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Design and Simulation of Dual and Triple Band Fractal Circular Patch Micro-Strip Antenna for C-Band Application

Rakesh Kumar

***Abstract*— In the design of the systems are always important Some applications require the antenna to be as miniaturized as possible. Fractal antennas have entered the view of many as a very promising solution. It would be highly beneficial to design an antenna with similar radiation properties as the quarter-wavelength monopole while retaining its radiation properties. Fractal antennas size can be shrunk from two to four times with surprising good performance. 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. Design dual and triple band fractal antenna for c-band application.**

***Index Terms*—Micro-strip antenna, fractal antenna, design of dual band and triple band fractal antenna.**

I. INTRODUCTION

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. 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. Fractal antenna theory uses a modern (fractal) geometry that is a natural extension of Euclidian geometry. 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.

It might be possible to discover structures that give us better performance than any Euclidean geometry could provide. Fractals represent a class of geometry with very unique properties that can be enticing for antenna designers. Fractals are space filling contours, meaning electrically large features can be efficiently packed into small areas [1]. Since the electrical lengths play such an important role in antenna design, this efficient packing can be used as a viable miniaturization technique.

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. 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.

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II. MICRO-STRIP ANTENNA

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. Fig.1. show the basic structure of Micro-strip antenna .Which consists radiating patch, substrate and ground plane. Bottom layer of dielectric is fully covered with conductor that acts as a ground plane. The thickness of substrate layer can increase the bandwidth and efficiency, but unfortunately it will generate surface wave with low propagation that causes lost of power [2-4].

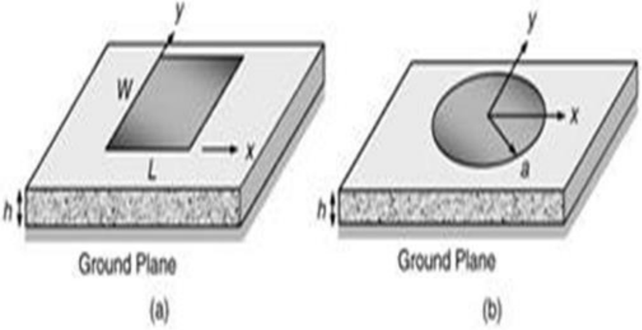


Fig 1. Basic Structure of Micro-Strip Antenna

III. FRACTAL 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. *Types of Fractal*

Fractal came into two major variations:
Deterministic Fractal
Random Fractal

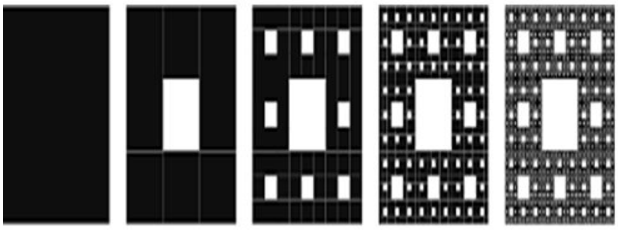


Fig 2. Sierpinski Carpet Fractal Geometry

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.

C. Fractals Geometry

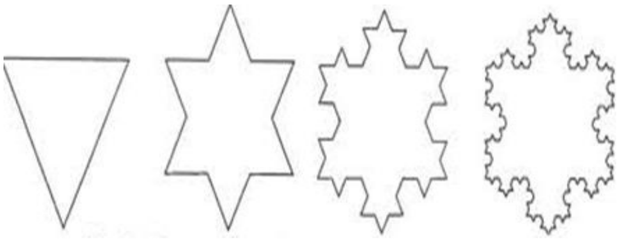


Fig 3. Koch Curve Fractal Geometry

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:

D. 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. It can be shown in a polar plot 360 degree. 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.

E. Bandwidth, BW

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 %:

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

III. DESIGN OF DUAL BAND FRACTAL CIRCULAR PATCH MICROSTRIP ANTENNA FOR C-BAND APPLICATION

A. Operating Frequency

The circular patch antenna with fractal produces a dual band operation for the C-band application. Range of C- band is 4GHZ - 8 GHz. The designed antenna is operates for dual band at 6.6GHz and 7.5GHz with increase in gain and bandwidth. Such type of antenna in range of C-band is useful in Telecommunication, Satellite communication, Radar , Wi-Fi, Commercial and Military application.

