Chapter 1

Introduction

1.1 Brief Technical Overview

In present scenario in order to face the technological development, mankind needs to keep up with the evolution. This evolution leads to the development of cellular devices and many other portable devices. This brought up many new areas of investigation only to meet the continuously increasing needs. As from portable device point of view an antenna with small sizes are required to transmit and receive signal. Also if the device contains communication at different frequencies then a solution required for an antenna to have multiband characteristics. The main problem of common antennas is that they only operate at one or two frequencies, restricting the number of bands that equipment is capable of supporting. Another issue is the size of a normal antenna. Due to the very restricted space that a handset has, setting up more than one antenna is very difficult. To help these problems, the use of antennas having fractal shape is being studied. In this project design and simulation of planar Minkowski fractal antenna is done which is having smaller size compare to their planar counterparts and the multiband characteristics of fractal antenna has also been exploited so that the same antenna can be used to radiate at different frequency.

1.2 Objective

The goal of this assignment is to study, analyse and design a Minkowski fractal antenna capable of facing needs of modern wireless communication transceivers. Objective of this project is to design and simulate planar Minkowski fractal antenna having different iterations from a basic square patch antenna radiating in L-band. The optimisation will be done by varying certain things like feeding point, values of dielectric constant and dielectric loss of dielectric substrate etc to obtain desired frequency range. Simulation is done using ADS software. .

1.3 Methodology

- Understanding of basic concept of planar and fractal antennas.
- Studying various type of fractal geometry and selecting one among them.
- Selecting the simulation software and learning it.
- Implementing the basic square patch antenna using simulation software and obtaining result.
- Performing iterations to shows the improvement in size and also the shift in frequencies of its multiband.
- Study the change in antenna properties and comparison among results.

1.4 Report Organization

This report is organized in 6 chapters. Following this chapter, a review on antenna theory is presented. Microstrip, patch and monopole antennas are also referred in chapter 2.

In chapter 3 fractal antennas are introduced and its geometries are described. The generation of the Minkowski structure is also presented in this chapter.
Chapter 4 includes the design of square patch antenna which is radiating in L-band.
Chapter 5 presents the simulation of the planar Minkowski fractal antenna. In this chapter the simulation results of first three orders of Minkowski fractal antenna is shown.
Chapter 6 gives the final conclusion of this project which also includes future work which can be expected.

CHAPTER 2

THEORY OF ANTENNA

2.1 INTRODUCTION

An antenna is basically a transducer which is a metallic structure that sends or receives electromagnetic (EM) waves, such as radio waves. In other words, antennas convert radio frequency fields into electrical currents. This chapter consist of all the basic information and parameters required to be known to understand what an antenna is. It presents a review of the theory of antennas. Antenna parameters (input impedance, gain, radiation pattern, VSWR, Half-power beam width (HPBW), directivity, bandwidth and polarization) are described with an overview on scattering parameters. Microstrip antennas technology including microstrip patch and monopole antenna is then presented together with its advantages and disadvantages. Matching techniques are also described in the end of this chapter.

2.2 ANTENNA BACKGROUND

There is a variety of antenna structures some operating on just one band and having narrow band characteristics, other at several bands, known as multi-band or broadband antennas. Narrow band antennas include single dipoles or verticals and also directive arrays. Such arrays have high directivity and gain to make the antennas more efficient in a particular direction. With these antennas due to its high Front to back ratio, signals coming from the back will be rejected. Front to Back ratio is the ratio of the maximum directivity of an antenna to its directivity in the opposite direction. Yagi-Uda antenna is the commonest directive antenna in the world. Yagi-Uda antenna was developed by Dr. Hidetsu Yagi and Dr. Shintaro Uda.

The directivity of Yagi-Uda antenna depends on the number of parasitic elements, usually known as directors. The directors are placed in front of the driven element. The most interesting multi-band antenna is the log-periodic antenna, also knows as log-periodic dipole array (LPDA). These antennas are multi-element, unidirectional broadband, with an impedance and radiation characteristics that are continually repeated as a logarithmic function of the excitation frequency. These antennas could be considered as fractal antennas as they are calculated to be self-similar. LDPA was originally designed at the University of Illinois in the USA.

2.3 ANTENNA PARAMETERS

- **VSWR:** Voltage Standing Wave Ratio is the ratio of maximum frequency voltage to minimum voltage on a transmission line. It is given by

$$\textbf{VSWR}=\frac{V_{\max}}{V_{\min}} \tag{2.1}$$

The VSWR can also be calculated from the reflection coefficient also known as return loss (S_{11}). It is discussed in next section of this chapter. Return loss is very important parameter which is used to determine the mismatching occur between the characteristic impedance of the transmission line and the antennas terminal input impedance. VSWR can be calculated from reflection coefficient according to the equation given by:

$$\textbf{VSWR}=\frac{1+|S_{11}|}{1+|S_{22}|} \tag{2.2}$$

Where S_{11} is reflection coefficient and $|S_{11}|$ signifies magnitude of reflection coefficient. As mismatch increases between transmission line and antenna terminal, the reflection coefficient also increases and thus The VSWR increases and it decreases with a good matching due to decrease in reflection coefficient. The minimum value of VSWR is 1:1 and most equipments can handle a VSWR of 2:1. VSWR or we can say reflection coefficient determines the bandwidth of antenna. For values of VSWR under 2:1 or the return loss is -10dB or lower, antenna is considered of having good performance. So it is important to achieve reflection coefficient less than -10dB.

- **Input Impedance:** It is the impedance seen from the input side of transmission line while seeing towards load side is called its input impedance. Here antenna is considered as a load while transmitting. This input impedance of an antenna can be determined by the following expressions:

$$\mathbf{Z_i = R_l + R_r + jX_a} \tag{2.3}$$

Where Z_{in} represents the input impedance, R_l is the loss resistance, R_r is the radiation resistance and X_a represents the reactance.
If the reflection coefficient is known then input impedence will be given by:

$$\textbf{VSWR} = \mathbf{Z_0}\left(\frac{1+|S_{11}|}{1+|S_{22}|}\right) \tag{2.4}$$

Where Z_{in} represents the input impedance, Z_0 is the characteristic impedance of the transmission line and S_{11} is a S-parameter also known as reflection coefficient, a parameter which is explained in next section. The input impedance can be used to determine the maximum power transfer between the transmission line and the antenna, this will only occurs when both impedances are equal. If there is a mismatch between both impedances, power will be reflected back to the transmitter which is known as reflected power. Reflected power might cause damage to the device and may cause frequency instability of the source.

- **Gain:** There are two types of gain, Absolute Gain and Relative Gain.
  The Absolute Gain of an antenna is defined as the ratio between the antennas radiation intensity in a certain direction to the radiation intensity of an isotropic antenna fed by the same input power, therefore it can be given by:

$$G(\theta,\phi) = \frac{U(\theta,\phi)}{U_0} \quad (2.5)$$

$$\text{Where } U_0 \text{ is given by, } U_0 = \frac{P_{in}}{4\pi} \quad (2.6)$$

where $G(\theta,\phi)$ is the gain of the antenna in a direction characterised by θ and φ, $U(\theta,\phi)$ is the radiation intensity in a certain direction and U_0 is the radiation intensity of an isotropic antenna. P_{in} is the input power.
The Absolute Gain is expressed in dB_i as its reference is an isotropic antenna.The Relative Gain of an antenna is defined as the ratio between the antenna radiation intensity in a certain direction and the intensity that would be generated by a reference antenna considered. The Relative Gain is expressed according to reference antenna. Generally short dipole and short monopole are used as reference antenna.

- **Directivity:** Directivity allows us to measure the concentration of radiated power in a certain direction. Hence it is one of the important parameter. It is given by:

$$D(\theta,\varphi) = \frac{4\pi U(\theta,\phi)}{P_{rad}} \quad (2.7)$$

Where $D(\theta,\phi)$ is the directivity of the antenna in a certain direction, $U(\theta,\phi)$ is the radiation intensity in a certain direction. Another way of measuring the directivity of an antenna is to calculate the HPBW (half power beam width).

- **Efficiency:** An antennas efficiency is defined as the ratio of the total radiated power to the input power and it is given by:

$$\eta = \frac{P_{rad}}{P_{in}} \quad (2.8)$$

Using the equations 2.5, 2.6 and 2.8 we can achieve a relation between an antennas gain and its directivity:

$$G(\theta,\phi) = \frac{4\pi U(\theta,\phi)}{P_{rad}} = \eta\left(\frac{4\pi U(\theta,\phi)}{P_{rad}}\right) = \eta\, D(\theta,\varphi) \quad (2.9)$$

- **Radiation Pattern:** The radiation pattern is a graphical representation of the characteristics of an antenna radiation in a certain direction as shown in 2.3 . These characteristics include radiation intensity, field intensity and polarization. It is normally represented with rectangular or polar plots and it is expressed in dB. The radiation pattern is a plane cut and represents one frequency and one polarization.

- **HPBW:** The HPBW Half Power Beamwidth is a way of measuring the antenna directivity. This means that if the main lobe of an antenna is too narrow, the directivity is higher. It can be determined by taking out 3dB (half power) with respect to the main lobe power level. Example of radiation pattern is shown in figure 2.1. 2-dimensional rectangular radiation pattern is shown in figure 2.2. The HPBW can be determined in the polar plot of an antenna radiation pattern, see figure 2.3.

- **Polarization:** Represents the sense and orientation of the electromagnetic waves far from the source. There are three main types of polarization:
  – Linear: Vertical, Horizontal
  – Circular: Circular left hand, Circular right hand
  – Elliptical: Elliptical left hand, Elliptical right hand

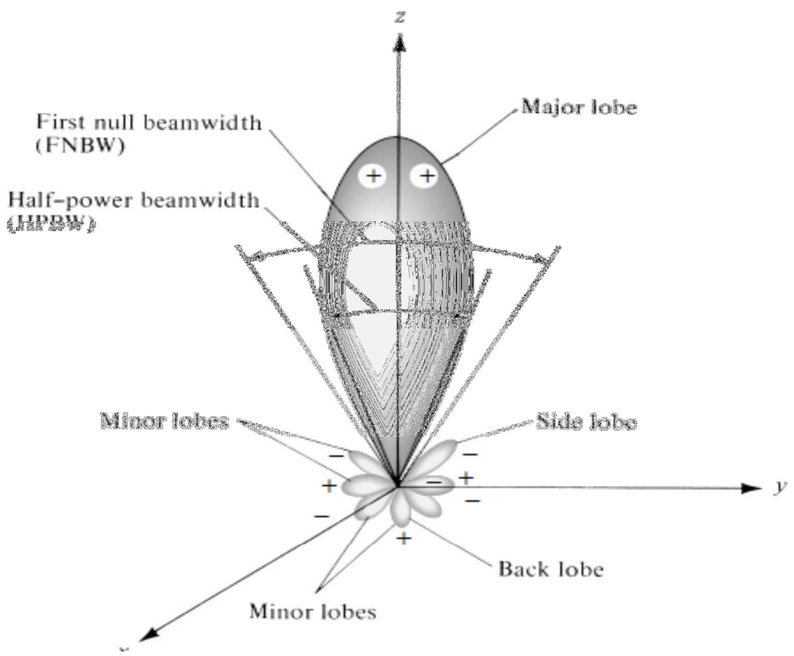

Figure 2.1: Example of Radiation pattern (adapted from [13])

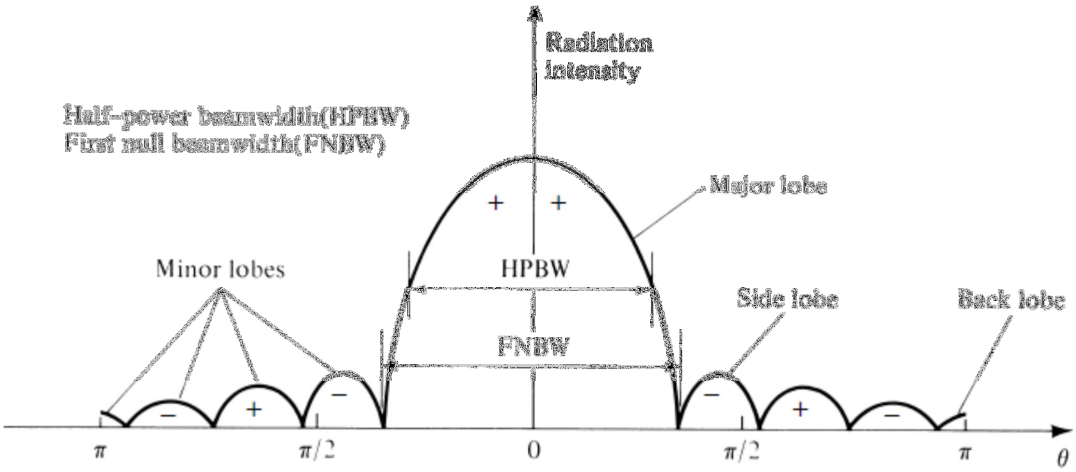

Figure 2.2: Example of radiation pattern, two dimensional plot (adapted from [13])

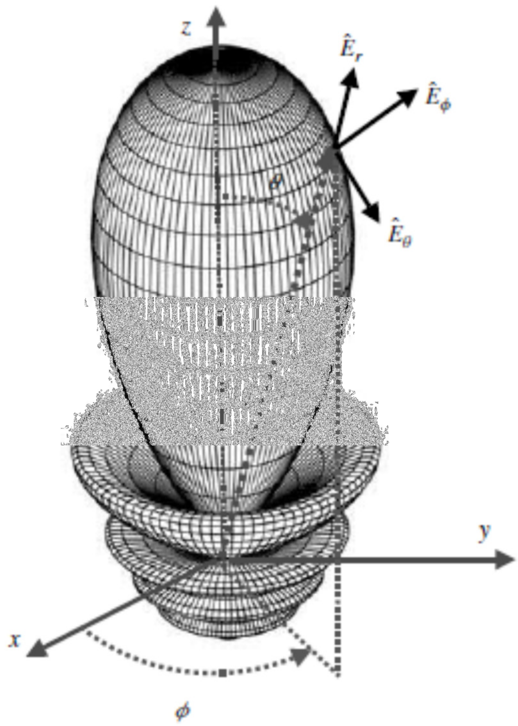

Figure 2.3: Example of radiation pattern, normalised plot (adapted from [13])

- **Bandwidth:** The Bandwidth BW is a measure of how much frequency variation is available while still obtaining a coefficient reflection or a VSWR within a specified interval.

$$\mathbf{BW} = \left(\frac{F_h - F_l}{F_c}\right) * \mathbf{100} \qquad \mathbf{(2.10)}$$

$$\mathbf{F_c} = \frac{F_h - F_l}{2} \qquad \mathbf{(2.11)}$$

where, F_h represents the highest frequency which the VSWR (2:1 or less) or the coefficient reflection (see section 2.4) (-10dB or less) is still acceptable; F_l represents the lowest frequency which the VSWR (2:1 or less) or the coefficient reflection 2.4 (10dB or less) is still acceptable; F_c represents the central frequency.

