DESIGN OF AN OCTAGONAL FRACTAL SLOT LOOP ANTENNA LOADED WITH DIELECTRIC RESONATOR AND OPTIMIZATION OF ITS PARAMETRES

A Dissertation Submitted in partial fulfilment of the requirements for the award of

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in

Electronics and Communication Engineering

Submitted by

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DECLARATION

I, Sahil Gupta, hereby declare that the work which is being presented in the dissertation entitled **"Design of an octagonal fractal slot loop antenna loaded with dielectric resonator and optimization of its parameters"** by me in partial fulfilment of the requirement for the award of degree of M.E. in Electronics and Communication submitted in Electronics and Communication Engineering Department of Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Sukhwinder Kumar, Lecturer, Thapar University, Patiala.**

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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ABSTRACT

Today’s modern wireless communication system has transformed the universal telecommunication system into an integrated system as it is able to provide communication services to customer anywhere and anytime, whether in motion or fixed. Antenna is the very important constituent of the wireless communication system as it is responsible to radiate and receive the EM waves which are then converted into electrical signals for further processing. Performance of the antenna employed will affect the performance of the whole system. Today there is a great demand of devices which are smaller in size and capable of handling multiple frequencies for their operation, so compact size antennas with multiband behaviour and satisfactory gain are required. Fractal antennas are very much efficient in providing both the features hence; fractal geometry is applied on the designed antenna. Four concepts are used in the designing of the proposed antenna i.e. slot antenna, fractals, DGS (defected ground structure) and DRA (dielectric resonator antenna) to improve the radiation characteristics of antenna. Fractal slot loops are employed to increase the resonating bands and to decrease the fundamental frequency, Minkowski fractal geometry is applied on the boundaries of the octagonal shaped slot loop and iteration is carried up to second stage. CPW feed is used for excitation of antenna and stub matching technique is applied for the prevention of power loss. DGS is applied on the ground plane for reducing the size of antenna. A dielectric slab with high dielectric constant is placed on the designed prototype for increasing the bandwidth, increasing the gain and directivity of antenna. All the simulations are performed in CST (computer simulation technology) and simulated results are compared with the measured results. The antenna designed can operate at several wireless communication frequency ranges which can be used for GSM, Bluetooth, WLAN, WiMAX, IMT etc.

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CPW	Coplanar Waveguide
CST	Computer Simulation Technology
dB	Decibel
DGS	Defected Ground Structure
EBG	Electromagnetic Band Gap
FBR	Front to Backward Ratio
GHz	Giga Hertz
GPS	Global Positioning System
GSM	Global System for Mobile Communication
IEEE	Institute of Electrical and Electronics Engineering
IMT	International Mobile Telecommunication Band
LOS	Line of Sight
MHz	Mega Hertz
MMIC	Monolithic Microwave Integrated Circuits
PCB	Printed Circuit Board
PIFA	Planar Inverted F-Antenna
RF	Radio Frequency
RFID	Radio Frequency Identification
RL	Return Loss
UWB	Ultra-Wideband
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
Wi-Fi	Wireless Fidelity
WiMAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network

CHAPTER 1

INTRODUCTION

1.1 Overview

Now a days, no of communication services are increasing, most of the wireless systems used are multifunction in nature i.e. they can perform various functions. In the previous time, different antenna was required for different application as each antenna works on only single frequency, this causes problem because of availability of limited space, as each manufacturer tends to produce antenna which as compact as possible. This problem is overcome by using multiband antenna, i.e. single antenna which can operate at different frequencies. In the present scenario wireless communication has a huge demand for high speed and high data rate communication. Versatile antennas are required that must possess feature of compactness, multi-band behaviour and should be discreet in nature. To attain these features, a multiband and miniaturized antenna is designed accordingly. As the demands of wireless bands are growing day by day, therefore the available spectrum band is becoming more crowded. This means that high speed communication is required by the modern communication systems. As the memory chips and devices are reducing their size, therefore the compact antennas are needed which must fit in the small integrated circuits. This is the fact that if the size of antenna is reduced then efficiency of antenna will also reduce as the antenna efficiency reduces below the one fourth of its wavelength. There are many techniques to construct a multiband antenna, one of the most famous one is applying fractal geometry on the designed antenna. Fractal shaped antennas not only provide the multiband function but also forms a compact and simpler structure and easy integration with system**.** By incorporating fractal geometry to the antenna becomes compact in size and also can work in UWB i.e. Ultra-Wide Band. Multiband behaviour of these antennas is due the presence of self-similar shapes at different scales. The irregular shapes and discontinuities present increases the bandwidth as well as the radiation pattern. 'Fractus' is the word from where the fractal is derived and meaning of this word is irregular and iterative. 'Fractus' word is given by researcher named 'Mandelbrot' [1]. As the word describes, fractals are self-repeating and iterative in nature. This is only due to the self-repeating shape property that the electrical length of the antenna is increased as compared to physical length and hence, antenna can be used for long range communication. This technology can be satisfactorily employed to defence applications, mobile communications, RFID tags, WLAN standards etc. Before going to fractal antenna let us discuss briefly about the antenna, its various types and different parameters on which its characteristics mainly depends.

“Everybody wants to go wireless”: trend of wireless communication in modern days can be actually described by this statement. James clark Maxwell at the end of nineteenth century initially gave the theory about electromagnetic radiation [2]. He said, “The energy, by the engagement of electric and magnetic waves could be transported through materials and space at a finite velocity.” [3]. In 1888th experiments of Heirich Hertz were supported by Maxwell theory. It was proved that velocity of light and electromagnetic waves are same [4].

The experiments performed with these electromagnetic waves initiate the wireless communication system by invention of radio and wireless telegraph. Later on, many scientists gave their efficient efforts in this field and with their efforts people have obtained much better and stronger freedom to communicate. It was only the initial success of wireless communication that led to today’s area of personal communication system.

In chapter 1, different types of antennas and a review on theory of antennas is presented. Different antenna parameters like antenna gain, radiation pattern, directivity, polarisation, voltage wave standing ratio (VSWR), input impedance etc. are described. Technology of micro-strip antenna is discussed with its advantages and disadvantages. Aspects of fractal geometry are also discussed.

1.2 Theory of antenna

A metallic structure which receives or sends EM waves like radio waves is called antenna. It can convert electrical currents into radio frequency and vice-versa. An antenna also known as areal can be referred to as an electrical equipment or device which can convert electrical signals into radio waves and radio signals into again electrical waves. When antenna is acting as a transmitter, a radio transmitter delivers an electric signals oscillating at radio frequency to the antenna's terminals, and energy is radiated in for of EM waves, and when acting as a receiver it accepts some of the power of an electromagnetic wave to produce a tiny voltage at its terminals, and that voltage is delivered to a receiver for amplification. Antenna was first designed by Heinrich Hertz who was a German scientist in 1888. He did those experiments to prove the existence of EM waves which were predicted by Maxwell. A dipole antenna was placed at the focus of parabolic reflector for the purpose of receiving and transmitting.

Antennas plays very important role in the equipment which works on the radio waves. They are used in systems such as broadcasting, two way radio, Bluetooth-enabled devices, wireless computer networks , and satellite communications, as well as other devices such as room door openers, communications receivers, radar, cell phones, wireless microphones, baby monitors, and RFID tags on merchandise.in short we can say that antenna plays a very important role in our all day to day activities.

Antenna could be directional or omnidirectional in nature i.e. they could receive or transmit in all the direction or only in particular direction. Antennas may include some other devices or components for their effective working like parasitic elements, parabolic reflectors etc. which have no surface connection with them and can direct the radiation to the desired directions. According to their size, radiation pattern and many other factors antennas are categorised into different types .Some of them are listed below Wire antennas, Travelling wave antennas (helical antennas, Yagi-Uda antennas, spiral antennas), Aperture antennas, Reflector antennas, Micro strip antennas, Fractal antennas

1.3 Different antenna parameters

Performance of the antenna is measured by various parameters which are discussed in this section [5], [6].

1.3.1 VSWR

It stands for Voltage Wave Standing Ratio. It is the ratio of maximum to the minimum radio frequency voltage measured on the transmission line. It is defined as:

$$VSWR = \frac{V_{max}}{V_{min}} \qquad \dots (1.1)$$

We can calculate VSWR by using return loss also, which is an indicator that VSWR is also the measure of antenna’s efficiency also. The mismatch between the terminal input impedance of antenna and the characteristic impedance of transmission line can be determined with the return loss. VSWR can be determined as given below if the magnitude of reflection coefficient is known.

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \quad \ldots (1.2)$$

As the mismatch between the antenna and transmission line increases, the value of VSWR increases and similarly, as the mismatch decreases, means good matching, the value of VSWR decreases. The minimum value of VSWR is '1', and practically equipment can afford its value up to '2', which means, return loss is '-10Db' or lower.

1.3.2 Input Impedance

Generally, an antenna can be recognised as a load having certain impedance attached to the transmission line. It impedance is known as input impedance of the antenna it is determined by using following expression

$$Z_{in} = R_l + R_r + jX_a \quad \ldots (1.3)$$

Where $\mathrm{Z_{in}}$, $\mathrm{R_l}$, $\mathrm{R_r}$ and $\mathrm{X_a}$ represents input impedance, loss resistance, radiation resistance and reactance respectively. Similarly as in case of VSWR, if the value of reflection coefficient is known then,

$$Z_{in} = Z_0 \left(\frac{1+|S_{11}|}{1-|S_{11}|}\right) \quad \ldots (1.4)$$

Where Z_{in} denoted the input impedance and Z_0 denotes transmission line characteristic impedance. S_{11} is defined as the reflection coefficient. Through the input impedance only we can calculate the maximum power which is transfer between the antenna and transmission line. By the maximum power transfer theorem, it is proved that when both the characteristic and input impedances are equal then the transferred power will be maximum. If there is mismatch between the two impedances, then instead of transferring, the power will be reflected back, which could may harm the device.

1.3.3 Antenna Gain

There are two types of antenna gains, namely relative gain and absolute gain. Absolute antenna gain is defined as ratio of the radiation intensity in a particular direction to the intensity which is generated by an isotropic antenna when the input feed given to both the antennas is same whereas the relative gain is taken with respect to some reference antenna.

Absolute gain is represented in *dBi* where *'i'* present after *'dB'* denotes the isotropic antenna.

1.3.4 Directivity

It is very important parameter to determine the concentration of power radiated in certain direction. It is represented as eqn. 1.5.

$$D(\theta, \emptyset) = \frac{U(\theta,\emptyset)}{U_0} \qquad \ldots (1.5)$$

Where, $D(\theta, \emptyset)$ and $U(\theta, \emptyset)$ represents the directivity of antenna and radiation intensity respectively. U_0 is the radiation intensity of the isotropic antenna.

1.3.5 Antenna Efficiency

Ratio of total radiated power to the input power is defined as the antenna efficiency.

$$e_{cd} = \frac{P_{rad}}{P_{in}} \qquad \ldots (1.6)$$

1.3.6 Radiation Pattern

The graphical representation of characteristics of antenna in certain direction is called radiation pattern. Some examples of radiation pattern are shown in fig. 1.1. It can be represented by rectangular plot or polar plot as shown in fig. 1.1 and expressed in dB.

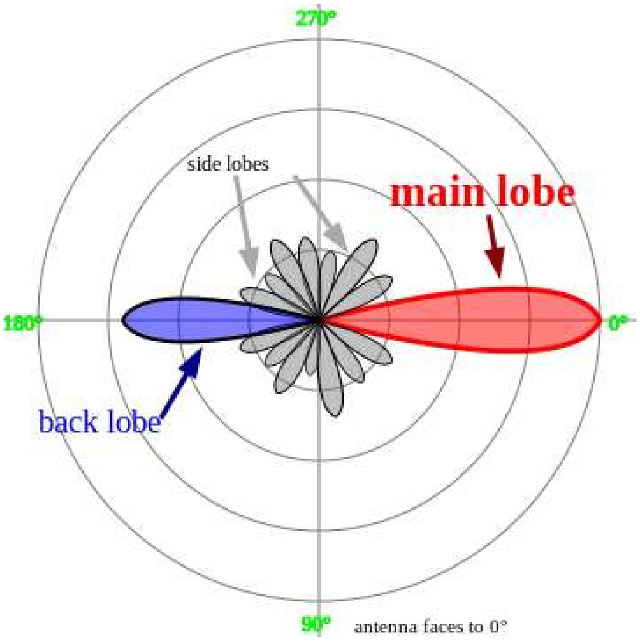


Fig. 1.1 Radiation pattern [6]

1.3.7 Beam Width

The beam width is the parameter that is used to describe the capability of resolution of antenna so that it can be get distinguished between the two nearby radiating antennas shown in fig. 1.2. It is used as a trade-off between it and the level of its side lobe. If the beam width is decreased, the level of side lobe increases and vice-versa. There are two types of beam-width commonly measured.

a. **Half-power beam width (HPBW)** - it is measured in the direction of the maxima of the beam. It is described as the angle between the two directions where the intensity of radiation is half the value of beam.

b. **First null beam-width (FNBW)** – it is defined as the angular separation between the pattern's first nulls.

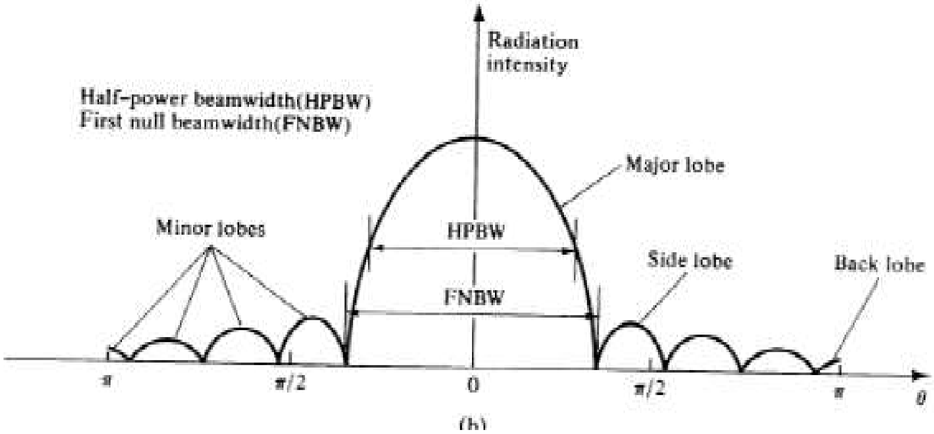


Fig. 1.2 Beam width [5]

1.3.8 Bandwidth

Bandwidth of antenna is described as range of certain frequencies over which antenna gives acceptable gain, return loss and VSWR or we can say that bandwidth of antenna is the band of frequencies over which antenna is functioning properly. Practically we use the frequencies over which return loss is '-10dB' or lower than that. An example of bandwidth is shown in fig. 1.3.