B. Antenna Geometry

The antenna structure based on a fractal geometry shown in Fig. 4. This antenna has been designed on the substrate dielectric constant Ɛr= 2.3, thickness = 4mm with L-probe feeding. In the designing of a circular antenna, the following formula was implemented to calculate the radius of the circle.

$$a = K_{nm} \times c / 2 \times 3.14 \times f_{nm} \times er \qquad (4.1)$$

where,

f_{nm} = resonant frequency of the circular patch.

c = velocity of light in free space.

Ɛr= relative permittivity of the medium.

K_{nm} = mth zero of derivative of Bessels function of order n.

In our application we have considered the fundamental mode TM_{11} for which K value is 1.84118.

So,

$$a = (1.84118 \times 3 \times 10^8)/(2 \times 3.14 \times 4 \times 10^9 \times \sqrt{2.3})$$

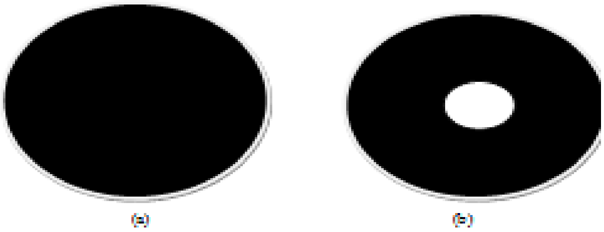
= 14.4mm

After optimized,

a = 16mm

This equation 4.1 is been used to determine the all necessary dimension of micro-strip patch antenna. The most significant parameter required for the design of this antenna is the radius (a). The results are very sensitive to change in a radius of antenna.

A circular patch micro-strip antenna of radius a = 16mm has been taken as base to fractal antenna. In the first iteration shown in figure 4. (b) we divide this circle into five small circle with radius = 5.1mm and then removed the circle at the centre as the remaining circle is four. In the 2nd iteration shown in figure 4. (c) we divide each remaining four circle into five circle of radius = 1.35mm. Then the entire centre circle for each remaining circle. The remaining small circle for this stage is sixteenThe entire centre circle for each remaining circle is omitted. The infinite iterative structures are not possible due to the fabrication constraint.



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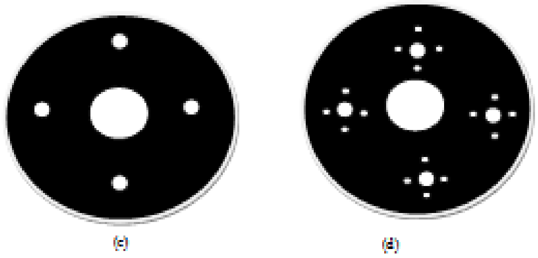

Fig 4. Geometry for each antenna

C. Calculation for Different Iterations Of Circular Patch Antenna Is Shown In Table 4.1

First Iteration: For basic circular patch antenna the total area is (3.14*16*16), A0=803.84mm^2. After first iteration there total area become =722.16mm^2. Area for small circle is 81.6mm^2.The A1 is the scale factor for the fractional area after first iteration.

Second Iteration: The A2 is the scale factor for the fractional area after second iteration. After second iteration the total area become 716.44mm^2.Area for one small circle is 5.1mm^2 and the total area for small circle that has been removed is5.72mm^2.

First iteration	Second iteration
Area1=803.84mm^2- 81.6714mm^2 =722.16mm^2 A1=Area1/A0 =722.16/803.84 =.898 N1=No. of circle=5^1 L1=Scale factor for radius of circle =(1/3)^1 =.333 .333*16=5.3mm After optimized, 5.1mm=radius for small circle.	Area2=Area1- 5.72mm^2 =722.16mm^2- 5.72mm^2 =716.44mm^2 A2=Area2/A0 = 716.44/803.84 =.891 N2=No. of circle=5^2 L2=Scale factor for radius of circle =(1/3)^2 =.111 .111*16=1.7mm After optimized, 1.35mm=radius for small circle.

D. Signal Feed System

There are number of techniques to feed signal to a micro-strip patch, although the most advantageous for this design is L –probe feeding [6-8]. A description of technique is included in Fig. 5.

E. L Probe Feeding

To obtain a large bandwidth this type of feeding is used. In particular L-probe antenna has an excellent feeding structure suitable for wideband patch antenna with an air substrate [9-10]. In general, this type of field can easily be implemented by bending a straight strip or probe into an L shape. The L –feed antenna not only perform better in respect of bandwidth but radiation pattern is also good.

