Design of Pentagonal Fractal Antenna for Ultra Wideband Applications

A Thesis submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology in

Electronics and Communication Engineering

Submitted by

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CERTIFICATE

This is to certify that the thesis entitled "Design of Pentagonal Fractal Antenna for Ultra Wideband Applications" was submitted by Ajay Gantayet, 109EC0218 and Debashis Rout, 109EC0232 in partial fulfilment of the requirements for the degree of Bachelor of Technology in Electronics and Communication Engineering during session 2012-2013 at National Institute of Technology, Rourkela. The candidates have fulfilled all the prescribed requirements. The thesis, which is based on candidates' own work, has not been submitted elsewhere for a degree or diploma. In my opinion, the thesis is of the standard required for the award of a Bachelor of Technology degree in Electronics and Communication Engineering.

Place: Rourkela (Prof. S.K Behera)

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ABSTRACT

Ultra Wide band fractal antenna based on pentagonal geometry has been proposed in this thesis. Fractal shapes and their properties are discussed. The proposed antenna is microstrip line fed and its structure is based on fractal geometry where the resonance frequency of antenna is lowered by applying iteration techniques. Analysis of fractal antenna is done by using Software named CST Microwave Studio Suite 12. This antenna has low profile, is lightweight and easy to be fabricated and has successfully demonstrated multiband and broadband characteristics. The antenna size inclusive of the ground plane is compact with dimensions 7 X 7 cm^2 and has wide operating bandwidths of 8 GHz. The antenna exhibits omnidirectional direction radiation coverage with a gain from 2 to 6.5 dBi in the entire operating band. Measured results show that this antenna operates from 4.7 to 12.7 GHz with a fractional bandwidth of above 90% and has relatively stable radiation patterns over its whole operation band.

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1. INTRODUCTION

1.1 PROJECT BACKGROUND

In modern wireless communication systems, antennas with wider bandwidth, multiband and low profile characteristics are in great demand for both commercial and military applications. This has initiated research on antennas in various directions. Generally, all antennas operate at single or dual frequency bands, where different antennas are needed for different applications. This will cause a limited space problem. In order to solve this problem, multiband antennas are used where a single antenna can operate at many frequency bands [1]. One technique is to construct a multiband antenna is by applying fractal shape into the antenna geometry. The construction of wideband antenna extends the bandwidth over the entire region within its cut-off frequencies.

This project takes inspiration from the Sierpinski gasket fractal with triangle as the base structure and Sierpinski carpet with rectangle as the base structure. Many UWB antennas have been constructed using these three-sided and four-sided structures. Hence, we decided to construct an UWB antenna with a pentagon as the base geometry. The focus on UWB was because it has a wide range of applications across numerous fields ranging from military operations to tracking to personal area networks.

In this project, we have constructed such a wideband antenna using pentagonal fractal geometry. Addition of slots became imminent in order to achieve ultra-wideband bandwidth. The parametric study of addition of slots and their placement has been provided for reference. In addition to the theoretical design procedure, numerical simulations were performed using software (CST) to obtain design parameters such as size of patch and feeding location. The proposed antennas have been analysed and designed by using the software CST Microwave Studio Suite 12.

1.2 OBJECTIVE

The objective of this project is to design and simulate ultra-wideband antennas using pentagonal fractal geometry. The antenna has to satisfy the UWB characteristics of having a fractal bandwidth greater than 25% or a general bandwidth greater than 1.5 GHz within the frequency range of 3.6 to 10.2 GHz. The behaviour and properties of this antenna are investigated.

1.3 SCOPE OF THE PROJECT

The scope defined for this project:

- Understanding the basic concept of antennas.
- Designing the fractal geometry with desired characteristics.
- Conducting a parametric study on the optimum dimensions of the antenna.
- Performing simulations using CST Microwave Studio software
- Studying the antenna properties.
- Comparing the results of the measurement and simulations.

1.4 THESIS ORGANIZATION

Chapter 1: In the first chapter basic overview of the project done is provided. This chapter gives the project background and the objective of the project.

Chapter 2: This chapter describes the microstrip antenna, its characteristics and various antenna properties along with the terms associated with it. Basic feeding techniques as well as methods of analysis are described and a small discussion is done on the advantages and disadvantages of the MSA and the various types of feeding methods.

Chapter 3: This chapter describes how the use of fractal geometry in MA design had been of a great use. Some efficient fractal geometries are described in this chapter.

Chapter 4: This chapter includes the design process and simulation results of the proposed pentagonal fractal antenna. The parametric study and results of simulations have been provided to give a deeper insight into the design process.

Chapter 5: This chapter includes the design process and simulation results of some other fractal antennas with slightly different base geometrical shapes.

Chapter 6: This chapter includes the conclusion of the project and the scope for future work on the subject matter.

2. MICROSTRIP ANTENNA

2.1 INTRODUCTION

Deschamps first proposed the concept of the Microstrip antenna in 1953 [2], [3]. However, practical antennas were developed later by Munson and Howell in the 1970s. The numerous advantages of MSA, such as low weight, small volume, and ease of fabrication using printed-circuit technology, led to the design of several antennas for various applications. The requirements for personal wireless communication, the huge demand for smaller and low-profile antennas has brought the MSA to the limelight. An MSA in its simplest form, consists of a radiating patch on one side of a dielectric substrate and a ground plane on the other side. Radiation from the MSA occurs from the fringing fields between the periphery of the patch and the ground plane.

Microstrip antenna is a simple antenna consisting of a radiating patch component, a dielectric substrate, and a ground plane. The radiated patch and ground plane are thin layers of copper or gold, which are good conductors. The dielectric substrates have their own dielectric permittivity values. This permittivity influences the size of the antenna [4]. Microstrip antenna is a low profile antenna with several advantages like being light weight, having small dimension, being cheap and easy to integrate with other circuits which make it chosen in numerous applications.

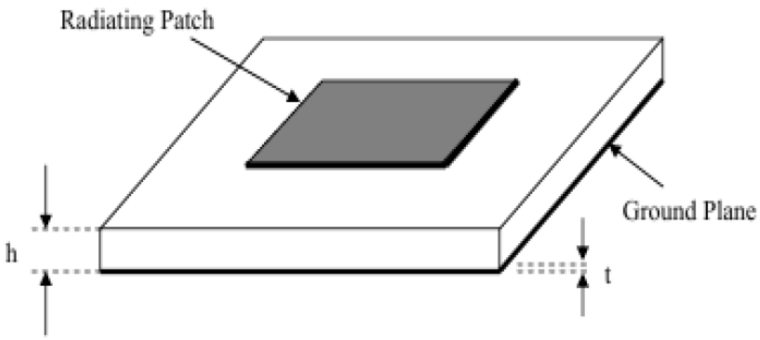


Figure 2.1: Parts of a Microstrip Antenna. In the figure, h= substrate thickness; t= ground plane thickness.

2.2 ANTENNA PROPERTIES

The performance of the antenna is determined by several factors. Properties of those factors are as follows:

Frequency

Bandwidth is the difference between the high and low frequencies of operation of the antenna[1]. For instance, an antenna transmitting between frequencies of 35 and 45 MHz has a bandwidth of 10 MHz This means that the energy of the signal is contained between 35 and 45 MHz (the energy in any other frequency range is considerably negligible).

Directivity

Directivity, D, shows the ability of the antenna to focusing radiated energy. It is the ratio of maximum radiated power to the power radiated by a reference antenna [1]. The reference antenna is usually an isotropic radiator where the radiated energy is same in all directions and has a directivity of 100% or 1. Directivity is mathematically defined by the following equation:

$D = F_{max} / F_0$

Where, F_{max} = the Maximum radiated energy

F_0 = Energy radiated by an Isotropic radiator

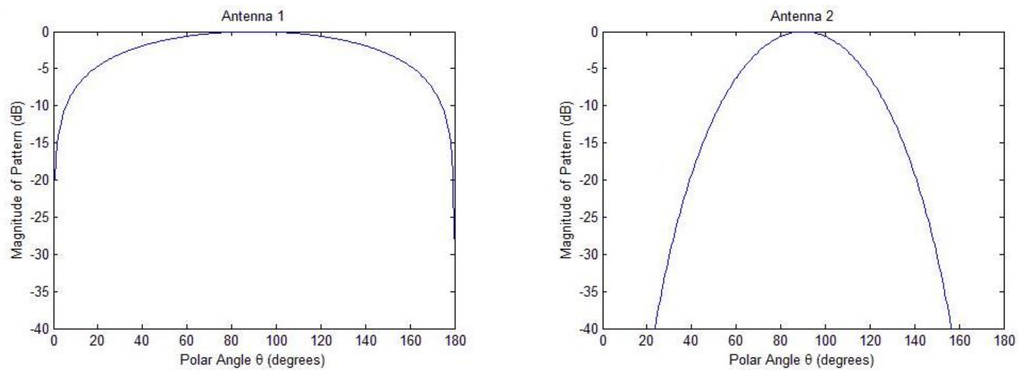


Figure 2.2: Directivity of two antennas. The second antenna has better directivity than first one

Gain

The gain of an antenna is a measure of the antenna's overall efficiency in radiation. If the antenna is 100% efficient, it would have a gain equal to its directivity. There are numerous factors that affect and reduce the overall efficiency of an antenna [5]. The most significant factors that impact antenna gain include the impedance matching, the network losses, the material losses and the random losses.

Input Impedance

Generally, the input impedance is important to determine maximum power transfer between transmission line and antenna. This transfer only happens when the input impedance of antenna and input impedance of the transmission line match [5]. If they do not match, reflected wave will be generated at the antenna terminal and travel back towards the source. This reflection of energy results causes a reduction in the overall system efficiency and thus is avoided.

Radiation Patterns

The radiation patterns of an antenna provide the information that describes how the antenna directs the radiated energy. Antennas, which are 100% efficient, radiate the same total energy for equal input power regardless of the shape of the pattern [1], [6]. The radiation patterns are generally drawn on a relative power dB scale.

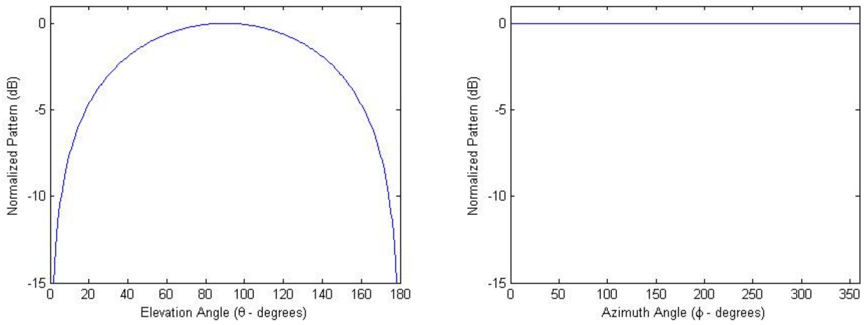


Figure 2.3: Radiation Pattern

Polarization

The polarization of an antenna describes the orientation and sense of the radiated wave's electric field vector [1],[7]. There are three basic types of polarization:

• Linear polarization

• Elliptical polarization

• Circular polarization

Generally, most antennas radiate with linear or circular polarization. Antennas with linear polarization radiate in the same plane with the direction of the wave propagation.

Bandwidth

The term bandwidth simply defines the frequency range over which an antenna meets a certain set of specifications. There are basically narrowband and wideband antennas [1]. An antenna is considered broadband if $f_h/f_L \geq 2$.

