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Design and Analysis of a Circular Monopole Fractal Antenna

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ABSTRACT

This paper presents the design of a circular monopole fractal antenna with good radiation patterns designed for various applications. This design employs the principle of fractal geometry to make the model more attractive while still getting the desired bands. The designed antenna operates in the digital cellular system (DCS), personal communication system (PCS), wireless local area networks (WLAN), Bluetooth, and World Interoperability for Microwave Access (WiMAX). The antenna is designed to operate at 2.4GHz. Due to fractal geometry, it can operate in multiband frequencies and produce other resonant frequencies at around 1.9GHz, 4,4GHz, and 6.1GHz. The virtual analysis and characteristics of the antenna are performed in CST (Computer Simulation Technology) simulation tool.

KEYWORDS:Fractal, Monopole, Multiband, CST simulation tool, Return loss, Gain, Directivity

1. INTRODUCTION

Antennas with larger bandwidths and lower dimensions than previously conceivable are required for modern communications systems. This has sparked interest in antenna research in a variety of approaches, including the use of fractal-shaped antenna elements. Several fractal geometries for antenna applications have been introduced in recent years, with varying degrees of success in enhancing antenna properties. Some of these geometries have shown to be very effective in terms of lowering antenna size, while others try to incorporate multiband properties. Yet, no major progress has been achieved in correlating these geometries' fractal qualities with antennacharacteristics. The goal of the research described here is to look at the geometrical properties of fractals and how they affect the performance of antennas that use them. In recent years, several antenna layouts based on fractal geometries have been reported [1] – [2]. These low-profile antennas have a moderate gain and may be used in a variety of frequency bands, making them multi-functional. The multi-band (multifunctional) component of antenna designs is extensively investigated in this paper, with a focus on identifying fractal aspects that influence antenna multi-band characteristics. Using Hilbert curve fractal geometry, smaller antennas have been created. Furthermore, antenna design equations are derived in terms of geometrical characteristics such as fractaldimension. The fractal dimension of the geometry has also been linked to antenna properties.

Fractals have found widespread application in numerous sectors of science and engineering since they were mathematically re-invented by Mandelbrot. Fractal modeling of naturally occurring processes has benefited several disciplines, including geology, atmospheric sciences, forest sciences, and physiology. On the application of fractals in physical sciences, there are several publications and monographs accessible. One of the fields of engineering that has profited greatly from the use of fractals is fracture mechanics [9]. Fractal geometries' ability to fill space has led to a number of novel applications. For finite element analysis of vibration problems, fractal mesh production has been proven to reduce memory needs and CPU time [10]. Image compression utilizing fractal image coding [11] - [13] is one application that has had the largest impact on modern technology. The use of fractal picture rendering and image compression algorithms has resulted in significant memory and processing time savings. Scattering and diffraction from fractal screens have been researched extensively in electromagnetics. Self-similarity of diffracted fields from a self-similar Sierpinski gasket in the Franhauffer zone has been demonstrated [14]. Fractal electrodynamics [15] - [17] is the study of wave interactions with such self-similar structures. Some of these investigations show that fractal geometries have imprinted features on scattering patterns. Frequency selective screens have also utilized fractal geometries in recent years [18] - [20]. The dual-band aspect of their frequency response is thought to be responsible for the fractal geometry's self-similarity. The surface impedance of metallic fractal topologies on a dielectric slab has also been studied [20]. The 1990s saw the development of fractal antenna arrays and fractal-shaped antenna elements.

The major objective for fractal antenna engineering is to extend notions of antenna design and synthesis beyond Euclidean geometry [12] - [13]. The usage of fractals in antenna array synthesis and fractal-shaped antenna components has been investigated in this area. The primary goal of the research on fractal antenna arrays is to get specific antenna properties by employing a fractal distribution of components. It is well understood that the qualities of antenna arrays are dictated by their dispersion rather than by the attributes of individual components. Because array spacing (distance between elements) is frequency-dependent, most conventional antenna array designs are band-limited. Self-similar arrays feature multi-band frequency independence [16]. Several unexpected properties of fractal and random fractal arrays have been discovered [17]. The radiation properties of such antenna arrays have been discovered to be affected by variations in the fractal dimension of the array dispersion. The usage of Random fractals reduces fractal dimension, resulting in greater control of side lobes [14]. It has also been investigated how to synthesize fractal radiation patterns [18]. It has been discovered that the array's current distribution influences the fractal dimension of the radiation pattern. It is reasonable to deduce that fractal features like self-similarity and dimension play an important role in the creation of such arrays.

