A NOVEL APPROACH FOR DESIGNING FRACTAL ANTENNAS

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Abstract: Designing fractal antennas for broadband communications, various modifications and optimisations to the fractal patterns, such as Koch or Sierpinski, are adopted for better frequency responses. In this article, we explore a new approach by defining a set of complex functions, $z^q \Pi C_i$, where $C_i = \exp(i*g_i(z))[(z-v_i)/(1-\underline{v}_i z)]$, and then using the shapes of the solution domains of the functions directly as patterns of fractal antennas.

1 INTRODUCTION

Design of fractal antennas is currently targeted for highly desirable characteristics such as compact size, low profile, conformal, multi-band and broadband, as described in (Cohen,1995), (Gianvittorio, 2002), and (Werner). Most of the designers adopt operations such as translation, rotation, iterations, etc. on the fractal generator motifs, such as Koch, Minkoski, Cantor, Torn Square, Mandelbrot, Caley Tree, Monkey's Swing, Sierpinski Gasket, Julia etc. for the creation of the self-similar shapes. To further improve the frequency responses, they applied modifications on the created shapes, such as in (Puente, 2000). Recently, new approaches, such as Generic Algorithm, are studied for handling antenna optimisation on multi-dimensional parameters (Altshuler, 2002). However, these approaches do not provide the initial conditions, namely, the original shapes for optimisation.

In this article, we explore a novel approach based on the methodologies used in the area of dynamic systems in conjunction with fractal geometry as described in (Mandelbrot, 1977), (Milnor, 2000), and (Falconer, 1990). We define a set of complex functions, $z^q \Pi C_i$, based on relationship of moving and observing entities. By solving the functions for a given domain on the complex plane, we obtain a solution domain based on the criteria of function convergence (Ni, 2006). Then we extract the internal and external contours of the shapes of the solution domains and directly use them as topologies of antenna or antenna arrays.

Of our particular interest, we adopt fractal shapes known as Herman Rings for the fractal antennas. Herman Rings are characterized by fractal internal and external contours. We observe the broadband characteristics from these antennas.

2 FUNCTIONS

We define the function set, $f = z^q \Pi C_i$, which may have the following forms:

$$f = z^q C_1 C_2$$
$$f = z^q C_1 C_2 C_3 \text{ and so on} \quad (1)$$

where z is a complex variable, q is an integer, and C_i has following form:

$$C_i=\exp(i*g_i(z))[(z-v_i)/(1-\underline{v}_i z)] \quad (2)$$

here $\underline{v_i}$ is the complex conjugate of v_i. We propose this form based on the following form known in the theory of special relativity by A. Einstein:

$$1/(1 - v^2/c^2)^{1/2} \quad (3)$$

The z^q term in Equation (1) has implication of time and is used to ensure that the function may converge. The term

$$\exp(i*g_i(z)) \quad (4)$$

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In Equation (2) represents the phase, where $g_i(z)$ is a complex function. A given domain can be a domain of complex numbers, x+yi, with $(x^2 + y^2)^{1/2} \leqq 1$

The function f will go through iteration as:

$$f^n(z) = f \circ f^{n-1} \quad (5)$$

Here, n is a positive integer indicating the order of iteration.

3 DOMAINS

The domains shown in the following figures are the normalized solution domains. Figure 1a and 1b show the impact of iteration number and phase on the solution domains.

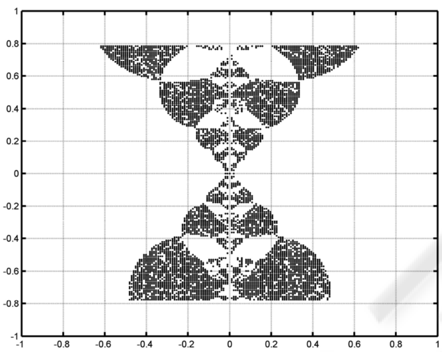

Figure 1 a: Bow-tie like Fractal Domain.

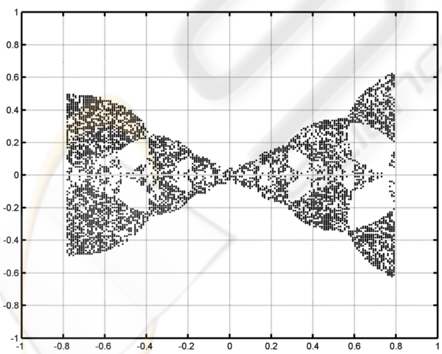

Figure 1 b: Bow-tie like Fractal Domain.

