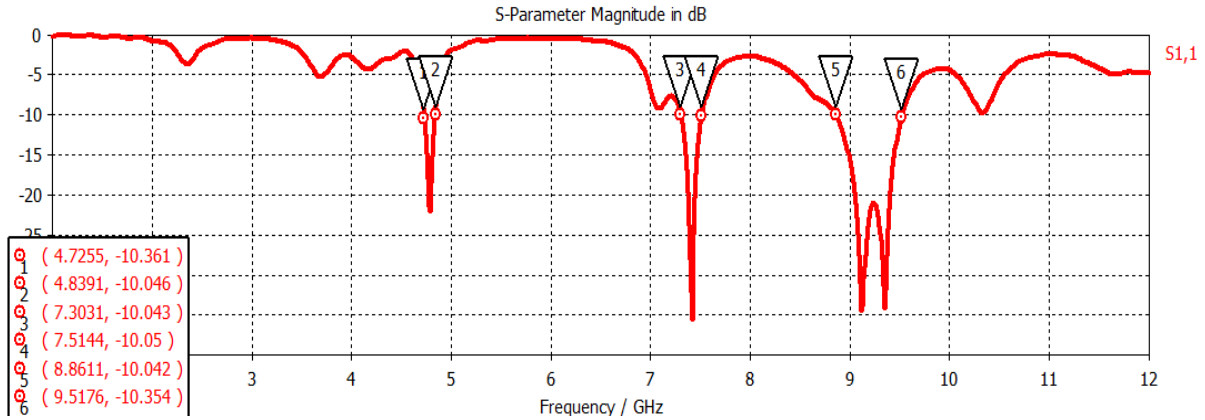


Fig 3.3 Return Loss Plot of the Sierpinski Hexagonal Antenna after First Iteration

As the figure 3.3 reveals that after first iteration three band three bands are obtained around 4.8 GHz, 7.4 GHz and 9.4 GHz respectively. But these frequency bands are not of much use so to shift these bands to left another Fractal iteration is done because this is the property of the fractals that each iteration makes the antenna frequencies shift towards left.

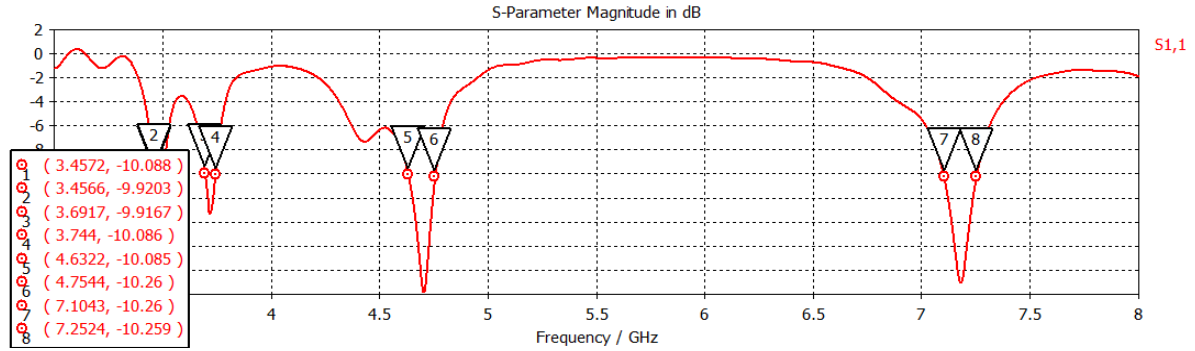


Fig 3.4 Return Loss Plot of the Sierpinski Hexagonal Antenna after second iteration

The return loss plot shown in figure 3.4 shows that after applying the second iteration the antenna showed four operating bands centred around 3.48 GHz, 3.72 GHz, 4.7 GHz and 7.2 GHz. But the antenna performance obtained was not acceptable so some design techniques are applied to improve the same.

3.4 Design of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground:-

Though the antenna discussed above is good in terms of return loss but poor in terms of gain and bandwidth. So by using some techniques performance of this antenna has been improved. By introducing the concept of reduced ground in y direction basically the effect of surface wave diffraction is minimized from the ground plane edges and this effect leads to suppression of back radiations and hence increases the gain.

The use of stub is done to match the impedance when connected parallel to the feed line it reduces the effect of reflected wave and thus gives better return loss. Figure 3.5 shows the improvement in the antenna performance after using these techniques.

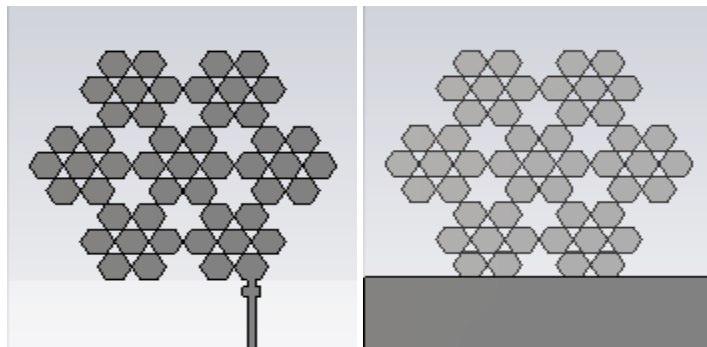


Fig 3.5 Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground

3.5 Simulation Results of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground:-

The simulation results including return loss plot, bandwidth, gain plots and surface currents are shown in the following figures.

3.5.1 Return Loss Plot of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground:

It can be seen clearly from the return loss plot shown in figure 3.6 of the proposed antenna after applying tuning stub and partial ground that it is a multiband antenna with four bands centred around 3.04 GHz, 4.04 GHz, 7.8 GHz and 11.6 GHz and with more bandwidth around resonant frequencies are obtained. The return loss at all these bands is below -16dB which depicts that the antenna is matched properly.

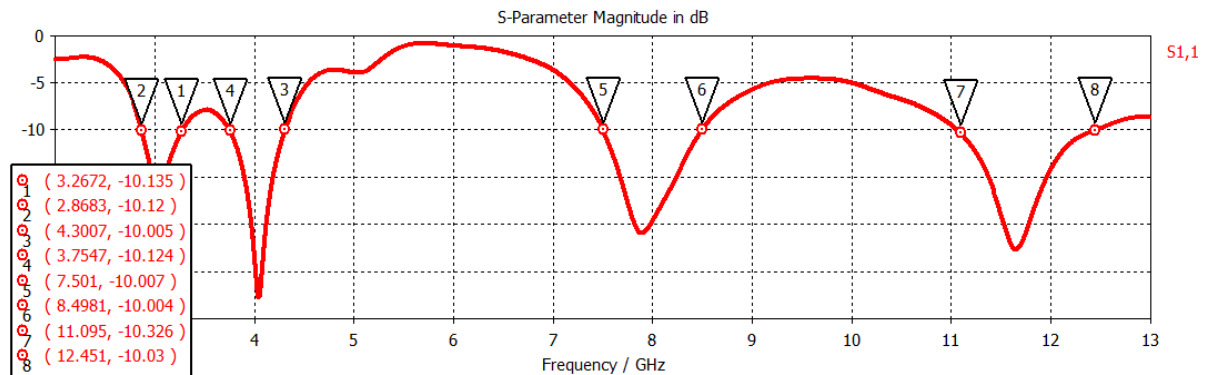


Fig 3.6 Return Loss Plot of Sierpinski Hexagonal Antenna with a Stub and Reduced Ground

The bandwidth around all the four bands is 400 MHz, 542 MHz, 1 GHz and 1.45 GHz respectively. This is much more as compared to the antenna without stub and reduced ground. Thus the antenna can be used for UWB applications.

3.5.2 Gain Plots of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground:

Though the gain of the antenna is a dimensionless quantity but it is of utmost importance. Gain of the antenna is in general the capability of the antenna to radiate in one particular direction as compared to the other directions or technically the ratio of the radiation intensity

in one direction to the radiation intensity if antenna were an isotropic radiator. The gain plots are shown in figures 3.7-3.9 at the resonant frequencies.

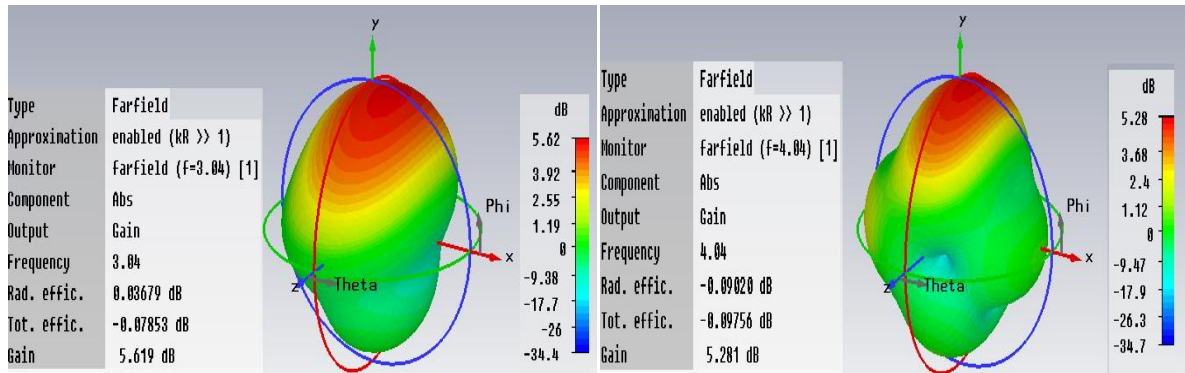


Fig 3.7 Gain Plots of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 3.04 GHz & 4.04 GHz

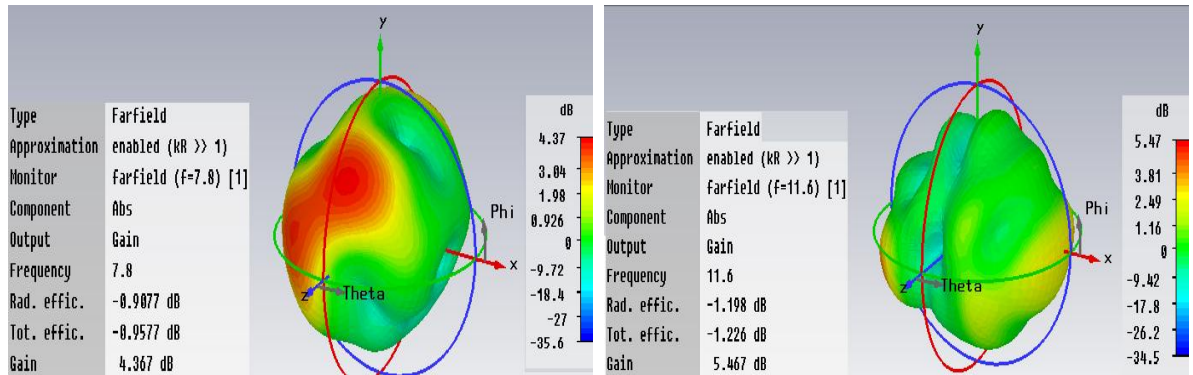


Fig 3.8 Gain Plots of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 7.8 GHz & 11.6 GHz

The gain at the resonant frequencies is 5.62dB, 5.28dB, 4.37dB and 5.47dB respectively. It can be concluded that the antenna has got a very good amount of gain at all the resonant frequencies which shows that the antenna is properly matched and possesses low amount of losses and leads to high directivity. Thus for the applications which require high directivity, this antenna can be a strong candidate and for UWB applications also.

3.5.3 Surface Current Distribution of Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground:

The surface current distribution gives some insight of the cause of the occurring of certain resonant frequency. By analyzing the current distribution it can be known which part of the

patch is more active for the resonance. Figure 3.9-3.12 shows the surface current distribution of the resonant frequencies. Peak currents obtained are 78.8 A/m, 91.5A/m, 142 A/m, 78.3 A/m at 3.03 GHz, 4.04 GHz, 7.8 GHz and 11.6 GHz respectively. It is also quite clear that the overlapping edges contribute a lot.

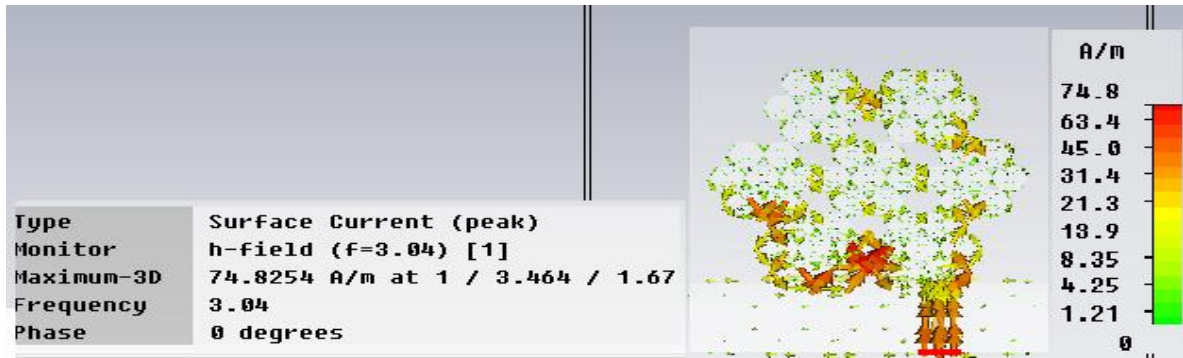


Fig 3.9 Surface Current Distribution of the Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 3.04 GHz

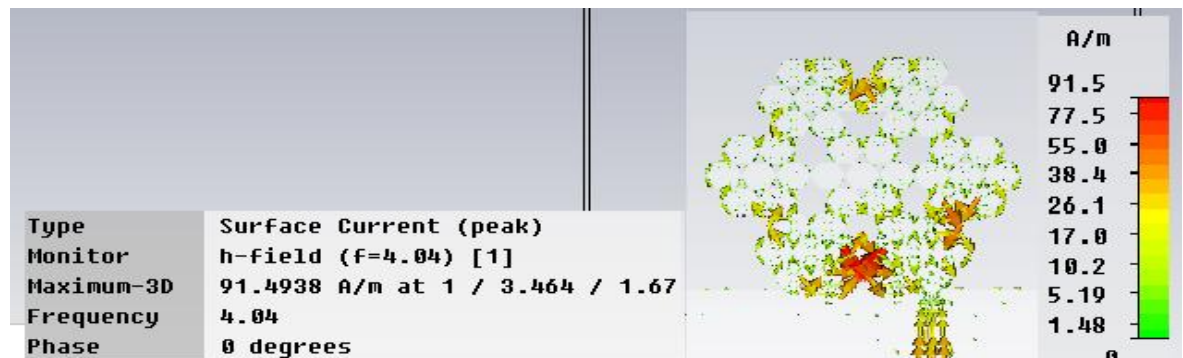


Fig 3.10 Surface Current Distribution of the Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 4.04 GHz

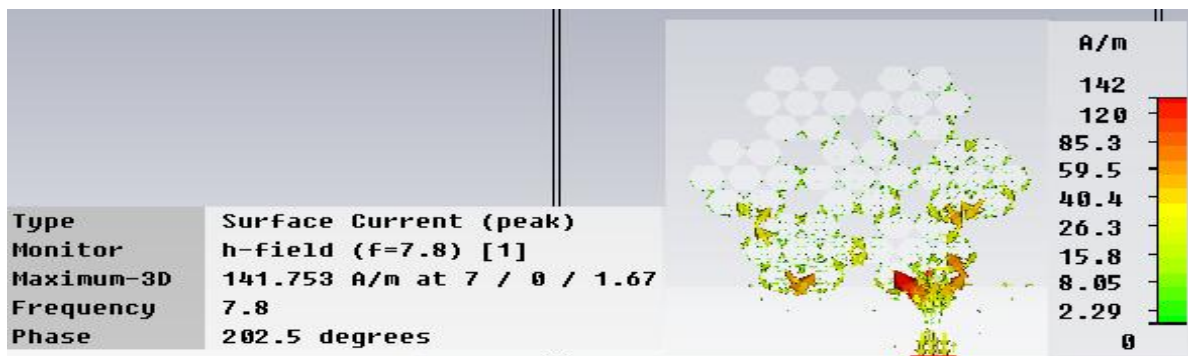


Fig 3.11 Surface Current Distribution of the Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 7.8 GHz

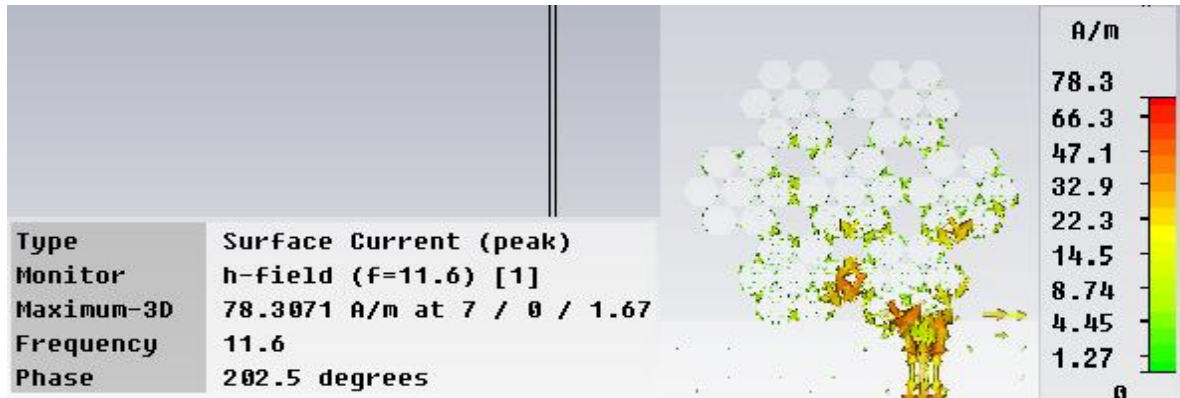


Fig 3.12 Surface Current Distribution of the Sierpinski Hexagonal Gasket Antenna with a Stub and Reduced Ground at 11.6 GHz

From the figure shown above a conclusion can be drawn that the resonances occurred mainly due to the more overlapping edges rest of the patch is inactive. The role of the stub has played a very important role in the antenna performance. At some resonant frequencies ground currents have also been effective.

