Study of Fractal Circular Patch Micro-Strip Antenna over Traditional Antenna

Rakesh Kumar, Gunjan Gupta

Abstract—Today's antenna systems demand versatility and unobtrusiveness. Operators are looking for systems that can perform over several frequency bands or are reconfigurable as the demands on the system changes. Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Fractal antennas have entered the view of many as a very promising solution. Fractal antennas size can be shrunk from two to four times with surprising good performance over Traditional antenna. Because FEAs(Fractal Element Antenna) are self-loading, no antenna tuning coils or capacitors are necessary. Fractal antenna theory is built, as is the case with conventional antenna theory, on classic electromagnetic theory. Fractal antenna theory uses a modern (fractal) geometry that is a natural extension of Euclidian geometry. Dual and Triple band Fractal circular micro-strip antennas offers increase in bandwidth and gain at all multiband as well as the size of antenna gets reduced.

Index Terms— Fractal's definition, fractal antenna element, types of fractal, fractal geometry, micro-strip antenna.

I. INTRODUCTION

Micro-strip antenna was a simple antenna that consists of a radiated patch component, dielectric substrate and ground plane. The radiated patch and ground plane are thin layers of PEC or gold which is a good conductor. Each dielectric substrate has its own dielectric permittivity value. This permittivity influences the size of the antenna. Micro-strip antenna is a low profile antenna. They have several advantages like light in weight, small dimension; cheap and easy to integrate with other circuit make it chosen in various applications.

However, fractal antennas and its superset fractal electrodynamics is a state of affairs for research activity. Although fractal geometry has been known to mathematics for a century, fractal antenna engineering research is a relatively very recent development because considerable computing speed is required to complete their design. In the research journals, we see reports of active research covering such diverse areas of Fractals use in antenna field and their advantages. Fractals are self-similar objects and possess structure at all scales. Fractal geometries have found an intricate place in science as a representation of some of the unique geometrical features occurring in nature. Fractal geometry was first discovered by Benoit Mandelbrot as a way to mathematically define structures whose dimension cannot be limited to whole numbers. Benoit Mandelbrot, the pioneer of classifying this geometry, first coined the term 'fractal' in 1975 from the Latin word fractus, which means broken. The field is quite extensive with many applications from statistical analyses, natural modelling, and compression and, of course, computer graphics [1]. Soon after scientists discovered the practical aspect of fractal geometry, research began in the field of electrodynamics [2].

Fractals are structures of infinite complexity with a self-similar nature. What this means, is that as the structure is zoomed in upon, the structure repeats itself. This property could be used to design antennas that can operate at several frequencies. A fractal can fill the space occupied by the antenna in a more effective manner than the traditional Euclidean antenna. This can lead to more effective coupling of energy from feeding transmission lines to free space in less volume. Therefore, Fractals can be used in two ways to enhance antenna designs. The first method is in the design of miniaturized antenna elements. These can lead to antenna elements which are more discrete for the end user. The second method is to use the self similarity in the geometry to blueprint antennas which are multiband or resonant over several frequency bands. This would allow the operator to incorporate several aspects of their system into one antenna. Such antennas could be used to improve the functionality of modern wireless communication receivers such as cellular handsets. Because fractal antennas are more compact, they would more easily in the receiver package. Currently, many cellular handsets use quarter wavelength monopoles which are essentially sections of radiating wires cut to a determined length. Although simple, they have excellent radiation properties. However, for systems operating at 900 MHz such as GSM, the length of these monopoles is often longer than the handset itself, posing a nuisance to the user. It would be highly beneficial to design an antenna with similar radiation properties as the quarter-wavelength monopole while retaining its radiation properties. The theory of fractal antenna operation is steeped in mathematics, but in its most basic form, it comes down to this: In order for an antenna to work equally well at all frequencies, it must satisfy two criteria [3]:

1. It must be symmetrical about a point.
2. It must be self-similar, having the same basic appearance at every scale.

Fractal satisfies above conditions that is why it shows wideband and multiple resonant frequencies behaviour.

The advantages of fractal over conventional antennas are [4]:

1. Multiband performance is at non-harmonic frequencies.
2. Improved Impedance, Improved SWR(standing wave ratio) performance on a reduced physical area when compared to non fractal Euclidean geometries.
3. Compressed resonant behaviour.
4. At higher frequencies the FEA is naturally broadband.
5. Polarization and phasing of FEAs also are possible.
6. In many cases, the use of fractal element antennas can simplify circuit design.
7. Reduced construction costs.
8. Improved reliability.
9. Often they do not require any matching components to

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Rakesh Kumar, M.Tech Scholor Mewar University, Rajasthan, India.
Gunjan Gupta, Assistant Professor R.K.G.I.T, Ghaziabad, India.

achieve multiband or broadband performance.
10. Perturbation could be applied to shape of fractal to make \ it to resonate at different frequency.

