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Circular and Elliptical Shaped Fractal Patch Antennas for Multiple Applications

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***Abstract:** In this paper fractal concept is applied to the antenna patch. Two antennas are designed of circular and elliptical shaped fractal patch.Antennas aredeigned and simulated up to iteration-3 in CST software. The designedcircular fractal antenna resonates in 1GHz to 12 GHz frequency bands and provides good gain at resonating frequencies. Ellipse shaped fractal antenna resonates in frequency band of 1GHz to 12GHz. Good bandwidth and positive gain is achieved. The designed antennas have multiple applications in bands of 1GHz to 12 GHz like2.4 GHz for Wi-Fi, 4-6 GHz band frequency for C band applications and 8-12 GHZ forradar, satellite communication and wireless computer networks.The designed antennas are fabricated and tested using microwave vector network analyzer (VNA). Measured and simulated results are compared.*

***Index Terms**: antenna, circle, ellipse,fractal, micro strip patch.*

I. INTRODUCTION

Now a days, demand forwireless services is increased for high data rate. This can be fulfilled by compact size antenna. Fractal antenna has two basic properties: multiband (more than one resonating frequency band) and miniaturization (small size) [1]. In fractal, self-similar structure is generated but at small scale [2]. So fractal concept is applied to antenna geometry.

A circle fractal antenna of size 28mm x 112mmis presented. The antenna is fabricated for 2-16 GHz bands with bandwidth 64% [3]. A multiband fractal antenna of size 90mm x 90 mm is simulated for RF energy harvesting [4]. Antenna operating frequencies are 2.4GHz, 5.8 GHz. Other circlefractal antennas are reported in literature [5-7]. Ellipse shaped slot cut antenna is fabricated and tested for frequencies 1.32GHz, 1.66 GHz and 2.01 GHz [8]. It is designed for dual band. Elliptical patch antennas are reported [9-10]. Patch antennas of different shapes are reported in literature like square, triangular, octagon, decagon etc. Similarly a hexagonal shaped fractal patch antenna for ambient computing applications is presented [11]. The presentpaper is divided into three sections. Section-2 gives antenna design and simulated results. Section-3 gives measured results and conclusion is given in section-4.

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II. ANTENNA DESIGN

A. Circular Fractal

Theantenna is designed using FR-4 of size 60 x63 mm^2. Micro strip feed of width 2.3mm and length 9.6 mmis taken. Ground of size 60 mm x 9.5mm is considered.Iteration –0 is a single mono pole circle of radius 24.5mm. Iteration-0 is designed for frequency 1.68 GHz. For circular patch radius (R), resonating frequency (f_r)is given by equation (1-2) [12]

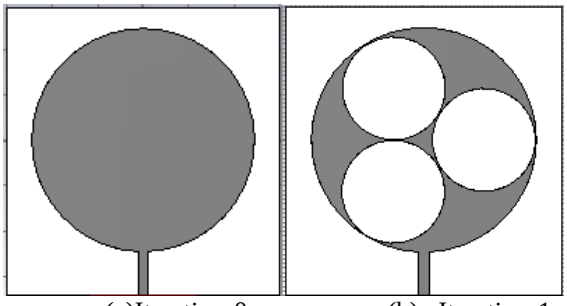
$$R = \frac{F}{\{1+\frac{2h}{\pi\varepsilon_{rF}}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\}^{\frac{1}{2}}} \quad (1)$$

Where $F = \frac{8.791*10^9}{f_r\sqrt{\varepsilon_r}}$ (2)

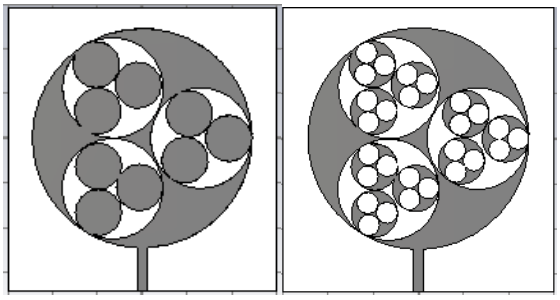
Now f_r=1.68 *10^9 Hz, h = 0.16 cm, ε_r=4.4

So $F = \frac{8.791*10^9}{1.68*10^9\sqrt{4.4}}$= 2.498≅ 2.5

Then by solving the equation (1) circular patch radius (R) is obtained as24.5 mm.



