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Editor in chief: SERGIY YEKIMOV

e-mail: **praha@rusnauka.com**

Technical editor:

Mgr. Helena Krzyzankova

Editorial address:

OFFICE2, VELOCITY TOWER, 10
ST. MARY'S GATE, SHEFFIELD, S
YORKSHIRE, ENGLAND, S1 4LR

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TECHNICAL SCIENCE

Sliusar I.I., Slyusar V.I., Voloshko S.V., Smolyar V.G.

THE MULTI-BAND ANTENNA BASED ON FRACTAL

The article presents the simulation results of antennas based on fractal. Due to the complexity of describing the interaction of the antennas of non-Euclidean geometry with radio waves their synthesis made use of the program MMANA-GAL. The proposed sequence of stages of modeling allows to provide multiple frequencies ranges and broadband. The result of the research is recommendations for practical application of fractal structures for systems and networks 802.11x and 5G.

Keywords: antenna, beam pattern (BP), standing wave ratio (SWR), fractal, MMANA.

INTRODUCTION

The growth of interest to systems 5G, Internet of Things (IoT) and the extension of the application of 802.11x there is a need to develop devices that operate in respective networks. In turn, the need to work in several diapasones with the simultaneous implementation of access technology based on Orthogonal Frequency Division Multiple Access (OFDMA), Multi User MIMO (MU-MIMO) and others, requires the minimization of dimensions of multi-element antenna systems.

As a result, an urgent task is the development of antennas that have both small size, a sufficient gain and provide many ranges. One of the ways of solving this issue is the use of antennas with non-Euclidean geometry, among which should be allocated to the fractal antenna [1÷3]. However, given the complexity of the description of the interaction of the antennas of non-Euclidean geometry [4] with radio waves, it is advisable to execute their development with the help of numerical methods using software packages through mathematical modeling.

Thus, the aim of this paper is to synthesis of multiband antennas based on fractal structures.

MAIN

As you know, one of the priority directions of development of telecommunications is the 5th generation of mobile communication. According to forecasts [5], large-scale deployment of the 5G infrastructure could be expected by 2020, and to 2021 the 5G services will account for 1.5% of total mobile data traffic. Thus, one connection 5G on average will generate 4.7 times more traffic than a 4G connection, and 10.7 times more than a 3G connection. Currently, for the development of 5G networks in Europe at the initial stage it is planned to use frequency bands 694÷790 MHz, 3.4÷3.8 and 24.25÷27.5 GHz. On the other hand, the introduction of 802.11ax will allow to increase the efficiency of Wi-Fi networks.

All this testifies to the expediency of integration into a single device functionality to simultaneously work in networks of Wi-Fi, 5G, IoT, Wireless Sensor Networks (WSN) and others. This approach was already considered in [6]. It provided for the creation on the basis of geometric fractals antennas for 5 GHz (Wi-Fi) and higher frequencies ranges. However, the simultaneous operation of the antenna system in the ranges of 3.4÷3.8 and 2.4 GHz (Wi-Fi) in theoretical terms yet require additional research.

As a result, the paper presents the results of the synthesis of antenna elements (AE) based on fractal structures operating in the 3.4÷3.8 and a 2.4÷2.5 GHz.

Currently, simulation is viewed as a necessary and indispensable process of design and subsequent testing of antenna structures. Generally, there is a big lot of software applications for modeling and design of antennas. In this context the program MMANA-GAL [7] here will be used. Antenna in MMANA-GAL is described as a set of single straight wires. The results of the calculation are displayed in a 2D and 3D Beam Pattern (BP) and the many graphics dependencies. Computing the basis MMANA-GAL (as well as many commercial software simulation) is a program MININEC. MMANA-GAL contains a library with information on more than 200 antennas. The benefits of this program are freeware, easy, user-friendly interface, the ability to scale the antenna to an arbitrary frequency, a parameter calculation device approval.

During the studies implemented the following sequence of modeling: the choice of a fractal structure; the basic design of the antenna in MMANA-GAL based on the geometric parameters; characterization of antennas and their subsequent optimization for a specific wireless telecommunications technology (e.g. Wi-Fi); scaling the antenna on the estimated frequency; the study of the characteristics of scalable antenna; the search for an optimal power supply antenna; determine the necessary parameters of the device approval.

As an assumptions was considered following provisions.

To evaluate the performance of the antenna is performed in conditions of free space on the basis of the material without loss.

The diameter of the wire (the option is MMANA-GAL – R) is equal to 0.5 or 1 mm, including after a procedure of scaling.

The bandwidth BW_{SWR} is calculated when Standing Wave Ratio (SWR) < 2,0. Given the likely asymmetry BW_{SWR} is further defined by its center frequency, which further defines the parameters of the device approval: $F_m=0.5*(F_{min}+F_{max})$.

The resulting 3D BP needs to get as close to omnidirectional.

