A Novel Approach In Fractal Antenna Design Using Sierpinski Arrowhead Geometry

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***Abstract*—A fractal antenna is an antenna that posses a unique geometrical pattern, which can be repeated to produce various iterative structures or shapes with unique radiation characteristics. This paper is based on a novel approach in Fractal Antenna design using Sierpinski Arrowhead Geometry. Appropriate substrate materials have been chosen to generate optimum response in each case. On simulation, promising results are obtained in perspective of Return Loss, Gain, VSWR and Bandwidth. In cases of repetitive iterative design, forming altogether different patch structures with unique geometrical shapes, variations in response are observed, which have been discussed in detail along with sequential snapshots, comparative analysis and necessary plots.**

***Index Terms*—Fractal Antenna, Iterative design, Sierpinski Arrowhead Geometry**

I. INTRODUCTION

A microstrip antenna generally consists of a dielectric substrate sandwiched between a radiating patch on the top and a ground plane on the other side. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate. For simplicity of analysis, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape.

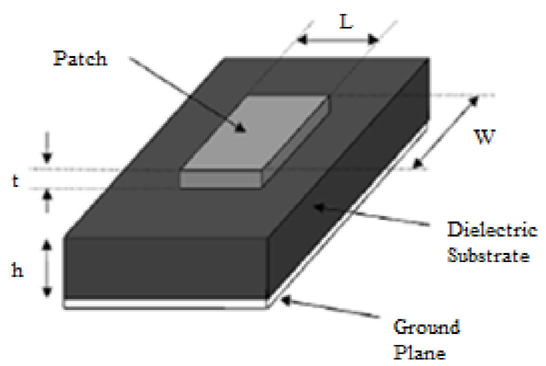

Fig. 1 *Microstrip Patch Antenna*

For a rectangular patch, the length L of the patch is usually in the range of $0.3333\ \lambda_o < L < 0.5\ \lambda_o$, where λ_o is the free space wavelength. The patch is selected to be very thin such that $t << \lambda_o$ (where t is the patch thickness). The height h of the substrate is usually $0.003\ \lambda_o \leq h \leq 0.05\ \lambda_o$. The dielectric constant of the substrate ϵ_r is typically in the range $2.2 \leq \epsilon_r \leq 12$. [3] An effective dielectric constant (ϵ_{reff}) must be obtained in order to account for the fringing and the wave propagation in the line. The value of ϵ_{reff} is slightly less than ϵ_r because the fringing fields around the periphery of the patch are not confined in the dielectric substrate but are also spread in air.

The expression for ϵ_{reff} is given by [1] as,

$$\epsilon_{reff} = \frac{\epsilon r+1}{2} + \frac{\epsilon r-1}{2}\sqrt{1+12\ h/W} \quad (1)$$

where,

ϵ_{reff} = Effective Dielectric Constant
ϵ_r = Dielectric Constant of Substrate
h = Height of Substrate
W = Width of Patch

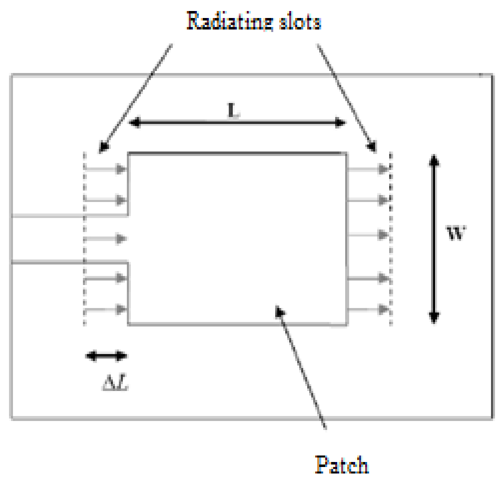

Fig. 2 *Top view of antenna*

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The fringing fields along the width can be modeled as radiating slots and electrically the patch of the microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have now been extended on each end by a distance ΔL, which is given empirically by [1] as:

$$\Delta L = 0.412\, h \frac{(\varepsilon reff + 0.3)\,(W/h + 0.264)}{(\varepsilon reff - 0.258)\,(W/h + 0.8)} \quad (2)$$

