ICTRS 2017

In Memory of Blagovest Shishkov

Sixth International Conference on Telecommunications and Remote Sensing

Proceedings

Delft, The Netherlands • 6-7 November 2017

ICPS Published by ACM

Organized by: CREST

Co-Organized by: TUDelft ARSit

Under the Auspices of: U.R.S.I.

Cooperating Organizations: Aristotle University of Thessaloniki, Bulgarian Academy of Sciences, AMAKOTA

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Organized by
IICREST – Interdisciplinary Institute for Collaboration and Research on Enterprise Systems and Technology

Co-Organized by
TU Delft – Delft University of Technology
ARSIT - Association for Radio Systems and Intelligent Telecommunications

In Cooperation with
AUTH – Aristotle University of Thessaloniki
IMI – the Institute of Mathematics and Informatics of Bulgarian Academy of Sciences
AMAKOTA Ltd.

In Memory of Blagovest Shishkov

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ISBN 978-1-4503-6364-8

http://www.ictrs.org

Printed in Bulgaria

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ABSTRACT

The variety of fractal curve types opens up additional structural and electrodynamic possibilities in the design of antennas. The article describes experimental results of studying characteristics of different types of fractal antennas (fractal triangular Koch antenna, fractal square Koch antenna and anisotropic fractal antenna). These types of curves are extreme cases in the direction of deformation of fractals. In this paper, we propose a new dual band wire dipole antenna based on an anisotropic fractal. We obtained the frequency reflection coefficients and the radiation patterns at the resonance frequency of each antennas at the second iteration (n = 2). We made an analysis of the parameters of each antenna. It is shown that a half-wave vibrator configured on the base of the original anisotropic fractal has a maximum effective capture area. The Computer Simulation Technology High Frequency Structural Simulator (HFSS) software was used to design and analyze the antenna. Computed bandwidths are 0.2 to 2.7 GHz. This bandwidth covers the IEEE 802.11.

CCS CONCEPTS

• **Hardware** → Wireless devices • **Networks** → Network reliability

KEYWORDS

fractal antenna, anisotropic fractal, captured area, radiation pattern, return loss

ICTRS'17, November 6–7, 2017, Delft, Netherlands

ACM ISBN 978-1-4503-6364-8/17/11...$15.00
https://doi.org/10.1145/3152808.3152811

1 INTRODUCTION

Multi-band and broadband antennas are of great interest in the field of radio engineering and telecommunications. Modern wireless and satellite communications require antennas with higher performance, wider bandwidth, inexpensive and conditionally smaller design sizes. The properties of such antennas and their characteristics, namely the input resistance, radiation patterns (RP) and directivity factor vary within specified limits in a very wide frequency band. Theoretical studies of electromagnetic waves from scattering and propagation in fractal media have prepared a basis for creating real technical devices that use the physical properties of fractal systems. Such devices include fractal antennas. Fractal antennas have some advantages over traditional antennas based on Euclidean geometry.

Fractals are self-similar objects and they do not have a dedicated scale [1]. Real fractal systems have the maximum and minimum lengths. This property gives grounds to believe that the radiating systems with fractal geometry will have not one, but several resonant frequencies. Fractal geometry allows you to combine antennas of different frequencies, avoiding interference.

Fractal antennas have a number of advantages (multiband for emitted and received frequency, various radiation patterns, strict manufacturing algorithms) and are widely discussed in the scientific literature on radio and telecommunications [2 - 5]. It is interesting to define a fractal type based on which it is possible to create the antenna with the best characteristics for certain purposes. The question is how the shape and structure of the fractal affect the characteristics of fractal antennas? Therefore, we chose those fractals that have different directions (anisotropic, omnidirectional and isotropic) deformation.

The purpose of this study is to determine the reflection coefficient, RP of anisotropic fractal and to compare our results with the results obtained for other types of fractal antennas. We chose the second iteration of fractal curves: anisotropic, triangular Koch and square Koch. Computer models of antennas were designed in HFSS software. The actual samples of the antennas were tested experimentally.

2 MODEL OF FRACTAL ANTENNA

2.1 Structure of Fractals

It should also be noted the importance of developing mathematical models for projected antennas. Mathematical models should be consistent with the results of experimental studies. All this will allow us to calculate and predict their electrodynamic characteristics in advance.