(a)Iteration-0 (b) Iteration-1



(c) Iteration-2 (d) Iteration-3

Fig 1:Fractal- CircleIterations

Fractals are not restricted to geometric shapes and designs, but can depict processes in time involving bio and nature-inspired problems. There have been recent works on biological, natural antennas and cavity resonators also[13-19]. Circle is considered because it is symmetric in nature. Iteration-1 is generated by dividing the monopole circle into three small circles and these three circles are subtracted from monopole circle.

Then iteration 1's circles are filled with circles of smallerradiiand iteration-2 is achieved. Final iteration is achieved by subtracting three small circles from each smaller circle of iteration-2.So in iteration-3 total 27 circles are subtracted. In each iteration radius fractal ratio of 1.27 is maintained. Circle fractal iterationsareshown in fig 1.

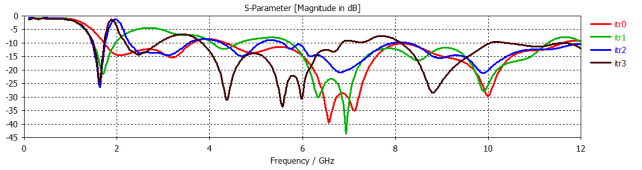


Fig 2: Reflection Coefficients of Fractal-Circle Iterations

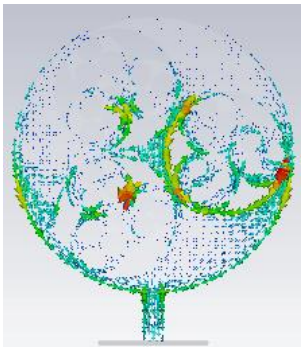
Reflection coefficients of fractal-circle iterationsareshown in above fig 2. In all iterations instead of full ground, less ground of size 9.5mm is considered. Resonating frequency and bandwidth of iteration-3 is summarized in table1.

Table 1: Resonating Frequency and Bandwidth of Circle Fractal Iterations.

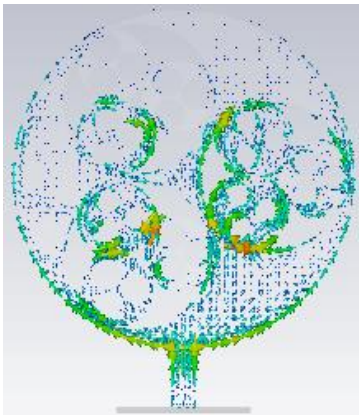
Iteration	Resonating Frequency (GHz)	Lower frequency (GHz)	Upper frequency (GHz)	BW (%)
3	1.62	1.49	1.72	14%
	2.45	2.19	2.90	29%
	4.37	3.84	6.84	56%
	5.56			
	6.0			
	8.81	8.14	10.04	22%

Here total six resonating frequencies in range of 0.1GHz to 12 GHzareachieved in iteration-3. Here at 1.62 GHz bandwidth of 14%, at 2.45 GHz bandwidth of 29%, 4.37GHz, 5.56 and 6.0 GHz of bandwidth 56%and at 8.81 GHz bandwidth of 22% is achieved.All bandwidths are considerable.

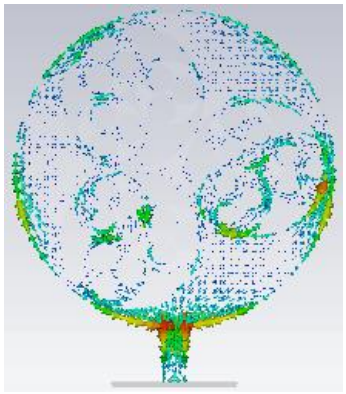
Fig 3 illustrates surface current distribution of the designed circle fractal antenna.