The effective length of the patch L_{eff} now becomes,

$$L_{eff} = \frac{c}{2\, fo\, \sqrt{\epsilon reff}} \quad (3)$$

where f_o is the resonant frequency

For a given resonant frequency f_0, the effective length is given by

$$L_{eff} = L + 2\, \Delta L \quad (4)$$

For a rectangular microstrip patch antenna, the resonant frequency for any TM mode is given by [1] as,

$$f_o = \frac{c}{2\sqrt{\epsilon reff}} \left[(m/L)^2 + (n/W)^2\right]^{1/2} \quad (5)$$

where m and n are the modes along L and W respectively.

For effective radiation, the width W is given by [3] as,

$$W = \frac{c}{2\, fo\, \sqrt{(\epsilon r + 1)/2}} \quad (6)$$

II. FRACTAL ANTENNA

Fractals were first defined by Benoit Mandelbrot in 1975 as a way of classifying structures whose dimensions were not whole numbers. Fractal geometry has unique geometrical features occurring in nature. It can be used to describe the branching of tree leaves and plants, rough terrain, jaggedness of coastline, and many more examples in nature. Fractals have been applied in various field like image compression, analysis of high altitude lightning phenomena. Fractals are geometric forms that can be found in nature, being obtained after millions of years of evolution, selection and optimization. Examples are the Sierpinski Gasket and the Sierpinski Carpet geometrical forms. Most fractals have infinite complexity and detail that can be used to reduce antenna size and develop low profile antennas. For most fractals, self-similarity concept can achieve multiple frequency bands because of different parts of the antenna are similar to each other at different scales. The combination of infinite complexity and self similarity makes it possible to design antennas with various wideband performances. This work is a novel approach in Microstrip Patch design using Sierpinski Arrowhead Geometry.

The Sierpinski Arrowhead curve draws an equilateral triangle with triangular holes at equal intervals. It can be described with two substituting production rules: (A → B-A-B) and (B → A+B+A). A and B recur and at the bottom do the same thing — draw a line. Plus and minus (+ and -) mean turn 60 degrees either left or right. The terminating point of the Sierpinski arrowhead curve is always the same provided you recur an even number of times and you halve the length of the line at each recursion. If you recur to an odd depth (order is odd) then you end up turned 60 degrees, at a different point in the triangle. In code, given these drawing functions: void draw_line(double distance); void turn(int angle_in_degrees); The code to draw an (approximate) Sierpinski arrowhead curve looks like this. [9], [10]

```
void sierpinski_arrowhead_curve( unsigned order, double
length)
{
  // If order is even we can just draw the curve.
  if ( 0 == (order & 1) ) {
    curve( order, length, +60);
  }
  else /* order is odd */ {
    turn( +60);
    curve( order, length, -60);
  }
}
void curve( unsigned order, double length, int angle)
{
  if ( 0 == order ) {
    draw_line( length);
  } else {
    curve( order - 1, length / 2, - angle);
    turn( + angle);
    curve( order - 1, length / 2, + angle);
    turn( + angle);
    curve( order - 1, length / 2, - angle);
  }
}
```

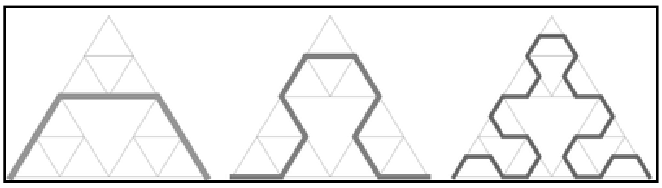

Fig. 3 *Steps of Arrowhead Geometry construction*

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III. DESIGNED ARRAY OF HEXAGONAL PATCHES BASED ON SIERPINSKI ARROWHEAD GEOMETRY

