1 INTRODUCTION

An antenna is a transducer between a guided wave and a radiated wave, or vice versa. The structure that "guides" the energy to the antenna is most evident as a coaxial cable attached to the antenna. A patch antenna is a type of radio antenna with a low profile, which can be mounted on a flat surface. It consists of a flat sheet of metal, usually copper, mounted on a larger sheet of metal called a ground plane.

A patch array antenna is, in general, some arrangement of multiple patch antennas that are all driven by the same source. Frequently, this arrangement consists of patches arranged in orderly rows and columns (a rectangular array). The reason for these types of arrangements is higher gain. Higher gain commonly implies a narrower beamwidth and that is, indeed, the case with patch arrays.

In telecommunication, a **microstrip antenna** (also known as a **printed antenna**) usually means an antenna fabricated using microstrip techniques on a printed circuit board (PCB). It is a kind of Internal Antenna. They are mostly used at microwave frequencies. An individual microstrip antenna consists of a patch of metal foil of various shapes (a patch antenna) on the surface of a PCB, with a metal foil ground plane on the other side of the board. Most microstrip antennas consist of multiple patches in a two-dimensional array.

The most common type of microstrip antenna is the patch antenna. Antennas using patches as constitutive elements in an array are also possible. A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Common microstrip antenna shapes are square, rectangular, circular and elliptical, but any continuous shape is possible.

Some patch antennas do not use a dielectric substrate and instead are made of a metal patch mounted above a ground plane using dielectric spacers; the resulting structure is less rugged but has a wider bandwidth. Because such antennas have a very low profile, are mechanically rugged and can be shaped to conform to the curving skin of a vehicle, they are often mounted on the exterior of aircraft and spacecraft, or are incorporated into mobile radio communications devices. It is used in telecommunication

2 OBJECTIVE OF THE PROJECT & LITERATURE REVIEW

Objectives of the project

- Design and Analysis of Fractal Microstrip Antenna Using ANSYS High Frequency Structure Simulator (HFSS) based on a rectangular patch antenna as considered in our phase I report

Literature review

[1] Abolfazi Azari,"A New Super Wideband Fractal Microstrip Antenna" IEEE Transaction on Antenna &Propagation , vol 59, N0 5 , May 2011

The above paper gave us the idea about the fractals and their properties

[2] "Improvement in Radiation Parameters of Rectangular Microstrip Patch" by Monika Kiroriwal and Sanyog Rawat, International Journal of Engineering Research and General Science Volume 2, Issue 6, October-November, 2014

The above paper gave us the idea about the cut part of he triangle where we took it as the base and iterated it for the fractal geometry

[3] "Increase the Efficiency of Smart Antennas by Using Fractals"by Maha Abdulameer Kadhim, 2018 5th International Conference on Electrical and Electronics Engineering

3 ANSYS HFSS

ANSYS is the global leader in engineering simulation. ANSYS help the world's most innovative companies deliver radically better products to their customers. By offering the best and broadest portfolio of engineering simulation software, they help them solve the most complex design challenges and engineer products limited only by imagination.

HFSS stands for High Frequency Structural Simulator; it is one of the several commercial tools used for the antenna design. HFSS is a commercial finite element method solver for electromagnetic structures from ANSYS Corp under ANSOFT. It was developed by Prof. Zontal Cendes and his students at Carnegie Mellon University in the year 1989.

HFSS (High Frequency Structure Simulator) employs versatile solvers and an intuitive GUI to give you unparalleled performance plus deep insight into all your 3D EM problems. Through integration with ANSYS thermal, structural and fluid dynamics tools, HFSS provides a powerful and complete multiphysics analysis of electronic products, ensuring their thermal and structural reliability. HFSS is synonymous with gold standard accuracy and reliability for tackling 3D EM challenges by virtue of its automatic adaptive meshing technique and sophisticated solvers, which can be accelerated through high performance computing (HPC) technology.

Fig 3.1 ANSYS logo

Fig 3.2 ANSOFT logo (a corp. Under ANSYS deals with EM radiation fields)

4 MICROSTRIP ANTENNAS

Microstrip antennas are also referred to as patch antennas. They are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern and impedance.

Major operational disadvantages of microstrip antennas are their low efficiency, low power, high Q (sometimes in excess of 100), poor polarization purity, poor scan performance, spurious feed radiation and very narrow frequency bandwidth, which is typically only a fraction of a percent or at most a few percent. There are methods, however, such as increasing the height of the substrate that can be used to extend the efficiency (to as large as 90 percent if surface waves are not included) and bandwidth (up to about 35 percent). However, as the height increases, surface waves are introduced which usually are not desirable because they extract power from the total available for direct radiation (space waves). The surface waves travel within the substrate and they are scattered at bends and surface discontinuities, such as the truncation of the dielectric and ground plane, and degrade the antenna pattern and polarization characteristics.

4.1 BASIC CHARACTERISTICS

Microstrip antennas, as shown in Figure 4.1, consist of a very thin ($t \ll \lambda_0$, whereλ_0 is the free-space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda_0$, usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$) above a ground plane. The microstrip patch is designed so its pattern maximum is normal to the patch (broadside radiator). This is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by judicious mode selection. For a rectangular patch, the length L of the element is usually $\lambda_0/3 < L < \lambda_0/2$. The strip (patch) and the ground plane are separated by a dielectric sheet (referred to as the substrate). There are numerous substrates that can be used for the design of microstrip antennas, and their dielectric constants are usually in the range of $2.2 \leq \varepsilon_r \leq 12$. The ones that are most desirable for good antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size.

The radiating elements and the feed lines are usually photo-etched on the dielectric substrate. The radiating patch may be square, rectangular, thin strip (dipole), circular, elliptical, triangular, or any other configuration. Square, rectangular, dipole (strip), and circular are the most common because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation.

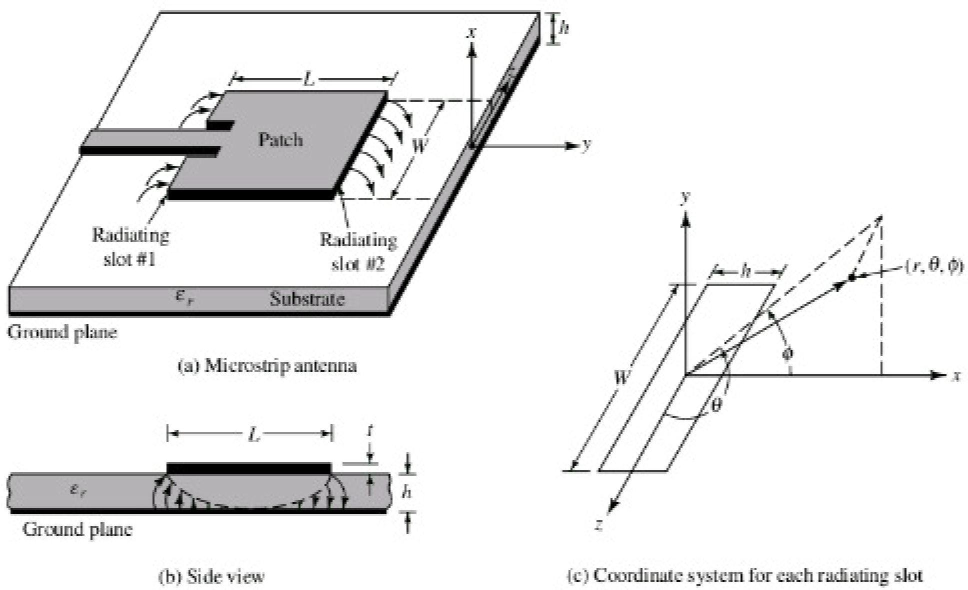


Fig 4.1 Microstrip antenna and coordinate system

There are many configurations that can be used to feed microstrip antennas. The four most popular methods are the microstrip line, coaxial probe, aperture coupling, and proximity coupling. The microstrip-line feed is easy to fabricate, simple to match by controlling the inset position and rather simple to model. However as the substrate thickness increases, surface waves and spurious feed radiation increase, which for practical designs limit the bandwidth.

There are various methods of analysis for microstrip antennas with the most popular models being the transmission-line, cavity, and full wave models (which include primarily integral equations/Moment Method). The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling.

The microstrip antenna parameters and its components are explained in detail in the Phase I report of project.

4.2 ADVANTAGES, DISADVANTAGES & APPLICATIONS OF PATCH ANTENNA

4.2.1 Advantages

1. Light weight and volume
2. Low profile planar configuration which can be easily made conformal to host surface
3. Low fabrication cost, hence can be easily manufactured in large quantities
4. Supports both, linear as well as circular polarization
5. Can be easily integrated with microwave integrated circuits
6. Capable of dual and triple frequency operations

4.2.2 Disadvantages

1. Narrow bandwidth
2. Low efficiency
3. Low gain
4. Extraneous radiation from feeds and junctions
5. Poor end fire radiator except tampered solt antennas
6. Low power handling capacity

4.2.3. Applications

After analyzing the advantages and disadvantages of the microstrip antennas, it can be observed that its advantages significantly overshadow its disadvantages. Due to the fact that most present-day systems demand for small size, lightweight, low cost and low antennas, the employment of microstrip technology arises extensively over the years. Even though conventional antennas possess far superior performance over microstrip antennas, it is still clearly disadvantaged by the other properties of the microstrip antennas. Shown below are some typical system applications which employ microstrip technology.

1. The telemetry and communications antennas on missiles.
2. Radar altimeters use small arrays of microstrip radiators.
3. Aircraft-related applications include antennas for telephone and satellite communications.
4. Satellite imaging systems.
5. Satellite communications
6. WLAN and WIMAX.
7. High speed GPS.

5 FRACTAL MICROSTRIP ANTENNAS

Modern communication systems require antennas with more band-width and smaller dimension. One of the main components of ultra wideband (UWB) communication systems is an UWB antenna. Customarily, wideband antennas need different antenna elements for different frequency bands. If antenna size is less than a quarter of wavelength, antenna will not be efficient. Fractal geometry is a very good solution to fabricate multi-band and low profile antennas. Applying fractals to antenna elements allows for smaller size, multi-band and broad-band properties. Thus, this is the cause of spread research on fractal antennas in recent years

Fractals have self-similar shapes and can be subdivided in parts such that each part is a reduced size copy of the whole. The self-similarity of fractals is the cause of multi-band and broad-band properties and heir complicated shapes provides design of antennas with smaller size.

Fractals have convoluted and jagged shapes such that these discontinuities increase bandwidth and the effective radiation of antennas. The space-filling property of fractals leads to curves which have long electrical length but fit into a compact physical volume.

Several UWB antenna configurations based on fractal geometries have been investigated including Koch, Sierpinski, Minkowski, Hilbert,Cantor, and fractal tree antennas in recent years. The numerical simulation and experimental results of these antennas are available in literature to date.

In this communication, a fractal microstrip antenna is presented. This new fractal geometry is based on an iterative octagon. The huge band-width is the main advantage of this fractal antenna over conventional fractal antennas.

The commercially available simulation software CST Microwave Studio has been used for the design and simulation of the proposed microstrip antenna,But we don't have the license for the CST microwave studio so we had done the design in ANSYS HFSS till the 2nd iteration of our design.

The fractals are generally calculated using Iterated Function Systems (IFS) algorithm to the previous structure based on our fractal structure mathematically

5.1 HISTORY OF FRACTALS

Antenna elements (as opposed to antenna arrays) made from self-similar shapes was first created by Nathan Cohen then a professor at Boston University, starting in 1988. Cohen's efforts with a variety of fractal antenna designs were first published in 1995. Cohen's publication marked the inaugural scientific publication on fractal antennas. Most varieties of fractal antennas are so-called "fractal element antennas".

Many fractal element antennas use the fractal structure as a virtual combination of capacitors and inductors. This makes the antenna so that it has many different resonances which can be chosen and adjusted by choosing the proper fractal design. This complexity arises because the current on the structure has a complex arrangement caused by the inductance and self capacitance. In general, although their effective electrical length is longer, the fractal element antennas are themselves physically smaller, again due to this reactive loading.

Thus fractal element antennas are shrunken compared to conventional designs, and do not need additional components, assuming the structure happens to have the desired resonant input impedance. In general the fractal dimension of a fractal antenna is a poor predictor of its performance and application. Not all fractal antennas work well for a given application or set of applications. Computer search methods and antenna simulations are commonly used to identify which fractal antenna designs best meet the need of the application.

Although the first validation of the technology was published as early as 1995, recent independent studies show advantages of the fractal element technology in real-life applications, such as RFID and cell phones.