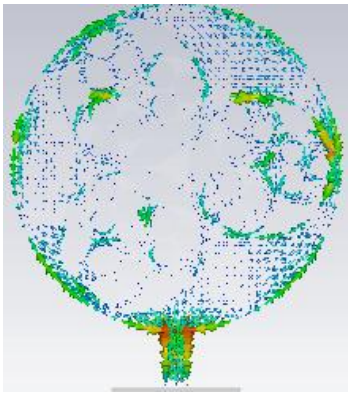
(a) 1.62 GHz



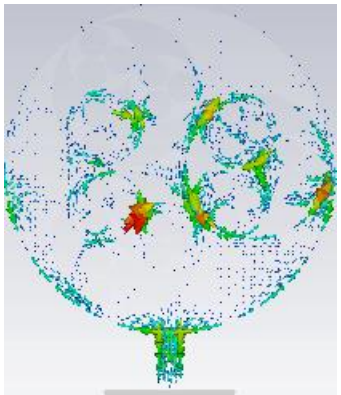
(b) 2.45 GHz



(c) 4.37 GHz



(d) 5.56 GHz



(e) 6.0 GHz

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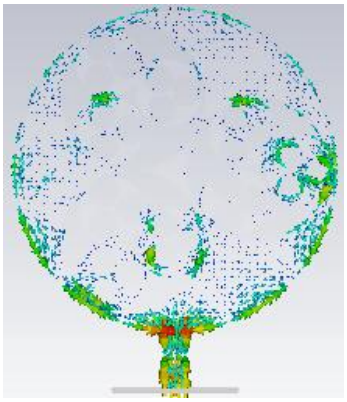
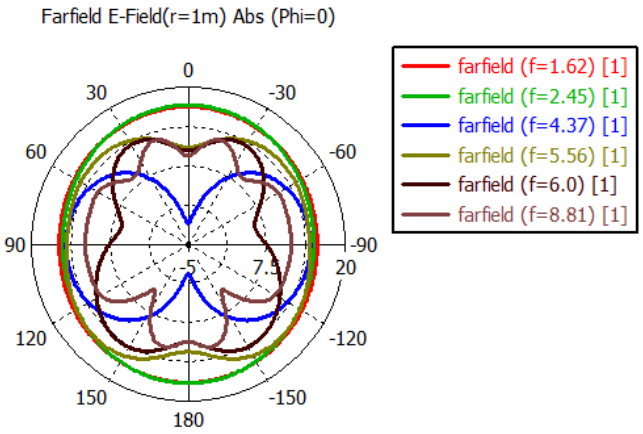


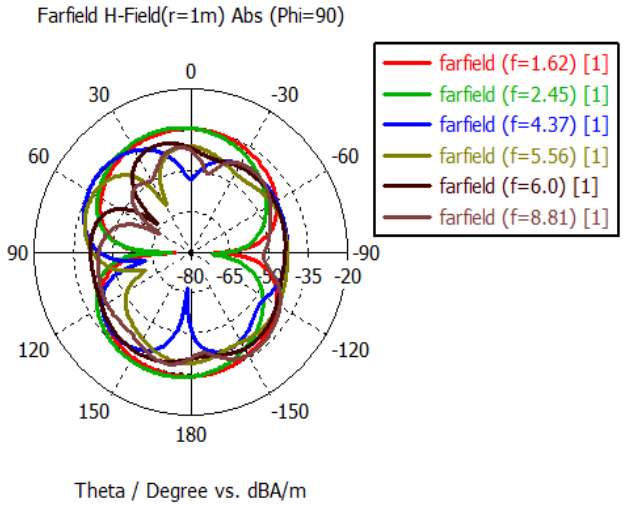
(f) 9.46 GHz

Fig 3: Surface Current Distribution of Fractal-CircleIteration-3

Fig 3 illustratesthat surface current distribution at each resonating frequency is symmetric in nature due to circularsymmetry.



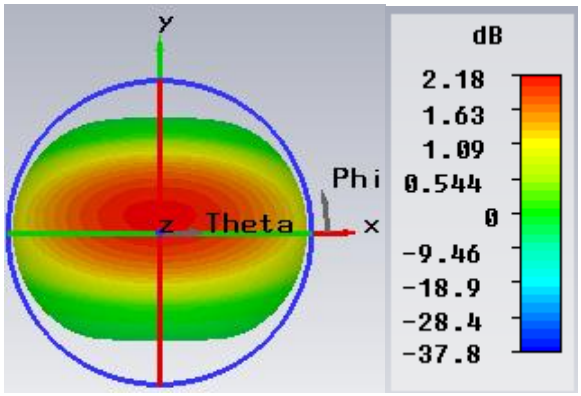
(a) E field radiation pattern at different frequencies