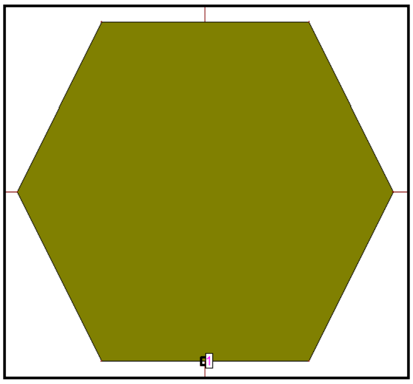

Fig. 4 *1st Iteration*

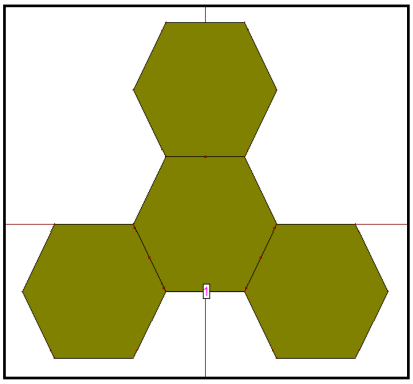

Fig. 5 *2nd Iteration*

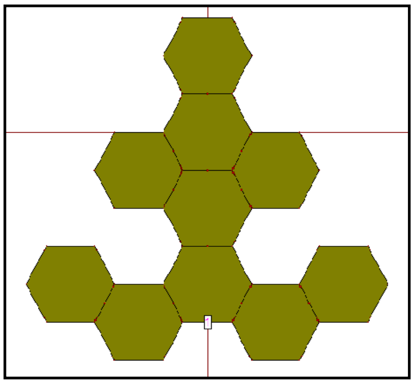

Fig. 6 *3rd Iteration*

IV. PATCH PARAMETERS

Chosen parameters of the designed patch:

1st Iteration: Fig. 4

- Length of each side of Hexagon: 5.5 mm
- Number of Hexagon(s): 1
- Substrate: Roger 4003
- Substrate height, h: 5 mm
- Dielectric Constant, ϵ_r: 3.4
- Loss tangent: 0.002

2nd Iteration: Fig. 5

- Length of each side of Hexagon: 5.5 mm
- Number of Hexagon(s): 4
- Substrate: Benzocyclobutene
- Substrate height, h: 10 mm
- Dielectric Constant, ϵ_r: 2.6
- Loss tangent: 0.00

3rd Iteration: Fig. 6

- Length of each side of Hexagon: 5.5 mm
- Number of Hexagon(s): 10
- Substrate: Roger 4350
- Substrate height, h: 10 mm
- Dielectric Constant, ϵ_r: 3.48
- Loss tangent: 0.004

S_{11} is a measure of how much power is reflected back at the antenna port due to mismatch from the transmission line. When connected to a network analyzer, S_{11} measures the amount of energy returning to the analyzer – not what's delivered to the antenna. The amount of energy that returns to the analyzer is directly affected by how well the antenna is matched to the transmission line. A small S_{11} indicates a significant amount of energy has been delivered to the antenna. S_{11} values are measured in dB and are negative, ex: -10 dB. S_{11} is also sometimes referred to as return loss, which is simply S_{11} but made positive instead (Return Loss = - S_{11}). So if the antenna Return Loss is 8 dB, S_{11} is -8 dB. When the antenna and transmission line are not perfectly matched, reflections at the antenna port travel back towards the source and cause a standing wave to form. The worse the mismatch, the larger the amplitude of these reflections. [6] Values of $S_{11} \leq -10$ dB (VSWR < 2) are considered as the margin for resonant peaks - TABLE I.