2.4 BRIEF OVERVIEW ON SCATTERING PARAMETERS

Scattering Parameters also known as S-Parameters, are the reflection and transmission descriptors between the incident and reflection waves, which for a two port system is given by**:**

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

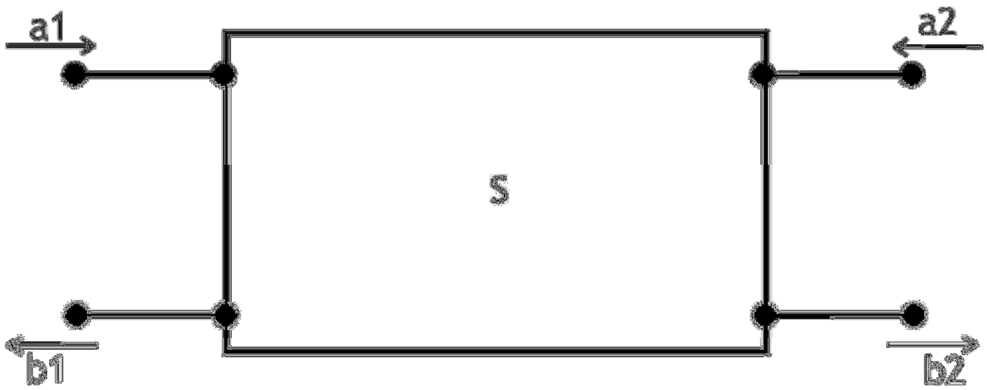

Figure 2.4: Generalized two port network,[S] represents the scattering matrix

S_{11}: reflection coefficient on the input with 50Ω terminated output. a_1 and b_1 represents electric fields. The ratio between these two electric fields results in a reflection coefficient.

$$S_{11} = \frac{b_1}{a_1}, \; a_2 = 0 \qquad \textbf{(2.12)}$$

S_{21}: forward transmission coefficient of 50Ω terminated output.

$$S_{21} = \frac{b_2}{a_1}, \; a_2 = 0 \qquad \textbf{(2.13)}$$

S_{12}: reverse transmission coefficient of 50Ω terminated input.

$$S_{12} = \frac{b_1}{a_2}, \; a_1 = 0 \qquad \textbf{(2.14)}$$

S_{22}: reflection coefficient on the output with 50Ω terminated input.

$$S_{22} = \frac{b_2}{a_2}, \; a_1 = 0 \qquad \textbf{(2.15)}$$

To measure S11 we inject a signal at port 1 with port two terminated with an impedance matched to the characteristic impedance of the transmission line (a2=0), and measure its reflected signal. No signal was injected into port 2 so we consider a2 = 0.
To measure S21 we inject a signal at port 1, terminate port 2 and measure the resulting signal exiting on port 2.
To measure S12 we inject a signal at port 2, terminate port 1 and measure the resulting signal on port 1.
To measure S22 we inject a signal at port 2, terminate port 1 and measure its reflected signal.
All the S-Parameter measurements are made with only one signal injected in one port at a time, the other port being terminated with a matched impedance.

2.5 MICROSTRIP ANTENNA

Microstrip antennas also known as printed antennas, as shown in figures 2.5 and 2.6, consist of a radiating patch on one side and on the other side of the substrate a ground plane. The size of a microstrip antenna is inversely desired to the pretended resonant frequency. Microstrip antennas only make sense when talking about UHF and above due to the fact that antennas for these frequencies are centimeter antennas.

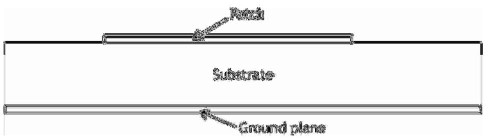

Figure 2.5: Side view of microstrip patch

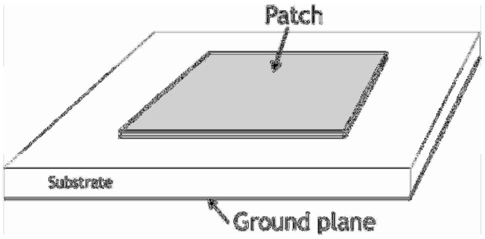

Figure 2.6: Top view of microstrip patch

Advantages in using microstrip antennas:

1. Easily built with PCB technology
2. Light weight and small size
3. Low profile structure allowing it to be mounted in thin devices
4. Supports both linear and circular polarizations
5. Capable of multi-band operation (use of fractals)
6. Resonant type antennas due to efficient radiation (around 95% efficiency)
7. Low cost to fabricate

Disadvantages in using microstrip antennas:

1. Narrow bandwidth
2. Not capable of handling high powers
3. Surface wave excitation
4. Low gain

The low profile of these antennas allows them to be mounted on mobile radio communication devices, such as GSM Phones. Most fractal antennas use this type of implementation due to its complex geometries, therefore the fractal geometries are printed on the dielectric substrate**.**

2.6 MICROSTRIP PATCH ANTENNAS

Microstrip Patch is an antenna type which is printed on a substrate and has a feed line (transmission line) and a patch on one side and ground plane on the other side of the substrate as shown

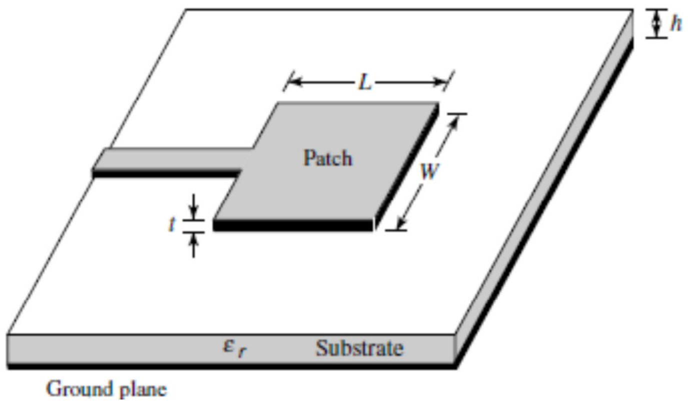

Figure 2.7: Microstrip patch antenna (adapted from [13])

The patch and ground plane are usually made of copper and can take any shape. This helps to face the high complex geometry factal antennas use. Microstrip patch antennas are good radiators due to the fact that they have a fringing field between the patch edge and the ground plane. The best performance of an antenna is achieved with a thick dielectric substrate with a low dielectric constant. This kind of substrate will provide better efficiency, larger bandwidth and better radiation. Unfortunately this leads to a larger antenna, therefore, a substrate with higher dielectric constant must be used. The feeding system shown in figure 2.7 is known as microstrip transmission line, a strip line is connected directly to the microstrip patch. The length LTX and width WTX are calculated so that at the end of the strip line the impedance matches the patch impedance.

2.7 MONOPLOE ANTENNA

A monopole antenna is a kind of vertical dipole antenna in which half of it is replaced with a ground plane at right angles to the remaining half. The antenna will perform as dipole as if its reflection in the ground plane formed the missing half of the dipole. This is the kind of antenna used in our project, since we use a ground plane at right angles to the antenna. This will make the antenna radiate like a monopole and not as a patch antenna. The ground plane also provides a define impedance for the feed line, which can be controlled by changing the width of the microstrip line.

2.8 MATCHING TECHNIQUES

Most transmitters have an output impedance of 50Ω or 75 Ω unfortunately an antennas input impedance is not always close to these values consequently, a matching technique needs to be applied. When an antenna is not properly matched, if the reflected power is high it can damage the device connected to it, thus to avoid excessive heating on the equipment matching techniques are used to reduce the VSWR. For example, a 1/2 wave dipole has a midpoint impedance of 73 ohms, so coaxial cable transmission line which has a characteristic impedance of 75 ohms is used to feed the antenna.
The theory of matching techniques is described in [1].

There are numerous matching techniques:

- **Delta match:** This type of matching is used with an unsplitted $\lambda/2$ dipole antenna. Considering the dipole resonance, its capacitive reactance (X_c) and inductive reactance (X_l) cancel each other making the input impedance only resistive. Consequently the antenna impedance is the resistance between any two middle points from the centre and thus transmission lines having characteristic impedances of 300Ω to 600Ω may be used by using two points of the antenna to feed the signal to the antenna in a position where it offers a feed point impedance equal to transmission line impedance. _
- **T match:** In this type of impedance performance, two coaxial cables are held side by side and both their outer covering are connected to the midpoint of the non divided dipole, while two points are choosen on the dipole where inner parts going parallel to each other are connected.
- **LC network match:** The LC network match consists of a network of capacitors and inductors that are used to transform the antenna impedance into the feed line impedance. There are three types of LC matching networks:
  - L-network
  -T-network
  -π -network
  The advantage of this type of matching is that any two values of impedance may be matched and there are formulas available that permit computation of all component values necessary to achieve a match. The only disadvantage, and for some applications it is a very important issue, is that the network will only match the impedances over a relatively narrow bandwidth.
- **Stub match:** An open stub of l =4 can be connected to the dipole. Here the low midpoint impedance of 73Ω of the dipole is repeated at the close end of the stub. However there are certain points on the stub which would offer as high as 600Ω impedance while matching with 73 Ω transmission line.

- $\lambda/4$ **transformer match:** The most used technique is the quarter-wave transformer. One of the advantages of using this type of technique is that it can easily built and it is applied to a wide range of frequencies. A disadvantage is that it is only useful in narrow bandwidth. Considering that the antennas impedance is real, the transformer is attached directly to the load. If the impedance is complex, the transformer is placed at a distance d away from the load. This distance is used to guarantee the input impedance toward the load is real. To match the antennas impedance the characteristic of the transformers impedance should be:

$$Z_0 = \sqrt{ZlZin}$$

2.9 FEEDING TECHNIQUES

Feeding techniques [1-2-13] are important in designing the antenna to make antenna structure so that it can operate at full power of transmission. Designing the feeding techniques for high frequency, need more difficult process. This is because the input loss of feeding increases depending on frequency and finally give huge effect on overall design. There are a few techniques that can be used.

1. Microstrip line feeding
2. Coaxial probe feeding
3. Aperture coupled feeding
4. Proximity coupled feeding
5. CPW feeding

1. **Microstrip Line feeding: -** It has more substrate thickness i.e. directly proportional to the surface wave. Radiation bandwidth limit is 2-5%.It is easy to fabricate and model. Microstrip line feed is one of the easier methods to fabricate as it is a just conducting strip connecting to the patch and therefore can be consider as extension of patch. It is simple to model and easy to match by controlling the inset position. However the disadvantage of this method is that as substrate thickness increases, surface wave and spurious feed radiation increases which limit the bandwidth.

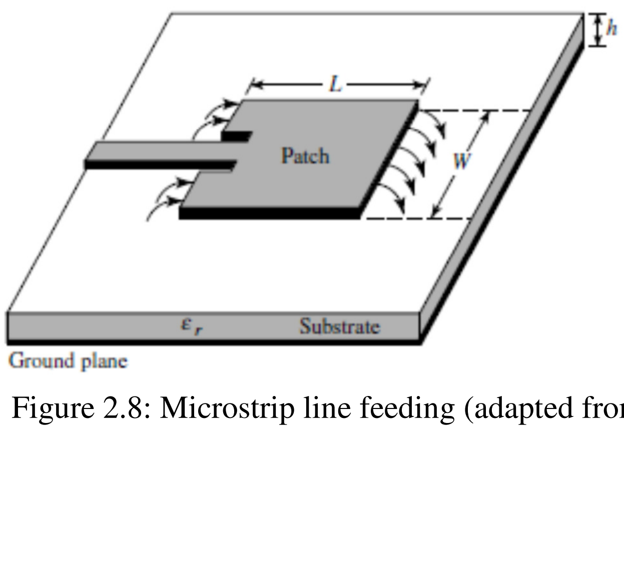

Figure 2.8: Microstrip line feeding (adapted from [13])

2. Coaxial Probe feeding:-It has low spurious radiation and narrow bandwidth. It is easy to fabricate but difficult to model. Coaxial feeding is feeding method in which that the inner conductor of the coaxial is attached to the radiation patch of the antenna while the outer conductor is connected to the ground plane.

Advantages

- Easy fabrication
- Easy to match
- Low spurious radiation

Disadvantages

- Narrow bandwidth
- Difficult to model specially for thick substrate
- Possess inherent asymmetries which generate higher order modes which produce cross-polarization radiation

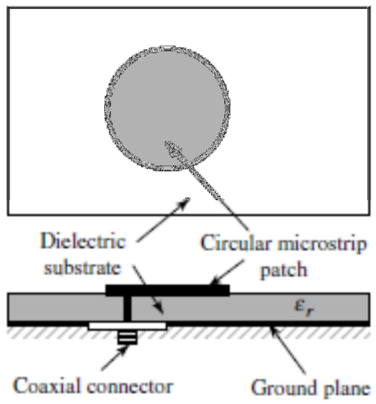

Figure 2.9: Coaxial Probe feeding (adapted from [13])

3. Aperture Coupled feeding

It has narrow bandwidth and moderate spurious radiation. Aperture coupling consist of two different substrate separated by a ground plane. On the bottom side of lower substrate there is a microstrip feed line whose energy is coupled to the patch through a slot on the ground plane separating two substrates.