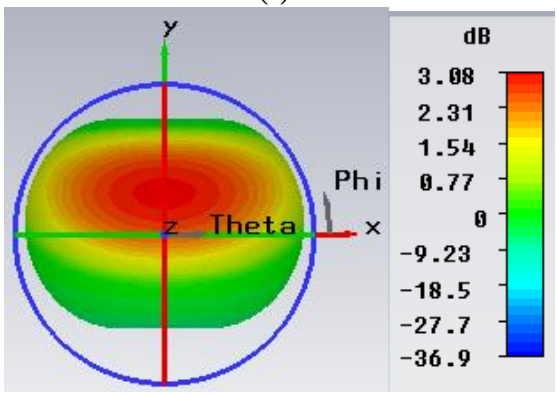
(b) H field radiation pattern at different frequencies

Fig 4: Radiation Pattern of E and H Field

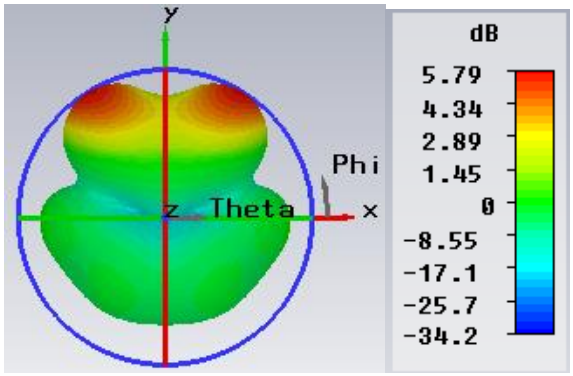
Electric and magnetic field distribution of iteration-3 is shown in fig 4.



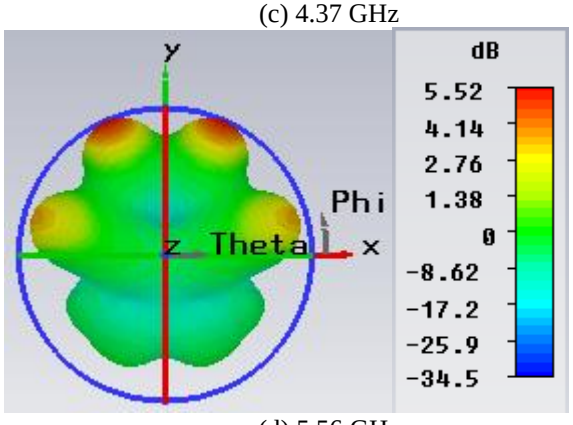
(a) 1.62 GHz



(b) 2.45 GHz



(c) 4.37 GHz



(d) 5.56 GHz

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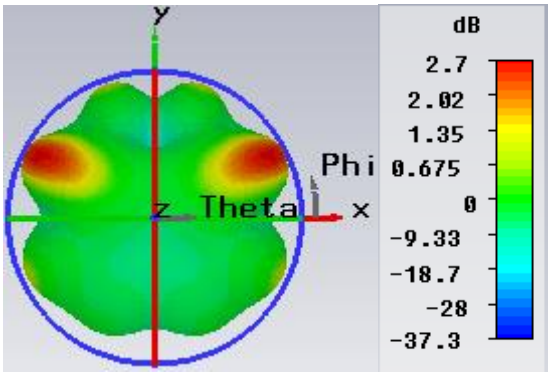
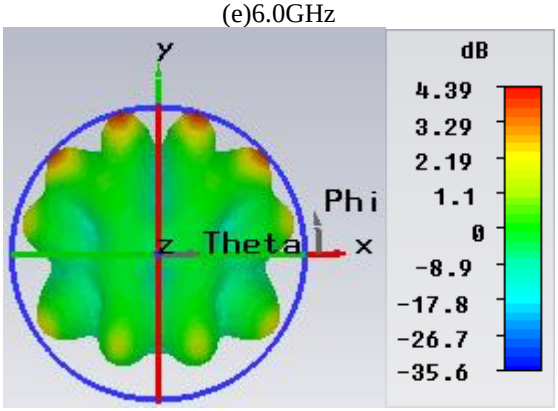


(e)6.0GHz



(f) 8.81 GHz

Fig 5: Gain for Fractal – Circle Iteration-3

Fig 5 gives the gain for thecircularfractal antenna. Here positive gain is achieved of minimumvalue 2.18 dB at 1.62 GHz andofmaximum value5.79 dB at 4.37 GHz.