TABLE I

Return Loss, S11, VSWR and Reflection Loss [7]

Return Loss (dB)	**S_{11}**	**VSWR**	**Reflection Loss (dB)**
3.0	-3.0	5.85	3
6.0	-6.0	3.0	1.26
7.0	-7.0	2.6	0.97
8.0	-8.0	2.3	0.75
9.0	-9.0	2.1	0.58
10.0	-10.0	1.9	0.46
11.0	-11.0	1.8	0.36
12.0	-12.0	1.7	0.28
13.0	-13.0	1.6	0.22
14.0	-14.0	1.5	0.18
15.0	-15.0	1.4	0.14
16.0	-16.0	1.4	0.11
17.0	-17.0	1.3	0.09
18.0	-18.0	1.3	0.07
19.0	-19.0	1.3	0.06
20.0	-20.0	1.2	0.04

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V. SIMULATION RESULTS

The different patch structures are designed and simulated in IE3D environment with sequential analysis of the obtained results.

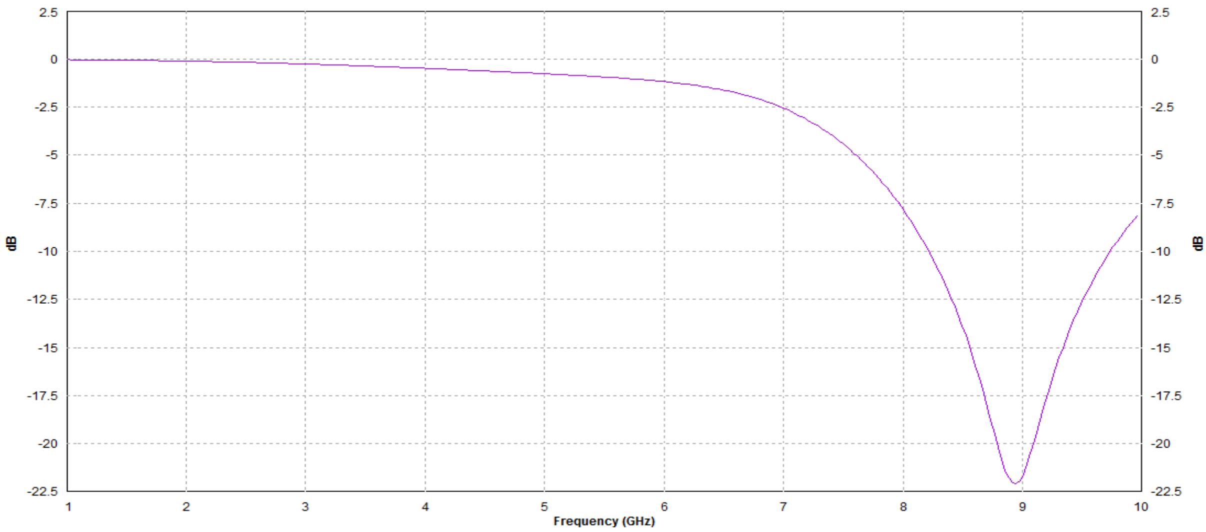

Fig. 7 S_{11} *vs Frequency* (1st Iteration)

