ISSN: 2229-6948(ONLINE)
DOI: 10.21917/ijct.2013.0095

BANDWIDTH AND GAIN ENHANCEMENT OF MULTIBAND FRACTAL ANTENNA BASED ON THE SIERPINSKI CARPET GEOMETRY

Manas Ranjan Jena[1], B.B. Mangaraj[2] and Debasis Mishra[3]
Department of Electronics and Telecommunication Engineering, Veer Surendra Sai University of Technology, India
E-mail: [1]manas.synergy@gmail.com, [2]bbmangarajuce@yahoo.com and [3]debasisuce@gmail.com

Abstract
In this paper, we have achieved a compact multiband fractal antenna based on Sierpinski carpet geometry. The simulation of the proposed antenna is done by CST Microwave Studio EM simulation software. The Sierpinski carpet fractal antenna proves that it is capable to create multiband frequencies. There are four resonant frequencies appeared at 0.85 GHz, 1.83 GHz, 2.13 GHz and 2.68 GHz. Simulated results indicates that the return loss is better than 15 dB, the VSWR is less than 1.3,the directivity is greater than 6dBi & the gain is more than 6dB in each band. So this fractal antenna can be suitable for fixed microwave & aviation applications.

Keywords:
Fractal Antenna, Sierpinski Carpet, CST, IFS, Multiband

1. INTRODUCTION

Antennas are regarded as the largest components of integrated, conformal & low-profile wireless communication systems. Therefore, it is desired for the antenna miniaturization in achieving an optimal design for wireless communications [3].

It is well known that the dimension of the antenna is a function of its operating wavelength (λ), i.e., if the antenna's size is less, it becomes inefficient because its radiation resistance, gain, directivity and bandwidth are insolvent. Fractal geometry provides a pleasant solution for this problem on account of its two major characteristics: self-similarity and space filling. So, fractal theories have become an pioneering approach for designing & characterizing wideband and multiband antennas [3], [1].

A 'Fractal' is a repeated generated structure having a fractional dimension which provides wide flexibility in antenna design & analysis. Fractal antenna engineering is the field, which utilizes fractal geometries with IFS for antenna design. Presently, it has become one of the budding fields of antenna engineering due to its advantages over conventional antenna design. Most of the fractal geometries have the following characteristic features: infinite complexity and detail, fractional dimension self-similarity, space filling & frequency independent [1].

These important characteristic features of fractals can be utilized in antenna design to achieve the following advantages:

Miniaturization:

We know that an antenna radiates efficiently only when its size is a corresponding fraction of the wavelength of operation. Therefore size of the antennas will be very large that operate at very low frequencies. The benefit of fractal antenna is that using fractional dimension of the fractals provides antennas that are electrically very long but physically small [2].

Multiband/wideband antennas:

We know that an antenna must have no characteristic size or it must have many characteristic sizes to operate over multiple frequencies simultaneously to be frequency independent. Due to the self-similarity & space filling property of fractals there are multiple copies of the geometry in a fractal object and hence they can be utilized for multiband/wideband antennas [3], [4].

Better efficiency:

Fractal geometry have sharp corners and edges that cause rapid changes in the direction of current and can be used to increase the radiation parameters. So fractals are efficient radiators of electromagnetic energy that can be used designing antennas with better efficiency.

Now-a-days, the advancement of wireless communication systems led to the development of several wireless communication applications including compact antenna design. To incorporate more than one communication service in a wireless system device, multiband antennas should be used. Multiband antenna provides solution to the space problem comparative to the traditional way of using different antennas for different frequency bands [7].

2. ANTENNA DESIGN

The Sierpinski carpet is a deterministic fractal that is a generalization of the Cantor set presented over two dimensions. This fractal is build starting with a square in the plane, subdividing it into nine smaller congruent squares dropping the open central one, then subdividing the eight remaining squares into nine smaller congruent squares in each of which the open central one is dropped [4]. This process is continued infinitely often obtaining a limiting configuration which can be seen as a generalization of the Cantor set. The designs up to three iteration are proposed in this paper that as shown in Fig.1.