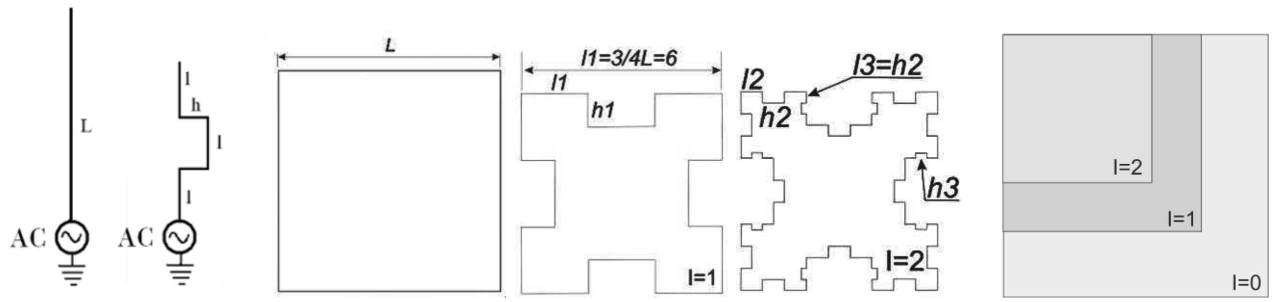
As the base construction is selected antenna that has a frequency of the first resonance (F_{res}) when Spectrum Response Ratio (SRR) $\rightarrow$ min, X $\rightarrow$ 0 (the imaginary component of the wave resistance (Z)), R $\rightarrow$ 50 Ohms (real component of Z), the parameter MMANA-GAL for which F/B $\rightarrow$ 0 and satisfying the condition of paragraph 4.

The scaling of the basic antenna on the estimated frequency (F_{des}) is performed without taking into account the shift of resonant frequencies inherent in fractal structures.

According to [6], and subject to the restrictions MMANA-GAL, one of the base antennas of the selected loop Minkowski 2-th iteration (as the initiator is a square frame, and the generator is broken Minkowski). The essence of fractal transformations is explained by Fig. 1.a [8, 9]. Thus, a square frame of side L is taken as the zero iteration (I = 0). Appropriate geometrical dimensions for the iterations are of value: for the first (I = 1): l_1 = L/4, h_1 = l_1/2; for the second (I = 2): l_2 = l_1/4, h_2 = l_2/2, l_3 = h_2,

$h_3 = l_3/2$. As a consequence, the geometric dimensions of the antenna (Fig. 1.c) for each iteration is described by the expression: $L_I = (3/4)^I * L$, where I is the iteration number.

The effect of miniaturization allows to build a combined multi-band antenna, which consists of a loop Minkowski and the internal antenna element (AE) which is designed for a higher frequency range. As an example, the latter should be considered a fractal structure, shown in Fig. 2. The resulting BP of these structures is shown in Fig. 3.



a) b) c)

Fig. 1. The process of forming the Minkowski loop 2nd iteration: a) – fractal transformation based on Minkowski broken; b) – the sequence of formation of the 2nd iteration;
c) – the geometric ratio of the first two iterations

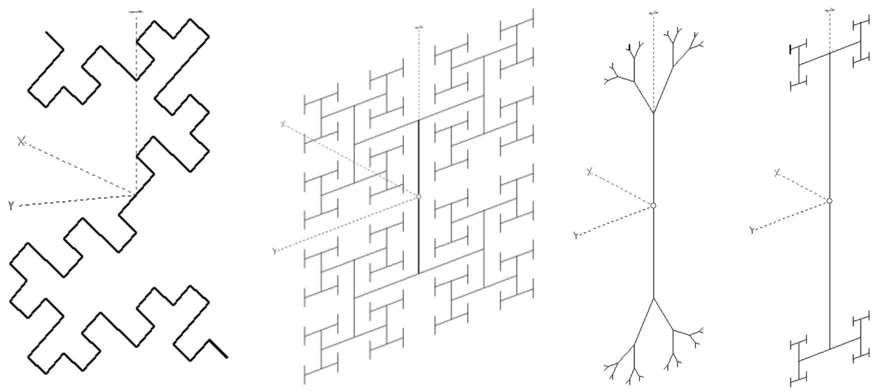


Fig. 2. Options inner element combined fractal antenna

Based on the conducted studies the article suggested to implement internal AE as a 2D recursive tree with an angle of 60º breakdown. Characteristics of the basic models of these antennas are given in Table 1 and in Fig. 4÷6. Selection for each iteration of a fractal structure based on the constraints of the program MMANA-GAL version 1.2.0.20. According to the above stages of modeling was calculated basic antennas for frequency ranges 2.4 GHz and 3.4 GHz (Table 2). Their resulting BP is shown in Fig. 7.