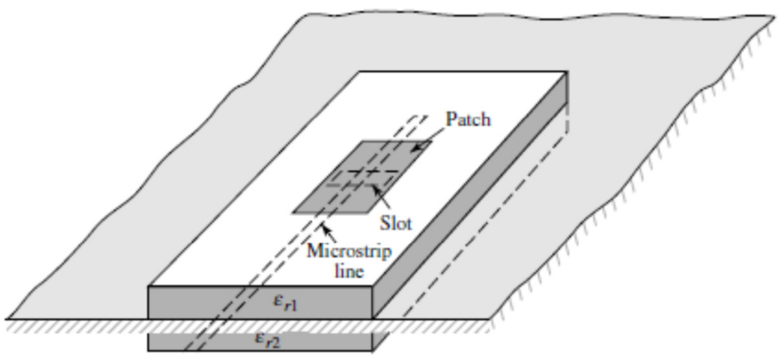

Figure 2.10: Aperture couple feeding (adapted from [13])

This arrangement allows independent optimization of the feed mechanism and the radiating element. Normally top substrate uses a thick low dielectric constant substrate while for the bottom substrate; it is the high dielectric substrate. The ground plane, which is in the middle, isolates the feed from radiation element and minimizes interference of spurious radiation for pattern formation and polarization purity.

Advantages

Allows independent optimization of feed mechanism element.

4. Proximity Coupled feeding

Proximity coupling has the largest bandwidth, has low spurious radiation. However fabrication is difficult. Length of feeding stub and width-to-length ratio of patch is used to control the match.

Advantage

- It has largest bandwidth
- It is easy to model

Disadvantage

- It has spurious radiation and is difficult to fabricate

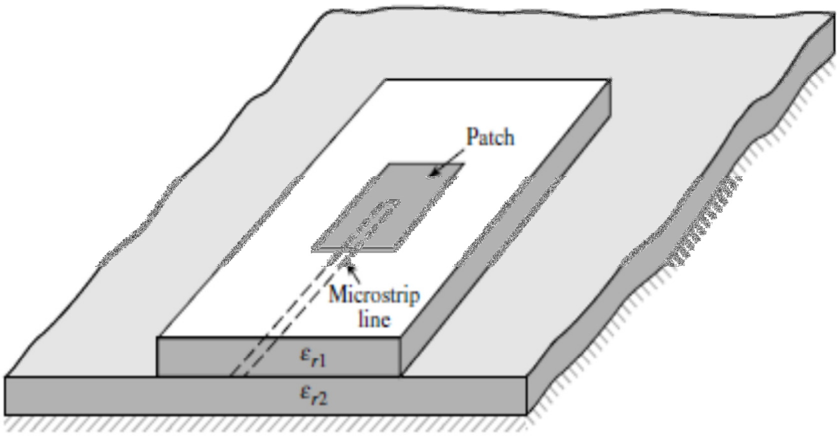

Figure 2.11: Proximity couple feeding (adapted from [13])

5. CPW feeding

A coplanar waveguide structure consists of a median metallic strip of deposited on the surface of a dielectric substrate slab with two narrow slits ground electrodes running adjacent and parallel to the strip on the same surface. This transmission line is uniplanar in construction, which implies that all of the conductors are on the same side of the substrate.

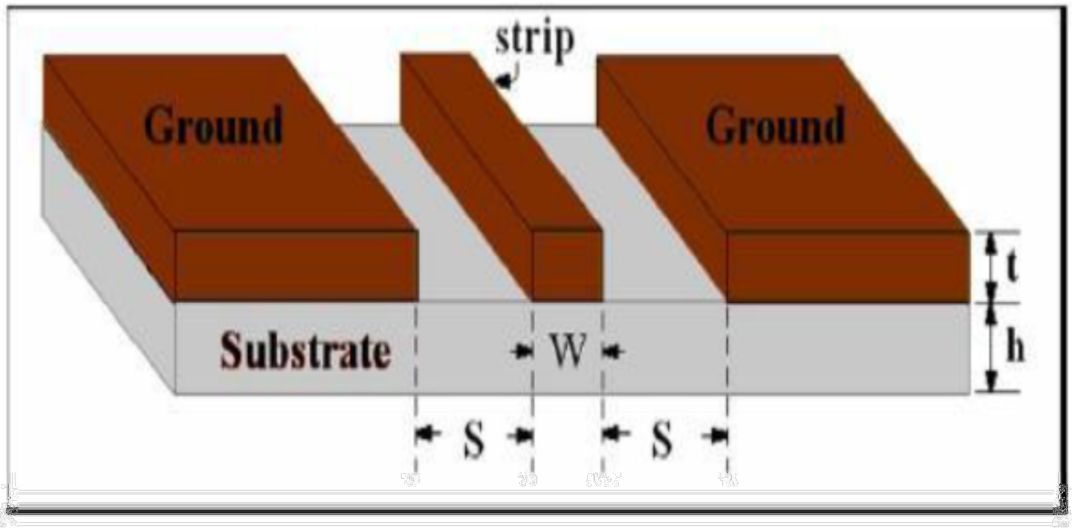

Figure 2.12: Structure of coplanar waveguide feed

They have many features such as low radiation loss, less dispersion, easy integrated circuits and simple configuration with single metallic layer, and no via holes required. The CPW fed antennas have recently become more and more attractive because of its some more attractive features such as wider bandwidth, better impedance matching, and easy integration with active devices or monolithic microwave integrated circuits. Etching the slot and the feed line on the same side of the substrate eliminates the alignment problem needed in other wideband feeding techniques such as aperture coupled and proximity feed. CPW feed is used in this project.

2.10 SUMMARY

In this chapter the theory of antennas was presented. The parameters that define an antenna and its efficiency were detailed namely, VSWR, input impedance, gain, radiation pattern, HPBW, directivity, polarization and bandwidth. A brief overview on scattering parameters was accomplished to a better understanding of the coefficient reflection. Advantages and disadvantages of using microstrip antennas are listed as well as reference to microstrip patch antennas. Monopole antennas are also briefly mentioned. Although they were not used, matching techniques are also described. In the next chapter a study about fractal antennas is made with an overview on fractal geometries.

CHAPTER 3

FRACTAL ANTENNAS

3.1 INTRODUCTION

In this chapter the approach to fractal antennas is described by steps, firstly a description of natural fractal geometries can be found followed by a brief overview on fractal antennas. The generation process, using IFS iterations, of fractal antennas is discussed in this chapter for a better understanding of the complexity of generating fractal structures. Some fractal geometries are described, mainly the Koch Curve, the Sierpinski Gasket, the Minkowski Curve and the Cohen-Minkowski Curve.

3.2 FRACTAS

Although fractal geometries have been known for almost a century, the study of fractal antennas is a relatively new area. The fractal term was coined in 1975 by the French mathematician, Benoît B. Mandelbrot. Since Mandelbrot work a wide variety of application areas for fractals have been found and studied, an area in particular is fractal electrodynamics [2]. This area combines electromagnetic theory with fractal geometry, this combination results in new radiation patterns, propagation and scattering problems, as described in [2,3]. Studies in this area show that fractals have good electromagnetic radiation patterns and advantages over traditional antennas. Such advantages face modern wireless communication problems. For instance, they can be used as compact multi-band antennas.

A fractal can be described as a rough or fragmented geometric shape that can be separated into parts which are an approximation to the whole geometry but in a reduced size. Fractals are known as infinitely complex because of its similarity at all levels of magnification. There are only two types of fractals, natural and mathematical. Fractal geometries, to a certain level, can be found all around us, even though we are not aware of that, these are the natural fractals. Examples of natural fractals are: coastlines 3.1, lightning 3.2, earthquakes, plants, vegetables 3.3, rivers, galaxies, clouds, all these examples have fractal geometry.

Figure 3.1: Coastline
(adapted from [5])

Figure 3.2: Lightning
(adapted from [5])

Figure 3.3: Brocoli
(adapted from [4])

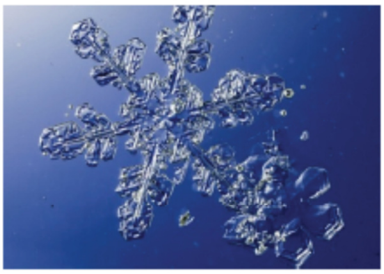

Figure 3.4: Snowflake
(adapted from [4])

The mathematical fractal geometry has been known for a century and these are based in equations that undergo iteration, a form of feedback based on recursion. Examples of these mathematical structures are: von Koch snowflake 3.8, Sierpinski carpet 3.5, the Mandelbrot set 3.7, the Lorenz attractor 3.6, and the Minkowski curve.

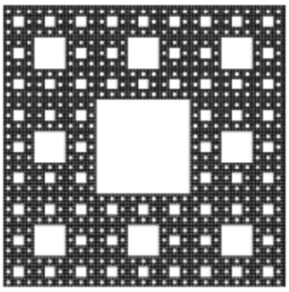

Figure 3.5: Sierpinksi Carpet Figure

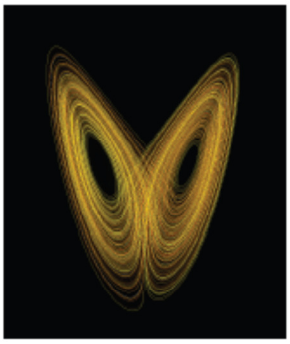

Figure 3.6: Lorentz attractor

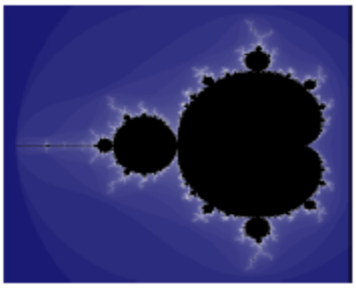

Figure 3.7: Mandelbrot set Figure

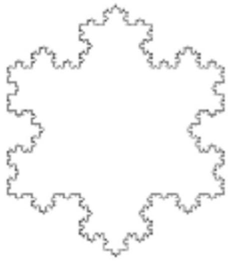

Figure 3.8: Koch Snowflake

3.3 FRACTAL ANTENNAS

Nathan Cohen built the first known fractal antenna in 1988, then a professor at Boston University [5]. Cohen's efforts were first published in 1995, the first scientific publication about fractal antennas, since then a number of patents have been issued. In a series of articles Cohen introduced the concept of fractalizing the geometry of a dipole or loop antenna. This concept consists in bending the wire in such fractal way that the overall length of the antenna remains the same but the size is respectively reduced with the addition of consecutive iterations. If this concept is properly implemented an efficient miniaturized antenna design can be achieved. In [6] Cohen compares the perimeter of an Euclidean antenna with a fractal antenna and he states that the fractal antenna has a perimeter that is not directly proportional to area. He concludes that the in a multi-iteration fractal the area will be as small or smaller than an Euclidean antenna.

Cohen also defines a parameter named Perimeter Compression (PC) and it is given by the ratio of full-size antenna element length to the fractal-reduced antenna element length. He states that the radiation resistance of a fractal antenna decreases as a small power of the PC and a fractal loop or island presents a higher radiation resistance compared to the Euclidean loop antenna of equal size. Despite the fractal antenna being smaller than the Euclidean it exhibits the same or higher gain, frequencies of resonance and a 50Ω termination impedance. Fractal antennas use a fractal, self-similar design to maximize the length and with this technique we can achieve multiple frequencies since different parts of the antenna are self-similar at different scale. Compared to a conventional antenna, fractals have greater bandwidth and they are very compact in size. With fractal antennas we can achieve resonant frequencies that are multiband and these frequencies are not harmonics, also stated by Cohen in [6]. Fractal antennas can have different geometries, the most interesting ones are: the Koch curve, the Sierpinski gasket and the Minkowski curve.

The fractal dimension D of a curve can be given by the Hausdorff-Besicovitch equation:

$$\mathbf{D} = \frac{\log(\mathbf{N})}{\log(\mathbf{r})} \quad \textbf{(3.1)}$$

The total length l of a curve is given by:

$$\mathbf{l} = \mathbf{h}\left(\frac{N}{r}\right)^{n} \quad \textbf{(3.2)}$$

where N represents the number of segments the geometry has, r the number that each segment is divided on each iteration and h the height of the curve. n is the number of iterations.

3.4 ITERATED FUNCTION SYSTEM (IFS)

Certain fractals can be constructed using iterations, this procedure is normally called Iterated Function Systems (IFS). Fractals are made up from the sum up of copies from itself, each copy smaller than the previous iteration. IFS works by applying a series of affine transformations w to an elementary shape A through many iterations. The affine transformation w, compromising rotation, scaling and translation, is given by [7]:

$$W(x) = Ax + t = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x1 \\ x2 \end{bmatrix} + \begin{bmatrix} e \\ f \end{bmatrix} \tag{3.3}$$

The matrix A is given by:

$$A = \begin{bmatrix} (1/s) & \cos(\theta) & -(1/s) & \sin(\theta) \\ (1/s) & \sin(\theta) & (1/s) & \cos(\theta) \end{bmatrix} \tag{3.4}$$

Where:

x1, x2 are coordinates of a point x
r is the scale factor
θ is the rotation angle
t is the translation factor
s is the scaling factor

3.5 FRACTAL GEOMETRIES

3.5.1 Koch Curve

The von Koch curve was firstly introduced by the Swedish mathematician Helge von Koch. The Koch curve was created to show how to construct a continuous curve that did not have any tangent line. The von Koch antenna was first studied to reduce the size of quarter-wave monopoles for low frequency applications. It is known that the Koch geometry is very complex, so it is most reliably implemented using printed antenna techniques (microstrip patches), as mentioned in section 2.5. The antenna is printed on a PCB using a dielectric substrate instead of the common wire, allowing precision on making the antenna work on specific bands. Studies made by C. Puente et al. in [8] show that the input resistance increases with the increase length of the antenna and the reactance is reduced. Furthermore, the resonant frequency is shifted to lower frequencies making it resonant in the small antenna region, such behaviour can be physically explained by the increasing number of sharp corners and bends of the antenna improving its radiation. IFS algorithm can also be applied effectively to the von Koch curve to generate its basis.