1.3.9 Return loss

Return loss is defined as loss in the power when the wave is reflected back. It can be considered as power transferred to the antenna for radiation. High value of return loss is desirable as high the value, less will be the power which would reflect back. The back reflection could be due to the discontinuity or mismatch of the transmission line. Return loss is described mathematically as equation 1.7.

$$RL\ (\,dB) = 10log_{10}\,{}^{P_i}\!/_{P_r} \qquad \ldots (1.7)$$

Where, $RL\ (\,dB)$ is the return loss in dB, P_i and P_r are incident and reflected powers respectively. Return loss, standing wave ratio and reflection coefficient are interrelated to each other. If return loss is increased SWR gets decreased.

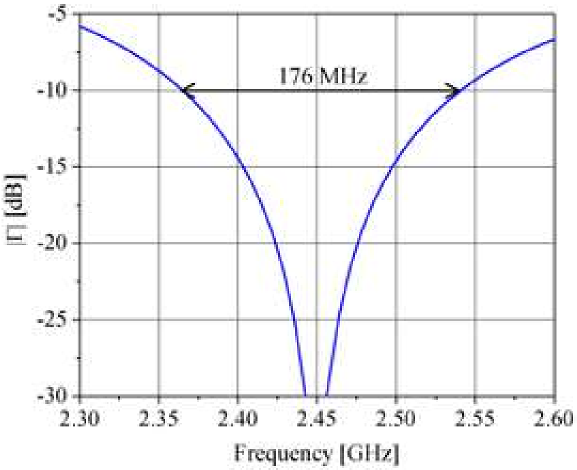


Fig. 1.3 Example of bandwidth plot [6]

1.4 Different Types of Antenna

Based on the aperture, radiation characteristics, polarisation, geometry etc. antennas are distributed in different categories. Some of the commonly used antennas are described below:

1.4.1 Antennas based on the radiating aperture: Based on the aperture of the radiating element, the antennas are defined as:

- **Wire antenna:** These antennas are commonly used in ships, buildings, automobiles etc. that is why these types of antenna are very much familiar to the people. This type consists of a straight wire i.e. dipole antenna, loop antenna and helical antenna. Loop antenna can acquire any shape of the geometry like triangle, rectangle, circle etc.
- **Aperture Antennas:** Aperture antennas are very much convenient with the skin of aircraft or space craft, i.e. they are generally used there. These antenna

have a protective layer of dielectric material around them to protect them from environmental hazardous climatic conditions.

- **Micro strip Patch Antennas:** These antennas become very popular in 1970's due to their small size and compatibility with the integrated circuits. This antenna consists of a ground plane and a dielectric substrate mounted on it. Above the dielectric substrate, radiating patch is present. Different feeding techniques are present to provide power to the antenna. these antennas can be mounted on any surface of aircraft, automobile, satellite, ships, mobile phones etc.
- **Reflector Antennas:** Reflector antennas are parabolic shaped aperture and are used in the places where the signals have to travel through distance of millions of miles. Diameter of aperture is even larger than 305 m to attain high gain.
- **Array antennas:** An array antenna is the collection of antennas used when the single antenna cannot achieve the required radiation pattern. Antennas are arranged in a way so that maximum gain and improved radiation pattern is achieved in the desired direction.

1.4.2 Based on Radiation Characteristics: Based on the radiation characteristics, antennas are defined as:

- **Directional antennas**: Directional antennas are employed in the places where the RF radiations are to be focused on some particular direction. Directional antennas possess high gain in desired direction and negligible gain in the other directions. These antennas can also be reffered to as beam antennas. These antennas are employed to cover line of sight applications i.e. the target must be in the direct line of sight of antenna eg. Long hallways, corridors etc. overage area is not large due to the less angular area which is the main disadvantage of these types of antennas. These antennas are difficult to mount and model.
- **Omni-directional antennas:** Unlike the directional antennas, omnidirectional antennas radiates equally or uniformly in all directions. These antenna are employed in cellular phones, wireless routers etc. as they are easy to mount because of no direction consideration unlike the case of directional antennas. These antennas are vertically polarised, so interference cannot be reduced as they can't be used as cross polarised antennas.

1.4.3 Based on Polarisation: based on the polarisation, antennas are defined as:

- **Circularly polarised antennas:** Circularly polarised antennas radiates in cork skew-like pattern i.e. they radiate in both the planes and make one complete rotation in one wavelength. They can radiate in any direction. Losses in this antenna are more than linearly polarised antennas as the power gets divided in two planes.
- **Linearly polarised antennas:** This type of antenna can't radiate in both the planes simultaneously. Either it will radiate in vertical plane or in horizontal plane. These antennas are of low constant and easy to manufacture. This type of antenna can be used in RFID tag application, broadcasting for AMI radio etc. as they generally gave higher range when compared to circularly polarised antenna.

1.4.4 Other types of antenna

There are many other types of antennas like travelling wave antennas, slot antennas, fractal antennas, dielectric resonator antenna, Yagi-Uda antennas, horn antennas, NFC antennas, and spiral antenna etc. which are not discussed here. Three major types of antennas i.e. slot antenna, fractal antenna and dielectric resonator antenna which are used in designing of the antenna for the thesis, are described in detail in subsequent sections of this chapter.

1.5 Slot Antenna

Slot antenna can be called as a dipole antenna as the radiation of the slot is very much similar to that of the dipole antenna as shown in fig. 1.4. Slot antenna constitutes a plane and a flat conducting sheet or plate from where a hole or we can say slot is etched out. When energy is given to this plate the slot starts radiating EM waves whose radiation pattern and way of radiating the waves is same as that of dipole antenna as already said. The radiation pattern distribution and the driving frequency are determined by the shape and size of the slot which is etched out for radiation. Slots antennas are incorporated on the places where ultra-high frequencies (UHF) and microwave frequencies are used. These antennas are very much used in base station of cell phones as sectors antennas, radar antennas etc.

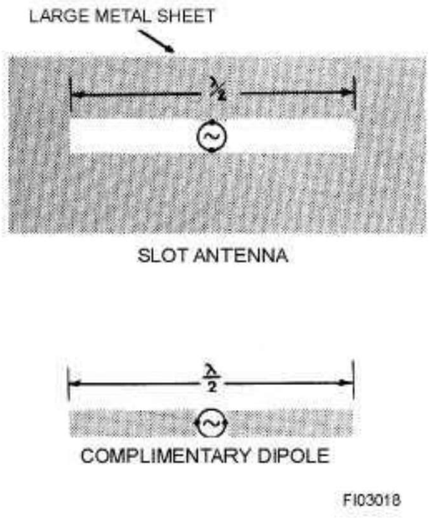


Fig. 1.4 Slot antenna and its complimentary dipole [6]

1.6 Concept of Fractals

Today’s booming requirement of small hand-held devices is forcing the industry of antenna manufacturing to design portable antenna which must be highly efficient and can work on multiply frequencies. These requirements led the researchers to think over different direction, so that they can get techniques to make high performance antenna with compact size and Fractal shaped antenna elements is one of them. Several fractal geometries are introduced in recent years for efficient antennas which have varying degree of success in enhancing the characteristics of antenna. Some of them are very efficient in reducing the size of antenna, while due to other designs, we get multiband or wideband antenna. In this section, brief introduction about fractals, fractal geometry, fractal antenna, some fractal curves are discussed.

1.6.1 Fractals

Fractals can be generated through a mathematical technique or sometimes they may found in nature. Benoit Mandelbrot who is considered as father of fractal geometry gave the word ‘fractal’. He defined fractal as a shape which is made of parts similar to the whole in same way [1]. In a simple way we can define fractal as an object which appears to be self-similar when it is magnified to any extent and also possesses similarity on scale. Then major and important characteristics of fractals are:

- Self-similarity
- Scaling

- Space filling
- Statically property

Among these properties of fractals, the two are main and essential for designing fractal antennas. The first one is self-similarity and second is space filling, as due to these properties only we can reduce the size of antenna.

1.6.2 Some examples of Fractal Geometries

Some of the commonly studied and investigated fractal curve geometries for the designing of antenna are:

1.6.2.1 Koch curve

Koch curve generated by Helge Von Koch in 1904 have infinite length. Each segment having length ‘l’ is replaced with four segments of length ‘l/3’. At zeroth iteration initiator is present and it is converted to Koch curve as shown in fig. 1.5.

Similarly at second iteration each segment is again broken in four segments, now length of each segment is ‘l/9’ and the process continues. It can be considered as a best example in space filling self-similar fractal used to produce multiple band antennas with compact size. It works as a very efficient radiator as its shape is highly uneven and rough.

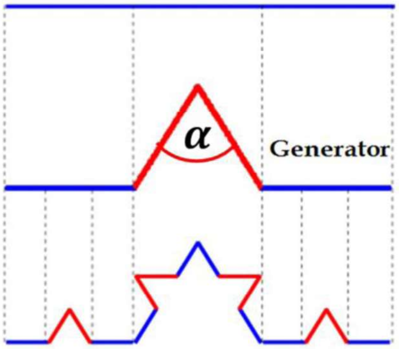


Fig. 1.5 Koch Curve

1.6.2.2 Minkowski loop

Minkowski loop shown in fig. 1.6 is also used to miniaturize the antenna as it increases the efficiency by filling up the occupied volume with electrical length. It is mainly analysed in the places where the parameter equal to one wavelength. Due to coupling between the wires, Minkowski fractal antennas gives us wideband applications as well as multiple bands. As the iterations are increased, coupling becomes more complicated and hence antenna is able to resonate at different frequencies. Hence we can say that, miniaturization in antenna systems can be achieved by using Minkowski island fractal, keeping identical electromagnetic performance as obtained by square loop antenna.

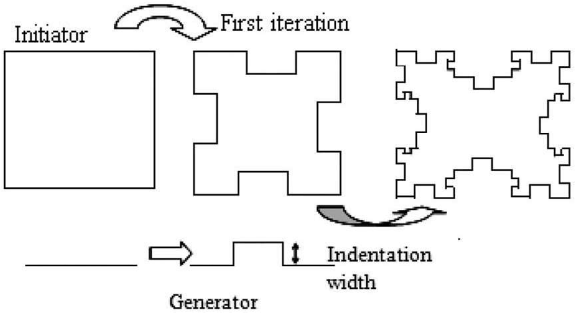


Fig. 1.6 Minkowki Fractal Square loop [15]

1.6.2.3 Sierpinski Gasket

Sierpinski gasket is also known as Sierpinski triangle or Sierpinski Seive. It is an attractive fixed set fractal introduced by 'Waclaw Sierpinski' a Polish mathematician in 1915. Its scaling factor and mass ratio are 2 and 3 respectively. It possesses multi-band behaviour because of its self-similar shape as shown in fig. 1.7. Area remaining after the iteration is ¾ of the original shape.

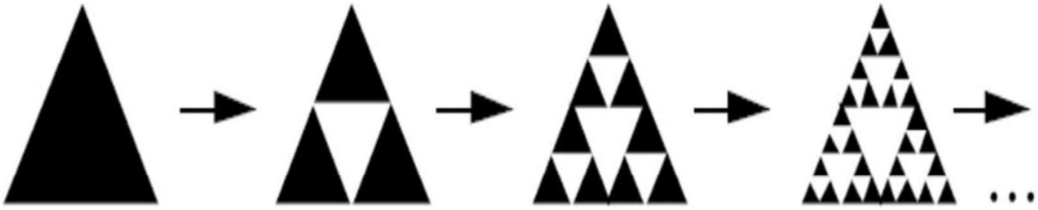


Fig.1.7 Generation of Sierpinski Gasket

1.6.2.4 Sierpinski Carpet

It is another type of fractal geometry formed by squares described by Waclaw Sierpinski in 1916. Its scaling factor and mass ratio are 3 and 8 respectively a shown in fig. 1.8.

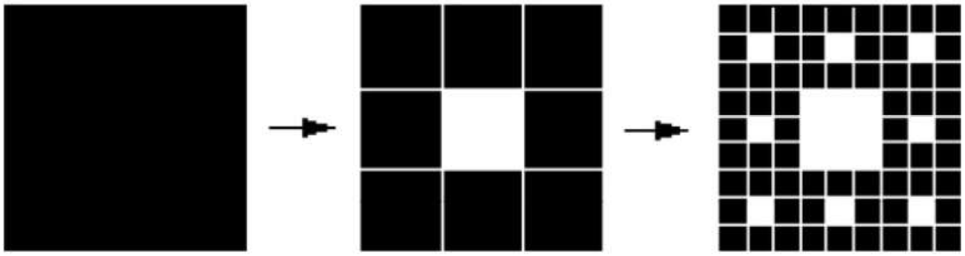


Fig. 1.8 Generation of Sierpinski Carpet

1.6.2.5 Fractal loops

Loop antennas are very well understood by using different Euclidean geometries. It is seen that fractal loops shown in fig. 1.9 provide better input impedance and SWR as they have reduced area when compared to non-fractal loops. For obtaining resonance, non-fractal loops require large area as small loops have very low input impedance. Fractal loops can overcome all these limitations as they have small area and hence compact the whole size. Fractal antennas can be more easily matched with the transmission feed line.

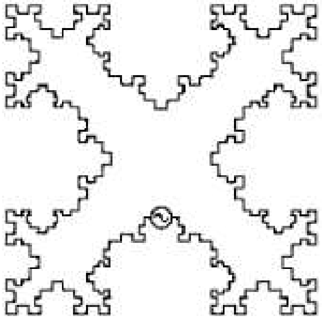


Fig. 1.9 Fractal Loops

1.6.3 Fractal Antenna Technology

Kim and D.L. Jaggard gave the first application of fractals in the field of antenna theory [9]. Methodology was introduced for designing of ow side lobe arrays which was based on random fractal theory. Carles Puente Baliarda proposed fractal as radiating elements to explore their multi-frequency property and introduced Sierpinski monopole antenna in those studies [7], [8], [10], [11]. The monopole antenna formed was able to operate at five frequency bands. Such multiband behaviour was only due to the self-similarity structure of fractal antenna. It was concluded that as the fractal iteration is increased, the resonant frequency is decreased. Antenna size is very critical parameter as its behaviour is dependent on the dimension related to free space wavelength (λ_0). In designing of small micro strip patch antennas, Hilbert and Koch fractal curves have been very useful. Small fractal loop antennas are very useful in reducing the size of antenna as due to these loops, input resistance can be increased. Koch island can be used to increases the input resistance. Fractals are used to reduce or miniaturize patch or wire elements. There are many important features of fractal antenna shown in table 1.1. There are many other factors which differentiate fractal antennas from the micro strip antennas like fractals do not have any particular shape as they are highly convoluted forming irregular shapes. Fractals have infinite range of scales inside them, as the smaller area is the replica of the larger one, but differ only in scaling factor. It means that when the structure is magnified or zoomed up, it will repeat itself. This property is used to radiate antenna at different frequencies.