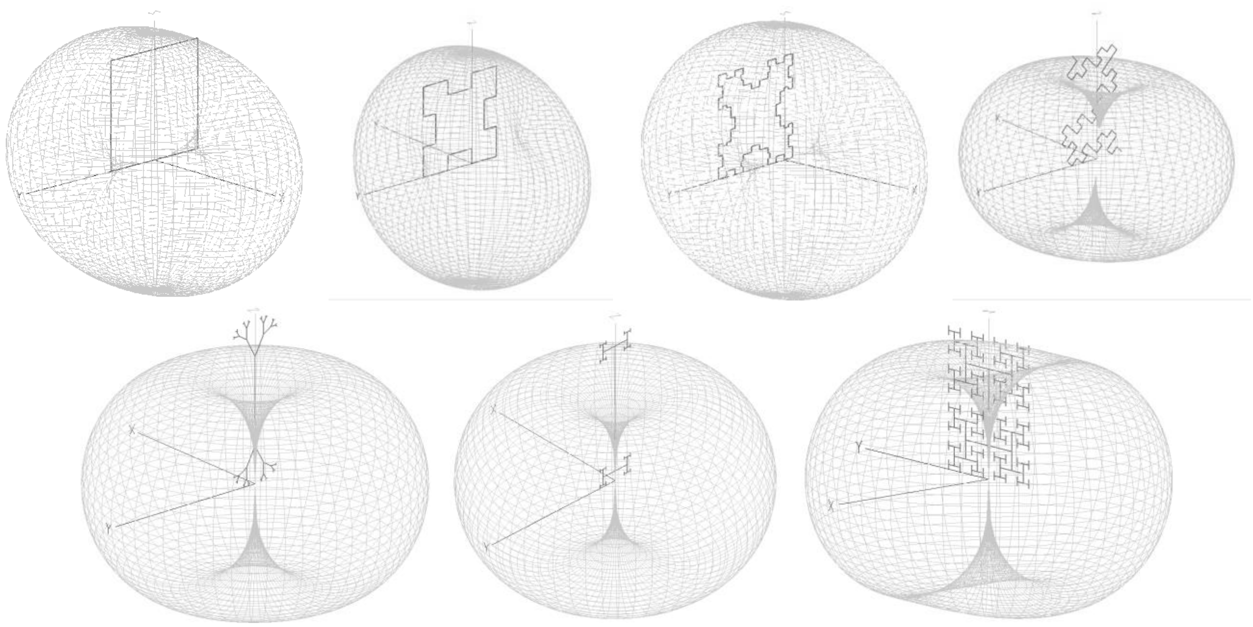
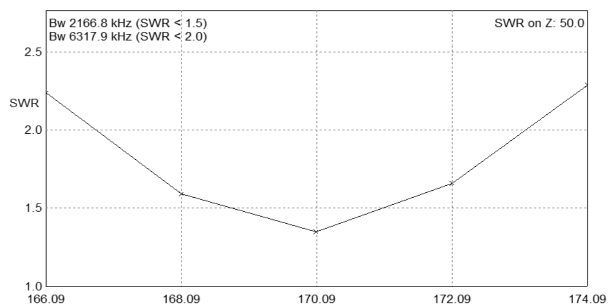
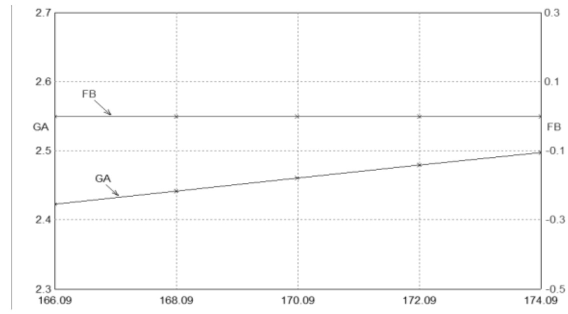


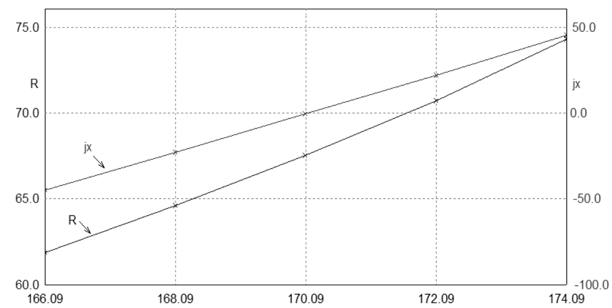
Fig. 3. The resulting 3D BP antennas obtained in MMANA-GAL



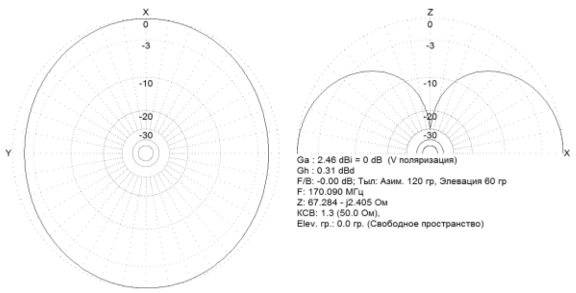
a)



b)



c)



d)