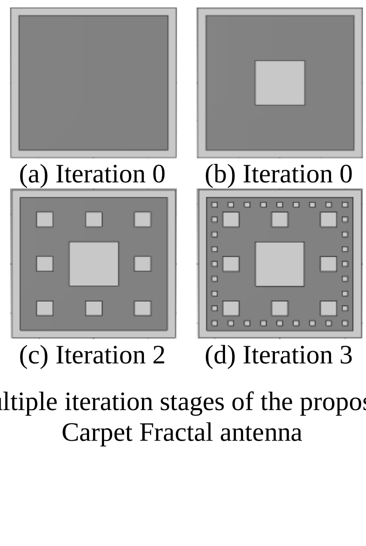

Fig.1. The multiple iteration stages of the proposed Sierpinski Carpet Fractal antenna

Let's consider that N_n be the number of black boxes, L_n is the scale factor for length of a side of green boxes, A_n is the scale factor for fractional area of black boxes after the n^{th} iteration.

$$N_n = 8 \tag{1}$$

$$L_n = \left(\frac{1}{3}\right) \tag{2}$$

$$A_n = L_n^2 N_n = \left(\frac{8}{9}\right)^n \tag{3}$$

The proposed multiband antenna is presented in Fig.1. Here we have used Probe Feed technique for the designed antenna. The total length and width of ground plane is 70 mm each as it is Square Carpet Antenna. The length and width of probe feed carpet patch are 63 mm each. We have used FR4 with $\epsilon_r = 4.4$ as a material for substrate and PEC as a conducting material for probe.

We have started the antenna design process with Sierpinski Carpet Planar Monopole Antenna. In the first iteration, the first basic square patch is segmented into nine congruent squares by taking scale factor $1/3$ and then middle square is detached from it. For second iteration segments are done on enduring eight squares and then detaching their respective middle squares. For further iterations, the same procedure is used with same scale factor. By using this method we have designed three iterations as shown in Fig.1.

3. RESULTS AND DISCUSSIONS

CST Microwave Studio EM simulator software is used for design and simulation. Results like Reflection coefficient (return loss), VSWR, 3D radiation patterns are simulated. Simulation results of multiple iterations are summarized in Table.1, Table.2, Table.3 and Table.4.