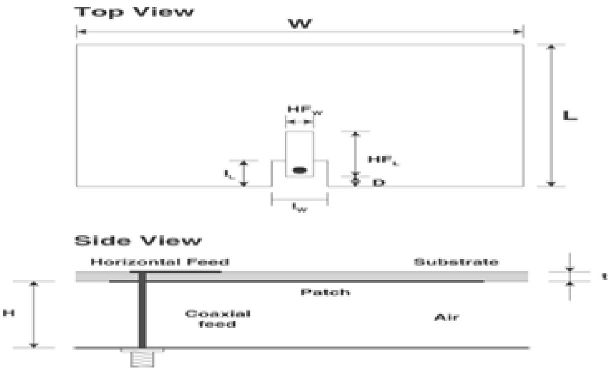

Fig 5. Probe Feed Technique

F. Software Simulation

The designed model is simulated using CST microwave studio software based on finite difference time domain method. CST is stand for computer simulation techniques. The simulated result for various parameters like return loss, radiation pattern and gain has been obtained from this software.

Table 4.1 shows the various parameters used in the designing of dual band fractal circular patch antenna for c-band.

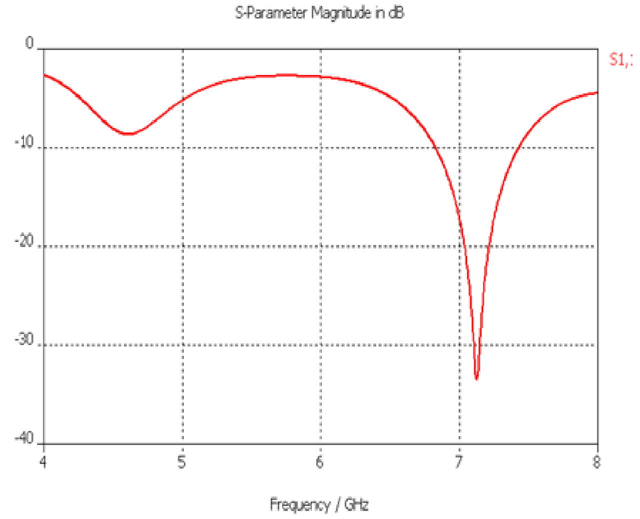

Figure 6. Return loss response of circular patch antenna 0th iteration.

G. Simulation Result

The simulation result for return loss at 0th iteration is shown in fig 7. there exist one band frequency around 7.12 GHz and return loss is quite around -35dB.Bandwidth in percentage for 7.12GHz is around 8.87 and gain is 6.77 shown in Table 4.2.

Table 4.2. Operating frequency, frequency band, bandwidth and gain for 0^{th} iteration

Circular patch antenna	Operating frequency	Frequency band(GHz)	Bandwidth(GHz)	Gain(dBi)
0^{th} iteration	7.12GHz	6.8243-7.4505	.6198(8.67%)	6.77

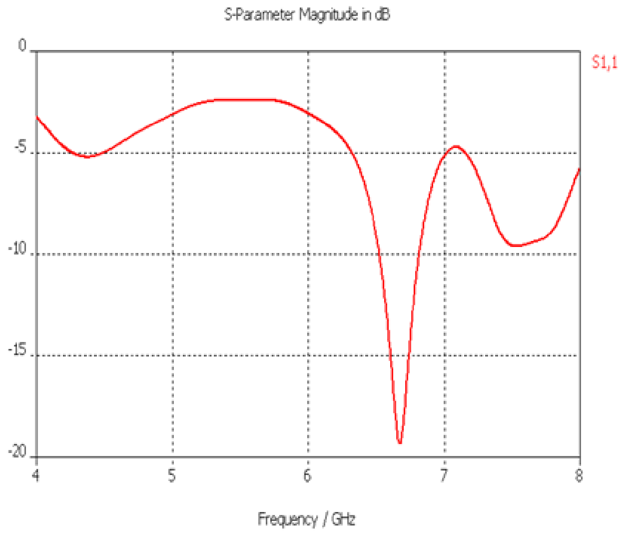

Fig 7. Return Loss Response of Circular Patch Antenna At 1st Iteration

Table 4.3 Operating frequency, frequency band, bandwidth and gain for 1st iteration

Circular patch antenna	Operating frequency	Frequency band(GHz)	Bandwidth(GHz)	Gain(dBi)
1st iteration	6.6GHz	6.524-6.8243	3003(4.5%)	6.28

Then the same antenna is fractal again for 1st iteration. The results are shown in Table 4.3 and Fig 7. Only one frequency band are existing at 6.6GHz with bandwidth of 4.5 in percentage and gain of 6.28 and return loss response is reached at -20dB.