3.5.4 Optimization of the Antenna parameters:

To achieve better performance dimensions of the stub have been optimized whose variation results in variations in the return loss and the results obtained with various dimensions are compared and the one with most suitable results have been selected as shown in figure 3.12.

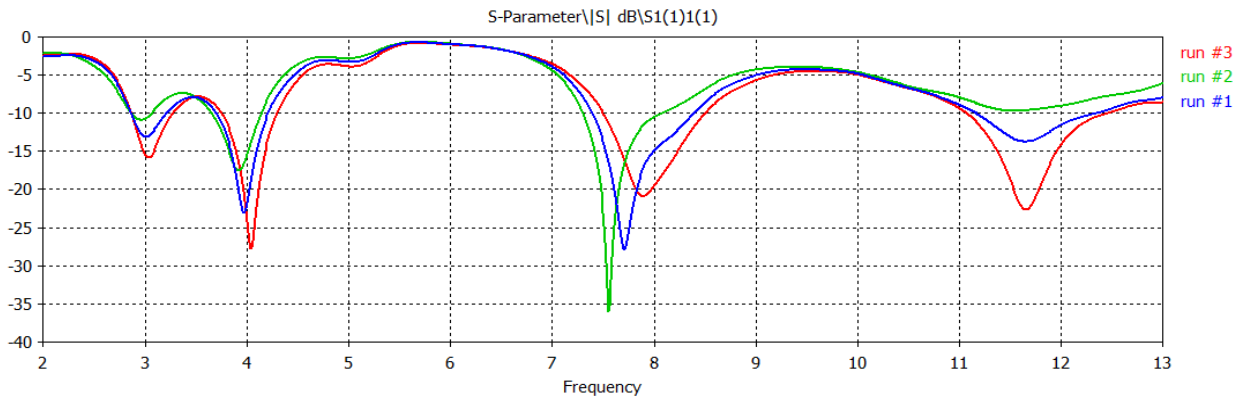


Fig 3.13 Optimization of the Stub Dimensions

The stub parameters at run 3 have been selected which give the better return loss at useful frequencies and the stub parameters are 2 mm along the Y-axis.

3.6 Design of Sierpinski Hexagonal wideband antenna:

The multiband behaviour is the basic property of the fractal antennas. Here this behavior is converted into wideband by applying the ground plane reduction and optimizing the feed line width shown in following figure.

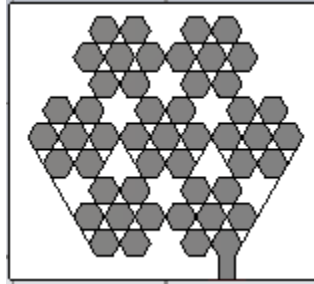


Fig 3.14 Design of Sierpinski Hexagonal Wideband Antenna

3.7 Simulation Results of Sierpinski Hexagonal Wideband Antenna:

3.7.1 Return Loss Plot of the Sierpinski Hexagonal wideband Antenna:

The return loss plot of this antenna shows that an antenna with the wide operating band is obtained. The dB value of the return loss is also very good, below -13dB for the entire operating band. The band covered is from 3.68-5.54 GHz with the bandwidth of 1.86 GHz as shown in the figure below.

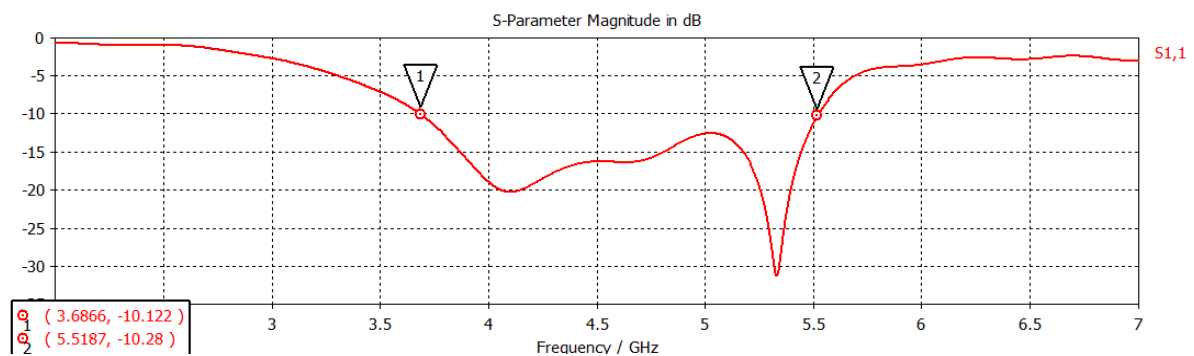


Fig 3.15 Return Loss Plot of the Sierpinski Hexagonal wideband antenna

Thus it can be concluded from the return loss plot of the antenna that it covers one band of WiMAX and one band of Wi-Fi. The antenna is applicable of other UWB applications also like location tracking etc.

3.7.2 Gain Plots of Sierpinski Hexagonal wideband Antenna:

The gain plots at some frequencies falling in the operating range of the antenna are shown in the figures 3.16-3.17. The gain depicts how well the antenna radiates in one direction as compared to others.

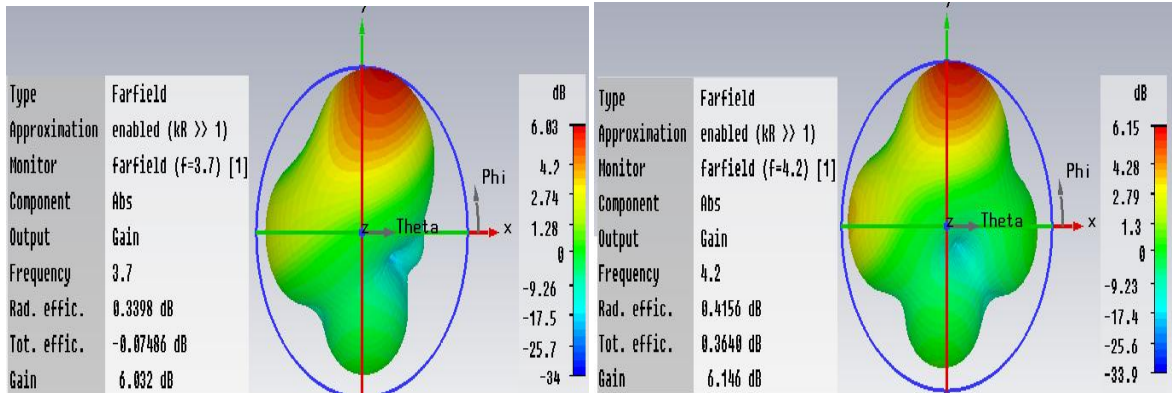


Fig 3.16 Gain Plot of Sierpinski Hexagonal Wideband Antenna at 3.7 GHz and 4.2 GHz

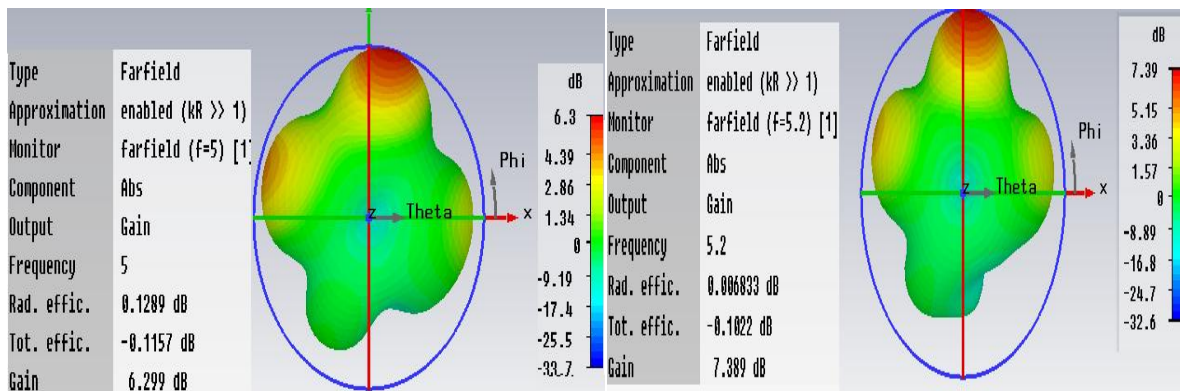


Fig 3.17 Gain Plot of Sierpinski Hexagonal Wideband Antenna at 5 GHz and 5.2 GHz

The gain plots shown above shows that the antenna is a very good gain antenna and has the 6.53dB, 6.15dB, 6.3dB and 7.39dB at 3.7 GHz, 4.2 GHz, 5 GHz and 5.2 GHz respectively. This antenna proved to be a good bandwidth and gain antenna which make it just a perfect candidate for some of the UWB and WLAN applications.

3.7.3 Surface Current Distribution of Sierpinski Hexagonal wideband Antenna:

The surface current distribution of this antenna at some frequencies falling in the operating band is shown in the figures 3.18-3.21. The distribution shows that the currents are distributed over the entire patch which leads to ultra wide band behaviour. The currents are

49.9 A/m, 49.2A/m, 63.2A/m, 64.5 A/m at 3.7 GHz, 5.2 GHz, 4.2 GHz, 5.2 GHz, 55.2 GHz, and 5.2 GHz respectively.

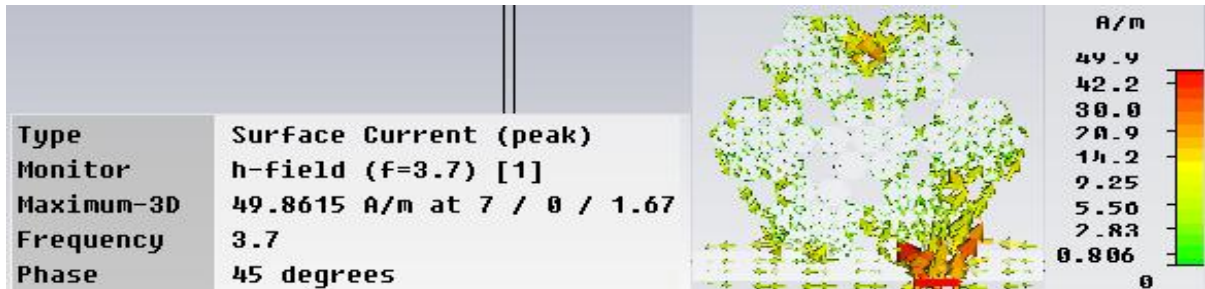


Fig 3.18 Surface Current Distribution of Sierpinski Hexagonal Wideband Antenna at 3.7 GHz

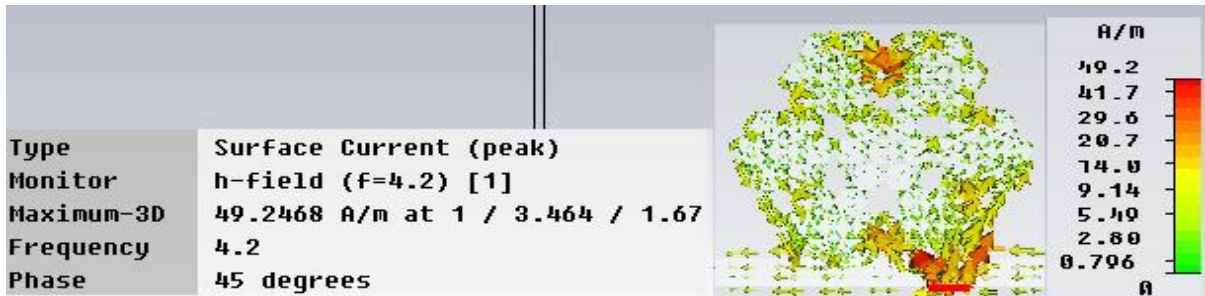


Fig 3.19 Surface Current Distribution of Sierpinski Hexagonal Wideband Antenna at 4.2 GHz

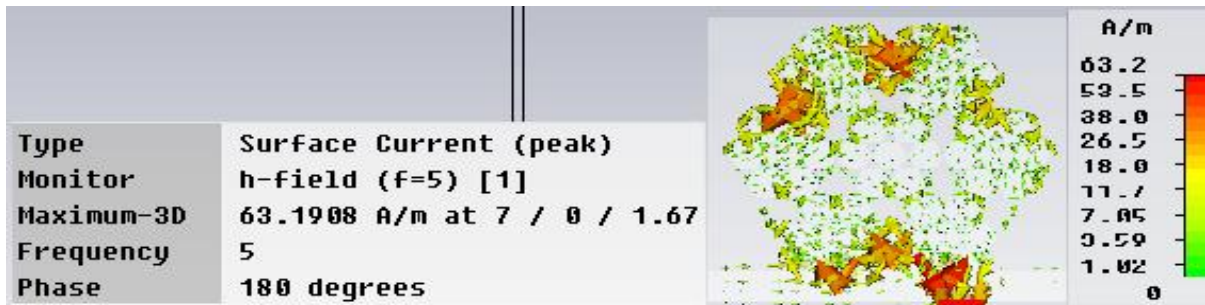


Fig 3.20 Surface Current Distribution of Sierpinski Hexagonal Wideband Antenna at 5 GHz

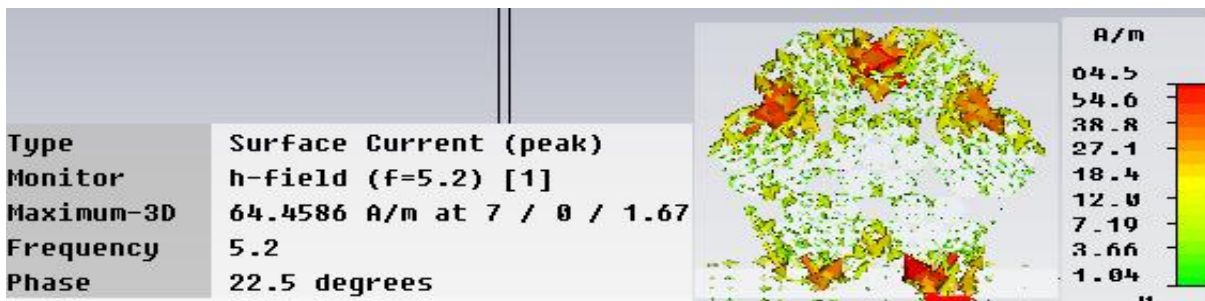


Fig 3.21 Surface Current Distribution of Sierpinski Hexagonal Wideband Antenna at 5.2 GHz

The figures shown above reveals the cause of the ultra wide band behavior of the antenna is the flow of the current over the entire patch. The red color shows the maximum amount of current flowing and the green shows the minimum flow of current.

3.7.4 Optimization of the Ground Plane and the Stub Dimensions:

The antenna results are optimized by varying the dimensions of the stub and the length of the ground plane. Among all the results one with the best outcomes are selected as shown in figure 3.22-3.23.