Table 1.1 Features of Fractal Antenna

Feature	Application
Self-similarity	Useful in making multi-band antenna
Space filling	This feature is used to miniaturize the antenna as it increases the electrical length into compact physical volume.
Small dimension	Useful in designing antennas whose electrical lengths are small
Increasing number of iteration	It decreases the resonant frequencies
Sharp edges, corners and discontinuities	These properties help in radiating efficiently

1.6.4 Advantages and disadvantages of fractal antenna

There are many advantages and disadvantages of fractal antenna over micro-strip antenna. These are discussed below:

1.6.4.1 Advantages

- Size can be reduced from 4-5 times with efficient performance.
- Reliability is improved.
- Construction cost is reduced due to compactness in size.
- No extra matching component is required to achieve multi-band or broadband performance.

1.6.4.2 Disadvantages

In spite of having lot of advantages of using fractal geometry in micro strip antenna there are some disadvantages which are associated with them. Some of them are listed below:

- Fractals have low gain as compared to micro strip antennas.
- It has very complex geometry to design.
- There is no particular mathematical analysis associated with fractals.
- Theoretically more iterations give better results but practically only few iterations are possible after that results start to diminish.

1.7 Dielectric resonator antenna (DRA)

A dielectric resonator antenna is utilised mainly at microwave or higher bands of frequency range. It is made by the materials having high dielectric constant generally ceramic or glass. For working of dielectric resonator it must be designed in a way that it is to be placed on dielectric substrate with ground or metal surface. Radio waves are imported inside the resonator through external transmission circuit, and these waves rebound back and forth around the walls of resonator, results into the formation of standing waves. The peripherals of the resonator are partly transparent to the EM waves, hence allowing the waves to evacuate into space. Radiation pattern can be changed for a given DRA geometry by exciting it to different resonating modes. DRA can be fabricated in many shapes as shown in fig. 1.10 which is the fascinating property about it. Out of all the shapes available only some of them like rectangular, hemispherical and cylindrical are investigated [12].

Dielectric resonator components provide resonance only for limited frequency range generally in microwave or radio frequency range. These components can be considered as cylindrical or rectangular cavities in fundamental way. The high dielectric constant of DRA elements illustrates that more no of fields are occupied as compared to metallic properties, fringing fields also exists and leakage from the dielectric peripherals also exists [13]. These resonators are cheaper and even compact than the metallic cavities [14] . Coupling of resonators to the transmission lines and incorporation in to the microwave integrated circuit is very simple.

Fig. 1.10 Different shapes of DRA

For antenna applications, materials with dielectric constants ranging from 10-100 are ideally appropriate. For high dielectric constant, at a given resonant frequency, maximum of its energy is stored or present in the resonator. Conductor losses may not be present here, but losses occurring due to dielectric increases as the dielectric constant increases. Dielectric resonator can emit radiation when not surrounded completely by any conducting boundary, and hence it starts acting as an antenna, named as Dielectric Resonator Antenna.

1.7.1 Features of DRA

Dielectric resonator provides many characteristics which depicts its importance. Some of them are mentioned below:

- Dimension of DRA to be chosen is proportional to the $\lambda_0 / \sqrt{\mathcal{E}_r}$ where λ_0 and $\mathcal{E}_r$ are the free space wavelength and dielectric constant of resonator respectively. Hence, we can say that if we want to decrease the dimension of DRA, it can be done by choosing large value of $\mathcal{E}_r$.

- Easy coupling techniques are provided by DRA.
- With the different shapes and sizes of DRA, it can be exited in different number of modes, and their outcomes give us different radiation patterns.
- Correlated exterior and exclusive interior distribution of fields are consisted by every mode of Dielectric Resonator Antenna. Hence, we can obtain different features of radiation by the help of exciting different modes of DRA.

1.8 Feeding Techniques

To operate the antenna, it’s very much obvious that some external power is required. This external power is known as giving feed to antenna. There are many techniques for feeding antenna which varies according to its structure, design, shape, parameters etc. feeding is very important part of antenna designing as operation of antenna at full power of transmission only depends on feeding mechanism. For designing high frequency antenna, feeding mechanism is somehow difficult as losses in input depends on the frequency and hence, high frequency causes high losses and ultimately, a great effect on overall efficiency of antenna. Some of the commonly used feeding techniques are listed below [5]:

- Micro strip line feeding
- Coaxial probe feeding
- Proximate coupling feeding
- Aperture coupling feeding
- Coplanar waveguide feeding (CPW)

1.8.1 Micro strip line feeding

Micro strip feed line is the easiest type of feed to fabricate and model. It is just a conducting strip attached to the patch i.e. it can be considered as just an extension of the patch designed. As already said, it is very simple to model as well as very much easier to match with the feeding device by just controlling the inset position of line. One of the main disadvantages of the feed is that, as we increase the thickness of the substrate, spurious feed and surface wave radiation grows or we can say increased, hence bandwidth is decreased. Micro-strip feed line type feeding is shown in fig. 1.11.

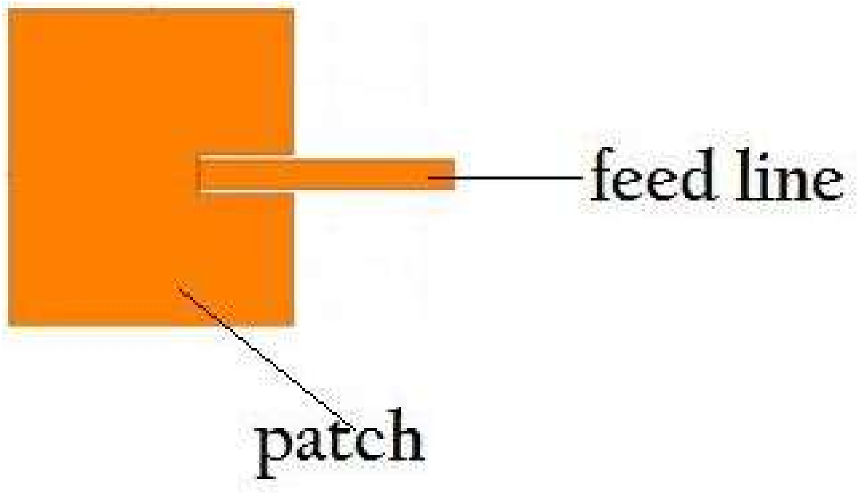


Fig. 1.11 Microstrip Feed Line [5]

1.8.2 Coaxial Probe Feeding

Spurious radiations in this type of feeding techniques are very much lower and hence, narrow bandwidth. Fabrication is very much easier but it is very much difficult to model. In this feed, two types of conductors are present namely inner conductor and outer conductor. Inner conductor is connected to the radiating patch and outer one is connected to the ground plane. Cross polarization radiations are produced as this feed possesses inherent asymmetries which cause modes of higher order. Co-axial probe type feeding is shown in fig. 1.12.

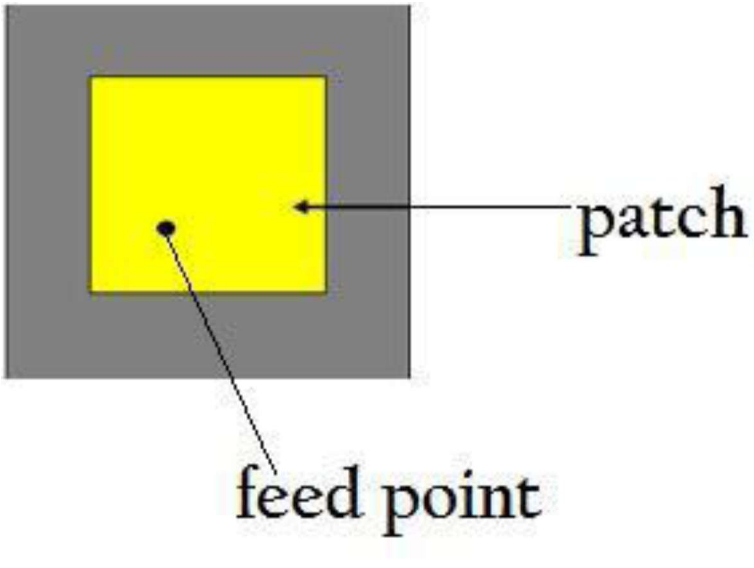


Fig. 1.12 Coaxial Probe Feed [5]

1.8.3 Aperture Coupled Feeding

It is the type of feed having narrow bandwidth and spurious radiation in moderate range. Two types of substrates are present in aperture coupling feed line and a ground plane is present in between both the substrates. A slot in the ground plane couples the energy to the patch which is delivered by micro-strip feed line present on the bottom side of the lower substrate. Dielectric constant of the top substrate is lower than the bottom one. The ground plane present is used to reduce the spurious radiation as it isolates the feed line and radiating patch. The main advantage of this type of feeding is that independent optimization is allowed for the feed mechanism element. Aperture coupled type feeding is shown in fig. 1.13.

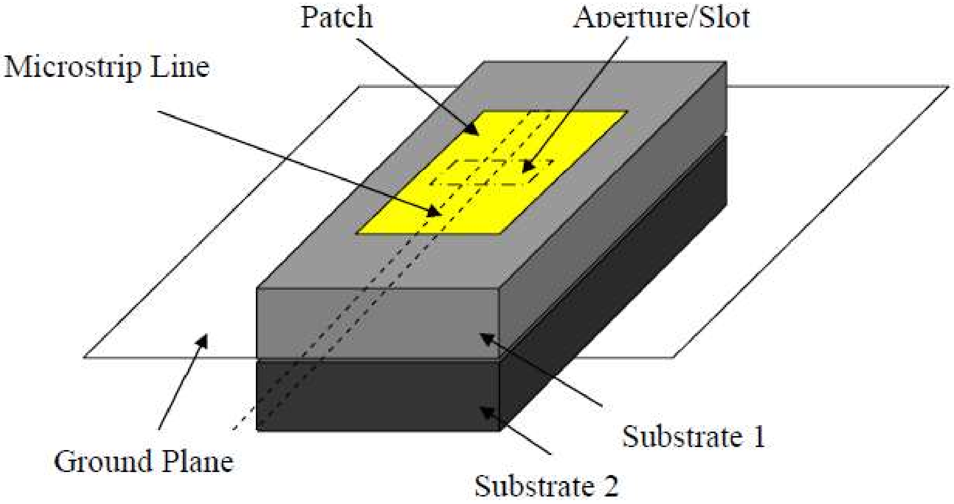


Fig. 1.13 Aperture Coupled Feed [5]

1.8.4 Proximate Coupling Feed

This type of coupling is the best coupling as it has very less spurious radiations and hence, provides high bandwidth. Fabrication of proximate feeding is tough and difficult to model. Two factors control the matching of impedance in this field: one is the length of stub used for feeding and other is the ration of width to the length of patch. Proximate coupling feed is shown in fig. 1.14.

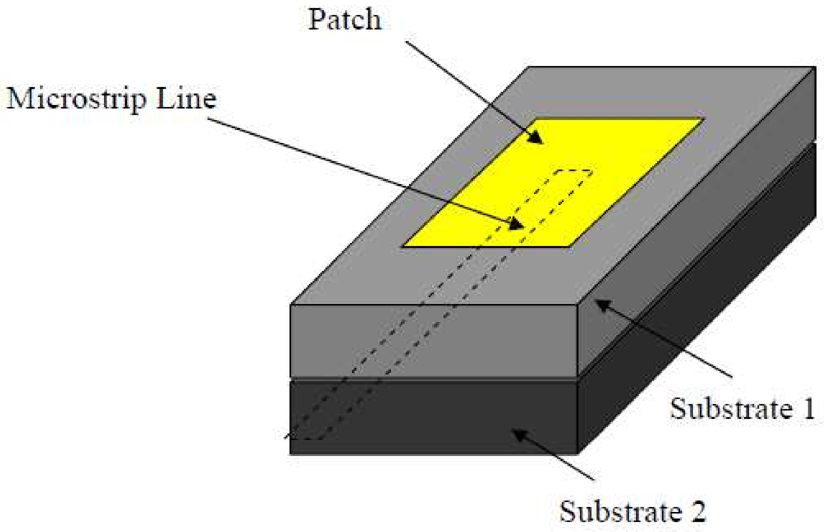


Fig. 1.14 Proximate Coupling Feed [5]

1.8.5 CPW Feed

It is known as coplanar waveguide feeding technique. In this technique both the ground and the radiating patch is present on the same plane.

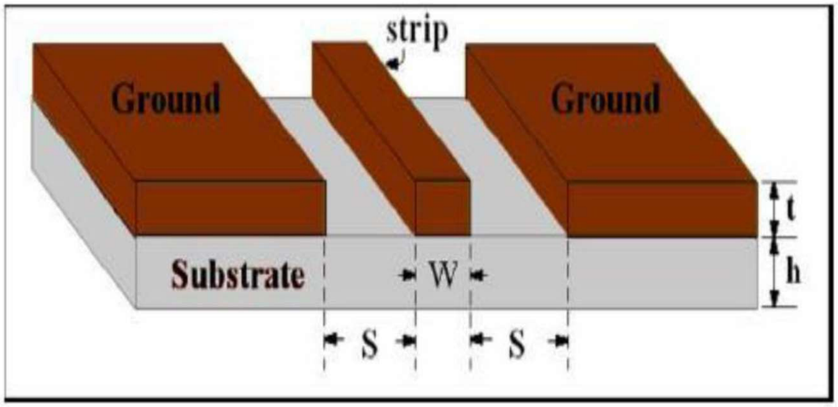


Fig. 1.15 CPW Feed [6]

This feed consists of a metallic sheet placed on the dielectric substrate having 2 small slits which could be referred to as ground electrodes present parallel and adjacent to the conducting strip on the same plane. It can be said that the transmission line formed in this feed is uniplanar in modelling. There are many characteristics of this feed like less radiation loss, very easy fabrication, less dispersion and simple configuration which makes it better from other types of feed. The performance parameters like bandwidth, impedance matching, radiation pattern, are also improved by using this type of feed. Alignment problem is also reduced as the slots are etched from the same side from where feed is etched. CPW type feed is shown in fig. 1.15.

1.9 Organisation of Thesis

The thesis report is organised as follows:

CHAPTER 1 introduces the different concepts of antenna i.e. antenna parameters, theory of antenna, types of antenna etc. after that the concepts like fractal antenna, slot antenna, dielectric antenna, feeding techniques which are used in designing of the proposed antenna are illustrated in brief. History from where the fractal antenna originates and some important fractal geometries are discussed. At the end of the chapter objectives of the thesis are listed.

CHAPTER 2 is the literature survey i.e. references from where the concepts are understood. It's a deep study on the work which has been already done in this field of antenna. Objectives of thesis are also discussed in chapter 2.

CHAPTER 3 illustrates the complete design procedure of the antenna. Parameters and steps which are used for designing of the octagonal shaped slot loop antenna are discussed. Different stages of fractal iterations are explained separately. Feeding mechanism used for the transfer of power is also explained.