When the same result is fractal to 2nd iteration two frequency bands exist at 6.6GHz and 7.5GHz with increase in bandwidth. Return loss response is reached at -18dB for 6.6GHz and -12dB for 7.5GHz. The results are shown in figure 4.5 and Table 4.4.

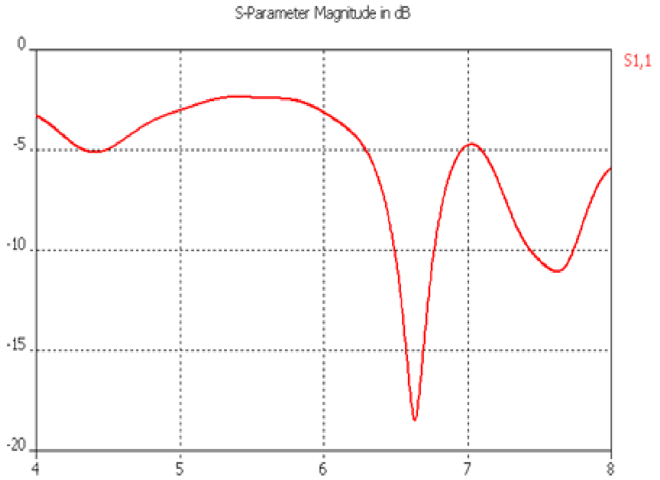

Fig 8. Return loss response of circular patch antenna at 2nd iteration

Table 4.4 Operating frequency, frequency band, bandwidth and gain for 2nd iteration

Circular patch antenna	Operating Frequency	Frequency band(GHz)	Bandwidth(GHz)	Gain(dBi)
2nd iteration	6.6GHz	6.4984-6.7796	.2812(4.23%)	6.29
2nd iteration	7.5GHz	7.738-7.441	.293(3.86%)	7.62

Table 4.5 S11 result for measured and simulated circular patch antenna.

Circular patch antenna	Operating Frequency	Frequency band(GHz)	Bandwidth(GHz)
0th iteration	7.12Ghz	6.8243-7.4505	.6198(8.67%)
1st iteration	6.6Ghz	6.524-6.8243	.3003(4.5%)
2nd iteration	6.6Ghz	6.4984-6.7796	.2812(4.23%)
2nd iteration	7.5Ghz	7.738-7.441	..293(3.86%)

Table 4.6 Gain result for simulated circular patch antenna.

Circular patch antenna	Efficiency	Directivity	Gain(dbi)
0th iteration	.9923	6.832	6.77
1st iteration	.9776	6.429	6.28
2nd iteration	.9807	6.422	6.29
2nd iteration	.9987	7.636	7.62

H. 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. 9 – 12 shows the radiation pattern different iteration. The radiation pattern has been observed well at all the frequency.

At 7.12GHz

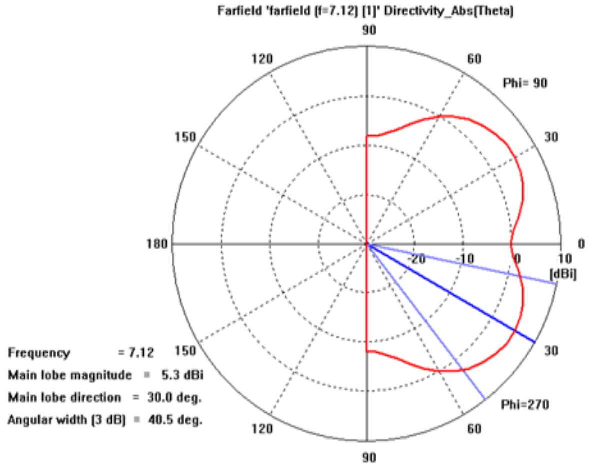

Fig 9. Radiation Pattern At 0th Iteration.