Simulated Results of Iteration – 0

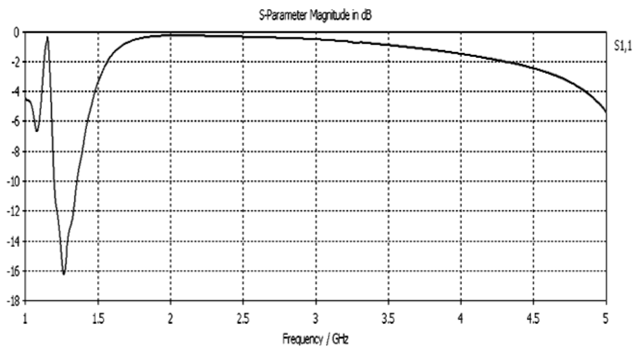

Fig.2(a). Variation of simulated reflection coefficient (S11) with frequency

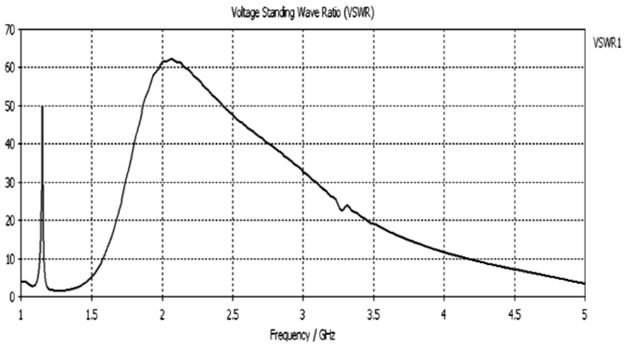

Fig.2(b). Variation of VSWR with frequency

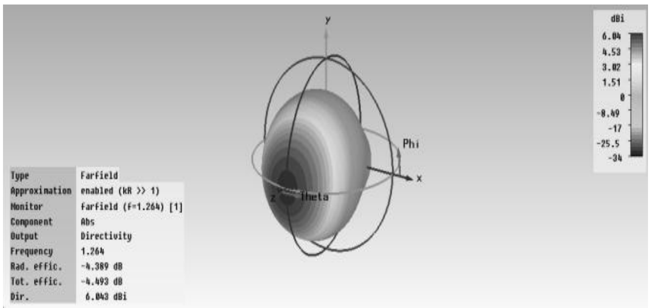

Fig.2(c). 3D Radiation pattern (Directivity) at f_r = 3.288 GHz

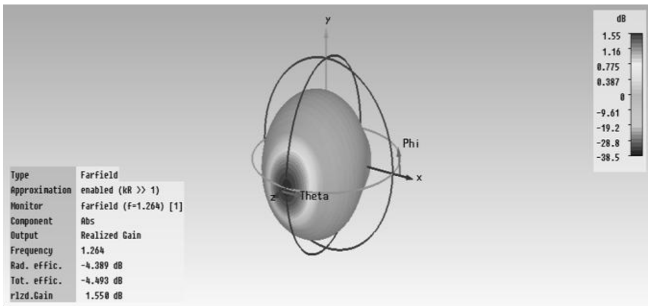

Fig.2(d). 3D Radiation pattern (Directivity) at f_r = 3.288 GHz

Table.1. Simulation results of Iteration – 0

f_r (GHz)	RL (dB)	VSWR	Directivity (dBi)	Gain (dB)
1.264	-16.19	1.36	6.043	1.550

Simulated Results of Iteration – 1

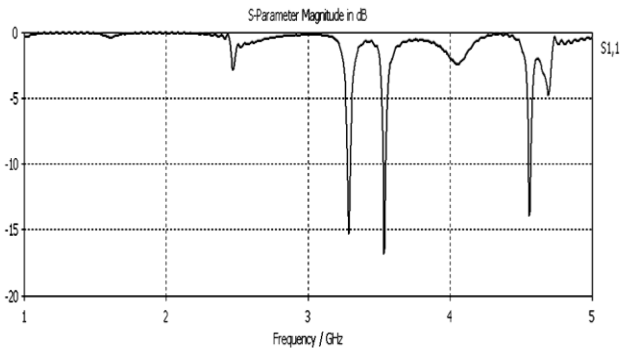

Fig.3(a). Variation of simulated reflection coefficient (S11) with frequency

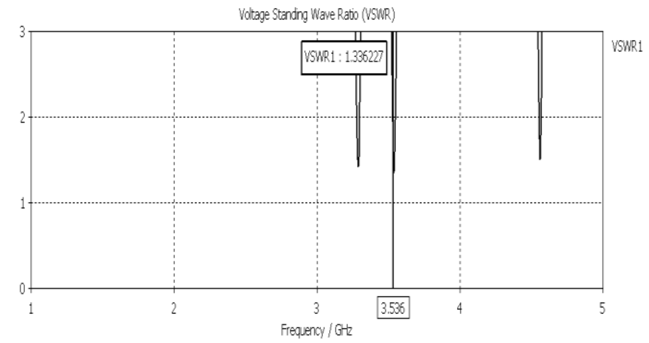

Fig.3(b). Variation of VSWR with frequency