II. FRACTAL CIRCULAR PATCH MICRO-STRIP ANTENNA

A. Fractal's Definition

According to Webster's dictionary a fractal is defined as being "derived from the Latin fractus meaning broken, uneven, any of various irregular curves or shapes that repeat themselves at any scale on which they are examined.

B. Fractal Background

In modern wireless communication system and increasing of other wireless application, wider bandwidth, multiband and low profile antenna research in various directions, one of them is by using fractal shaped antenna elements. Traditionally, each antenna operates at single or dual frequency band, where different antenna is needed for different application.

Fractal shaped antenna have already been proved to have some unique characteristics that are link to the geometry of the fractal. Fractal geometry has unique geometrical features occurring in nature. It can be used to describe the branching of tree leaves and plants, jaggedness of coastline and many more examples in nature. Fractal is defined by as set of F such that [5-7]:

1. F has a finite structure with detail on arbitrarily small scales.
2. F is too irregular to be describing by traditional geometry.
3. F is having some forms of self similarity.
4. F can be described in a simple way, recursively.
5. Dimension of F is greater than its topological dimension.

C. Fractal Antenna Elements

There are many benefits when we apply nature power (fractal) to develop various antenna elements. By applying fractals to antenna element:

1. We can create smaller size.
2. Achieve resonance frequencies that are multiband.
3. May be optimized for gain.
4. Achieve wideband frequency band.

Most fractals have infinite complexity and detail can be used to reduce antenna size and low profile antenna .For most fractals, self similarity concept can achieve multiple frequency band because different part of the antenna are similar to each other at different scales. The combination of infinite complexity, design and self similarity make it possible to design antennas with very wideband performances [8-9].

D. Types of Fractal

Fractal came into two major variations:
1. Deterministic Fractal
2. Random Fractal

The first category consists of those fractals that are composed of several scales down and rotate copies of it, such as Koch curves. They are called geometrical fractals. Julia set also falls in same category. The whole set can be obtain by applying a non linear iterated map to all arbitrary small section of it. Thus the structure of Julia set is already contain in any small fraction. They are called algebraic fractals. Since generation requires use of particular mapping or rule which is repeated recursively over and over again. They exhibit the property strict self similarity. The second category (Random fractals) includes those fractals which have an additional element of randomness allowing for simulation natural phenomena, so they exhibit property of statistical self similarity.

(A) Geometric Fractals

The fractal of this class is visual. In two dimensional cases they are made of broken line so called the generator. Each of the segments which form the broken line is replaced by broken line generator at corresponding scale for a step of algorithm. As a result of infinite repeating the steps geometrical fractals arises.

(B) Algebraic Fractals

Algebraic is the biggest class of fractals. They are creating by using non-linear process in n-dimensional spaces.

(C) Stochastic Fractals

The stochastic fractals are got in the case iterate process has accidental parameters. Using the way object like natural can be created. Two-dimensional stochastic fractals are used for designing surface of sea or relief modelling.

E. Fractals Geometry

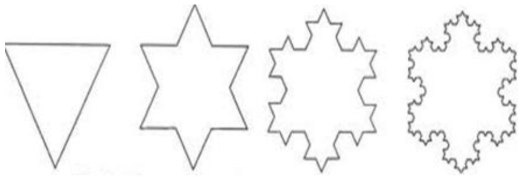

Fig 2.2. Koch Curve Fractal Geometry

There is much fractals geometry that has been found to be useful in developing new and innovative design for antennas. Some of these unique geometries are:

(A) Sierpinski Carpet Fractal Geometry

The Sierpinski Carpet is constructed analogously to the Sierpinski gasket but it use square instead of triangle. In order to start this type of fractal antenna, it begins with a square in plane, and then divided it into nine smaller congruent squares then the open central square is dropped. The remaining eight squares are divided into nine small congruent squares which each central are dropped.[10-11].

(B) Koch Curves Fractal Geometry

The geometrical construction of standard Koch curves is fairly simple. It starts with a straight line as an initiator. This is portioned into three equal parts, and the segment at the middle is replaced with two others of same length. This is the first iterated version of geometry and is called generator. The process is reused in the higher iteration [12].