These two domains show asymmetrical features. Figure 2 shows a nebular-like domain, which may be seen as an antenna array. Figure 3 shows a Spiral-like fractal domain, which has potentially broadband radiation characteristics.

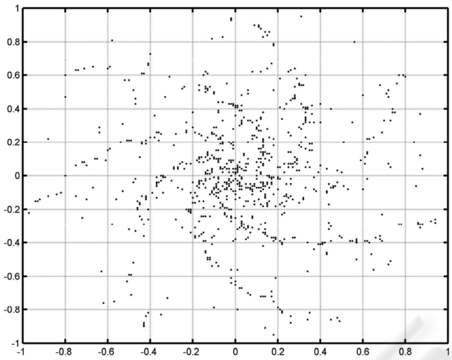

Figure 2: Nebular-like Fractal Domain.

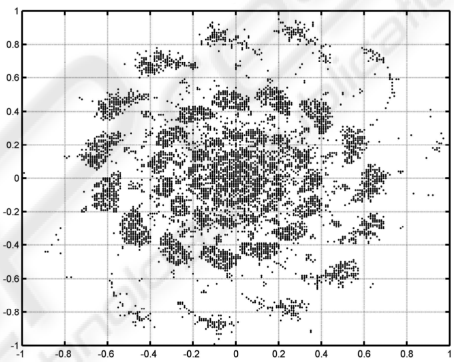

Figure 3: Spiral-like Fractal Domain.

Other solution domains look like some natural objects, such as shells (Figure 4). This domain shows external and internal structures or contours varying with iteration orders and locations. In short, the proposed functions have richness of solution domains, which may look like the objects in the nature.

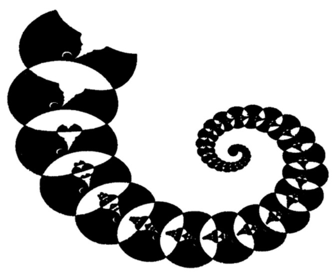

Figure 4:Shell-like Fractal Domain.

4 ANTENNAS

We adopted commercially available tools and platforms, such as Matlab and Zeland (IE3D), for domain creation, contour capture, and antenna performance analysis. Figure 5 shows a set of 772 data points in the Nebular-like fractal domain (Fig.2) imported to a Matlab GUI, which treats each data point as antenna, and plots the radiation pattern. The fractal domain is shown at center of the plotted pattern.

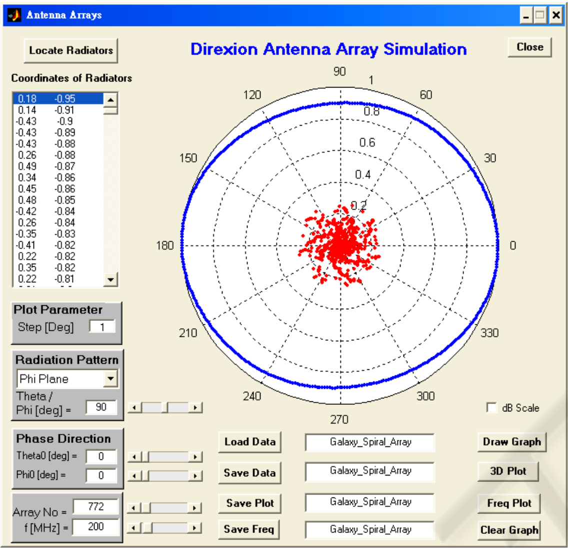

Figure 5: Radiation Pattern of an Antenna array.

To demonstrate the use of the solution domains for broadband fractal antennas, we select the domain as in Figure 6 for building a patch antenna on 1.6 mm thick FR4 substrate. The ground plane size of FR4 sample is about 4cm x 4cm.

Figure 6: Spiral-like Fractal Domain.

We fed the signals at the centre of this Spiral-like antenna and observed the activated modes as shown in Figure 7. Matched modes were observed down to 1 GHz range close to the simulated results. It was noticed that high harmonic modes were suppressed from these samples. Potentially, we can construct a broadband antenna with bandpass characteristics based on the observations.

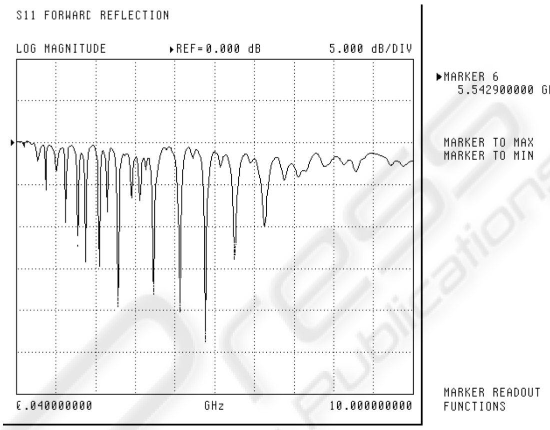

Figure 7: Measurement on S_{11} of Spiral-like Antenna.