Fig. 4. Characteristics of basic antenna № 1: a) – SWR; b) – Ga and F/B; c) – Z; d) – BP

Table 1. Characteristics of the synthesized base of the antenna device without approval

№	Description antenna	F_{res}, MHz	BW_{SWR}, kHz	Ga, dBi	SWR	Dimensions, sm
1.	The Minkowski loop 2nd iteration (R=1)	170.09	6317.9	2.46	1.35	36×36
2.	2D a recursive tree with a split angle of 60º of the 3rd iteration (R=0.5)	167.03	12136.2	1.95	1.08	18×58

Table 2. Features scalable antennas with matching Z and SWR

№	Description antenna	F_{des}, MHz	F_{res}, MHz	BW_{SWR}, MHz	Ga, dBi	SWR without the consent of	Dimensions, sm
1.	The Minkowski loop 2nd iteration (option 1)	1914	2442.5	465.15	2.86	2.05	3.19×3.19
	The Minkowski loop 2nd iteration (option 2)	1914	2442.5	490.33	2.89	2.04	3.19×3.19
2.	2D a recursive tree with a split angle of 60º of the 3rd iteration (R=0.5 mm)	3438	3599.67	513.628	1.98	1.06	0.91×2.79

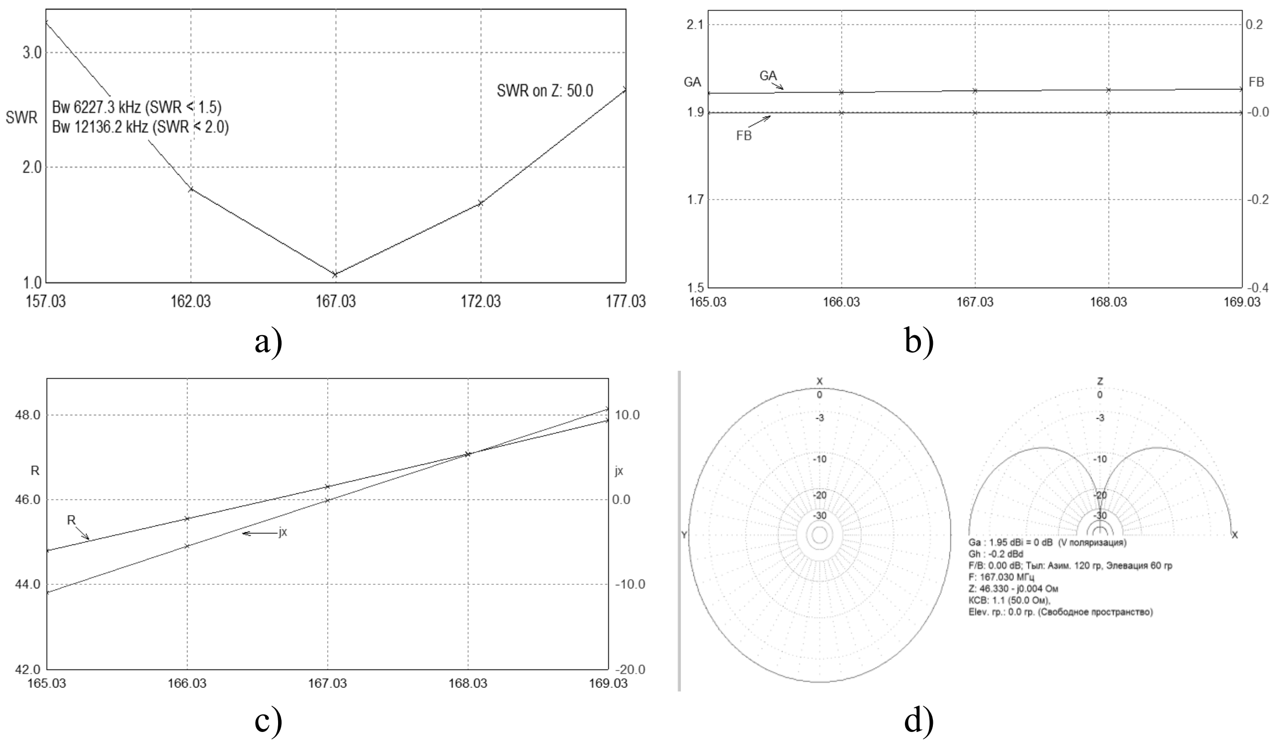
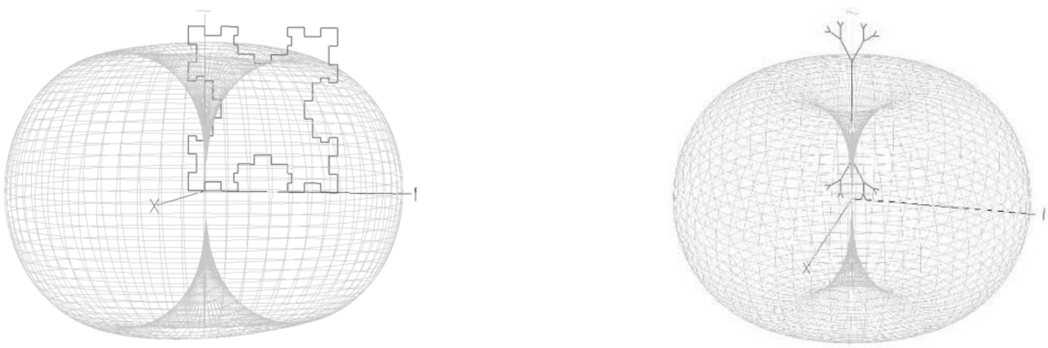