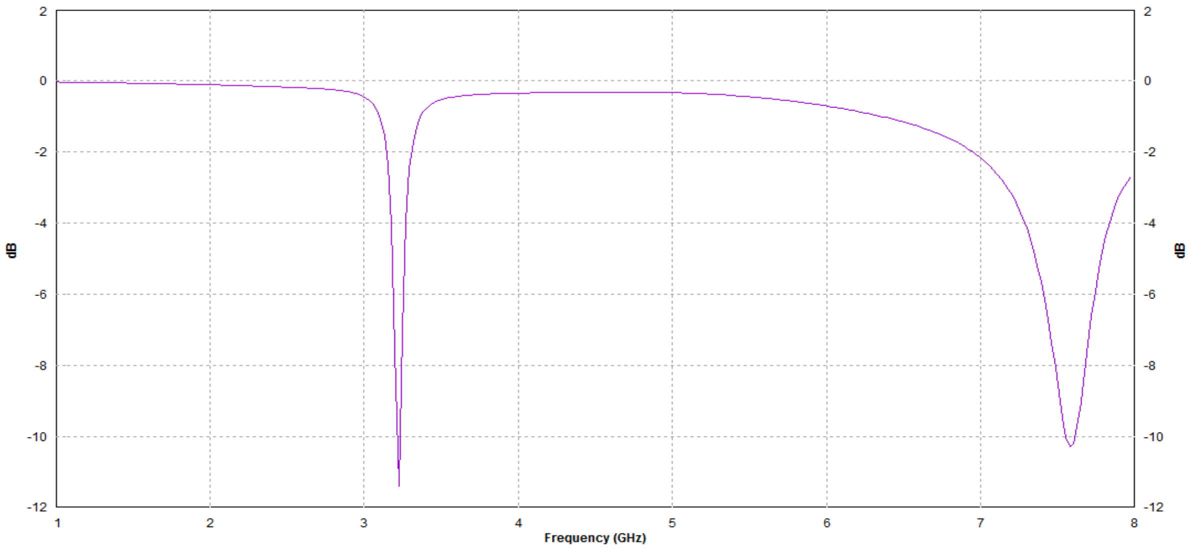

Fig. 8 S_{11} *vs Frequency* (2nd Iteration)

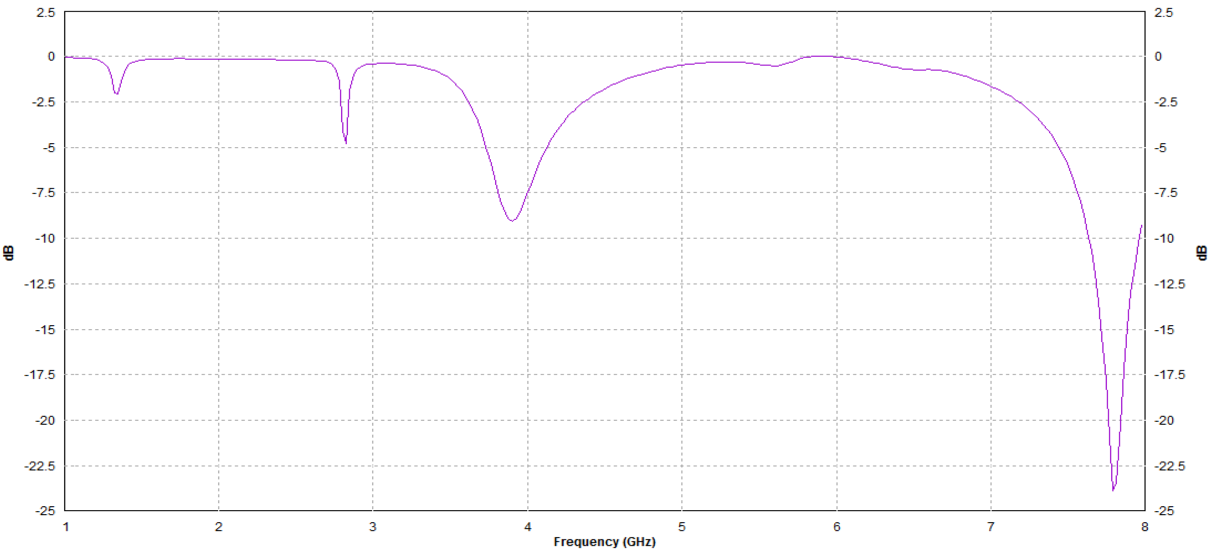

Fig. 9 S_{11} *vs Frequency* (3rd Iteration)

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Fig. 7, Fig. 8 and Fig. 9 represent the *S_{11} vs Frequency* curve for the patches shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

A resonant peak has been observed at a frequency of 8.9 GHz (S_{11} = -22).

Two resonant peaks have been observed from Fig. 9 at 3.2 GHz (S_{11}: -11.4) and 7.5 GHz (S_{11}: -10.3).

