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Design of a Novel Sierpinski Fractal Antenna Arrays Based on Circular Shapes with Low Side Lobes for 3G Applications

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Abstract A fractal is a recursively generated object having a fractional dimension. So many objects, including antennas, can be designed using this recursive nature of a fractal. In this paper we have used the fractal geometry arrangements for the design of planar antenna arrays with low side lobes. Iterated Function System (IFS) is used to generate the sierpinski fractal antenna arrays using circular shapes. CST Microwave Studio EM Simulation software is used for design & simulation of these antenna arrays. Two resonant frequencies like. 1936 GHz &. 222 GHz are achieved. Better performance parameters like return loss, VSWR, directivity, gain, bandwidth enhancement with low SLL are estimated.

Keywords: *fractal antenna arrays, Sierpinski fractal, IFS, random arrays, planar arrays, directivity, gain, bandwidth, SLL*

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1. Introduction

In recent years, the technology of fractal geometry has been used in almost all branches of science and engineering. In antenna engineering Fractal geometry is implemented with important properties like self similarity, frequency selective, conformal & frequency independent characteristics. Several fractal geometries have been explored for antennas with special characteristics, in the context of both antenna elements and spatial distribution functions for elements in antenna arrays. In many fractal antennas, the self-similarity and plane-filling nature of fractal geometries are often qualitatively linked to its frequency characteristics [1].

The term 'fractal' was defined by Benoit Mandelbrot in 1975 to classify multiple structures whose dimensions were not integer numbers. He has shown the advantages of fractal geometries by characterizing these unique occurrence nature which were difficult with the Euclidean geometries [2].

The word "fractal" named by Benoit Mandelbrot from the Latin adjective fractus, also referred as the father of fractal geometry. The corresponding Latin verb frangere means 'to break' to create irregular fragments. Therefore in addition to 'fragmented' (as in fraction or refraction), fractus should also mean 'irregular', both meanings being preserved in fragment" [3].

Mandelbrot defined fractal as "A fractal is a set for which the Hausdorff dimension strictly exceeds the topological dimension," which he later retracted and replaced with: "A fractal is a shape made of parts similar to the whole in some way." So, in the simplest way to define a fractal is as an object that appears self-similar under varying degrees of magnification, and in effect, possessing symmetry across scale, with each small part of the object replicating the structure of the whole. This is perhaps the loosest of definitions; however, it captures the essential, defining characteristic, that of self-similarity. Approximate fractals are easily found in nature. Examples include clouds, snow flakes, crystals, mountain ranges, lightning, river networks, cauliflower or broccoli, and systems of blood vessels and pulmonary vessels. Coastlines may be loosely considered fractal in nature [3].

Following structures are some common fractal geometries particularly useful in design & development of antennas for various wireless applications, e.g. Sierpinski carpet, Cantor set, Koch curves, Sierpinski gasket, Koch snowflake [4].

Fractal geometries are beneficial to antenna design particularly for antenna size minimization as these dimensions are not limited to integers leading discovery of antennas with improved characteristics. So the fractal antennas are suitable for antenna minimization & input matching improvement. These antennas are designed for multiband applications to operate effectively at various frequency bands.

Major advantages of fractal antenna are like antenna minimization over traditional antennas, improving input resistance of antennas which are difficult to match to the feeding transmission lines, self-similar nature that can be used for multiband operation [5].

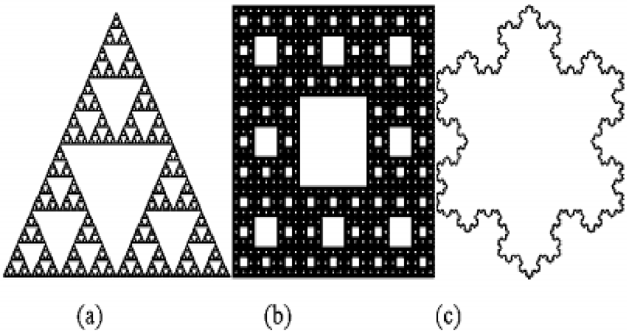

Figure 1. A typical view of common fractal antenna geometry (a) Sierpinski Gasket (b) Sierpinski Carpet (c) Koch Snowflake

2. Fractal Antenna Arrays

Antenna arrays are commonly used for imaging & communications. A typical antenna array consists of antenna elements placed on an x-y plane in multiple distributions like linear, planar, periodic & random [6].