Narrowband by % age

BW = $(\mathbf{f_h} - \mathbf{f_l}) / \mathbf{f_0} \times 100\%$

Broadband by ratio

BW= $\mathbf{f_h / f_l}$

where f_0 = Operating frequency

f_h = Higher cut-off frequency

f_l = Lower cut-off frequency

Ultra wideband was formerly known as "pulse radio". The International Telecommunication Union Radio communication Sector (ITU-R) currently defines UWB [5], [8] in terms of a transmission from an antenna for which the emitted signal bandwidth exceeds the lesser of 20% of the centre frequency or a bandwidth of 500 MHz

Frequency range	**-10 dB Bandwidth** **Fractional bandwidth (F)**
Narrowband	$F \leq 0.01$
Wideband	$0.01 \leq f \leq 0.20$

Ultra-wideband	F ≥ 0.20 GHz

Table 1: Frequency range

2.3 CHARACTERISTICS

The length *L* of the rectangular patch for the fundamental TM_{10} mode excitation is slightly smaller than λ/2, where λ is the wavelength in the dielectric medium [1]. The value of ε_e is slightly less than the dielectric constant ε_r of the substrate because the fringing fields from the patch to the ground plane are not confined in the dielectric only, but are also spread in the air. The fringing fields from the patch, which account for the radiation, are enhanced by increasing the width W [1], [7]. The fringing fields are also enhanced by decreasing the ε_r or by increasing the thickness of substrate, h.

The MSA has proved to be an excellent radiator for many applications because of its several advantages, but it also has some disadvantages. Advantages and disadvantages of the MSA are given below.

2.3.1 ADVANTAGES

MSAs have several advantages compared to the conventional microwave antennas. The primary advantages[1] of MSAs are as follows:

· Lightweight and has a small volume, a low-profile planar configuration.

· Can be conformal to the host surface.

· can be mass produced using printed-circuit technology leading to low fabrication cost.

· Easy to integrate with other MICs on single substrate.

· Allows both linear and circular polarisation.

· Can be made compact for use in mobile communication.

· Allows dual- and triple-frequency operations.

2.3.2 DISADVANTAGES

MSAs suffer from some disadvantages [1],[8] as compared to conventional microwave antennas such as the following:

· Narrow BW

· Lower gain

· Low power-handling capability

MSAs have narrow bandwidth, typically 1–5%, which is a major limiting factor for the widespread application of these antennas. Enhancing the BW of MSAs has been the major thrust of research in this field. Various broadband MSA configurations are summarized in this chapter.

2.3.3 APPLICATIONS OF MSAS

The advantages of MSAs make them suitable for numerous applications. Telemetry and communication antennas on missiles need to be thin and conformal and are often MSAs [8]. The Radar altimeters use small arrays of microstrip radiators. Many other aircraft-related applications include antennas for telephone and satellite communications and microstrip arrays have been used for satellite imaging systems. Smart weapon systems use MSAs because of their thin profile. Pagers, the global system for mobile communication (GSM), and the global positioning system (GPS) are major users of MSAs [1],[6]. Patch antennas have been used on communication links between ships or buoys and satellites.

2.4 FEEDING TECHNIQUES

Feeding techniques [1] are important in designing the antenna to make antenna structure so that it can operate at full power of transmission. 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.

- Microstrip Line feeding
- Coaxial Probe feeding
- Aperture Coupled feeding
- Proximate Coupled feeding
- CPW feeding

2.4.1 MICROSTRIP LINE FEEDING

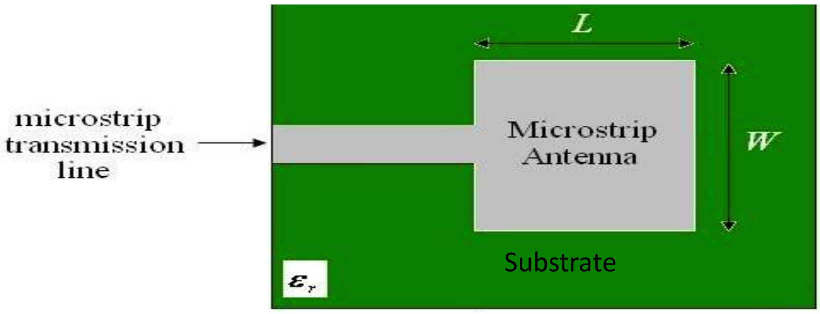


Figure 2.4: Microstrip line feeding

It has more substrate thickness i.e. directly proportional to the surface wave. The radiation bandwidth limit is 2-5%. 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 considered as an extension of the patch[1]. It is simple to model and easy to match by controlling the inset position. The disadvantage of this method is that, as substrate thickness increases, the surface waves and the spurious feed radiation increases which limits the bandwidth.

2.4.2 COAXIAL PROBE FEEDING

It has low spurious radiation and narrow bandwidth. 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 [1]. It is easy to fabricate but difficult to model.

Advantages

i. Easy to fabrication

ii. Easy to match

iii. Has low spurious radiation

Disadvantages

i. Has narrow bandwidth

ii. It is difficult to model specially for thick substrate

iii. It possesses inherent asymmetries which generate higher order modes which produce cross-polarization radiation.

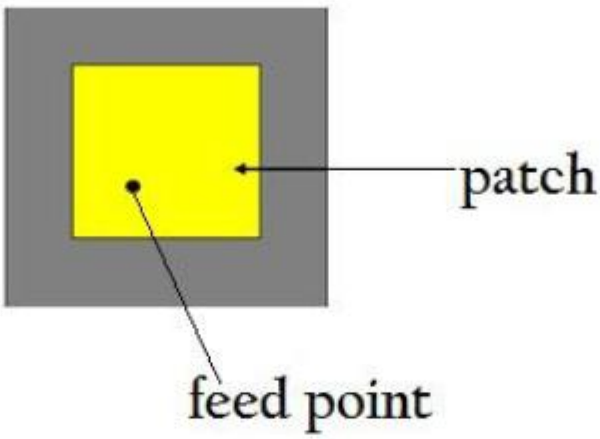


Figure 2.5: Coaxial Probe feeding

2.4.3 APERTURE COUPLED FEEDING

It has a narrow bandwidth and moderate spurious radiation. It consists of two different substrates separated by a ground plane. Below the 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. Such arrangement allows independent optimization of the feed mechanism and the radiating element. Normally, the top substrate uses a thick low dielectric constant substrate while the bottom substrate has high dielectric permittivity [1],[7]. The ground plane isolates the feed from radiation element and minimizes interference of spurious radiation for pattern formation and pure polarization.

Advantages:

It allows optimization of feed mechanism element.

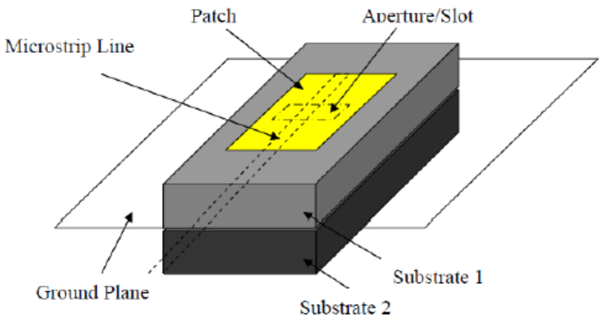


Figure 2.6: Aperture couple feeding

2.4.4 PROXIMITY COUPLED FEEDING

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

Advantage

i. It has largest band width.

ii. It is easy to model.

iii. It has low spurious radiation and is difficult to fabricate.

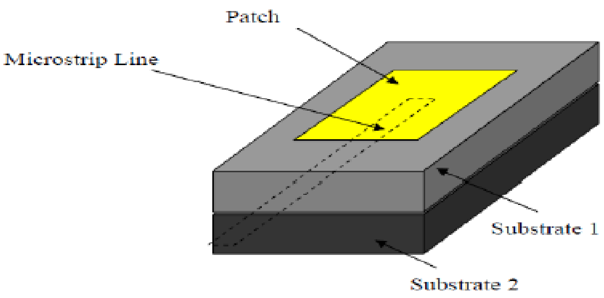


Figure 2.7: Proximity coupled feeding

2.4.5 CPW FEEDING

A coplanar waveguide structure consists of a median metallic strip 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. The transmission line is uniplanar in construction, implying that all of the conductors are on the same side of the substrate.

They have many features such as low radiation loss, less dispersion, simple configuration and easy integrated circuits with single metallic layer. The CPW fed antennas have recently become more and more attractive because of its some more attractive features such as wider bandwidth, good impedance matching and easier integration with active devices or monolithic microwave integrated circuits [1]. By etching the slot and the feed line on the same side of the substrate, we eliminate the alignment problem needed in other wideband feeding techniques such as aperture coupled and proximity feed.

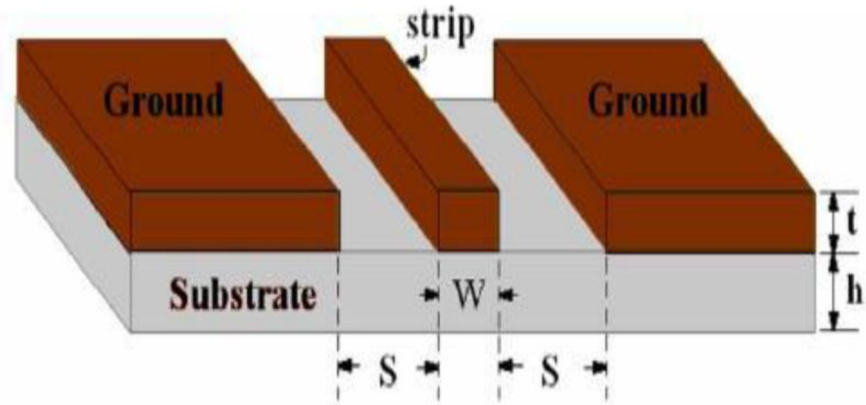


Figure 2.8: Structure of coplanar waveguide feed

2.5 METHODS OF ANALYSIS

The MSA generally has a two-dimensional radiating patch on a thin dielectric substrate and therefore may be categorized as a two-dimensional planar component for analysis purposes. The various analysis methods for MSAs can be broadly divided into two groups.

In the first group, the methods are based on equivalent magnetic current distribution [1] around the patch edges (similar to slot antennas). The three popular analytical techniques:

- Transmission line model;
- Cavity model;

- Full Wave analysis model

In the second group, the methods are based on the electric current distribution on the patch conductor and the ground plane (similar to dipole antennas). The numerical methods for analysing MSAs [1] are listed as follows:

- Method of moments (MoM);
- Finite-element method (FEM);
- Spectral domain technique (SDT);
- Finite-difference time domain (FDTD) method.

3. FRACTAL ANTENNA

3.1 FRACTAL THEORY

In modern wireless communication systems, multiband and low profile antennas are in great demand for both commercial and military applications. This has led to antenna research in various directions; one of them is using fractal shaped antenna elements. Traditionally, every antenna operates at a single or dual frequency bands, where different antennas are needed for different applications.

Fractal shaped antennas have already been proved to have some unique characteristics that are linked to the various geometry and properties of fractals. Fractals were first defined by Benoit Mandelbrot in 1975 as a way of classifying structures whose dimensions were not whole numbers. Fractals have unique geometrical features occurring in nature. It can be used to describe the rough terrain, jaggedness of coastline, branching of tree leaves and plants, and many more examples in nature [5],[6]. Fractals are applied in various fields like image compression and analysis of high altitude lightning phenomena. Fractals are geometric forms that can be found in nature, being obtained after millions of years of evolution and optimization.

There are many benefits when we applied these fractals to develop various antenna elements. By application of fractals to antenna elements:

• We can create smaller antenna size.

• We achieve resonating frequencies that are multiband.

• optimize for gain.

• Achieve wideband frequency band or multiband frequencies.