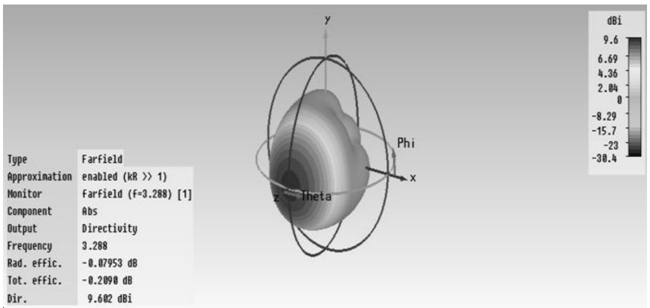

Fig.3(c). 3D Radiation pattern (Directivity) at f_r = 3.288 GHz

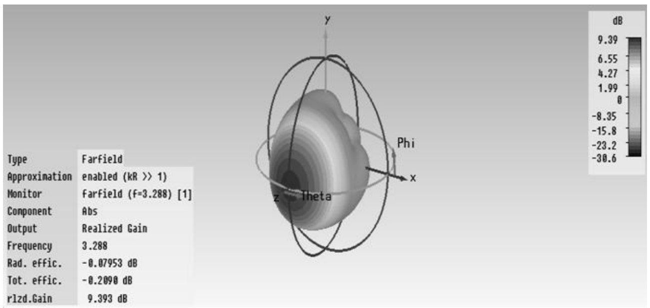

Fig.3(d). 3D Radiation pattern (Gain) at f_r = 3.288 GHz

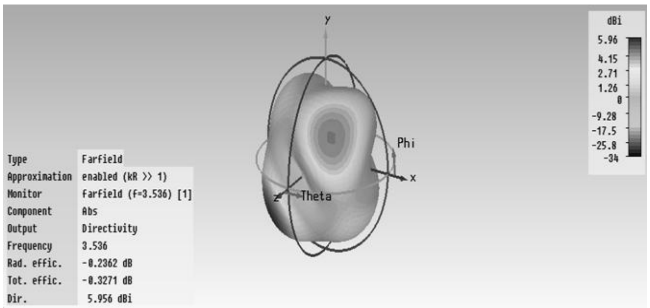

Fig.3(e). 3D Radiation pattern (Directivity) at f_r = 3.536 GHz

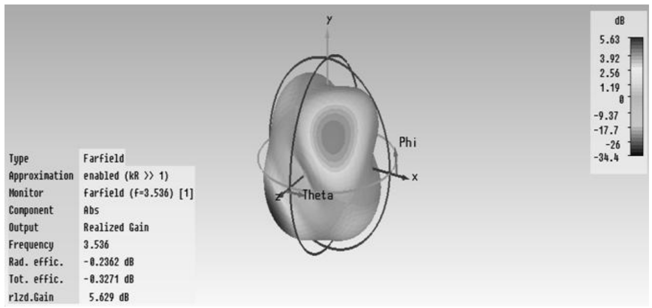

Fig.3(f). 3D Radiation pattern (Gain) at f_r = 3.536 GHz

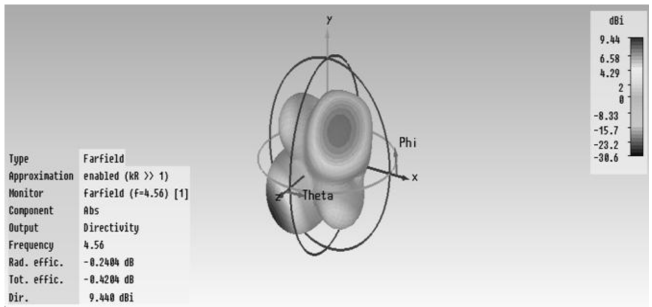

Fig.3(g). 3D Radiation pattern (Directivity) at f_r = 4.56 GHz

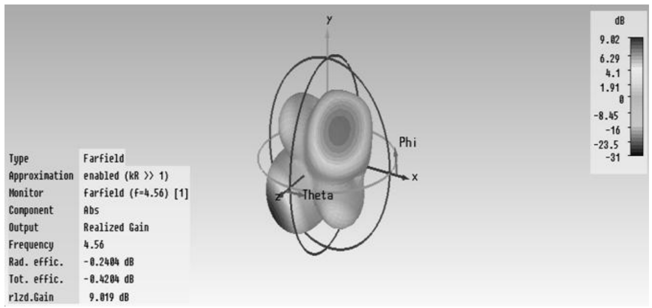

Fig.3(h). 3D Radiation pattern (Gain) at f_r = 4.56 GHz

Table.2. Simulation results of Iteration – 1

f_r (GHz)	RL (dB)	VSWR	Directivity (dBi)	Gain (dB)
3.288	-15.5	1.336	9.602	9.393
3.536	-17	1.3	5.956	5.629
4.56	-13	1.4	9.440	9.019