Usually the radiation pattern of a single element is relatively wide providing low values of directivity & gain. The directivity & gain of the antenna can be achieved by increasing electrical size of antenna. But with miniaturized antenna i.e without increasing size of elements performance of the antenna can be enhance by assembling multiple elements in an electrical & geometrical configuration which is called as antenna arrays. Here the elements are may be identical or non-identical.

An antenna arrays would have no side lobes. Side lobe level reduces the radiation pattern in the desired direction [6,8].

2.1. Linear Arrays

Linear array is the simplest array which is formed by placing multiple elements along a straight line. It is also called as single dimensional array. It is commonly used due to simplest presentation & better physical interpretation. An array of identical elements all of identical magnitude & with a progressive phase is called as a uniform array. Uniform arrays generally provide largest directivity. Here all the elements have the same phase excitation in addition to the same amplitude excitation.

2.2. Planar Arrays

Planar array is also called as rectangular array as individual elements are placed along a rectangular grid in addition to placing elements along a line. Here the elements are placed in one plane, so it is called as two dimensional array. This array provides additional variables that can be used to control & shape the pattern of the array. This is more versatile & provides symmetrical radiation pattern with lower side lobes. So these are commonly used in communications [9].

2.3. Periodic Arrays

This is the most popular planar array known due to the fact that the main beam tends to deteriorate rapidly as it is scanned towards the plane of the array. Here the elements are arranged in a periodic distribution by placing the elements in the grid.

Planar arrays are the antenna arrays where the elements are organized in a grid that have tendencies to produce main beams and side lobes of the same height.

Periodic arrays have very low side lobe levels, though very difficult can be achieved by using a very large number of elements [10].

2.4. Random Arrays

An array of electrically large antennas suffers degradation due to mutual coupling and prevents the full utilization of its instantaneous bandwidth. A solution to this problem is aperiodic distribution i.e. to remove the periodicity and spacing the *N* elements aperiodically into a larger aperture. This allows for greater bandwidth in beamforming across larger distances & reducing the need to have elements spaced close to each other.

A random array provide desirable behavior when compared to a well-populated periodic distribution as these can be designed to limit radiation outside of the desired direction and mitigate spatial constraints due to the array spacing and element size those are typically required to achieve broadband behavior.

Randomly distributed arrays have many unique capabilities like adequate phase control and synchronization these arrays can coherently add signals in the desired direction. Random arrays have higher side lobes & do not need multiple elements. These arrays have one important advantage is robust in sense i.e if one element fails, the antenna will continue to operate efficiently as before [14].

3. Antenna Design Specification

A circular microstrip patch can be designed by using following equation with specified information including dielectric constant of substrate (ϵ_r),resonant frequency (f_r) & height of the substrate (h).

The radius (a) of circular microstrip patch is

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi \epsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{1/2}}$$

Where

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}}$$

Here the proposed antenna is designed by using a substrate (RT / duroid 5880) with a dielectric constant of 2.2, h = 0.1588 cm to resonate at 1 GHz. By putting above parameters in the above equation radius of circular patch (a) is calculated as 52.5 mm [11,15]. We have used Co-axial Line Feed (Probe feed) technique.