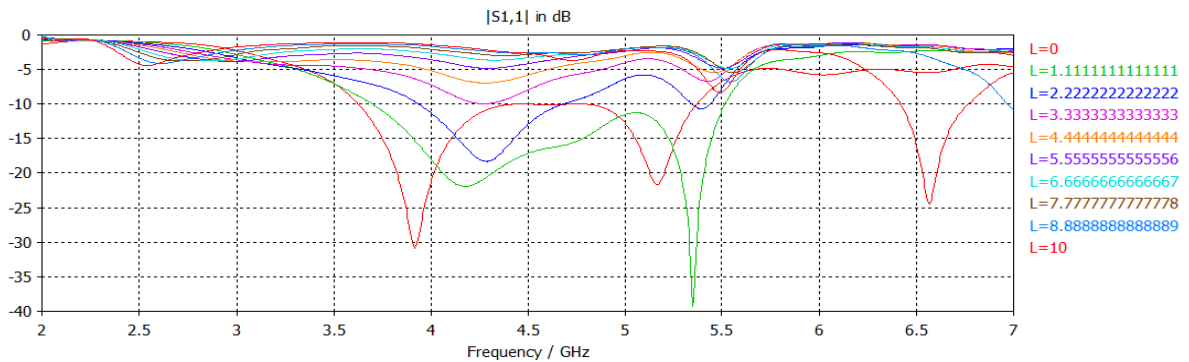


Fig 3.22 Optimization of the Length of the Ground Plane of Sierpinski Hexagonal Wideband Antenna

As it is clear from the figure 3.22 that among the entire plots one with the value $L=1.1$ shows the best results. The return loss is much better at this value as compared to others so the length of the ground plane is taken equal to 11.1 mm. After optimizing the ground plane dimensions the feed line width have been optimized. Figure 3.23 shows how the return loss plot varies by varying the feed width. The feed width value taken in run 4 has been selected which is 2mm.

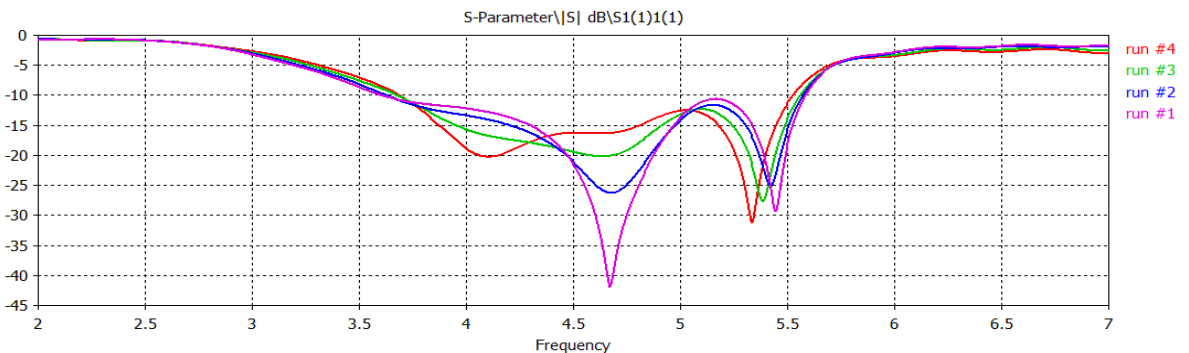


Fig 3.23 Optimization of the Feed Line Width Sierpinski Hexagonal Wideband Antenna

3.8 Conclusion:

In this chapter design of Sierpinski hexagonal gasket antenna is presented. Further the multiband antenna with fair amount of gain is obtained by using reduced ground and a tuning stub. The antenna behavior is converted to wideband behavior by variations in the feed line width and the gain is also improved.

CHAPTER-4

DESIGN OF A PYTHAGOREAN FRACTAL TREE ANTENNA FOR UWB APPILICATIONS

4.1 Introduction:

UWB applications require antenna geometries having ultra wide bandwidth, small size, high gain and multiband behaviour. In this chapter a novel design a Pythagorean tree antenna has been presented. This antenna has been designed using the Pythagoras theorem. According to this theorem the triangle enclosed by three touching squares is always the right angle triangle [18].

4.2 Design of Pythagorean Fractal Tree Antenna:

The antenna has been designed and simulated using the CST Microwave Studio V2010. The substrate chosen for the design is FR-4 with dielectric constant equal 4.4 and thickness 1.6mm and the thickness of the copper is taken as .35mm.

While designing the tree the dimension of the bigger square patch is taken equal to 19mm. The antenna is fed using CPW feed and matching is done by varying the feed dimensions and the gap between the feed and ground plane. Figure 4.1 shows the design of the antenna after first and second iteration.

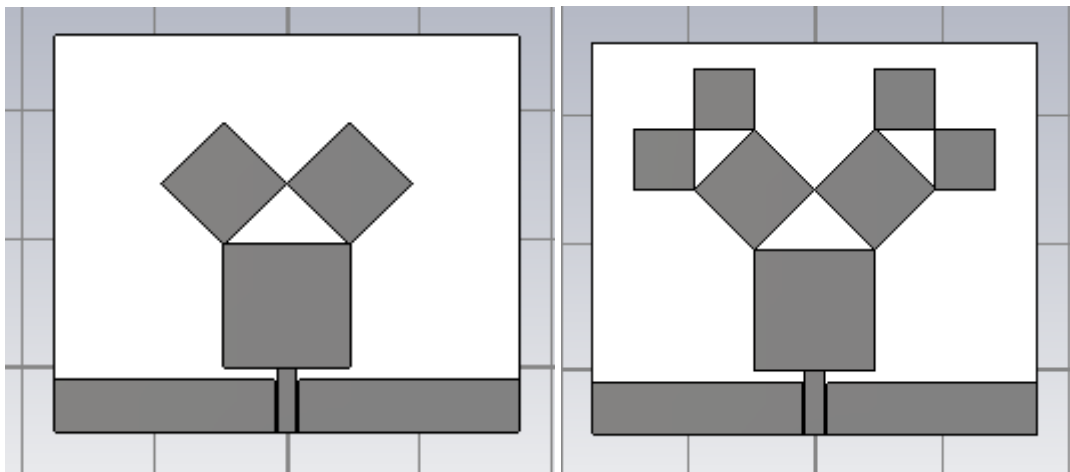


Fig 4.1 Geometry of the Pythagorean Fractal Tree Antenna

4.3 Simulation Results of Pythagorean Fractal Tree Antenna:

The simulation results such as antenna return loss, bandwidth and gain are shown in the following figures.

4.3.1 Pythagorean Tree Antenna Return Loss plots and Bandwidth:

The antenna has been designed using the Pythagorean tree. Two fractal iterations have been performed to create the tree as shown in figure 4.1. The simulation results of the S_{11} shows after first and second iterations as shown in figures 4.2-4.3 reveals that that it is a dual-band antenna and it is also vivid from the return loss plot that the antenna is properly matched with the feed line with low reflection losses.

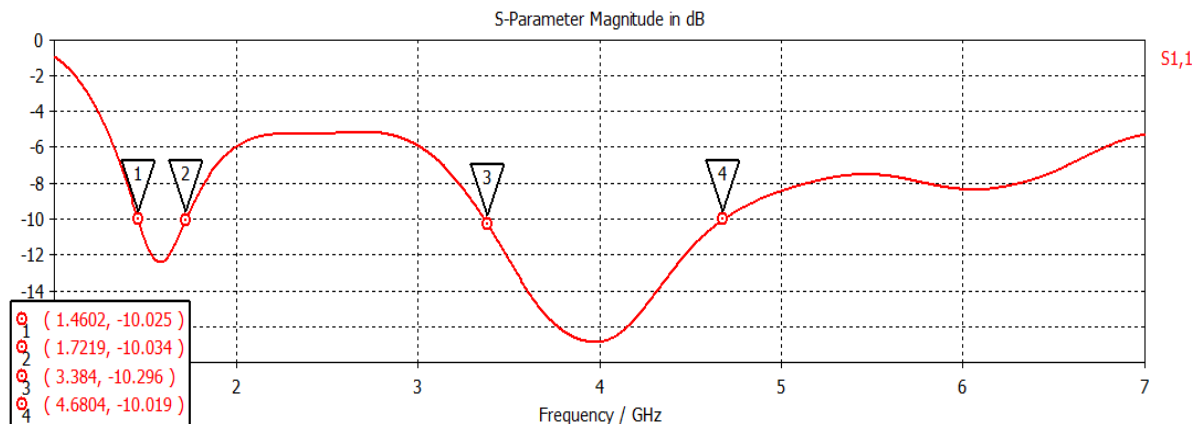


Fig 4.2 Return Loss Plot of the Pythagorean Fractal Tree Antenna after First Iteration

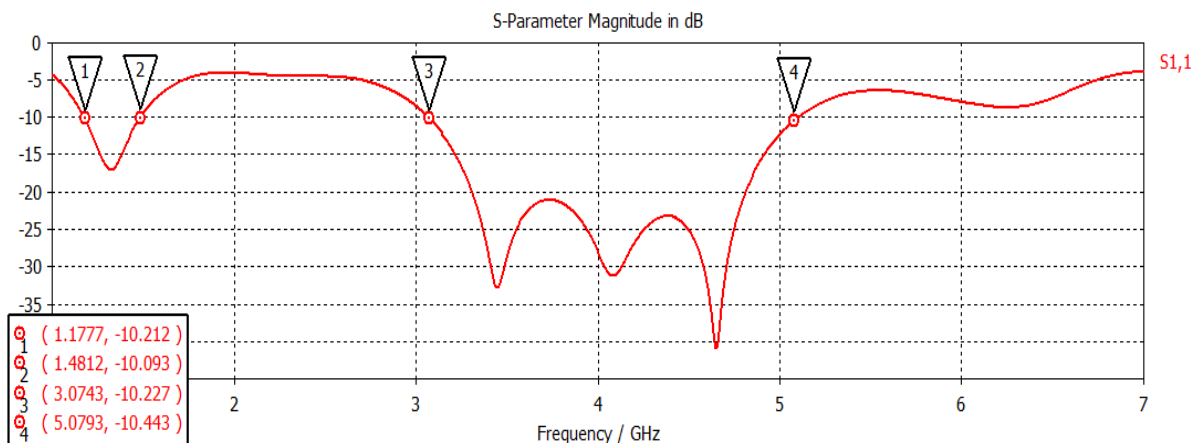


Fig 4.3 Return Loss Plot of the Pythagorean Fractal Tree Antenna after Second Iteration

Figure 4.2 shows the return loss plot of the proposed antenna after first fractal iteration. The plot has dual band behaviour but the return loss and bandwidth around these bands is not really good so the second fractal iteration is applied.

After applying the second iteration the return loss of the operating bands has been improved and the bandwidth has also got increased as shown in figure 4.3. The range of the bands obtained was from 1.164-1.492 GHz and 3.0568-5.1 GHz. The bandwidth of the antenna around 1.3 GHz is 382 MHz and around 4 GHz is 2.04 GHz. This antenna can be a good antenna for UWB and WiMAX applications.

4.3.2 Gain Plots of the Pythagorean Fractal Tree Antenna:

Gain plot of the antenna depicts the efficiency and the directivity of the antenna. It accounts for how efficiently the antenna radiates in a particular direction as compared to other directions. This antenna has got very good gain as shown in figures 4.4-4.5.

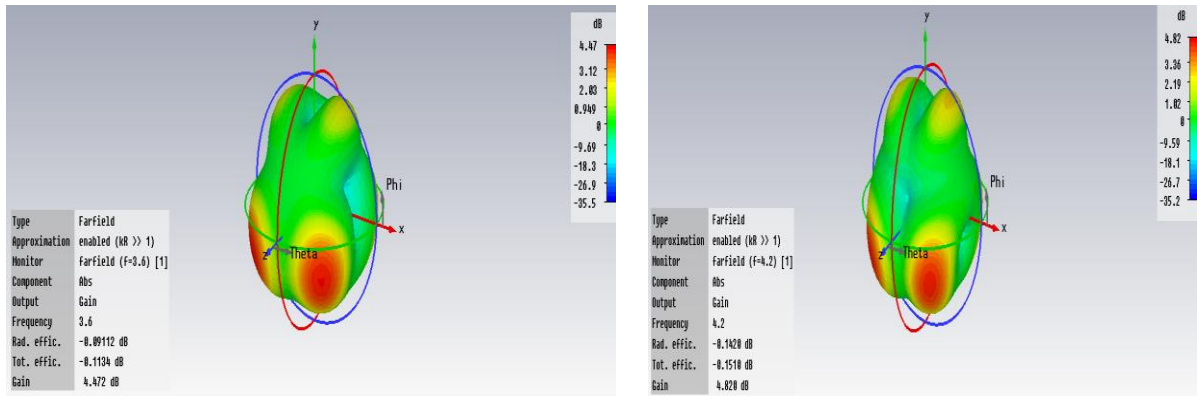


Fig 4.4 Gain Plot of Pythagorean Fractal Tree Antenna at 3.6 GHz & 4.2 GHz

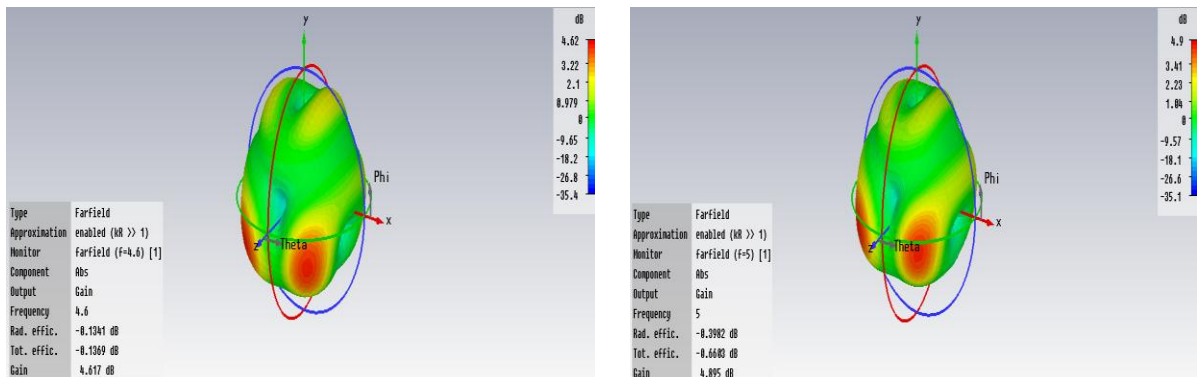


Fig 4.5 Gain Plot of Pythagorean Fractal Tree Antenna 4.6 GHz & 5 GHz

The gain plots shown above show that the antenna has very good gain. It has got a gain of 4.41dB, 4.32dB, 4.4dB and 4.9dB at 3.6 GHz, 4.2 GHz, 4.6 GHz and 5 GHz respectively and makes it really suitable for UWB applications.

4.2.3 Surface Current Distribution of the Pythagorean Fractal Tree Antenna:

The surface current distribution is very important parameter and depicts which part of the antenna is responsible for a particular frequency. The surface current distributions at some frequencies are shown in the figures 4.6-4.9.