Most fractals have infinite complexity and detail that can be used to reduce antenna size and develop low profile antennas. Self-similarity concept can achieve multiple frequency bands because of different parts of the antenna are similar to each other at different scales [2]. Combination of infinite complexity and self-similarity makes it possible to design antennas with various wideband performances.

We need fractal antenna for following reasons:

- They have broadband and multiband frequency response
- Compact size compared to conventional antennas
- Mechanical simplicity and robustness
- Characteristics of the fractal antennas are due to its geometry and not because of the addition of discrete components
- Design to suit particular multi frequency characteristics containing specified stop bands as well as specific multiple pass bands as required.

3.2 FRACTAL GEOMETRY

There are many fractal geometries that have been found to be useful in developing new and innovative design for antennas. Figure below shows some of the popular geometries.

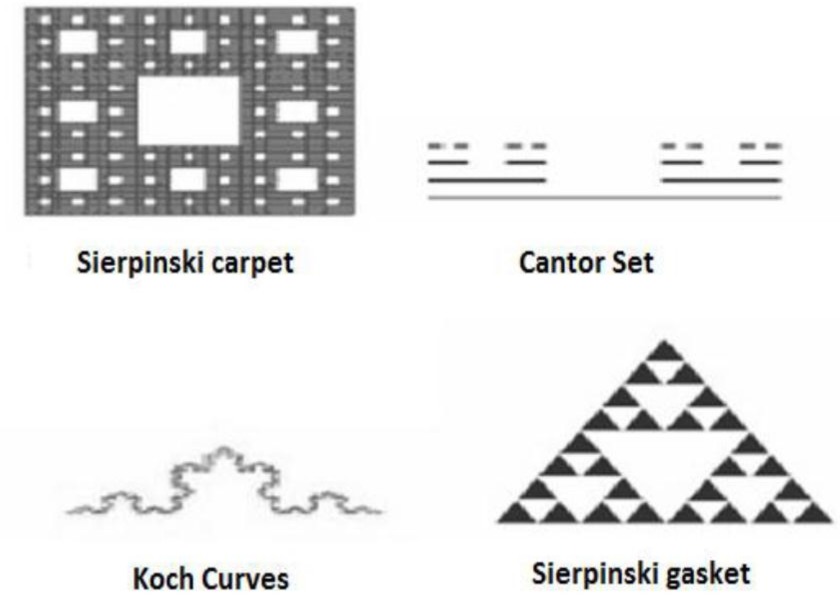


Figure 3.1: Types of fractal geometries

3.2.1 CONSTRUCTION

Fractal design has two components:

1) Initiator (0^{th} stage): the basic shape of the geometry.

2) Generator: the shape which gets repeated in a pattern on the initiator in subsequent stages of different dimensions.

In the figure, the initiator as well as generator has been presented. The generator is used to add or subtract from the area of the initiator n from each subsequent iteration stage in a fixed pattern thus culminating in the fractal structure.

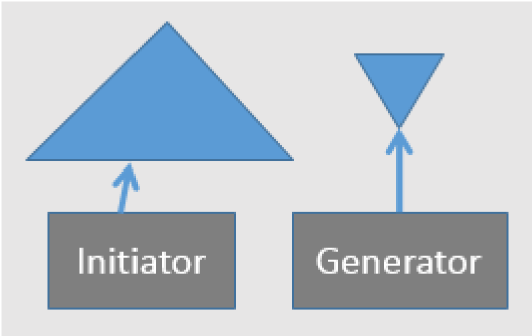


Figure 3.2: the initiator and generator of a Sierpinski gasket fractal

The iterated function system (IFS) [2],[8] is another mathematical way of generating fractals from a specific base geometry. It consists of a set of affine transformations that include shearing, scaling, translating and rotating the current stage to result in the next stage of iteration.

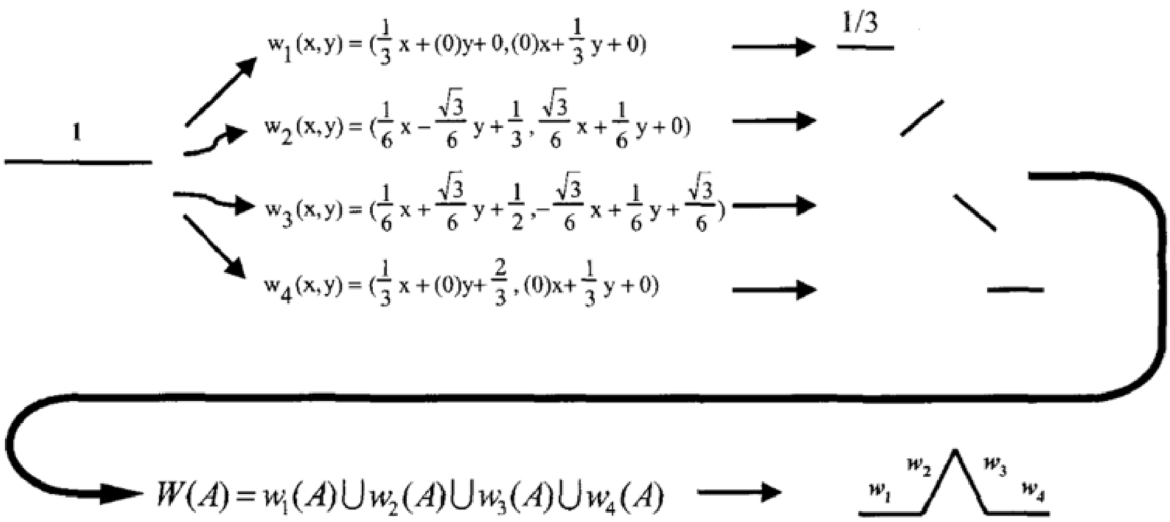
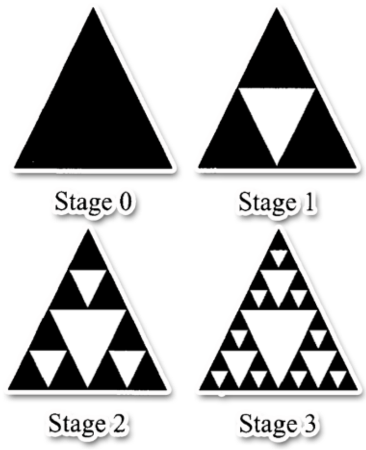


Figure 3.3: the standard Koch curve as an iterated function system (IFS)

3.2.2 SIERPINSKI GASKET GEOMETRY

Sierpinski gasket geometry is the most widely studied fractal geometry for antenna applications. Steps for constructing this fractal are described. 1st a triangle is taken in a plane. Then in next step a central triangle is removed with vertices that are located at the midpoint of the sides of the triangle as shown in the figure [3]. The process is then repeated for remaining triangles as shown in figure. Sierpinski gasket fractal is formed by doing this iterative process infinite number of times [3]. In the figure, the black triangular areas represent



a metallic conductor and the white triangular areas represent the region from where metals are removed.

Figure 3.4: Steps of construction for Gasket geometry

3.2.3 SIERPINSKI CARPET

The Sierpinski carpet [3] is constructed similar to the Sierpinski gasket, but unlike gasket, it uses rectangles instead of triangles. To start this type of fractal antenna, it begins with a square in the plane. Then divides it into nine smaller congruent squares where the open central square is dropped. The remaining eight squares are divided into nine smaller congruent squares[3].

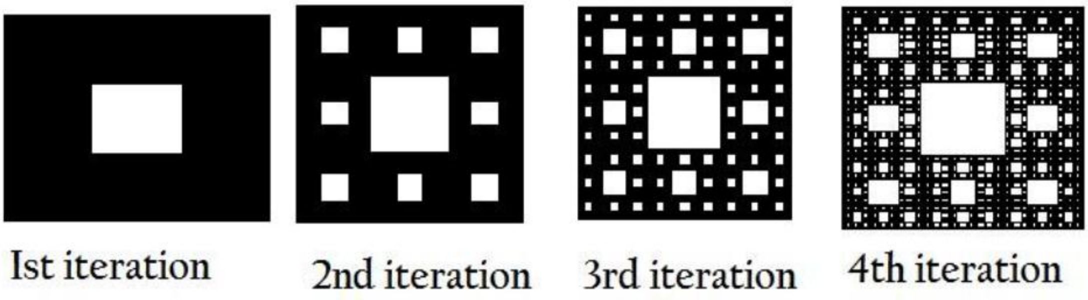


Figure 3.5: Steps of Iteration to get Sierpinski Carpet geometry

3.2.4 KOCH CURVES

The geometric construction of the standard Koch curve is simple, starting with a straight line as an initiator [4]. The straight line is partitioned into three equal parts. The segment at the middle is replaced with two others of the same length. Thus we have the first iterated version of the geometry and is called the generator [4]. The process is used again in the generation of higher iterations.

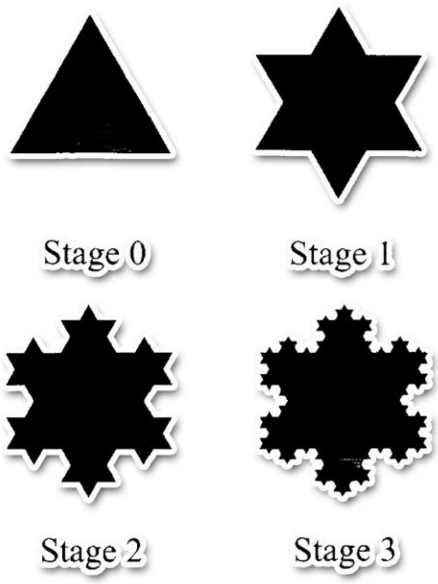


Figure 3.6: the first few stages in construction of Koch snowflake

3.2.5 THE CANTOR SET GEOMETRY

The Cantor Set [2] is created by the following algorithm. It starts with the closed interval [0, 1]. Say it as set A1 or the 0th (initial) set. Delete the middle portion. This leaves a new set, called A2 [0,1/3] U [2/3,1]. Each iteration through the algorithm removes the open middle third from each segment of the previous iteration[2]. Thus, the next two sets would be A3 [0,1/9] U [2/9,1/3] U [2/3,7/9] U [8/9,1] and according to the previous one A4 set will be A4 [0,1/27] U [2/27,1/9] U [2/9,7/27] U[8/27,1/3] U [2/3,19/27] U [20/27,7/9] U [8/9,25/27] U [26/27,1]. We can see that the set becomes sparser as the number of iteration increases. Cantor Set is defined as the set of the points that remain as the number of iterations tends to infinity.

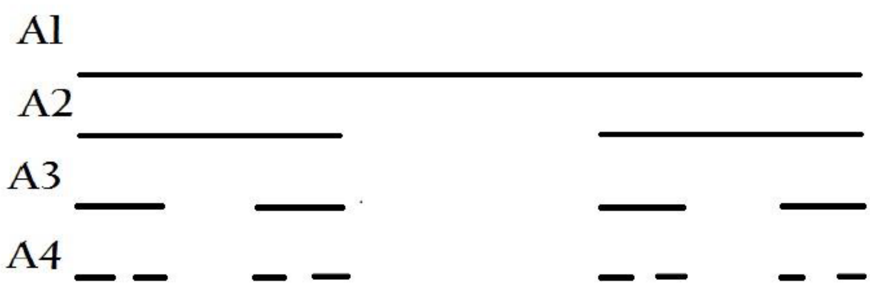


Figure 3.7: Steps for the Cantor Set geometry

4. PROPOSED PENTAGONAL FRACTAL ANTENNA

4.1 THE RADIATING PATCH

The radiating patch of the antenna is based on pentagonal geometry. The initiator is a pentagon with line feeding.

