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Design and Analysis of Hexagon Microstrip Patch Sierpinski Carpet Antenna

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Abstract: In the present paper a detailed study of a new compacted hexagon microstrip patch antenna using fractal ground plane and shorting pin is presented. The design process starts by a simple hexagon patch antenna fed by a microstrip line and simulated in the frequency range of 3.1GHz-10.8GHz. The fractal geometry used here is Sierpinski carpets method. Three iterations have been done and the third iteration gives best performance. The miniaturization strategy is performed in two stages. The first stage, a third order of the Sierpinski carpet is applied to the ground. Inserting a shorting pin linking the patch to the ground constituted the second stage. Both the stages are analyzed and compared, Sierpinski carpet the gives best output. The performances are analyzed in terms of return loss, directivity, gain, and radiation pattern.

Keywords: Fractal Antenna, Sierpinski Carpet, Array, Shorting Pin

1. Introduction

In military application system the performance of the antenna requires large gain, wider bandwidth, low cost and small size. The conventional microstrip antenna is not sufficient to fulfill the above requirements. Hence the researchers have doing some research work on some innovative antenna to satisfy these parameters. Among them Dr. Nathan Cohen found a different technology called fractal antenna in 1995 and his research is used in commercial and military applications.

These fractal antenna is a new antenna design which is used in military as well as commercial applications which provides more size reduction, wider bandwidth, compact size, better input impedance, consistence performance over huge frequency range, close packing of antennas, easy to manufacture, reliable, high gain, multiband, low price and instantaneous spectrum access. Conventional antenna requires tuning and matching circuits these can be replaced by a suitable antenna technology which has a unique feature and this antenna is called Fractal antenna. In fractal antenna the overall structure is comprised of a series of repetition of a single geometry and where repetition is at different scale. Fractal is a geometric shape that has the property of self-similarity that is each part of the shape is a smaller version of the original shape. The various shape of fractal antennas are snail shells, leaves on a tree, pine cones, triangular, circular, square etc. These structures are having a finite area but infinite perimeter. They are often constructed via some sort of iterative mathematical rule, that generates a fractal from a simple object step by step.

Fractals have been used to design compact multiband antennas and miniaturized filters. The various fractal geometries are Minkowski, Sierpinski carpet, Sierpinski Gasket, Hilbert curves, von Koch curves and so on. Fractal geometries have two common properties, space-filling and self-similarity different from Euclidean geometries. Fractal curves are well known for their unique space-filling properties. A fractal shape can fill the shape occupied by the antennas in an efficient manner than the Euclidean conventional antenna. The study of fractal shaped antenna elements and the use of fractals in antenna array are active areas of research in fractal antenna engineering. In this article the sierpinski carpet fractal geometry is used in circular patch which is used as array elements to form linear array as well as circular array.

It has been shown that the self-similarity and space-filling properties of fractal shapes, such as Minkowski and Koch fractal curves, can be successfully applied to the design of miniaturized microstrip dual-mode ring band pass filters. Most of the research efforts have been devoted to the antenna applications. Multi-band operation could be achieved by using multiple antennas only. Nowadays, a single small fractal antenna can be used for multiband performance because of its self-similar structure at different scales. Minkowski and Sierpinski fractal geometry has been used in the implementation of multiband antenna.

The first three iterations of Sierpinski carpet fractal are applied on the square patch antenna, the return loss and bandwidth are calculated. The triple frequency band symmetrical and asymmetrical circular fractal antenna array was designed. In this symmetrical fractal array showed better results than asymmetrical fractal array.

2. Fractal Antenna Array

Based on the distribution of antenna elements, antenna array are classified as linear arrays, planar arrays, periodic arrays and random arrays. Multiple elements are placed along a straight line and is called linear array. It is the simplest array and is also named as single dimensional array. Uniform array is an array of identical elements all of having same magnitude and with progressive phase. This array provides high directivity. In planar array, individual elements are placed along a rectangular grid. The elements are placed in one plane hence it is called two dimensional array. This array is also called rectangular array. Here the additional variables are used to control and shape the pattern of the array. This array provide symmetrical radiation pattern with low side lobes. In periodic array the elements are arranged in a grid as a periodic manner and have a tendency to produce main beams and side lobes of the same height.