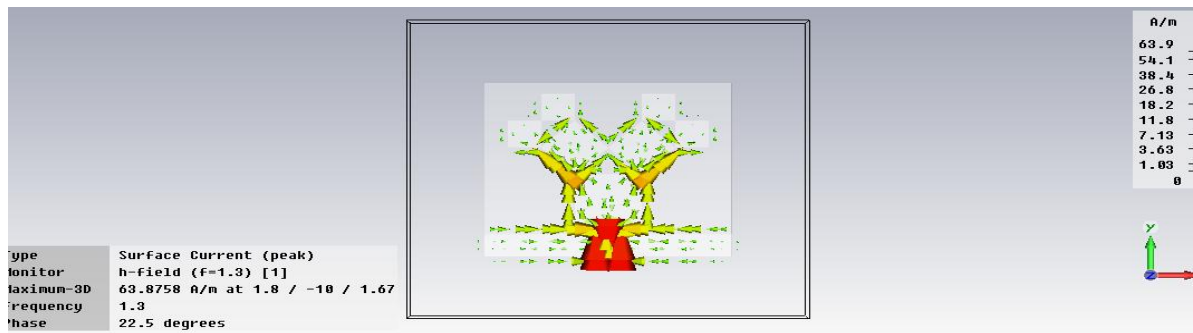


Fig 4.6 Surface Current Distribution of Pythagorean Fractal Tree Antenna at 1.3 GHz

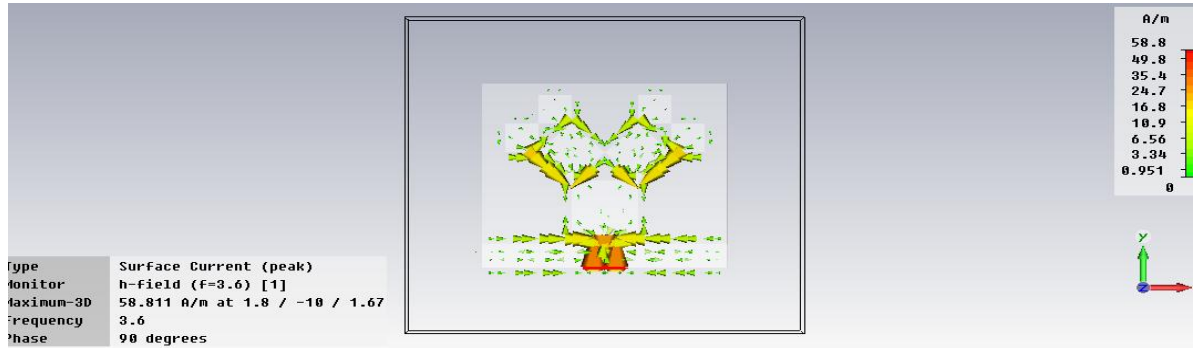


Fig 4.7 Surface Current Distribution of Pythagorean Fractal Tree Antenna at 3.1 GHz

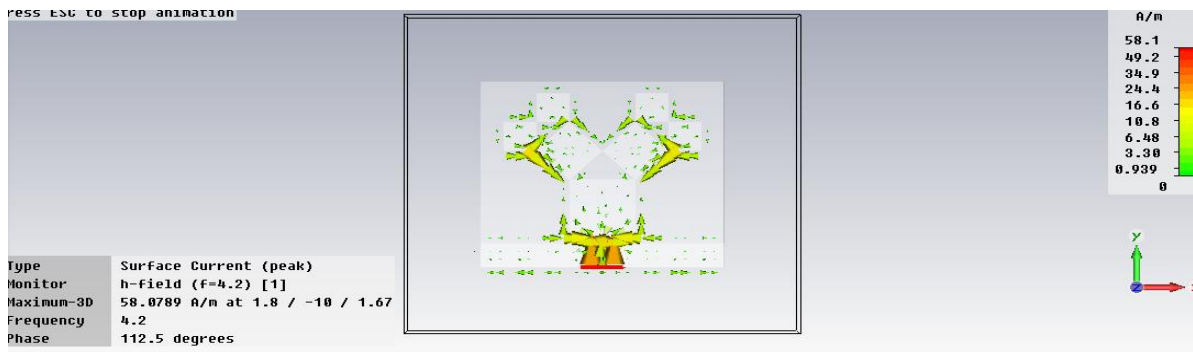


Fig 4.8 Surface Current Distribution of Pythagorean Fractal Tree Antenna at 4.2 GHz

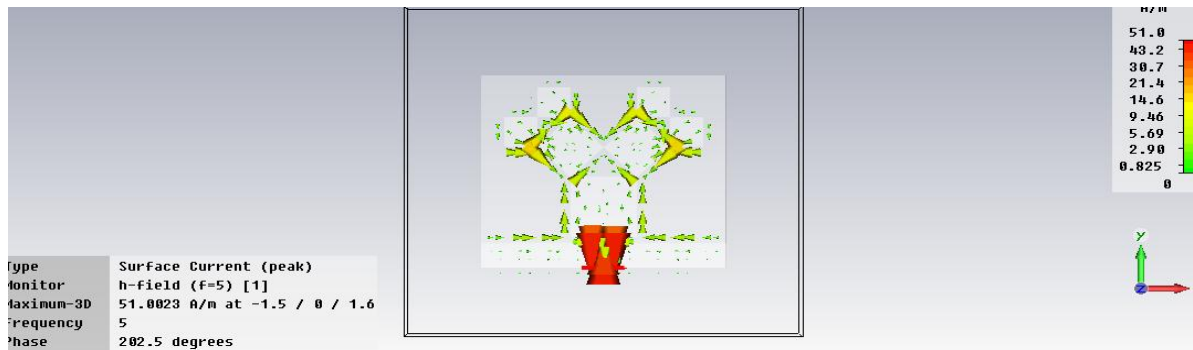


Fig 4.9 Surface Current Distribution of Pythagorean Fractal Tree Antenna at 5 GHz

As it can be concluded from the above figures that the currents are distributed all over the patch, edges of the patch, feed line and the ground plane electrodes which lead to wide band behaviour of the antenna.

4.2.4 Parameter Optimization of the Pythagorean Fractal Tree Antenna:

The parameters which affect the antenna performance always need to be optimized. In this case the gap between the feed line and the ground plane electrodes has been optimized which led to improvement in the return loss of approximately -10dB.

Among all the different parameters ones which help to obtain the best response have been chosen. The gap between feed line and the ground plane electrodes is varied and recorded and shown in the figure 4.10.

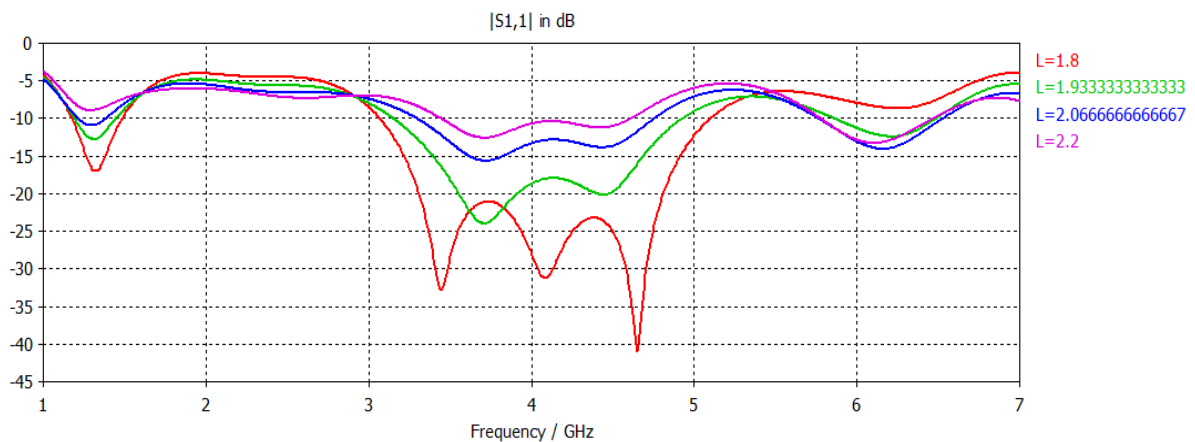


Fig 4.10 Optimization of the Gap between the Ground Plane and the Feed Line

Now the gap between the patch and the ground plane is optimized so that the results are optimized and the one with the best response is selected. Thus the gap between the ground and feed line is chosen equal to 1.8 mm.

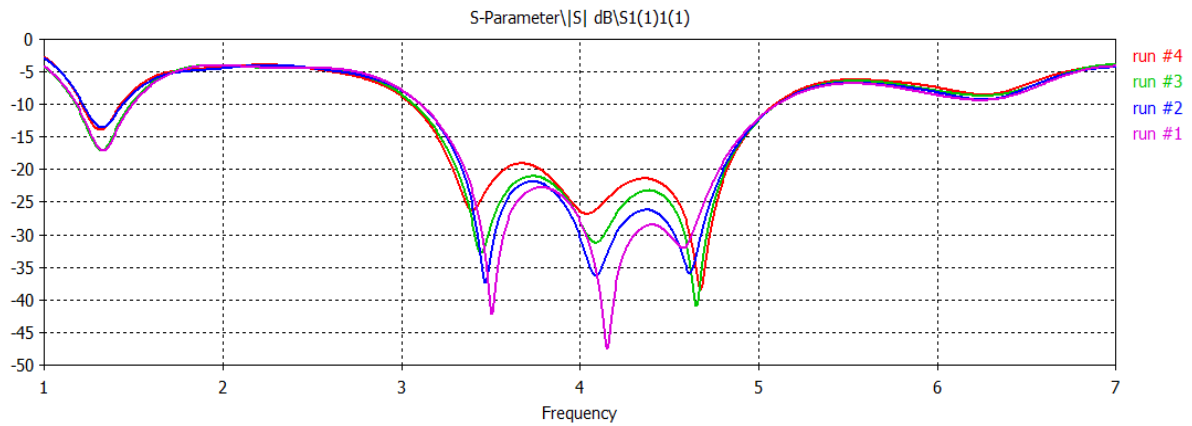


Fig 4.11 Optimization of the Gap between the Ground Plane and the Patch

Thus from the above shown results it is clear that the antenna is good candidate for radiolocation, UWB and WLAN applications. Due to high gain this antenna can be very good for those applications which require directional radiation pattern

4.3 Conclusion:

In this chapter a fractal Pythagorean tree antenna has successfully been designed and simulated using CST Microwave studio. The antenna behaviour is wideband and has good amount of gain which makes it a strong contender for UWB applications. The antenna parameters are optimized in order to obtain the best results.

CHAPTER-5

DESIGN OF FRACTAL FLOWER ANTENNA FOR UWB AND MOBILE APPLICATIONS

5.1 Introduction:

This chapter presents the design of a novel fractal type flower antenna. The featured advantage of the fractal antennas is the Multiband behavior and size reduction. The size reduction is the obtained by using this new antenna design. All these advantages make this antenna suitable for mobile and UWB applications.

5.2 Design of Fractal Flower Antenna:

In this chapter the circular monopole disc antenna is presented and only first iteration is performed on its periphery. The antenna is fed using the CPW feed. The antenna is modeled and simulated using CST Microwave Studio V 2010.

The radius of the circular monopole antenna is taken equal to 7mm and the copper thickness is taken equal to .035mm. the antenna is designed using the FR-4 epoxy substrate with dielectric constant equal to 4.4, thickness 1.6mm and .0009 as loss tangent. The initiator geometry and its return loss plots are shown in figures 5.1-5.2.

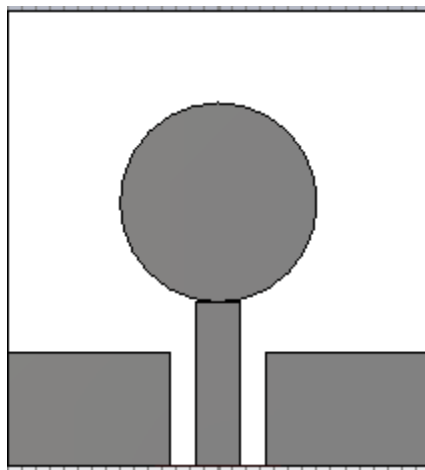


Fig 5.1 Circular Monopole Disc Antenna with CPW Feed

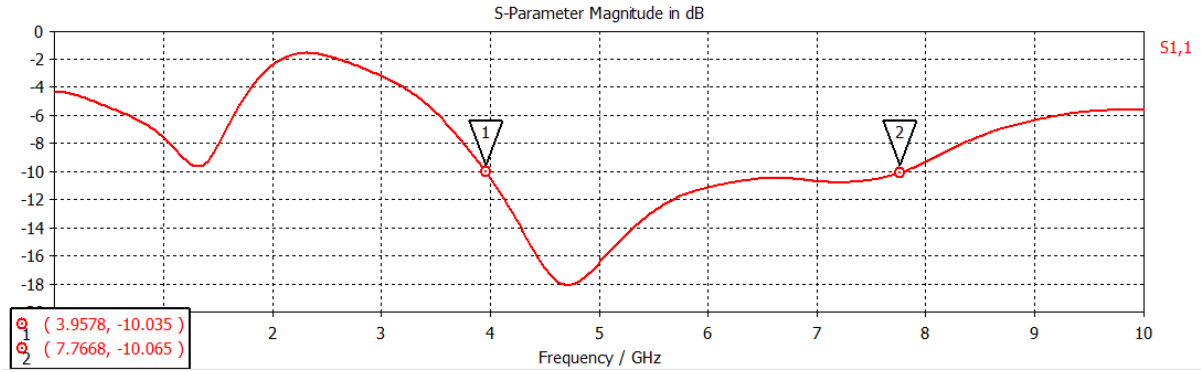


Fig 5.2 Return Loss Plot of the Circular Monopole Disc Antenna with CPW feed

The return loss plot of the Circular monopole disc antenna shows that the antenna is a wideband antenna covering a large bandwidth of the UWB band and another band around 1.3 GHz.

5.3 Circular Monopole Disc Antenna after First Fractal Iteration (Fractal Flower):

From the figure 5.2 it can be concluded that the return loss is not very good at the operating band so to improve the return loss and to shift the entire band towards the desired frequencies next iteration is done. The circumference of the monopole antenna has been increased by modifying it in other words by applying fractal iteration at the same.

Major advantage which has been gained by this technique is size reduction; size of the antenna gets reduced by 50%. The feeding technique used in this case is CPW. The antenna after applying first iteration is shown in figure 5.3.

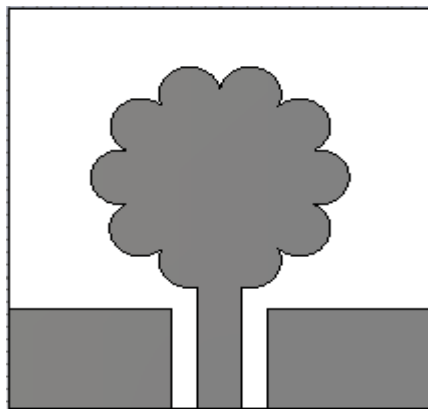


Fig 5.3 Circular Monopole Disc Fractal Flower Antenna with CPW feed

5.4 Simulation Results of Circular Monopole Disc Fractal Flower Antenna:

Various simulation results of the flower antenna are explained and shown below:

5.4.1 Return Loss Plot Circular Monopole Disc Fractal Flower Antenna:

The return loss plot shown in the figure 5.4 reveals that this antenna is an ultra wideband antenna. Two bands are obtained after simulation from .83-1.42 GHz and 3.8-8 GHz. Thus the antenna covers the full range of Wi-Fi and WiMAX and also covers some other useful frequencies for UWB application and GSM mobile applications.

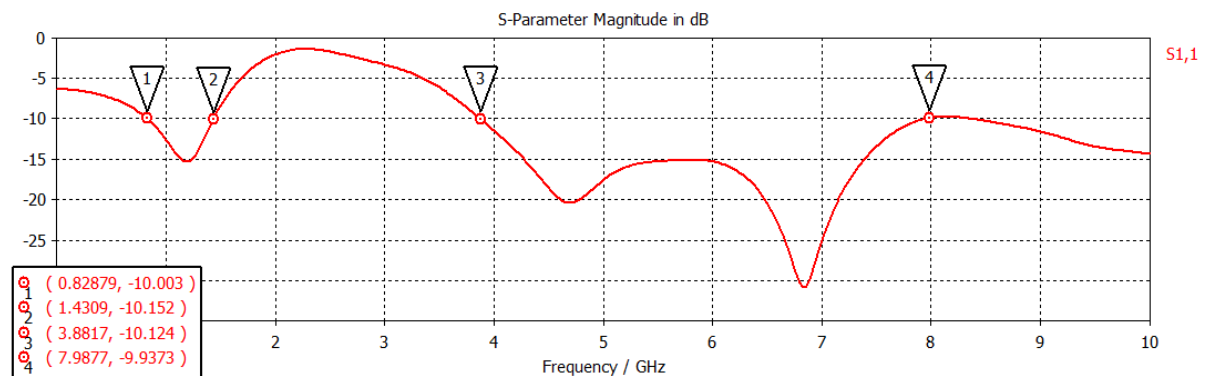


Fig 5.4 Return Loss Plot Circular Monopole Disc Fractal Flower Antenna

As it can be concluded from the return loss plot shown above that the antenna is properly matched. The return loss is below -15dB for both the operating bands. The bandwidth of the first band is 590MHz and bandwidth of the second band is 4.2 GHz.

The proposed antenna is applicable for the GSM-900MHz band application which is 880-960MHz. the second band is useful for Wi-Fi/WiMAX and UWB band applications.

5.4.2 Gain Circular Monopole Disc Fractal Flower Antenna:

The gain of the antenna is simply the measure of the capability or the extent of the antenna to which it can radiate in some direction. Instead of being a dimensionless quantity it is a direct measure of the directivity and efficiency of the antenna. The gain plots at some frequencies falling in the operating band of the antenna are shown below.