Figure 3.9: Three iterations of the Koch fractal (adapted from [9])

It is constructed by starting with a straight line. Divide the line in three parts. Replace the center part by an equilateral triangle with the base removed. This procedure is repeated on every straight line continuing in an infinite process resulting in a curve with no smooth sections. Figure 3.9 illustrates three iterations of this process. The whole length of the element, as described in [8, 10], is giving by: $l = h\left(4/3\right)^n$ where n is the number of iterations and h is the high of the monopole. The self-similarity dimension is given by: D=1.26

3.5.2 Sierpinksi Gasket

The Sierpinski gasket, also known as Sierpinski triangle was named after the Polish mathematician Sierpinski who described its main properties in 1916 as referred in [11]. This monopole is well known due to its resemblance to the triangular monopole antenna. Just like the von Koch fractal it is most reliable to implement this structure using printed antenna techniques, as referred in section 2.5. It is generated according to the IFS method as mentioned in [4, 11]. A triangular elementary shape is iteratively shaped, rotated and translated, then removed from the original shape in order to generate a fractal as we see in figure 3.10. Figures 3.10 and 3.11 show four-scaled versions of the Sierpinski gasket. The scale factor among the four iterations is d = 2 so we should also have resonance at frequencies spaced by a factor of 2, as mentioned in [11].

Figure 3.10: Four iterations of the Sierpinski fractal (adapted from [11])

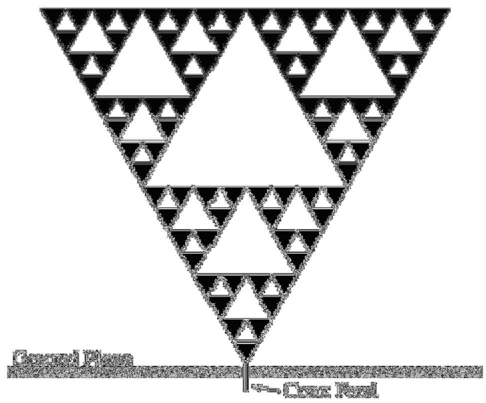

Figure 3.11: Sierpinski Gasket monopole (adapted from [11])

C. Puente et al. described in [12] the relation between frequency resonance and physical dimensions of fractal antennas. These dimensions, namely the total high, flare angle and the scale factor are the basic parameters that characterise the geometrical self-similarity properties of fractals. The formula below expresses the resonant frequencies of the antenna:

$$\mathbf{f_n = k\,\frac{c}{h}\,\cos(\alpha - 2)\;\delta^n} \qquad \textbf{(3.5)}$$

where c is the speed of light, n is a natural number that refers to the operating band, h is the high of the largest gasket and δ is the scale factor and α is the flare angle.
The self-similarity dimension of the Sierpinski gasket is given by: D = 1:585.
As we can observe in figure 3.12 the way of feeding this antenna is quite simple owing to the triangular structure. The feeding system is referred in 2.6. The monopole is fed

with current through a connector at the bottom, this current will be inducted in a certain region of the antenna allowing it to radiate on different frequencies, figure 3.13.

3.5.3 Minkowski Curve

The Minkowski curve is also known as Minkowski Sausage and was dated back to 1907 where Hermann Minkowski, a German mathematician investigated quadratic forms and continued fractions. The construction of the Minkowski curve is based on a recursive procedure, at each recursion an eight side generator is applied to each segment of the curve as we see in figure 3.14.

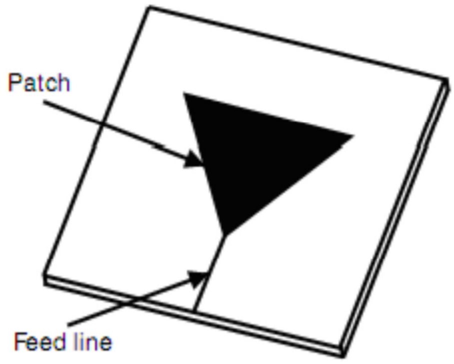

Figure 3.12: Feed line system (adapted from [2])

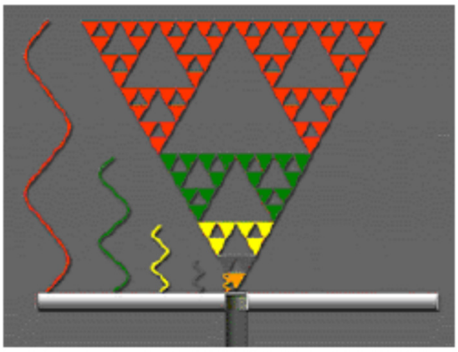

Figure 3.13: Frequency radiation (one antenna 4 bands) (adapted from [8])

It always starts with a straight line. M. Ahmed et al. demonstrate in [7] that Minkowski curve

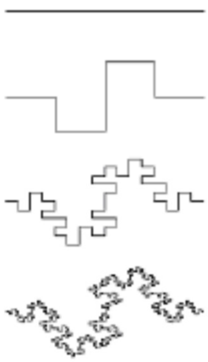

Figure 3.14: Three iterations of the Minkowski curve

fractal antenna reveals to have excellent performance at the resonant frequencies and has radiation patterns very similar to the straight wire dipole at the same frequencies. It is also demonstrated in [7] that Minkowski geometry helps reducing the size of an antenna by 24% in its first iteration and 44% on the second and that the self similarity of the fractal shape shows multiband behaviour. This was also concluded by Paulo H. da F. Silva in [12] who analyzed the frequencies from 2.620-2.650GHz and 5.725 –5.875 GHz and results were very promising. A third iteration of the Minkowski curve was used in [12] and a reduction of 45.6% was achieved.

The length of Minkowski curve increases at each iteration and is given by: $l = h\left(8/3\right)^n$ Where n is the number of steps of generation and h is the high of the monopole. The self-similarity dimension is given by: D = 1:5.

3.5.4 Cohen-Minkowski Geometry

As referred in section 3.3, Nathan Cohen was the first one to build a fractal antenna. He introduced the concept of fractalizing the geometry of a loop or dipole antenna. In patent [6] Cohen refers various kinds of geometries and the most interesting one for this project is the one he names Rectangular-Shaped Minkowksi Fractal. The length of the Cohen-Minkowski geometry increases at each iteration and is given by:-

$l = h\left(5/3\right)^n$ where n is the number of steps of generation and h is the high of the monopole. The self-similarity dimension is given by: D =1:46

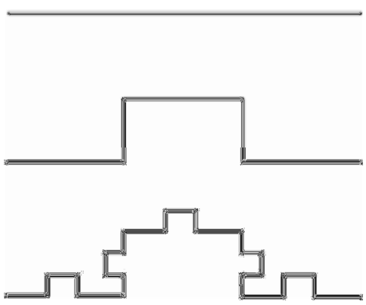

Figure 3.15: Two iterations of the Cohen-Minkowski geometry

3.6 SUMMARY

This chapter presented fractal antennas its geometries. Natural and mathematical fractals were presented as well as the most common geometries used in antennas namely, the Koch curve, the Sierpinksi gasket, the Minkowski curve and the Cohen-Minkowski geometry. The reasons for using fractal antennas are described and also calculations of a fractal dimension and the length of a curve are presented. The IFS procedure for designing fractal geometries is also described in this chapter. Design and simulation of square patch fractal antenna is shown in next chapter.

CHAPTER 4

DESIGN OF SQUARE PATCH ANTENNA

4.1 TRANSMISSION LINE MODEL

The rectangular patch is by far the most widely used configuration. Square patch antenna is a special case of rectangular antenna. In this chapter a square patch antenna is design and in next chapter this square patch antenna is going to be utilised in designing of Minkowski fractal antenna.

4.1.1 Fringing effect

Because the dimensions of the patch are finite along the length and width, the fieldsat the edges of the patch undergo fringing. This is illustrated along the length in for the two radiating slots of the microstrip antenna. The same applies along the width. The amount of fringing is a function of the dimensions of the patch and the height of the substrate. For the principal *E*-plane (*xy*-plane) fringing is a function of the ratio of the length of the patch *L* to the height *h* of the substrate (*L/h*) and the dielectric constant ε_r of the substrate. Since for microstrip antennas $L/h >> 1$, fringing is reduced; however, it must be taken into account because it influences the resonant frequency of the antenna. The same applies for the width. This is a nonhomogeneous line of two dielectrics; typically the substrate and air. As can be seen, most of the electric field lines reside in the substrate and parts of some lines exist in air. As $W/h >> 1$ and $\varepsilon_r >> 1$, the electric field lines concentrate mostly in the substrate. Fringing in this case makes the microstrip line look wider electrically compared to its physical dimensions. Since some of the waves travel in the substrate and some in air, an *effective dielectric constant* ε_{reff} is introduced to account for fringing and the wave propagation in the line. To introduce the effective dielectric constant, let us assume that the centre conductor of the microstrip line with its original dimensions and height above the ground plane is embedded into one dielectric, The effective dielectric constant is defined as the dielectric constant of the uniform dielectric material so that the line of Figure has identical electrical characteristics, particularly propagation constant, as the actual line of Figure. For a line with air above the substrate, the effective dielectric constant has values in the range of $1 < \varepsilon_{reff} < \varepsilon_r$. For most applications where the dielectric constant of the substrate is much greater than unity ($\varepsilon_r >> 1$), the value of ε_{reff} will be closer to the value of the actual dielectric constant ε_r of the substrate. The effective dielectric constant is also a function of frequency. As the frequency of operation increases, most of the electric field lines concentrate in the substrate. Therefore the microstrip line behaves more like a homogeneous line of one dielectric (only the substrate), and the effective dielectric constant approaches the value of the dielectric constant of the substrate.

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of the dielectric constant of the substrate. The initial values (at low frequencies) of the effective dielectric constant are referred to as ***the*** *static values.*

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (4.1)$$

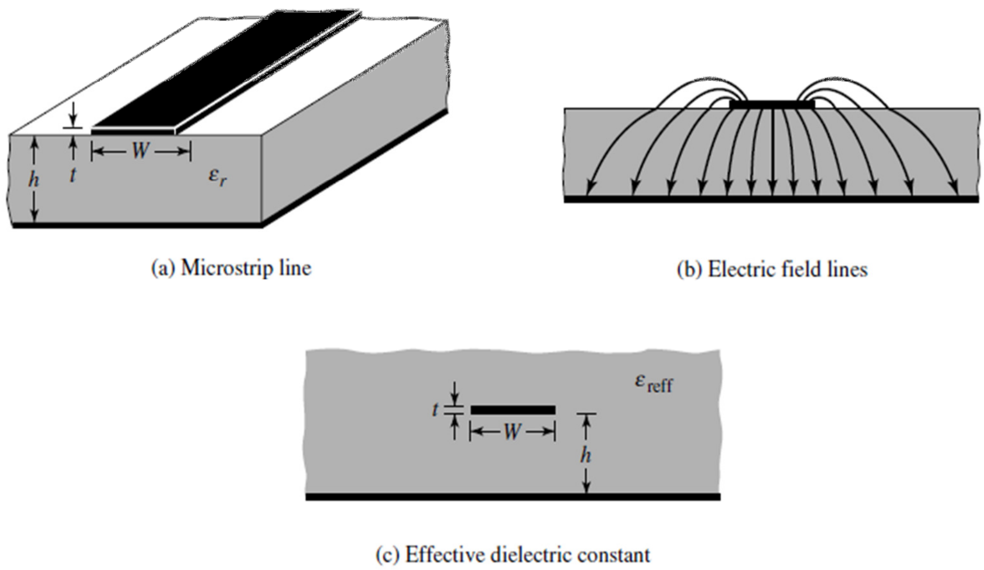

Figure 4.1: Microstrip line and its electric field lines, and effective dielectric constant geometry (adapted from [13])

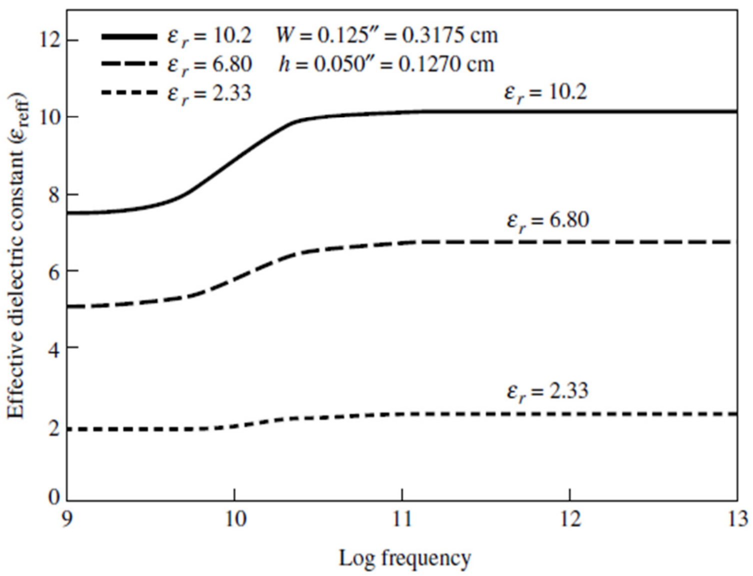

Figure 4.2: Effective dielectric constant versus frequency for typical substrates (adapted from [13])