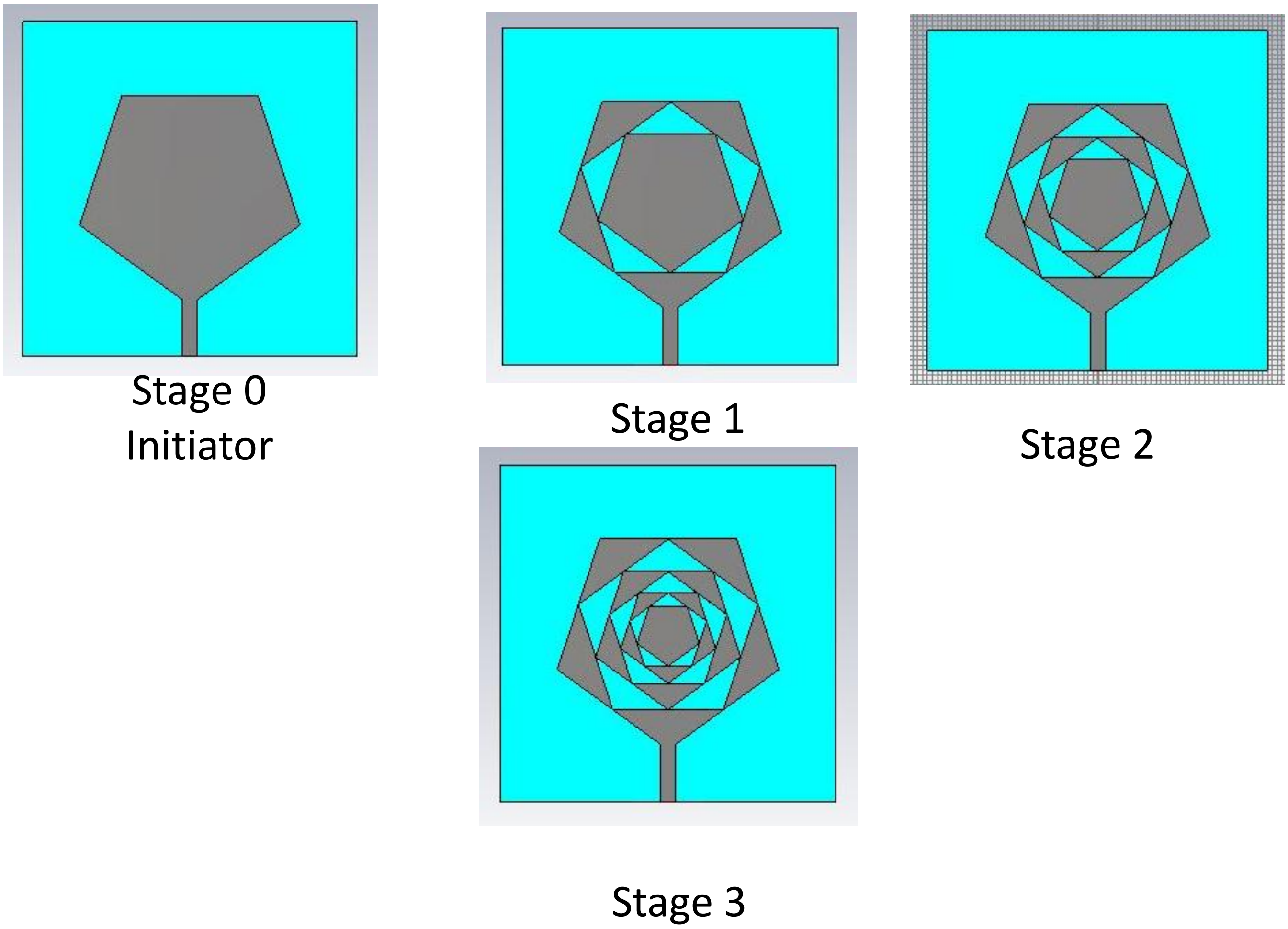


Figure 4.1: the radiating patch after each iteration. (Stages 0-3)

The subsequent iterative stages are achieved by

i. Scaling the pentagon in current stage by a scaling factor of 0.8

ii. Rotating this scaled pentagon by 72 degrees.

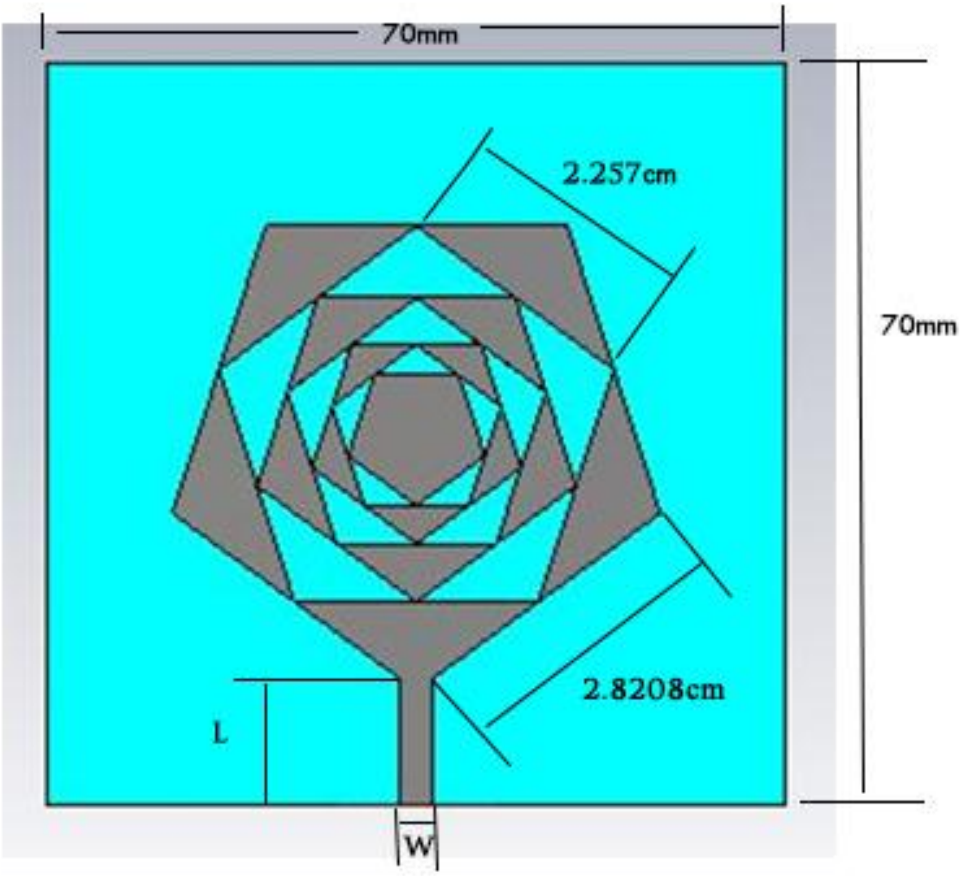
iii. Subtracting it from the previous stage.

iv. Rescale the above pentagon by 0.8

v. Rotate the smaller pentagon by 72 degrees

vi. Add the newly obtained pentagon to the previous structure.

The radiating patch can have as much iteration as required. After a few iterations, the results obtained get stabilised and thus no further iterations will be necessary. In this project we have studied the geometry up to the third stage of iteration.



The final dimensions of the radiating patch are:

Figure 4.2: dimensions of the radiating patch after the third iteration. L=17.4mm, W=3.08mm

Dimension	Values (mm)
Length (L)	17.4
Width (W)	3.08

Table 2: Dimensions of the radiating patch

4.2 THE SUBSTRATE

The substrate used in this antenna is FR4 with a dielectric constant or relative permittivity of $\varepsilon_r = 4.4$

Thickness of the substrate was taken to be 1.6mm. The width of the feed line was thus determined to be 3.08mm in order to obtain an impedance of 50 ohms.

$$when \left(\frac{W}{H}\right) \geq 1$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\left(\frac{H}{W}\right)\right)^{-1/2}$$

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}} \times \left[\frac{W}{H} + 1.393 + \frac{2}{3}\ln\left(\frac{W}{H} + 1.444\right)\right]}$$

Where,

ε_e is the effective relative permittivity due to the fringing effects.

Z_0 is the impedance of the feed line.

W/H is the feed line width to substrate height ratio. In this case, it is definitely greater than 1.

4.3 GROUND PLANE

The ground plane was modified from full ground plane to less than half of its area. Reduction of ground plane results in reduction of copper loss as well as surface waves and thus better radiation and bandwidth of radiation.

A comparative study was conducted and the best result was obtained when the dimensions of the ground plane were as follows:

Table 3: the dimensions of the ground plane before slot addition

Dimensions	Values
Ymax	-23mm
Ymin	-35mm
Xmax	35mm
Xmin	-35mm

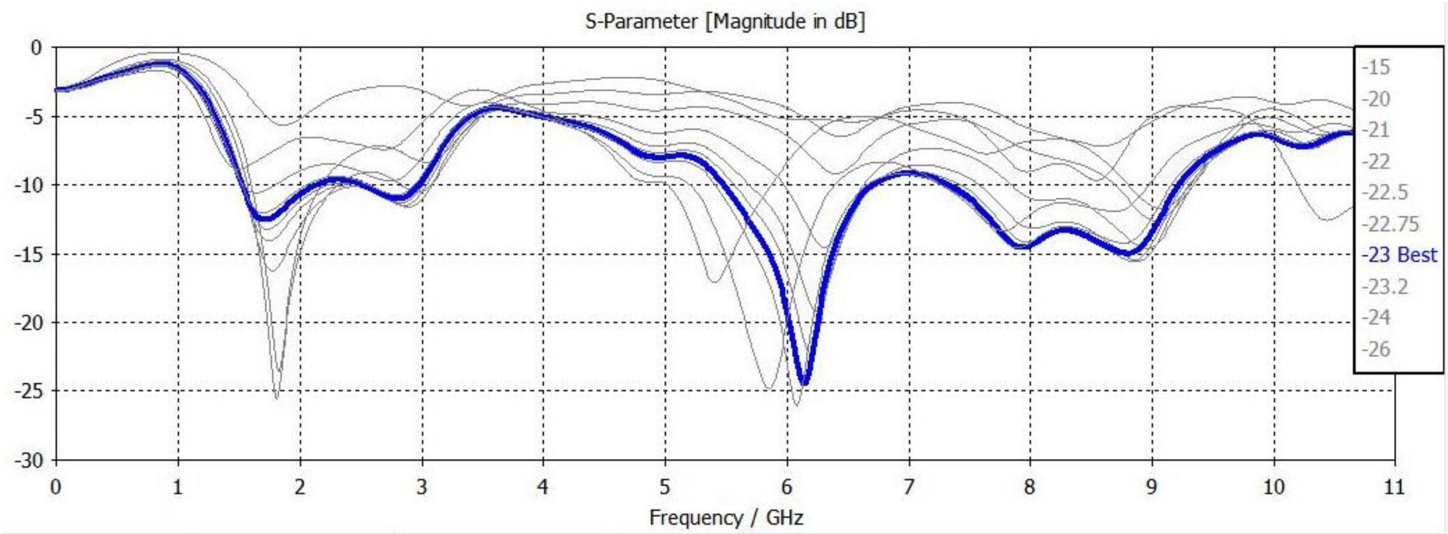


Figure 4.3: the parametric study of effect of reduction of ground plane on the return loss.[the numbers in the legend represent Ymax]

