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Synthesis of a Broadband Ring Antenna of a Two-Tape Design

Ihor Sliusar
Department of Computer Engineering
National University «Yuri Kondratyuk Poltava Polytechnic»
Poltava, Ukraine
islyusar2007@ukr.net

Vadym Slyusar
Central Research Institute of Armaments and Military Equipment of Armed Forces of Ukraine
Kyiv, Ukraine
swadim@ukr.net

Sergiy Voloshko
The National Defense University of Ukraine named after Ivan Cherniakhovskyi
Kyiv, Ukraine
sergijvolosko@gmail.com

Andrii Zinchenko
The National Defense University of Ukraine named after Ivan Cherniakhovskyi
Kyiv, Ukraine
zinchenko.andrei@ukr.net

Yuri Utkin
Department of Information Systems and Technologies
Poltava State Agrarian Academy
Poltava, Ukraine
1008utkin@gmail.com

***Abstract*—Proposed options the EMA on the basis of two-ring structures with end slots. They feature a design that contains two rings located one in one. To perform the fractal transformation, the arc acts as the initiator and as the generator acts "meander". Offered multiple templates of the generator allow you to create single or double-sided quasi-fractal 3D-structure. The range of models expanded variation of the mutual angular rotation templates. To simplify the synthesis of antennas vector description of multidimensional fractal transformation. For the analysis of spatial frequency characteristics of the designed antenna solutions used indicators such as return loss, beam pattern i voltage standing wave ratio. The estimates obtained fractional bandwidth δf = 1.22 … 1.32 indicate the prospects of the proposed approach for the realization of antenna systems with high bandwidth supports.**

Keywords—amplitude-frequency response, Ansoft HFSS, antenna, beam pattern, fractal, quasi-fractal, voltage standing wave ratio.

I. INTRODUCTION

To ensure the necessary levels of bandwidth supports and multi-band electrically small antennas (ESA) [1] telecommunications it is advisable to use circuit solutions on the basis of a fractal approach.

As is known, its advantages include the minimization of the dimensions of antennas in combination with ensuring their multi-resonance functioning and expansion of the working frequency bands. However, such antennas may require further coordination with the receiving and the transmitting tract due to the decrease in the input resistance and the use of mathematical modeling of the fractal structures in the design process of antennas due to the complexity of the analytical description of the interaction of the antennas of non-Euclidean geometry with radio waves.

To solve this problem you can use numerical methods for the electrodynamics modeling. The availability of appropriate tools in the form of applied software allows you to create a great variety of fractal structures based on the use of an initiator and/or generator simple geometric shapes.

As a result, there is increasing interest in the use of ring structures. This is because in comparison with a square, diamond or triangle, they have the highest gain (the greater the space covers the antenna element, the higher the gain). The bandwidth of the ring structures is several times wider than that of a conventional dipole. However, in comparison with him, they have a high input impedance. In this case, the application of the fractal approach can compensate for this factor.

It should be borne in mind that the geometric fractals are the perfect abstract shapes. Therefore, their use in the design of antennas requires precise repetition of the structure of the fractal at each change of scale. This feature of the fractal approach limits the ability to vary the size and provisions of the elements of the antenna, which in turn adversely affects the final characteristics of the synthesized antennas.

For removing this restriction apply quasi-fractal transformation. It does not have a strictly defined progression of the frequency of occurrence of elements at each iteration and provides incomplete or inaccurate similarity of the structure and its elements.

Thus, in the future, it is advisable to evaluate antenna solutions, where the geometry of the annular emitter described by the quasi-fractal.

II. ANALYSIS OF RECENT STUDIES AND PUBLICATIONS, WHICH DISCUSS THE PROBLEM

Usually, for the classical geometric fractals [2], which are used in antenna technology, as the initiator used a straight line. Therefore, one of the areas of synthesis of ESA is the use of fractals, which are inscribed in a circle, for example: the Koch snowflake [2] or its variations – spherical Haynes snowflake [3].

The next option fractals provides for the scaling of complex antenna elements at the base of the circle and formation on their base of the antenna [4, 5].

The third approach is sufficiently promising technologies of dielectric resonator antennas (DRA). For example, in the [6] proposed quasi-fractal DRA based on simple geometric shapes. As feed they used classic ring vibrator (that is, a fractal approach is used not only in the geometry of the hemispherical dielectric components).