4.1.2 EFFECTIVE LENGTH,RESONANAT FREQUENCY AND EFFECTIVE WIDTH

Because of the fringing effects, electrically the patch of the microstrip antenna looks greater than its physical dimensions. For the principal *E*-plane (*xy*-plane), this is demonstrated in Figure 4.3 where the dimensions of the patch along its length have been extended on each end by a distance *ΔL*, which is a function of the effective dielectric constant εreff and the width-to-height ratio (*W/h*). A very popular and practical approximate relation for the normalized extension of the length is

$$\left(\frac{\Delta L}{h}\right) = 0.412\,\frac{(\varepsilon_{reff}+0.3)\ \left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258\,)\ \left(\frac{W}{h}+0.8\right)} \qquad (4.2)$$

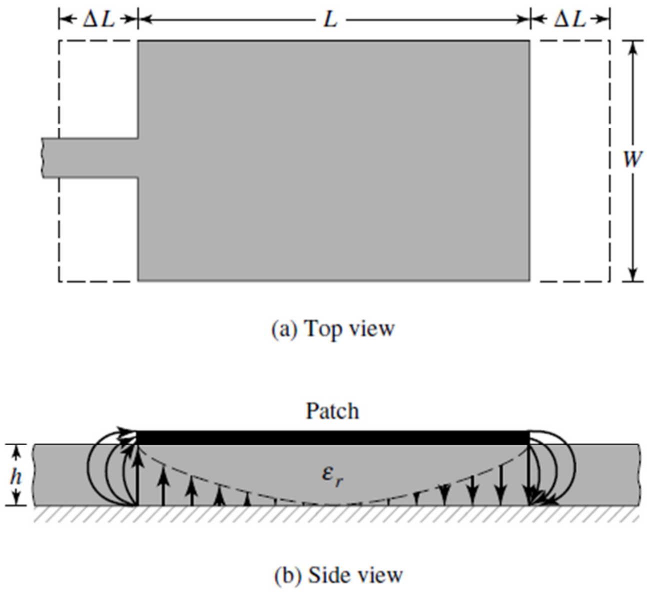

Figure 4.3: Physical and effective lengths of rectangular microstrip patch (adapted from [13])

Since the length of the patch has been extended by *ΔL* on each side, the effective length of the patch is now (*L* = *λ*/2 for dominant TM010 mode with no fringing)

$$L_{eff} + 2\Delta L \qquad (4.3)$$

For the dominant TM010 mode, the resonant frequency of the microstrip antenna isa function of its length. Usually it is given by

$$(f_r)_{010} = \frac{1}{2L\ \sqrt{\varepsilon_r}\ \sqrt{\mu_o\varepsilon_o}} = \frac{v_o}{2L\ \sqrt{\varepsilon_r}} \qquad (4.4)$$

Since above equation does not account for fringing, it must be modified to include edge effects and should be computed using following equation:

$$(f_{rc})_{010} = \frac{1}{2L\sqrt{\varepsilon_r}\sqrt{\mu_o\varepsilon_o}} = q\frac{v_o}{2L\sqrt{\varepsilon_r}} \quad (4.5)$$

Where

$$q = \frac{(f_{rc})_{010}}{(f_r)_{010}} \quad (4.6)$$

The q factor is referred to as the *fringe factor* (length reduction factor). As the substrate height increases, fringing also increases and leads to larger separations between the radiating edges and lower resonant frequencies.

4.2 DESIGN

Based on the simplified formulation that has been described, a design procedure is outlined which leads to practical design of rectangular microstrip antenna.

4.2.1 SPECIFICATION

1. $\varepsilon r = 4.4$
2. fr = 1.32 Ghz (in formulation it is in Hz)
3. h = 1.6 mm
4. loss tangent ($\tan\delta$) = 0.0002

4.2.2 DESIGN PROCEDURE

1. practical width

   $$W = \frac{v_o}{2f_r} * \sqrt{\frac{2}{\varepsilon_r+1}}$$

   W = 54mm
2. effective dielectric constant

   $$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2}$$

   ε_{reff} =4.16
3. extension of the length ΔL

   $$\left(\frac{\Delta L}{h}\right) = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

   ΔL = 0.816mm

4. actual length of the patch

   $$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_o\varepsilon_o}} - 2\Delta L$$

   L = 54mm

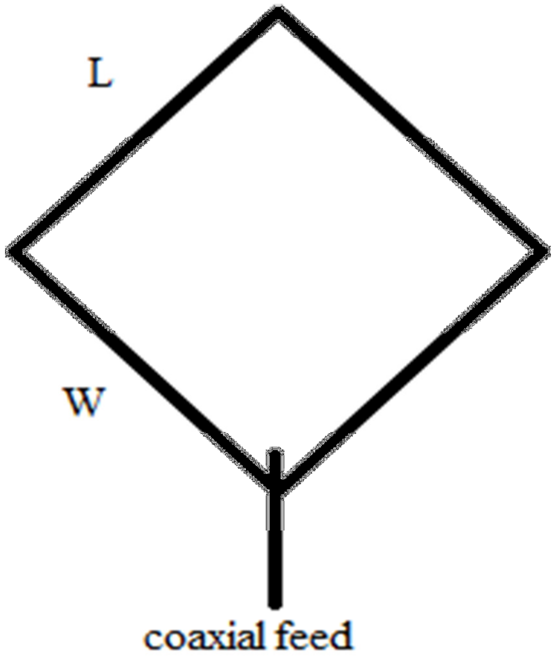

Figure 4.4: Square patch antenna with coaxial feed L=W=54mm

4.3 SIMULATION IN ADS

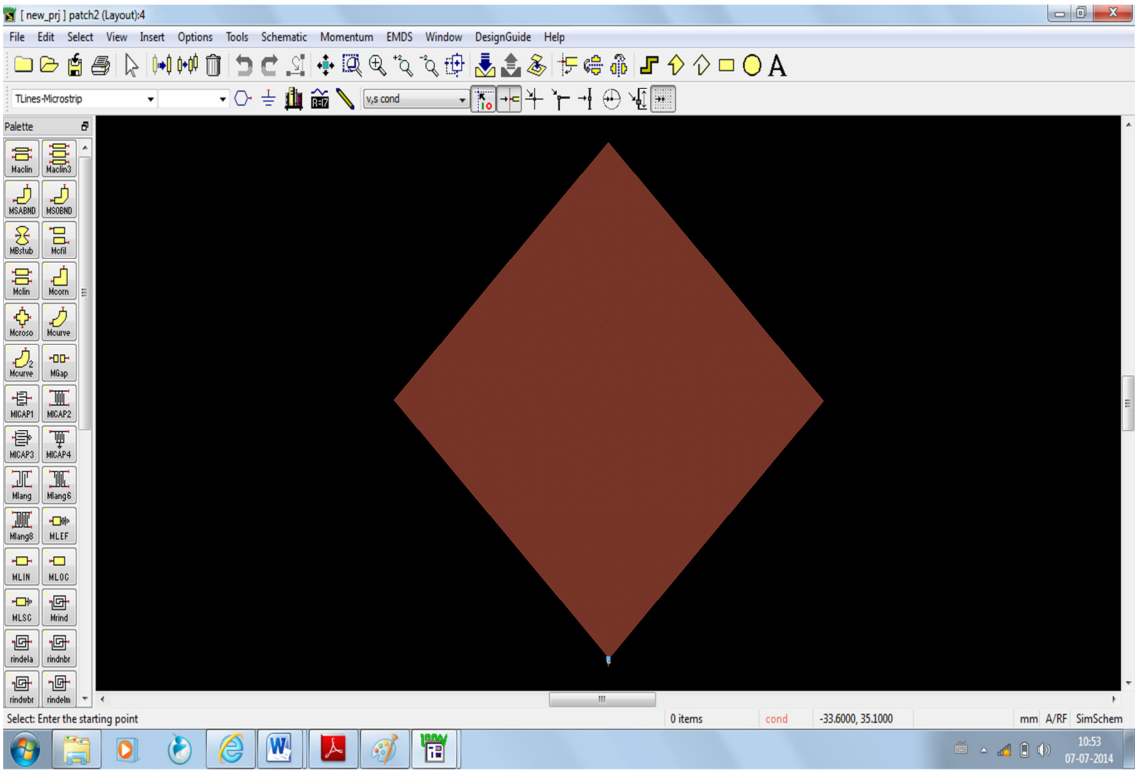

Figure 4.5: Design of square patch antenna in ADS

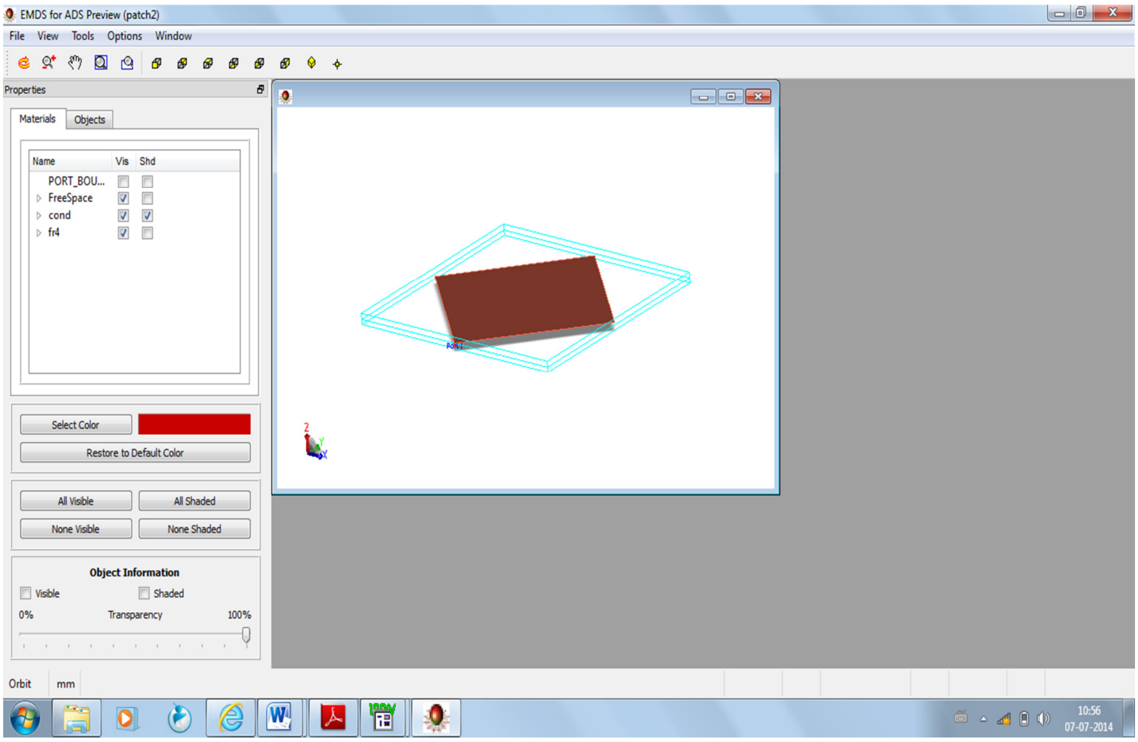

Figure 4.6: Design of square patch antenna in ADS (3D Geometry View)