The fractal used in this research has an original construction, it has been suggested by one of the authors [6]. We called this fractal anisotropic. The main feature of this fractal is that pre-fractals are formed only in one direction (Fig.1), whereas the local dimension of the first (n = 1, n – iteration number) pre-fractal,

$$D = \frac{ln5}{ln3} = 1.4649 \quad (1)$$

is realized only in one direction. This feature provides a number of distinctive characteristics of the antenna.

Triangular Koch (TKF), with fractal dimension D = 1.26, δ = 1/3, is formed by dividing into three equal parts of a single segment (initiator) and replacing the middle interval by an equilateral triangle without this segment (Fig. 1). The geometrical fractal of the square Koch (SKF) has an isotropic structure. It has fractal dimension D = 1.5, δ = 1/4. It consists of eight links of length 1/4. Six of them form two "Π" shaped elements, placed oppositely. All elements of this fractal are deformed in all directions with increasing number of iteration. The length of fractal curve of all samples is determined as follows:

$$L = L_0\delta^{-(D-d)n} \quad (2)$$

where, L_0 – length of the initial segment, in our case is 7 cm, d – topological dimension.

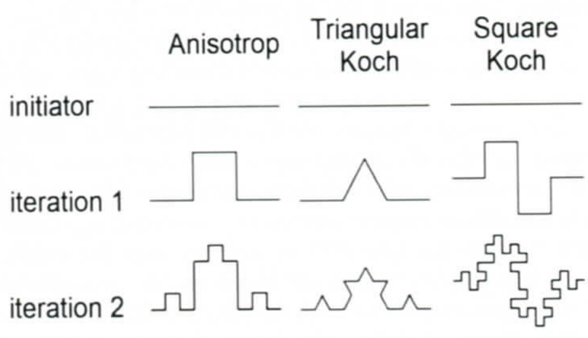


Figure 1: The second iterations of considered fractals. Anisotropic, triangular Koch and Square Koch fractals.

2.2 Simulation and Experiment

The antenna characteristics were obtained by modeling in the HFSS software using the finite element method. Fig. 2 shows a computer model only of an anisotropic fractal antenna. Fig. 3 demonstrates the physical model (prototype) of the antenna. Copper with a diameter d = 1 mm was used as a conductive material (permittivity ε = 1.0). The distance from the start and end points of the dipole antenna is 14.5 cm; 2·L0 + g, where g is distance between antenna segments, g = 0.5 cm. Computed bandwidths are 0.2 to 2.7 GHz. This bandwidth covers the IEEE 802.11

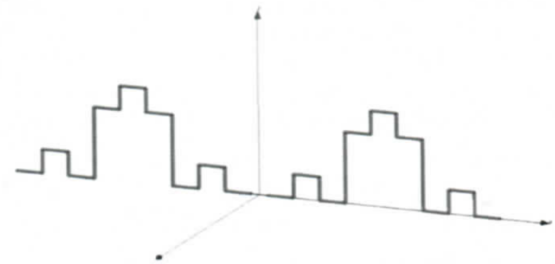


Figure 2: The simulated models of anisotropic fractal antenna (*n*=2).

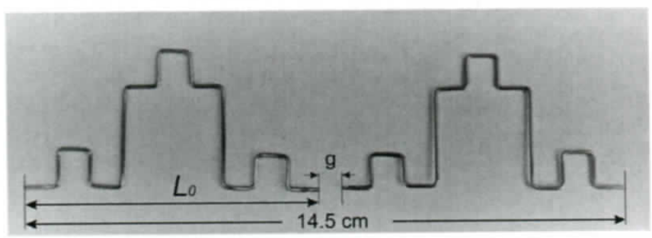


Figure 3: Prototype of fractal antenna (*n*=2).

To analyze antenna parameters in one device (or complex) we developed and assembled a special software and hardware complex (Fig. 4). It consists of: 1 – microwave frequency generator NI PXI-5652 (radiation occurs at resonant frequencies of antennas), 2 – omnidirectional monopole antenna, 3 – experimental fractal antenna, 4 – rotary system, 5 – spectrum analyzer Agilent and LabVIEW virtual graphic interface for collection and data processing.