CHAPTER 4 focuses on the effect of parameter on the return loss plot of the antenna. By studying that effect, final parameters are optimized. Discussion of the each graph obtained by varying different parameters is discussed separately.

CHAPTER 5 depicts the final simulated and measured results of the designed and fabricated antenna. Radiation patterns are also depicted for the resonant frequencies.

CHAPTER 6 concludes the thesis report and future scope of the thesis is discussed.

CHAPTER 2

LITERATURE REVIEW

2.1 Research work based on antenna design

Many researches in the field of fractal antenna design are being carried out till now. In this section, literature survey about those researches is presented. Research on each concept is presented separately.

Sayantan Dhar, et al. presented a multiband antenna fed with co-planer waveguide feed. In this paper concept of fractal slot loops and dielectric resonator is used. The idea of fractal slot loops is utilised for generating multiple frequency bands and dielectric resonator is used for improving the impedance bandwidth and at higher frequency range and also for improving the gain of antenna. The fractal slot loops used performs two task, i.e. it is acting as antenna as well as it is providing feed to the dielectric slab so that it can radiate. Effect on different parameter like iteration factor, indentation length, slab height etc. on the return loss plot of the designed antenna is discussed. It is concluded that the designed prototype is able to work multiple bands such as GSM 900, PCS 1900, IEEE 82.11b/g/n, WI-MAX 3.5, and IEEE 802.11 a/h/j/n [15]. **S.F. Roslan et.al** proposed a rectangular dielectric resonator antennas having multi input multi out (MIMO) system. Antenna was radiating or we can say operating at 2.6 GHz for long term evolution (LTE) applications. The designed antenna shows a reasonable gain, unidirectional and broadside radiation pattern. Correlation coefficient which was 0.03 and diversity gain of 10 dB over the working band shows the excellent performance of the designed prototype. Two types of waveguide feeds were used to excite the two orthogonal modes of rectangular dielectric resonator antenna; one was co-axial probe and other was coplanar waveguide feed (CPW). The designed antenna has a return loss up to 20dB. Gain was observed to be 4.97 dBi for the 1st port and 451 dBi for the 2nd one. It was concluded that antenna was very efficient and satisfactory for LTE applications [16].

K. Ismail and K.A Anis designed and fabricated a fractal antenna having geometry similar to sierpinski gasket antenna and simulated its results in CST (computer simulation technology) software. Antenna was designed on RT Duroid/ RO5880 substrate which have dielectric constant 2.2 and thickness 0.381 mm. Design included a ring shaped ground structure to improve the performance of antenna. Antenna was made to work on frequency 5.80 GHz with a return loss of -25.307 dB. A great reduction in size was seen in the designed antenna to suit the current demands of wireless communication systems. The DGS technique used helps in reducing the size and improving the electrical performance. Fractal geometry was also incorporated in the design which enhances the gain and directivity of antenna. It was concluded that the designed prototype is very much suitable for the RFID application [17].

A. Mehmood et al. also worked on DRA based phase array with the help of LC technology by introducing 1-by-4 DRA array, phase shifters based on LC i.e. liquid crystal, RF-feeding and some biasing networks. The main aim of using DRA was to reduce the surface currents and thus, radiating signal above from the antenna surface. Gain losses were reduced to great extent, hence increasing the antenna's beam scan angle. Anechoic chamber was used to measure the far field power structures for all different beam directions. It was concluded that losses were greatly reduced to 1.5 for the beam range of ±30° for broadside [18].

Mohsen Khalily et al. again worked on rectangular dielectric resonator antennas i.e. RDRA for the generation of linearly polarized with omnidirectional radiation patterns. Coaxial probe feed was used at the centre which offered impedance bandwidth of 130MHz with upper and lower frequencies of 5.15 and 5.35 GHz respectively with a return loss of 10dB confirming its application in 5.2 WLAN. Several inclined slits to the sidewalls and diagonals are etched out to generate circularly polarised fields. The circularly polarised DRA designed have a bandwidth of 210 MHz for WLAN applications [19].

Chitra Varadhan et al. presented two tri-band antennas, by using fractal geometry in microstrip antenna; one antenna for RFID reader and other for RFID tag. The reader one operates at 3.6 GHz, 5.8 GHz and 8.2 GHz whereas the tag antenna operates at 3.9, 5.9, 8.2 GHz frequencies. The designed antenna can be used for logistic management, tagometry i.e. telemetry using RFID and logistics management. Fractal geometry i.e. applied on the micro strip antenna is acting as a radiating element for the proposed prototype [20].

Wei-Chung Weng, Senior Member, IEEE, and Chia-Liang proposed an antenna with H-Shaped fractal geometry and conforms the multiband properties. Dielectric substrate used in designing was FR4 having 1.6 mm thickness. Radiation patterns and reflection coefficients concluded that the antenna is a good candidate for numerous wireless and antenna applications. DGS i.e. defected ground structure technique was used to enhance the directivity and overall performance of antenna. It was considered good to radiate at WLAN slandered frequency bands i.e. 2.4/5.8 GHz. The fabricated results were in agreement with the simulated results. The designed antenna presented a good example of multiband and wideband properties [21].

Sayantan Dhar et al. presented an antenna design which uses coplanar waveguide slot loop fed fractal geometry loaded with dielectric resonator. Minkowski shaped fractal geometry was used as slot loops. For bringing higher modes together and making the antenna wide band, self-similarity property of fractals was utilised. Comparison between Koch, sierpinski amd minkowski curves is presented. It was concluded that best antenna performance is yielded by Minkowski curve as it gives the widest impedance and a stable gain [22].

Peshal B. Nayak, Sudhanshu Verma and Preetam Kumar investigated that fractal antennas can also be used for spectrum sensing application in cognitive radio systems because of their multi band behaviour. The presented antenna works on four bands ranging from 900-4000 MHz. the antenna parameters like radiation patterns, return loss, gain, efficiency etc. confirms that the prototype totally suits the application of cognitive radio system. E- Shaped fractal geometry is applied on micro strip antenna. frequencies at which antenna is radiating are 945 MHz, 1945 MHz, 2470 MHz. Effect of various iterations and variation of air-gaps between the ground plane and substrate is presented [23].

Kevin A. O'Connor et al. proposed an antenna based on dielectric resonator concept for sub-GHz application. It is seen that when we employ high dielectric constant resonator materials, they require, low profile form factor, high power scalability and low volume. The designed micro strip feed line offered the characteristic impedance of 50 ohms. Dielectric constant of the material used was 100. Bandwidth of 475 MHz was obtained with a gain of 6 dBi [24].

S. Chaimool et al. proposed a fractal loop multiband antenna showing multiband characteristics. It is made up of short monopole which is loaded with a fractal loop. Parameters of the loaded fractal loops are optimised from the Minkowski fractal model. The miniaturized antenna formed is very much compact in size having dimension 10*45*0.8 mm which is very much satisfactory for USB dongle applications. From the simulated an measured results it was concluded that antenna covers many wireless bands like WiFi , WI-MAX , WLAN etc. [25].

Ahmed M. A. Salama presented his design on fractal antenna and iterated up to 2nd iteration and optimised his design for the application of passive UHF RFID tags at 900 MHz. Comparison between the designed fractal loop and conventional Koch fractal curve is shown using IE3D simulator. It was seen that the designed antenna have better radiation characteristics and even smaller in size when compared to Koch curve antenna. Experimented results were in agreement with the simulated ones. Different materials were selected and their effect on the performance of antennas was studied.it was concluded that antenna shows a very little variation or we can say that constant for the change in material [26].

Kamariah Ismail and Siti Hasyimah Ishak presented a fractal antenna having sierpinski geometry with defected ground structure working on centre frequency 5.8 GHz. Computer simulation technology (CST) software is used for design and simulation of antenna. FR4 substrate with thickness 1.6 mm having 0.025 value of loss tangent was used for fabrication of antenna. Measured results were in good agreement with the simulated ones. A compact sized prototype thus formed achieved all the specifications required. The defected ground structure used further miniaturized the antenna. It was concluded that antenna can be efficiently used in RFID application [27].

Yazi Cao, et.al presented a very compact sized multiband antenna designed by two open ended slots, one is T-Shaped and other one is E-Shaped, cut out from the edges of the ground plane making it a defected ground structure. The prototype designed can work on five frequencies to cover GSM 900, DCS 1800, PCS 1900, UMTS and 2.4 GHz WLAN band. This is controlled independently by five different slots each of monopole nature having different lengths. Antenna can be bend into E-Shape, inverted T-Shape so that volume could be reduced to make more compact sized antenna [28].

Wen-Chung Liu designed a monopole antenna having three operating bands fed by micro strip feed line type feeding. This multiband antenna is formed by defected ground structure with rectangular patch and two inverted L-Shaped slots for improving the gain and bandwidth. The dimensions of the antenna designed is 20*30 mm. it can work on frequencies 2.14–2.52 GHz, 2.82–3.74 GHz, and 5.15–6.02 GHz which confirms satisfactory for WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz applications. Measured and simulated results were in agreement with each other [29].

Yi-Fang Lin et.al designed a miniaturised antenna having dual-band characteristics fed by co-planer waveguide inductive slot. Dielectric resonator was used as a radiating element, and coplanar waveguide slot was treated as technique or way of giving feed to the dielectric resonator. Collectively due to both slots and DR, the antenna radiate at two different frequencies, one is because of dielectric resonator with broadside radiation pattern and other is due to the inductive slot used with dipole like radiation patterns. Detailed parametric study was done to study the effect of each parameter on designed prototype. Fabricated and simulated results were in agreement with each other [30].

Chih-Chiang Chen, et.al investigated that etching slots out of the radiating patch can increase the resonating bands of antenna i.e. multiband antenna. The designed antenna covers three bands: GSM, DCS and WLAN 2.4 GHz. Good radiation performance of the designed prototype was observed when it is completely designed and fabricated. For achieving low profile kind of antenna, idea of meandered patch having several slots was introduced. This antenna was very much efficient for GSM and WLAN dual band applications [31].

Rashid Ahmad Bhatti, Yun-Taek Im, and Seong-Ook Park presented an antenna for personal wireless communication systems i.e. PCS, which was covering ten frequency bands. Concept of parasitic antenna was introduced in the paper, where a shorted parasitic patch was very efficiently coupled to the original driven patch. The design was in such a way that a quarter wave resonator was attached to the feed strip which was in parallel to the original driven patch. Four slots were etched out from the the radiating patch which were responsible for the bands covering GSM-900, Digital communication system, personal wireless communication system, universal telecommunication system (UMTS) and also WLAN standards [32].

K.H. Chiang et al. proposed an antenna which has slots etched out from the ground plane. He suggested that if ground is made defected i.e. if slots are etched out of it, then by using proper shape and size of the slots, we can enhance the impedance bandwidth of the antenna. The designed antenna constitutes two U-Shaped slots etched out from the ground plane with the trapezoidal patch on the front as a radiating element. His simulated and fabricated results showed that there was 112.4 percent of bandwidth improvement as compared to the original conventional plane ground [33].

M.S.M Aras et al. presented his paper on the DRA design using the shape of disk. Operating frequency of disk was 2.4 GHz which is appropriate for WLAN working. Electric permittivity of the material used was 34.73. Antenna was excited with the micro strip feed line on the FR-4 substrate and simulations were performed on CST software [34].

R. H. Patnam presented a paper in which he designed a Koch fractal loop antenna with CPW feed. Radial Stub is used for impedance matching loaded with CPW feed acting as a lumped matching circuit. VSWR of the designed prototype is 2:1and 19 percent bandwidth operating between1.26 GHz – 1.52GHz, whereas for 1.21 GHz – 1.99 GHz VSWR is 3:1. The radiation patterns were very much well defined for the given bands [35].

N. Prombutr again investigated on Hilbert curve antennas and proposed a design that can transmit or receive at many frequencies. Fundamental frequency of the antenna was 18 GHz. It was found by calculating and experimentally that the difference in percentage of the proposed antenna was lower than 4.6 percent. Hence this design was very much helpful in designing of Hilbert curve fractal antenna. Characteristics of antenna were found out to be dependent on the outer dimension of the curve [36].

Tso Wei Li et al. presented a method for increasing the bandwidth of a dielectric resonator antenna, strip acting as a parasitic strip was placed on the dielectric material and it was seen that there was three times increase in bandwidth as compared to conventional micro strip DRA [37].

Xue sang yang presented a reconfigurable patch antenna based on Hilbert fractal curve. Design was taken up to the third iteration level. Slots were introduced in the antenna curve which corresponds to the different radiation pattern. The designed antenna could be efficiently used in radar or telecommunication systems [38].

C. T. P. Song et al. designed an antenna which described the geometry of shorted sierpinski gasket antenna. one half of the structure is similar to conventional sierpinski gasket antenna folded parallel to the ground plane forming a shape which looks like inverted L antenna. The designed prototype confirms its working on PHS, PCS, DCS, UMTS, Bluetooth and WLAN bands i.e. 802.11b and 802.11a [39].

S. Petko proposed a new design for making compact and redesigning the 3-D fractal tree antenna. It was found that density i.e. number of iterations and elevation angles are the two main factors which affect the parameters of the designed antenna. these observations lead to the designing of many more fractal tree structures and configurations with reduced size, efficient and improved antenna parameters like reflection coefficient, return loss, gain etc. some other fractal tree antennas were also presented that had RF switches placed at branches or along the main trunk of antenna tree. With the help of this technique, 57 percent size was reduced and bandwidth was increased up to 70 percent [40].

S. Petko et al. modified the structure of fractal tree antenna and gave the ways to make it more compact in size. Iterations were increased by increasing the number of branches and applying tree antenna on their end loads. This results in to increase in fractal dimension and higher numbers of bands were obtained [41].

J. anguera et al. proposed a compact sized antenna which was designed using Hilbert fractal curve. It shows that we can decrease the size of antenna by increasing the number of iterations and decreasing the length of the curve. Many number of fractal antennas with different configurations of Hilbert curves were designed and results were compared to the slandered λ/4 monopole antenna. it was observed that wire length of each Hilbert monopole was growing as the number of iterations were increased. Hence the wire length can be calculated as given below:

$$L(n) = \frac{4^{n+1} - 1}{2^{n+1} - 1}$$

Where 'n' is n^{th} iteration and 'L' is the length of Hilbert curve [42].

Liu ying et al. proposed a tri- band antenna which has great applications in mobile communication and wireless satellite communication [43]. **J. romeu et al.** further discovered the multiband nature of the sierpinski gasket that leads to the new collection of multiband fractal antennas. These antennas were collectively called mop-p sierpinski triangle antennas. He proposed that this collection of mop-p sierpinski triangle antennas were driven from the pascal triangle and they behave simmilary to log periodic behaviour of fractal antennas. Finally it was concluded that mop-p sierpinski gasket antennas are the generalised class of the conventional sierpiski fractal antennas [44].