At 6.6GHz

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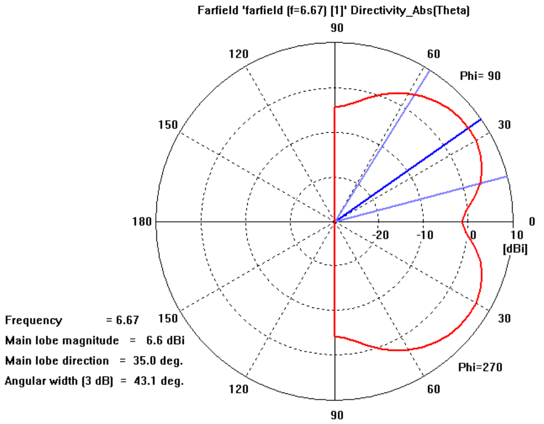

Fig 10. Radiation Pattern At 1st Iteration

At 6.6GHz

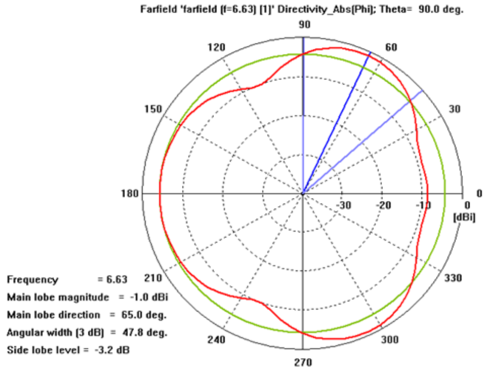

Fig 11. Radiation Pattern At 2nd Iteration.

At 7.5GHz

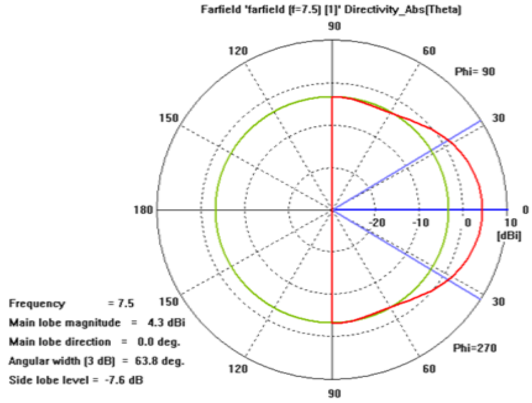

Fig 12. Radiation Pattern At 2nd Iteration

V. DESIGN OF TRIPLE BAND FRACTAL CIRCULAR PATCH ANTENNA FOR C – BAND APPLICATION

The fractal antenna has been designed on the substrate with dielectric constant 2.3 and thickness is 4mm and a shorting pin of radius 1mm. The design antenna has been fed with L-probe feeding. The proposed circular patch antenna produces a triple band operation for C-band application.

A. Operating Frequency

The operating frequencies at which the designed antenna work is in the range of C- band (4 GHz – 8 GHz). This antenna produces a triple band operation for C-band application. The designed antenna operates for triple band are at 4.4GHz and 6.4GHz and with increase in gain, bandwidth and reduction in antenna size. Such type of antenna operating at these frequencies is useful in many applications like Telecommunication, Satellite communication, Military and many more.

B. Antenna Geometry

The antenna structure based on fractal geometry is shown in Fig. 5.1.This shows the dimension of geometry. This antenna has been designed on the substrate with dielectric constant of 2.3, thickness of 4mm with L-probe feeding and shorting pin. In the designing of a circular antenna, the following formula was implemented to calculate the radius of the circle.

$$a = K_{nm} \times c/2 \times 3.14 \times f_{nm} \times er \qquad (5.1)$$

where,

f_{nm} = resonant frequency of the circular patch.

c = velocity of light in free space.

Ɛr= relative permittivity of the medium.

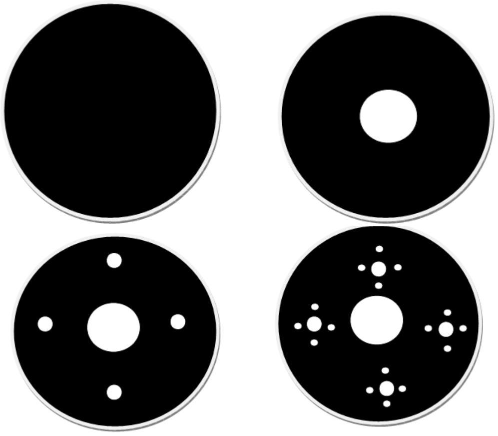

Fig 13. Geometry for each antenna

K_{nm} = mth zero of derivative of Bessel’s function of order n. In our application we have considered the fundamental mode TM_{11} for which K value is 1.84118.