One researcher has stated to the contrary that fractals do not perform any better than "meandering line" (essentially, fractals with only one size scale, repeating in translation) antennas. Specifically quoting researcher Steven Best: "Differing antenna geometries, fractal or otherwise, do not, in a manner different than other geometries, uniquely determine the EM behavior of the antenna."

However, in the last few years, dozens of studies have shown superior performance with fractals, and the frequency invariance demonstrates that geometry is a key aspect in uniquely determining the EM behavior of frequency independent antennas.

5.2 NATURAL FRACTALS & ITS PROPERTIES

In mathematics, a fractal is a subset of a Euclidean space for which the Hausdorff dimension strictly exceeds the topological dimension. Fractals tend to appear nearly the same at different levels, as is illustrated here in the successively small magnifications of the Mandelbrot set; Because of this, fractals are encountered ubiquitously in nature.

Fractals exhibit similar patterns at increasingly small scales called self similarity, also known as expanding symmetry or unfolding symmetry; If this replication is exactly the same at every scale, as in the Menger sponge, it is called affine self-similar.

The Fractal microstrip Antenna is the concept where it has been derived from the nature. The nature has many fractal structures in examples of Leaves, snail shells, microorganism shapes, etc.

The general properties of a natural fractals are:

1) Mathematical
2) Iterative
3) Self Similar Structures
4) Infinite & Scalable
5) Chaotic
6) Efficient

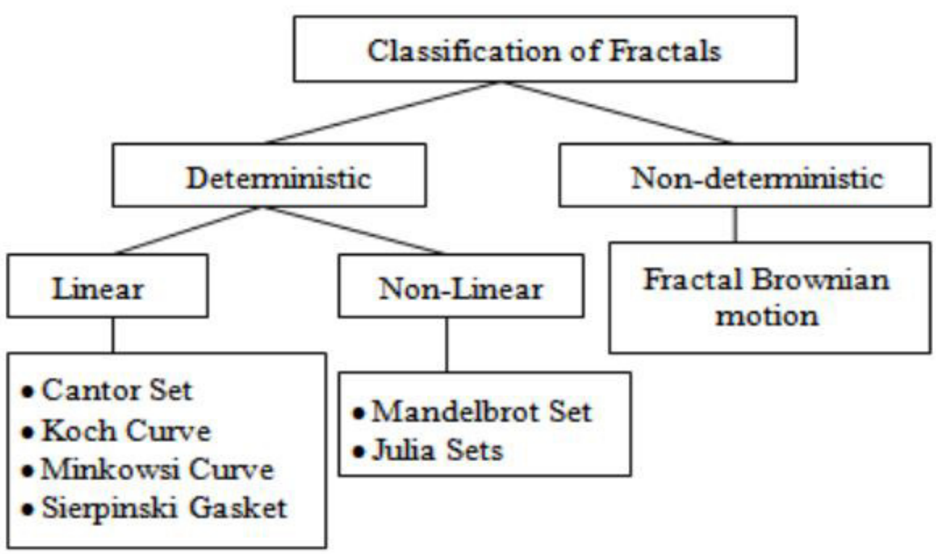


Fig 5.1 : A Leaf Representing a Fractal structure which is iterated through its leaf vein

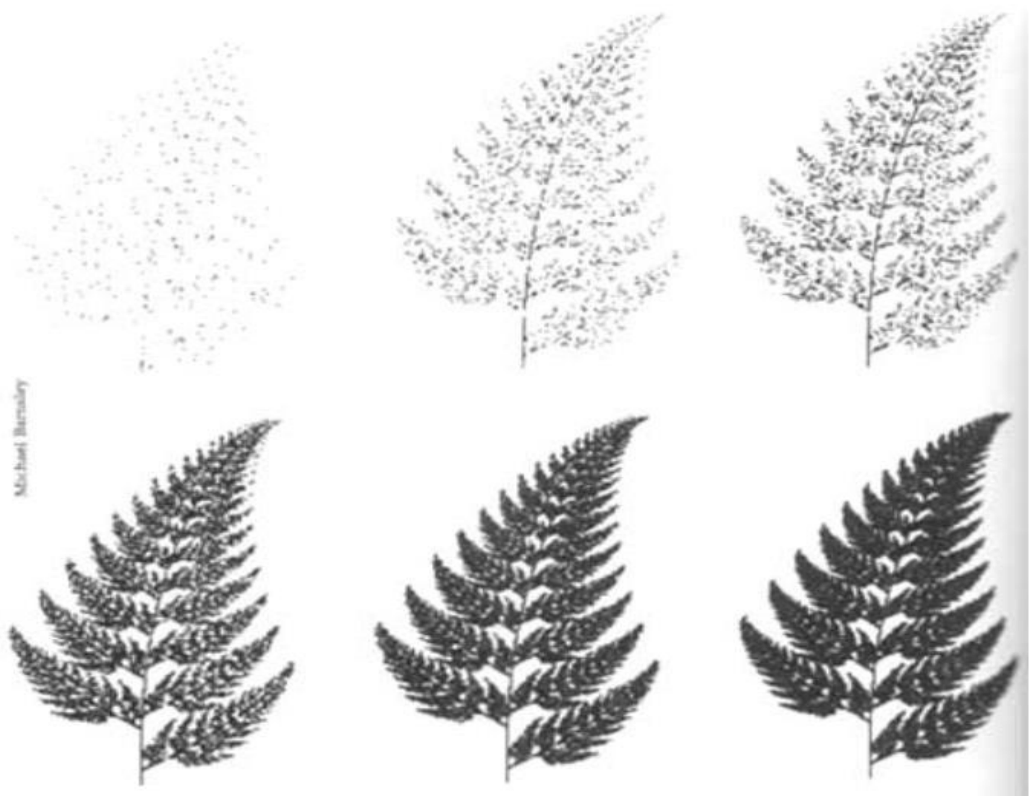


Fig 5.2 Depicts the dissection of the above leaf as iterative structure

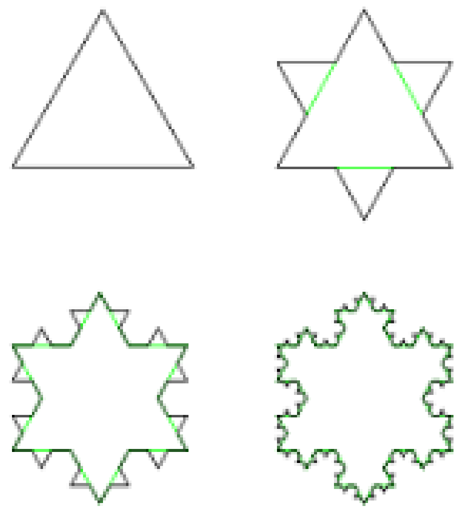


Fig 5.3 Koch fractal triangle pattern

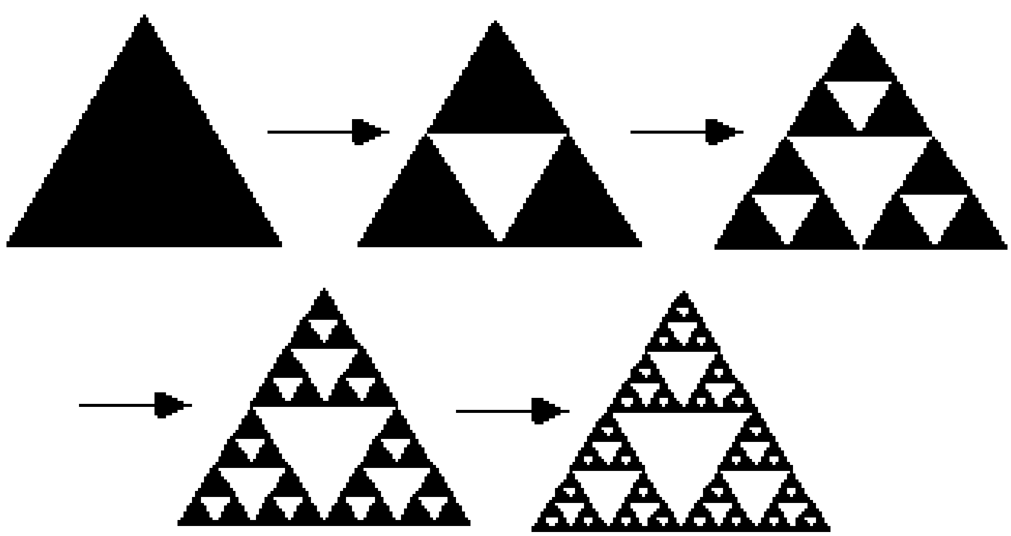


Fig 5.4 Sierpinski triangle

5.3 ADVANTAGES AND APPLICATION OF FRACTAL ANTENNAS

- Wideband / Multiband:
  Fractal geometry creates virtual combination of capacitance and inductance, driving multiple resonances across the same element structure.

- Smaller and Lighter:
  Fractal geometry's self-inductance and capacitance allow element to shrink in size versus traditional design

- Fewer Components:
  Antennas require less circuitry, with fewer radiative elements to reach desired bandwidth. There are no inductors or capacitors required

- Higher Gain:
  Fractal geometry allows for multiple current maxima across smaller element, increasing gain achieved by the element

- Design multi-band antennas:

Antennas are usually designed to operate over a small frequency band. In order to achieve a completely frequency-independent antenna it must be designed to not have any characteristic size, or the structure must at least include many characteristic sizes in order to be able to operate over many different frequency bands. Fractal structures with a self-similar geometric shape consisting of multiple copies of themselves on many different scales have therefore the potential to be frequency-independent or at least multi-frequency antennas.

- Design effective antennas:

Fractal antennas are of uneven shapes and sharp edges, corners, and discontinuities tend to enhance radiation of electromagnetic energy from electric systems. Fractal antennas have therefore the potential to be efficient. This is particularly interesting when small antennas are to be designed, since small antennas are not generally good at radiating electromagnetic energy.

Furthermore fractal antennas can also enrich applications that include multi-band transmissions. This area has many possibilities ranging from dual-mode phones to devices integrating communication and location services such as GPS, the global positioning satellites. Fractal antennas also decrease the area of a resonant antenna, which could lower the radar cross-section (RCS). This benefit can be exploited in military applications where the RCS of the antenna is a very crucial parameter.

6 DESIGN AND ANALYSIS OF FRACTAL PATCH ANTENNA

Considerations:

- Substrate : FR4 Epoxy (dielectric constant,εr = 4.4)
- frequency , fo : C Band (4-8GHz centered at 5.6 GHz)
- Medium : Vacuum
- Velocity of light(c): 3*10^8 ms-1
- substrate dimensions: 40mm*40mm*1.59mm

Patch parameters:

- Width:

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

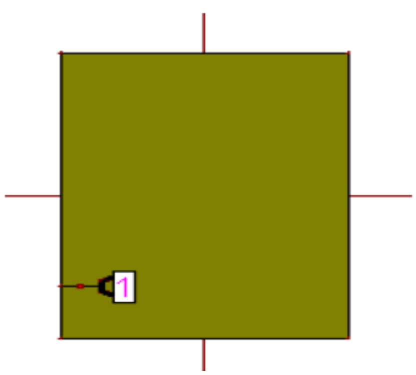
=>W=20mm

- Length:

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}}$$

=>Leff= 14mm

we modify the rectangular patch antenna by removing a triangular part for improvements in the radiation pattern Patch has length and width of 14mm and 20mm with thickness of 1.56mm using a FR4 epoxy material with dielectric constant of εr= 4.4 with subrating a triangular part whose sides are 12.2mm,12.2mm and 20mm as shown in the figure (an isosceles triangle)



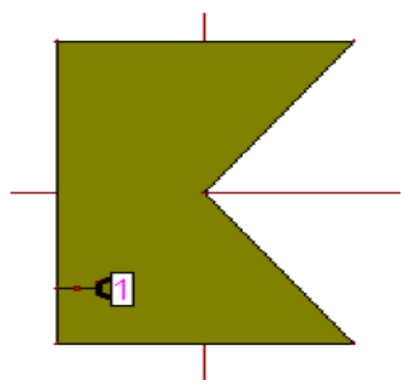


Fig 6,1 modified rectangular patch

6.1 DESIGN OF BASIC RECTANGULAR PATCH ANTENNA

From above design specs we are creating a rectangular patch antenna

Step 1: Initialize the project resources and set the solution type to the terminal as shown in the figure