K. J. Vinoy et al. studied the Hilbert's curve geometry and use this geometry in designing of antennas. It was then one of the most recent geometries. As the Hilbert's curve geometry was very much easy to design because of its easy predictable orders, therefore it reproduces more miniaturised antennas as compared to other ones. Variation in the antenna parameters like radiation pattern could be seen only by introducing interconnecting parts or segments to the antenna design. RF switches connected as the additional segments make the radiation pattern configurable in same way as we are connecting switches along the length of antenna. This technique results in formation of antennas which possess the frequency tuning characteristics [45].

Jaume anguera et al. proposed the fractal patch antenna with the improved antenna parameters like gain, radiation pattern, return loss, input reflection coefficient etc. multiband behaviour was observed due to the presence of fractal iterations [46].

Zhengwei du et al. again investigated on the fractal patch antenna and designs the square fractal patch and results were analysed. Results shows the multiband behaviour of fractal antenna and it was concluded that results are due to the driven element and not because from the parasitic fractal elements [47].

Baliarda et al. also worked on the same theory and concluded that it is only the self-repeating property of fractals that is helping in getting multiple bands as fractals possesses self-similarity nature. This s is the property which was used to predict the antenna behaviour when the flare angle was varied [48].

J. Romeu et al. designed a sierpinsiki micro strip antenna for multiband behaviour. This design mainly aims at improving the radiation pattern due to multiband behaviour by dropping the effects occurred due to higher modes of antenna [49].

M. sindou compared the calculated and experimental results of antenna parameters i.e. input reflection coefficient and return loss of the designed fractal tree and found that both the results gave the same conclusion that due to the present of iteration levels, the fractal tree generated also exhibit the multiple band behaviour. As it is already said that number of iteration levels in case of fractal tree are more as compared to sierpinsiki gasket antenna, therefore the multiband behaviour is transformed to wideband behaviour. This is all due to presence of large number of radiating elements present in the last iteration [50].

D.H Werner et al. also worked on the fractal tree antenna and presented a paper where the multiband electromagnetic behaviour of the fractal tree was discussed. Tri-band antenna was designed with the monopole structure and results were simulated. It was concluded that the antenna parameters were improved and not similar to the conventional monopole sierpinsiki gasket geometry [51].

N Cohen presented his theory that gain, radiation pattern, return loss, number of working bands etc. can be improved by applying fractals to the antenna elements. He confirmed that fractal antennas are highly efficient and worthwhile in many of applications. It was also found that they are very much versatile in the field of wireless communication application [52].

Puente et al. proposed a multiband fractal antenna based on sierpinski triangle or gasket. The antenna was experimented and results concluded the multiband property of the designed fractal antenna. Five bands were discovered and it was investigated that these bands were due to the self-similarity property of the fractals, i.e. they repeat their shape at different scales. This paper gave researchers a new approach to design multiband antennas. An equilateral triangle was chosen as a generator for creating the sierpinski gasket geometry; five iterations were performed at different scales which confirmed the five working bands of the prototype. Antenna was fabricated and it was seen that fabricated results were in agreement with the simulated ones. Both the results concluded that the self-repeating pattern of fractals is converted into electromagnetic behaviour [53].

C. Puente et al. investigated that with the change in flare angle, input parameters and radiation patterns are accordingly varied and multiband behaviour can be obtained [54]. **Y. kim et al.** introduced a new way of random array synthesis for the first time. This theory was based on the application of self-similarity property of fractals in the antenna array theory. Many examples were discussed for the procedure of synthesis and also advantages of this technique in making low profile and highly efficient were presented [55].

2.2 Thesis Objectives

The main objective or aim of the thesis is to design a compact sized multiband fractal antenna and to study the parameters which are affecting the performance of the designed prototype. As in today's world of modern communications, the requirement of the frequency bands are increasing and size of the devices used for the communication systems is decreasing. Hence, the antennas are required which satisfies both the conditions i.e. it must be capable of handling many frequency bands and also of small and compact size. To cover number of bands with the same antenna, the conventional micro-strip antenna which consists of a single radiating patch is not sufficient. There are many more new methods which need to be applied on the basic micro-strip antenna for their efficient and improved working.

In this thesis research, four concepts are i.e. fractal geometry, slot loop antenna, dielectric resonator and DGS (Defected Ground Structure) are collectively used to design the antenna. Each concept is illustrated in the previous sections and subsequent chapters focus on the design of antenna. Effect of each parameter used in designing of antenna on its performance is also to be studied and need to conclude about the optimized parameters which can design the antenna for covering different bands of wireless standards like GSM, WLAN, Bluetooth, WiMAX etc. in short the main objectives of thesis are:

- To design, fabricate and test the octagonal shaped fractal slot loop antenna.
- To simulate the return loss plot at different frequencies and compare them with the measured results.
- To study the effect of iterations i.e. self-repeating property of fractals to show the multiband behaviour of antenna.
- To reduce the size of antenna and improve its radiation characteristics.
- To analyse the effect of DGS.
- To observe the effect of dielectric resonator slab on the return loss plot of antenna.

CHAPTER 3

ANTENNA DESIGN METHODOLOGY

3.1 Introduction

The aim of this chapter is to discuss the complete design parameters of the antenna. Detailed discussion about the various parameters used in designing of antenna is given. Effect of various parameters used in designing on the antenna performance parameters like radiation pattern, return loss etc. is discussed. Fractal antennas are very much helpful in designing multiband behaviour, so fractal geometry is involved in this design in order to have multiple resonances. As antenna is fractal in nature, therefore different iterations are used to make the final prototype shown in fig. 3.7. Every iteration has its own results which are also discussed in subsequent chapters. The antenna is designed using four different concepts i.e. fractal geometry, slot antenna and dielectric resonator and defected ground structure. The four concepts are already well explained in chapter 1. This chapter presents how these four concepts combine to form the dielectric loaded fractal slot loop antenna. The designed antenna confirms many wireless applications mentioned in chapter 4.

3.2 Antenna design parameters

The design procedure consists of three steps in designing of the antenna. In the first stage, the fractal octagonal shaped slot loop is constructed on the substrate of dielectric material by etching slots from the conducting material placed on the substrate. After etching octagonal slot loop, feed is given to excite the antenna for working. CPW type of feed is used. In the second stage, defected ground structure is formed i.e. slots are etched from the ground plane for having better performance and finally in the third stage, a slab of high dielectric material is placed on the slot loop for improving the gain and bandwidth of antenna. In the subsequent sections of the chapter the three stages are discussed deeply.

3.2.1 Stage I (Formation of Fractal Slot Loop)

Antenna is designed on the FR-4 substrate having dielectric constant of 4.4 and thickness 1.6 mm. Dimensions of the substrate chosen are L*W=65*70 mm. a sheet of copper with the similar dimensions is placed the substrate FR-4 so that it completely covers the substrate surface. Now, a cuboid is formed which have dielectric substrate at the bottom and conducting copper sheet on the top as shown in fig. 3.1(a) and 3.1(b).

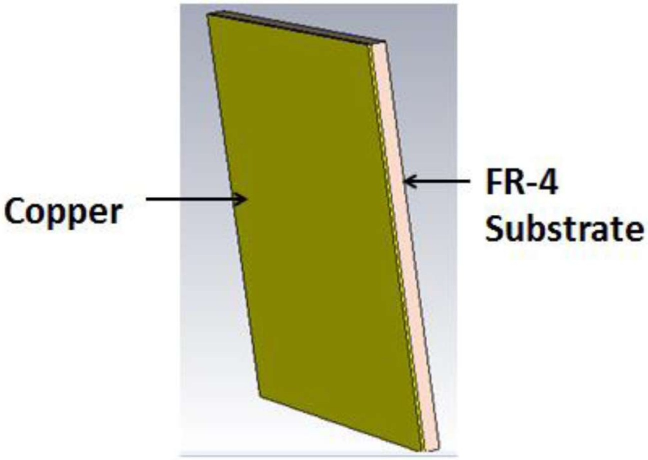


Fig. 3.1(a) 3-D view of copper plate placed on FR-4 substrate

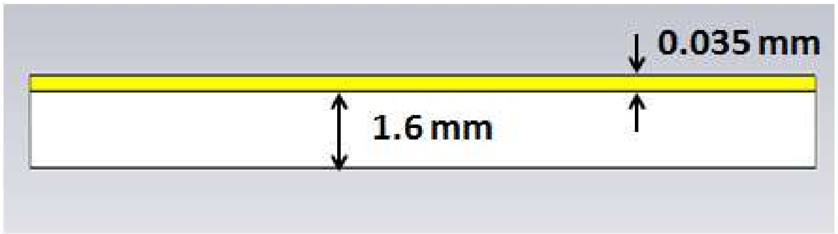


Fig. 3.1(b) Bottom view of copper plate placed on FR-4 substrate

Slots are etched from this copper plate to form the slot loop antenna. Slot loop as shown in fig. 3.2 in shape of octagon having side of length ‘l’ is formed and Minkowski fractal geometry is applied on the boundaries of the octagonal slot. Width of the slot is taken as ‘g’ as shown on fig. 3.7. Coplanar waveguide feed (CPW) is applied to excite the antenna. Distance of the central conductor for the coplanar waveguide feed is ‘s = 4.2’ mm as shown in fig. 3.7 to design the 50 ohm characteristic impedance. Gap between the strips is also ‘g’ i.e. 0.3 mm. fractal geometry is taken up to many stages, but in this design it is taken up to 2^{nd} stage i.e. only two iteration, as they are sufficient for our needs.

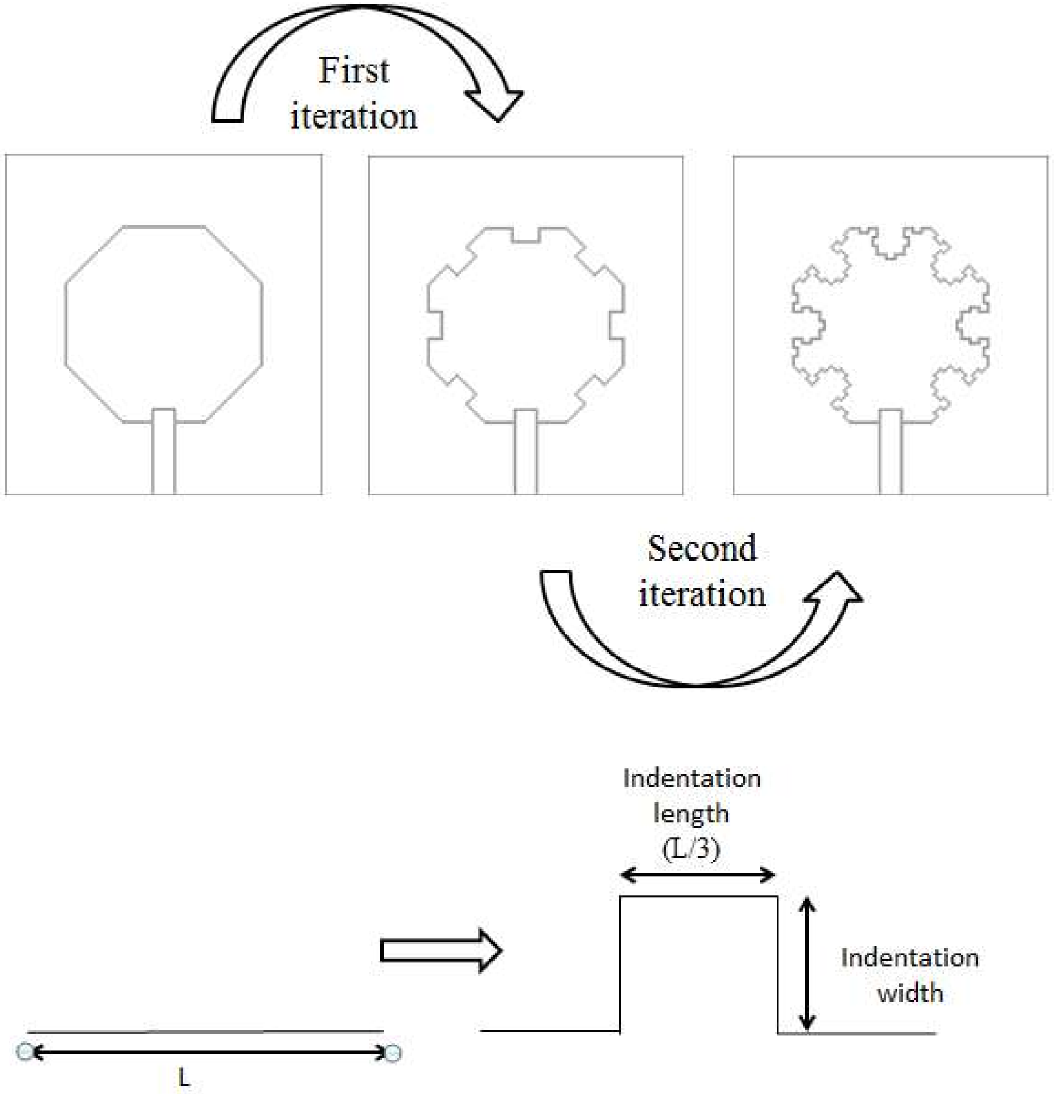


Fig. 3.2 Generation of Fractal Slot Loop

To generate the fractal loop, we have to apply Minkowski fractal geometry on each segment of the octagon having length ‘l’ as shown in fig. 3.2. Each side is indented inwards i.e. by shifting middle one third part which is called indentation length inside to some extent. The length to which it is shifted inside is called indentation width. Ratio of this indentation width to the indentation length is scale indentation factor ‘i’. For the each iteration this indentation factor is defined as i_1, i_2….. i_n. As we are considering only two iterations so only two indentation factors are defined i.e. i_1 and i_2. Effect of this factor on the antenna’s performance is well discussed in next chapter.

$$i = \frac{indentation\ width}{indentation\ length}$$

It is seen that due to characteristic impedance mismatch between the slot width and the central conductor width of the coplanar waveguide feed which have length of s=4.2mm, radiations can’t occur properly. Input power will not able to transfer completely and hence, loses will occur. There is very much need to remove this problem for the efficient working of antenna. This problem is solved by using open circuited coplanar waveguide stub of length ‘l_s’ is used as shown in fig. 3.7. Stubs are very much helpful in matching for impedance for proper transfer of power. Effect of introducing stub in the return loss is shown in fig. 3.3(a)

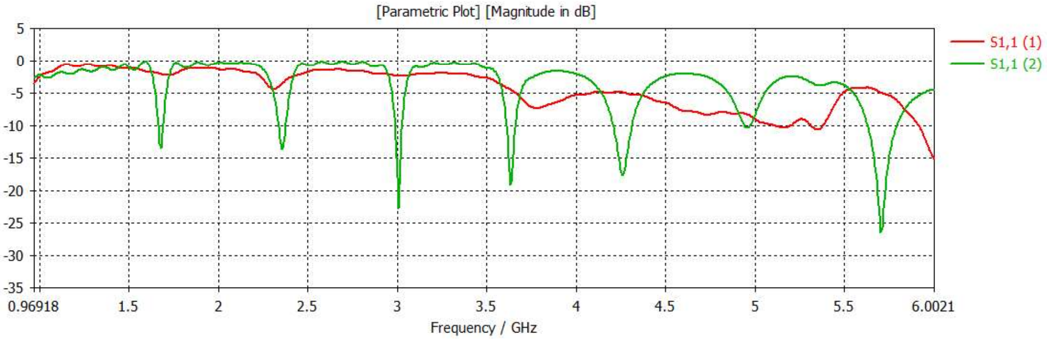


Fig. 3.3 (a) Simulated S_{11} (dB) with and without stub matching

Fig.3.3 (b) Antenna with and without tuning stub

The area left after the etching of octagonal slot and CPW feed, is called ground part of the antenna. Presence of ground has very much importance in improving the far field radiation pattern of the antenna. Ground part is made up of some conducting material and in this case copper is used as a ground. Researches show that etching slots in the ground plane improves the gain and bandwidth of the antenna and thus we proceed towards our next stage i.e. DGS formation.