By optimising the ground plane, we are able to obtain –10 dB S_{11} floor from 3 GHz to 10 GHz for these fractal antennas (Fig. 8).

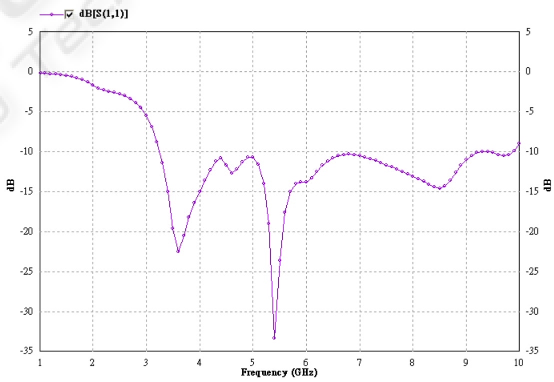

Figure 8: Simulated S_{11} of Spiral-like Antenna.

We also observed multi-mode radiation patterns through the frequency bands although the patterns are rather stable through the bands. Figure 9 shows the E-field patterns at 3.6 GHz, 5.4 GHz, and 8.5 GHz. The simulated scalar and vector current distributions show that the areas of radiation on fractal antenna are not changed too much over the observed frequencies.

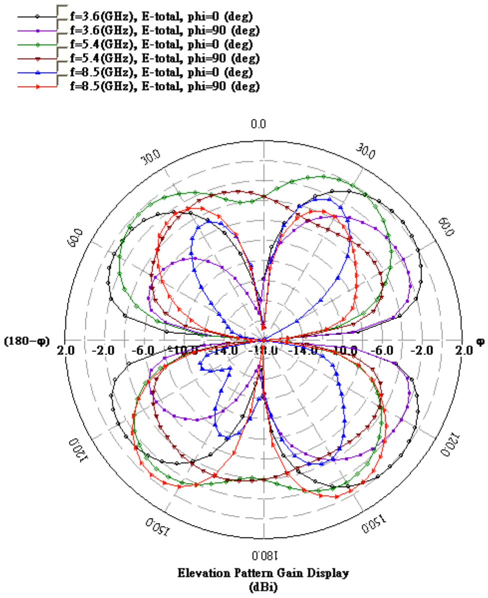

Figure 9: Simulated Radiation Patterns.

The asymmetrical nature of the fractal domains shows radiation distribution toward to one direction. Figure 10 shows this observation when the Spiral-like antenna is on a square ground plane. The gain is about two fold of uniform radiation patterns.

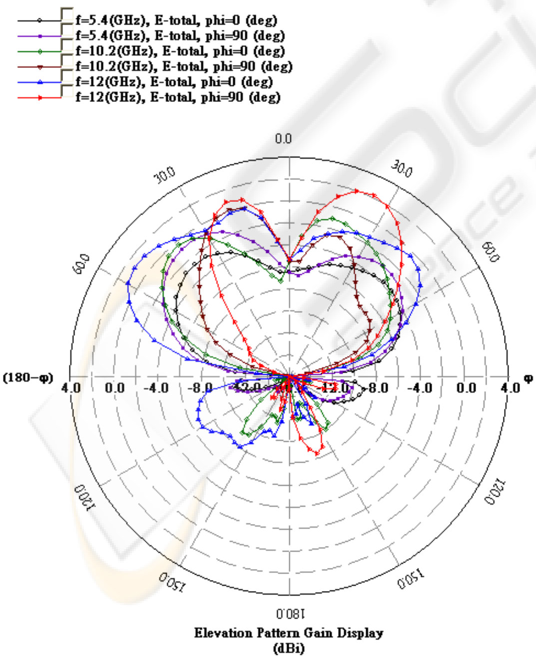

Figure 10: Simulated Radiation Patterns.

5 CONCLUSIONS

We have explored a new approach to develop fractal antennas by computing a set of complex functions, $z^q\Pi C_i$, based on the methodologies in the area of dynamic systems. The topological solution domains are directly used as antenna elements or arrays. By selecting the desirable domains, we can potentially build broadband antennas with characteristics of frequency filtering. This approach provides detailed patterns initially for fast optimisation.

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