3. Antenna Design

The Resonant frequency corresponding to the various modes TM_{mn} of this antenna can be evaluated by (1);

$$f_{mn} = \frac{2c}{3a\sqrt{\varepsilon_r}}(m^2 + mn + n^2)^{\frac{1}{2}} \quad (1)$$

Where c is the free space speed of the light, m and n are number of modes, a is the side length of the patch.

The Effective length a_e is given by (2);

$$a_e = a\left[1 + 2.199\frac{h}{a} - 12.583\frac{h}{a\sqrt{\varepsilon_r}} + 16.436\frac{h}{a\varepsilon_r} + 6.182\left(\frac{h}{a}\right)^2 - 9.802\frac{1}{\sqrt{\varepsilon_r}}\left(\frac{h}{a}\right)^2\right] \quad (2)$$

Dimensions of the patch can be calculated to excite the first resonant frequency corresponding to the mode TM_{10} by using (3);

$$f_{10} = \frac{2c}{3a_e\sqrt{\varepsilon_r}} \quad (3)$$

4. Results and Discussions

Hexagon patch Sierpinski carpets antenna using the FR-4 substrate with dielectric permittivity ε_r=4.4, thickness h=1.6mm. The back side of the dielectric is entirely recovered by a square ground plane with side length WxL=40x40mm. The width and length of the microstrip feed line are respectively W=3mm and L=13mm. This configuration will be our reference antenna (antenna 1)

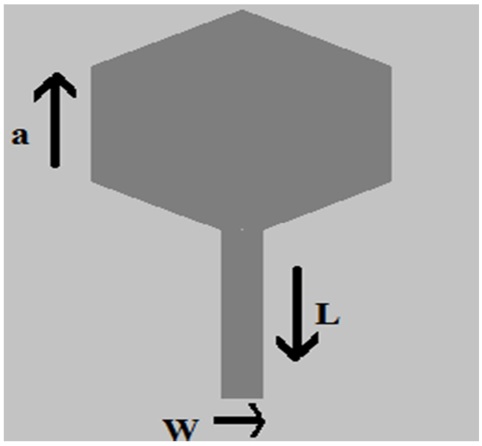

Figure 1. *Geometry of the hexagon reference antenna.*

The hexagon reference antenna frequency resonates around 8.5GHz with a Return loss of -6db. The gain is 4.6dBi and directivity 6.4dBi.