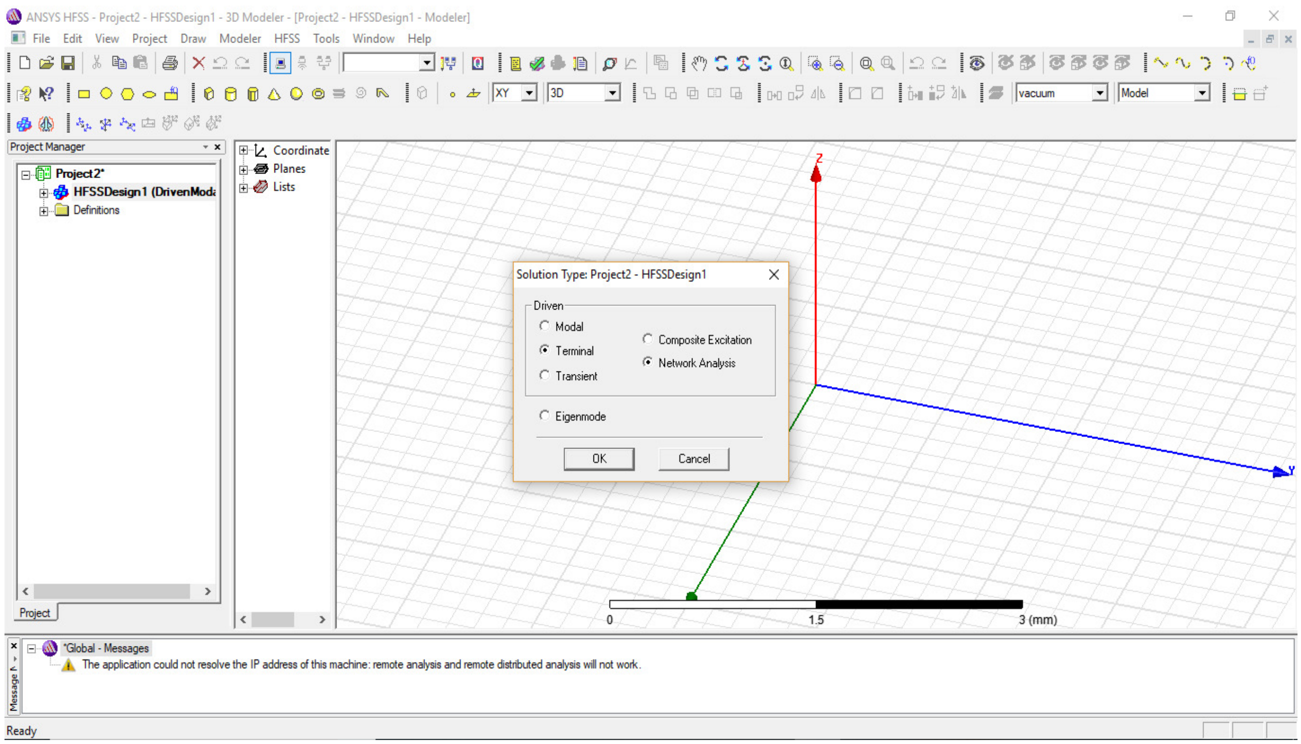


Fig 6.2 selecting the solution type to terminal

Step 2: Create the substrate using box and name it as 'substrate', select material colour, transparency and dimensions. Set the position of the substrate such that the origin of the 3D axis lies on the centre of the top surface of substrate and select the material as FR4 epoxy which has a dielectric constant of 4.4

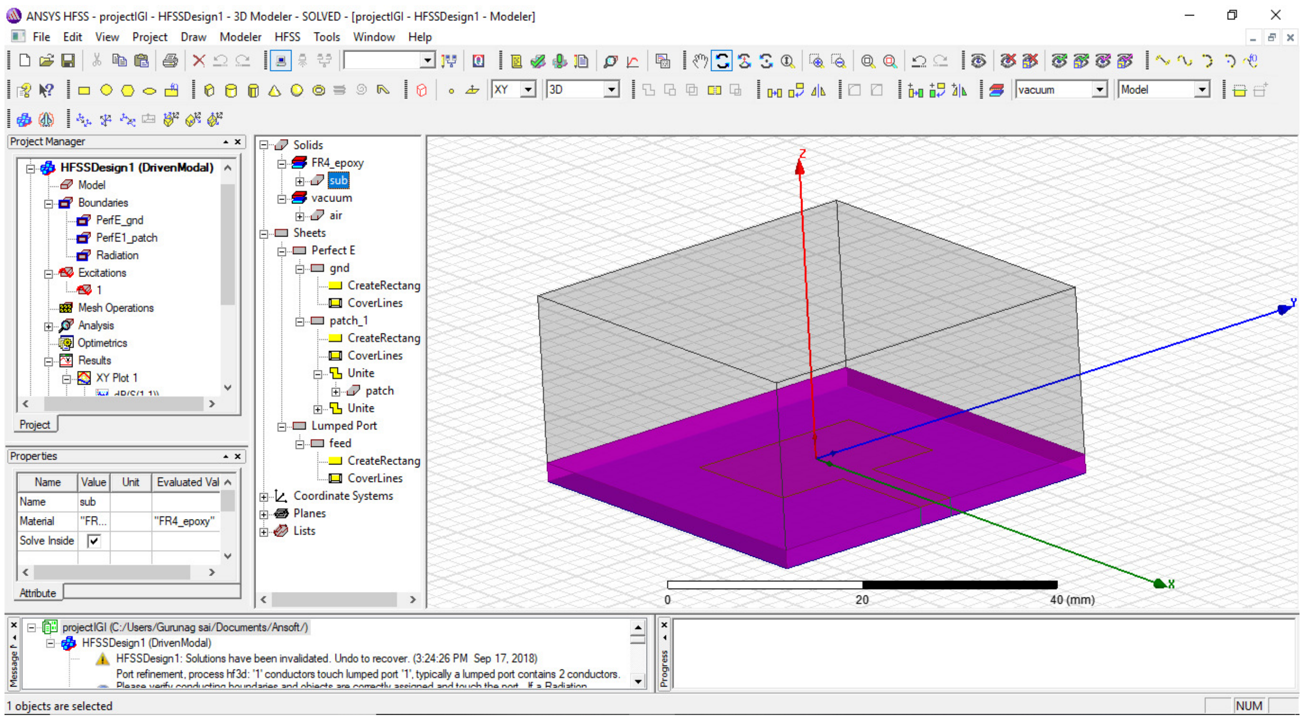


Fig 6.3 setting up the substrate (the pink shaded region)

Step 3: Create a ground plane below the substrate and mention its dimensions.

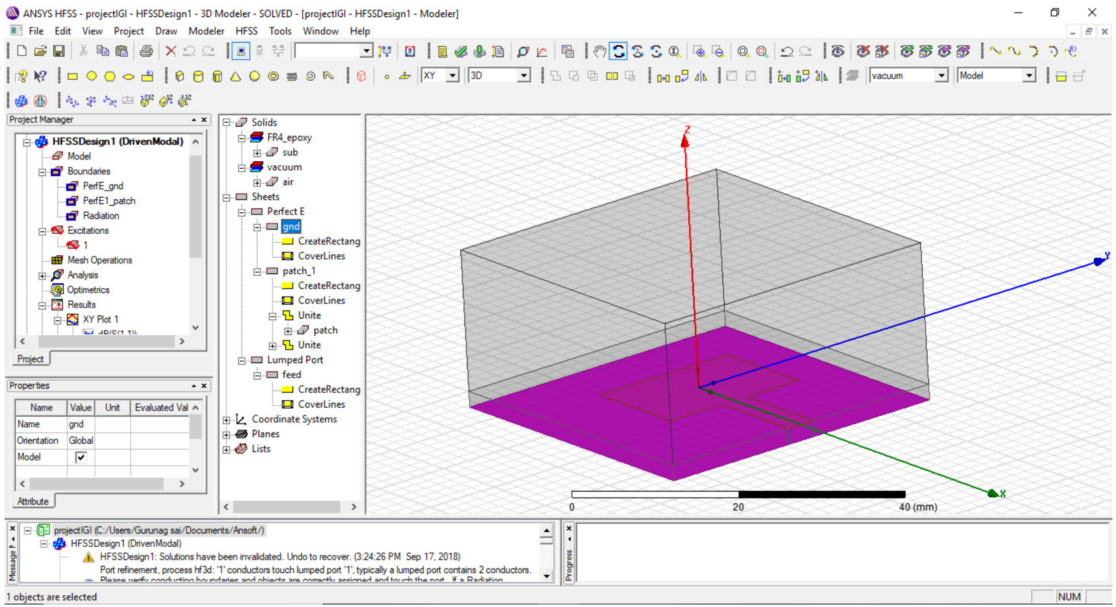


Fig 6.4 Ground plane (the pink shaded region)

Step 4: Set up the rectangular patch which is used to radiate the signal by using a rectangle surface. Assign the dimensions, colour and transparency as per the theoretical design requirements and add a microstrip feed line as shown in the figure.

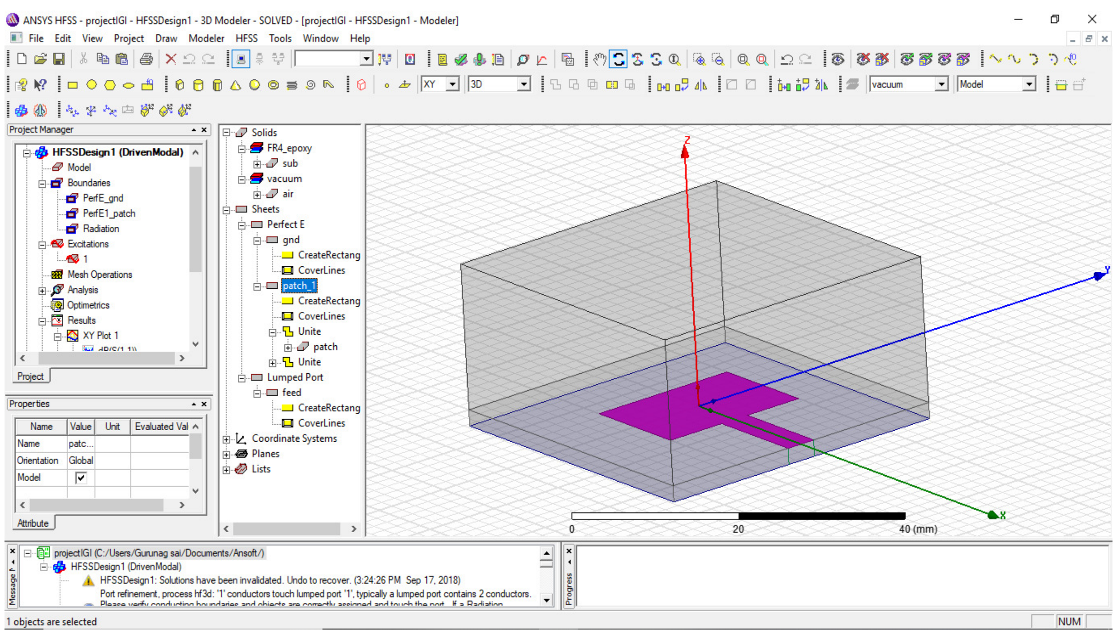


Fig 6.5 Patch with 14*20mm is designed with a microstrip feed line (the pink shaded region)

Step 5: A source is created for transferring of RF power from ground plane to patch.

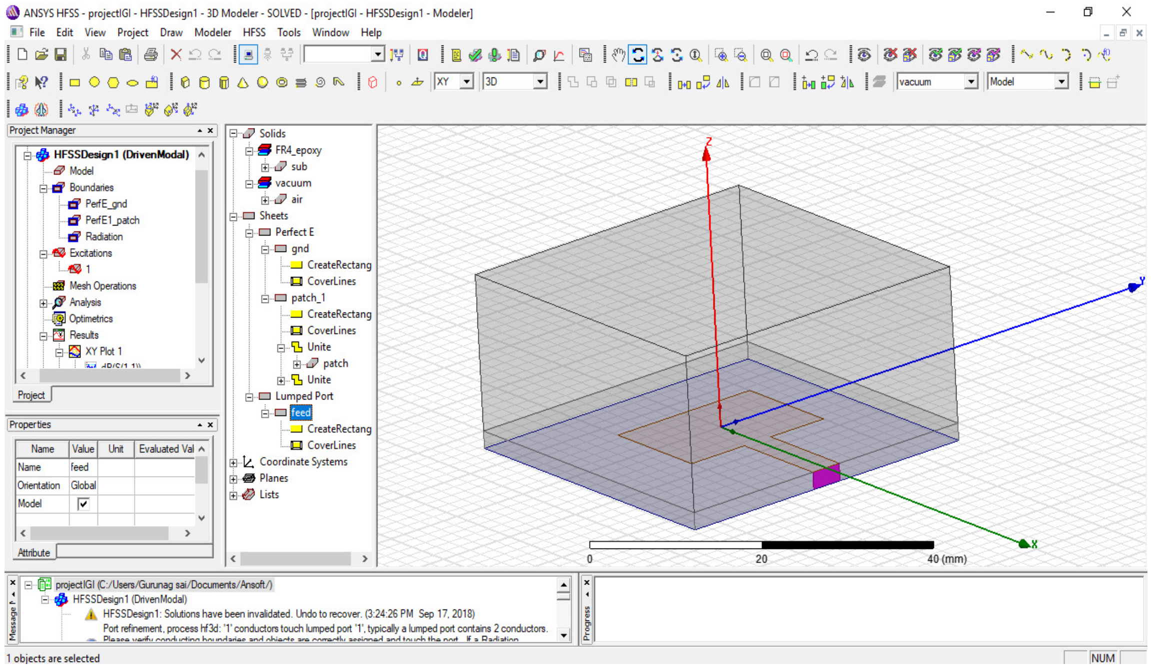


Fig 6.6 Create a source.