3.2.2 Stage II (DGS Formation)

As already discussed that introducing DGS technique improves the performance of antenna therefore, six squared loops having side length of f1, f2, f3, f4, f5, f6 with their bottom side eliminated (fig. 3.4) are etched from the ground plane as shown in fig. 3.5.

Values corresponding to all the DGS slot loops are given in table 3.1.

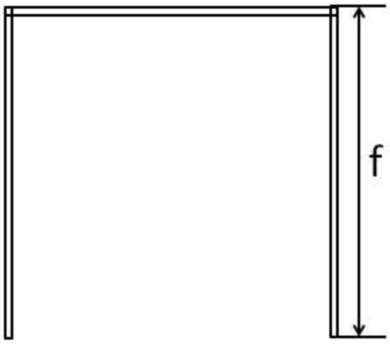


Fig. 3.4 Shape of the slot loop etched for DGS

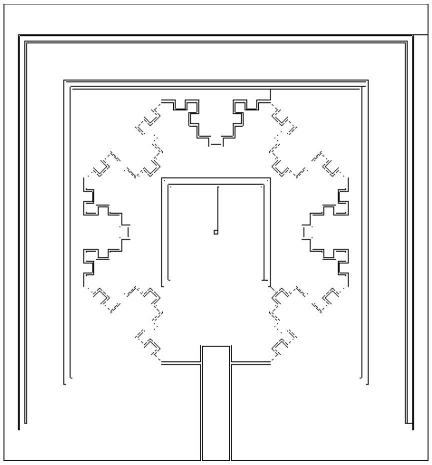


Fig. 3.5 Final design after etching slots corresponding to DGS

TABLE 3.1 Value of the square loops etched out for DGS

Parameter	f1	f2	f3	f4	f5	f6	f7
Value (mm)	0	14	16	44	46	58	60

3.2.3 Stage III (loading of dielectric resonator slab)

The uneven nature of the slots in fractal loop will create diverging E-fields hence reducing the gain and directivity of the designed antenna. Also it can be observed that as slot lines always tends store more energy and hence radiate less, this problem could be solved by using DRA structures, i.e. by placing a dielectric slab of dimension A*B on the antenna which would enhance the radiations and improve directivity as shown in fig. 3.7. We can also increase the effective permittivity of the slot antenna which reduces the resonant frequency by placing a resonator i.e. dielectric slab on top of the antenna. Tuning of frequency can also be done by using this property. The entire 5-6 GHz band can also be utilised, which is another reason for using this dielectric slab. 5-6 GHz band is very useful in IEEE Wireless Local Area Network (WLAN).

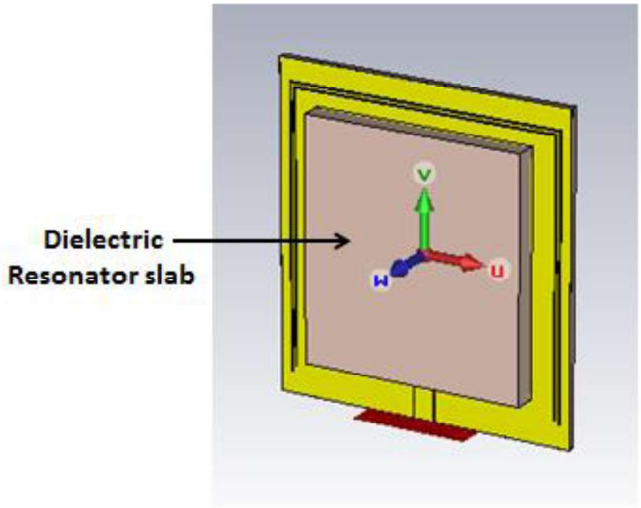


Fig. 3.6 Placing of dielectric slab on the designed prototype

The dimensions of the slab are chosen in such a way that it resonates around 5 Ghz WLAN band. The model named Marcatilli's model is used to calculate the dimensions of the resonator slab placed on designed antenna. Equations corresponding to this model are 3.1 and 3.2.

$$f_r = \frac{c}{\sqrt{\varepsilon_r}} k = \frac{c}{\sqrt{\varepsilon_r}} \sqrt{k_x^2 + k_y^2 + k_z^2} \qquad \dots (3.1)$$

Where,

$k_x = \frac{\pi}{A}$;

$k_z = \frac{\pi}{2H}$;

$k_y \tan(k_y \, \mathrm{B}) = \sqrt{(\varepsilon_r - 1)\, k_0^2 - k_y^2}$

and

$$k_x^2 + k_y^2 + k_z^2 = \varepsilon_r k_0^2 \qquad \dots (3.2)$$

For simulation of results material chosen as a dielectric slab have the dielectric constant of value 10. Fig. 3.7 shows how the slab is placed on the designed prototype.

3.3 The Final Design Parameters

In the previous sections, details designing concept of antenna is shown. In this section all the parametric value and the final design thus formed in depicted in fig. 3.7. The value of each parameter is shown in table 3.2

Table 3.2 Final optimized value for antenna design

Parameter	Values
Ground plane dimensions (L*W)	65 mm * 70 mm
Substrate dimensions	65 mm * 70 mm
Octagon single side dimension (l)	16.5mm
Stub length (l_s)	3mm
Slot width (g)	0.3 mm
First indentation factor	1
Second indentation factor	0.7
Dielectric slab dimension (A*B*H)	48mm* 52mm* 5mm

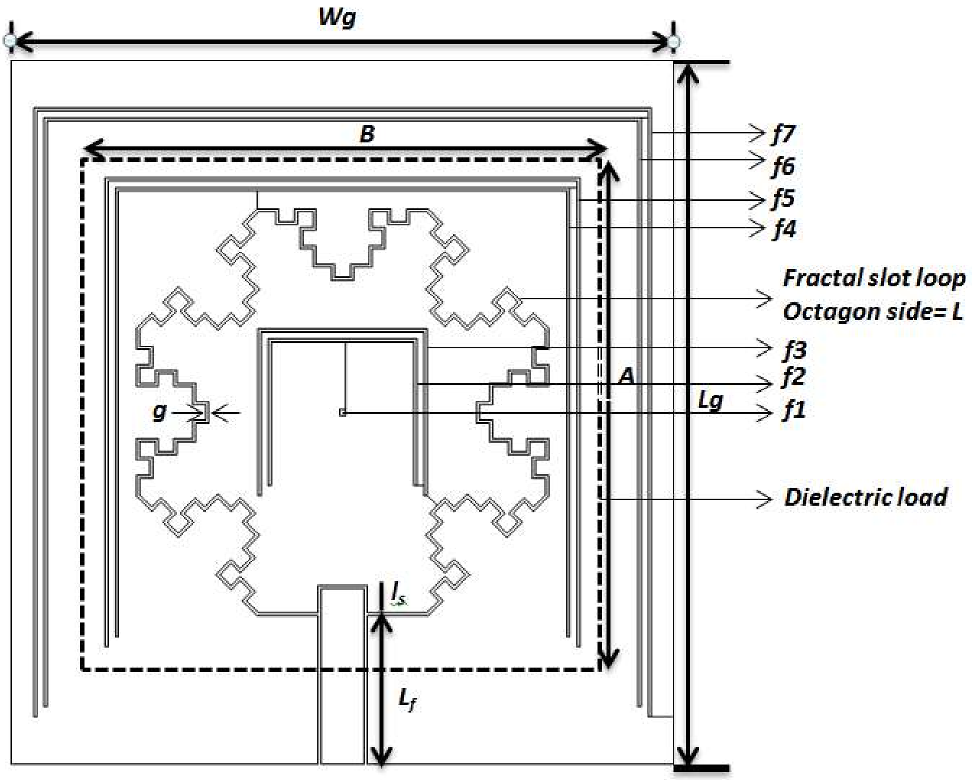


Fig. 3.7 Design of the proposed antenna

CHAPTER 4

PAREMETRIC STUDY

4.1 Introduction

In chapter 3, an octagonal fractal slot loop antenna with DGS and dielectric resonator is designed. It is seen that there are many parameters present, which are used in designing of the antenna. In chapter 4, effect of these parameters on the antenna's performance is shown with the help of return loss plot simulated in CST (computer simulation technology) software. The parameters are listed below:

- Number of iterations
- Indentation factors (i_1 and i_2)
- Slot width (g)
- Initial length of octagon (l)
- Height of the dielectric resonator slab
- Effect of DGS

4.2 Effect of Iterations

It is seen that when the fractal geometry is employed on the antenna structure the number of bands are increased and fundamental frequency of the antenna is decreased.

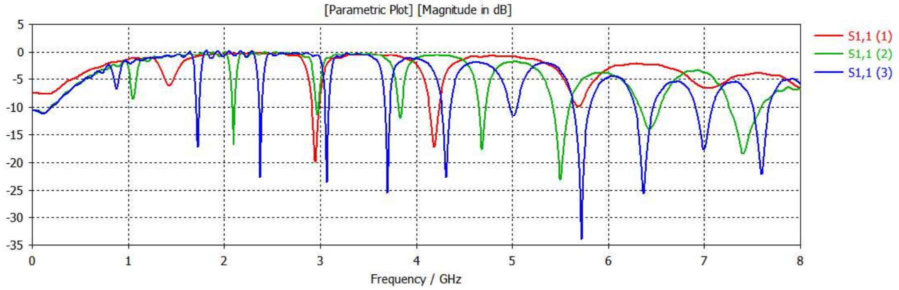


Fig. 4.1 Simulated S_{11} (dB) for the three iterations.

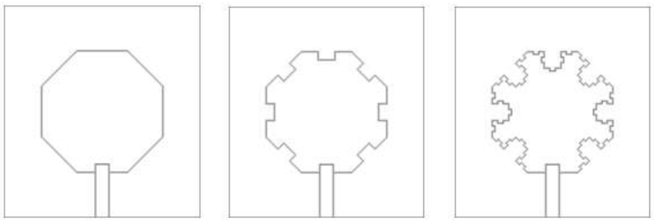


Fig. 4.1 Three iterated stages

The reason for the increase in antenna's performance is that effective length of the current path is increased and hence, surface density is increased. The comparison of the return loss of initiator octagon, first iteration and second iteration is shown in fig. 4.1. From the figure it is shown clearly that as the iterations are increased the resonant frequency is decreased and return loss is also improved. Plot in red colour depicts the initiator octagon, green for the first iteration and blue colour for the second. Return loss of the second iteration is the best when compared from both the first and initiator one.

4.3 Effect of Indentation Factor

As in the previous chapter, indentation factor is described as ratio of indentation width to the indentation length. The factor 'i' is varied as, keeping the indentation length fixed and changing the indentation width.

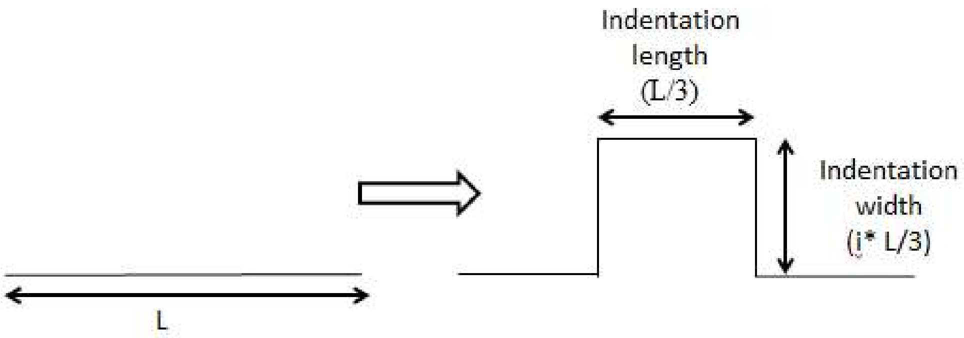


Fig. 4.3 Generation of fractal slot loop

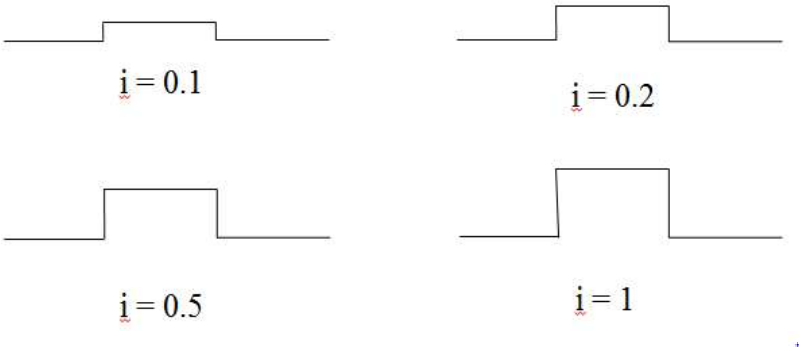


Fig. 4.4 Indentation factor affecting shape of loop

The fig. 4.4 shows examples various indentation factors to understand its concept clearly. The fig. 4.5 and 4.6 shows the return loss plot for various values of indentation factors i_1 and i_2. From these return plots it is clear that optimized values for the two indentation factors are 1 and 0.7 respectively .