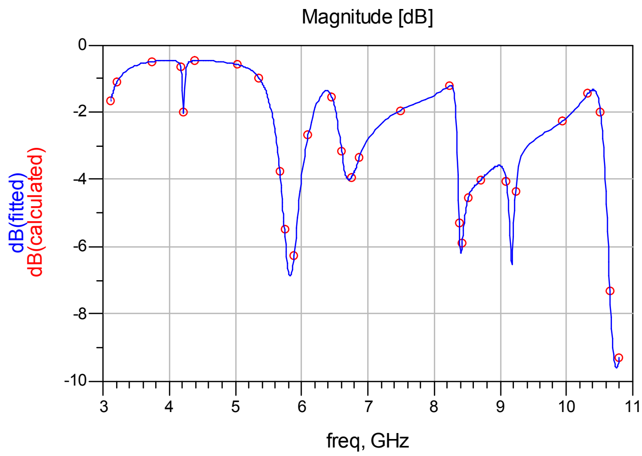

Figure 2. *Return loss of the hexagon reference antenna.*

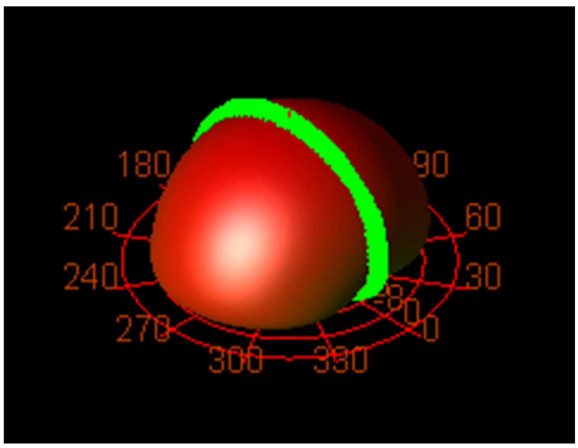

Figure 3. *Radiation pattern.*

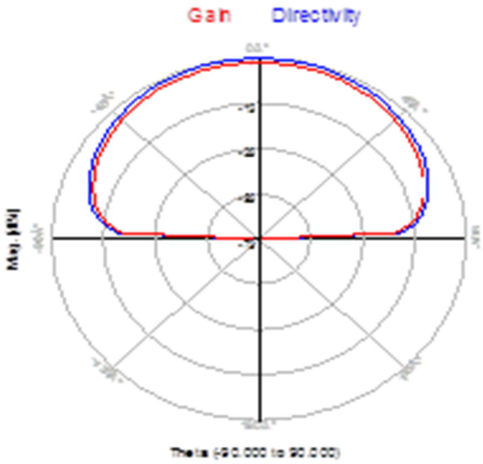

Figure 4. *Gain and Directivity.*

In this second configuration consists of sierpinski carpet fractal geometry is used to generate a fractal element is successive iteration are applied on a simple hexagon patch as shown in figure 1. (a). which is known as zeroth order iteration. The first order iteration is retrieved subtraction from of the one third dimensions of the main hexagon patch and is shown in figure 1 (b). The second and third iteration in to each square which are 9 time of 27 times smaller than main patch shown in figure 1 (c) and figure 1 (d) respectively. The second order iteration is carried out eight times on the main patch and the third order iteration is 64 times on the main patch. When the iteration can be done more the shape becomes more complex and loading causes multiple resonances and the resonant frequency is shifted down. The same center point is shared by are the iterations. The scale factor is 1/3. For all the four iteration the WxL of the square are 40mm, 4.44mm, 1.48mm and 0.49mm respectively. The substrate used in this paper is FR4 with a dielectric constant 4.4 and a loss tangent 0.001.

Figure 5. *Fractal element: (a) 0^{th} iteration (b) 1^{st} iteration (c) 2^{nd} iteration (d) 3^{rd} iteration.*

The antenna is designed by using ADS software and its frequency range is 3.1GHz-10.8GHz. Four iterations have been done and all the iterations antenna parameters such as return loss, gain, bandwidth and directivity are analyzed. The return loss for zeroth iteration is -15 db and its gain and directivity is 4.6db and 4.6db respectively. From the above iterations the return loss for third iteration is -17 db.

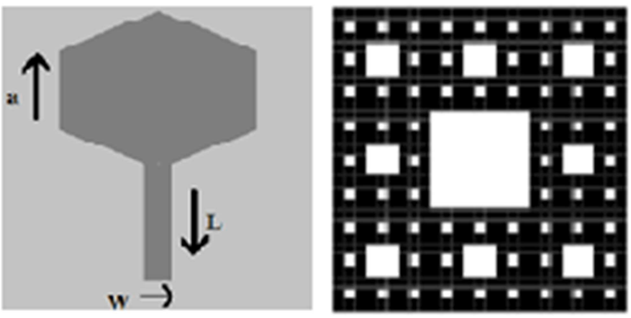

Figure 6. *Hexagon patch antenna with Sierpinski Carpet (a) Front view (b) Back view.*

Hexagon microstrip patch Sierpinski Carpet Antenna frequency resonates around around 8.5GHz with a Return loss of -38db. The gain is 4.3dBi and directivity 6.4dBi.