Step 6: Create air box to model free space radiation.

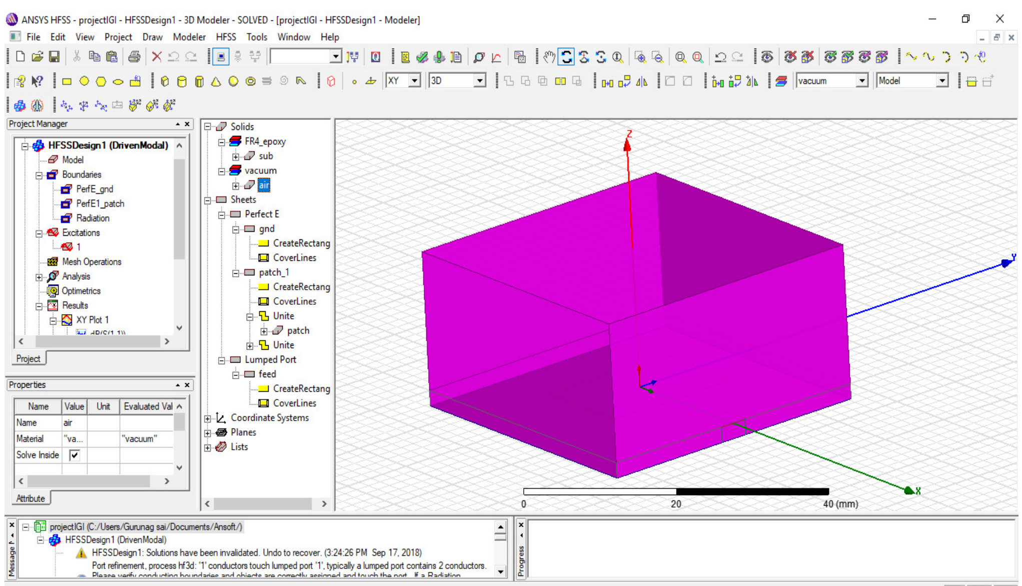


Fig 6.7 Create airbox.

Step 7: Assign boundaries to ground and patch as Perf E conductor.

Step 8: Assign excitation to feedline strip.

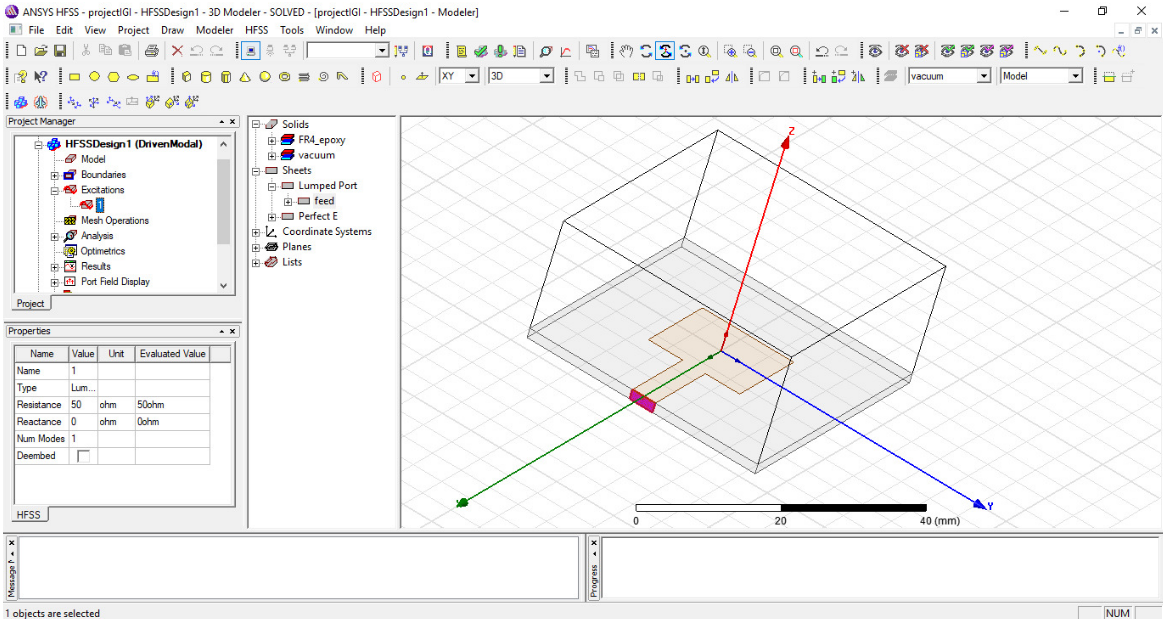


Fig 6.8 Assign excitation.

Step 9: Assign radiation to all faces of air box except ground surface.

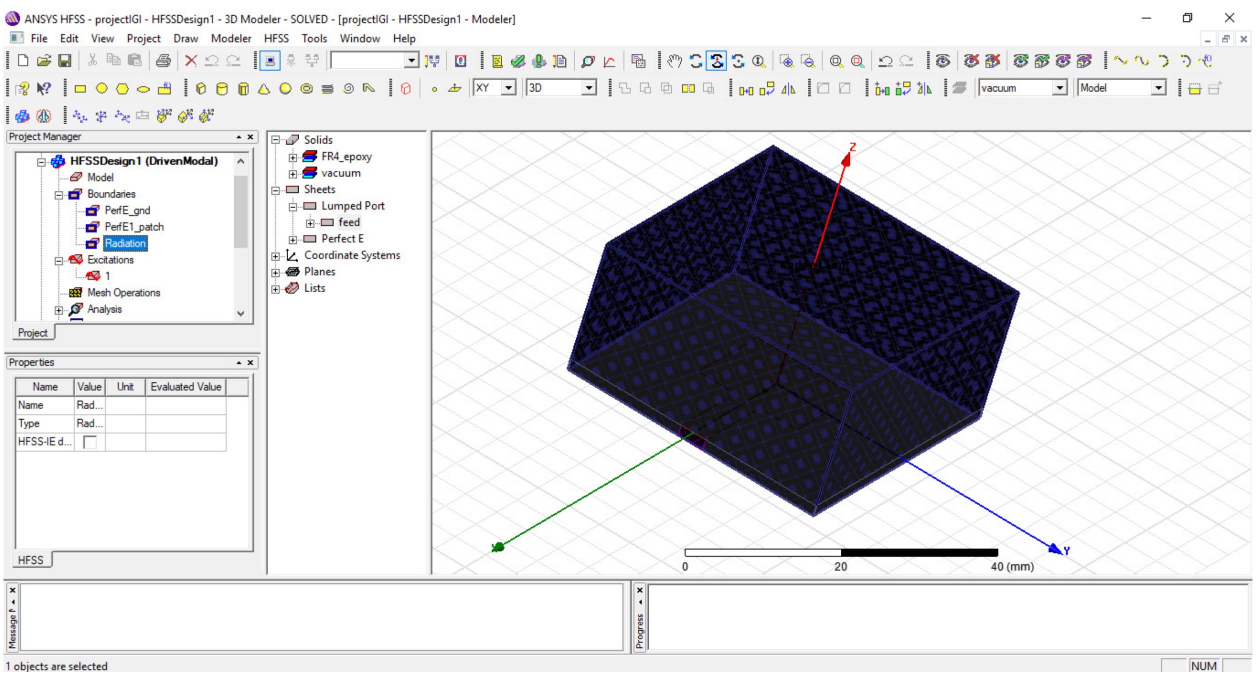


Fig 6.9 Assign radiation.

Step 10: Add solution setup and add sweep frequency.

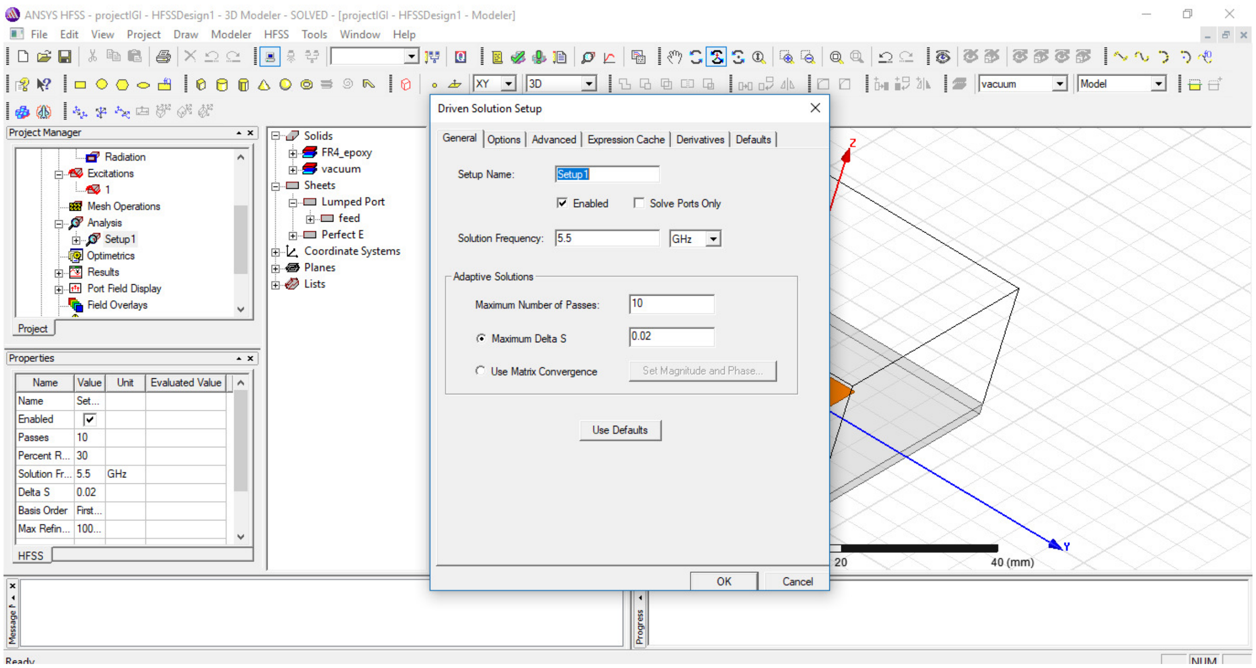


Fig 6.10 Add solution setup.

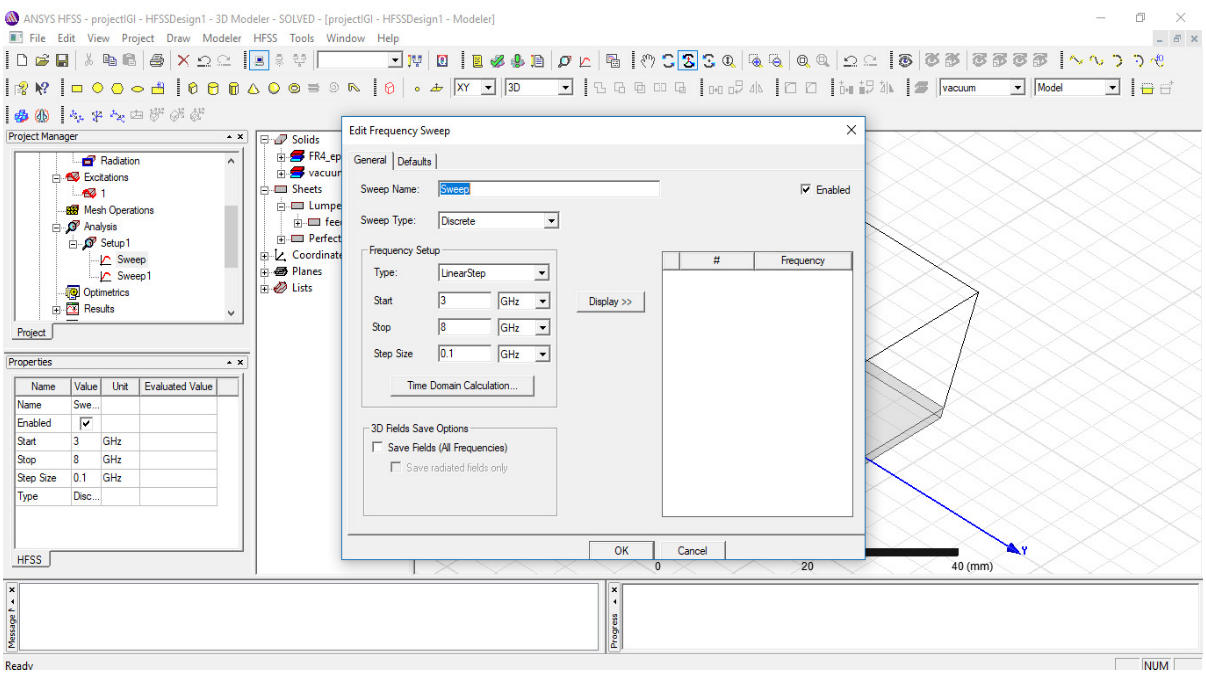


Fig 6.11 Add sweep frequency.