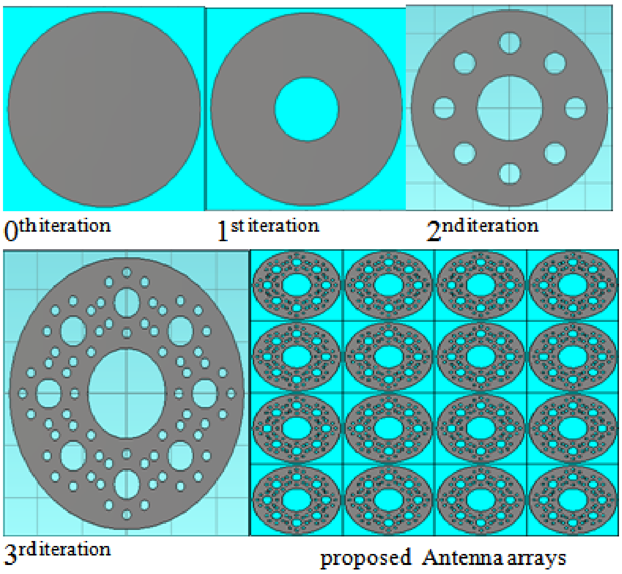

Figure 3.1. Multiple iterations of sierpinski fractal antenna using circular shapes & proposed 16 element Antenna arrays

The sierpinski fractal structures can be designed by taking multiple iterations on basic geometrical shapes like rectangle, square, circle or triangle [12]. Sierpinski fractal antenna is realized by successive iterations applied on a simple circular patch which is called as zeroth iteration. This circular microstrip patch antenna is designed with a radius of 52.5 mm as obtained by the above numerical analysis. First order iteration is designed from this circular microstrip patch antenna by removing a central slot of 1/3 dimension of the circular patch. Further iterations are designed by increasing number of slots with 1/3 reduced dimension. Finally the proposed planar antenna array is designed by taking 16 elements in periodic distribution. Here each elements are taken from 3rd iteration of sierpinski fractal antenna [13].