In General, summarizing the results of the existing sources shows that the study mainly focused on two-dimensional combination quasi-fractal geometry and ring structures. Thus, the fractal approach is one-sided and does not reveal the full potential of such antennas for the realization of their bandwidth supports and multi-band. This indicates the imperfection of traditional methods of synthesis

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quasi-fractal ring 3D-structures.

As a consequence, for the design of ESA, it is advisable to rely on the decomposition of the initial geometric shapes and multi-dimensional fractal transformation [7]. Thus, the use of vector descriptions of the fractal transformation of individual segmented parts of the initial geometric form, simplifies the development of 3D fractal structures using several types of fractals, including with a different number of iterations.

Given in [7] an example of applying this methodology allowed us to synthesize quasi-fractal ring vibrator (Fig. 1), which has the minimum level return loss: -28 dB, and the bandwidth is 18 GHz. Its power is supplied through a port that has a resistance of 50 Om. In this case, as the initiator of the fractal arc stands, and as the generator is the square wave. At the level of first iteration fractal transformation is performed only with respect to the tangential geometric shapes (using a cylindrical coordinate system). This testifies to the prospects of this research area.

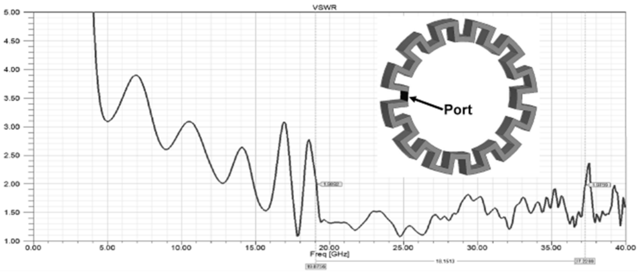


Fig. 1. Quasi-fractal ring vibrator and its VSWR

As a result, it is advisable to deepen it by expanding the range of 3D-layouts quasi-fractal annular vibrator, which will provide improved spatial-frequency characteristics of the antenna.

In General, the analysis of existing antenna solutions shows that the theoretical framework still remains to be improved the antennas on the basis of quasi-fractal ring structures. All this testifies to the relevance of research.

III. The Aim of Research

Thus, the purpose of this paper is to increase the efficiency of antenna systems on the base of the ring structures through the use of quasi-fractal transformation of their design.

IV. The Main Results of the Study

According to [7] for the design quasi-fractal two-ring ESA was used the source structure shown in Fig. 2.

Thus, the paper introduced a number of assumptions, the essence of which was as follows.

During the simulation it is assumed that the space between the rings is identical to the environment around circles. The rings are made in the form of copper strips which have a constant diameter, the thickness, width and relative position. The thickness of the strips is the same and equal to 3 mm. Their width is the same and is 9 mm. The distance between the rings equal to the thickness of the strips. The outer radius of the synthesized model does not exceed 23.55 mm.

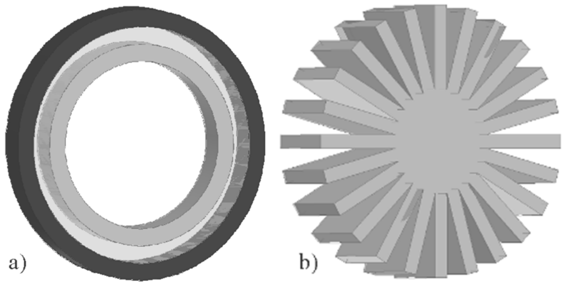


Fig. 2. The original 3D-structure for the synthesis quasi-fractal ring vibrator: a) – two-ring antenna element; b) – pattern generator type "meander"

To compare the spatial-frequency characteristics of the synthesized models with the options which are given in [7], the template generator type "meander" contains 24 identical segments. The thickness of each of them coincides with the thickness of the strips. The angular size for all segments is the same and equal:

$$Angle_{seg} = 360 / N = 360 / 24 = 15 \text{ deg.}$$

During the evaluation of antennas parameters analyzed the return loss (RL), beam pattern and voltage standing wave ratio (VSWR) [8] in the range up to 40 GHz. Although there are several interpretations of the bandwidth, we use the definition of strip by the criterion of return loss, for which the module S_{11} [9] is less than -10 dB (although more accurately for a VSWR ≤ 2 corresponds to a level of RL ≤ -9.542 dB).