4.4 RESULTS OF SIMULATION

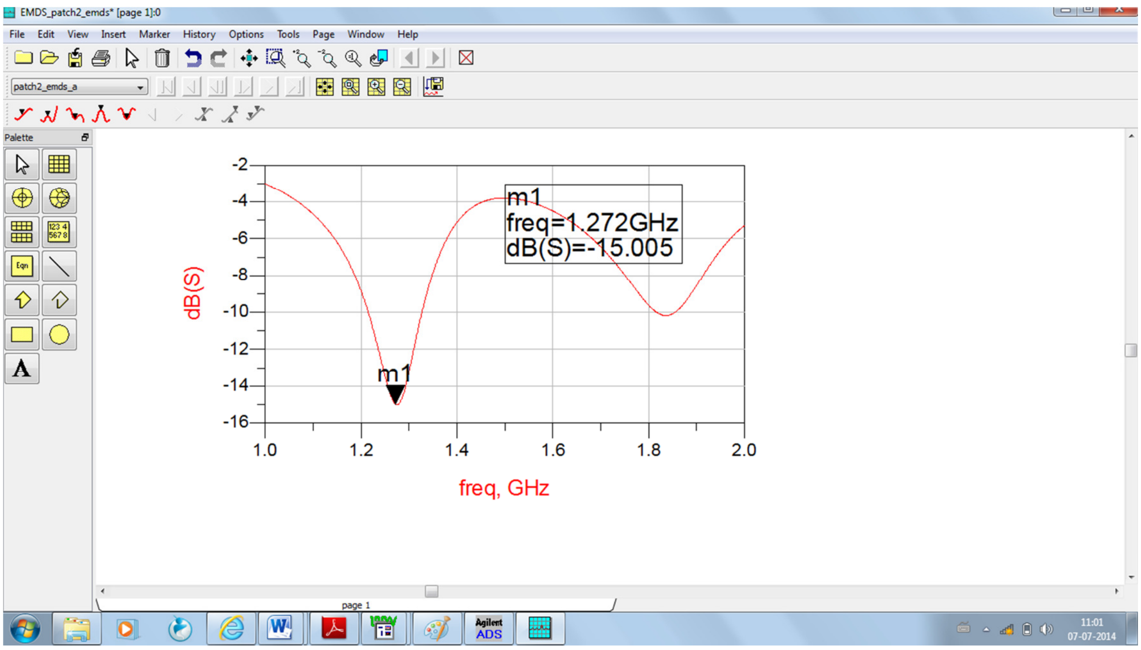

Figure 4.7: S-Parameter Display for square patch microstrip antenna

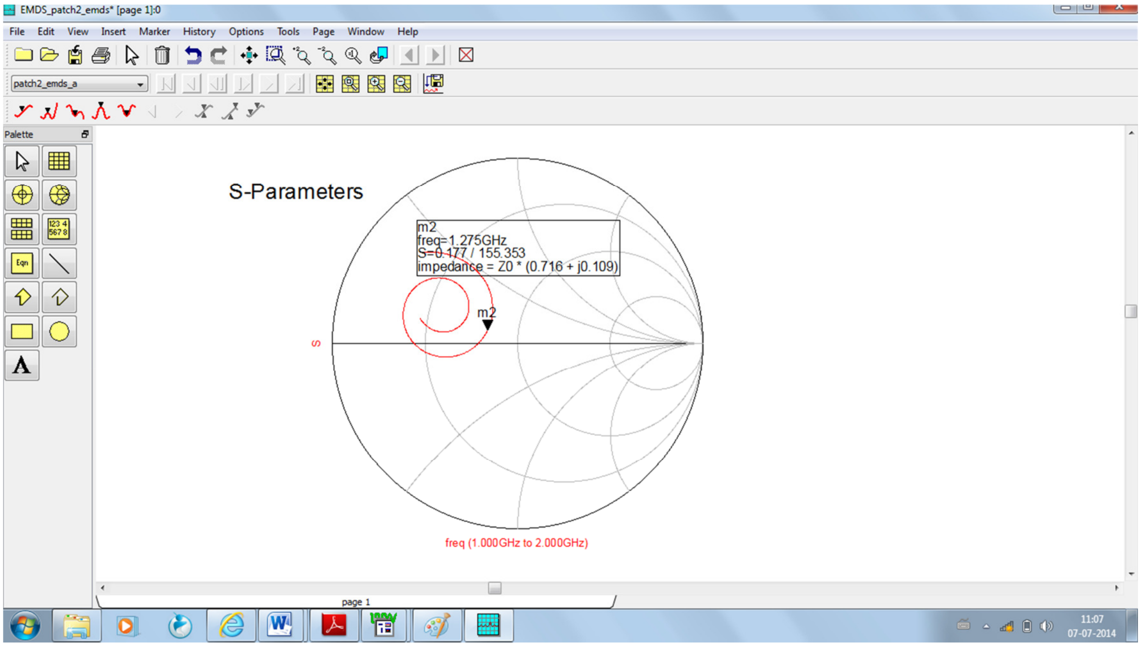

Figure 4.8: Smith chart display for square patch microstrip antenna

4.5 RESULT

The design of square patch antenna, radiating in L-band has been obtain. The resonating frequency is 1.272GHz and reflection coefficient is -15.005db which is well above the satisfactory limit of -10db.

4.6 SUMMARY

In this chapter the design of square fractal antenna has been shown step by step. The square patch antenna is design to show improvement it achieve when it be used as basic antenna for Minkowski fractal antenna which is shown in next chapter. Simulation of square patch antenna is shown in this chapter. The theoretical resonant frequency is 1.32GHz while from simulation it is around 1.27GHz. So the aim of designing an L-band antenna is also achieve.

CHAPTER 5

DESIGN OF MINKOWSKI FRACTAL ANTENNA FROM SQUARE PATCH ANTENNA

5.1 INTRODUCTION

In this chapter design of different order of Minkowski fractal antenna from the square patch antenna is shown. The square patch fractal antenna will act as the reference antenna for Minkowski fractal antenna.

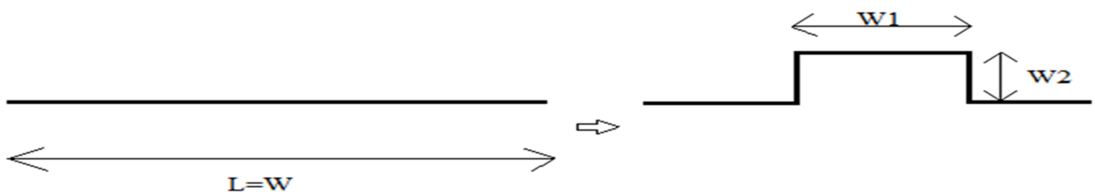

Figure 5.1: Generator for Minkowski fractal antenna

Condition W1>W2 is necessary to maintain. In this design process W1=1.5W2 is maintain. The procedure includes modification of antenna and each modification is regarded as iteration. The substrate and feeding technique will remain same.

5.2 DESIGN OF FIRST ORDER MINKOWSKI FRACTAL ANTENNA

The first order Minkowski fractal antenna can be obtain from basic square patch antenna with the help of generator that has been shown above.

5.2.1 SPECIFICATION

1. W = L= 54mm
2. L_{11} = W/3 = 18mm
3. L_{12} = L_{11}/1.5 = 12mm

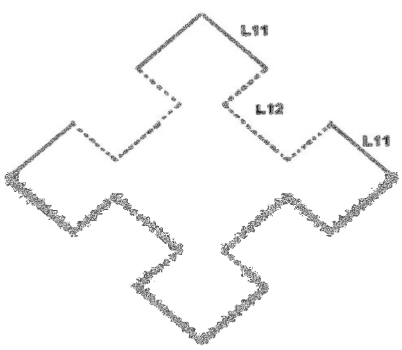

Figure 5.2: First order Minkowski fractal antenna

5.2.2 SIMULATION IN ADS

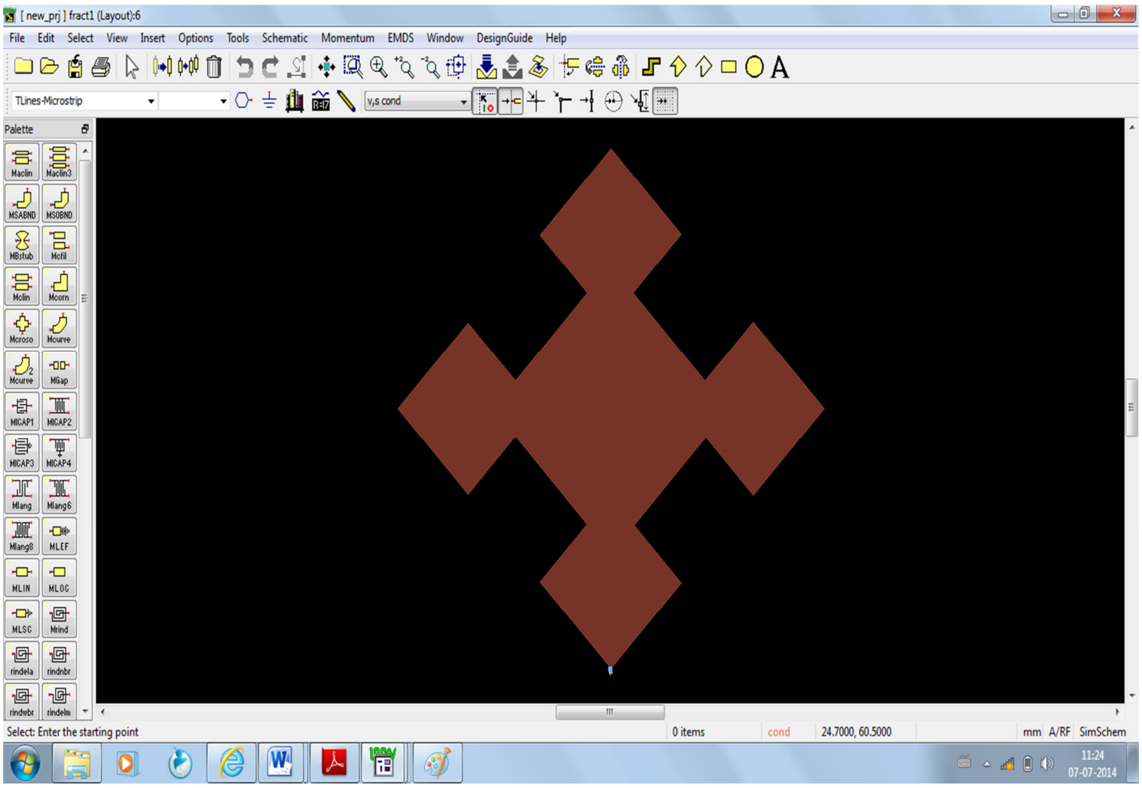

Figure 5.3: Design of first order Minkowski fractal antenna in ADS

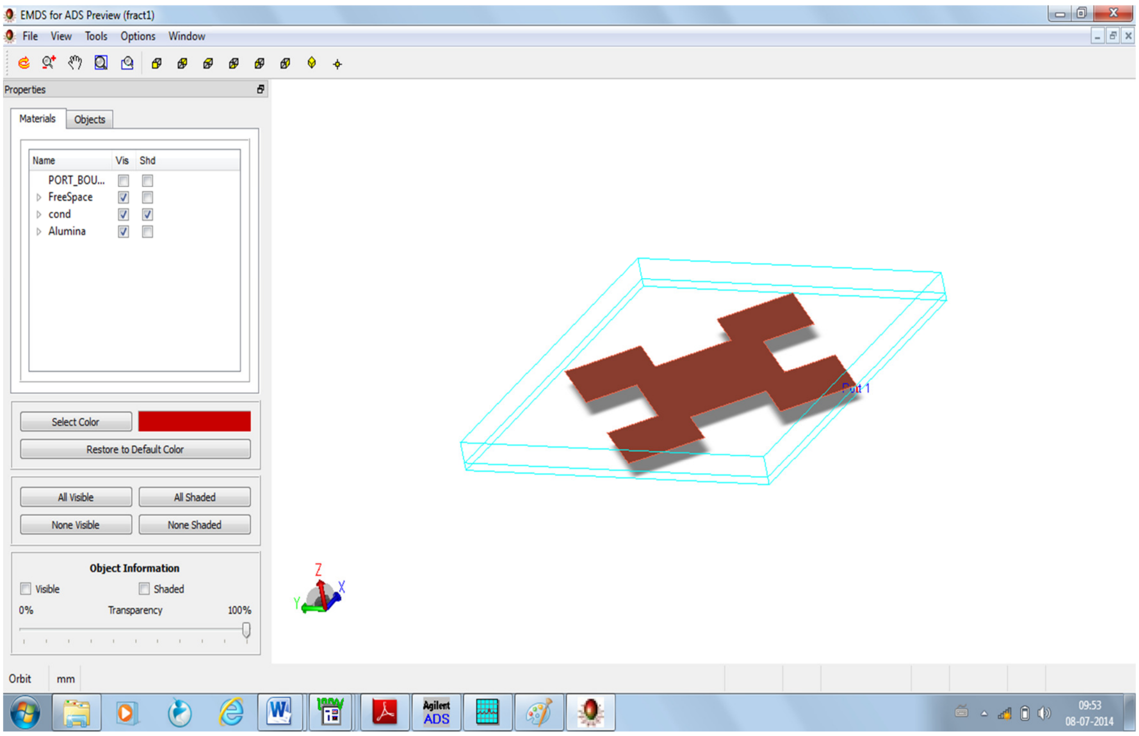

Figure 5.4: Design of first order Minkowski fractal antenna in ADS (3D Geometry View)