Wider bandwidth, multiband [1-8], and low-profile antennas are in high demand in current wireless communication systems and an expanding number of other wireless applications for both commercial and military uses. This has prompted antenna research in a variety of areas, one of which is the use of fractal-shaped antenna components. Traditionally, each antenna works at a single or dual frequency band [7-8], with different antennas required for various purposes. This will result in difficulty with restricted space and placement. To address this issue, a multiband antenna can be utilized, which allows a single antenna to function over many frequency bands. Using the fractal form in antenna design is one method for creating a multiband antenna [9]. The circular monopole fractal antenna [21] with the size of 55 mm × 40 mm × 1.6 mm is presented in this study, and the antenna behavior of this shape is explored. In addition to the theoretical design method, numerical simulation utilizing software (CST) was undertaken to get design parameters such as patch size and feeding position. The antenna is constructed and analyzed using the CST Microwave Studio Suite.

2. ANTENNA DESIGN

A. Materials

A general microstrip patch antenna construction is formed by an area of metallization that supported above a ground plane and fed against the ground at a suitable point or point. Figure (1) depicts the proposed circular antenna architecture. The antenna is built on an FR4 substrate with a relative permittivity of 4.4, a dielectric dissipation factor of 0.018, and a thickness of 1.6 mm. In this construction, a modified form of a circular patch is employed, and the signal is launched using microstrip line feeding. For the updated version of the circular patch, fractal geometry is taken into account.

B. Design Equations

$$R = \frac{F}{\left\{1+\frac{2h}{\pi \varepsilon_r F}\left[\ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{\frac{1}{2}}} \quad (1)$$

$$\text{Where,} F = \frac{8.791 \; X \; 10^{9}}{f_r \sqrt{\varepsilon_r}} \quad (2)$$

R = radius of the patch
h = height of the dielectric substrate
ε_r= relative permittivity of the substrate
f_r = resonant frequency of the antenna

The antenna is designed with a radius of R which is obtained from equation (1). Where h is the height or thickness of the substrate, $f_r$is the resonance frequency and ϵ_r is the relative permittivity of the dielectric material.

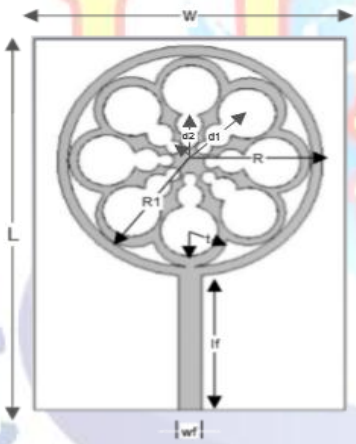

Fig. 1. Geometry and front view of circular monopole fractal antenna

C. Structure Design

The antenna is designed on FR4 substrate with length 'l' and width 'w' as shown in figure (1). A conducting material PEC is used for ground with length and width same as substrate and with a height of 0.036mm. Circular cuts are made by radius 'a' further decreasing the cuts with a scaling factor 's_f' wheres_f = an/an − 1. The antenna is fed through microstrip line feed with a length of feed line as 'l_f' and width as 'w_f'. The advantage of using this feed is to match the impedance of the feedline to the patch without the need for any matching element. The development of the suggested antenna is indicated by multiple structural changes in the circular patch, as shown infigure (2).

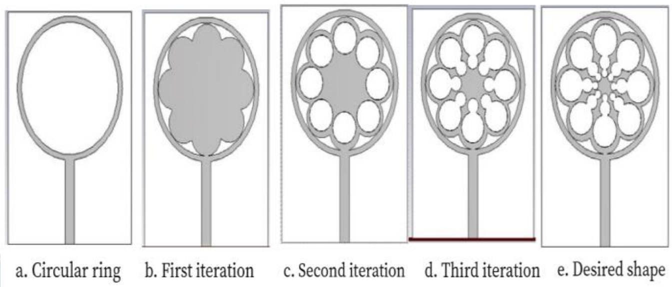

Fig. 2. Fractal iterations of the presented antenna.