(C) Sierpinski Gasket Fractal Geometry

The Sierpinski Gasket Geometry is explained in the Fig.2.3. Although the geometry presented here consists of an equilateral triangle,

the description here holds good for any triangular geometry. Explanation of its generation is in two ways:
1. The multiple copy approach.
2. Decomposition approach.

For the first generation, start with a small triangle.

Two more copies of these triangles (same size) are generated and attach to the original triangle.

This process can be done in numbers of times, n being the order of fractal iteration. In the decomposition approach, first start with a large triangle. The midpoints of the sides are joined together and a hollow space in the middle is created. This process divides the original triangle to the three scales down version of a large triangle. The same division process can be done on each of the copies. After n such division, the geometry shown in Fig. is obtained.

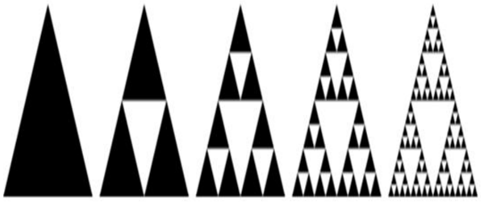

Figure2.3. Sierpinski Gasket Fractal Geometry

F. Input Impedance

It is used to determine maximum power transfer between transmission line and antenna. The maximum power is only transmitted if input impedance of transmission line and antenna are matched. If it is not matched then the reflected wave is generated at the terminal and travel back towards the energy source. So, this causes reduction in the system efficiency. If the return loss is known then input impedance is given by:

$$Z_{in} = Z_o(1+S_{11}/1-S_{11}) \qquad (2.1)$$

G. VSWR

Voltage Standing Wave Ratio (VSWR) is ratio between maximum voltage and minimum voltage along transmission line. It is derived from incident and reflected wave level. VSWR is increases if there is mismatch between the antenna and transmission line and it is increases if there are good matching. The VSWR is given by:

$$VSWR = Z_o(1+S_{11}/1-S_{11}) \qquad (2.2)$$

H. Gain

The gain of an antenna is measure of antenna overall efficiency. If the gain is 100% efficient then gain becomes equal to the directivity. But there are many factors that affect and reduce the overall efficiency of an antenna. Some of the most significant factors that impact antenna gain include impedance, matching network losses, random losses and material loss. Gain is simply defined as a product of efficiency and directivity given by 2.3: [13]

$$G = \eta D \qquad (2.3)$$

I. Radiation Pattern

The radiation pattern of antenna provides the information that how antenna directs the energy it radiates. Radiation pattern are presented on relative power dB scale. In many cases, the convention of an E-plane and H-plane is used in presentation of antenna pattern data. The E-plane is a plane that contains antenna radiated electric field potential where the H-plane is a plane that contains the antenna radiate in magnetic field potential. These planes are always orthogonal. Radiation pattern shown in fig 2.4.

J.3-Db Beam Width (HPBW)

2 dB beam width of antenna is a measure of angular width of -3dB points on antenna pattern relative to pattern maximum.-3dB point is a point on the pattern where power level is 3dB down of value at pattern maximum.

K. Directivity

Directivity, D is an important parameter that shows the ability of the antenna focusing radiated energy. Directivity is a ratio of maximum radiated to radiate by reference antenna. Reference antenna is an isotropic radiator where the radiated energy is same in all the direction and have directivity of 1.Directivity can be definition as,

Where,

$$D = F_{\max} / F_o \qquad (2.4)$$

$F_{\max} =$ Maximum radiated energy

$F_o =$ Isotropic radiator radiate energy

L. Polarization

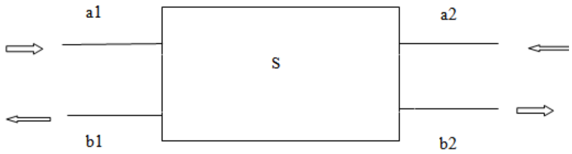

Fig 2.5.S-paramemter for a two port network

Polarization is describing the orientation of radiated wave electric field vector. There are three types of basic polarization:

1. Linear Polarization.
2. Circular Polarization.
3. Elliptical Polarization.

M. Bandwidth

It is define the frequency range over which an antenna meets a certain set of specification performance criteria. There are two methods for computing an antenna bandwidth.