Step 11: Insert far field setup to infinite sphere.

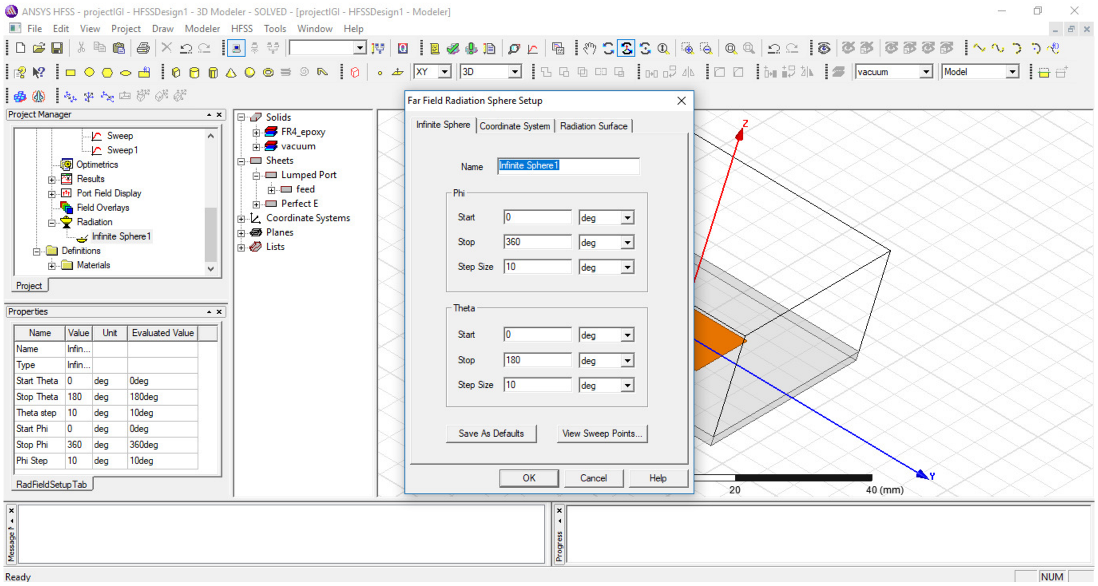


Fig 6.12 Insert far field setup.

Step 12: Perform validation check.

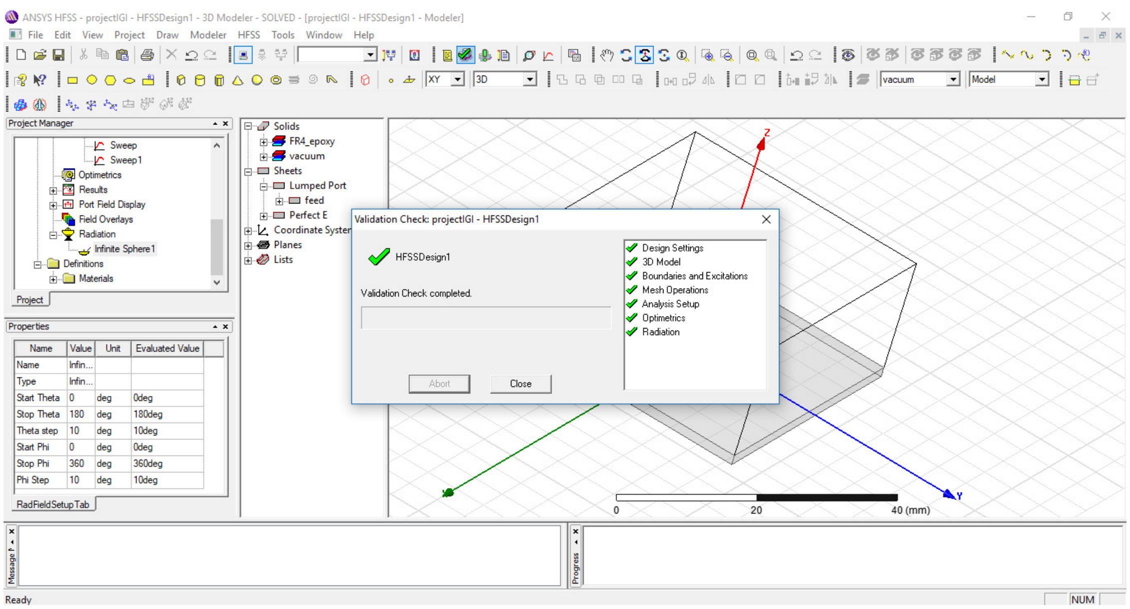


Fig 6.13 Validation check

Step 13: Simulate all setups.

Step 14: Observe the results

S(1,1) VS FREQUENCY PLOT:

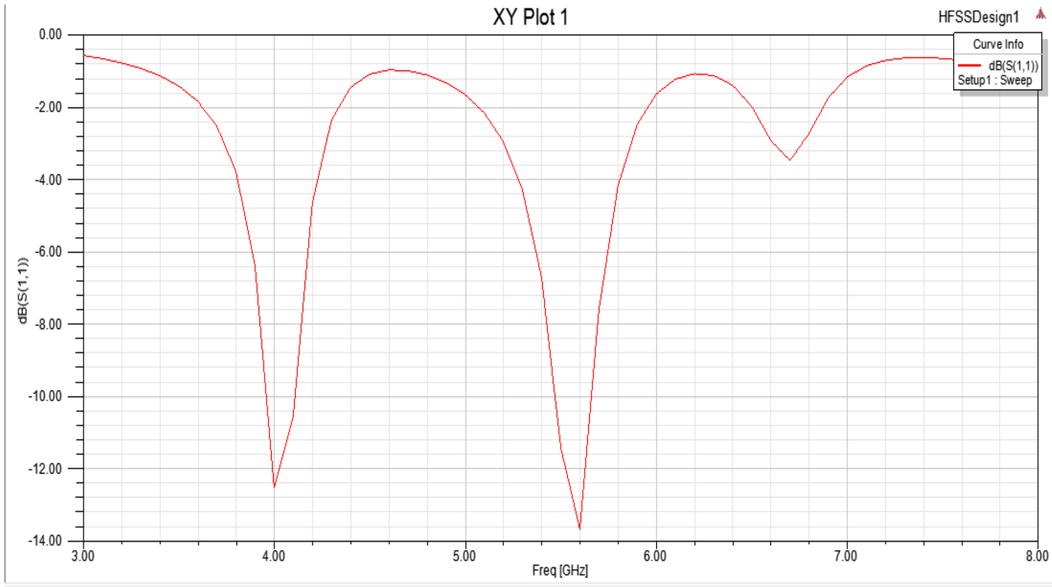


Fig 6.14 s(1,1) vs. frequency graph

In the above result at frequency 5.6 Ghz, The S parameter has a -13.6dB value i.e. > 11dB where it shows that the antenna radiates the frequency of 5.6 GHz and at 4.5GHz it also has a return loss of -12dB

RADIATION PATTERN:

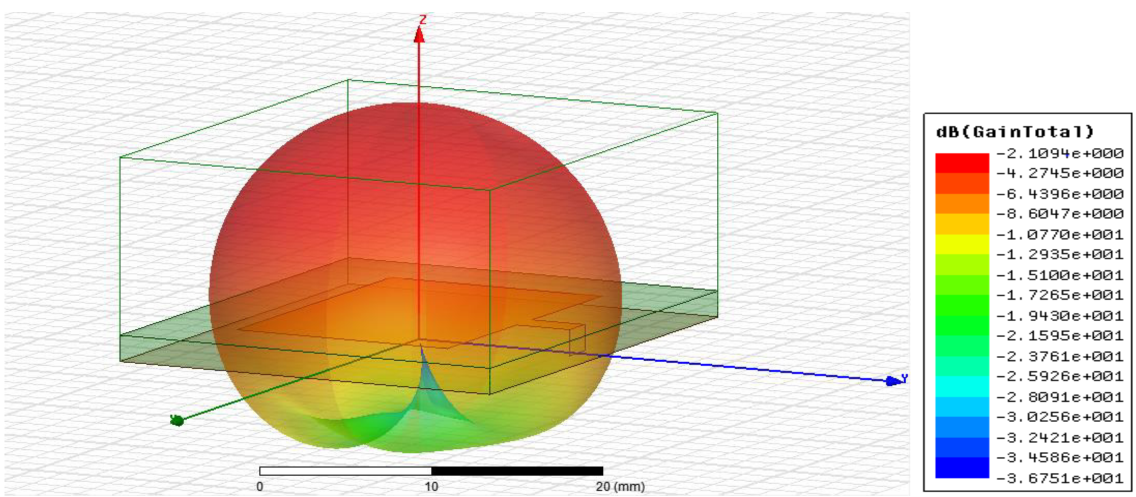


Fig 6.15 Radiation pattern

In the above result radiation pattern, the antenna radiates above the patch where the voltage variation is given by the various colours used.with a gain of -2.5dB

6.2 DESIGN OF FRACTAL PATCH ANTENNA

6.2.1 1st ITERATION:

As show in the design specifications , the triangle cut is made on the rectangular patch as shown in figure 6.1, following the same design steps the results of it are stated below:

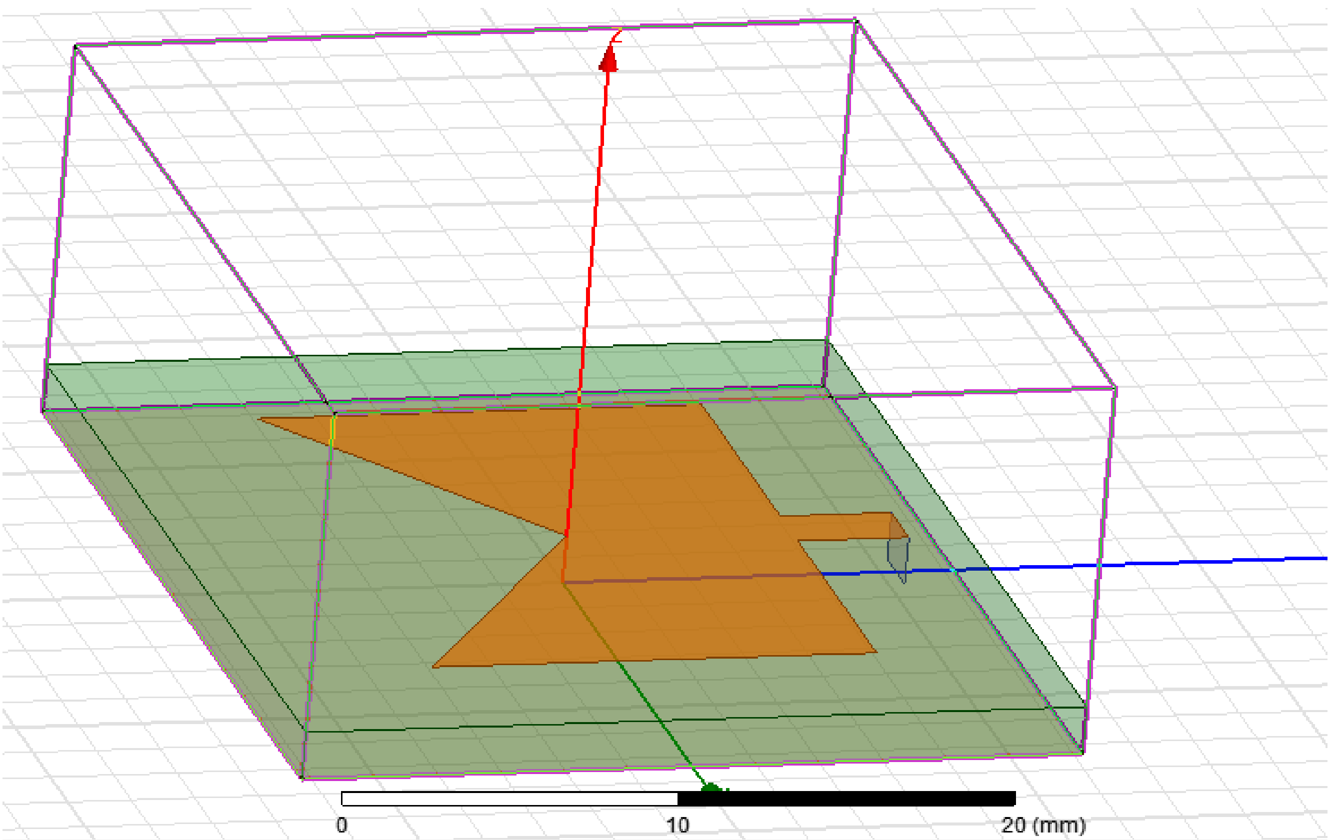


Fig 6.16 : the base , 1st iteration fractal antenna structure

S(1,1) VS FREQUENCY PLOT:

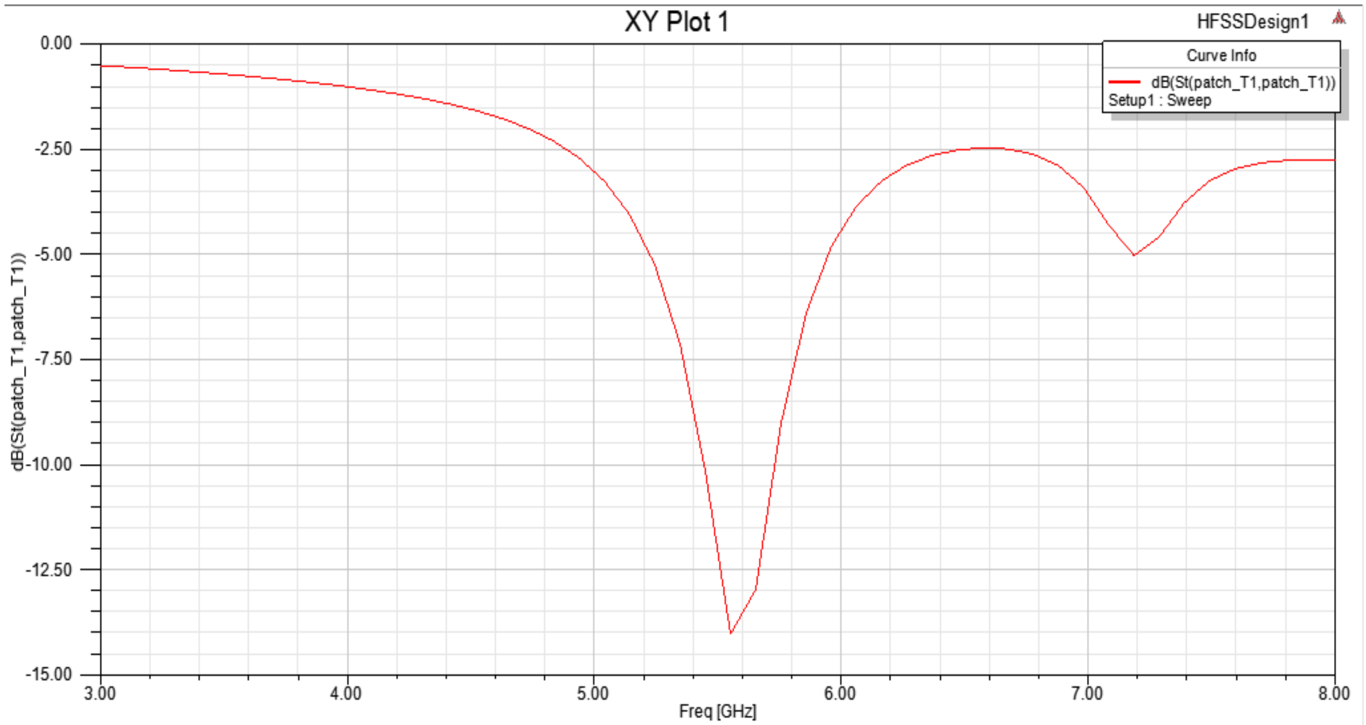


Fig 6.17 Return loss vs Frequency curve of the 1st iteration fractal antenna

RADIATION PATTERN:

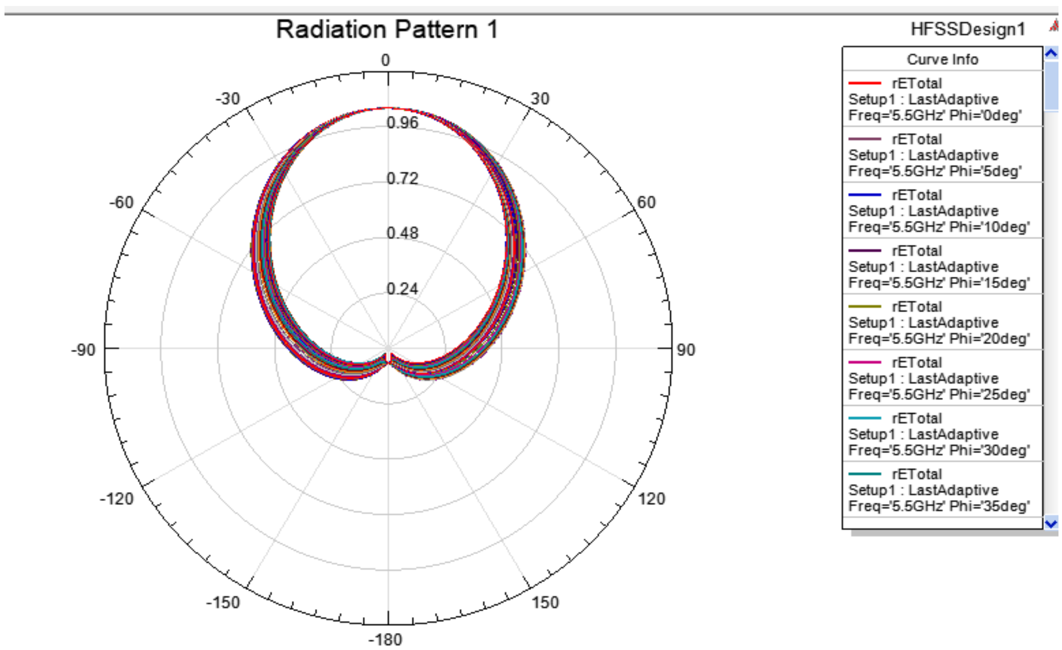


Fig 6.18 2D radiation pattern graph

In the above result at frequency 5.6 GHz, The S parameter has a -14.6dB value i.e. > 11dB where it shows that the antenna radiates the frequency of 5.6 GHz with the gain of 2.92 dB

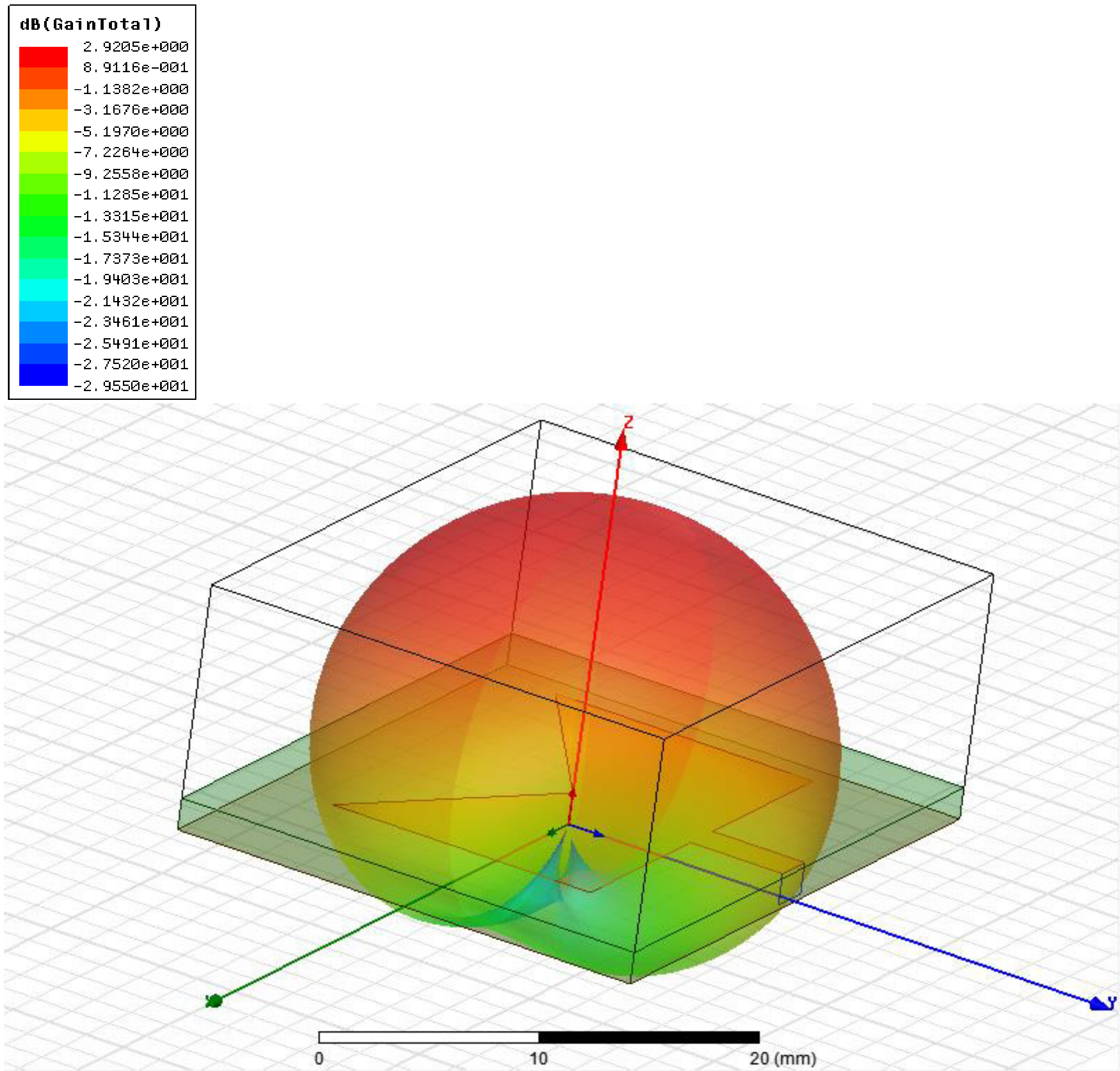


Fig 6.19 3D radiation pattern of the 1st iteration fractal

Comparing the results of base rectangle patch and fractal patch antenna we get the following conclusions

parameter	Rectangular patch antenna	1st iteration fractal antenna
Resonant frequency	5.6GHz	5.6GHz
Return Loss	-13.6 dB	-14.5 dB
Peak Gain	0.61527	1.5919
Radiation Pattern	Main lobe above the patch with more HPBW	Main lobe above the patch with less HPBW compared to rectangular patch
Peak Directivity	0.9089dB	2.7919
Radiated Power	0.0023156 W	0.0064621W
Radiation Efficiency	0.67687	0.70177

Table 6.1: comparison between rectangular patch and 1st iteration fractal patch antennas

6.2.2 2^{nd} ITERATION:

As the lower part of rectangle consists of 2 smaller rectangles of size $1/4^{th}$ to the main rectangle, we remove the triangle slots for them in order to get our 2^{nd} iteration fractal antenna. Similarly this process can be continued to infinity iterations as a property for the fractal