Simulated Results of Iteration – 2

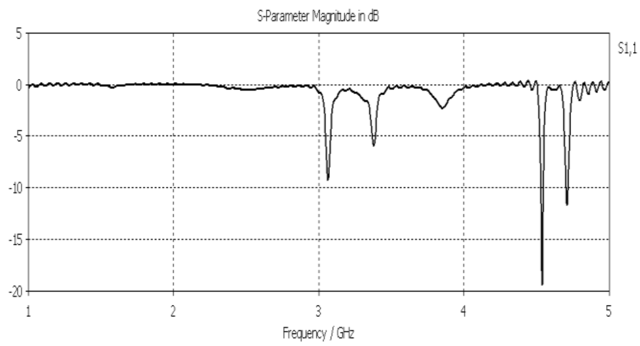

Fig.4(a). Variation of simulated reflection coefficient (S11) with frequency

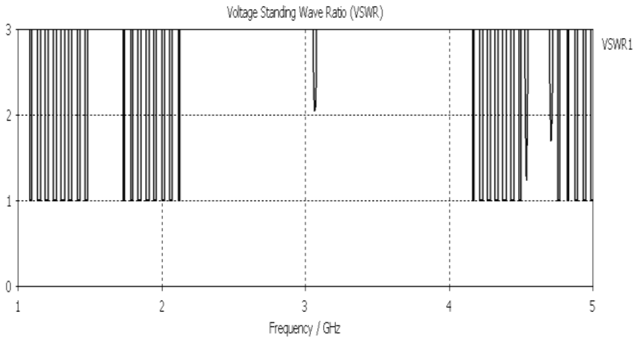

Fig.4(b). Variation of VSWR with frequency

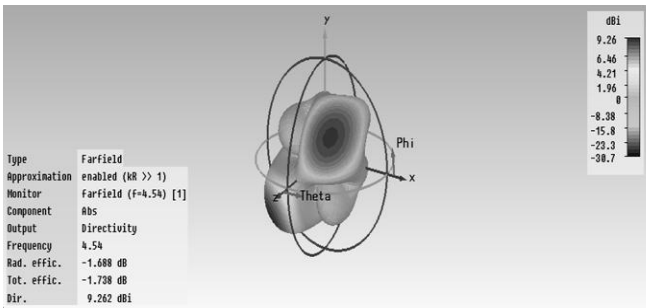

Fig.4(c). 3D Radiation pattern (Directivity) at f_r = 4.54 GHz

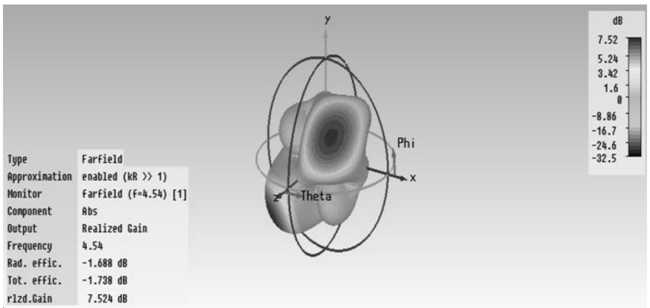

Fig.4(d). 3D Radiation pattern (Gain) at f_r = 4.54 GHz

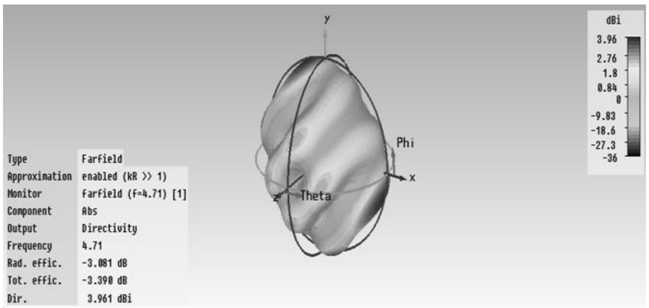

Fig.4(e). 3D Radiation pattern (Directivity) at f_r = 4.71 GHz

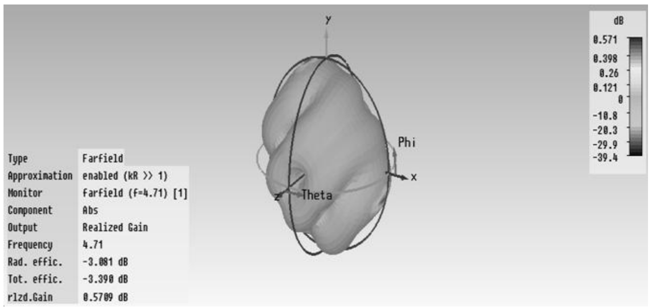

Fig.4(f). 3D Radiation pattern (Gain) at f_r = 4.71 GHz

Table.3. Simulation results of Iteration – 2

f_r (GHz)	RL (dB)	VSWR	Directivity (dBi)	Gain (dB)
4.54	-19.43	1.22	9.262	7.524
4.71	-11.6	1.72	3.961	0.5709