4. Simulation Results & Analysis

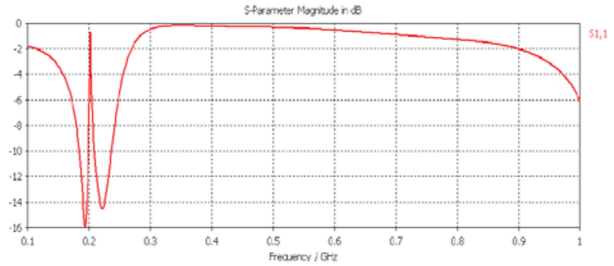

Figure 4.1. Variation of reflection coefficient (s_{11}) with frequency

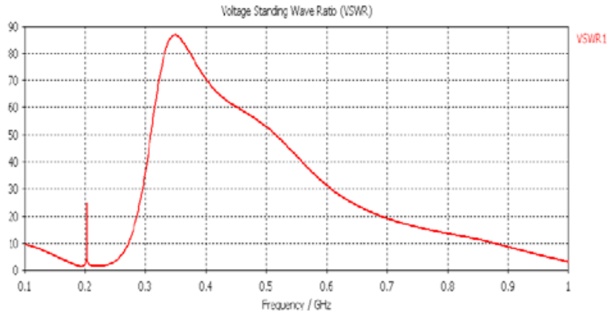

Figure 4.2. Variation of VSWR with frequency

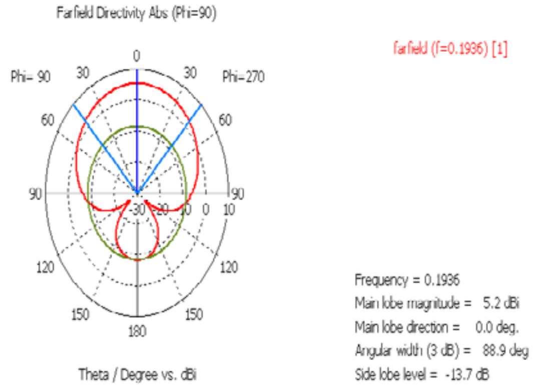

Figure 4.3. Polar radiation pattern (Directivity) at f_r=0.1936 GHz

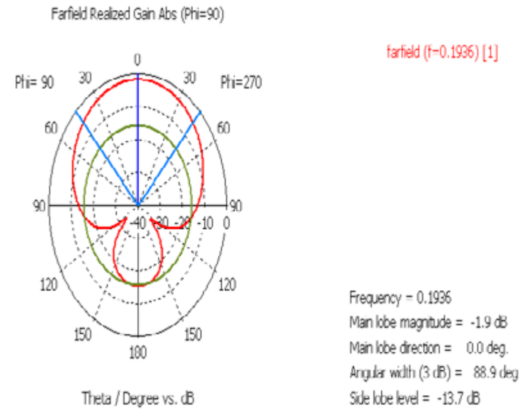

Figure 4.4. Polar radiation pattern (Gain) at f_r=0.1936 GHz

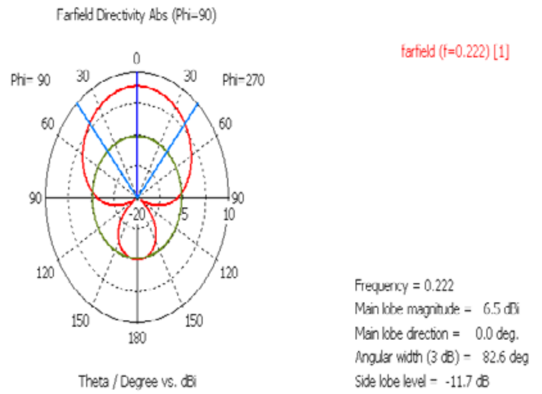

Figure 4.5. Polar radiation pattern (Directivity) at f_r=0.222 GHz

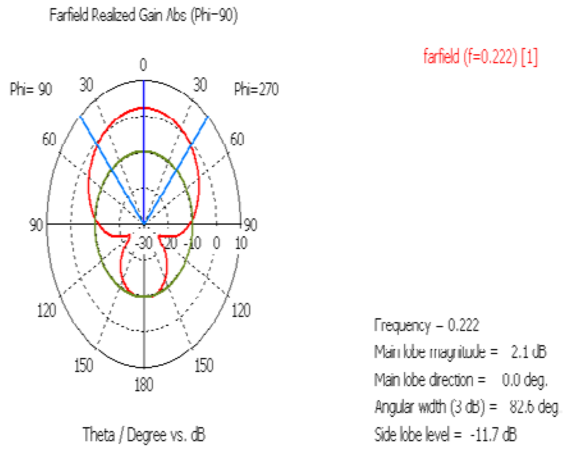

Figure 4.6. Polar radiation pattern (Gain) at f_r=0.222 GHz

Table 1. Comparision of performance parameters

Resonant Frequency	Return Loss	VSWR	Directivity	Gain	BW	SLL
0.1936 GHz	-15.95	1.378	5.247 dBi	1.912 dB	14.5 MHz	-13.7 dB
0.222 GHz	-14.53	1.461	6.489 dBi	2.072 dB	27.7 MHz	-11.7 dB

4.1. BW Enhancement Calculation

For 1st band

fc=.1936GHz, f_L =4.504GHz & f_H =.1936GHz

$$\text{So BW} = \left(\frac{fH - fL}{fc}\right) \times 100\% = 7.48\%$$

For 2nd band

fc=.222 GHz, f_L =4.67GHz & f_H =.222 GHz

$$\text{So BW} = \left(\frac{fH - fL}{fc}\right) \times 100\% = 12.47\%$$

So the Bandwidth (**BW**) enhancement for the 2 resonant frequencies at .1936 GHz & .222 GHz are 7.48% & 12.47%. This Proposed antenna design produces low SLL (Side Lobe Level) that is useful to reduce side lobe loss & back lobe loss of the antenna radiation thus enhancing the directivity & gain [16].

5. Conclusion

In this paper, we have achieved a novel sierpinski fractal antenna arrays using circular shapes that provides better performance with low SLL.

The designed antenna provides multiband performance with resonant frequencies like 0.1936 GHz & 0.222 GHz at the bandwidth of 14.5 MHz & 27.7 MHz, high directivity of 6.489 dBi, high gain of 2.072 dB with low SLL of -13.7 dB. Bandwidth (**BW**) enhancement at the two resonant frequencies at .1936 GHz & .222 GHz are 7.48% & 12.47% respectively.

Due to the better performance parameters the proposed antenna can be suggested for the 3G applications.

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