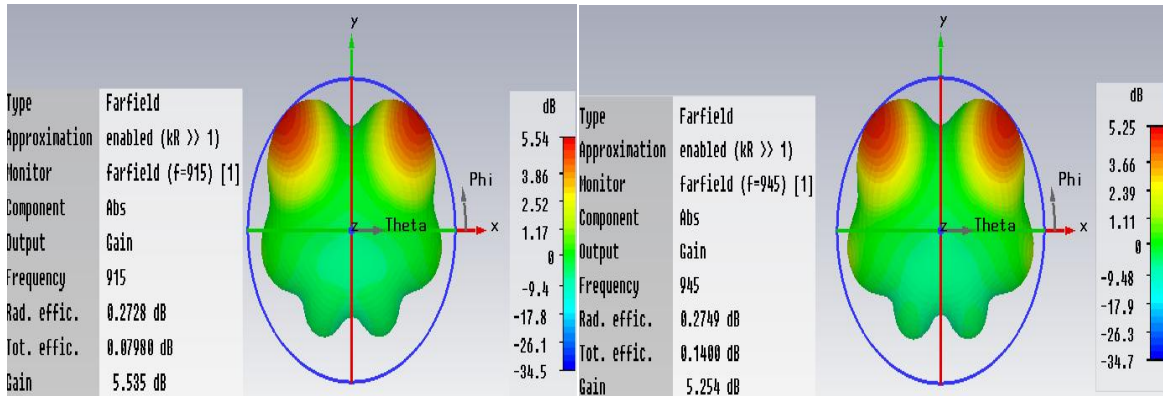


Fig 5.5 Gain Plot of the Fractal Flower Antenna at 915 MHz & 945 MHz

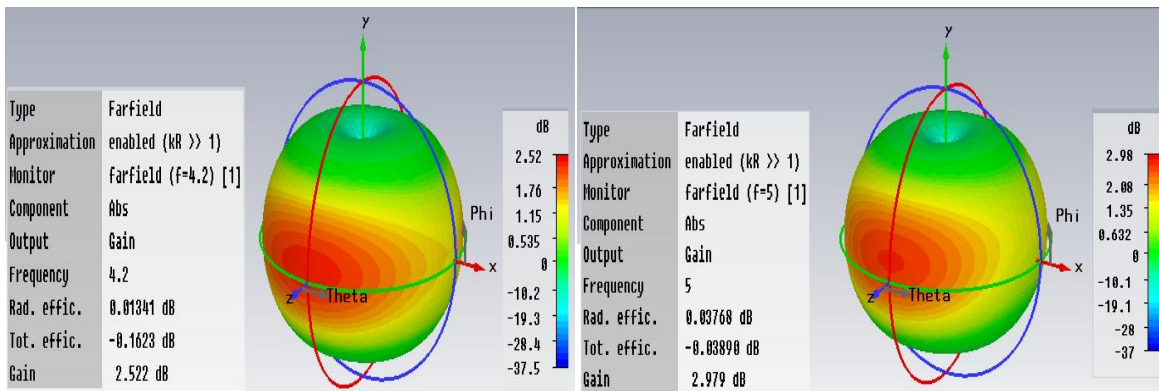


Fig 5.6 Gain Plot of the Fractal Flower Antenna at 4.2 GHz & 5 GHz

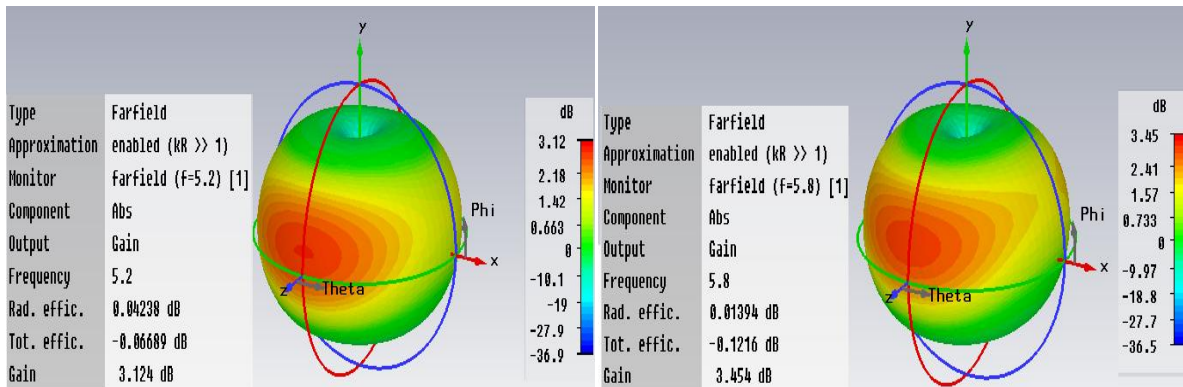


Fig 5.7 Gain Plot of the Fractal Flower Antenna at 5.2 GHz & 5.8 GHz

From the gain plots it is clear that antenna gives reasonable amount of gain at GSM 900MHz band frequencies. Thus the proposed antenna can be a very good candidate for the GSM mobile applications. The less amount of gain at UWB frequencies can be due to the large bandwidth of the antenna because the gain bandwidth product is always a constant.

5.4.3 Surface Current Distribution of the Fractal Flower Antenna:

The distribution of the surface currents gives good insight into the antenna behavior up to certain extent. The distribution of currents reveals what part of the patch is responsible for the occurrence of certain resonance frequency. Surface currents at those frequencies which fall in the operating bands of the antenna are shown in figures 5.8-5.12.

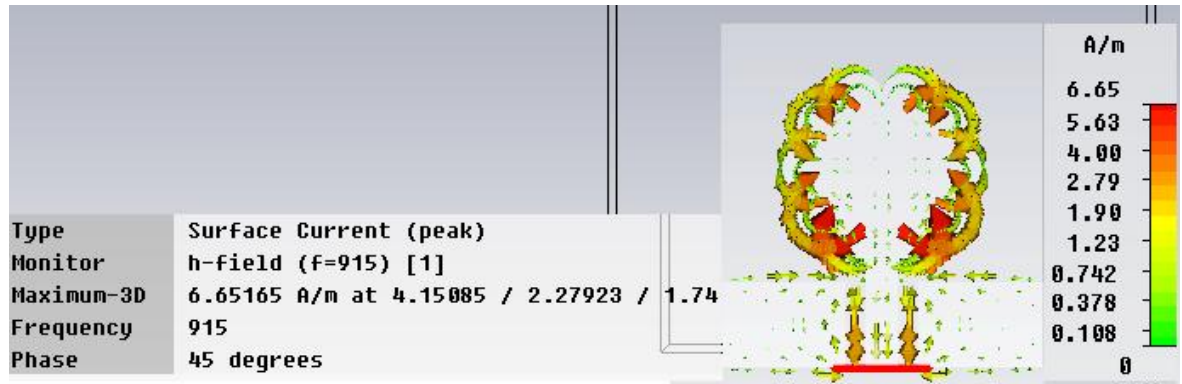


Fig 5.8 Surface Current Distribution of Fractal Flower Antenna at 915 MHz

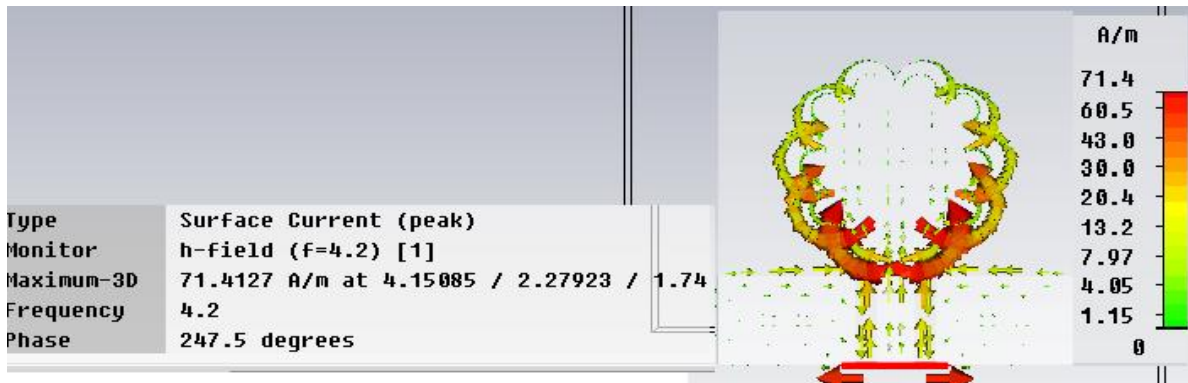


Fig 5.9 Surface Current Distribution of Fractal Flower Antenna at 4.2 GHz

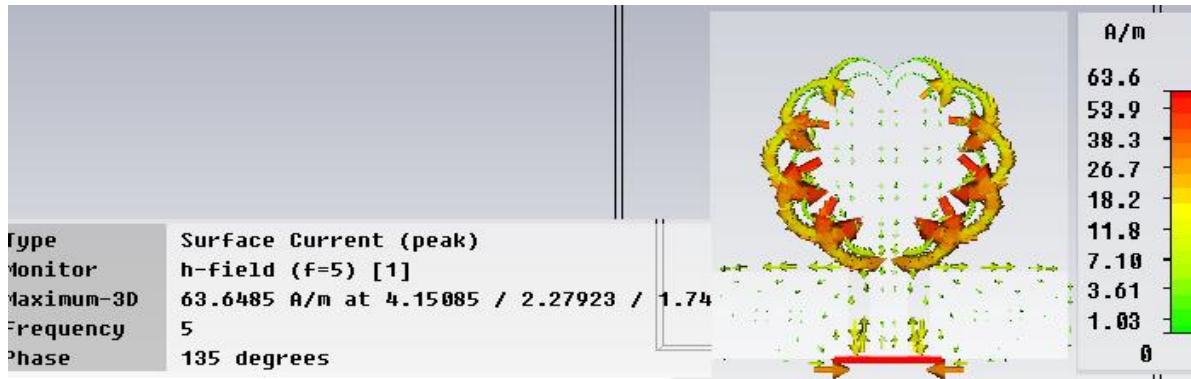


Fig 5.10 Surface Current Distribution of Fractal Flower Antenna at 5 GHz

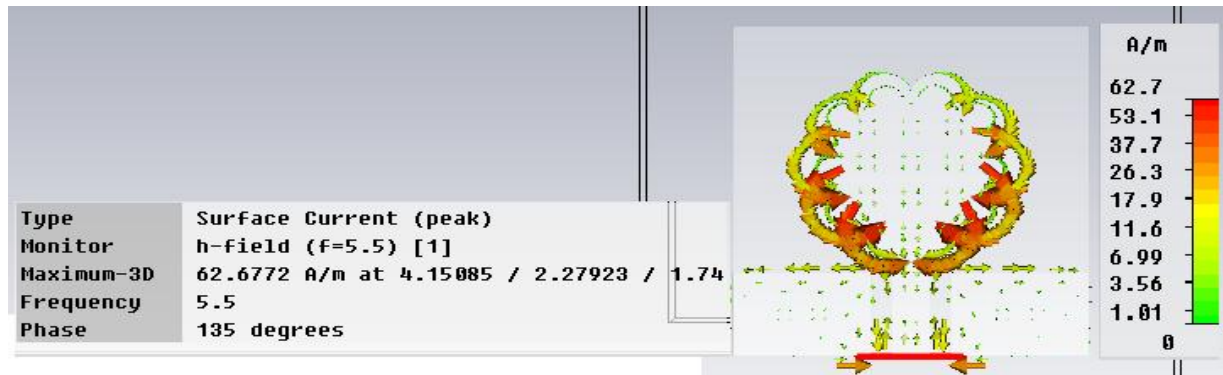


Fig 5.11 Surface Current Distribution of Fractal Flower Antenna at 5.5 GHz

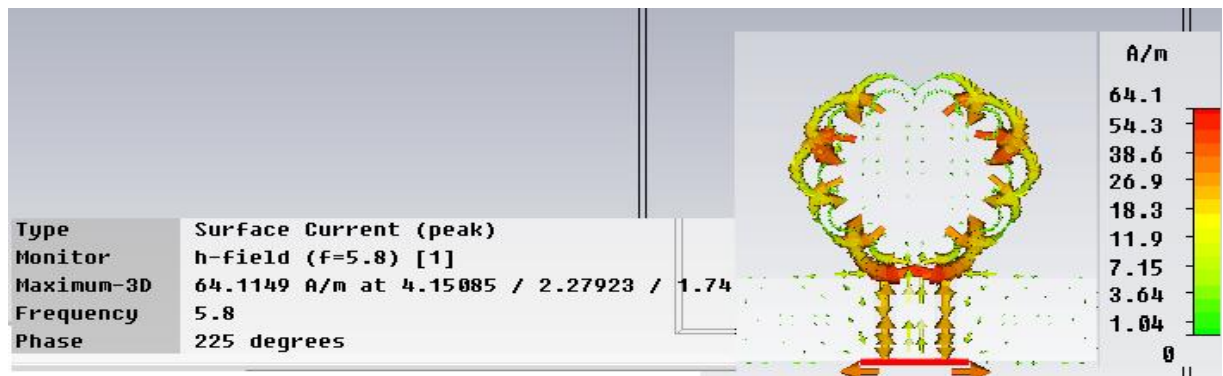


Fig 5.12 Surface Current Distribution of Fractal Flower Antenna at 5.8 GHz

The current distribution at 915MHz shows that due to increased circumference of the flower patch the path through which the current travels get elongated which further leads to increased electrical length and lower resonant frequency. Thus this type of geometry has proved useful for reducing the size by almost 50%.

The distribution of current at frequencies falling in the UWB band shows that the currents are distributed all over the patch around the circumference of the flower, feed line and also the ground electrodes, which leads to the ultra wide band behaviour of the antenna.

5.4.4 Optimization of the Fractal Flower antenna Parameters:

In order to get optimized results the parameters such as the gap between the feed line and the ground plane, and the ground plane and patch has been optimized. The optimized results and values are shown figures 5.13-2.14.

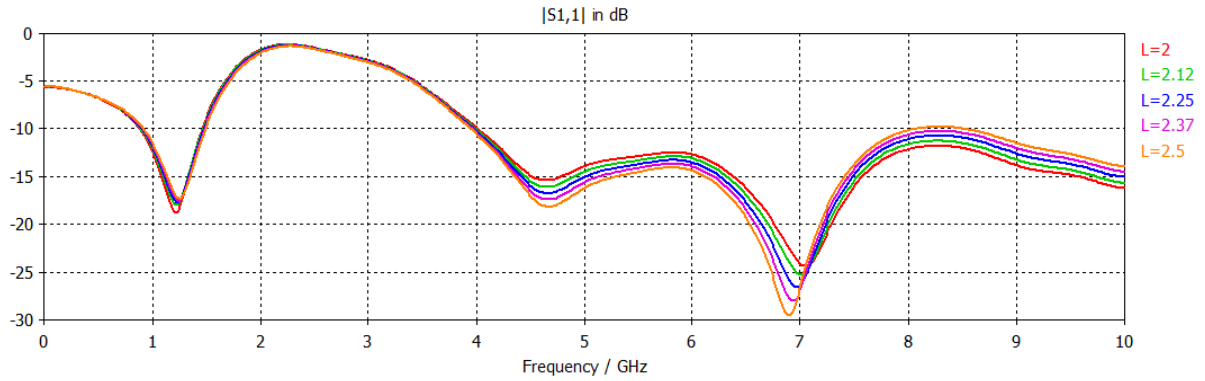


Fig 5.13 Optimization of the Gap between Ground Plane and Patch

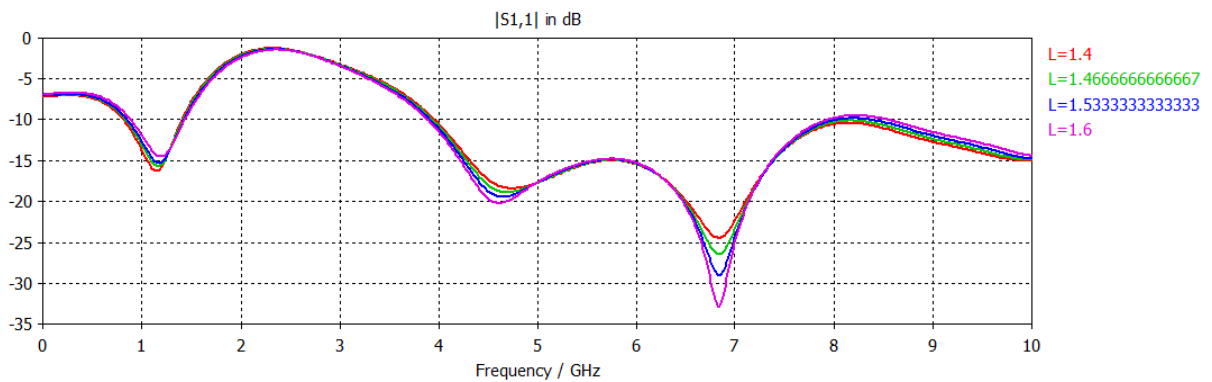


Fig 5.14 Optimization of the Gap between Ground Plane and Feed Line

From the above two graphs it can be concluded that when the gap between the ground plane and the patch is 2mm and the gap between the ground plane and the feed is 1.6mm the antenna delivers best results so these parameters are selected for the proposed design.

5.5 Conclusion:

In this chapter an antenna named fractal flower circular monopole disc antenna is presented. The antenna results after simulation are studied and it is found that this antenna can be used for 900MHz GSM applications and UWB applications. Further in order to get desired results the antenna parameters are optimized.