Narrowband by %: $BW_p = ((f_H - f_L)/f_o) \times 100$ (2.5)

Where, $f_o =$ operating frequency

$f_H =$ higher cut-off frequency

$f_L =$ lower cut-off frequency

Broadband by %:

$$BW_b = f_H / f_L \qquad (2.6)$$

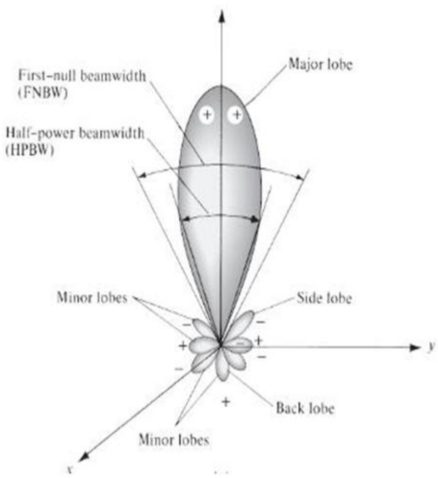

Fig. 2.4. Radiation Pattern

N. S-Parameters

When designing RF or Microwave systems, the scattering parameter representation plays a central role. System characterization can no longer be accomplished through simple open and short circuit measurement for high frequencies. This is because of the wire itself posses an inductance that can be of substantial magnitude at high frequencies. When we short circuit it, while open circuit leads to capacitive loading at the terminal [13].

S- Parameter is power wave descriptor that defines input output relation of a network in term of incident and reflected power waves.

Based on the directional convention shown in Fig. 2.5. above, the position to define the S-parameter:

where the terms are,

$$\begin{pmatrix} b1 \\ b2 \end{pmatrix} = \begin{pmatrix} S11 & S12 \\ S21 & S22 \end{pmatrix} \begin{pmatrix} a1 \\ a2 \end{pmatrix}$$

S_{11} is the electric field leaving the input divided by the electric field entering the input, under the condition that no signal enters the output. Since b1 and a1 are the electric field, their ratio is a reflection coefficient.

$S_{11} = b1/a1$, when a2 = 0 reflected power wave at port1/incident power wave at port1.

S_{21} is term the transmission coefficient related which the electric field is leaving the output divided by the electric field entering the input, when no signal enters the output.

$S_{21} = b2/a1$, when a2 = 0, transmitted power wave at port2/incident power wave at port1.

S_{12} is a transmission coefficient related to the isolation of the component and specifies how much power leaks back through the component in the wrong direction.

$S_{12} = b1/a2$,when a1 = 0,transmitted power at port 1/incident power wave at port 2.

S_{22} is similar to S_{11} but looks in the other direction into the component.

$S_{22} = b2/a2$, when a1 = 0 reflected power wave at port2/incident power at port 2.

III. FEED TECHNIQUES OF FRACTAL CIRCULAR PATCH MICRO-STRIP ANTENNA

Micro-strip antenna is feed by variety of method. These methods are classified into two categories Contacting and Non Contacting. In Contacting method- the RF power is fed directly to the radiating patch using connecting element such as micro-strip line. In non-contacting method- Electromagnetic field coupling is done to transfer power between micro-strip line and radiating patch.

A. Inset Feed

Since this typically yields a high input impedance, we would like to modify the feed. Since the current is low at the ends of a half-wave patch and increases in magnitude toward the center, the input impedance (Z=V/I) could be reduced if the patch was fed closer to the center. One method of doing this is by using an inset feed (a distance R from the end) as shown in Fig. 2.6.

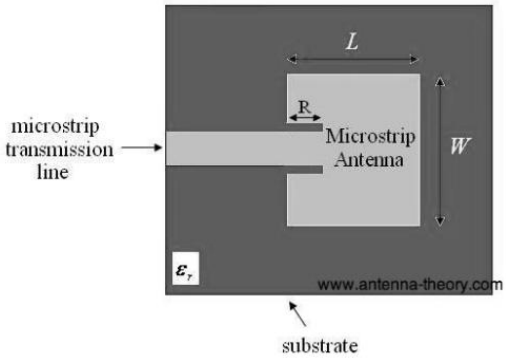

Fig 2.6. Patch Antenna with an Inset Feed

Since the current has a sinusoidal distribution, moving in a distance R from the end will increase the current by cos(pi*R/L) - this is just noting that the wavelength is 2*L, and so the phase difference is 2*pi*R/(2*L) = pi*R/L.