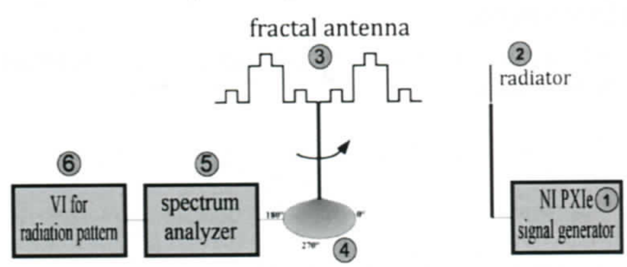


Figure 4: Block diagram of the experimental setup.

On this complex, all the manufactured fractal antennas were tested. The spectral characteristics of the considered fractal antennas are analyzed. The following parameters of the fractal antennas were measured: the passband, the radiation patterns, the width of the RP, the directivity factor, and the gain. Radiation patterns of antennas in the polar coordinate system in 100 steps were built in LabVIEW in real time. Below are results of the physical experiment and computer simulation.

3 RESULTS AND DISCUSSIONS

We determined the parameters of all our antennas by computer simulation and measurement: the reflection coefficient S11, the radiation pattern at resonant frequencies, the widths and maxima of the main lobe. Fig. 5 shows the frequency reflection coefficients for all types of antennas. The simulation results are shown by solid lines. In the selected frequency range, all antennas have two f1 and f2 resonant frequencies, their values are given in Table 1. SKF has the lowest frequencies (0.5 GHz and 1.36 GHz) with the full length of the fractal curve equal to L = 56.5 cm than other models, TKF has the highest frequencies (0.74 GHz and 2.21 GHz) at L = 25.28 cm, i.e. the dependence f ~ 1 / L is satisfied. This means that the values of resonance frequencies depend on the total length of the antenna (fractal length), rather than the length of the last prefractal.

The measured results are shown in Fig. 5 by the dashed line. Experimental results have confirmed that the designed antennas showed improved performances in terms of directivity and beamwidth and other characteristics.

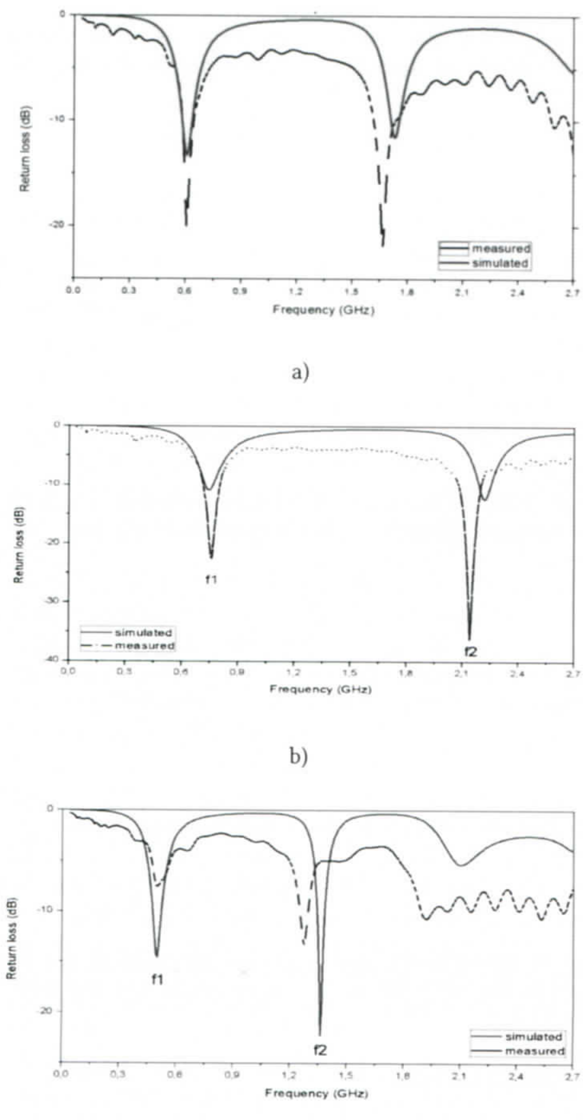
Table 1: Frequency Resonances for Fractal Antennas at n = 2

