ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree on «6D071900 – Radiotechnics, Electronics and Telecommunications» specialty

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Electrodynamic characteristics of anisotropic fractal antennas

General description of work

The work is devoted to experimental and theoretical study of a wire dipole antenna based on an anisotropic fractal (fractal of Z.Zh.Zhanabaev, hereinafter - "ZhF"), as well as a comparison of the main electrodynamic and radio technical characteristics of this antenna with other fractal antennas having isotropic, triangular structures. The results of physical experiments, computer simulations are described and compared by a theoretical model. It is fundamentally important to determine the resonant frequencies of antennas with fractal shapes, since classical methods are performed for antennas with linear shapes. A new method is proposed for calculating the resonant frequency of wire fractal dipole antennas using scaling indices γ of fractals. All generations of the ZhF fractal are analytically described through Heaviside unit step functions. The unique structure of ZhF antennas makes it possible to use them to solve a wide range of applied problems in the field of antenna-feeder devices.

Relevance of the topic

An important element of any transceiver wireless devices are antennas, the type and design of which greatly determines the quality of the transmission and reception of information. Currently, the bulk of wireless technology operates on high-frequency bands. Mobile devices and other transceivers designed for various wireless technologies require appropriate multi-band, small-sized, in some cases, broadband antennas. The development of a wide band of the frequency spectrum is due to modern trends in the development of wireless communications, increasing the speed of information transfer, increasing the level of noise immunity, as well as the security of transmitted information. Modern electronic and radio devices tend to be miniaturized, with corresponding requirements for all types of electronic components, including antennas. At the same time, it is envisaged to increase the productivity of small-sized radio devices. There is great interest in creating innovative designs of multi-band antennas for wireless communications. The integration of materials with the design of antennas still attracts attention, especially in reducing the size and improving their characteristics.

Recently, special attention has been paid to fractal antennas in the field of radio engineering and telecommunications, as evidenced by numerous scientific publications. For example, the most famous magazines in the field of antenna devices “IEEE Transactions on antennas and propagation” and “IEEE Antennas and wireless propagation letters” annually publish at least 8-10 articles, not taking into account other scientific and technical journals that can publish articles around this topic. First of all, this is due to the fact that antennas based on geometric fractals have very interesting properties in the multiband field compared to antennas with forms of Euclidean geometry based on objects of integer dimension. The self-similarity of the fractal structure allows such antennas to resonate over several frequency ranges, and those made in the form of a patch (strip) have an ultra-wide passband. As well as researchers and developers in the field of antenna-feeder devices, fractal geometry is considered as one of the technical solutions to the miniaturization problem when creating small-sized wireless communication devices. As a result of numerous experiments and simulations, it was established that antennas with fractal forms make it possible to obtain practically the same electrical and radiophysical characteristics as traditional ones, but with much smaller sizes. Compactness while maintaining its characteristics is achieved due to the effective filling of the plane by dividing the structure of the antenna into segments, the so-called pre-fractals, from which new pre-fractals, in turn, appear and thus before filling the entire plane. Of the majority of works, it has been observed that antenna miniaturization is most effectively realized only for a few initial iteration numbers (the appearance of pre-fractals) of the fractal structure (up to 4-5), approaching a certain limit.

The emergence and rapid development of a new direction (90s) formed the field of fractal electrodynamics (the term was introduced by D.L. Jaggard). In addition to scientific interests, there are practical applications for solving a number of telecommunication and radar problems. One such company is Fractal Antenna Systems, a world leader in radio frequency and electromagnetic innovations [www.fractenna.com].

Despite the huge amount of publication and research work done, the natural question arises, what kind of fractal topology can ensure the effectiveness of electrodynamic, radiophysical characteristics? Research is known for antennas based on isotropic (Minkowski type), triangular (Koch type) and other intermediate (between purely isotropic and anisotropic) fractals. In the work of Zhanabaev Z.Zh. a new geometric fractal was proposed [Zhanabaev Z.Zh., 1988], the so-called "anisotropic fractal", in which the deformation (fractalization) of elements occurs in only one direction. We note that the term “anisotropic fractal” is also used in work [Li J., Ostoja-Starzewski M., 2009], where a porous medium with

various possible fractal dimensions in different directions is considered. In this dissertation, the fractalization of a continuous medium is considered only in one direction with a specific dimension. From the point of view of the specifics of the topology, an antenna based on this fractal intuitively reveals the possibility of implementing better radiation directivity characteristics, a simpler technology for the automation of antenna assembly-disclosure, etc.

An analysis of literature shows that the creation and implementation of new types of antennas is relevant, and the use of fractal geometry to solve this problem becomes promising, in addition, studies in this direction are carried out only by foreign authors.

The study carried out in the framework of this work is associated with promising areas of modern radio engineering and telecommunications, which use new generations of antennas and methods for evaluating performance.

The aim of the work is to create a theoretical model of fractal antennas that takes into account the basic laws of the fractal and experimental study of the electrodynamic, radio technical characteristics of the dipole antenna based on the ZhF fractal, as well as its comparison with other fractal antennas.

Research objectives:

1 Mathematically describe the structure of the ZhF fractal.

2 Construct a theoretical model describing the electrodynamic parameters and directional properties of wire fractal dipole antennas taking into account the dimension of fractal structures.

3 Experimentally study, measure and compare the electrodynamic and radio-technical characteristics of wire antennas with different fractal forms.

4 Experimentally determine the average power value and the signal-to-noise ratio of signals received by fractal antennas under the same conditions and parameters.