The voltage also decreases in magnitude by the same amount that the current increases. Hence, using Z=V/I, the input impedance scales as:

$$Z_{in}(R) = Cos^2(\pi R/L)\ Z_{in}(0) \tag{2.7}$$

In the above equation, Zin(0) is the input impedance if the patch was fed at the end. Hence, by feeding the patch antenna as shown, the input impedance can be decreased. As an example, if R=L/4, then cos(pi*R/L) = cos(pi/4), so that [cos(pi/4)]^2 = 1/2. Hence, a (1/8)-wavelength inset would decrease the input impedance by 50%. This method can be used to tune the input impedance to the desired value.

B. Fed With A Quarter-Wavelenth Transmission Line

The micro-strip antenna can also be matched to a transmission line of characteristic impedance Z0 by using a quarter-wavelength transmission line of characteristic impedance Z1.

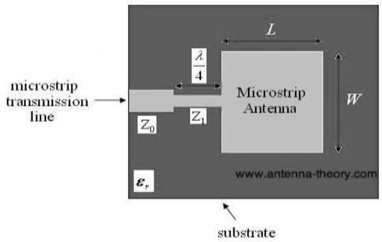

Fig 2.7. Patch Antenna with a quarter- wavelenth matching section

The goal is to match the input impedance (Zin) to the transmission line (Z0). If the impedance of the antenna is ZA, then the input impedance viewed from the beginning of the quarter-wavelength line becomes

$$Z_{in} = Z_0 = Z_1^2 / Z_A \tag{2.8}$$

This input impedance Zin can be altered by selection of the Z1, so that Zin=Z0 and the antenna is impedance matched. The parameter Z1 can be altered by changing the width of the quarter-wavelength strip. The wider the strip is, the lower the characteristic impedance (Z0) is for that section of line.

C. Coaxial Cable Or Probe Feed

Microstrip antennas can also be fed from underneath via a probe as shown in Fig. 2.8.

The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is extended up to the patch antenna. The position of the feed can be altered as before (in the same way as the inset feed, above) to control the input impedance.

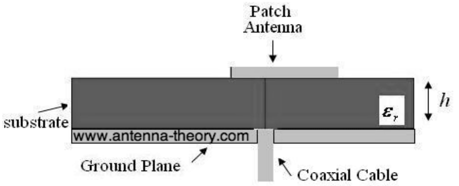

Fig 2.8. Coaxial cable feed of patch anteena

Advantages

Feed can be placed at any desired location inside the patch in order to match with its input impedance.

1. Low Spurious radiation.
2. It is easy to fabricate.

Disadvantages

1. Narrow bandwidth.
2. Difficult to model specially for thick substrate.

D. Coupled (Indirect) Feeds

The feeds above can be altered such that they do not directly touch the antenna. For instance, the probe feed in Fig. 3 can be trimmed such that it does not extend all the way up to the antenna. The inset feed can also be stopped just before the patch antenna, as shown in Fig. 2.9. Advantage of the coupled feed is that it adds an extra degree of freedom to the design. The gap introduces a capacitance into the feed that can cancel out the inductance added by the probe feed.

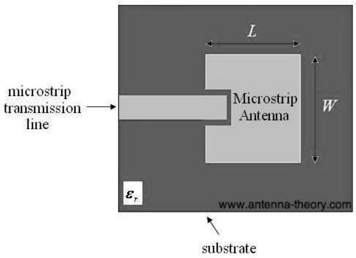

Fig 2.9. Coupled (indirect) Inset feed

E. Aperture Feeds

Another method of feeding microstrip antennas is the aperture feed. In this technique, the feed circuitry (transmission line) is shielded from the antenna by a conducting plane with a hole (aperture) to transmit energy to the antenna, as shown in Fig. 2.10. The upper substrate can be made with a lower permittivity to produce loosely bound fringing fields, yielding better radiation. The lower substrate can be independently made with a high value of permittivity for tightly coupled fields that don't produce spurious radiation. The disadvantage of this method is increased difficulty in fabrication.