So,

$$a = (1.84118 \times 3 \times 10^8)/(2 \times 3.14 \times 4 \times 10^9 \times \sqrt{2.3})$$

= 14.4mm

After optimized,

a = 16mm

This equation 4.1 is been used to determine the all necessary dimension of micro-strip patch antenna. The most significant parameter required for the design of this antenna is the radius (a). The results are very sensitive to change in a radius of antenna.

A circular patch micro-strip antenna of radius a = 16mm has been taken as base to construct fractal antenna. The 3rd iterative structure has been generated from this circular patch. In the first iteration shown in fig 13. (b) we divide this circle into five small circle with radius = 5.1mm and then removed the circle at the centre as the remaining circle is four. In the 2nd iteration shown in Fig 13. (c) we divide each remaining four circle into five circle of radius = 1.35mm. Then the entire centre circle for each remaining circle. The remaining small circle for this stage is sixteen.

C. Calculation For Different Iterations Of Circular Patch Antenna Is Shown In Table 5.1

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Table 5.1: Calculation for different iteration of circular patch antenna.

First iteration	Second iteration
Area1=803.84mm^2- 81.6714mm^2 =722.16mm^2 =722.16/803.84 =.898 N1=No. of circle=5^1 L1=Scale factor for radius of circle =(1/3)^1 =.333 .333*16=5.3mm After optimized, 5.1mm=radius for small circle.	Area2=Area1- 5.72mm^2 =722.16mm^2- 5.72mm^2 =.891 N2=No. of circle=5^2 L2=Scale factor for radius of circle =(1/3)^2 =.111 0.111*16=1.7mm After optimized, 1.35mm=radius for small circle.

First Iteration: For basic circular patch antenna the total area is (3.14*16*16), A0=803.84mm^2. After first iteration there total area become =722.16mm^2. Area for small circle is 81.6mm^2.The A1 is the scale factor for the fractional area after first iteration.

Second Iteration: The A2 is the scale factor for the fractional area after second iteration. After second iteration the total area become 716.44mm^2.Area for one small circle is 5.1mm^2 and the total area for small circle that has been removed is 5.72mm^2.

D. Effect Of Shorting Pin

The trends for technology in recent times are towards miniaturization and demand for more compact and robust design has been growing. In some application operation at two or more bands and an arbitrary separation of band is desired. Further all bands may be required to have the same polarization, radiation pattern and input impedance characteristics. Therefore short circuit micro-strip antenna is widely used because the.

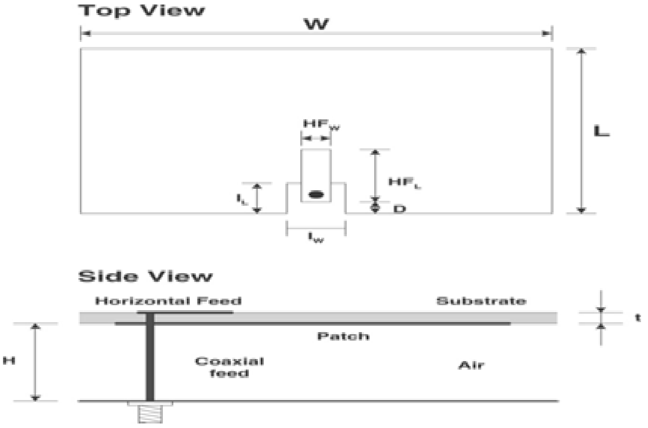

Fig 14. L-Probe Feeding Technique

Short circuit antenna can realized the same resonant frequency, at about half of the size of standard micro-strip antenna. Physically this short circuit may be complete by wrapping a copper strip around the edge of the antenna or it may be simulated by shorting post. [11]. By loading of micro-strip antenna with shorting post, the size of the micro-strip antenna is reduced as well as multi frequencies operations can be achieved. Depending on the application, shorting pin may be located at the edge or centre of the patch. However the effect of the shorting post depends on different parameters like number of post, the radius of each post and the thickness of micro-strip antenna which determine the length of the post.

Table 5.2: Geometry Parameters

Shape	Circular
Frequency of operation	4.4GHz 6.4GHz
Dielectric constant of substrate	2.3
Height of dielectric substrate	4mm
Feeding method	L-Probe feeding
Applications	Telecommunication, satellite communication, commercial, military Wi- Fi etc
Maximum iteration	3

In this antenna design the shorting pin is of radius 1mm with PEC as a dielectric and thickness of micro-strip antenna which determines the length of the pin is 4mm and the pin is situated at the edge of the patch.