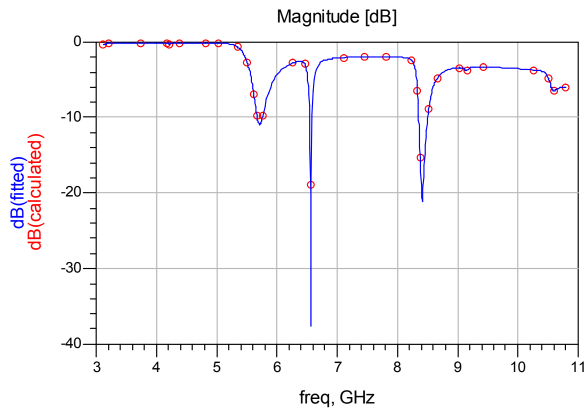

Figure 7. *Hexagon patch antenna with Sierpinski Carpet Return loss.*

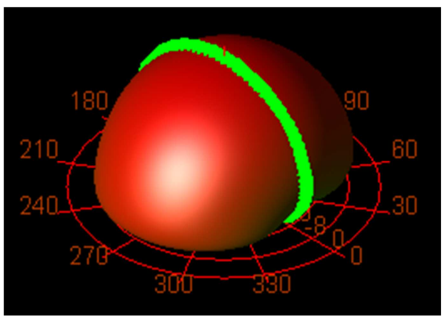

Figure 8. *Radiation pattern.*

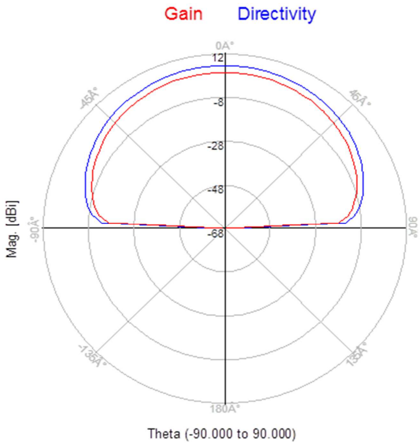

Figure 9. Gain and Directivity.

The third configuration (antenna 3) consists of adding a shorting pin situated on the straight line connecting the tip to the bottom side of the hexagon. The final structure is presented in figure 10.

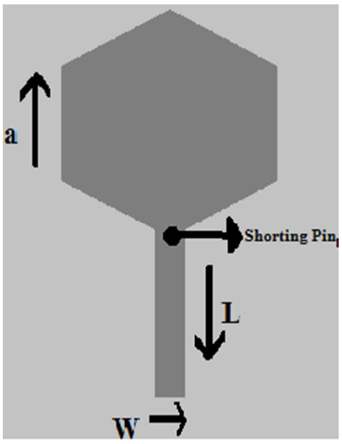

Figure 10. Compact hexagon antenna with fractal and shorting pin.

Hexagon microstrip patch Sierpinski Carpet with shorting pin Antenna frequency resonates 8.5GHz with a Return loss of -48db. The gain is 4.3dBi and directivity 6.4dBi.

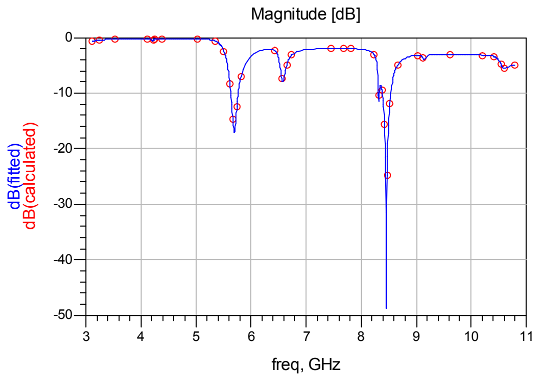

Figure 11. Shorting pin with Sierpinski Carpet Return loss.

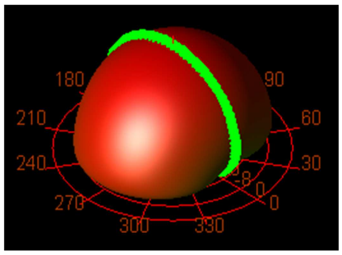

Figure 12. Shorting pin with Sierpinski Carpet Radiation pattern.

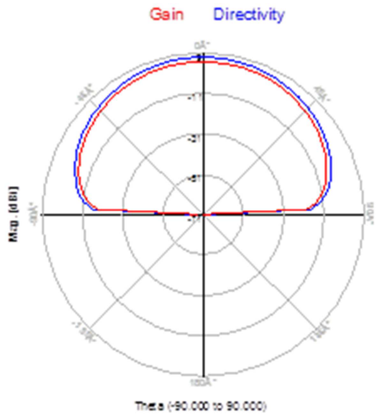

Figure 13. Shorting pin with Sierpinski Carpet Gain and Directivity.

Table 1. Simulation Results.

S-parameter	Reference Antenna	Sierpinski carpet antenna	Shorting pin antenna
Return loss (dB)	-6	-38	-48
Resonance Frequency (GHz)	8.5	8.5	8.5
Gain (dBi)	4.6	4.3	4.3
Directivity (dBi)	6.4	6.4	6.4

5. Conclusions

The hexagon microstrip patch with Sierpinski carpet antenna are designed and simulated at 3.1GHz to 10.8GHz. The miniaturization strategy is performed in two stages. The first stage, a third order of the Sierpinski carpet is applied to the ground. Inserting a shorting pin linking the patch to the ground constituted the second stage. Both the stages are analyzed and compared. The performances are analyzed in terms of return loss, directivity, gain, and radiation pattern. The hexagon microstrip patch with Sierpinski carpet fractal antenna the gives best output.

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