Simulated Results of Iteration – 3

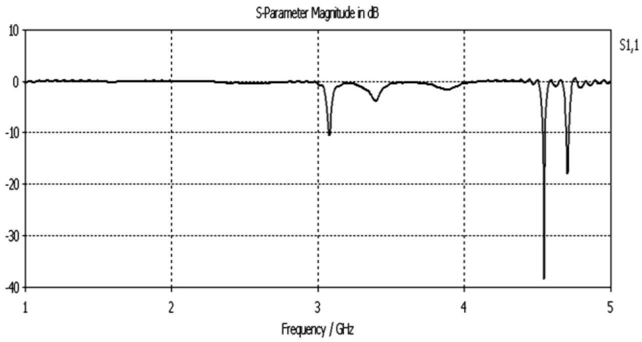

Fig.5(a). Variation of simulated reflection coefficient (S11) with frequency

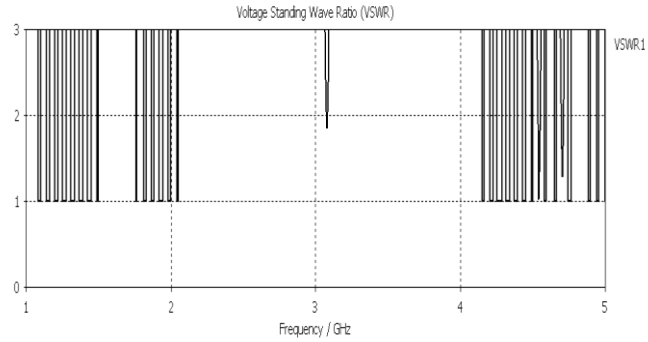

Fig.5(b). Variation of VSWR with frequency

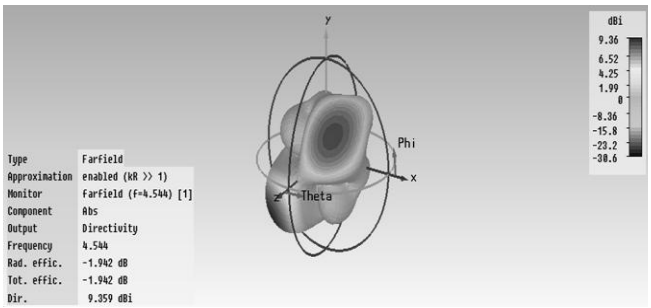

Fig.5(c). 3D Radiation pattern (Directivity) at f_r = 4.544 GHz

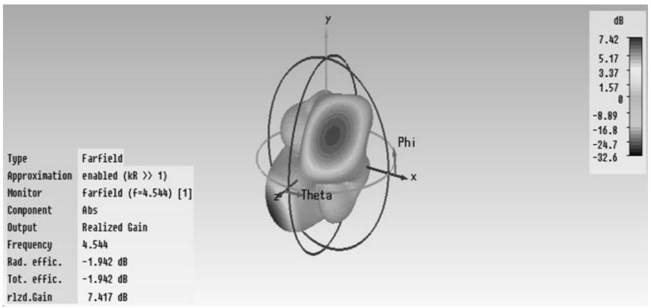

Fig.5(d). 3D Radiation pattern (Gain) at f_r = 4.544 GHz

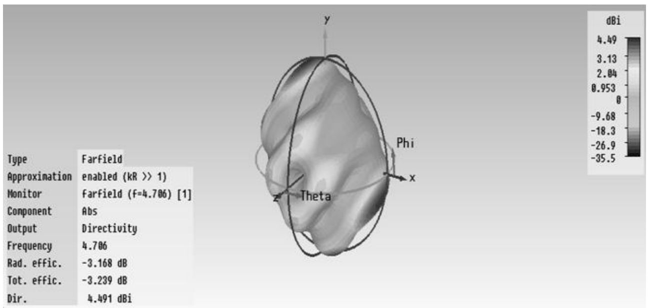

Fig.5(e). 3D Radiation pattern (Directivity) at f_r = 4.706 GHz

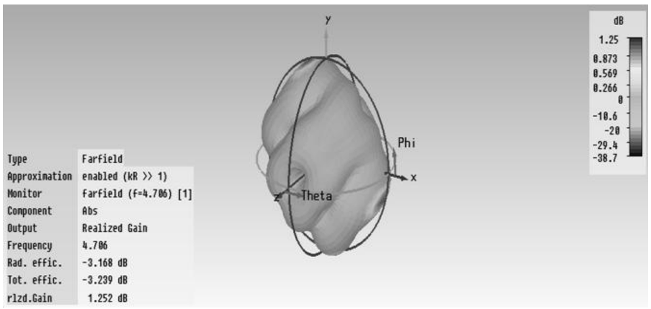

Fig.5(f). 3D Radiation pattern (Gain) at f_r = 4.706 GHz

Table.4. Simulation results of Iteration – 3

f_r (GHz)	RL (dB)	VSWR	Directivity (dBi)	Gain (dB)
4.544	-38.53	1.036	9.359	7.417
4.706	-17.47	1.21	4.491	1.252

With the above simulated results analysis of VSWR and Return Loss measurements, the designs shows multiband characteristics at various operating frequencies with multiple iterations. For the First iteration we get VSWR of 1.336 at frequency 6.48GHz as shown in Fig.3(a) and Fig.3(b). To minimize the VSWR towards ideal condition we go for second and