E. Signal Feeding Technique

There are number of techniques to feed signal to a micro-strip patch, although the most advantageous for this design is L –probe feeding. A description of technique is included in Fig.5.2.

F. L Probe Feeding

To obtain a large bandwidth this type of feeding is used. In particular L-probe antenna has an excellent feeding structure suitable for wideband patch antenna with an air substrate. In general, this type of field can easily be implemented by bending a straight strip or probe into an L shape. The L –feed antenna not only perform better in respect of bandwidth but radiation pattern is also good.

G. Software Simulation

The designed model is simulated using CST microwave studio software based onfinite difference time domain method. CST is stand for computer simulation techniques. The simulated result for various parameters like return loss, radiation pattern, gain etc have been obtained from this software. Table 5.2 shows the various parameters used in the designing of dual band fractal circular patch antenna for c-band application.

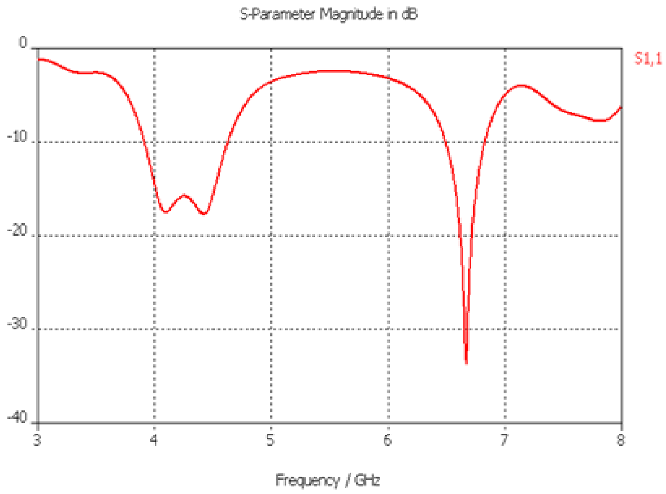

Fig 15. Return Loss Response Of Circular Patch Antenna At 1st Iteration

Table 5.3: operating frequency, frequency band, bandwidth and gain for 1st iteration

Circular patch antenna	Operating frequency	Frequency Band (GHz)	Bandwidth (GHz)	Gain(dBi)
1st iteration	4.4GHz	3.9105-4.6294	.7189(16.8%)	8.4238
1st iteration	6.6GHz	6.4904-6.8259	.3355(5%)	6.4915

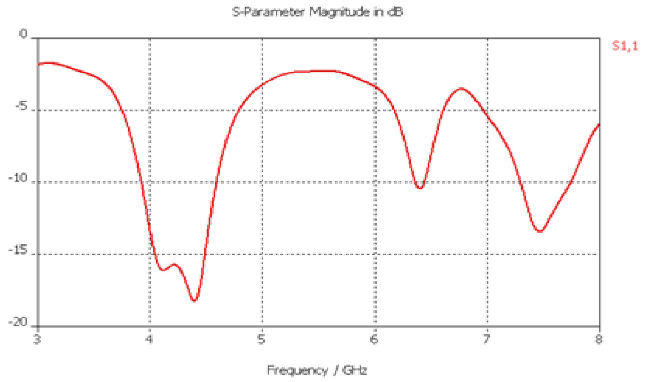

Fig 16. Return Loss Response Of Circular Patch Antenna At 2nd Iteration

Table 5.4: Operating frequency, frequency band, bandwidth and gain for 2nd iteration

Circular patch antenna	Operating frequency	Frequency Band GHz)	Bandwidth (GHz)	Gain(dBi)
2nd iteration	4.4GHz	3.9345-4.5974	.6629(15.5%)	8.5049
2nd iteration	6.4GHz	6.3706-6.4505	.0799(1.2%)	5.4261
2nd iteration	7.5GHz	7.2971-7.7524	.4883(6%)	6.809

H. Radiation Pattern For Triple Band Fractal Circular Patch Micro-Strip Antenna

Table 5.5. S11 result for measured and simulated circular patch antenna.