B. Elliptical Fractal

Next designed antenna is fractalellipse. FR-4 substrate of size 56mm * 42mm is considered. Ellipse is having tworadiir1(major axis) = 24.5mm and r2 (minor axis) =16.0mm. Fractal concept is applied to the patch to generate iterations 1, 2 and 3. Ellipse shaped patch antennas are presented in [20-22].

Ellipse has two axes: major axis (r1) and minor axis(r2). In Iteration-0, resonating frequency of elliptical patch is calculatedaccording to the following equations[23]

$$\text{Eccentricity of ellipse (e)} = \sqrt{\frac{(r1)^2-(r2)^2}{(r1)^2}} \quad (3)$$

$$q_{11} = -0.00492 * e + 3.788 * e^2 - 0.7278 * e^3 + 0.314 * e^4 \quad (4)$$

$$a_{eff} = r1\ [1+ (\frac{2*h}{r1*\pi*\varepsilon_r}) (\ln\ (\frac{a}{2*h}) + (1.41 *\varepsilon_r + 177) + \frac{h}{r1}(0.268 *\varepsilon_r + 1.65))] \quad (5)$$

$$\text{(Resonating frequency) } f_{11} = \frac{15}{\pi*e*a_{eff}\sqrt{\frac{q_{11}}{\varepsilon_r}}} \quad (6)$$

The proposed elliptical patch has r_1= 2.45 cm,r_2 =1.6 cm, h=0.16cm,

So eccentricity of ellipse (e) from equation (3) is 0.76

Now next step isq_{11}= 2.643 (from equation -4)

Effective axis (a_{eff})=3.24

So resonating frequency f_{11}= 2.50 GHz

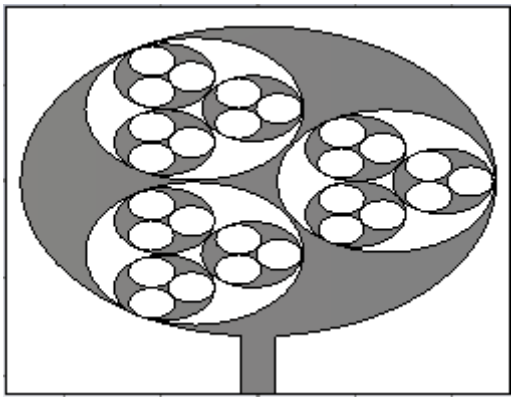


Fig 6: Ellipse Fractal Iteration-3

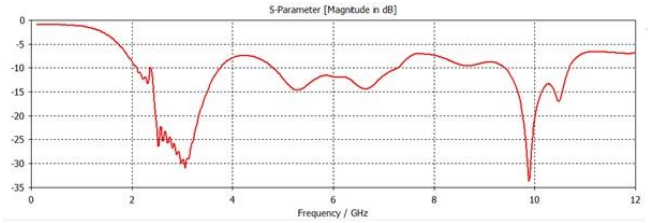
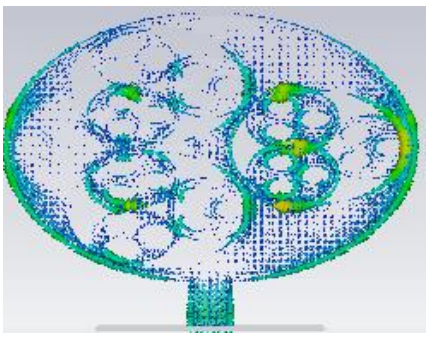


Fig 7: Reflection Coefficient of Fractal-EllipseIteration-3

Table 2: Resonating Frequency and Bandwidth of FractalEllipse

Itr-3	Resonating frequency (GHz)	Lower frequency (GHz)	Upper frequency (GHz)	BW (%)
	2.96	2.10	3.74	55.4%
	5.28	4.81	7.27	40.9%
	6.74			
	9.90	9.40	10.68	12.2%
	10.47			

Reflection coefficient of fractal–ellipse;iteration-3 is shown in fig 7. It is clear from above figures and table that above antenna resonates at five different frequenciesof maximum bandwidth 55.4% and minimum bandwidth of 12.2%. Minimum gain of 2.74 dB and maximum of 5.14dB is obtained.