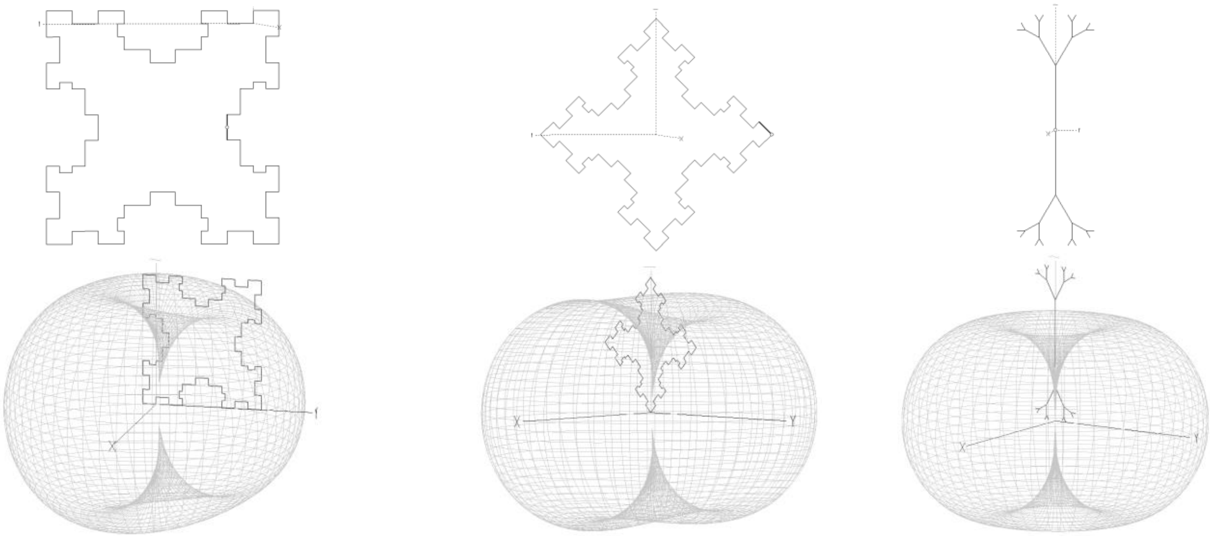
Fig. 5. Characteristics of basic antenna № 2: a) – SWR; b) – Ga and F/B; c) – Z; d) – BP



a) b)

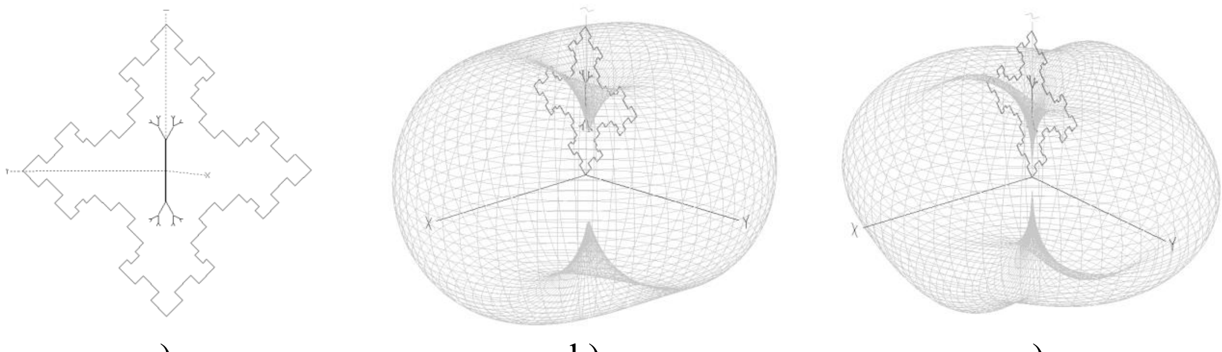
Fig. 6. 3D BP of basic antennas: a) – № 1; b) – № 2

Further, on the basis of scalable antennas have been developed several models of composite structures (Fig. 8÷10). Given the possibility of the implementation of the technology MU-MIMO and Digital Beamforming (DBF), during studies evaluated the mutual influence of AE and the dependence of the spatial-frequency characteristics from the power supply circuit.