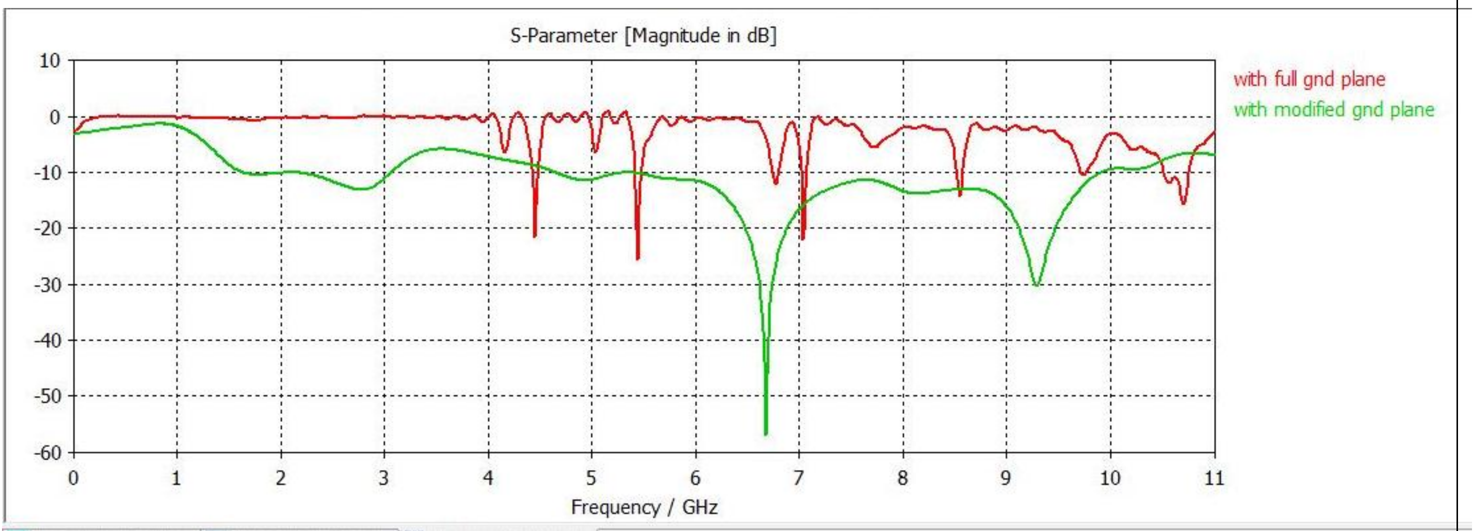


Figure 4.4: comparison between the effects of a full ground plane and reduced ground plane on the return loss of the antenna

4.4 ITERATIONS

The antenna was simulated for the different stages of iteration and the results were compared for finding the best configuration in terms of return loss. The study revealed that the effects of iteration were too small after a couple of stages of iteration.

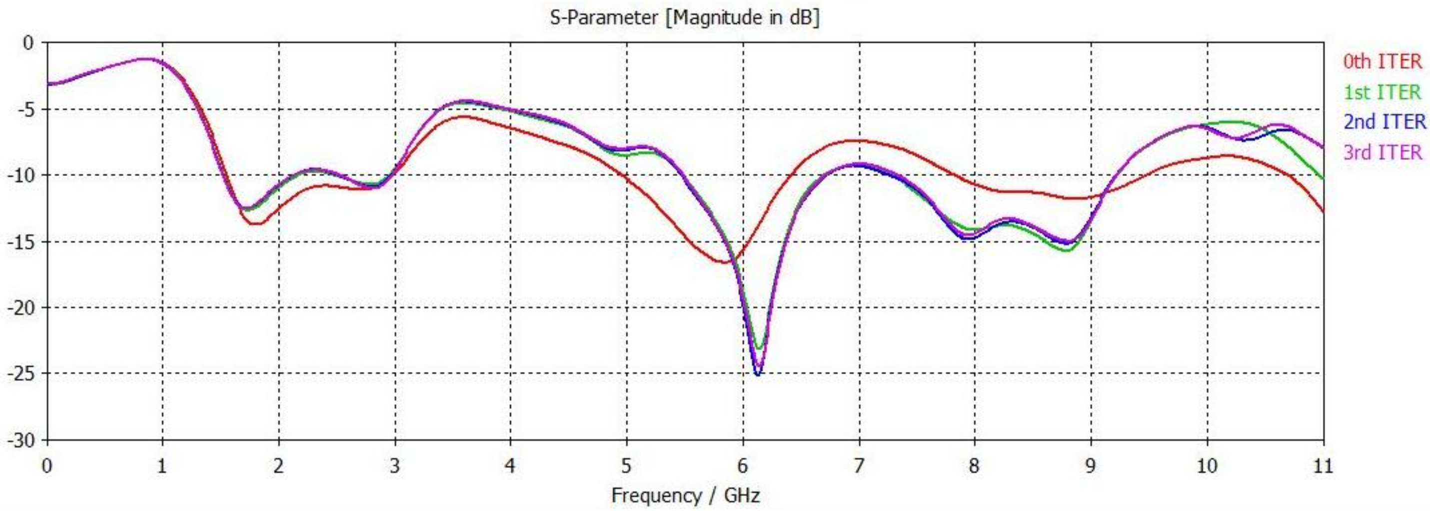


Figure 4.5: the return loss for the different stages of iteration

The frequency range obtained from

i. 1.5-2.1 GHz

ii. 2.6-3 GHz

iii. 5.5-6.6 GHz

iv. 7.3-9.2 GHz.

4.5 SLOTS

The reason to use fractal geometry to construct an ultra-wideband antenna is that it is very easy to obtain both narrowband and wideband characteristics using this geometry.

When we used this geometry we were able to obtain narrowband characteristics and then by reducing the surface area of the ground plane wide band characteristics over several bands was achieved. But in order to obtain an antenna which functioned over a large bandwidth (somewhere in the range of 7-8 GHz). And to achieve these, slots were used.

4.5.1 ADDITION OF SINGLE SLOT

The slot was placed in the middle of the ground plane.

Keeping the position constant, the parameters such as length and width were varied to obtain the optimum configuration.

The length of the mid slot was varied from 1 mm to 6 mm. The best results were obtained at 5mm.

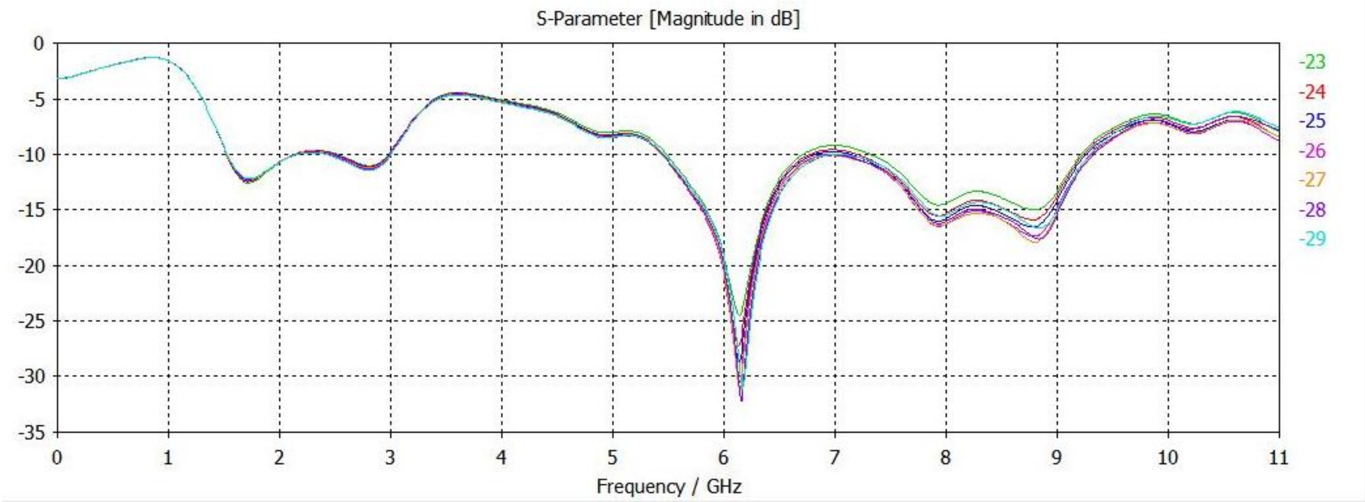


Figure 4.6: comparison of effect of variation of slot length.[in the figure the base -23 represents 0mm and -29 represents 6mm]

The width of the mid slot was varied from 1 mm to 4mm.Best results were obtained at 3.5mm

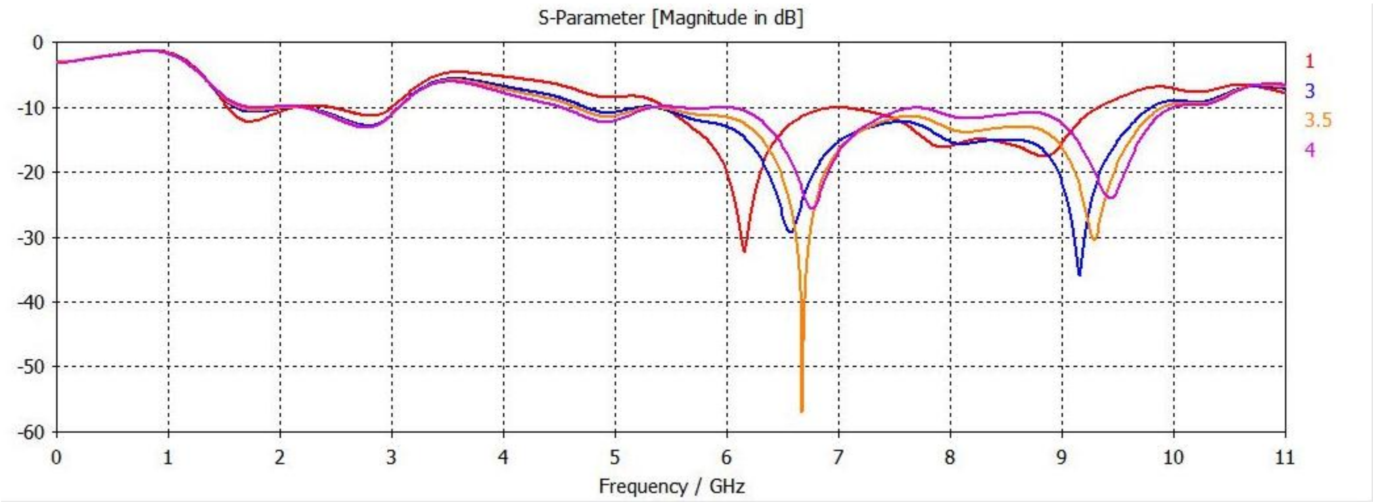


Figure 4.7: comparison of effect of variation of slot width.