(a) 2.96 GHz

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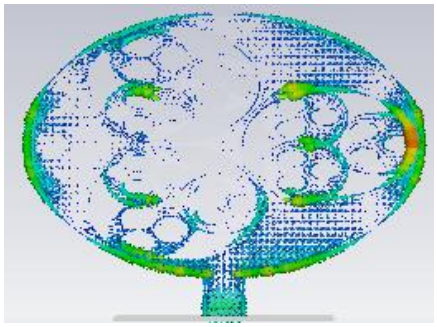
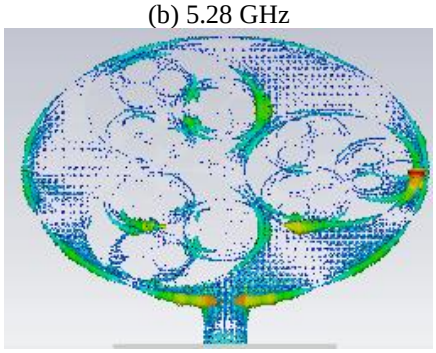
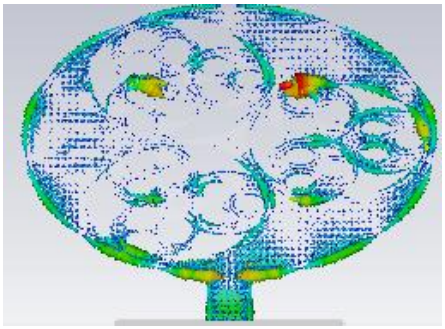


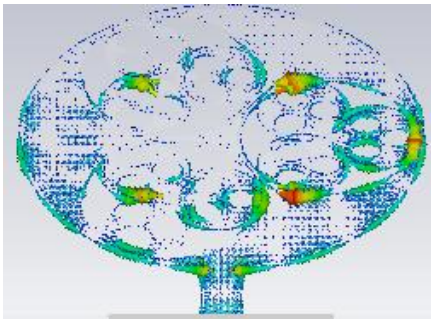
(b) 5.28 GHz



(c) 6.74 GHz



(d) 9.90 GHz



(e) 10.47 GHz

Fig 8: Surface current distribution of fractal- ellipse iteration-3

Surface current distribution in fractal-ellipseisalsosymmetric as shown in fig 8.

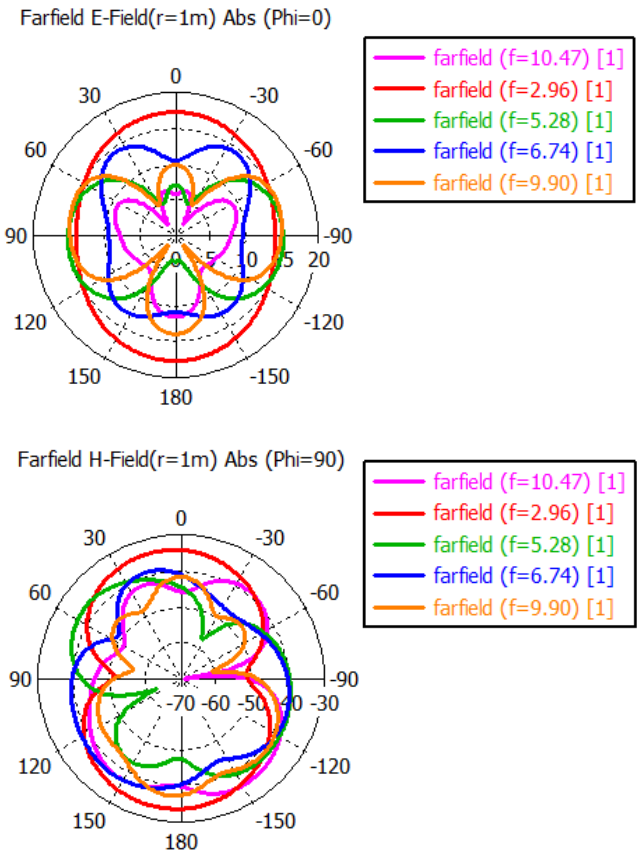
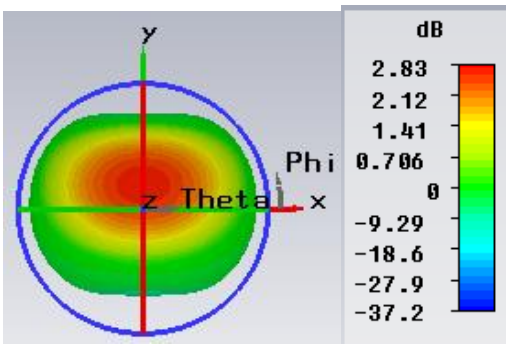
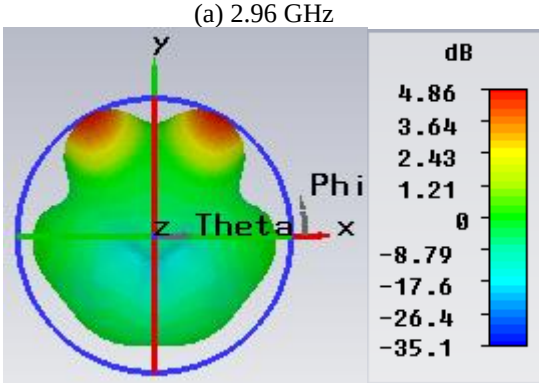