a) b) c)

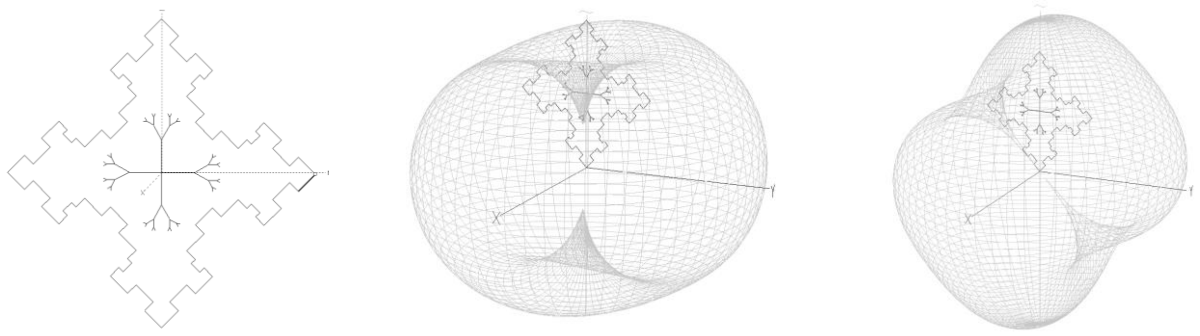
Fig. 7. 3D BP of scalable antennas: a) – № 1 (the first option); b) – № 1 (the second option); c) – № 2



a) b) c)

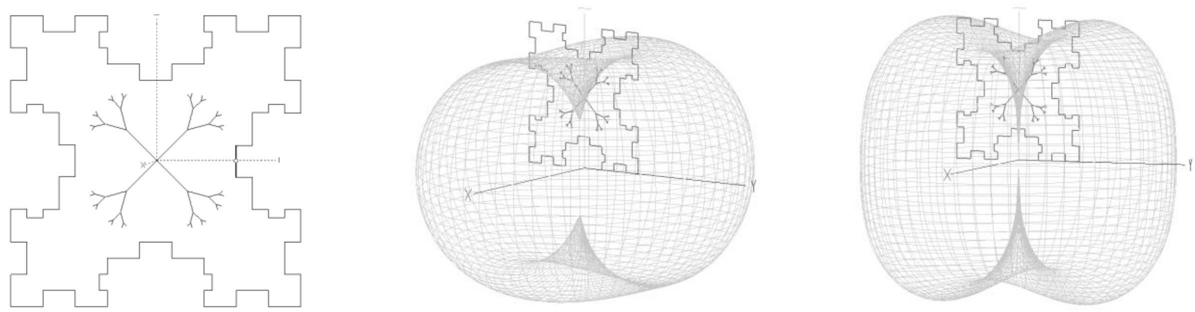
Fig. 8. Combined antenna № 1 and its BP: a) – layout; b) – 2.4 GHz; c) –

3.4 GHz



a) b) c)

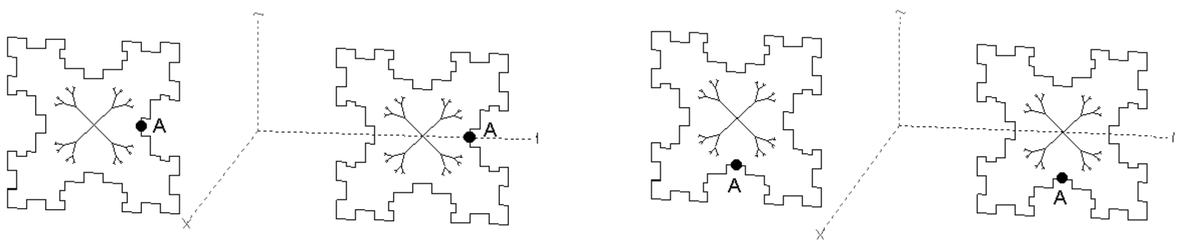
Fig. 9. Combined antenna № 2 and its BP: a) – layout; b) – 2.4 GHz; c) – 3.4 GHz



a) b) c)

Fig. 10. Combined antenna № 3 and its BP: a) – layout; b) – 2.4 GHz; c) – 5 GHz

At the same time, as the basic structure of the linear antenna array was considered antennas system with two or three AE’s (subject to the restrictions depending on the version of MMANA-GAL). Its formation was carried out with the help of operation «stack» with the placement of the AE’s on the the distance in the half of the wavelength (F_{res}=2442.5 MHz). Examples of results are shown in Fig. 11 (A – power point).