CHAPTER-6

DESIGN OF SIERPINKSI GASKET BOW-TIE ANTENNA FOR UWB, ISM AND MOBILE APLLICATIONS

6.1 Introduction:-

In this chapter the design of a bow-tie antenna with Sierpinski gasket fractal geometry applied on it is presented. The conventional bow-tie antenna is very good candidate for applying fractal geometry due to its multi-frequency [42]. This antenna has become so popular because of its smaller size as compared to the conventional rectangular patch antenna. The antenna has been designed for the UWB and mobile applications.

6.2 Design of Sierpinski Gasket Bow-Tie Antenna:-

The substrate used while designing this antenna is FR-4 with thickness 1.6mm and having dielectric constant 4.4, the side length of the equilateral triangle is 20mm and the thickness of the copper layer is taken as .035mm. The matching of the feed line is done through an iterative process. The antenna has been designed and simulated using CST Microwave Studio Suite 2010. Figure 6.1 shows the design of the conventional bow-tie triangular patch antenna

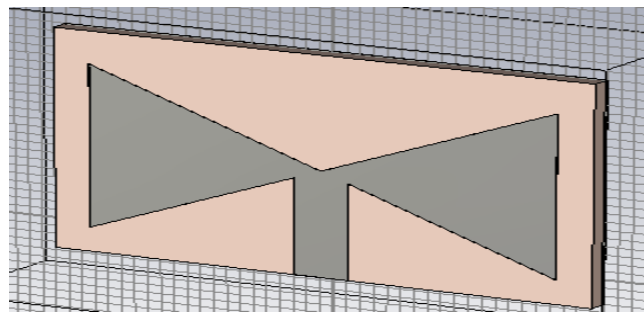


Fig 6.1 Design of the Conventional Bow-Tie Antenna

6.3 Simulation Results of Bow-Tie Antenna:-

6.3.1 Return Loss Plot of the Bow-Tie antenna after Zeroth Iteration:

This antenna is designed to operate on 2 GHz. The antenna is fed using Micro strip feed line which is matched through an iterated manner. The S_{11} plot which is shown in figure 6.2

shows that the antenna coupling is really good. This antenna covers the two bands and as it is clear that the antenna is an ultra wide band antenna and covers the most of the UWB range.

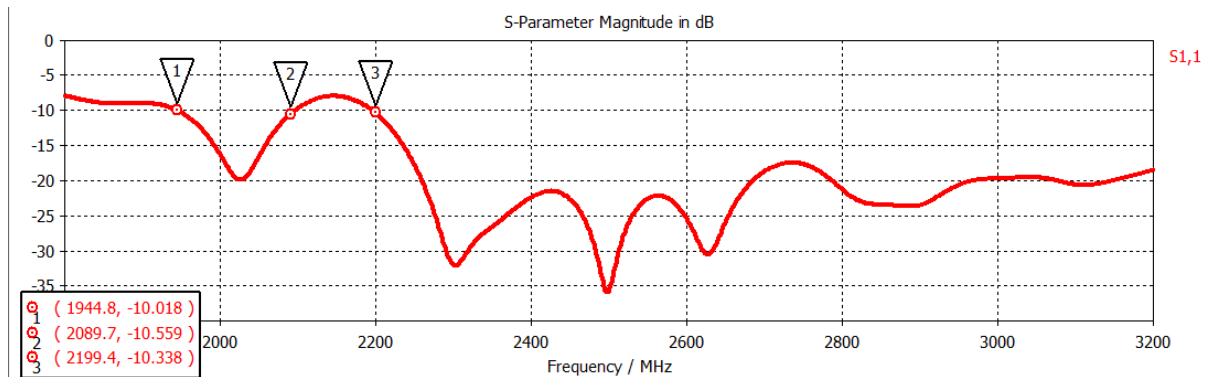


Fig 6.2 Return Loss Plot of the Conventional Bow-Tie Antenna

As it is quite clear from the return loss plot of the return loss plot that this antenna is an ultra wide band antenna which covers the ISM band and UWB band. The first band is around 2.1 GHz around which the bandwidth is 225 MHz and the second band starts from 2200 MHz covering ISM and UWB application band. To shift the plot towards left next Sierpinski iteration is done which is explained in the next section.

6.4 Return Loss Plot after the First Sierpinski Iteration:

As it is known after applying the Fractal iterations the antenna starts resonating at lower frequencies due to increased path for the currents to travel. Same has been done here by applying the first Sierpinski iteration as shown in figure 6.3 which has helped to lower the resonant frequency of the antenna.

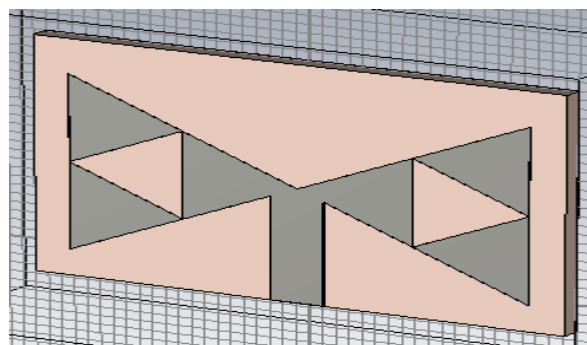


Fig 6.3 Bow-Tie Antenna after the First Sierpinski Iteration

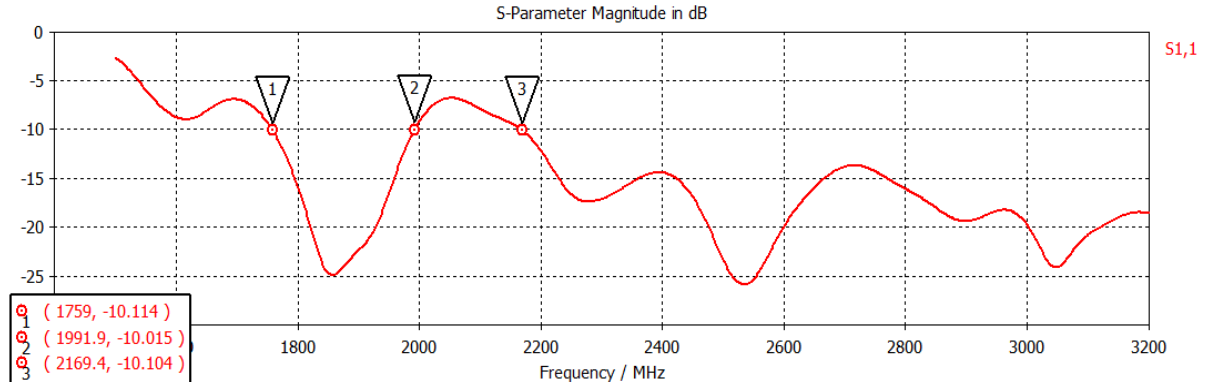


Fig 6.4 Return Loss Plot of the Bow-Tie after First Sierpinski Iteration

So it can be concluded from the above plot that the resonance has been shifted to the left i.e. antenna started resonate at lower frequencies. Now this antenna covers two band one around the 1850 MHz and other starting from 2190 MHz covering GSM and UWB applications band.

6.5 Bow-Tie Antenna after Second Order Sierpinski Iteration:

After applying the second Sierpinski iteration looks as shown in figure 6.5. This has been done in order to obtain the antenna resonance across GSM band.

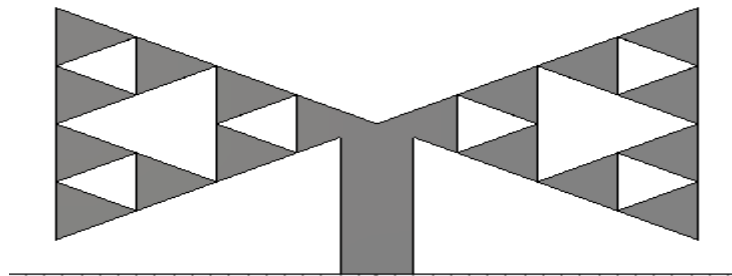


Fig 6.5 Bow-Tie Antenna after Second Sierpinski Fractal Iteration

After simulation is seen that the resonant frequency shifts towards the left end and covers the 1800 MHz of the GSM mobile applications in the first band , and the second band which starts from 2100 MHz covers the ISM, IMT and a part of UWB applications band as shown in figure 6.6. The bandwidth around 1800 MHz is 248 MHz (1713-1961 MHz) and it covers the entire ISM band which has a range of 2400-2500 MHz.

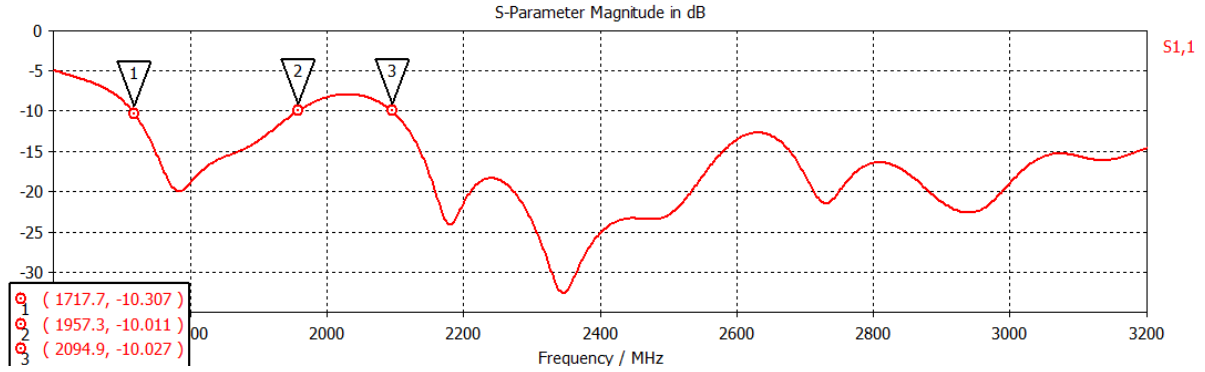


Fig 6.6 Return Loss Plot of the Bow-Tie Antenna after Second Sierpinski Fractal Iteration

The graph shows the amount of variation by which the response has shifted towards lower frequencies because the path travelled by the currents becomes longer which leads to longer electrical lengths and lower frequencies. This antenna can find its application in GSM 1800MHz band, 2400-2500MHz & 5725-5875MHz ISM band, and UWB applications which include generic and PMSE applications.

6.5.1 Gain and Directivity Plots of Bow-Tie Antenna after Second Order Sierpinski Iteration:

The simulation results of the bow-tie antenna after the second order Sierpinski iteration have been studied. The gain of the antenna depicts the efficiency and directivity of the antenna depicts the ability of the antenna to radiate in the desired direction. Gain plots at some important frequencies are shown in the figures 6.7-6.8.

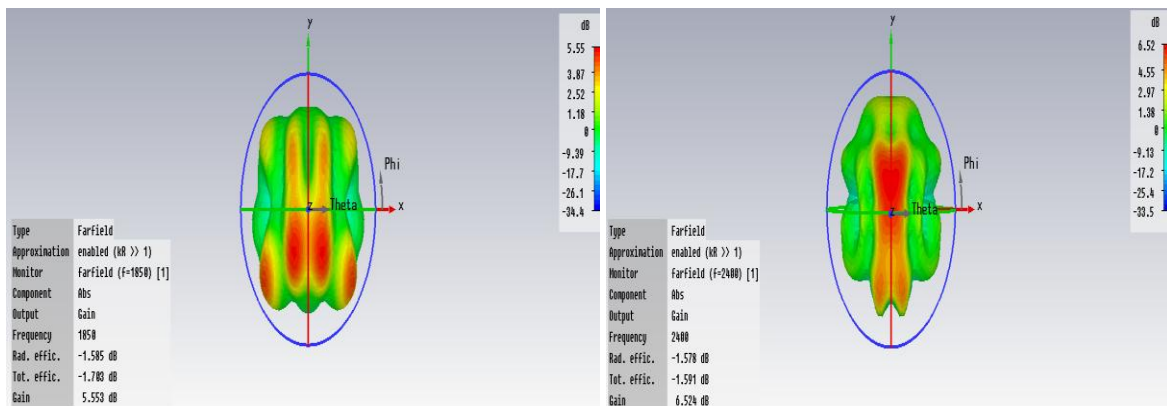


Fig 6.7 Gain Plot of the Sierpinski Gasket Bow-Tie Antenna 1850 MHz & 2400 MHz

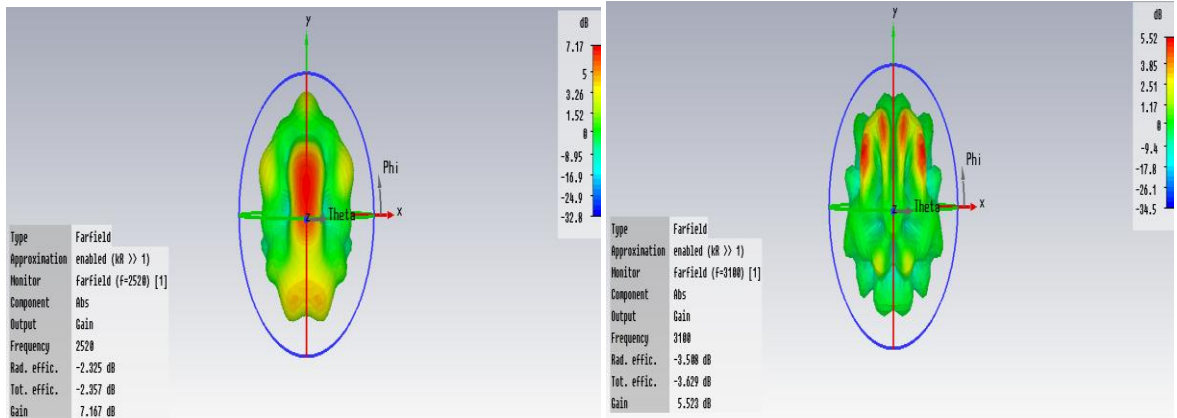


Fig 6.8 Gain Plot of the Sierpinski Gasket Bow-Tie Antenna at 2520 MHz & 3100 MHz

Thus it is quite clear from the gain plots that this antenna may have gain value up to 7.17dB. The gain of the antenna is 5.55dB, 6.52dB, 7.17dB, and 5.52dB at 1850 MHz, 2400 MHz, 2520 MHz and 3100 MHz respectively. Instead of having a wide band width this antenna has a very good gain at the operating frequencies. So this antenna can be used for GSM mobile, ISM and UW application because it satisfies all the requirements of these applications.

6.5.2 Surface Current Distribution of Bow-Tie Antenna after Second Order Sierpinski Iteration:

The surface current distribution depicts which portion of the patch is responsible for a particular frequency. The polarization of the antenna can also be depicted from the current distribution. Surface current distribution at some frequencies is shown in figures 6.9-6.13.