third iteration. For second iteration the three bands obtained are 4.44 – 4.55 GHz, 8.15 – 8.4 GHz and 10.8 – 11.24 GHz as observed from Fig.4(a) and Fig.4(b), and for third iteration as 4.32 – 4.44 GHz, 8.12 – 8.4 GHz and 10.8 – 11.20 GHz, can be observed from Fig.5(a) and Fig.5(b). Comparing VSWR plots for designs of all iterations only second and third iteration designs achieve desired results at frequencies of 4.4 GHz and 8.2 GHZ and 11GHz and acts as multiband antennas.

BW Calculation

a) For 0th iteration

f_c = 1.264 GHz, f_L = 1.196 GHz & f_H = 1.356 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 1\%$$

b) For 1st iteration

For 1st band

f_c = 3.288 GHz, f_L = 3.224 GHz & f_H = 3.338 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 3.46\%$$

For 2nd band

f_c = 3.536 GHz, f_L = 3.507 GHz & f_H = 3.567 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 1.69\%$$

For 3rd band

f_c = 4.56 GHz, f_L = 4.523 GHz & f_H = 4.589 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 1.44\%$$

c) For 2nd iteration

For 1st band

f_c = 4.54 GHz, f_L = 4.504 GHz & f_H = 4.593 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 1.96\%$$