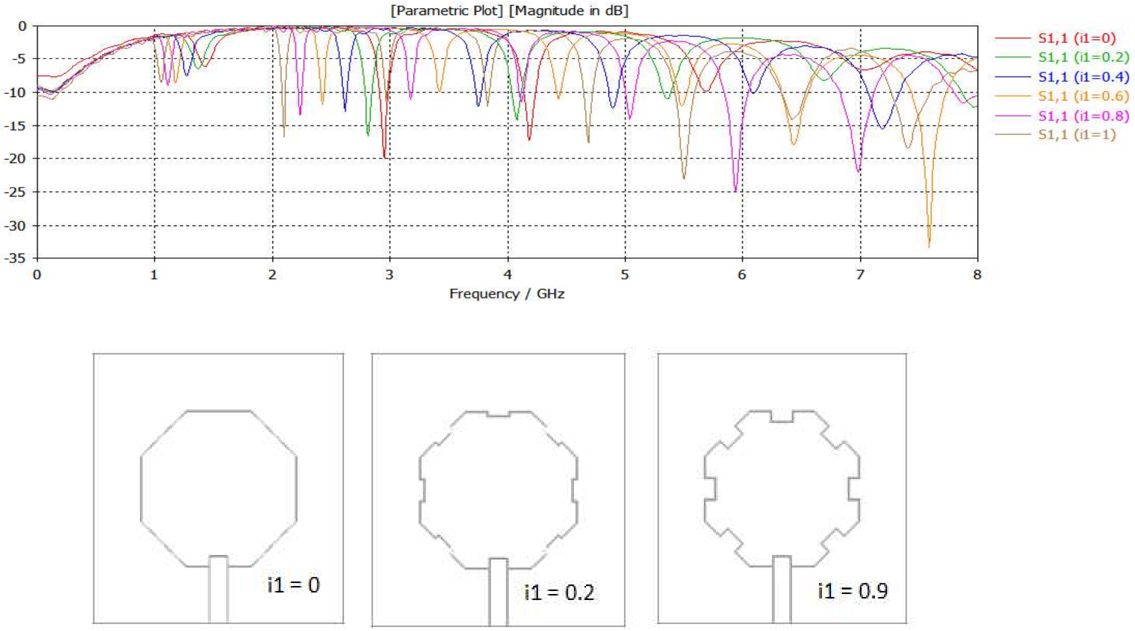


Fig. 4.5 S_{11} (dB) Simulated for various indentation factors 'i_1'

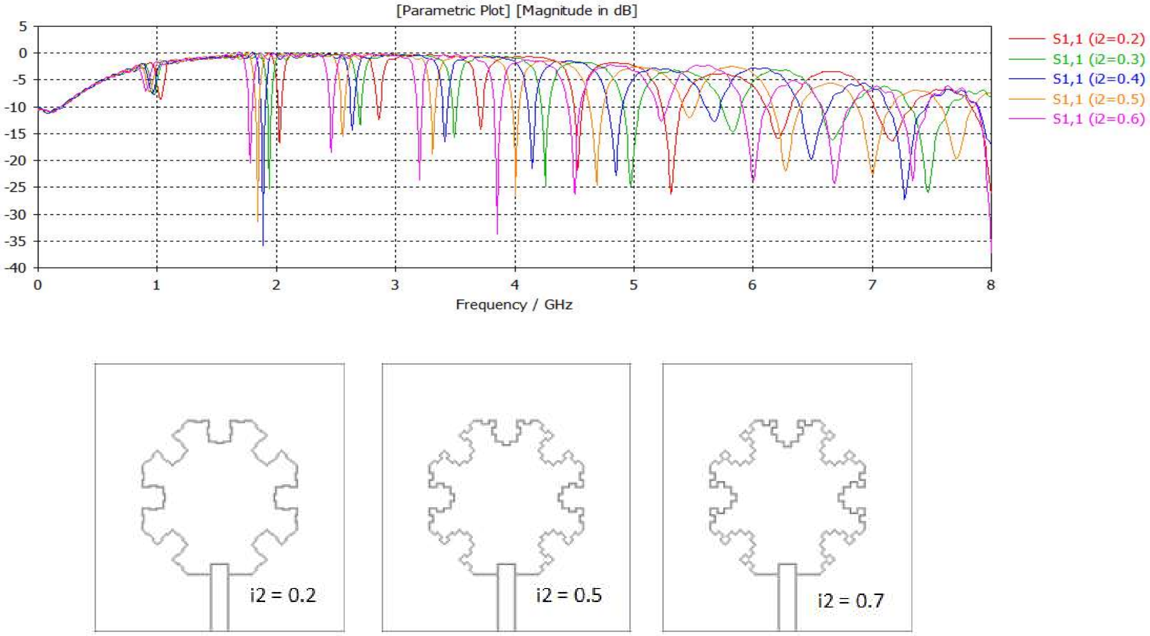


Fig. 4.6 S_{11} (dB) Simulated for various indentation factors 'i_2'

From the above two graphs it is very much clear that as the indentation factor is increased, fundamental frequency is decreased and return loss is improved. As the i_1 is approaching towards ‘1’ from ‘0.1’ the fundamental resonating frequency approaches towards 1 GHz and when second iteration is applied the fundamental frequency even get decreased before 1 GHz. It is also seen that number of resonating bands are increased as the indentation factor is increased.

4.4 Slot Width

The slot width ‘g’ is also varied from 0.2- 0.4 and is it concluded from return loss plot shown in fig. 4.7 that fundamental frequency and gain is best at 0.3 mm. hence we chose this slot width for our final fabricated antenna.

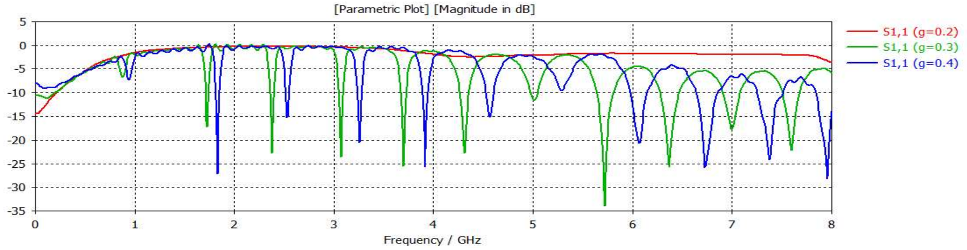


Fig. 4.7 S_{11} (dB) Simulated for various slot width ‘g’

4.5 Height of Dielectric Resonator Slab

The dimensions of the slab are chosen in such a way that it resonates around 5 GHz WLAN band. In fig. 4.8

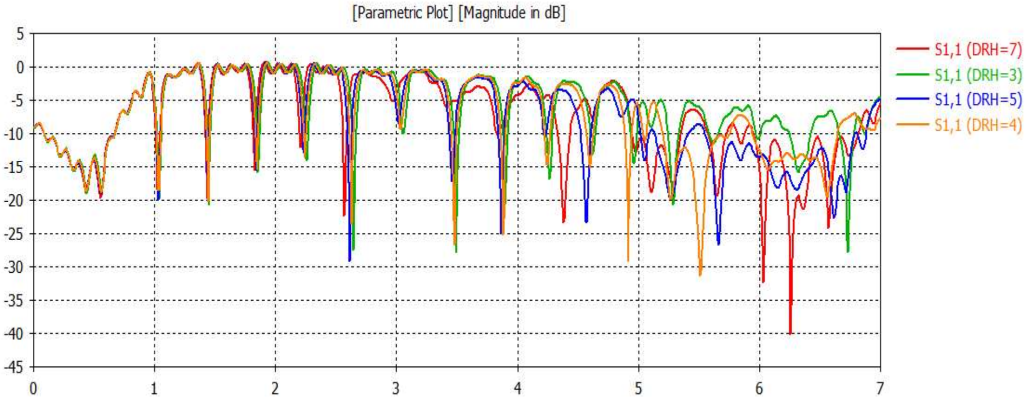


Fig. 4.8 S_{11} (dB) Simulated for different heights of dielectric slab

It is shown that how the gain varies by varying the height of the dielectric slab. As the slab is made to resonate around 5 GHz, it can be seen in the graph that maximum variation occurs around 5 GHz as the height is changed. We can also increase the effective permittivity of the slot antenna which reduces the resonant frequency by placing a resonator i.e. dielectric slab on top of the antenna. Tuning of frequency can also be done by using this property. The entire 5-6 GHz band can also be utilised, which is another reason for using this dielectric slab. 5-6 GHz band is very useful in IEEE Wireless Local Area Network (WLAN).

4.6 Effect of DGS on Antenna

After making this octagonal fractal slot loop, 7 square loops with one side eliminated having one side dimension f1, f2, ….f7, as shown in fig. 3.7 are also etched out. These slots improve the gain and fundamental frequency of the antenna. These square looped slots can be said to be working like defected ground structure (DGS). 6-7 GHz band is mainly because of these slots. The current path increases and we get more number of bands in smaller size. It is also seen that the square slot loops are responsible for reducing the size of antenna as due to these slots the antenna size is reduced to 65 * 75 mm from 100 * 100 mm [15]. Plot in red is with DGS and in green is without DGS as shown in fig. 4.9.

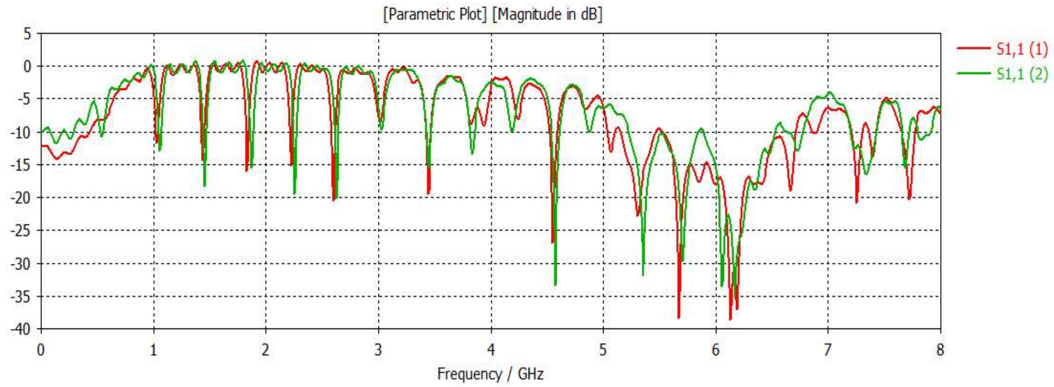


Fig. 4.9 Simulated S_{11} (dB) for with square loops and without square loops

4.7 Optimizing Initial Length of Antenna

Initiator length is very much important to optimize as the size of the antenna mainly depends on it. Antenna initiator length of octagonal shaped loop optimized by taking different value of the lengths and simulating it one by one. The graph of the values which were giving the best results are shown in fig.- it can be seen that as the length is increased the fundamental frequency starts decreasing and multiple bands starts increasing. But we can increase the length up to certain limit only as more the initiator length, greater will be the size of antenna which will affect the compactness feature and also gain starts decreasing as the length is increased. It can be clearly seen from the plot that as the length increased from 10 mm to 16 mm, the fundamental frequency is decreased but at the cost of gain i.e. return loss plot goes upward. At length of 17 mm, the return loss plot even goes above the 10db line which is not satisfactory for the antenna performance. Hence, we optimize our length to 16.5 mm, which is giving the satisfactory and the desired results. Table 4.3 shows the length corresponding to each plot shown in fig. 4.10.

Table 4.3 Length corresponding to each plot shown in fig. 4.10

Plot no.	Corresponding initiator length
S1,1(1)	10 mm
S1,1(2)	12 mm
S1,1(3)	14 mm
S1,1(4)	15 mm
S1,1(5)	16 mm
S1,1(6)	16.5 mm
S1,1(7)	17 mm

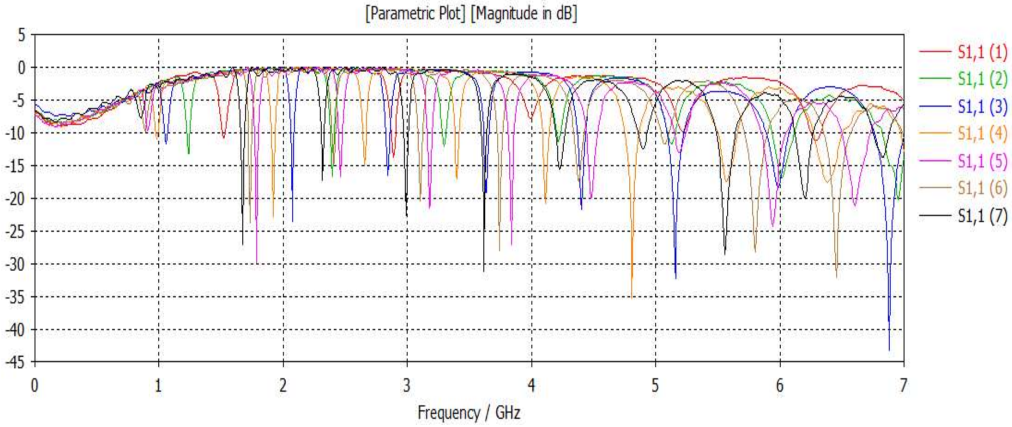


Fig. 4.10 Simulated S_{11} (dB) for different initiator length of the octagonal fractal slot loop

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

In today's world, we require greater bandwidth for voice and data application in mobile communication world. Number of frequency bands is also increased, as there is different band for different application. It is very difficult to employ different antenna for different bands as in today's world devices, a single devices needs to perform various applications, therefore we require multi-bands antennas which can satisfy our need. In the previous chapters, the design parameters and effect of each parameter on the performance of antenna. This chapter shows the final simulated results after placing of a dielectric slab and the fabricated results. As already said, simulation is performed on CST (computer simulation technology) software and testing of fabricated results is done on VNA tester available in antenna research lab, Thapar University, Patiala.

5.2 Simulated Results of Proposed Antenna

Final results of the proposed antenna shown in fig. 3.7 are obtained after placing a dielectric slab having dielectric constant of value '10' on it. The return loss plot is shown in fig.5.1. From the return loss plot, it is clearly seen that the fractal antenna proposed exhibits multiband behaviour. The antenna confirms its operation on many standards of wireless communication. Return loss plot shows that the frequency where the plot is below 10dB can be used for operation. From the above graph, it can be concluded that antenna can satisfactorily work on GSM 1800 (1710-1805 MHz), IMT i.e. international mobile telecommunication system (2.3-2.4 GHz), Bluetooth (2.5-2.69 GHz), WiMAX (3.4-3.6 GHz), IMT (4.4-4.6 GHz) and WLAN (5.2-5.8 GHz). From the return loss plot, it is clear that the antenna covers wide bandwidth in the frequency range of approximately 5-7 GHz (5.2 – 6.8 GH, which is also shown separately in fig. 5.2), this band after 6 GHz will be used for 5G in future. The above mentioned frequency ranges are slandered ranges. Beyond these applications, antenna is also radiating at other frequencies also like 0.5 GHz, 1.1 GHz, 1.4 GHz, 6.7 GHz, and 6.9 GHz etc. These frequencies can be used for RADAR and Satellite communication.