Resonant frequency	Types of antenna		
	AF	TKF	SKF
f1, GHz	0.61	0.74	0.5
f2, GHz	1.72	2.21	1.36

Fig. 6, 7 and 8 show antenna patterns for the resonance frequency f2 of each antenna separately. All antennas radiate equally at frequency f1 and have the shape of a radiation pattern as in a standard half-wave vibrator. AF and SKF antennas have two main directed lobes (Fig. 6 and Fig. 8) in the E plane, the radiation pattern of the TKF antenna consists of 4 small lobes (Fig. 7). The multi-lobe form of the radiation pattern of the TKF antenna is shown in [7]. Table 2 shows the numerical characteristics of the radiation pattern of antennas. The largest width of the main lobe is observed in the AF antenna, equal to α = 117.010.

Table 2: Parameters of the radiation pattern of the antennas

	Types of antenna		
	AF	TKF	SKF
width of main lobe α, degree	117.01	43.56	76.09
maximum value, V	8.36	8.80	4.57

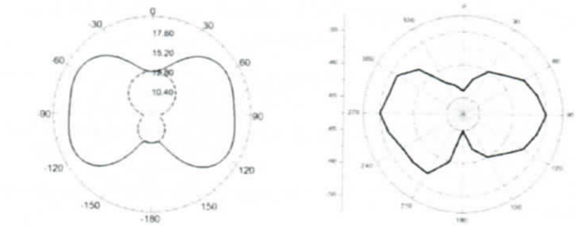


a)

b)

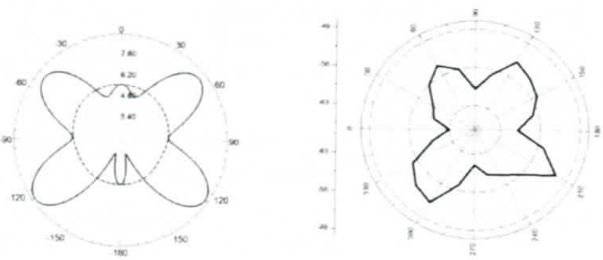
c)

Figure 5: The dependence of input reflection coefficient on frequency for AF (a) TKF (b) and SKF (c).



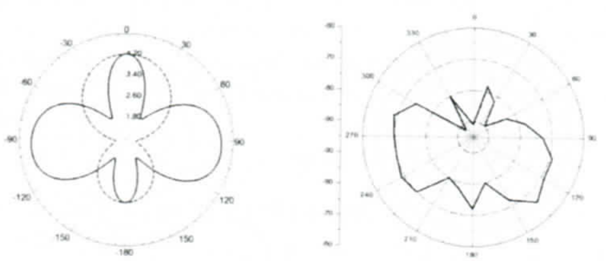
a) b)

Figure 6: RP in the E and H planes obtained in the HFSS environment (a) and in the experiment (b) for AF at f2, n = 2.



a) b)

Figure 7: RP in the E and H planes obtained in the HFSS environment (a) and in the experiment (b) for TKF at f2,n = 2.



a) b)

Figure 8: RP in the E and H planes obtained in the HFSS environment (a) and in the experiment (b) for SKF at f2,n = 2.

4 CONCLUSIONS

In this paper, we obtained reflection coefficients in the range 0.2 – 2.7 GHz, radiation patterns at resonant frequencies of wire dipole antennas on the basis of fractal curves. These fractal curves differ from each other by the deformation directions.

The results of measurement and computer simulation showed better characteristics for an anisotropic fractal antenna. It has a wider angle of the radiation pattern than other samples. The maximum capture area of the anisotropic antenna also provides the maximum gripping power. This effect can be observed when receiving signals and when the antennas emit electromagnetic waves.

The antenna on the basis of the anisotropic fractal has technological advantages of manufacturing in terms of automatic detection and collection. This advantage allows using it for space purposes, namely in satellites of the CubeSat format, as well as for the application of IEEE 802.11.

ACKNOWLEDGMENTS

This work has been supported by the Ministry of Education and Science of Kazakhstan under Grants Nos. 3837/GF4 and 0755/GF4.

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