A resonant peak has been observed at a frequency of 7.8 GHz (S_{11} = -23.9).

VI. CONCLUSION

The Simple Hexagonal Patch shows good results at 8.9 GHz, with extremely high bandwidth. The patch formed by the combination of 4 Hexagonal Patterns shows promising results at resonant frequencies of 3.2 GHz and 7.5 GHz respectively and is applicable for dual band operation. The Patch formed by the combination of 10 Hexagonal Patterns shows a resonant frequency point at 7.8 GHz with a good return loss factor. The observed gain is ≥ 5 dBi in all cases. It is to be noted that the choice of substrate material plays a significant role in this regard; therefore patch parameters should be appropriately chosen for each iterative design to generate optimum results. The number of iterations can be increased to form different patterns with different characteristics, which require further experimental investigation and is the future scope of this work.

REFERENCES

1. C. A. Balanis, "Antenna Theory - Analysis and Design", John Wiley & Sons, Inc 1997.
2. C. A. Balanis, "Advanced Engineering Electromagnetics", New York, John Wiley and Sons, 1989.
3. Garg, R., Bhartia, P., Bahl, I., Ittipiboon, "A., Microstrip Antenna Design Handbook", Artech House, Inc, 2001.
4. John D. Kraus, Ronald J. Marhefka; "Antennas-For All Applications"; Fifth reprint 2004 pp. 324
5. D. Orban and G.J.K. Moernaut; "The Basics of Patch Antennas"; Orban Microwave Products; www.orbanmicrowave.com
6. http://antenna-theory.com/definitions/sparameters.php
7. http://info.lsr.com/LSR-Wireless-RF-Design-blog/bid/282190/Terms-Definitions-of-Basic-Antenna-Design-II
8. http://www.microwaves101.com/encyclopedia/vswr.cfm#vswr
9. Peitgen et al., Chaos and Fractals, Springer-Verlag, 1992.
10. Roger T. Stevens, Fractal Programming in C, M&T Books, 1989.
11. Asok De, N.S. Raghava, Sagar Malhotra, Pushkar Arora, Rishik Bazaz; "Effect of different substrates on Compact stacked square Microstrip Antenna"; Journal of Telecommunications, Volume 1, Issue 1, February 2010
12. Ankan Bhattacharya; "Design, simulation and analysis of a Penta Band Microstrip Patch Antenna with a Circular Slot"; International Journal of Science, Engineering and Technology Research; Vol. 2 Issue 10 October 2013.
13. Ankan Bhattacharya; "Effect Of Patch Dimensions On The Behavior Of Resonant Peaks Of A Microstrip Patch Antenna – A Comparative Discussion"; International Journal of Engineering Research and Technology; Vol. 2 Issue 8 August 2013.
14. Ankan Bhattacharya; "Design, simulation and analysis of a Probe Feed Patch Antenna with Benzocyclobutene as the substrate material"; International Journal of Science, Engineering and Technology Research; Vol. 2 Issue 7 July 2013.
15. Roger T. Stevens, Fractal Programming in C, M&T Books, 1989.
16. Julie K. Petersen (2003). Fiber Optics Illustrated Dictionary. CRC Press. ISBN 0-8493-1349-X.
17. John T. Taylor and Qiuting Huang (1997). CRC Handbook of Electrical Filters. CRC Press. ISBN 0-8493-8951-8.
18. "Radiation from Microstrip Radiators," IEEE Transactions on Microwave Theory and Techniques, April 1969, Vol. 17, No. 4 pp.235-236
19. Trevor S. Bird, "Definition and Misuse of Return Loss", IEEE Antennas & Propagation Magazine, vol.51, iss.2, pp.166-167, April 2009.
20. U. Chakraborty, S. Chatterjee, S. K. Chowdhury and P. P. Sarkar; "A compact microstrip patch antenna for wireless communication," Progress In Electromagnetics Research C, Vol. 18, 211-220, 2011.

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