Fig 9: H and E field Distribution



(a) 2.96 GHz



(b) 5.28 GHz

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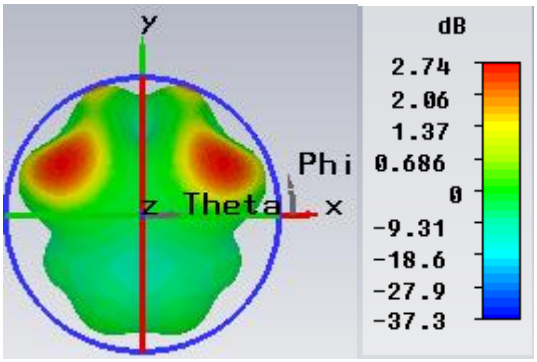
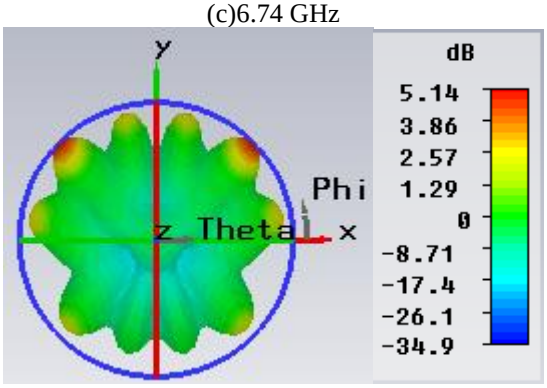
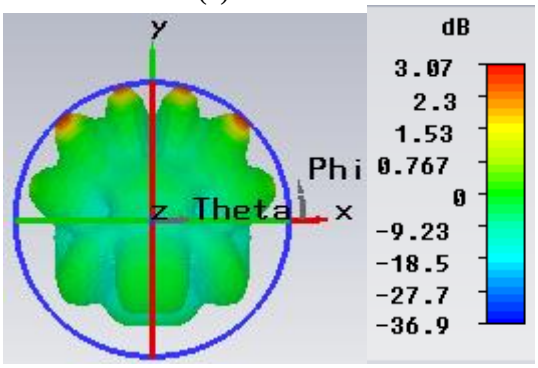


(c)6.74 GHz



(d) 9.90 GHz



(e) 10.47 GHz

Fig 10. Gain of Fractal- Ellipse Iteration-3

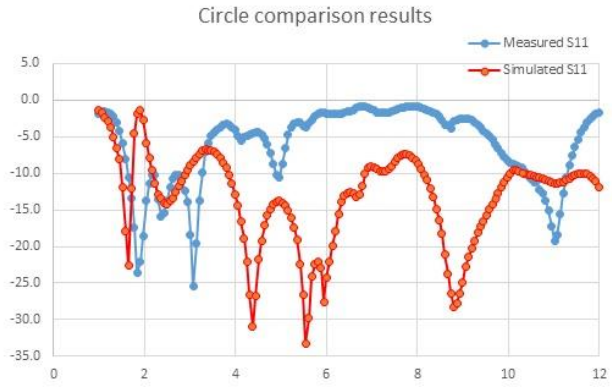
The proposed antenna design 1 (fractal-circle) is multiband antenna whichresonates at 1.63GHz, 2.45GHz, 3.21GHz, 4.70GHz, 6.62GHz and 9.84 GHz. The antenna design2(fractal-ellipse) resonates at 2.4GHz, 5.17GHz, 6.32GHz and 9.74 GHz.