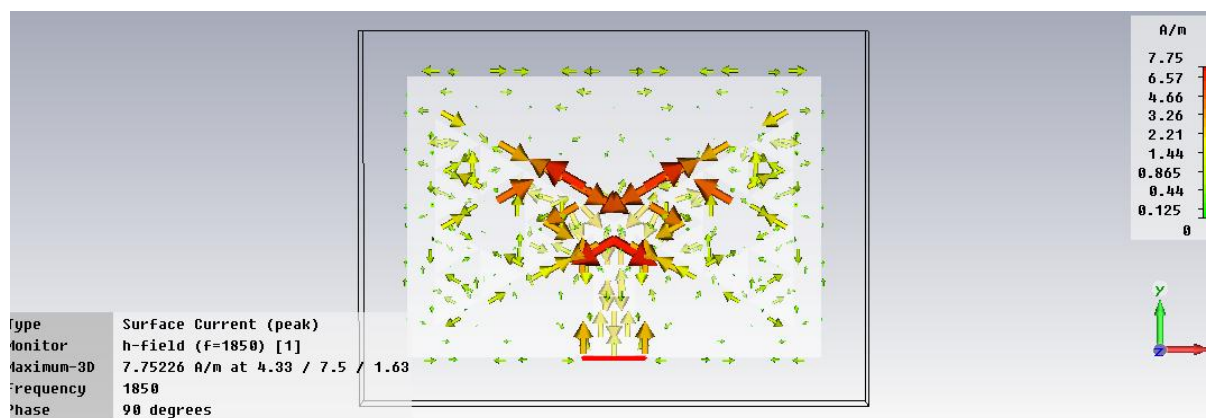


Fig 6.11 Surface Current Distribution of the Sierpinski Gasket Bow-Tie Antenna at 1850 MHz

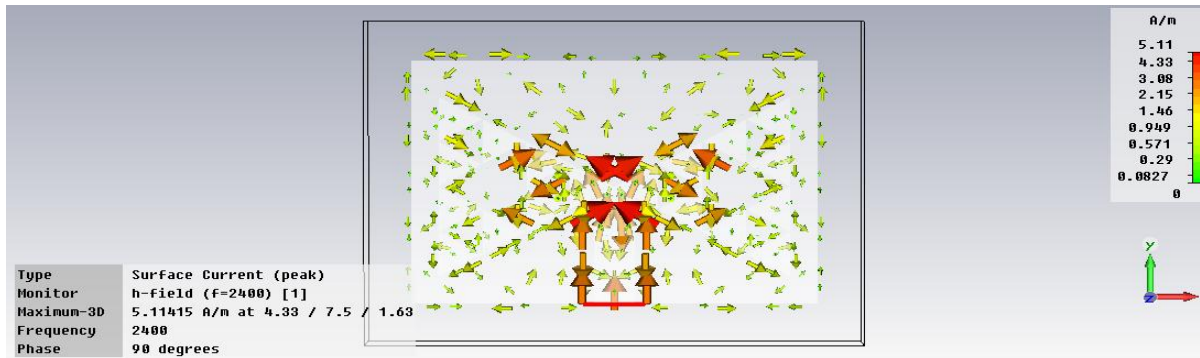


Fig 6.12 Surface Current Distribution of the Sierpinski Gasket Bow-Tie Antenna at 2400 MHz

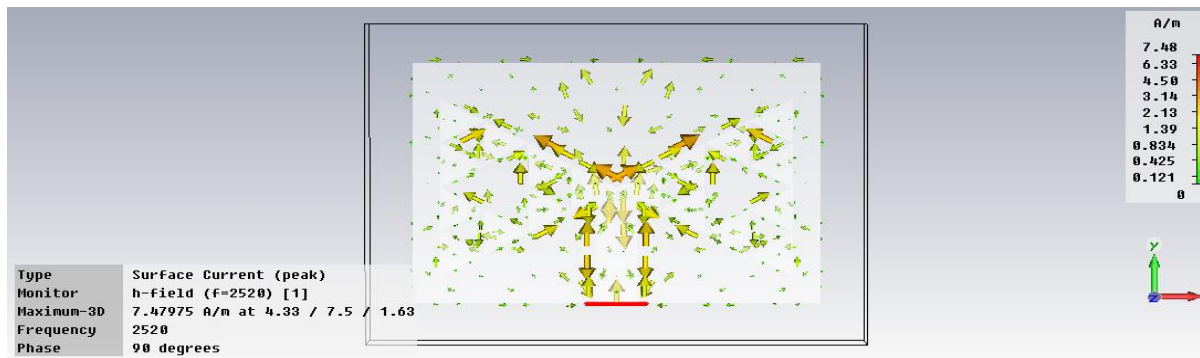


Fig 6.13 Surface Current Distribution of the Sierpinski Gasket Bow-Tie Antenna at 2520 MHz

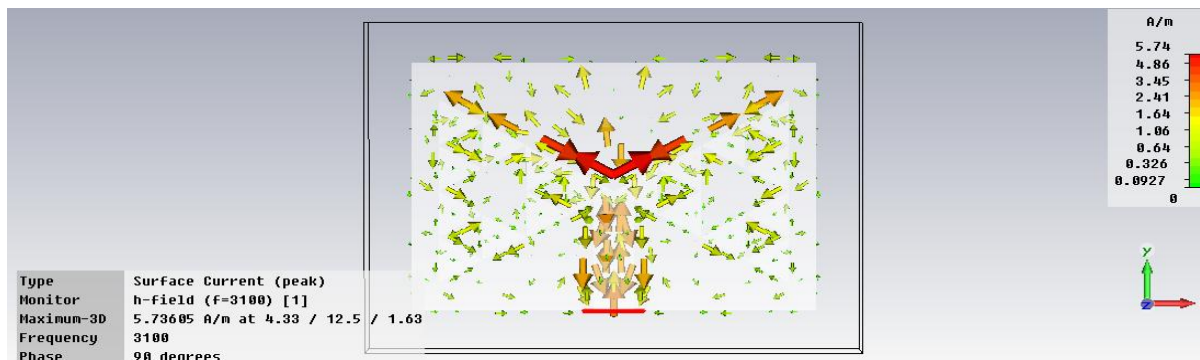


Fig 6.14 Surface Current Distribution of the Sierpinski Gasket Bow-Tie Antenna at 3100 MHz

6.5.3 Effect of Varying the Width of the Feed Line of Bow-Tie Antenna after Second Order Sierpinski Iteration:

The dimensions of the feed line have to be optimized in order to get better impedance matching which further leads to good antenna performance. Here the effect of varying width

of the feed line has been studied and is found that the antenna return loss is getting affected by this. The effect of varying the feed line width is shown in the figure 6.15.

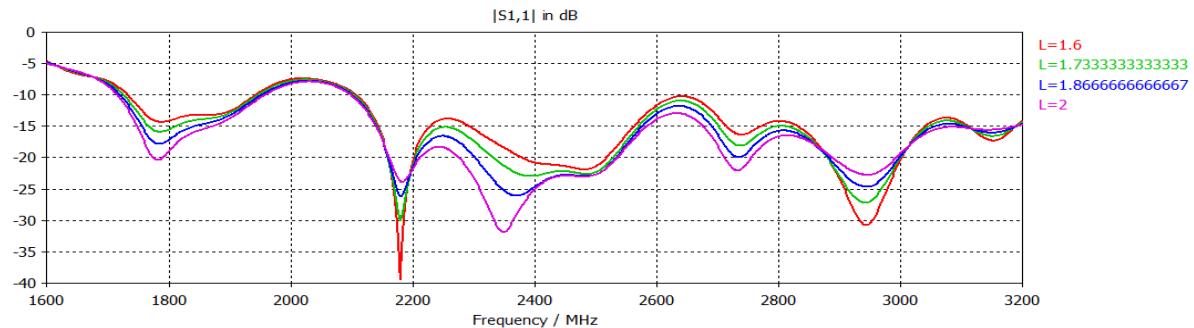


Fig 6.15 Optimization of the Feed Line Width of the Sierpinski Gasket Bow-Tie Antenna

From the figure 6.15 it is clear that the feed width affects the return loss of the antenna and the one feed line width which gives better return loss and the bandwidth has been selected which is equal to 2mm.

6.6 Conclusion:

In this chapter a bow-tie Sierpinski gasket antenna is presented which is designed to operate on 2000MHz and the Sierpinski iterations are done in order to obtain the desired results. The antenna comes out as wideband antenna which can be applicable for GSM, ISM and UWB application. The antenna gain is also very good irrespective of its high bandwidth.

CHAPTER-7

FABRICATION AND TESTING

7.1 Introduction:

This chapter includes the fabrication and testing of the two antennas one is Pythagorean Fractal Tree Antenna and Fractal Flower Antenna.

7.2 Fabrication Procedure:

The fabrication process is of four steps which are explained below:

- 1) In the first phase of fabrication process antenna is designed in software such as ORCAD and the .Max file is printed using LASER printed so that accuracy of the antenna dimensions is assured.
- 2) After that PCB is cut to a required size using PCB cutting machine and the surface of the PCB is cleaned using sand paper to remove the unwanted particle. After the cleaning is done the PCB is dipped into a photo resistive material and which is then dried in an oven unit for 3-5 minutes.



Fig 7.1 Oven Unit

- 3) After that the positive is placed on the PCG and is placed in a UV chamber or photo resistive developer and the extra copper becomes soft and the next job is to remove extra copper from the PCB material.

4) To remove the extra copper from the PCB is put in the etching unit in which ferric chloride is used and only the desired part remains. In the last step is cleaned with water to remove chemicals. This process is also known as chemical etching. The fabricated antennas are shown in figure 7.2-7.3.

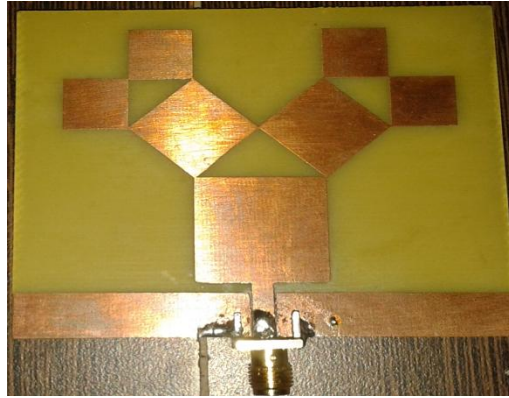


Fig 7.2 Fabricated Pythagorean Fractal Tree Antenna



Fig 7.3 Fabricated Fractal Flower Antenna

In order to test the antenna fabricated using photolithography process, a Vector Network Analyser is used.

7.3 Vector Network Analyzer:

It is the measurement tool that helps to measure the input impedance as a function of frequency along with that it can measure other parameters also such as gain, amplitude and phase. It helps to measure the response of the device under test such as antennas, phase shifters, attenuators, couplers and other microwave devices. It can also be used for the

troubleshooting of all these devices. VNA used here for the testing of these antennas is Anritsu MS46322A. It can be used between the frequency ranges of 1-20 GHz.

It also has a USB port which enables it to connect with PC, keyboard and other devices. It has fast sweep speed which makes the testing of the devices faster. The device can operate up to the temperature of 55°C . Simulated and testing results of the Pythagorean Fractal Tree antenna are shown in the figures 7.4 & 7.5.

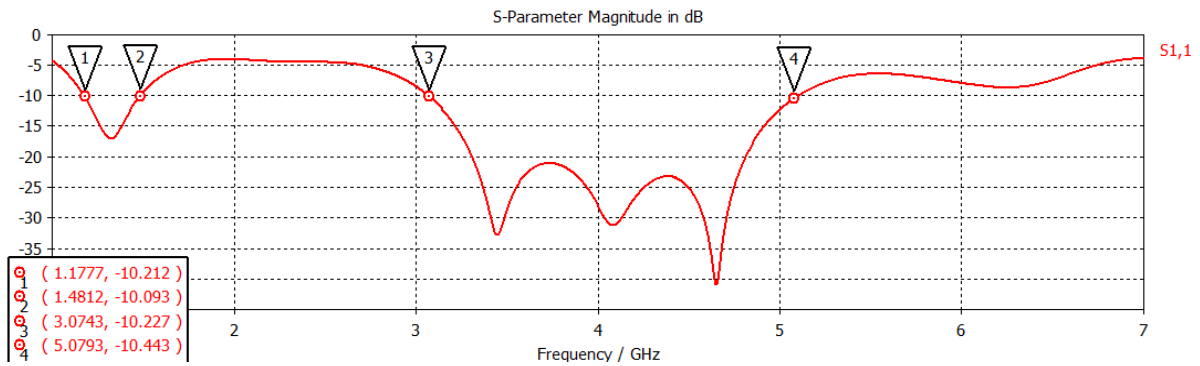


Fig 7.4 Simulation results of Pythagorean Fractal Tree Antenna

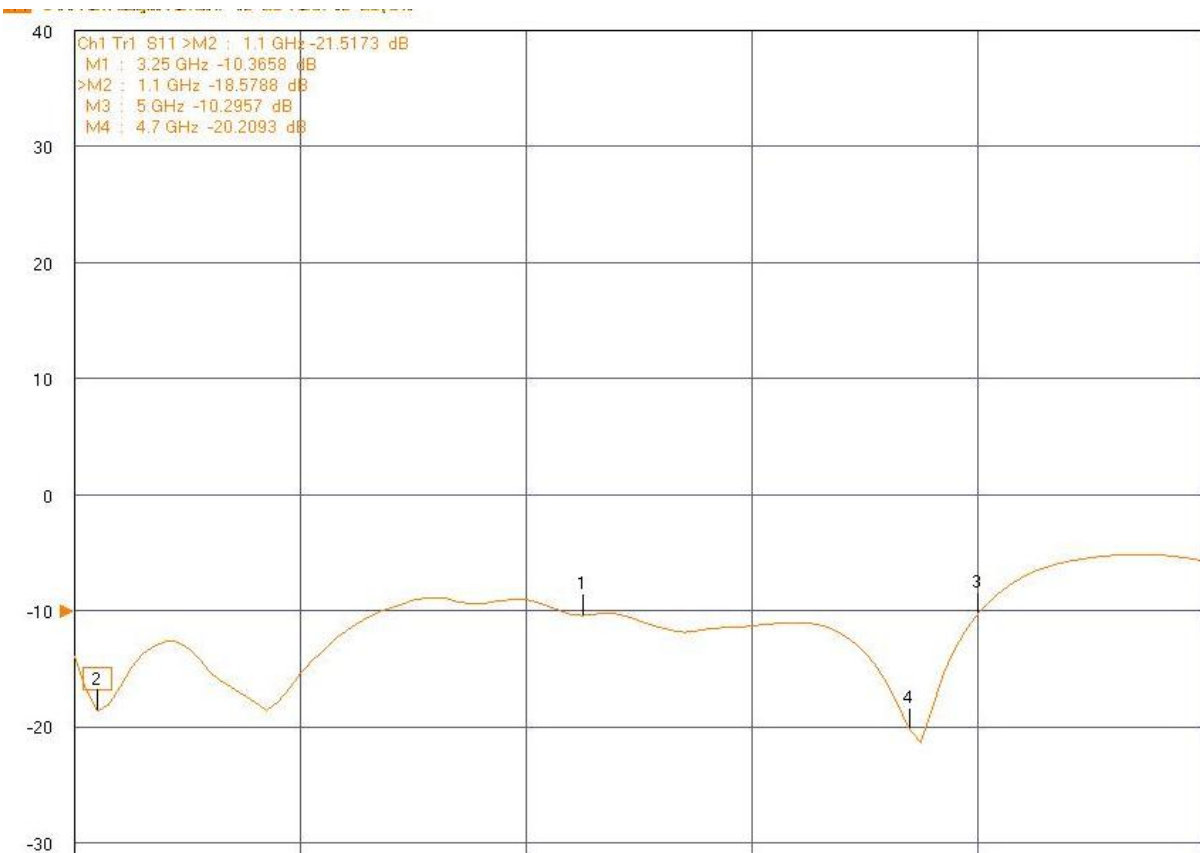
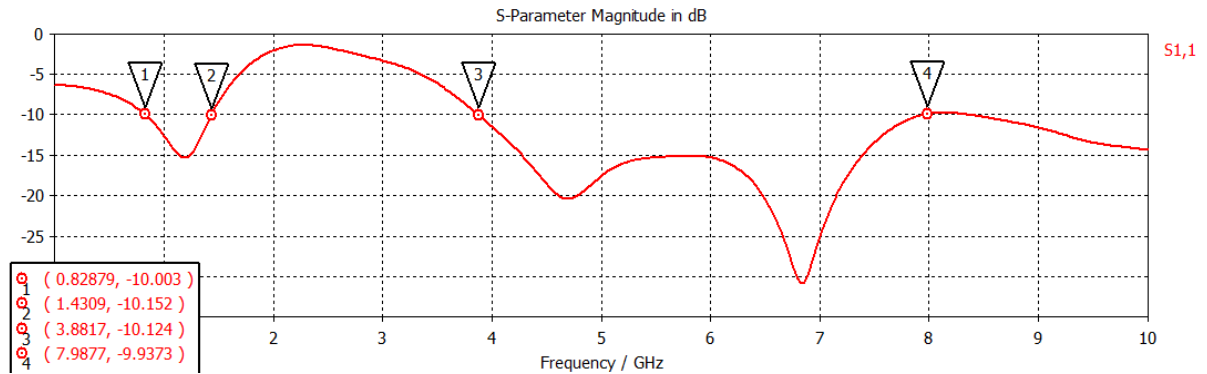


Fig 7.5 Testing Results of Pythagorean Fractal tree antenna

As it is clear from the above figure that the antenna is an UWB antenna with a very large bandwidth and covers 3.25-5 GHz in UWB band and almost same bandwidth is covered across GSM 1800 MHz and 900 MHz bands. The return loss's minimum value obtained is -22 dB. The testing results of this antenna shows that the antenna is suitable for practical applications be it the UWB applications or the mobile application. The simulated and testing result of the Fractal Flower antenna is shown in figure 7.5 & 7.6.