Dimensions of Ground plane

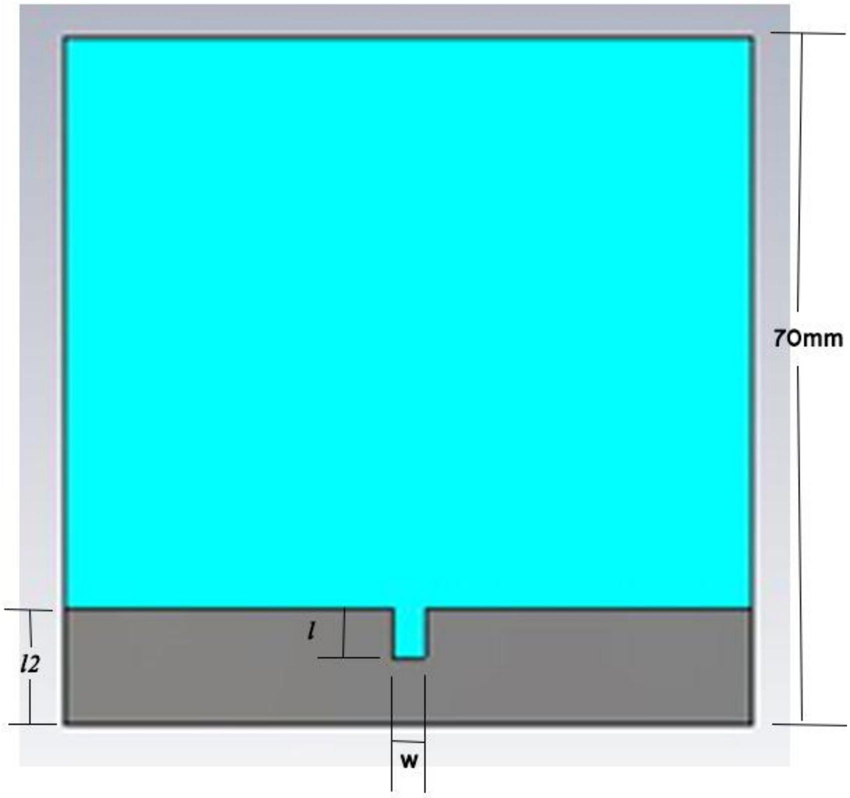


Figure 4.8: ground plane with a single slot

Ground plane:

L2= 12mm

Slot length, l= 5mm

Slot width, w= 3.5mm

Simulation results

The addition of slot to the third stage of iteration has finally yielded a ultra wide band from 4.7-9.8 GHz.

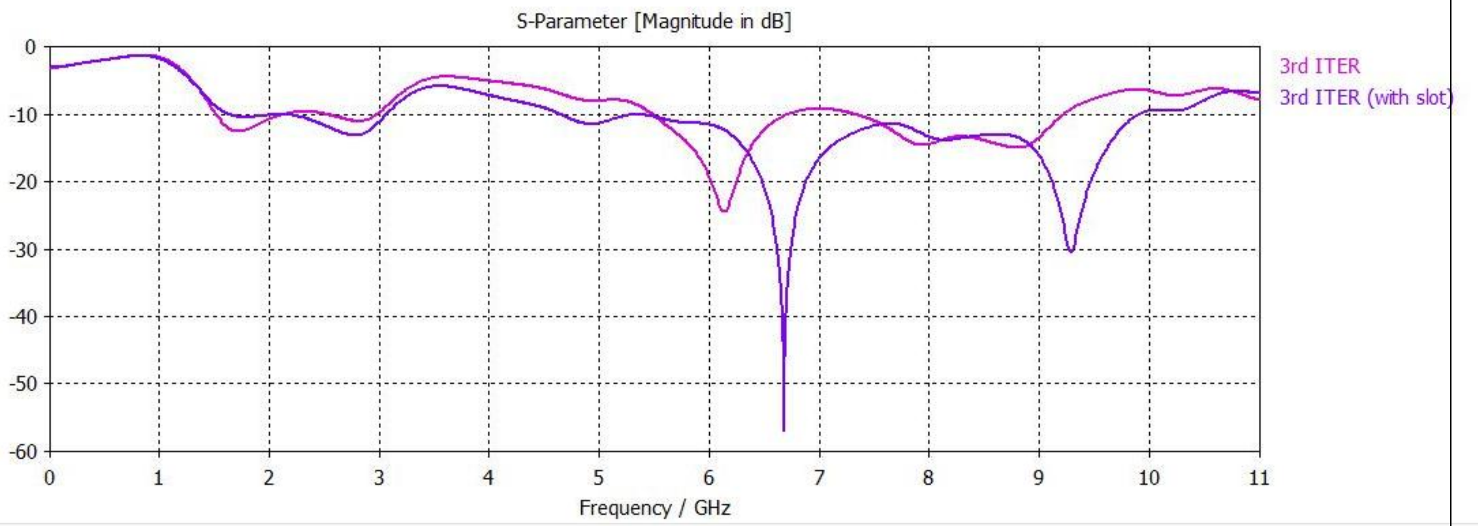


Figure 4.9: the final return loss chart (comparison between antenna with and without slot)

The proposed antenna satisfies the required VSWR<2 for a wide range of frequencies.

i. 1.6 - 3.1 GHz
ii. 4.7 – 9.9 GHz

It was found to have maximum gain of 5 dB at the frequency of 8.2 GHz.

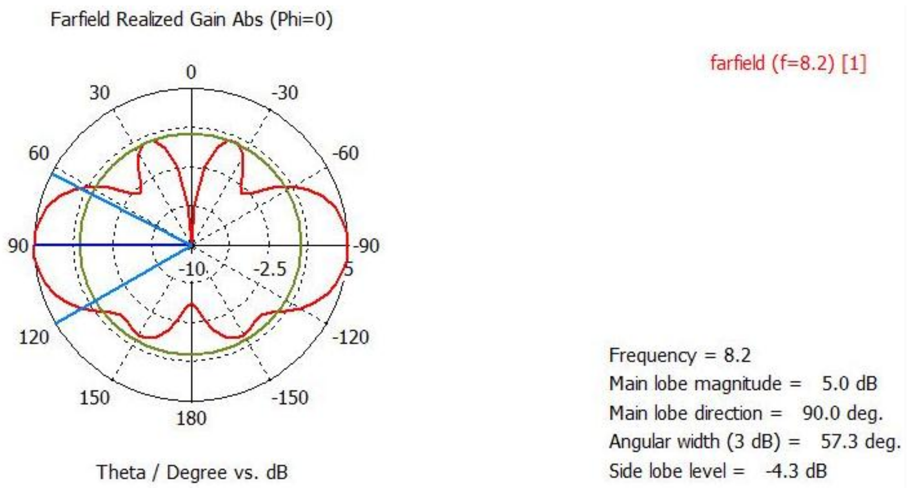


Figure 4.10: the radiation pattern at frequency 8.2 GHz with a gain of 5.0 dBi

Fractional Bandwidth = $(f_h - f_l) / f_0$

Where, f_h and f_l are the high and low cutoff frequencies

f_0 is the intermediate frequency given by, $f_0 = (f_h + f_l) / 2$

The fractional BW of the antenna is found to be 71.23%.

4.5.2 ADDITION OF THREE SLOTS

Slots were then placed at three places equidistant from each other. One was placed at the centre of the ground plane and the others were placed accordingly.

Keeping these positions constant the dimensions (length and breadth) were then changed.

The best results were obtained at length of 2.5 mm.

The width of the middle slot was varied and best results were obtained for width of 3.5mm.

The width of the side slots was varied and best results were obtained for width of 1mm.

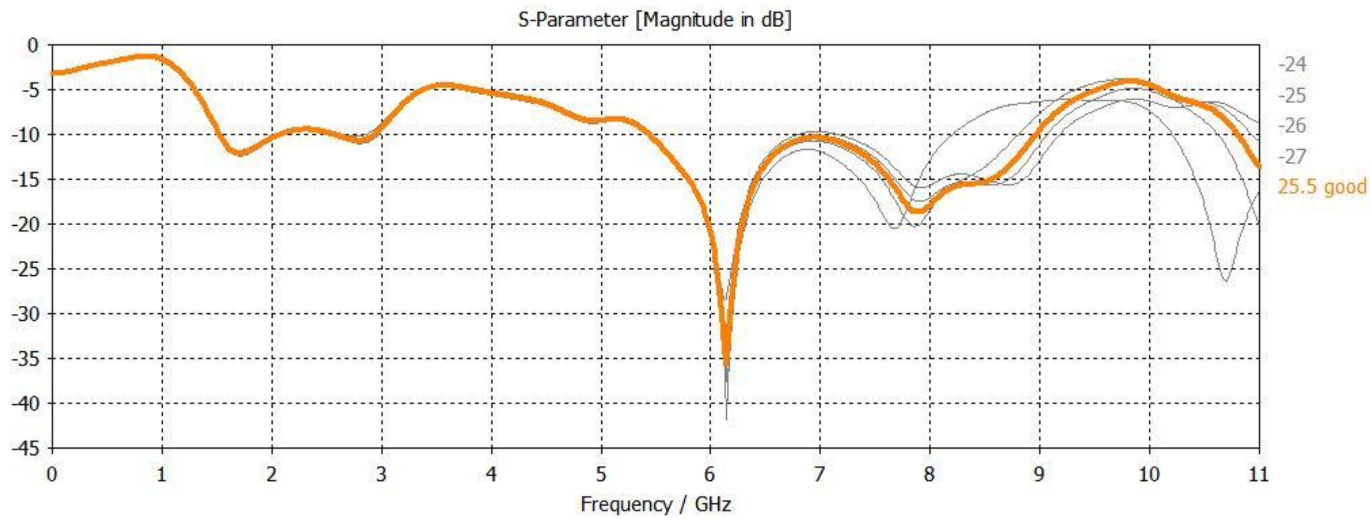


Figure 4.11: the results obtained by varying the length of the three slots and the best result is obtained at 2.5mm.

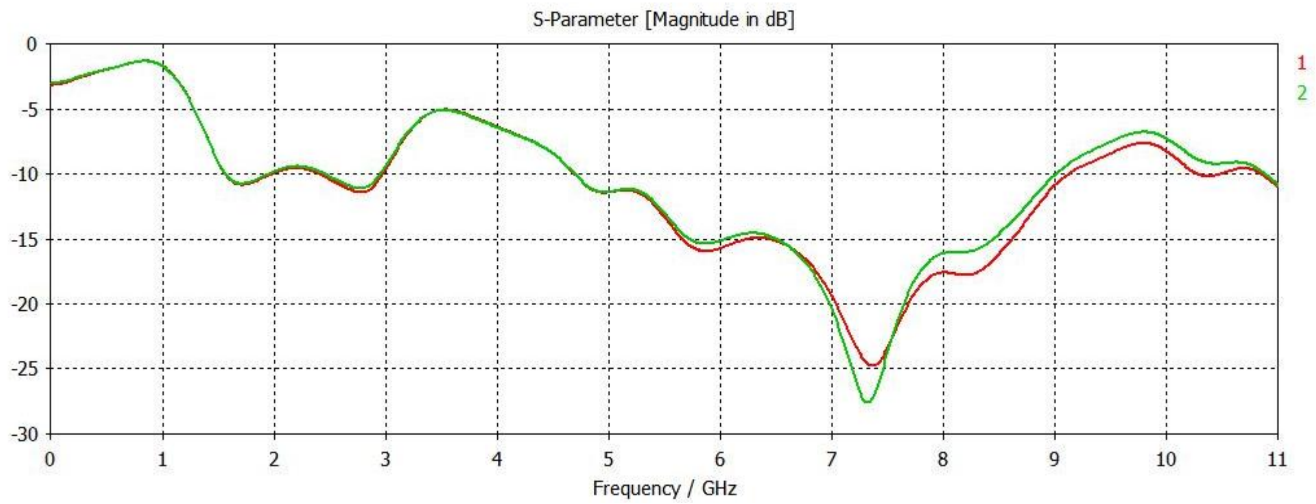


Figure 4.12: the results obtained by varying width of the symmetrical slots with the best results obtained at 1 mm.