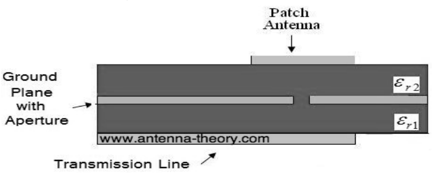

Fig 2.10. Aperture coupled feed

IV. APPLICATIONS OF FRACTAL CIRCULAR PATCH MICRO-STRIP ANTENNA

1. Astronomy: Fractals may be revolutionized the way that the universe is seen. Cosmologists usually assume that matter is spread uniformly across space. But observation shows that this is not true. Astronomers agree with that assumption on "small scales", but most of them think that the universe is smooth at large scales. However, a group of scientist claims that the structure of universe is fractals at all scales.
2. Nature: Take a tree for an example. Pick a particular branch and study it closely. Choose a bundle of leaves on that branch. All three of the objects describe- the tree, the branch and the leaves are identical. To many, the word chaos suggests randomness, unpredictability and perhaps even messiness.
3. Computer science: Actually the most useful use of fractal in computer science is the fractal image compression. This kind of compression uses the fact that real world is well described by fractal geometry. By the way, images are compressed much more than by usual way (example: JPEG format etc).
4. Medicines: Biosensors interaction can be studied by using fractal.
5. Surface Physics: Fractal used to describe the roughness of surface. A rough surface characterized by a combination of two different fractals.
6. Global positioning system: Such as tracking of vehicle as well as marine.

Fractal circular patch micro-strip antenna is also used in-

1. WLAN: Wireless local area network.
2. Bluetooth.
3. Wi-Max.
4. Wi-Fi application.
5. Satellite Communication.

V. ADVANTAGE OF FRACTAL CIRCULAR PATCH MICROSTRIP ANTENNA OVER CONVENTIONAL ANTENNA

1. Size can be shrunk from two to four times with surprising good performance.
2. Multimedia performance is at non-harmonic frequencies.
3. Improved impedance, improved SWR.
4. Physical area when compared to non fractal Euclidean geometries are small.
5. Reduced construction cost.
6. Improved reliability.

VI. WHY WE USE FRACTALS?

1. Traditionally single antenna can operate in single or dual frequency band. Where a different antenna is needed for different application. This will cause space and place problem. To overcome this problem multiband antenna can be used where a single antenna can operate at many frequency bands. One technique to construct multiband antenna is by applying fractal into antenna.
2. Numerical method were used to decrease the micro-strip patch antenna size such as making use of high dielectric materials, short circuit, ground planes, shorting pins, antenna environment and many more.

These methods are often narrowband and hard to implement. Enlarging the path of current on the patch by introducing notches and slots is one of the ways of miniaturizing the antenna size.

3. The most effective way to enlarge the perimeters of a shape, while maintaining same area is done by using fractals because it has size reduction ability.

VII. RADIATION PATTERN FOR DUAL BAND FRACTAL CIRCULAR PATCH MICRO-STRIP ANTENNA

The simulated radiation pattern of dual band fractal circular patch micro-strip antenna for c band application is shown in Fig.2.11. The radiation pattern has been observed well at the frequency given below-

At 7.12GHz

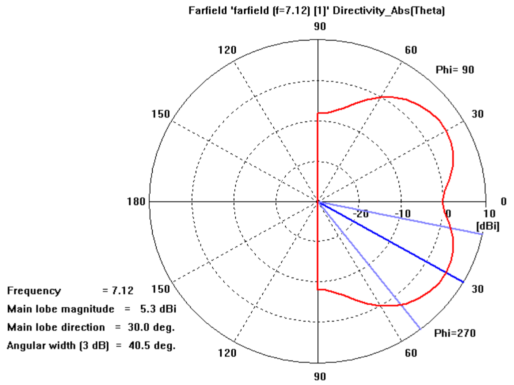

Fig 2.11. Radiation pattern of Dual band Fractal anteena for C- band application at 7.12 GHZ

VIII. CONCLUSION

The compact, multi- band fractal antenna presented in this report are excellent alternative to traditional antenna system. The antenna can operate at 6.6GHz and 7.5GHz for dual band fractal antenna and 4.4GHz, 6.4GHz and 7.5GHz at triple band fractal antenna and demonstrate space filling through its self similar fractal structure. Both the antennas offers increase in bandwidth and gain at all multiband as well as the size of antenna gets reduced. Such type of antenna are useful for Telecommunication, satellite communication, WI-FI, Wireless local area network, Commercial, Military and many more application. The goals of this design project were thus successfully accomplished.

IX. FUTURE WORK

Since the area of fractal antenna engineering research is still in its infancy, there are many possibilities for future work on this topic. A possible venue for future work is to investigate other type of fractals for antenna application. To further improve on the performance of this project, a few recommendation of future work suggested as follows:

1. To increase the bandwidth of a circular patch micro-strip antenna, a multilayer or stack can be done.
2. The polarization of this type of antenna can be investigated by changing the feed location.
3. The position of the ground plane can be changed to reduce the space.
4. More than one shorting pin is used to reduce the size of the antenna as well as for multi band.

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