Research objects: wire dipole antennas based on the following fractal curves to the third number of the pre-fractal: ZhF fractal, Minkowski isotropic fractal (MF) and Koch triangular fractal (KF).

Research subject: electrodynamic, electrical, directional and frequency properties of fractal antennas in range 0.1 – 3,0 GHz, described by the laws of fractal geometry; features of the shape and directivity of the main lobes of the radiation patterns and their theoretical explanations.

Method of investigation

1 Theoretical and numerical study of models describing the directional and frequency characteristics of wire fractal antennas;

2 Computer 3D modeling (simulation) of electrical and directional properties of wire fractal antennas by the finite element method in the HFSS software Ansoft - High Frequency Structural Simulator;

3 Experimental research and determination of the characteristics of antennas using a hardware-software complex of high-frequency measuring instruments and devices;

4 Processing, analysis and comparison of the data obtained as a result of the above methods.

Main provisions to be protected

1 Anisotropic geometric ZhF fractal and its pre-fractals having a local fractal dimension are analytically described through Heaviside unit step functions.

2 Resonant frequencies of wire fractal antennas (ZhF, MF, KF) obtained theoretically for $n + 1$, n prefractals and measured experimentally correspond within an error of no more than 3-5%.

3 The width of the main lobe by the radiation pattern at the level of 0.707 from the maximum value of the ZhF antenna is more 1.5 times than MF and KF antennas.

4 The average value of the power of radio waves at resonant frequencies received by the ZhF antenna in the perpendicular and parallel modes of signal reception is 10–15% higher than for MF and KF antennas at the same regular lengths and distances to the emitter.

The scientific novelty of the work is that for the first time

1 A new type of ZhF fractal for designing antennas is proposed; its analytical equation is derived that describes all levels of the pre-fractal.

2 It has been experimentally and theoretically shown that the frequency characteristics of wire fractal dipole antennas depend on the fractional dimension of the fractal structure itself.

3 The modes of transverse (normal) and axial radiation of radiation patterns of wire fractal antennas in the first two resonant frequencies are revealed.

4 A shift of the resonances of wire fractal antennas to the low-frequency region with an increase in the number of the pre-fractal is revealed, as well as the appearance of additional high-frequency resonances due to this shift.

Theoretical and practical significance of the work

Due to the high density of elements (pre-fractals) and their miniature size, in addition to multi-band and relatively wide-band properties, the use of fractal-curve antennas is promising in means of wireless communication devices, radar, radio navigation, as well as in small and medium-sized satellites. For the first time, the modes of transverse and axial radiation of wire fractal antennas with rectangular

pre-fractals are shown and explained. This effect may be a new solution for devices that contain separate bipolar antennas.

And also the practical significance of the work lies in the substantiated effectiveness and possible universal applicability of the proposed new fractal antenna based on the ZhF fractal, which has a local fractal dimension, while the Hausdorff dimension of the remaining geometric fractals is constant. This specificity allows the antenna to contain different lengths of the emitter and will give technological advantages of manufacturing from the point of view of automatic disclosure and collection.

The results of the created theoretical model of wire fractal antennas can serve for more detailed study, research, as well as the general theory of fractal antennae at the moment is almost completely undeveloped. The peculiarity of this model is that it does not take into account and does not consider the classical model - the Maxwell system of equations, which describes the electromagnetic field and its relationship with electric charges, currents in vacuum and continuous media. This system cannot be applied to emitters having fractal structures, since they do not have derivatives and integrals. The proposed model provides an opportunity to take into account the basic laws of fractal geometry. Thus, the theoretical and experimental patterns established in this work are of practical importance for improving antenna technology.

The research materials, as well as the used and created software and hardware complexes for obtaining the radiative properties of the antennas under consideration during operation, the key points of 3D modeling in the environment of software packages and the results obtained can be further used in educational processes for training specialists in the field of antenna-feeder devices and in further scientific research.

The subject of the research are the basic theoretical principles of fractal geometry, antenna-feeder devices, electricity and magnetism, as well as the results of original scientific works listed in the list of sources used.

Personal contribution of the author lies in the fact that the main results of a physical experiment, numerical analysis and computer calculations, modeling were obtained personally by the applicant. The setting of tasks and discussion of the results were carried out jointly with scientific consultants.

Reliability of results

The reliability of the scientific conclusions of the work is confirmed by the reproducibility of experimental results, the correspondence of computer simulation data with experimental results, the consistency of the results with theoretical assumptions and conclusions obtained by other authors in similar works, using proven methods of numerical analysis.

Approbation of work

According to the materials of the thesis, 15 works were published, including 7 in the editions recommended by the Committee for control in education and science of the Ministry of Education and Science of the Republic of Kazakhstan, 1 in the peer-reviewed journal (Journal of engineering sciences and technology (JESTEC)), 5 publications in the book of abstracts of international conferences, including 1 foreign (6th International Conference on Telecommunications and Remote Sensing. Delft, Netherlands) and 1 report in the proceedings of the international conference (The IEEE 12th International Conference "Application of Information and Communication Technologies" .- Almaty, Kazakhstan).

Relationship of the thesis topic with the plans of scientific works

The dissertation was carried out in accordance with the fundamental research projects of the Ministry of Education and Science of the Republic of Kazakhstan "Grant financing of scientific research" on the topic "3837 / GF4 Development of a multi-band fractal antenna for ultra-wideband wireless systems" with priority: "Information and telecommunication technologies".

The structure and scope of the dissertation

The dissertation consists of an introduction, four sections, conclusion, references and contains three appendices. The work is set out on 109 pages of typewritten text, illustrated by 97 figures, 57 formulas, 8 tables, a list of references contain 142 items.