Circular patch antenna	Efficiency	Directivity	Gain(dbi)
1st iteration	.9834	8.566	8.4238
1st iteration	.9750	6.658	6.4915
2nd iteration	.9886	8.603	8.5049
2nd iteration	.6675	8.129	5.4261

Table 5.6. Gain result for simulated circular patch antenna

Circular patch antenna	Operating frequency	Frequency band(GHz)	Bandwidth(GHz)
1st iteration	4.4GHz	3.9105-4.6294	.7189(16.8%)
1st iteration	6.6GHz	6.4904-6.8259	.3355(5%)
2nd iteration	4.4GHz	3.9345-4.5974	.6629(15.5%)
2nd iteration	6.4Ghz	6.3706-6.4505	.0799(1.2%)
2nd iteration	7.5GHz	7.2971-7.7524	.4553(6%)

At 4.4GHz

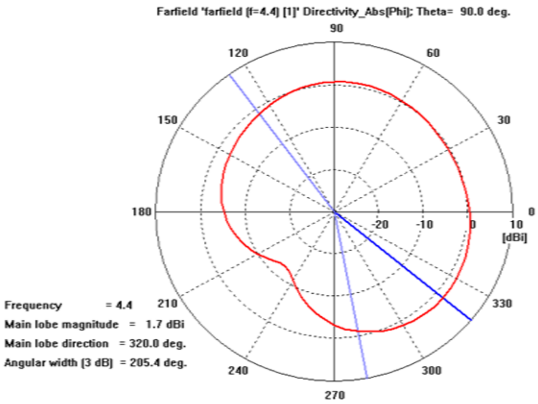

Fig 17. Radiation Pattern At 1st Iteration

At 6.6GHz

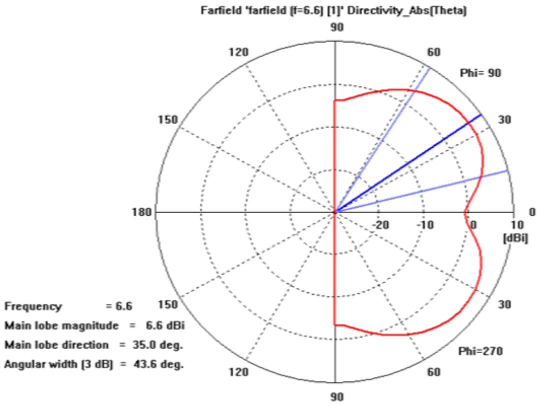

Fig 18. Radiation Pattern At 1st Iteration

At 4.4GHz

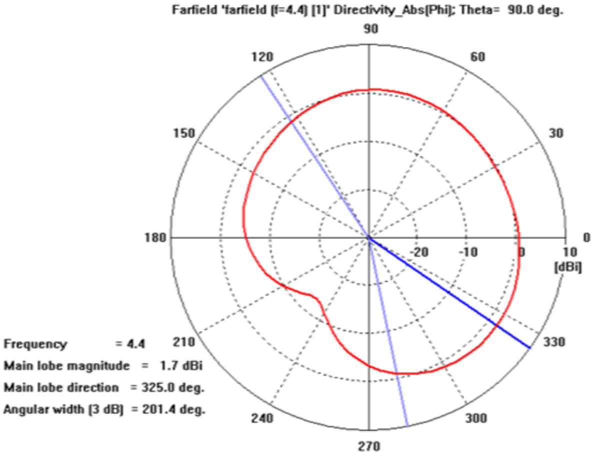

Fig 19. Radiation Pattern At 2nd Iteration

At 6.4GHz

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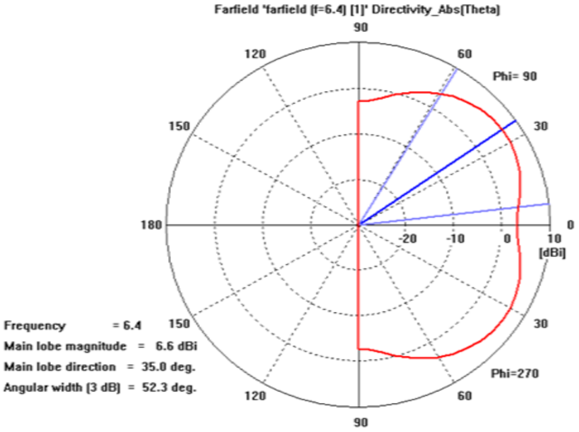

Fig 20. Radiation Pattern At 2nd Iteration

VI. CONCLUSION

The antenna can operate at 6.6GHz and 7.5GHz for dual band fractal antenna and 4.4GHz and 6.4GHz at triple band fractal antenna. Both the antennas offers increase in bandwidth and gain at all multiband as well as the size of antenna gets reduced. Further increase the bandwidth of a circular patch micro-strip antenna, a multilayer or stack can be done. The polarization of this type of antenna can be investigated by changing the feed location.

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