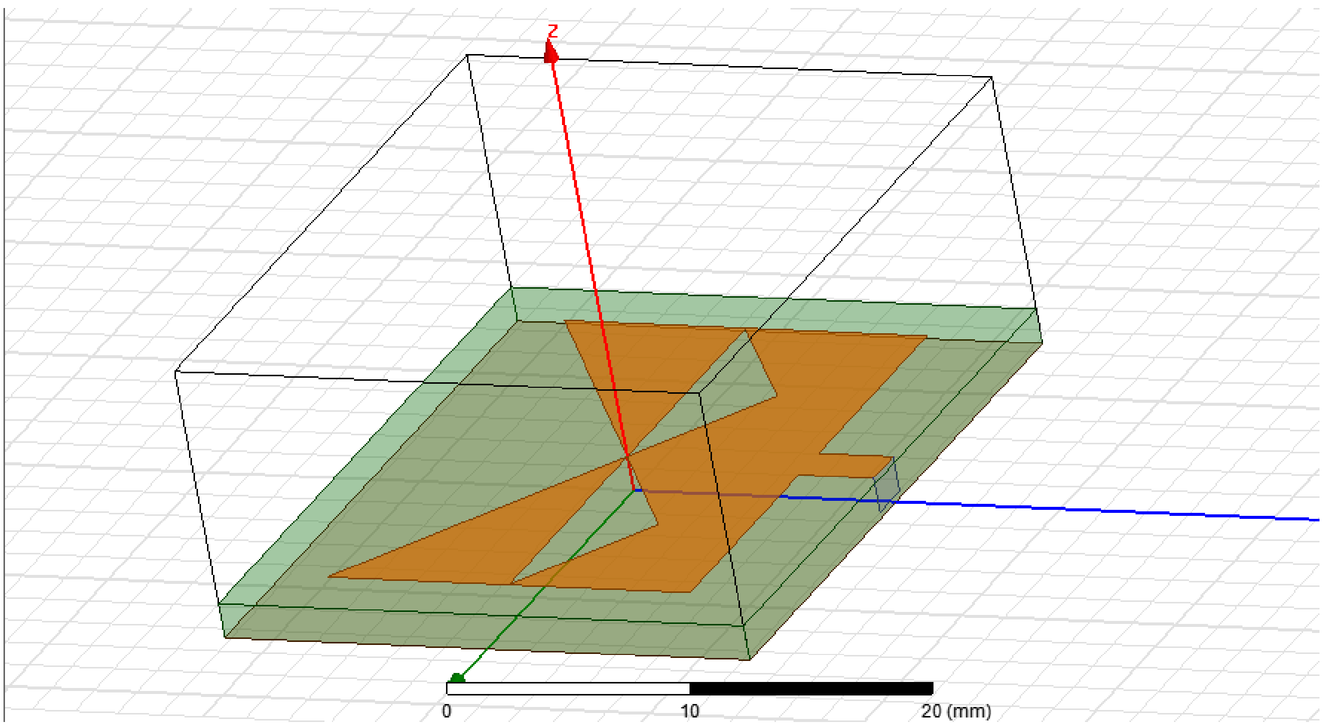


Fig 6.20 : the base , 2^{st} iteration fractal antenna structure

S(1,1) VS FREQUENCY PLOT:

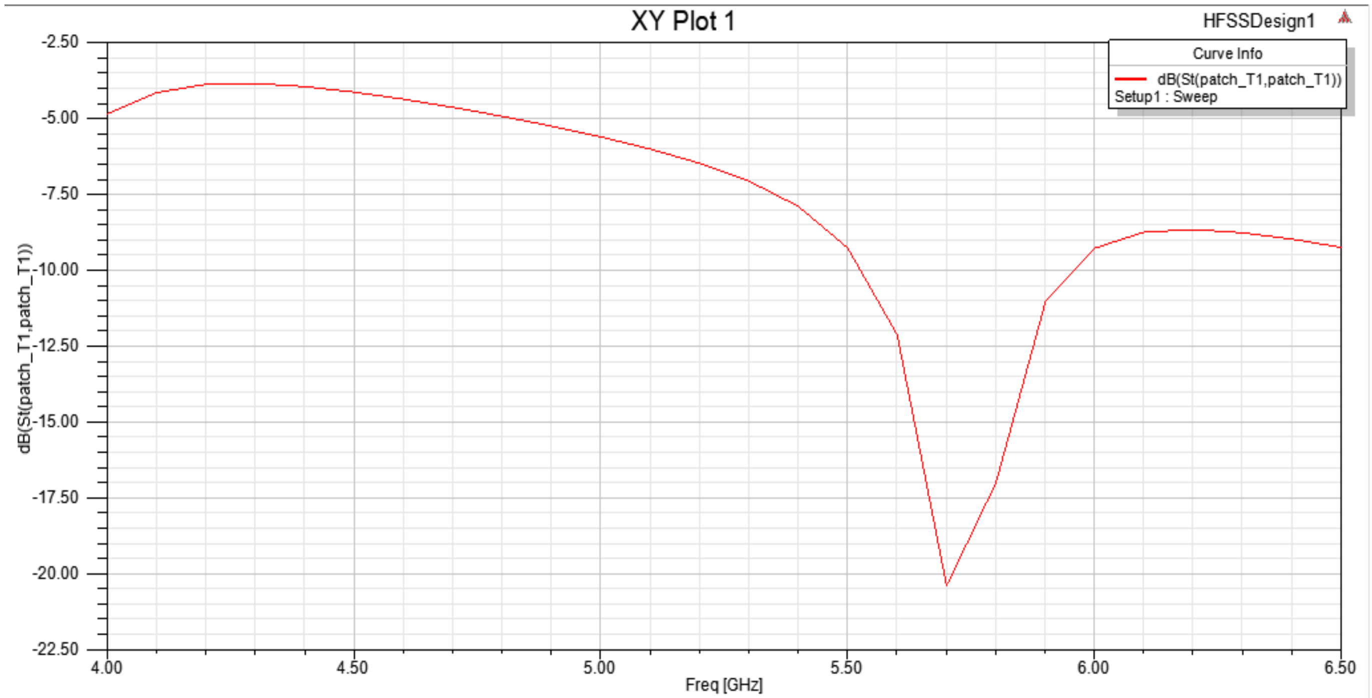


Fig 6.21 Return loss vs Frequency curve of the 2nd iteration fractal antenna

RADIATION PATTERN:

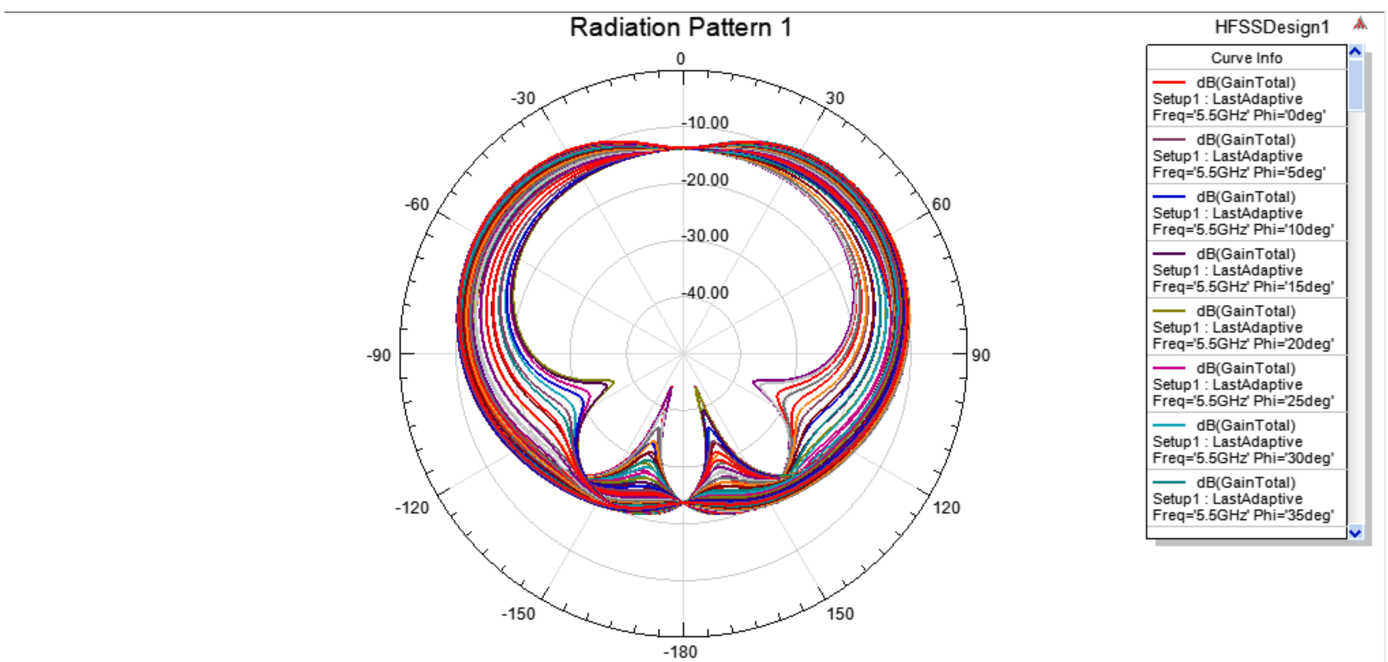


Fig 6.22 2D radiation pattern graph

In the above result at frequency 5.6 Ghz, The S parameter has a -20.5dB value i.e. > 11dB where it shows that the antenna radiates the frequency of 5.6 GHz with the gain of -717 dB

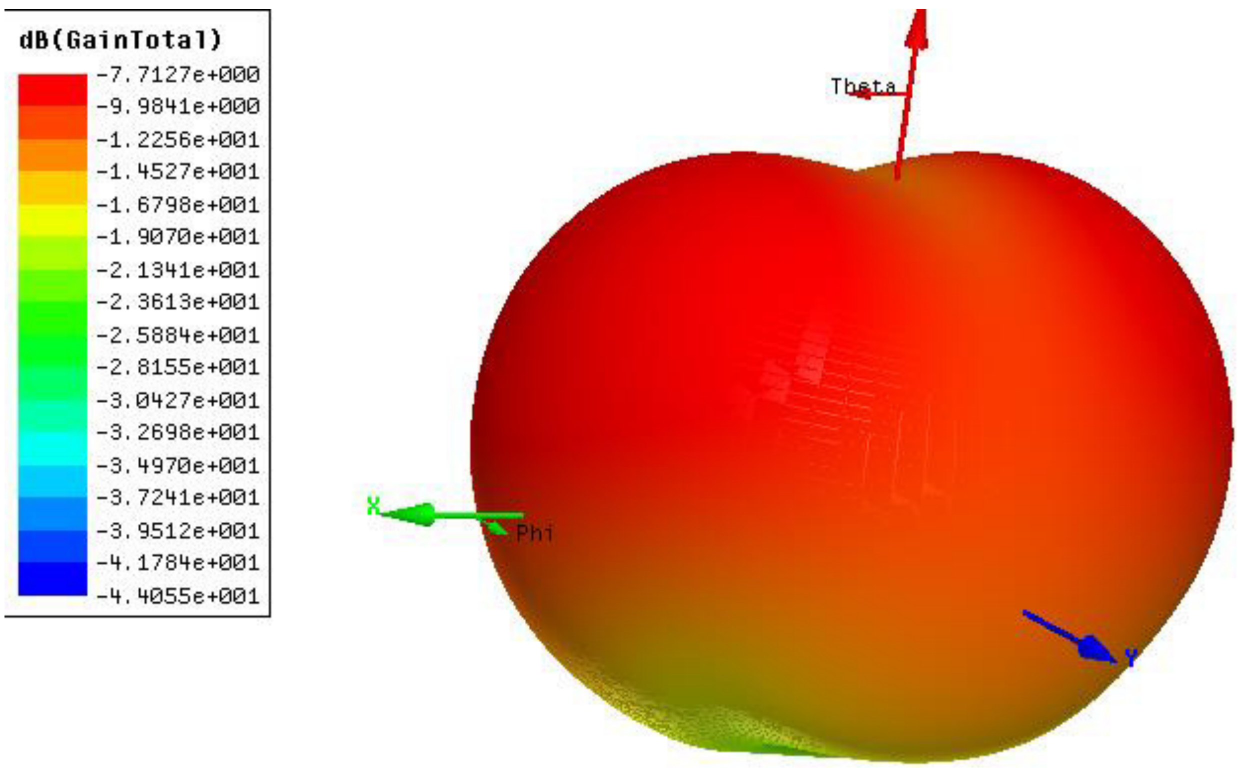


Fig 6.23 3D radiation pattern of the 2nd iteration fractal

Comparing the results of base rectangle patch and 2nd iteration fractal patch antenna we get the following conclusions

parameter	Rectangular patch antenna	1st iteration fractal antenna
Resonant frequency	5.6GHz	5.6GHz
Return Loss	-13.6 dB	-20.5 dB
Peak Gain	0.61527	0.69933
Radiation Pattern	Main lobe above the patch with more HPBW	Main lobe above the patch and we can see two back lobes also
Peak Directivity	0.9089dB	0.21499
Radiated Power	0.0023156 W	0.0055894W
Radiation Efficiency	0.67687	0.78762

Table 6.2 Comparison between rectangular patch antenna and 2nd iteration fractal patch antenna

6.3 THE TRIANGLE PATCH ANTENNA :

As we are subtracting a triangle piece of dimensions height as 7mm and base as 10 mm from our patch, we have made it as a patch and observed the results