In the initial version, a radiating element with a circular ring form is employed as shown in the figure (2). The width of the circular element is (R-R1) where R and R1 are outer and inner radiuses respectively. This structure is expected to resonate at lower frequencies between 2 and 2.5GHz. In the next step, the structure was modified by filling the dielectric material to minimize the reflection losses. In the third iteration, circular cuts are made by extracting the conductive material with a radius of 'a' with a distance of 'd' from the center. In the fourth and fifth iterations, the structure is modified by engraving the conductive material with circular cuts using a scaling factor.

TABLE I
DESIGN PARAMETERS OF THE PRESENTED ANTENNA

Parameter	Dimension (mm)
L	55
w	40
h	1.6
R	17
R1	15.7
l_f	20
w_f	3
h_f	0.036
d1	10.55
d2	5.5
d3	3
t	4.75
a	3.75
s_f	2

3. SIMULATION RESULTS

The simulation results of the presented antenna are shown below. The circular ring shape produces the resonance at 2.3GHz with a reflection loss of -12dB and harmonics at 3.2, 4.2, and 6.8 GHz. The first iteration shifts the resonance to lower frequencies by producing resonance at 2.7GHz by improving the reflection coefficient to -26dB at the fundamental resonance frequency and also improving the reflection losses at the harmonics. The multi-band operation can be seen in the next iterations due to the fractal geometry and structure of the antenna. In the second iteration as the circular cuts are added the reflection coefficient improves in all resonance frequencies. In the next iteration, the resonance produces at 1.9GHz, 2.5GHz, 4.4GHz, 5.1GHz, and 6.9GHz. The finalstructure produces the resonance at 1.9GHz with a reflection coefficient of -28dB, 2.4GHz with a reflection coefficient of -47dB, 4.4GHz with a reflection coefficient of -25dB, and 6.1GHz with a reflection of -14dB thus satisfying the multiband characteristics.

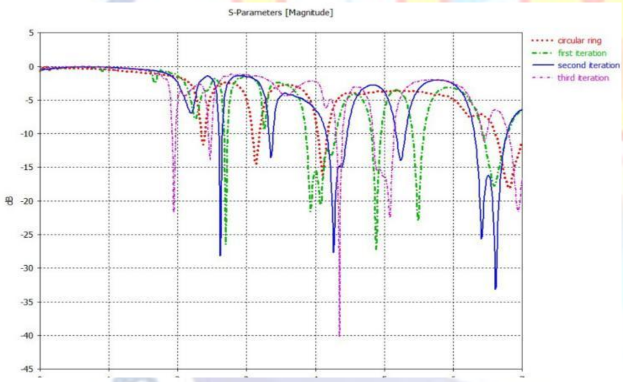

Fig. 3. simulated reflection coefficient of different iterations of the presented antenna