In turn, to determine the level of bandwidth supports antenna it is possible to use such a parameter as the fractional bandwidth [10]:

$$\delta F = \frac{2|f_1 - f_2|}{f_1 + f_2}$$

where f_1 and f_2 – are the values of the frequencies at which the magnitude of the VSWR or RL exceeds a predetermined level.

To supply the synthesized structure scheme is applied without coordination with the resistance, which contains only one port. During the research, various options were considered it is placed in the context of one of the ribbons and the space between them.

The formation of a ring structure of ESA takes place by cutout with two-ring antenna element of the meander pattern generator of quasi-fractal, for example, as shown in Fig. 3. The cutouts can be formed in both external and internal ring, or in both bands simultaneously, with one or both sides of the strip.

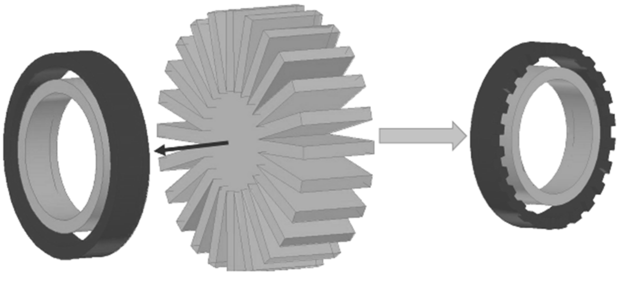


Fig. 3. The essence of the process of formation quasi-fractal 3D- structure

In Fig. 4 shows the thus obtained variant of the antenna with one-ring end cut and its spatial-frequency characteristics (beam pattern and RL). Depth "meander" is equal to 1.5 mm. On the frequency 27.38 GHz such ESA has a minimum level of RL: -29.6 dB. The largest bandwidth (4 GHz) corresponds to the range 13-17 GHz.

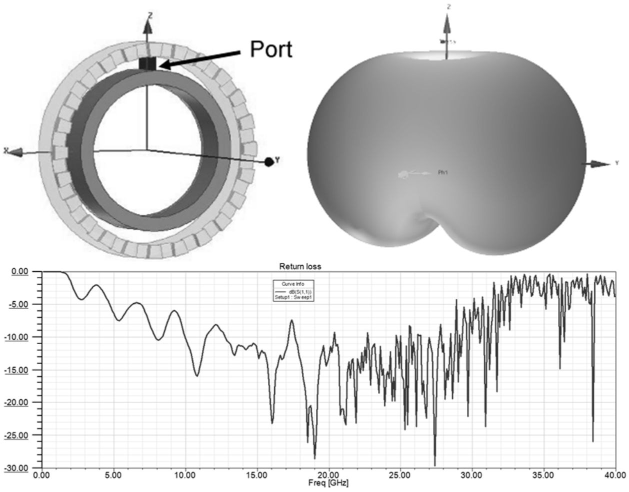


Fig. 4. Synthesized quasi-fractal antenna and its spatial-frequency and features

The subsequent step in the synthesis of ESA was the fractal transformation of the inner ring in addition to outside (Fig. 5). This ensured a minimum level of RL: -48.92 dB at frequency of 27.71 GHz. Unfortunately, the current version of the location grooves on the end surfaces of the strips had a negative impact on the bandwidth.