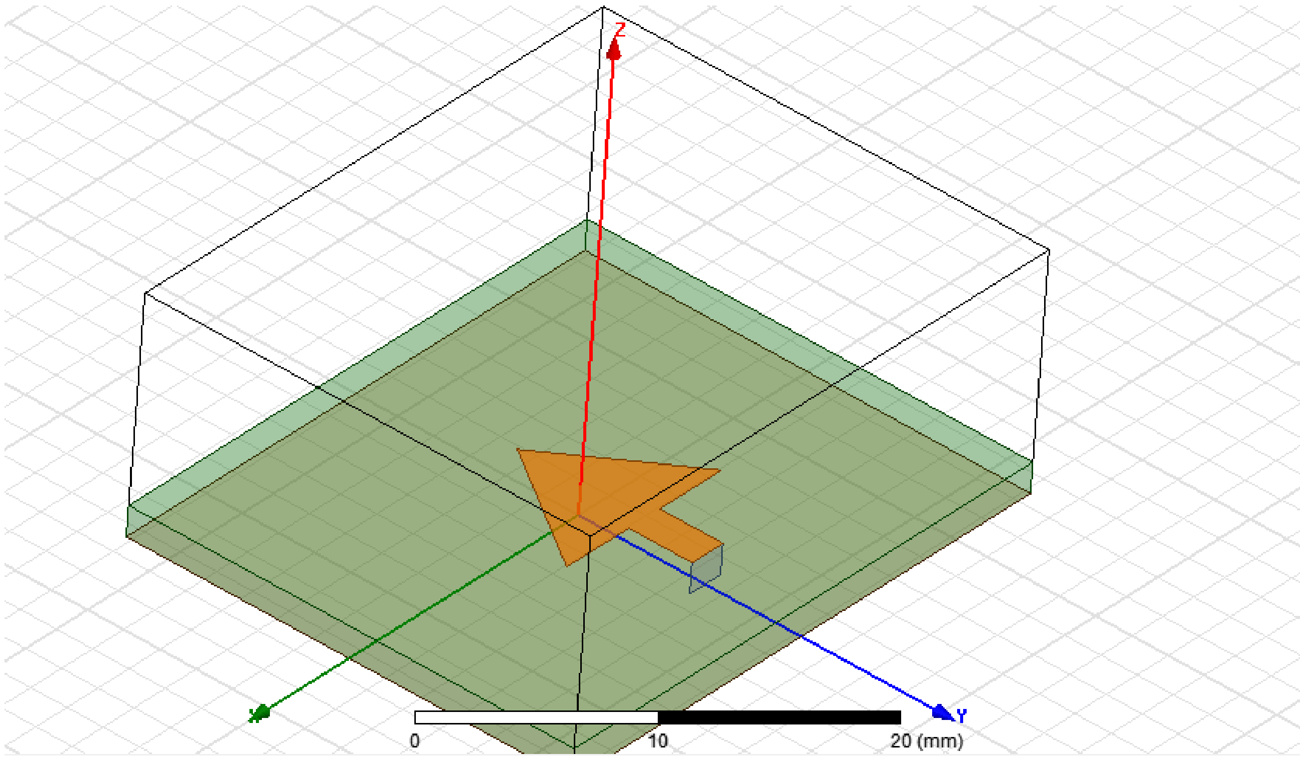


Fig 6.24 : Triangular antenna structure

The above antenna radiates at a frequency of 9.4 GHz has a return loss of -18dB and a a gain of 5.75dB

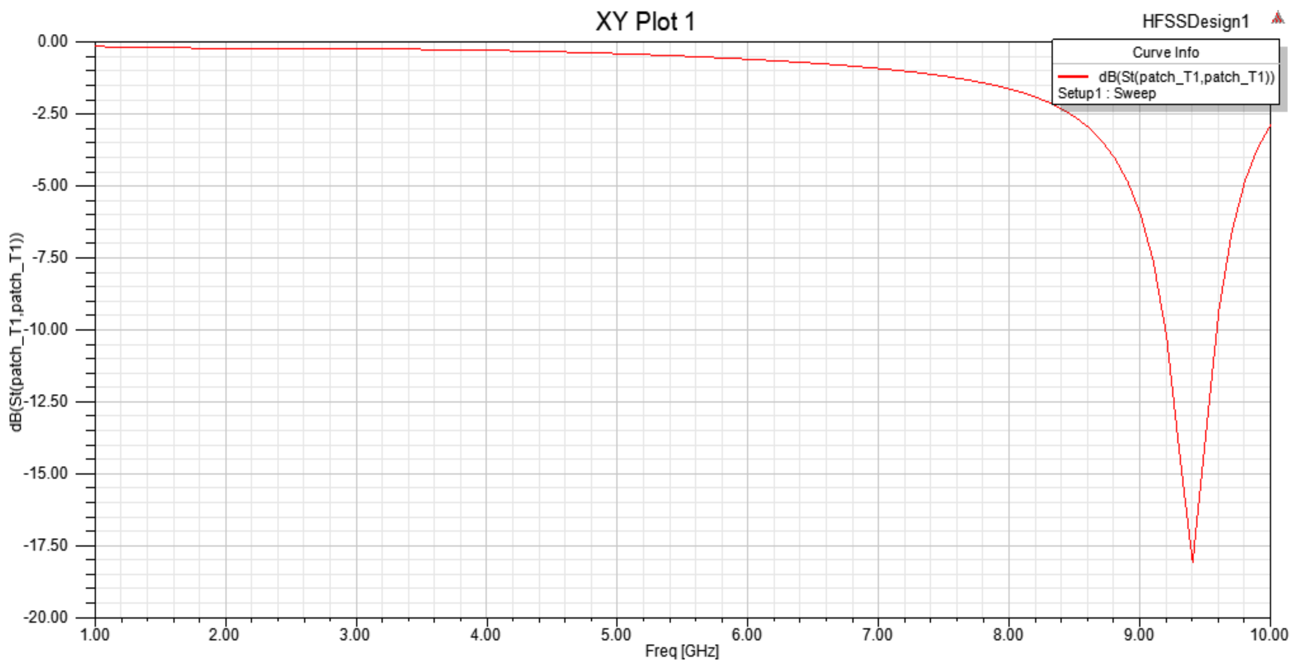


Fig 6.25 Return loss vs. Frequency curve of triangular antenna

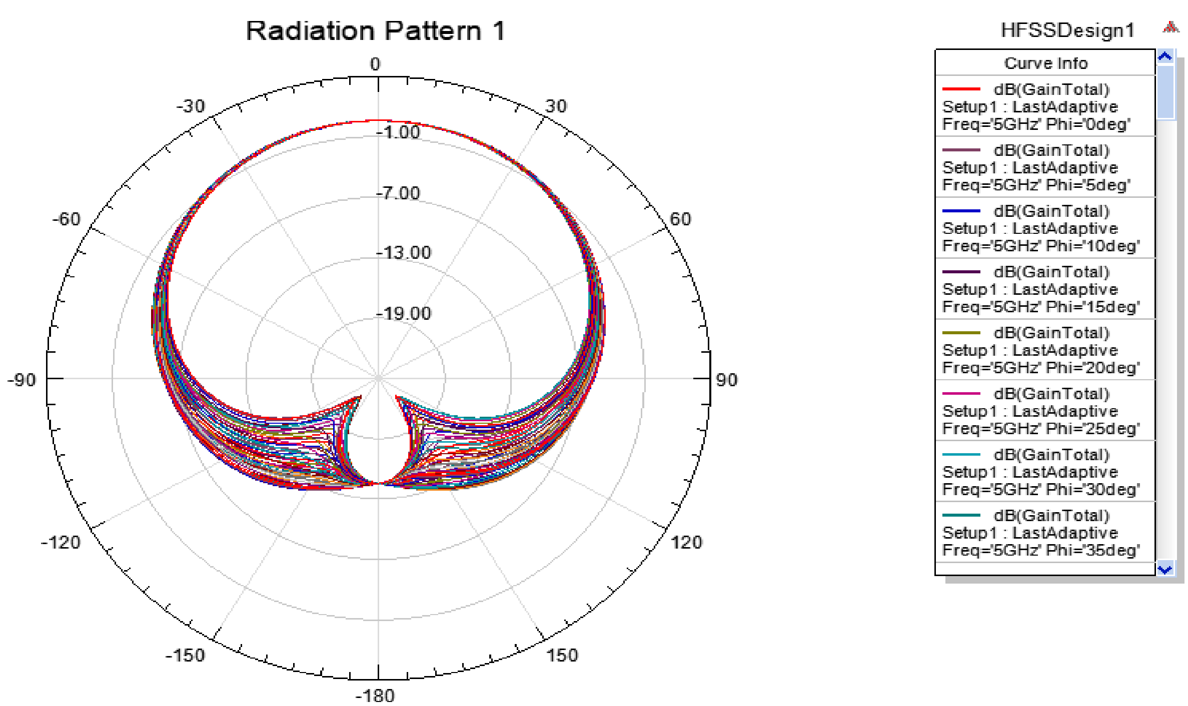


Fig 6.26 2D radiation pattern graph

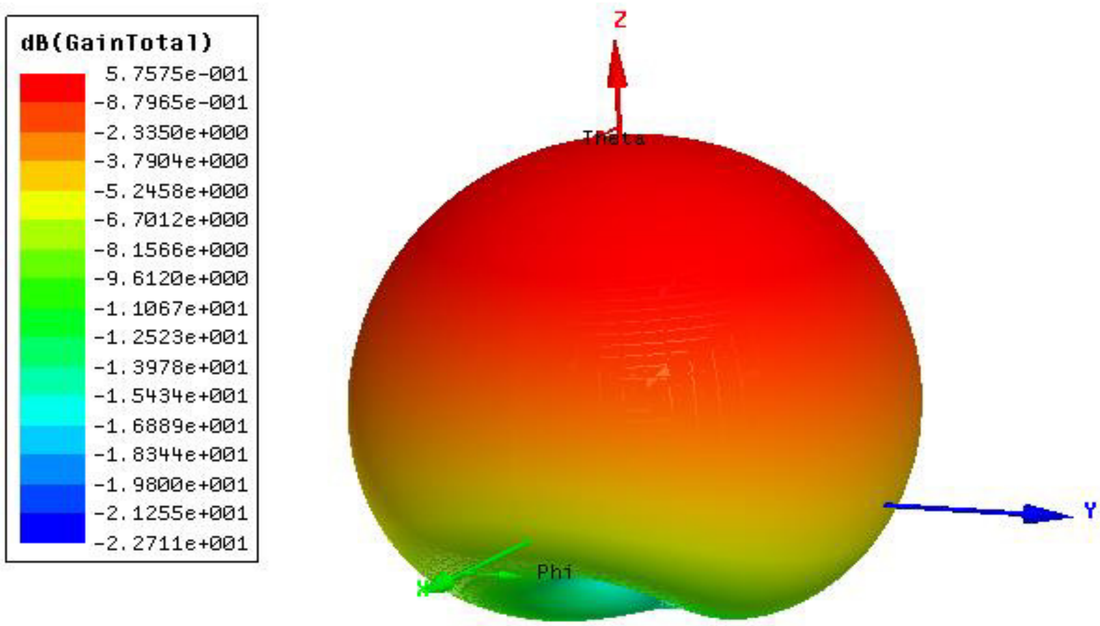


Fig 6.27 3D radiation pattern of the triangular antenna

Quantity	Freq	Value
Max U	5GHz	8.5476E-005 W/sr
Peak Directivity		1.9576
Peak Gain		1.1418
Peak Realized Gain		0.10742
Radiated Power		0.00054871 W
Accepted Power		0.00094079 W
Incident Power		0.01 W
Radiation Efficiency		0.58324
Front to Back Ratio		31.859
Decay Factor		0

7 CONCUSION

The radiation performance of proposed 1st iteration fractal microstrip patch antenna is compared with conventional rectangular patch antenna. Simulated results indicate that the new proposed antenna exhibits peak gain of 1.5919 compared to rectangular patch which has a peak gain of 0.61527 i.e. approximately double to the rectangular patch antenna and the radiation pattern improvement is also observed from iteration to iteration the antenna. There is also improvement in radiation characteristics like gain and efficiency. The radiation pattern is also found to be stable over the entire bandwidth

The satellite communications portion of the C band is highly associated with television receive-only satellite reception systems, commonly called "big dish" systems, since small receiving antennas are not optimal for C-band systems. As the fractals reduce the occupancy in a system , they can be used in various heavy applications such a satellites , cellular phones, etc.

The C band also includes the 5.8 GHz ISM band between 5.725 - 5.875 GHz, which is used for medical and industrial heating applications and many unlicensed short range microwave communication systems, such as cordless phones, baby monitors, and keyless entry systems for vehicles. The C-band frequencies of 5.4 GHz band [5.15 to 5.35 GHz, 5.47 to 5.725 GHz, or 5.725 to 5.875 GHz, depending on the region of the world] are used for IEEE 802.11a Wi-Fi wireless computer networks.

8 REFERENCES

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