Simulation results

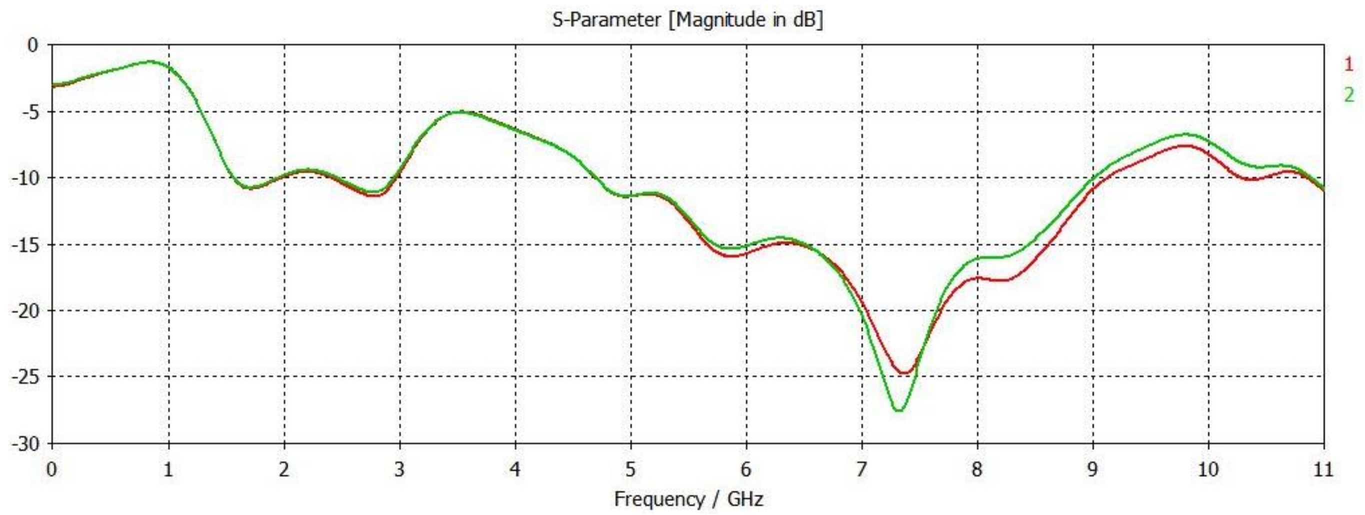


Figure 4.13: the final return loss chart

The proposed antenna satisfies the required VSWR<2 for a wide range of frequencies

i. 1.5-1.9 GHz
ii. 2.4-2.9 GHz
iii. 4.7-9 GHz

Fractional bandwidth of the antenna is 62.77%.

Varying slot position

The position of the symmetrical side slots with respect to the one at the center was then varied.

Keeping them symmetrical they were moved consecutively farther away from and closer to the slot at the center.

The best results were obtained by moving the slots 3 mm away from the center of the ground plane.

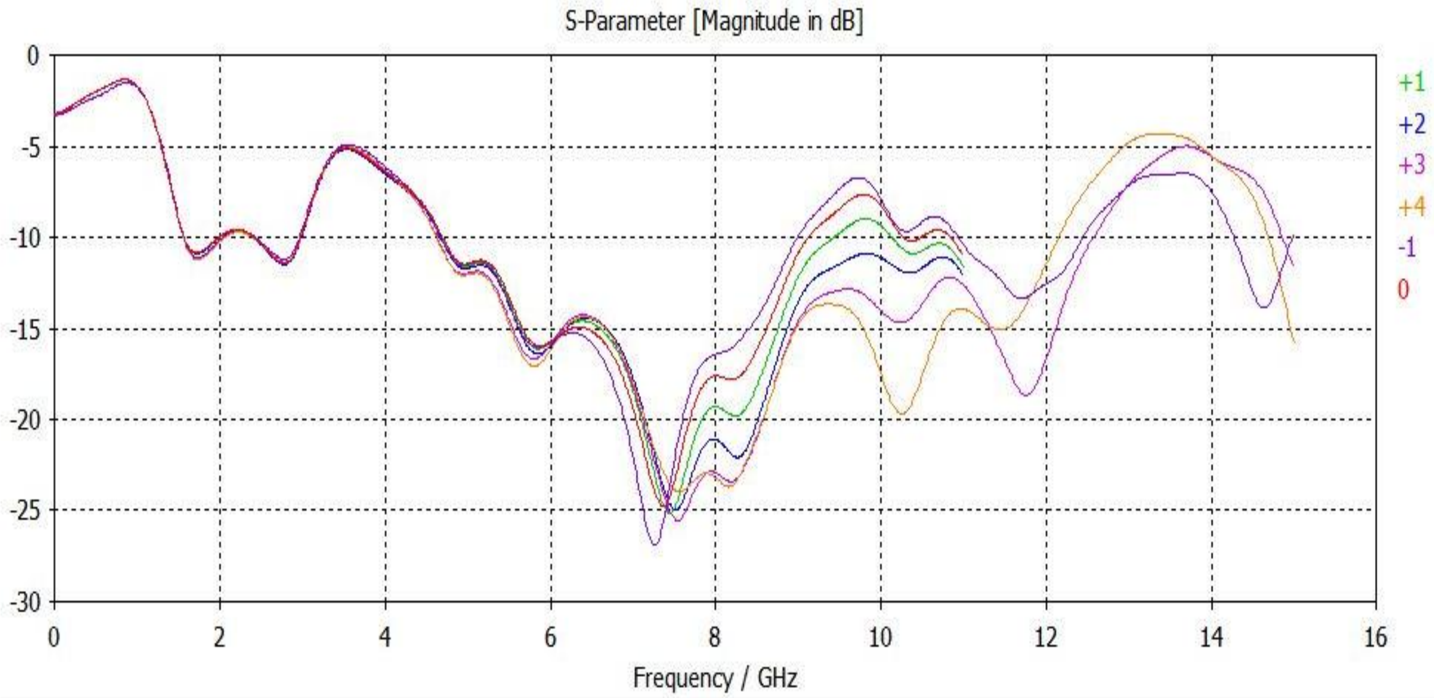


Figure 4.14: the results obtained by varying the position of the symmetrical slots. (The numbers on the right of the figure corresponding to each curve depict the distance the slots were moved away from or towards the centre of the ground plane in mm.)

Dimensions of the ground plane

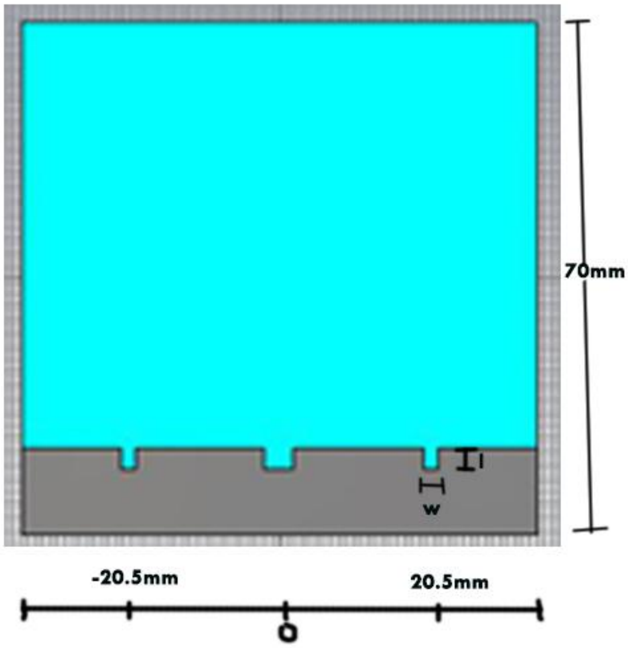


Figure 4.15: ground plane (with three slots)

L2= 12mm

Mid slot:

Slot length, l= 2.5mm

Slot width, w= 4mm

Side slots:

Length, l=2.5 mm

Width, w=1mm

Simulation results

The proposed antenna satisfies the required VSWR < 2 for a wide range of frequencies

i. 1.6-2.1 GHz
ii. 2.5-3 GHz
iii. 4.7-12.7 GHz

It was found to have a maximum gain of 6.77 dB at the frequency of 5.8 GHz.

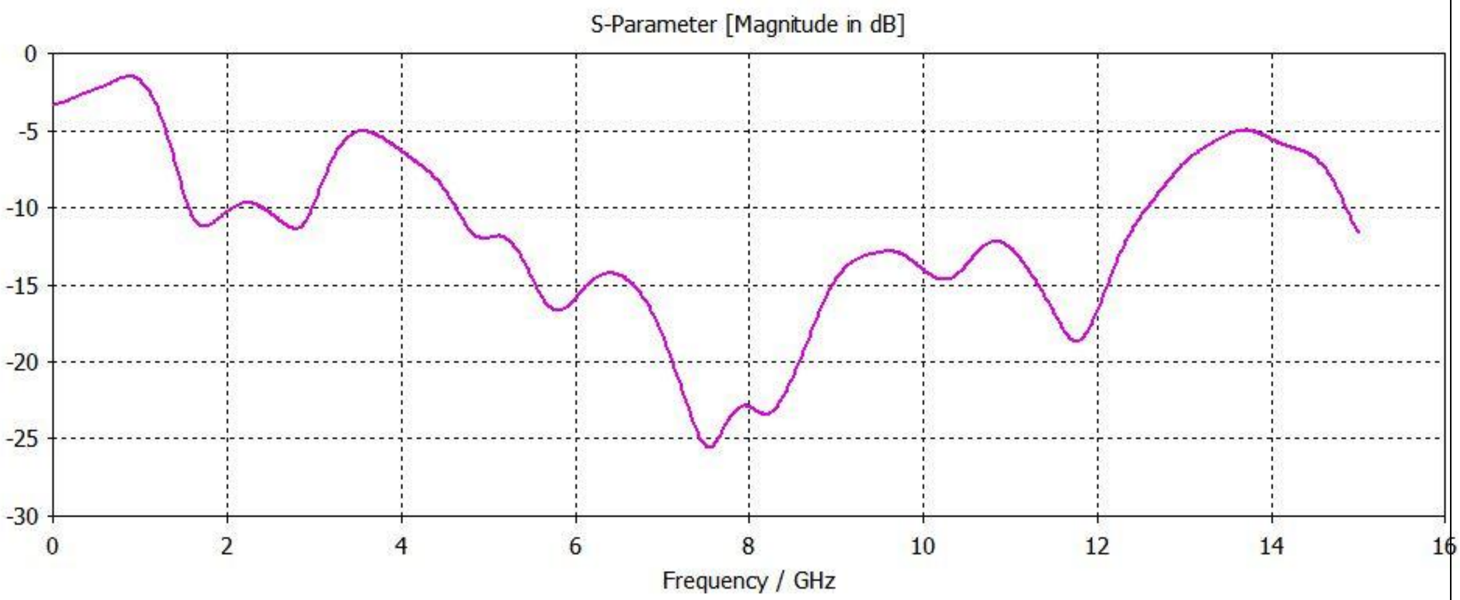


Figure 4.16: the best result obtained by varying the positions of the symmetrical side slots. (Obtained by moving the slots 3 mm away from the centre of the ground plane)

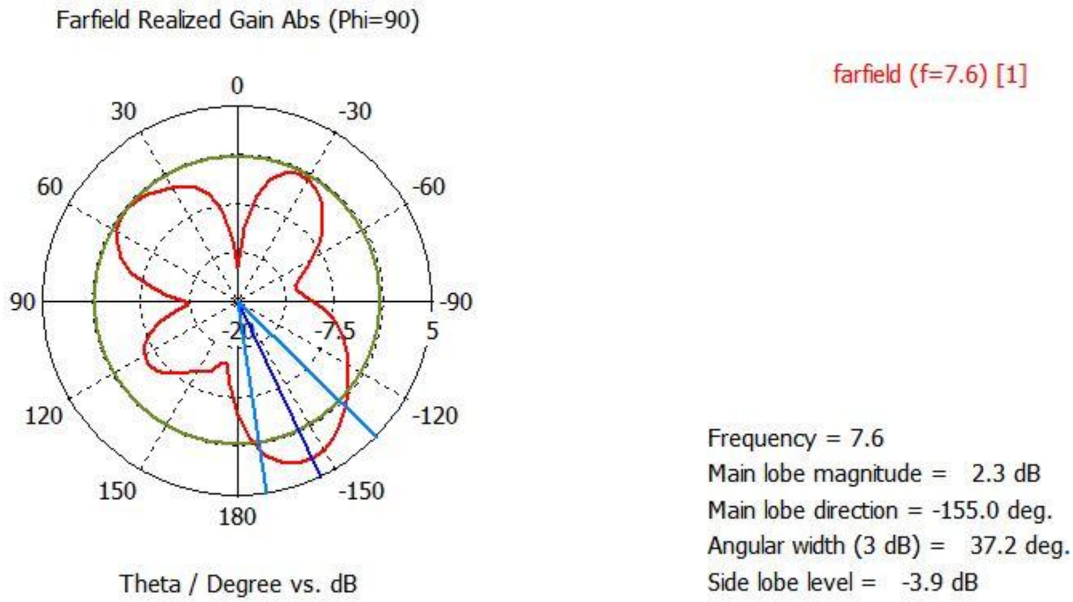


Figure 4.17: the E-Plane omnidirectional radiation pattern of the antenna obtained at the frequency 7.6 GHz.