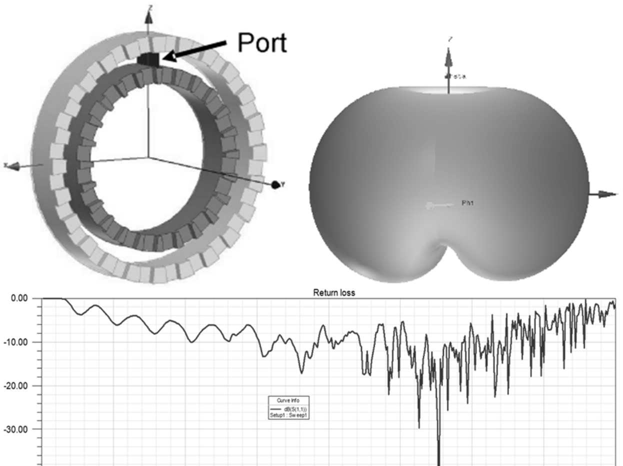


Fig. 5. Quasi-fractal antenna and its spatial-frequency and features

Given this, the studies were carried out further search of configurations which are optimal from the point of view of providing the most bandwidth. In this case, the effective factor was the selection circuit power port of the antenna (Fig. 6). The most successful variant should be considered as the formation of the slit in the outer strip of the width of its thickness and placement of the power port in the space between the rings directly from one edge of the specified slit.

As a result, it was obtained the model shown in Fig. 7. Thus, we have analyzed the model with end cutouts on the inner ring. In particular, it was applied the pattern "meander", which had an angular shift relative to the cut pattern of the outer ring half of the segment – 7.5 deg. The most successful on the obtained characteristics is the option indicated on Fig. 7 as "No. 1" for which the bandwidth reaches 11 GHz (in the range 15-26 GHz) or $\delta f = 0.54$, and a minimum RL (-46 dB) was at a frequency of 3 GHz.

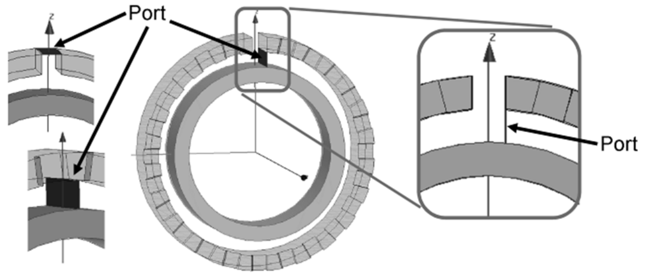


Fig. 6. Diagrams power of the antenna

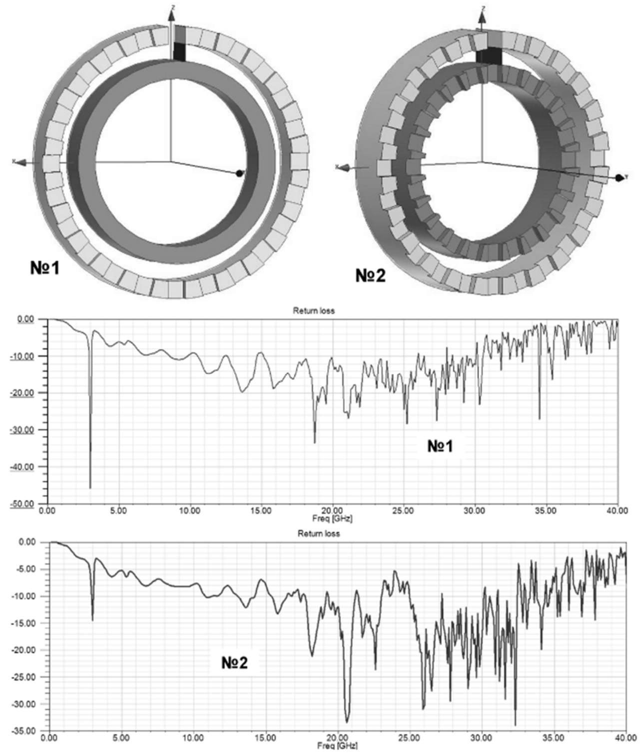


Fig. 7. Models of antennas and assessment of their RL, corresponding to the selected power scheme

Further, we investigated the model of ESA, which provided for the fractal transformation on both ends of the circles, for example, Fig. 8 and 9.

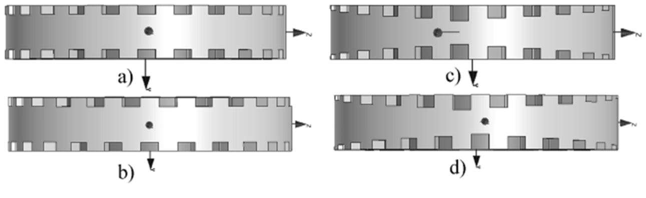


Fig. 8. Models of antennas with quasi-fractal outer ring (side view) to which the template is applied "meander": a) – symmetrical; b) – chess; c) – symmetrical non-uniform; d) – chess non-uniform

The principle of forming a non-uniform pattern location of grooves is depicted on the Fig. 10. It has symmetry about a plane which passes through the axes Oz and Oy. The segments with the angle of rotation of ±45° and ±135° are basic concerning them, the remaining segments are linear (see Fig. 10) for the Y coordinate, ensuring the depth of grooves from 0.5 to 2.5 mm.