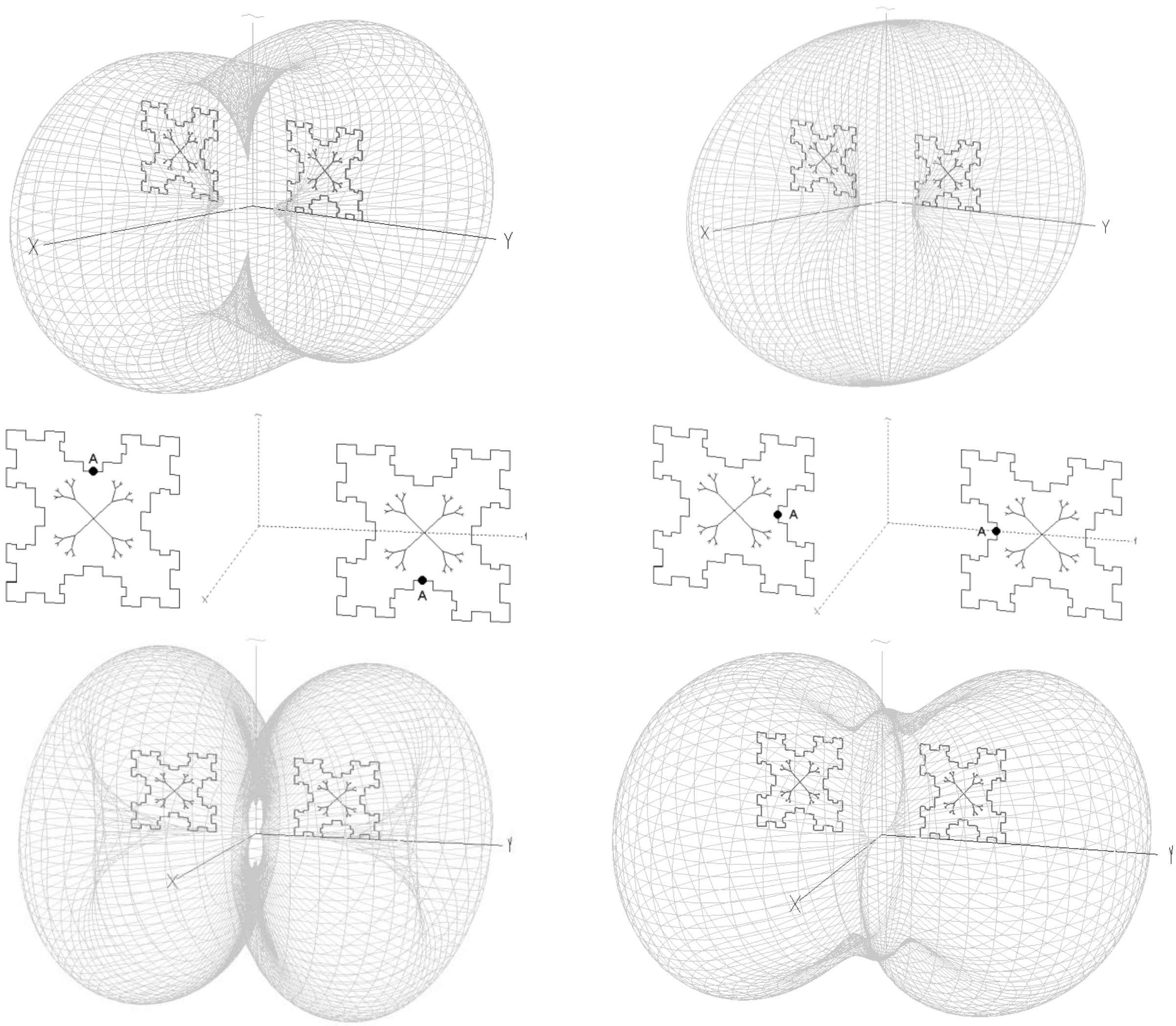


Fig. 11. The impact of the implementation of the scheme supply at BP (2.4 GHz)

As you know, from a technological point of view, very promising are printed antennas, which have spread as fairly compact and cheap solutions for systems-oriented work in several frequency bands. The above approach can be extended to calculate the printing embodiments of wire antennas. It is important that the design printed contour antennas using the obtained results should be based on their allocation on the basis of the transition from round wire to flat conductor (Fig. 12). That is, if you take the diameter of wire R, which is equal to 0.5 or 1 mm, for printed antenna in the form of the Minkowski loop the equivalent width of flat conductor will be 1 or 2 mm, respectively. According to [10] to improve the efficiency of antennas of this type can be applied multilayer structure (Fig. 13).