7.6 Simulated Results of Fractal Flower Antenna

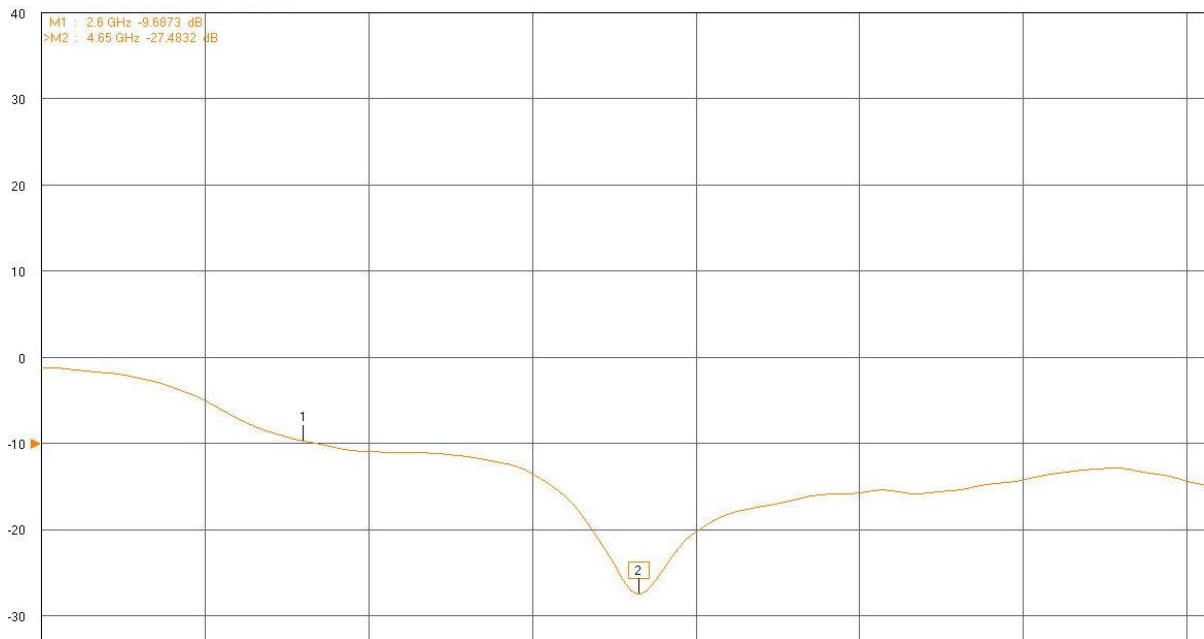


Fig. 7.7 Fabricated Results of Fractal Flower Antenna

The above figures show that the antenna is a UWB antenna and the return loss of this antenna is also good so this antenna is quite suitable for UWB application in practice also. The antenna covers the band for WLAN, WiMAX and UWB applications and also 5 GHz

Wi-Fi application band. The simulation and testing graphs are in a good agreement with each other as shown in figures 7.6 and 7.7. But the variations in the testing results may be due to the fabrication or testing errors or may be due to the conductivity variations.

7.4 Comparison between Simulated and Measured Results:

The following table 2 and 3 compares the simulated and measured results of Pythagorean Fractal Tree Antenna and Fractal Flower Antenna.

Table 2. Comparison between Simulated and Fabricated results of Pythagorean Fractal Tree Antenna

PARAMETER	SIMULATED RESULTS	FABRICATED RESULTS
Frequencies Covered	1.164-1.492 GHz in the first band and 3.0568-5.1 GHz in the second band	~900 MHz-2.4 GHz in the first and 3.5-5 GHz in the second band
Return Loss	-17 dB in the first band and -40 dB in the second	-18.5dB in the first band and -22 dB in the second band
Bandwidth	382 MHz in the first and 2.04 GHz in the second	~1.3 GHz in the first and 1.75 GHz in the second
Applications	WiMAX, UWB applications	Mobile, WiMAX, UWB applications

Table 3. Comparison between Simulated and Fabricated results of Fractal Flower Antenna

PARAMETER	SIMULATED RESULTS	FABRICATED RESULTS
Frequencies Covered	.83-1.42 GHz in the first band and 3.8-8 GHz in the second band	High bandwidth Starting from 2.6 GHz and ranging beyond 8 GHz
Return Loss	The minimum return loss obtained in -32 dB	Minimum return loss obtained is -27.48 dB
Applications Covered	GSM 900 MHz mobile applications, Wi-Fi, WiMAX and UWB applications	UWB, WLAN, Wi-Fi, WiMAX applications

From the above two tables it can be concluded that the fabrication and simulation results of the Pythagorean Fractal tree antenna and Fractal Flower Antenna are in close agreement with each other. Thus it is concluded that the antennas proposed in this thesis are suitable for the practical use in the applications such as UWB, WLAN, WiMAX and Wi-Fi applications.

CHAPTER-8

CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The main aim of this thesis has been to design antennas for UWB, WLAN, WiMAX and mobile applications. Four fractal antennas have been designed and simulated to operate on UWB and mobile applications. A sierpinski Hexagonal, Pythagorean fractal tree, fractal flower and a Sierpinski Bow-Tie antenna have been proposed in the current research work for covering GSM, UWB, WLAN bands. The antennas designed have been found suitable for these applications because of their small size, return loss, bandwidth and gain. Two antennas out of four have also been fabricated and tested to validate the results which have been found in good agreement with simulated ones. So it is concluded that all the objectives which have been defined have successfully been achieved.

A Hexagonal Sierpinski Gasket antenna with multiband behaviour has been designed and simulated successfully which has later been converted to a wideband antenna whose bandwidth is 1.86 GHz and gain is 6.74 dB. Then Pythagorean Fractal Tree antennas has also been designed and simulated with a bandwidth of 2.04 GHz and gain of 4.5dB.

Later on a Fractal Flower antenna has been designed and simulated which has proved very useful for size reduction and 590 MHz bandwidth of GSM 900 MHz band and 4.2 GHz bandwidth of UWB band have been covered by this antenna and at last Sierpinski Bow-Tie antenna has been designed which covers 248 MHz of GSM 1800 MHz and 2.4 GHz ISM band and some important UWB applications.

The results of the fabricated antennas i.e. Pythagorean Fractal Tree antenna and Fractal Flower Antenna have also been thoroughly studied and have been found in good agreement with the simulated ones.

8.2 Future Scope:

The proposed antennas have been found well suited for the wireless applications of UWB, WLAN, and WiMAX and mobile, the scope of this research work can be further extended to the following areas:

1. The size miniaturization to the extent in the field of the fractal antennas so that they can become wearable and useful for other BAN application.

2. The use of Fractal antennas for MIMO can be improved the gain, directivity and bandwidth up to a great extent.
3. The use of PIN diodes can make the Fractal antenna reconfigurable and this will lead to the use of single antenna for a lot of applications without making any major changes.
4. The use of shorting walls and shorting pins help to lower the frequency of resonance thus can be useful for reducing the size.
5. The design of metamaterial antennas can help to increase the gain, bandwidth and can suppress the surface wave propagation. These antennas can operate over a wide frequency range up to optical.
6. The use of stacking can be useful for enhancing the bandwidth of these antennas. The use of feeding techniques such as aperture and proximity feed can help to enhance the bandwidth and can provide better isolation.

REFERENCES

- [1] Andrea Goldsmith, "Wireless Communication," Cambridge University Press, 2005.
- [2] Theodore S.Rappaport, "Wireless Communication & Practice," Prentice Hall, 2nd Edition, 2009.
- [3] M.Abdul Matin, "Ultra Wideband Current Status and Future Trends" InTech, October 2012.
- [4] K.Siakavara, N.Nasimuddin, "Microstrip Antennas" Chapter-9, InTech, April 2011.
- [5] Constantine A. Balanis, "Antenna theory Analysis and Design," 2nd edition, John Wiley and Sons, 2009.
- [6] I.Singh, V.S. Tripathi, "Micro strip Patch Antenna and its Applications: a Survey," *International Journal of Computer Technology and Applications*, Vol. 2, pp. 1595-1599, 2011.
- [7] M.Singh, A.Basu, and S.K. Koul, "Design of Aperture Coupled Fed Micro-Strip Patch Antenna for Wireless Communication," *IEEE India Conference*, 2006.
- [8] S.Chaimool,P.Akkaraekthalin, R.C.Hicapie and J.C.Sierra, "Advanced Transmission Techniques in WiMAX," Chapter-2, InTech, Jan 2012
- [9] J.P.Gianvittorio and Y.Rahmat, "Fractal Antennas:A Novel Antenna Miniaturization Technique and Applications," *IEEE Antenna and Propagation Magazine*, Vol. 44, pp. 20-36, Feb 2002.
- [10] D.H.Werner and S.Ganguly, "An Overview of Fractal Antenna Engineering Research," *IEEE Antenna and Propagation Magazine*, Vol. 45, pp. 37-58, Feb 2003.
- [11] R.Kieda, M.Kitlinski, "Sierpinski Monopole Antenna - Uniplanar Feeding Technique," *IEEE Microwaves, Radar and Wireless Communications*, Vol. 2, pp. 477-480, May 2004.
- [12] C. Puente, J. Romeu, R. Pous, X. Garcia and F. Benitez, "Fractal Multiband Antenna based on Sierpinski Gasket," *IEEE Electronics Letters*, Vol. 32, pp.1-2, January 1996.
- [13] C.Puente, C. Borau, M.N. Rodero, and J.Romeu, "An Iterative Model for Fractal Antennas: Application to the Sierpinski Gasket Antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 48, No. 5, May 2000.
- [14] R.K.Mishra, R.Ghatak, D.R.Poddar, "Design Formula for Sierpinski Gasket Pre-

- Fractal Planar-Monopole Antennas,” *IEEE Antennas and Propagation Magazine*, Vol. 50, No. 3, pp. 104-107, June 2008
- [15] S.Yadav, R.Choudhary, U.Soni, B.Peswani and M.M. Sharma, ” Koch Curve Fractal Antenna for Wi-MAX and C Band Wireless Applications,” *IEEE International Conference on Confluence the Next Generation Information Technology Summit*, 2014.
- [16] K.J. Vinoy, K.A. Jose, V.K. Varadan, and V.V. Varadan, “Resonant Frequency of Hilbert Curve Fractal Antennas,” *IEEE Antennas and Propagation Society International Symposium*, Vol. 3, pp. 648-651, 2011.
- [17] P.W.Tang and P.F.Wahid, ”Hexagonal Fractal Multiband Antenna,” *IEEE Transactions on Antennas and Propagation*, Vol. 3, 2004.
- [18] A.Aggarwal and M.V.Kartikeyan,” Pythagorean Tree: A Fractal Patch Antenna for Multi-frequency and Ultra-wide Bandwidth Operations,” *Progress in Electromagnetics Research* , Vol. 16, pp. 25-35, 2010
- [19] L.Ghanbari, S.Nikmehr and M.Rezvani, ”A novel small UWB antenna using new fractal-like geometry,” *IEEE Applied Electromagnetics Conference*, 2011.
- [20] C.Puente, J.Romeu, R.Pous and A.Cardama, ”On the Behavior of the Sierpinski Multiband Fractal Antenna,” *IEEE Transactions on Antenna and Propagation*, Vol. 46, No.4, pp. 517-524, April 1998.
- [21] C. T. P. Song, P.S. Hall, and H.G.Shiraz, "Perturbed Sierpinski Multiband Fractal Antenna with Improved Feeding Technique," *IEEE Transactions on Antennas and Propagation*, AP-51, Vol. 5, pp. 1011-1017, May 2003.
- [22] A.Sundaram, M.Maddela and R.Ramadoss, “Koch-Fractal Folded Slot Antenna Characteristics,” *IEEE Transactions on Antennas and Propagation Letters*, Vol. 6, 2007.
- [23] D.D.Krishna, M. Gopikrishna, C. K. Anandan, P. Mohanan and K. Vasudevan, ”CPW-Fed Koch Fractal Slot Antenna for WLAN/WiMAX Applications,” *IEEE Transactions on Antennas and Propagation Letters*, Vol. 7, 2008.
- [24] M.N.Jahromi, A.Falahati, and R.M.Edwards, “Bandwidth and Impedance Matching Enhancement of Fractal Monopole Antennas Using Compact Grounded Coplanar Waveguide,” *IEEE Transactions on Antennas and Propagation*, Vol. 59, No. 7, July

2011.

- [25] A.Kaka, M. Toycan, V. Bashiry, H. Ademgil and S. D. Walker, "A Fractal Geometry, Multiband, Miniaturized Monopole Antenna Design UWB Wireless Applications," *IEEE Conference on Antennas & propagation in wireless communication*, pp. 584-587, 2011.
- [26] N.Bayatmaku, P.Lotfi and M.Azarmanesh, " Design of Simple Multiband Patch Antenna Mobile Communication Application Using E-Shape Fractal," *IEEE Antennas and Wireless Propagation letters*, Vol.10, 2011.
- [27] A.Kaka, M. Toycan, V. Bashiry, H. Ademgil and S. D. Walker, "A Fractal Geometry, Multiband, Miniaturized Monopole Antenna Design UWB Wireless Applications," *IEEE Conference on Antennas & propagation in wireless communication*, pp. 584-587, 2011.
- [28] K.Pahwa, P.Mishra, H.P.Sinha, S. S. Pattnaik and J. G. Joshi, "Design and Development of Diamond Shape Fractal Antenna for Wireless Communication," *International Journal of Microwave and Optical Technology*, Vol.7, No.2, 2012.
- [29] S.Shrestha, J.J.Park, S.K.Noh, and D.Y.Choi, "Design of 2.45 GHz Sierpinski Fractal Based Miniaturized Microstrip Patch Antenna," *IEEE Conference on Information and Networking*, pp.274-279, 2012.
- [30] S.M.Choudhury and M.A.Matin , " Effect of FSS Ground Plane on Second Iteration of Hex flake Fractal Patch Antenna," *IEEE International Conference on Electrical and Computer Engineering*, Dec. 2012.
- [31] K.K.Sawant, R.Kumar, A.N.Gaikwad," A Novel CPW-fed Circular square corner Fractal Antenna with Varying Notch-Band for UWB Applications," *IEEE International Conference on Communication, Information & Computing Technology*, Oct. 2012.
- [32] H.Oraizi and S.Hedayati, "A Novel Wide Slot Antenna Design using the Giuseppe Piano Fractal Geometry," *IEEE Iranian Conference on Electrical Engineering*, May 2012.
- [33] Basil.K.Jeemon , K Shambavi, Zachariah C Alex, "A Multifractal Planar Antenna for Wireless Applications" *IEEE International Conference on Communication and Signal Processing*, pp. 47-50, 2013.

- [34] T.Kalaimani, P.M. Venkatesh, R.Mohanamurali and T.Shanmuganatham, "A Modified Sierpinski Carpet Fractal Antenna for Wireless Applications," *IEEE International conference on Communication and Signal Processing*, April 2013.
- [35] V.R.Anitha, M.Y.Sindhu, "Simulation of a novel design fractal tree antenna for multiband applications with re-configurability," *IEEE Conference on Antennas & propagation in wireless communication*, pp. 1489-1492, 2013.
- [36] A.K. Singh, R.A.Kabeer, Z.Ali and D.Gurjar, "Performance Analysis of Compact Koch Fractal Antennas at Varying Iterations," *IEEE Students Conference on Engineering & Systems*, 2013.
- [37] S.Yadav, R.Choudhary, U.Soni, B.Peswani, and M.M. Sharma, "Koch Curve Fractal Antenna for Wi-MAX and C Band Wireless Applications," *IEEE International Conference on Confluence the Next Generation Information Technology Summit*, 2014.
- [38] S.Tripathi, A.Mohan and S.Yadav, "Hexagonal fractal ultra-wideband antenna using Koch Geometry with bandwidth enhancement," *IET Microwaves, Antennas & Propagation*, Vol. 8, Iss. 15, pp. 1445–1450, 2014.
- [39] C.J.Xi, G.Y.Lin, "Application of Koch Island Fractal on Dumbbell-shaped Defected Ground Structure Low-pass Filters," *IEEE Workshop on Advanced Research and Technology in Industry Applications*, 2014.
- [40] D.Kumar, M.Sharma, S.Bansal, "Novel Design of Key-Shaped Fractal Antenna for UWB Applications," *IEEE Sixth International Conference on Computational Intelligence and Communication Networks*, 2014.
- [41] K.Kharat, S.Dhoot, and J.Vajpai, "Design of Compact Multiband Fractal Antenna for WLAN and Wi-MAX Applications," *IEEE International Conference on Pervasive Computing*, 2015.

LIST OF PUBLICATIONS

- [1] Kamaljit Kaur, Amanpreet Kaur, “Analysis and Design of Microstrip Sierpinski Gasket Fractal Antenna for C-Band Operation” *National Conference on Recent Advances in Electronics & Computer Engineering*, 13-15 Feb, 2015.
- [2] Kamaljeet Kaur, Amanpreet Kaur, “A Hexagonal Sierpinski Gasket Antenna with a Microstrip Feed Line and a Stub for UWB Applications” *Journal of Electronic Design Technology*, Vol. 6, No 1, 2015.