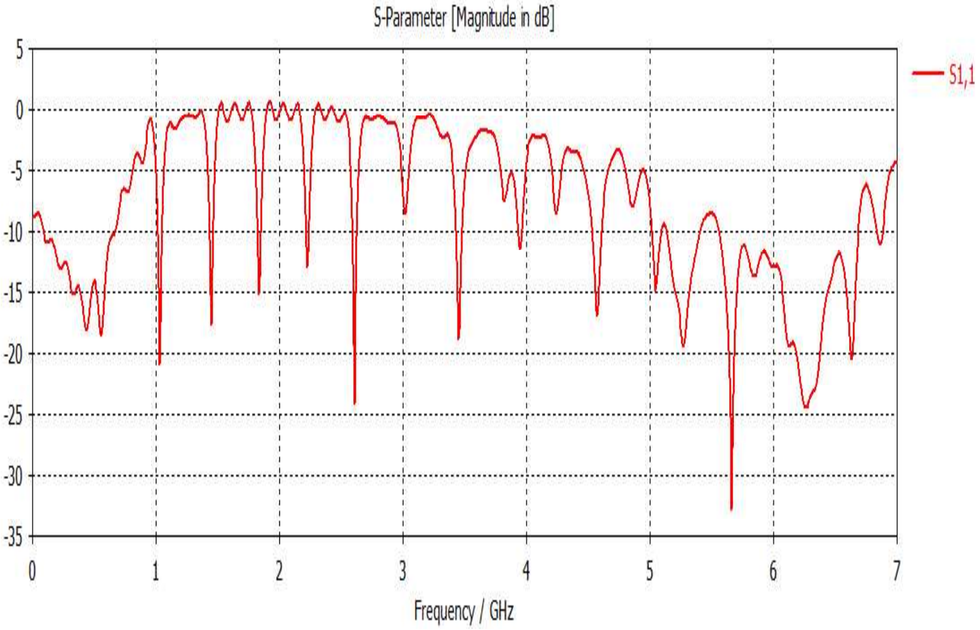


Fig. 5.1 Simulated S_{11} (dB) for the designed antenna

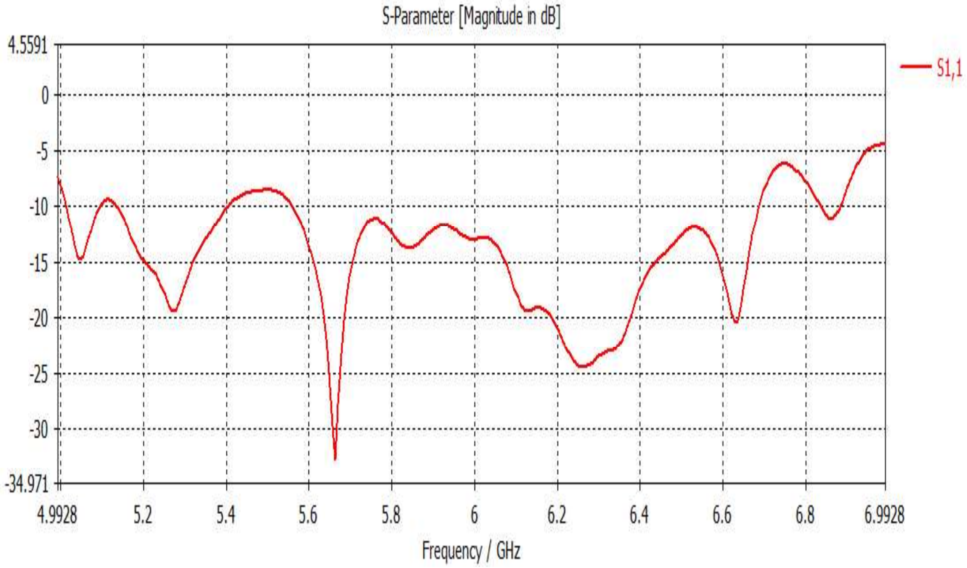
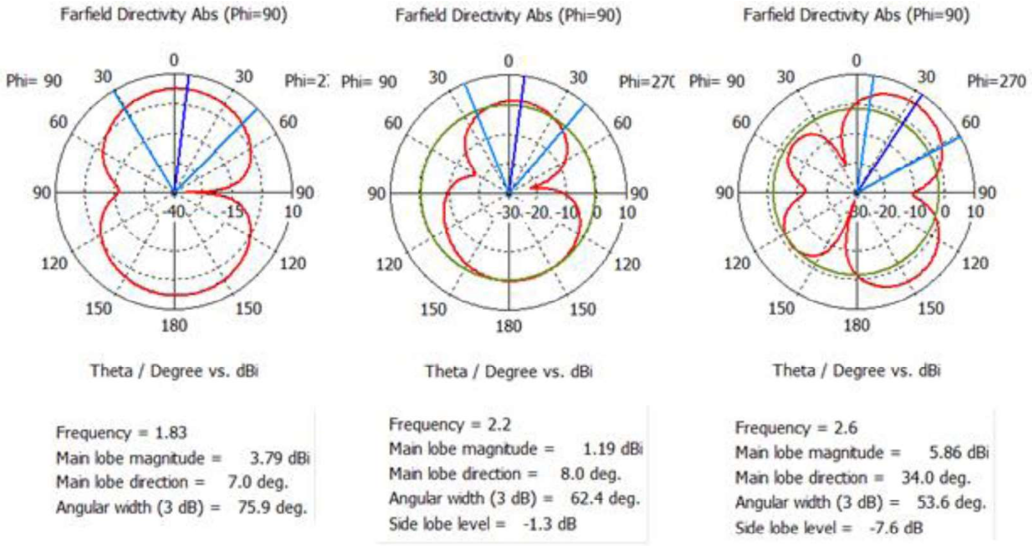


Fig. 5.2 Simulated S_{11} (dB) showing wide bandwidth around 5-7 GHz

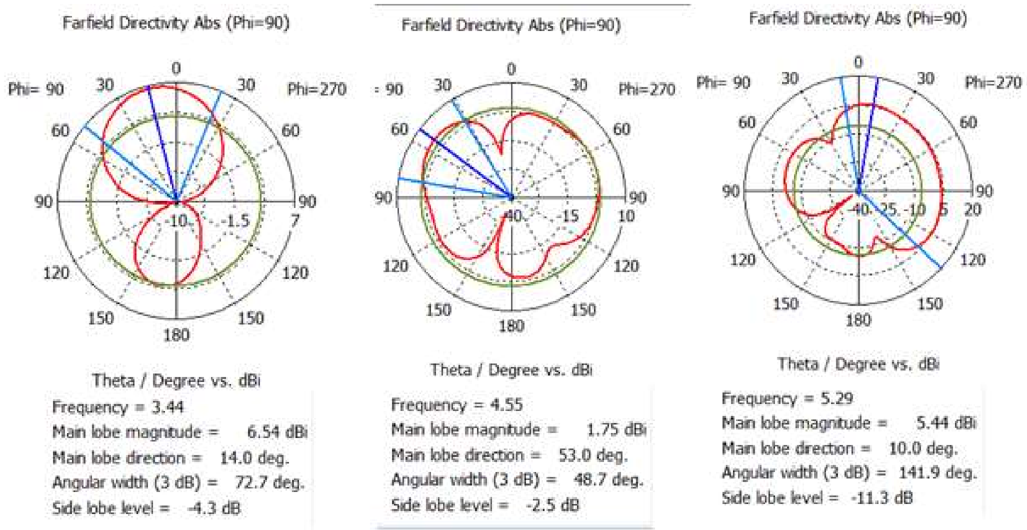


Frequency = 1.83
Main lobe magnitude = 3.79 dBi
Main lobe direction = 7.0 deg.
Angular width (3 dB) = 75.9 deg.

Frequency = 2.2
Main lobe magnitude = 1.19 dBi
Main lobe direction = 8.0 deg.
Angular width (3 dB) = 62.4 deg.
Side lobe level = -1.3 dB

Frequency = 2.6
Main lobe magnitude = 5.86 dBi
Main lobe direction = 34.0 deg.
Angular width (3 dB) = 53.6 deg.
Side lobe level = -7.6 dB

Fig. 5.3 Radiation patterns at 1.83, 2.2 and 2.6 GHz



Frequency = 3.44
Main lobe magnitude = 6.54 dBi
Main lobe direction = 14.0 deg.
Angular width (3 dB) = 72.7 deg.
Side lobe level = -4.3 dB

Frequency = 4.55
Main lobe magnitude = 1.75 dBi
Main lobe direction = 53.0 deg.
Angular width (3 dB) = 48.7 deg.
Side lobe level = -2.5 dB

Frequency = 5.29
Main lobe magnitude = 5.44 dBi
Main lobe direction = 10.0 deg.
Angular width (3 dB) = 141.9 deg.
Side lobe level = -11.3 dB

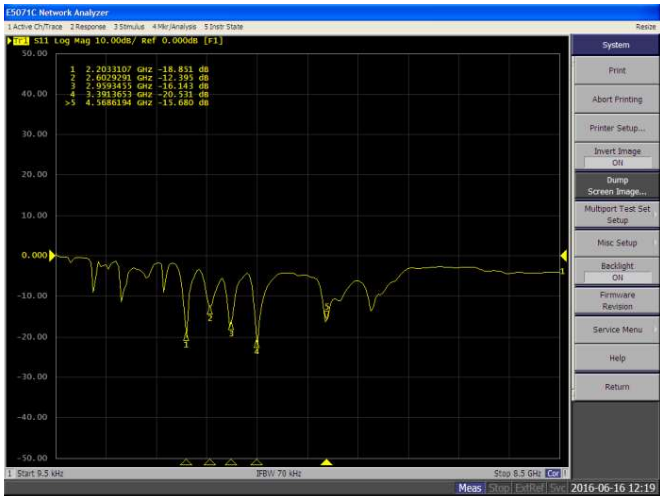
Fig. 5.4 Radiation pattern at 3.4, 4.55 and 5.29 GHz

Radiations patterns are also shown at different slandered frequencies are shown in fig. 5.3 and 5.4. It is seen that far field radiation is present i.e. antenna radiates efficiently. The antenna is radiating isotopically with almost equal gain in all the directions.

5.3 Fabrication and Measured Results

After the complete simulation and finalising the parameters used for designing the antenna, the simulated antenna was fabricated using the FR-4 substrate having height 1.6 mm and dielectric constant of value 4.4 and examined analytically. Photolithography technique was used for the fabrication and slots were etched by wet etching facility. Photograph of the fabricated antenna is shown in fig. 5.5. The return loss shown in fig. 5.6 of the fabricated antenna is tested in the antenna research lab, thapar university, Patiala by Agilent E5071C vector network analyser.

Fig. 5.5 Fabricated antenna



```
 1   2.2033107 GHz -18.851 dB
 2   2.6029291 GHz -12.395 dB
 3   2.9593455 GHz -16.143 dB
 4   3.3913653 GHz -20.531 dB
>5   4.5686194 GHz -15.680 dB
```

Fig. 5.6 Measured return loss plot

The antenna is tested without placing of the dielectric slab resonator as the material used is not easily available in market. All the bands of WLAN, IMT, Wi-MAX are obtained in the fabricated antenna but we place the slab also the gain will increase and the band of 5-7 GHz can also be obtained, as already discussed in chapter III, slab is designed for the antenna to resonate at 5 GHz.

CHAPTER 6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusions

The main objective or aim of this thesis report is to design the multiband antenna which can be employed in many equipments which are used in wireless communications. In today's world the need of wireless communication is increasing, and therefore frequency requirements are also increasing, hence the antennas are required which can work on multiple frequencies to reduce the number of antennas for a single device. In the chapter 1 of this report, we have studied various concepts of antenna theory, parameters used to judge the performance and efficiency of antenna, types of antenna, fractal antenna, slot antenna, dielectric resonator and techniques to give feed to the antenna. It was studied in chapter 1 that, by incorporating fractal geometry in the antenna design, multiband behaviour in the antenna's radiations is obtained due to the self-similarity property of fractals. This property is proved true by designing the octagonal shaped antenna as given in chapter 3. Results of the designed structure also show multiple bands due to the fractal nature of design. Effect of each iteration of the fractal antenna on the return loss plot is depicted in chapter 4, which concludes that fundamental frequency of antenna is reduced as we increase the number of iterations and resonating frequencies are increased. Fractal geometry is incorporated on the boundaries of the octagonal shaped slot loop. Concept of DGS is also included in the designing of the antenna as by using defected ground structure it is seen that gain and bandwidth is increased and size of antenna can be reduced. Dielectric resonator slab of high dielectric constant is used as a resonator for increasing the bandwidth and directivity of antenna. Chapter 4 presents the complete parametric study about the parameters which are used in designing of antenna and their effect on the antenna's performance. Chapter 5 is focused mainly on the results obtained of the designed antenna.

It is concluded that by combining the concepts of fractals, slot antenna, DGS and DRA, an antenna can be designed which possesses high gain, multiband behaviour and wide bandwidth which can be clearly seen from the simulated results obtained from the designed octagonal shaped slot loop antenna loaded with dielectric resonator.

The antenna confirms its operations on GSM 1800, WLAN 2.4 GHZ, Bluetooth, IMT, WiMAX, WLAN 5.8, RADAR and satellite communication application.

6.2 Future Scope

Antenna is designed to produce multiband behaviour and improved return loss. We have achieved our requirement to the great extent but though as every project have some scope for betterment in future, so as this antenna also have. There are some points, which if implemented in future to this designed prototype, can make this design better for wireless applications. Some of them are listed below:

1. Results are measured without placing of a dielectric resonator on the designed antenna. If the result would be measured with the resonating slab then bandwidth of approximately 1600 MHz could be obtained around 5.2-6.8 GHz frequency range as obtained in the simulated results. Due to this band, the antenna application could be extended up to 5G as after 6 GHz band is going to be utilised in 5G mobile applications in future.
2. The fractal geometry is iterated up to second iteration only, which could be extended to further iterations for decreasing the fundamental frequency and increasing the gain and bandwidth of antenna.
3. Size of antenna can be reduced further by employing some different geometrical DGS.
4. Minkowski fractal curve is employed at the boundaries of octagonal shaped loop, different curves like Koch curve, Hilbert curve etc. can be applied and results can be compared.
5. Instead of using octagonal shape, more geometrical shapes like pentagon, hexagon etc. can be designed and results can be compared with this designed prototype.

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List of Publications

1. Sahil Gupta, Sukhwinder Kumar and Ramanjeet, "octagonal shaped fractal slot loop antenna loaded with dielectric resonator," *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 59-66, June 2016.
2. Navjot Singh Dhindsa, Sukhwinder Kumar and Sahil Gupta, "Compact and Small Planar Monopole Rectangular Patch Antenna with Symmetrical Maze-Shaped Slots for Bluetooth/WLAN/IMT Applications," *International Journal of Latest Technology in Engineering, Management & Applied Science (IJLTEMAS)*, Volume V, Issue VI, pp 106-110, June 2016.
3. Sahil Gupta and Sukhwinder Kumar, "Study of effects of fractal geometry, DGS and dielectric resonator on antenna performance using octagonal and square slot loop antennas," **communicated** to *IEEE Wireless and Propagation Letters.*

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