Figure 4.18: the realized gain plot of the antenna

The realized gain was plotted and in the required bandwidth of 4.7 GHz to 12.7 GHz, the gain was found to be above 2.0 dB.

Fractional Bandwidth = $(f_h - f_l) / f_0$

Where, $f_h = 12.7$ GHz and $f_l = 4.7$ GHz

$f_0 = (f_h + f_l) / 2 = 8.7$ GHz

The fractional BW is found to be 91.95%.

5. SOME OTHER FRACTAL ANTENNAS WITH DIFFERENT BASE GEOMETRIES

5.1 HEXAGONAL FRACTAL ANTENNA

The same iteration pattern was applied to fractals with hexagon as the base geometry. The substrate and ground plane were taken the same as in the pentagonal fractal antenna.

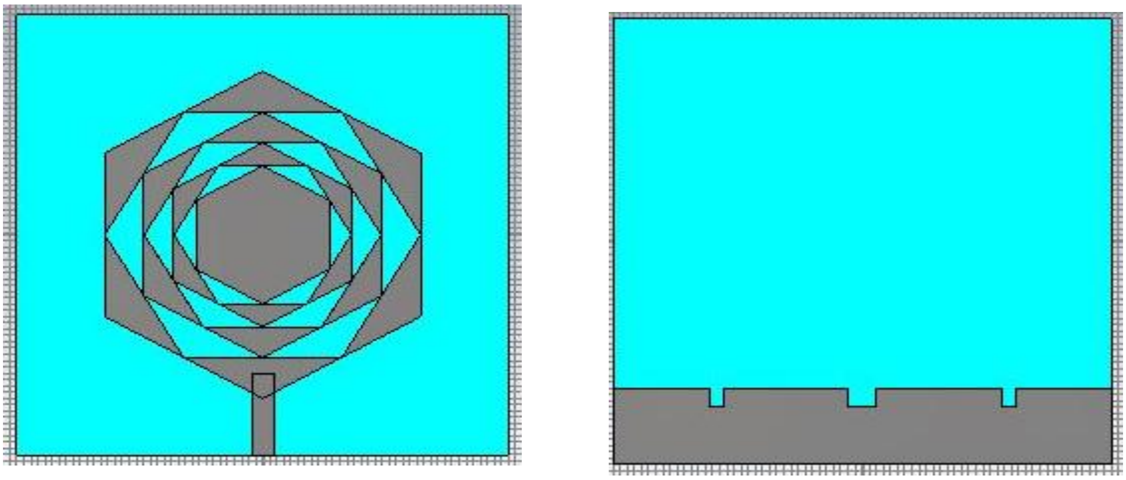


Figure 5.1: Hexagonal Fractal (third iteration) the radiating patch and the ground plane

The simulated result in the above fractal antenna was not as impressive as the pentagonal antenna. Further changes in its design parameters will be necessary for obtaining a wideband bandwidth.

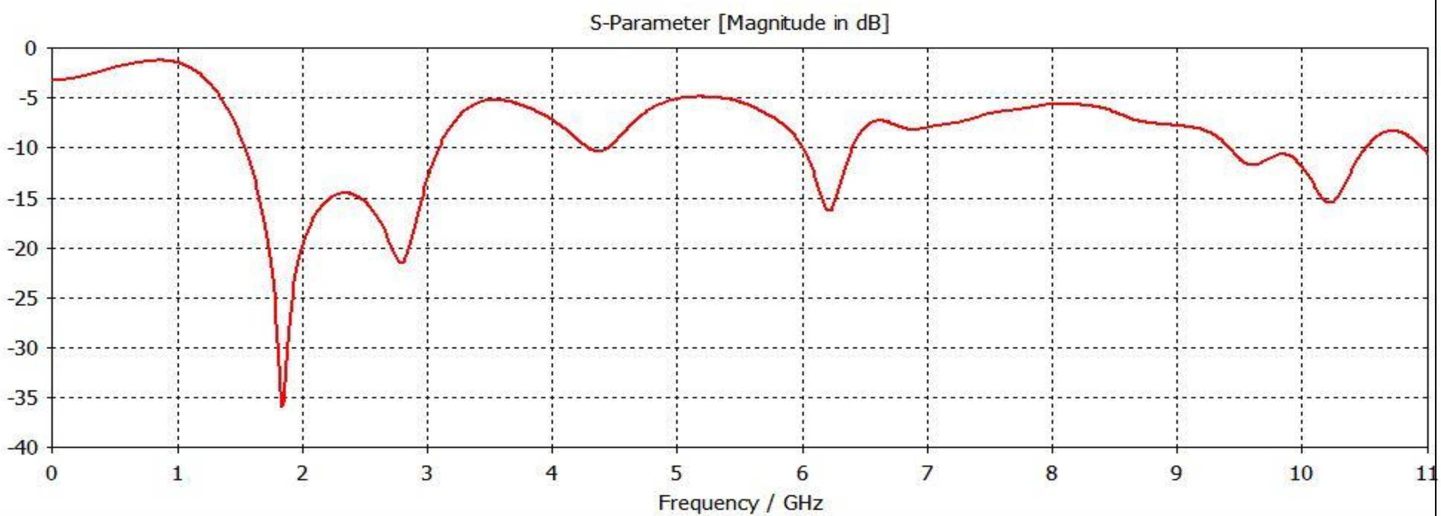


Figure 5.2: the return loss chart for the hexagonal antenna

The frequency bands obtained were 1.5 – 3.1 GHz, 6.1 – 6.3 GHz and 9.5 - 10.5 GHz.

5.2 OCTAGONAL FRACTAL ANTENNA

The same iteration pattern was applied to fractals with octagon as the base geometry. The substrate and ground plane were taken the same as in the pentagonal as well as the hexagonal antenna.

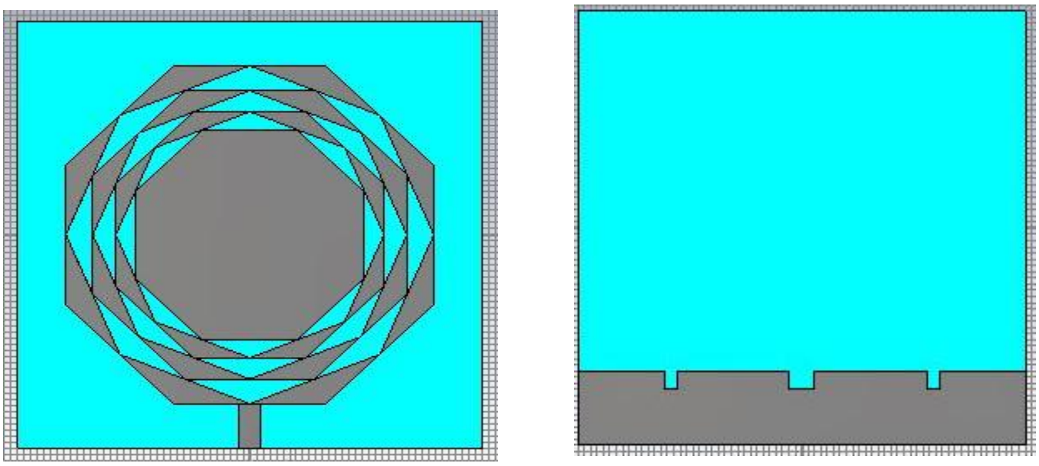


Figure 5.3: Octagonal Fractal antenna (third iteration) radiating patch and ground plane

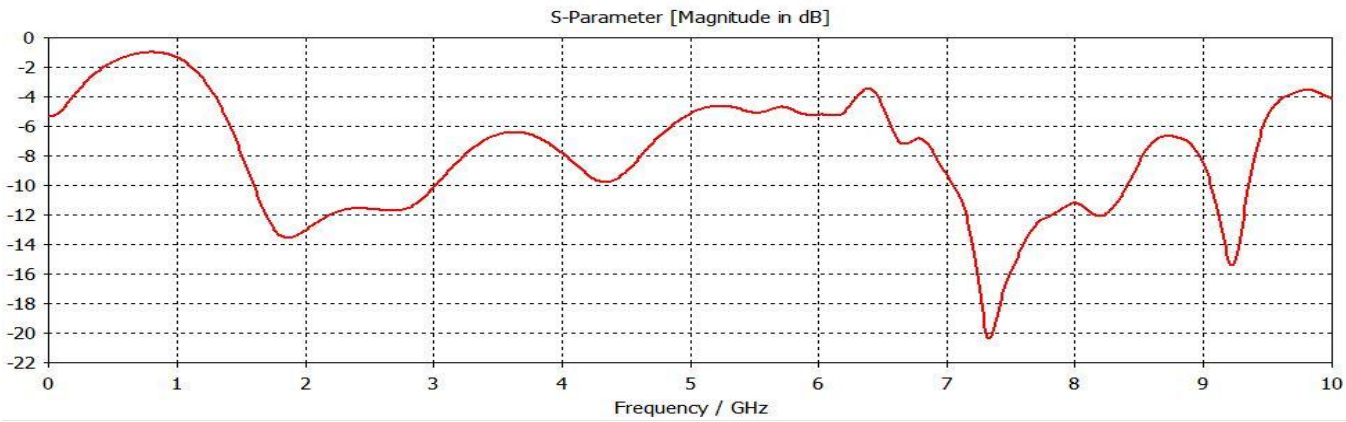


Figure 5.4: the return loss chart for the octagonal antenna

The simulated result in the above fractal antenna shows two frequency bands of operation. Further changes in its design parameters will be necessary for obtaining a wideband bandwidth.

The frequency bands obtained were 1.6 – 3 GHz and 7 – 8.4 GHz.

6. CONCLUSION AND FUTURE WORK

6.1 CONCLUSION

Antenna using pentagonal fractal geometry was successfully designed and simulated. The antenna own its had wideband frequency bandwidth. Addition of the slots has greatly improved the results as well as the variation in their position has increased the bandwidth.

Since both the proposed antennas have a fractional bandwidth much greater than 25% in the ultra-wide band region of 3.6 to 10.2 GHz, they are both capable of handling UWB operations. The single slot pentagonal fractal has a bandwidth of 5.2 GHz while the 3-slot antenna has a bandwidth of 8 GHz.

They cover a wide range of functionalities and can be used in communication networks using those frequencies. e.g. Personal Area Network.

6.2 FUTURE WORK

- More of the lower frequencies can be brought into the bandwidth, thus increasing the overall bandwidth for both antennas.
- The fractional bandwidth can then increase to 144.8% in the single slot antenna case and to 152.7% in the 3-slot antenna case.
- We intend to try and reduce the size of the antenna by scaling it to optimum configuration.
- The proposed antenna will be fabricated and measured result will be compared with simulated results.

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