For 2nd band

f_c = 4.71 GHz, f_L = 4.67 GHz & f_H = 4.74 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 1.48\%$$

d) For 3rd iteration

For 1st band

f_c = 4.544 GHz, f_L = 4.502 GHz & f_H = 4.596 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 2.09\%$$

For 2nd band

f_c = 4.706 GHz, f_L = 4.64 GHz & f_H = 4.76 GHz

$$\text{So, BW} = \left(\frac{f_H - f_L}{f_c}\right) \times 100\% = 2.54\%$$

Table.5. Comparison of different major parameters for multiple iterations

Parameters	0th iteration	1st iteration	2nd iteration	3rd iteration
Return loss	-16.19	-15.5 -17.12 -13.14	-19.43 -11.6	-38.53 -17.47
VSWR	1.356	1.336 1.3	1.22 1.72	1.036 1.21

		1.4		
Directivity	6.043	9.602 5.956 9.440	9.262 3.961	9.359 4.491
Gain	1.550	9.393 5.629 9.019	7.524 0.570	7.417 1.252
Presence of multiband	Nil	Yes(3)	Yes(2)	Yes(2)
BW enhancement	0.1%	3.46% 1.69% 1.44%	1.96% 1.48%	2.09% 2.54%
Size reduction		33.3%	44.4%	52.1%

4. CONCLUSION

A multiband fractal antenna based on Sierpinski carpet geometry is designed & simulated. The proposed Fractal antenna results are compared with a simple rectangular patch of 63mm × 63mm dimension. The simulated results show that return loss is more than -15 dB, VSWR is less than 1.3, directivity is more than 6 dBi, and gain is more than 6 dB. Multiband property is achieved with multiple iterations. Gain is enhanced with multiple iterations. Bandwidth enhancements for multiple iterations are compared. Antenna size is reduced by using fractal shapes with multiple iterations. So the designed antenna can be proposed for the fixed microwave & aviation applications.

ACKNOWLEDGEMENT

The authors sincerely thank to the Vice Chancellor & the Head of the Department of Electronics and Telecommunication Engineering, Veer Surendra Sai University of Technology, Burla for constant encouragement and support.

REFERENCES

[1] Balanis and Constantine, "*Antenna theory-Analysis and Design*", John Wiley & Sons Ltd, Reprinted 2008.

[2] B. B. Mandelbrot, "*The Fractal Geometry of Nature*" San Francisco, CA: Freeman, 1983.

[3] Philip Felber, "*Fractal Antennas-A Literature Study*", Illinois Institute of Technology, 2000.

[4] R. M. Crownover, "*Introduction to Fractals & Chaos*", Boston, MA: Jones & Bartlett, 1995.

[5] Noorsaliza Bt Abdullah "Microstrip Sierpinski Carpet Antenna Design", M.E. diss., Department of Electronics & Telecommunications, Universiti Teknologi Malaysia, 2005.

[6] J. P. Gianvittorio and Y. Rahmat-Samii, "Fractal Antenna:A novel antenna miniaturization technique and application", *IEEE Antenna and Propagation Magazine*, Vol. 44, No. 1, pp. 20-36, 2002.

[7] Best S. R, "On the Significance of Self-Similar Fractal Geometry in Determining the Multiband Behaviour of Sierpinski Gasket Antenna", *IEEE Antennas and Wireless Propagation Letters*, Vol. 1, No. 1, pp. 22-25, 2002.

[8] D. H. Werner, P. L. Werner, and K. H. Church, "Genetically engineered multi-band fractal antennas", *Electronics Letters*, Vol. 37, No. 19, pp. 1150–1151, 2001.

[9] D. H. Werner and S. Ganguly, "An overview of fractal antenna engineering research", *IEEE Antennas and Propagation Magazine*, Vol. 45, No. 1, pp. 38-57, 2003.

[10] N. Cohen, "Fractal Antenna Application in Wireless Telecommunications", *Professional Program Proceedings of Electronics Industries Forum of New England*, pp. 43-49, 1997.