5.2.3 RESULTS OF SIMULATION

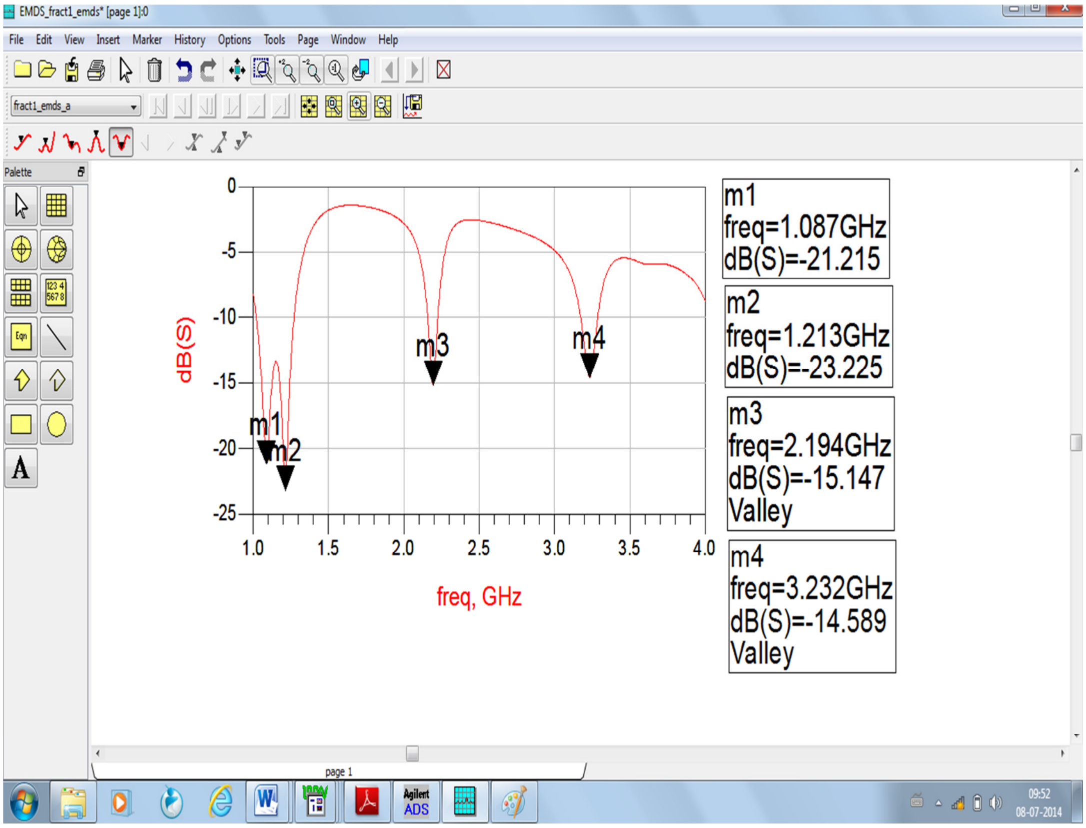

Figure 5.5: S-Parameter Display for order Minkowski fractal antenna

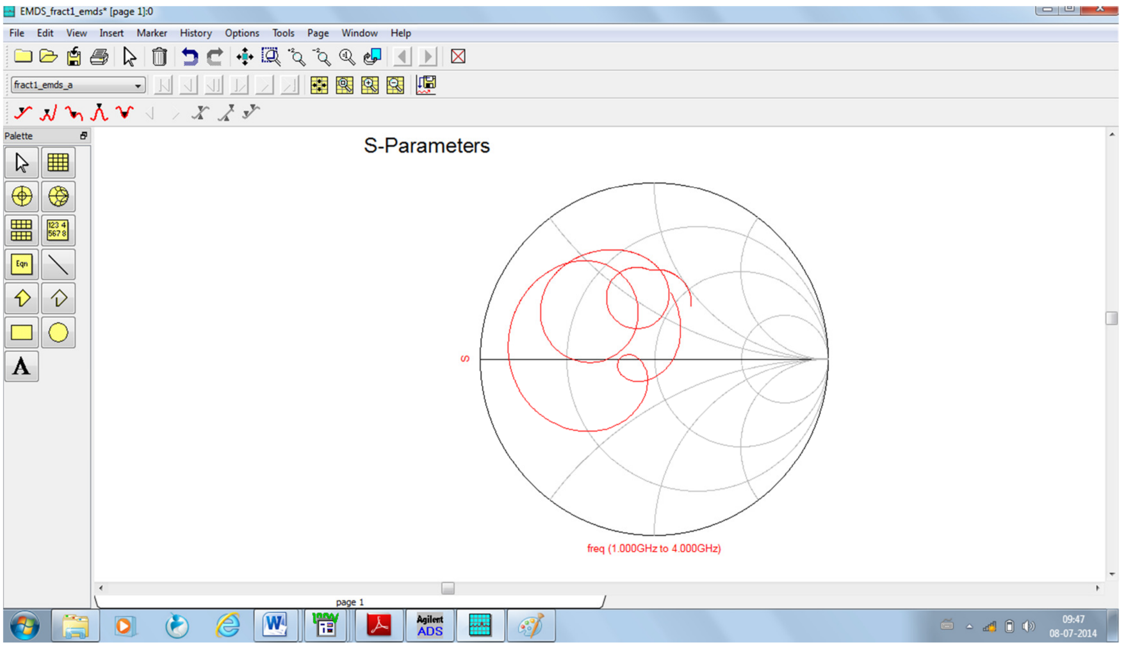

Figure 5.6: Smith chart display for first order Minkowski fractal antenna

5.3 DESIGN OF SECOND ORDER MINKOWSKI FRACTAL ANTENNA

The first order Minkowski fractal antenna can be obtain from basic square patch antenna with the help of generator that has been shown above.

5.3.1 SPECIFICATION

1. $W = L = L_{11} = 18mm$
2. $L_{21} = L_{23} = L_{11}/3 = 6mm$
3. $L_{22} = L_{21}/1.5 = 4mm$

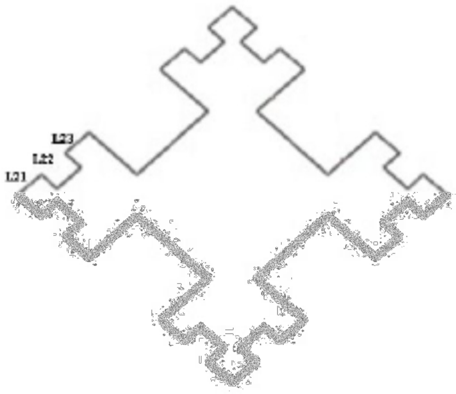

Figure 5.7: Second order Minkowski fractal antenna

5.3.2 SIMULATION IN ADS

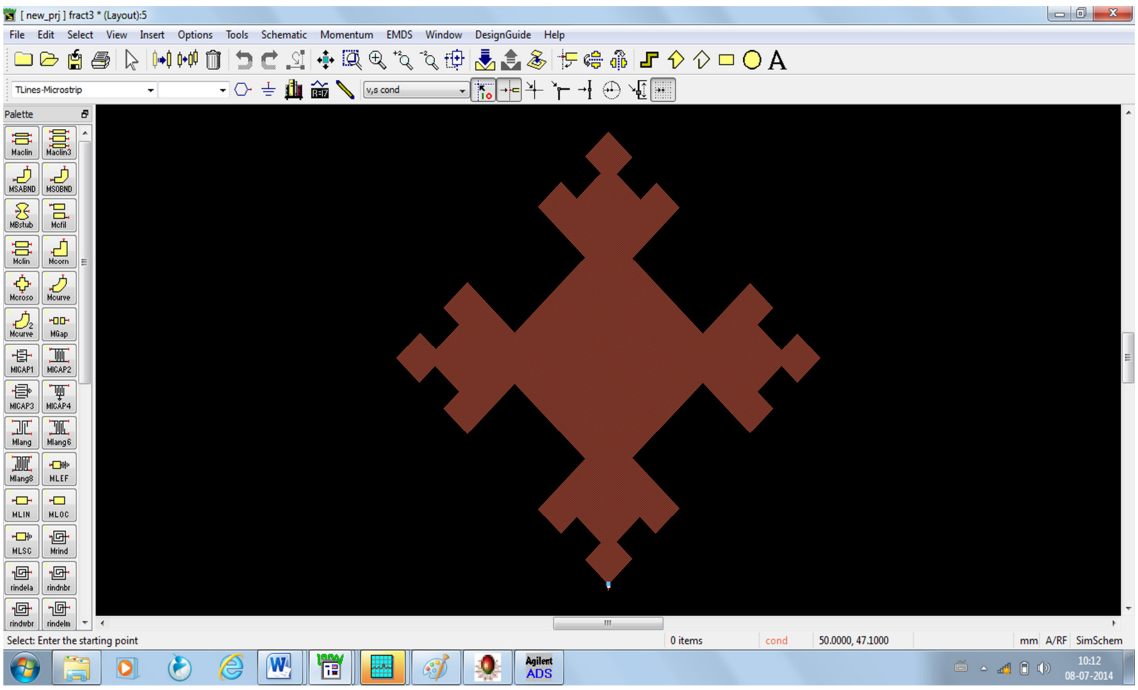

Figure 5.8: Design of second order Minkowski fractal antenna in ADS

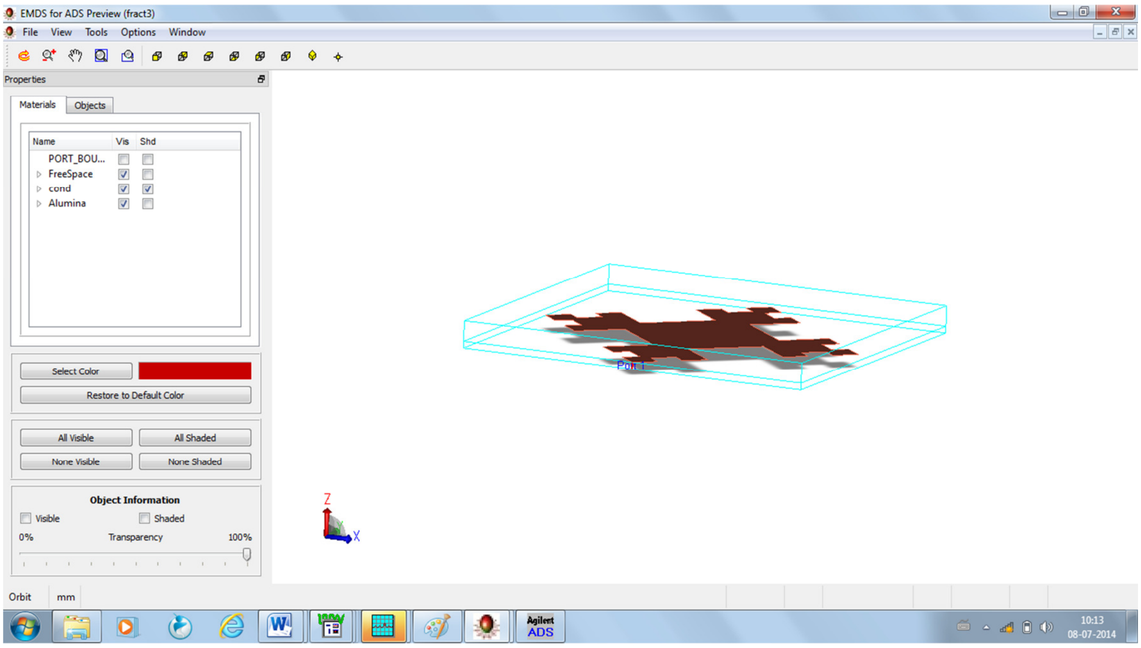

Figure 5.9: Design of second order Minkowski fractal antenna in ADS (3D Geometry View)

5.3.4 RESULTS OF SIMULATION

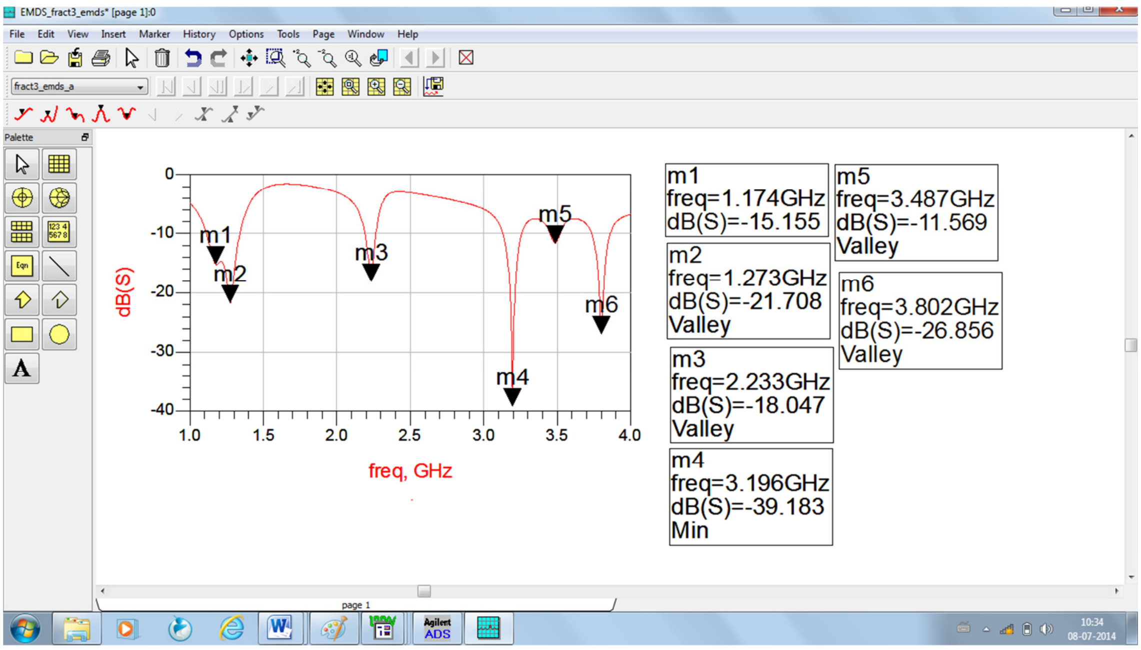

Figure 5.10: S-Parameter Display second order Minkowski fractal antenna

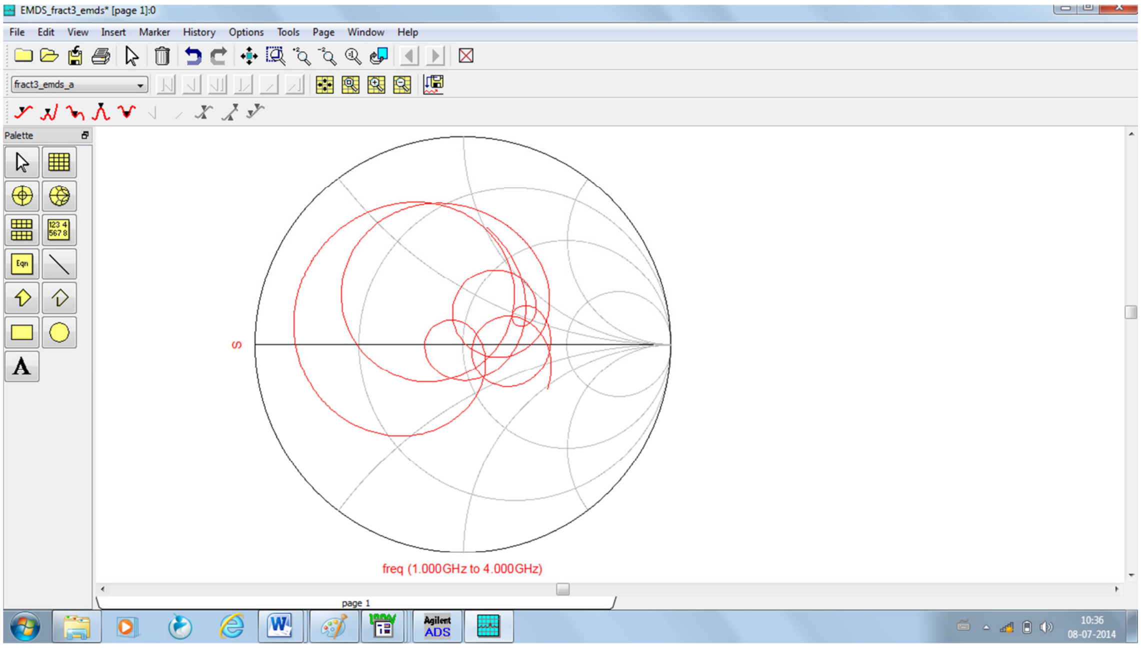

Figure 5.11: Smith chart display for second order Minkowski fractal antenna

5.4 DESIGN OF THIRD ORDER MINKOWSKI FRACTAL ANTENNA

The first order Minkowski fractal antenna can be obtain from basic square patch antenna with the help of generator that has been shown above.