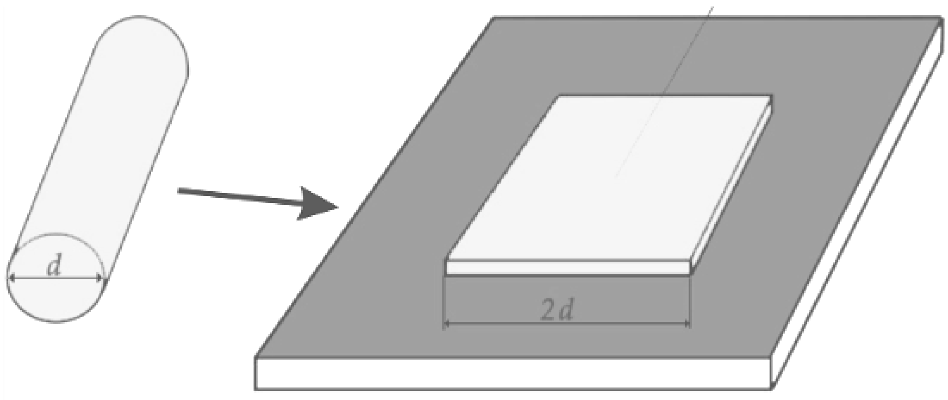


Fig. 12. The transition from round wire to a printed conductor

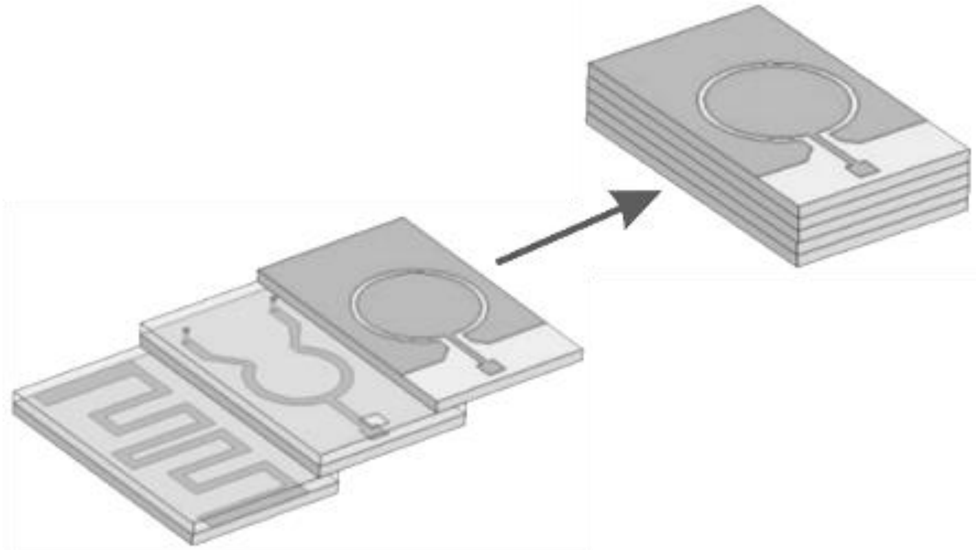


Fig. 13. Multilayer printed antenna

You should note that synthesized fractal constructs can also be extended to other antenna technologies. We are talking about the implementation of radiating surfaces (e.g., generalized Squares Curve based Fractal Rectangular Curve [2]), slotted vibrators [10] and other.

Thus, the results show a certain level of miniaturization of antenna systems. If we restrict the dimensions of the antennas available Wi-Fi routers (Fig. 14) [11], it is possible to implement a set of linear antenna arrays based on printed antennas with the goal of increasing the effectiveness of the technology MU-MIMO or DBF.

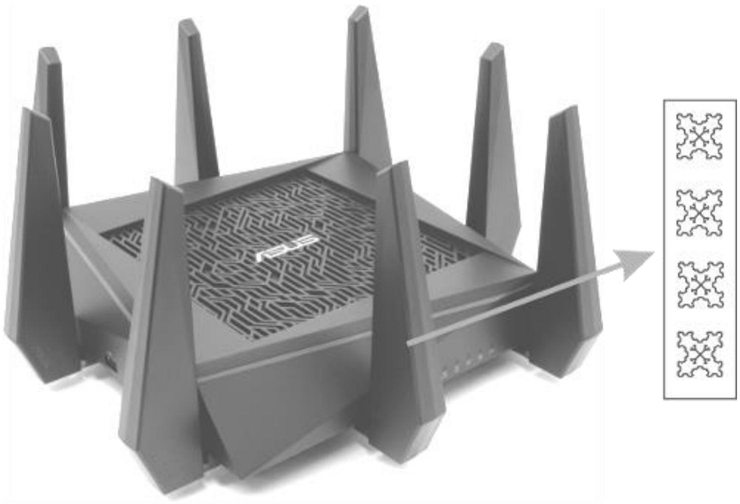


Fig. 14. The option of replacing the AE to extend the capabilities of routers with MU-MIMO on the example of constructive Asus RT-AC5300

CONCLUSIONS

In General, during the synthesis of antenna structures for performing fractal transformation is limited to the first 5 or 6 iterations. Use of the program MMANA-GAL allows to perform simulations of antennas, which consist of straight line segments, whose number does not exceed 8192. To align with the desired frequency range, it is necessary to experimentally find the frequency scaling.In the practical implementation of the synthesized antennas it is advisable to use the matching devices that are available in MMANA-GAL. Further studies will be aimed at determining the properties of 3D fractal antennas.

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