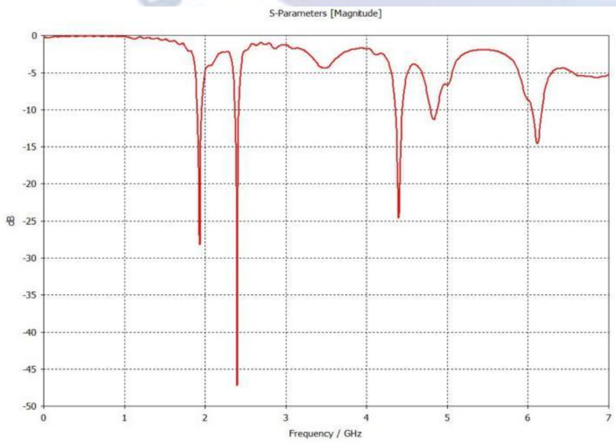

Fig. 4. simulated reflection coefficient of the presented antenna

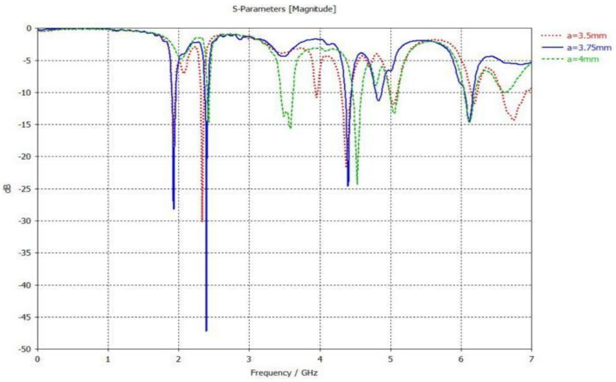

Fig. 5. Comparison of return loss with variation of radius of circular cuts

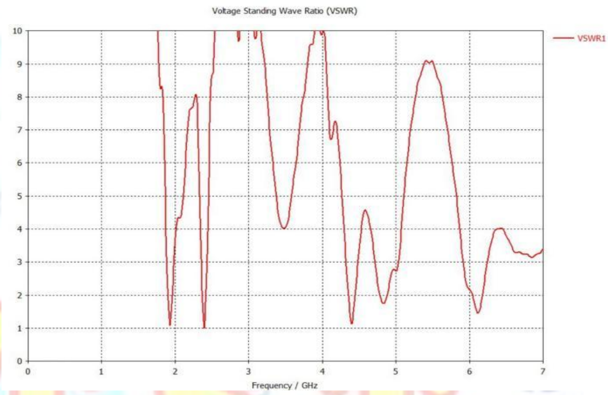

Fig. 6. Voltage standing wave ratio plot of presented antenna

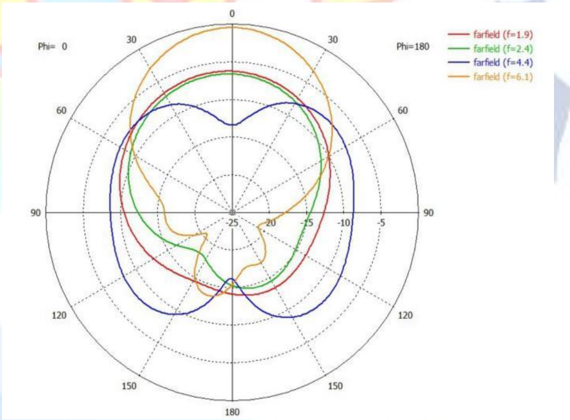

Fig. 7. Radiation pattern phi=0, E-plane

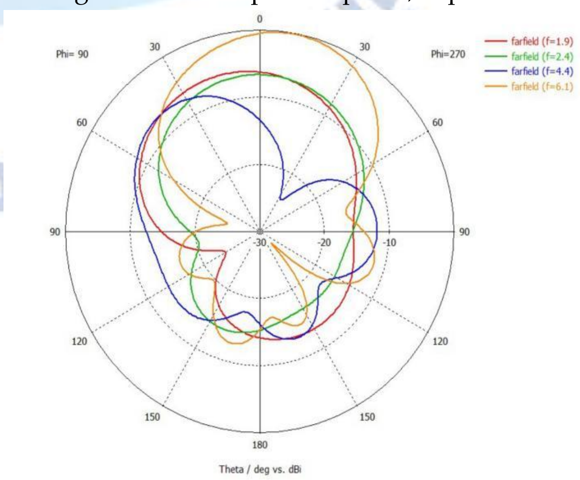

Fig. 8. Radiation pattern phi=90, H-plane

TABLE II

SIMULATED RESULTS OF PRESENTED ANTENNA

Frequency (GHz)	S11 (dB)	VSWR	Gain (dB)	Directivity (dB)
1.9	-28	1.1	4.5	5.1
2.4	-47	1	5	5.49
4.4	-24	1.1	1.8	2.77
6.1	-14	1.48	5.4	6.1

Figure 3 and 4 illustrates the simulation results of reflection coefficient of all iterations of the circular fractal antenna. The effect of radius of circular cuts on reflection coefficient is illustrated id figure 5. Voltage standing wave ratio for different resonance frequencies is shown in figure 6. Radiation patterns in both E-plane and H-plane of the presented antenna are shown in figure 7 and figure 8 respectively. Table II represents the simulated results of different parameters of the circular fractal antenna.

4. CONCLUSION

The design of the circular monopole fractal antenna is presented in this paper. The antenna is designed to operate in wireless applications such as PCS, Wi-Fi, WLAN, DCS, WiMAX, and Bluetooth. The simulated results show that the designed antenna has four resonance frequencies 1.9GHz with a bandwidth of 50MHz (1.9GHz to 1.95GHz), 2.4GHz with a bandwidth of 50MHz (2.36GHz to 2.41GHz), 4.4GHz with a bandwidth of 90MHz (4.35GHz to 4.44GHz), and 6.1GHz with a bandwidth of 140MHz (6.05GHz to 6.19GHz). The designed fractal antenna is far better than the traditional antennas as it provides multi-band operations with high gain, small size, and an easy fabrication process. By constructing an array with the designed antenna, we can improve the gain and directivities of the antenna.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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