5.4.1 SPECIFICATION

1. $W = L = L_{21} = 6mm$
2 $L_{31} = L_{33} = L_{21}/3 = 2mm$
3 $L_{32} = L_{31}/1.5 = 1.34mm$

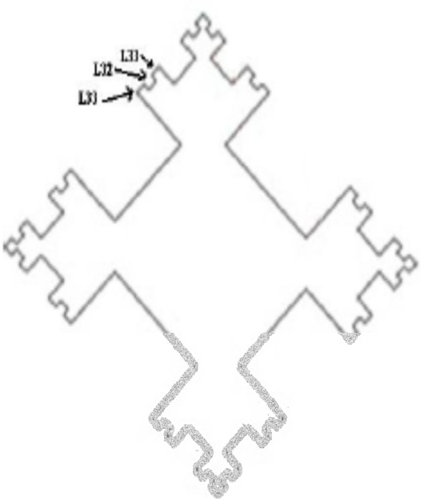

Figure 5.12: Third order Minkowski fractal antenna

5.4.2 SIMULATION IN ADS

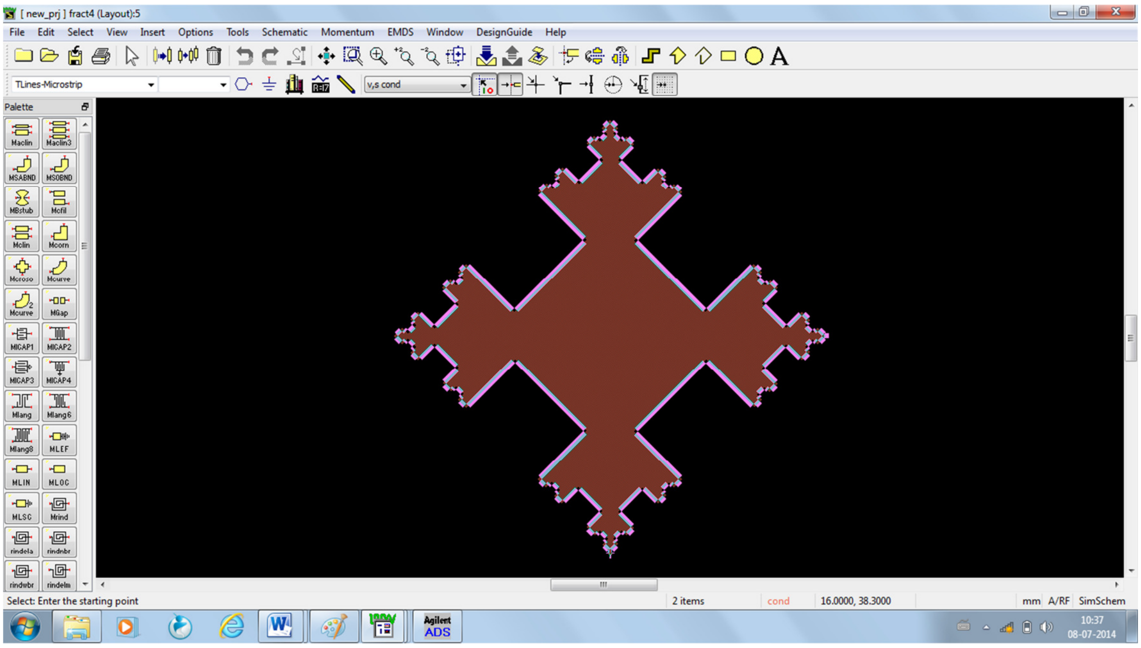

Figure 5.13: Design of third order Minkowski fractal antenna in ADS

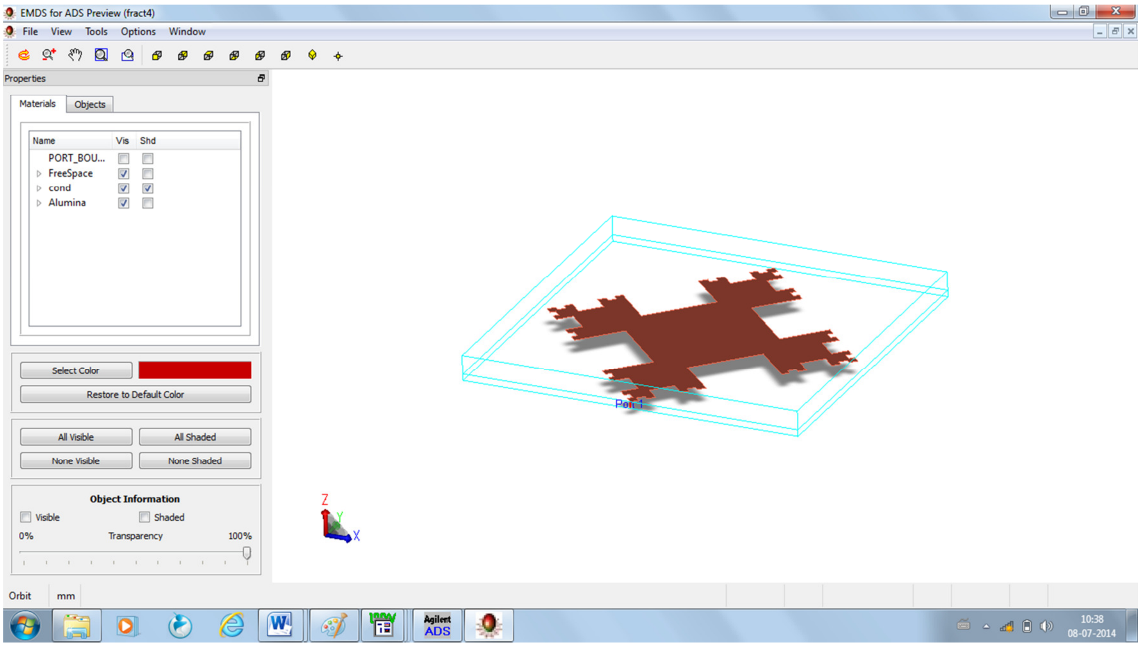

Figure 5.14: Design of third order Minkowski fractal antenna in ADS (3D Geometry View)

5.4.3 RESULTS OF SIMULATION

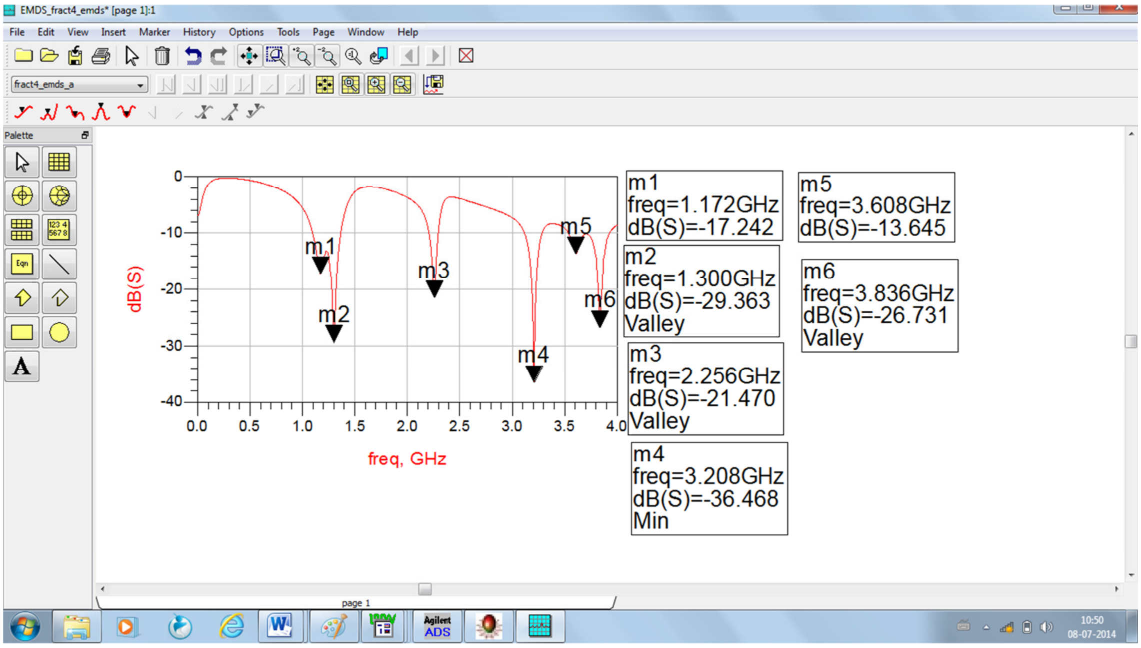

Figure 5.15: S-Parameter Display third order Minkowski fractal antenna

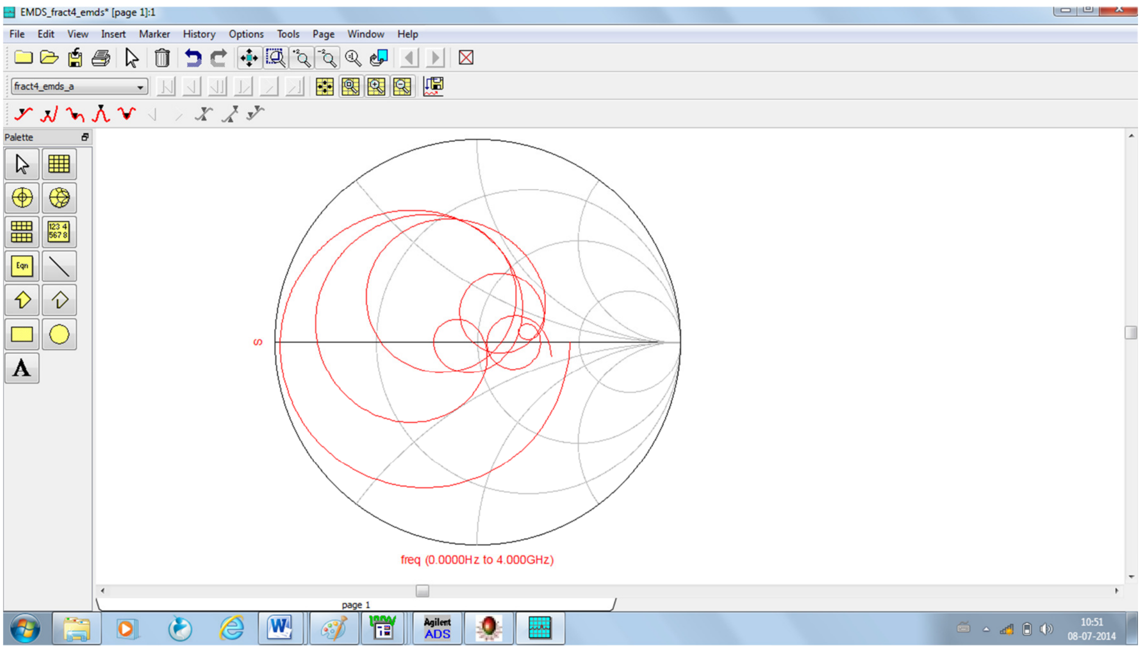

Figure 5.16: Smith chart display for third order Minkowski fractal antenna

5.5 RESULT

5.5.1 FOR FIRST ORDER MINKOWSKI FRACTAL ANTENNA

Resonant Frequency(GHz)	1.087	1.213	2.194	3.229
Reflection coefficient(dB)	-21.215	-23.225	-15.147	-14.540

5.5.2 FOR SECOND ORDER MINKOWSKI FRACTAL ANTENNA

Resonant frequency(GHz)	1.174	1.273	2.233	3.196	3.487	3.802
Reflection coefficient(dB)	-15.155	-21.708	-18.047	-39.183	-12.569	- 26.856

5.5.2 FOR THIRD ORDER MINKOWSKI FRACTAL ANTENNA

Resonant frequency(GHz)	1.172	1.3	2.256	3.208	3.608	3.836
Reflection coefficient(dB)	-17.242	-29.363	-21.447	-36.864	-13.616	-27.14

For first order Minkowski fractal antenna there are four bands while as the iteration increased to second and third order the number of bands increased to seven. All bands are lying from L-band to S-band. But from the designing we can see that as the number of iteration is increasing its getting more and more difficult to design an antenna.

5.6 SUMMARY

In this chapter the different order (first, second and third) of Minkowski fractal antenna has been design from basic square patch antenna which was design in last chapter. From the result it is clear that Minkowski fractal antenna has more number of bands suitable for radiation as compared to square patch antenna. Also the resonating frequency is varying by using fractal while maintain the same area as required for the square patch antenna.

CHAPTER 6

FINAL CONCLUSION AND FUTURE WORK

Final Conclusions

The main goal of this project was to implement a square patch antenna radiating in L-band and then using this antenna to design different order of planar Minkowski fractal antenna which can be used in modern communication so that it can meet the demands like small size and frequency of operation in around L and S band. Firstly a square patch antenna was designed which is radiating at 1.272 GHz and then different order of Minkowski fractal antenna has been obtained from it which were radiating at different frequencies lying in L and S band. Thus the goal of assignment is successfully accomplished.

Future work

For this project the Minkowski geometry was used, but other structures can also be used.
Other geometries could be simulated and described and finally compared so the best geometry for a certain application could be found. Usually the size of the antenna is very important, mainly for wireless applications so other fractal geometries need to be tested to achieve a reduced size with the best performance. Also as shown in [14] the area of patch fractal antenna can further be decreased and thus saving the material cost by using microstrip. This can also be implemented in future with this to have a much more cost effective antenna.

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