In similar fashion to above two antennas, an octagon and decagon shaped fractal patch antennasarealso presented for S, C and X band applications [24].

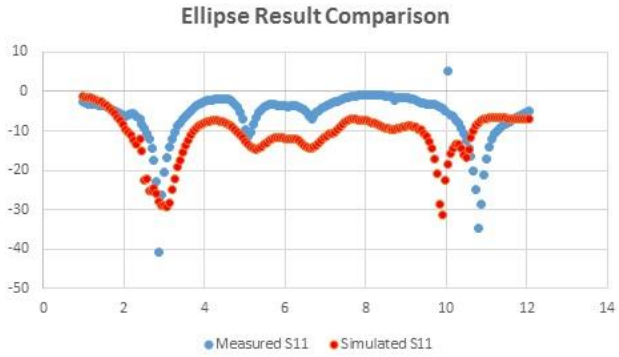
III. MEASURED RESULTS

Iteration-3 of above designed antennas are fabricated on FR-4 substrate and reflection coefficient is measured using microwavenetwork analyzer (14GHz).

Comparison of simulated and measured results is given in fig 11. Fabricated antennas are shown in fig 12.

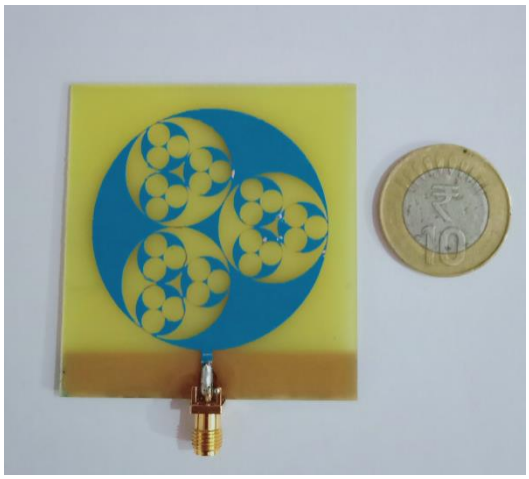


(a) Circle compared resuts

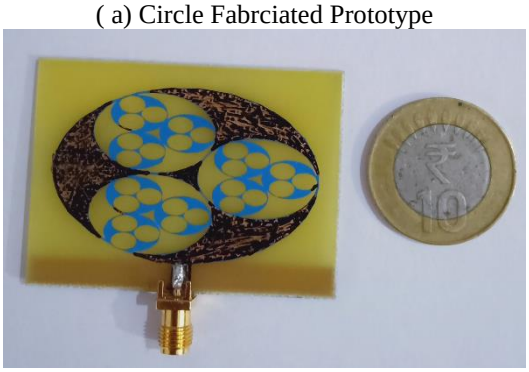


(b) Ellipse compared results

Fig 11. Simulated and Measured Comparison Results



(a) Circle Fabrciated Prototype



(b) Ellipse Fabrciated Prototype

Fig 12. Fabrciated Antennas

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There is little variation in measured and simulated results which may be due to fabrication error and measurement environment. In both cases almost same pattern is observed.

IV. CONCLUSION

Two fractal patch antennas on Fr-4 substratearedesigned. 1st antenna isfractal-circle and 2nd is fractal-ellipse. In circle-fractalantenna maximum bandwidth of 56% and maximum gain of 4.58 dB have been obtainedwhile in ellipse-fractal antenna maximum bandwidth of 55.4% andmaximum gain of5.14dB have beenachieved. Simulated and fabricated antennas' results are compared. The antennas are designed and fabricated for multiple applications like 2.4 GHz for Wi-Fi, biomedical,4-6 GHz for C band and 8-12 GHz for radar, satellite communication and wireless computer networks.

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