In the same way, was performed by modifications of the models taking into account the fractal transformation of the inner ring (see Fig. 9.b, c).

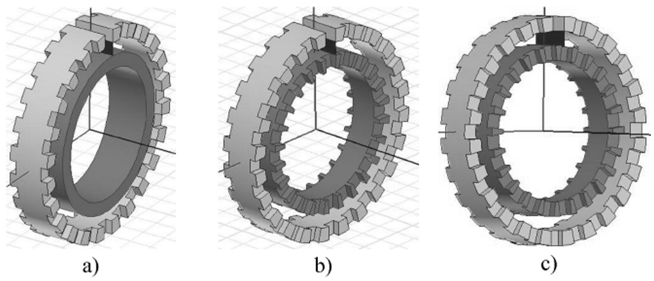

a) b) c)

Fig. 9. Model antennas that use the pattern "meander": a) – symmetrical to the outer ring; b) – symmetric to all ring; c) – symmetric inner ring with relative angular displacement

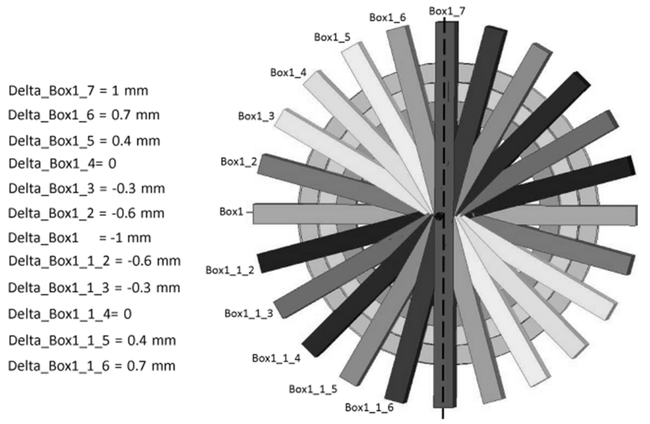


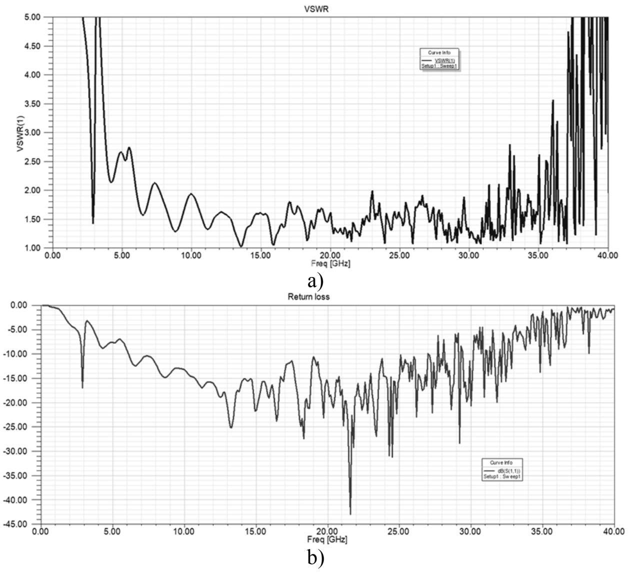
Fig. 10. The essence of formation of non-uniform unilateral template

Systematization of evaluations of the spatial-frequency characteristics of the given variety of the synthesized antenna allows you to select the layout that are candidates for further optimization.

For the model, which is depicted in Fig. 9.a, bandwidth equal to 19.5 GHz (6 to 25.5 GHz) or $\delta f = 1.24$ and the maximum value of return loss characteristics (RL) equal to -37.1 dB at the frequency of 26.89 GHz. A checkerboard pattern location of grooves (see Fig. 8.b) provides a minimum level of RL -36.43 dB and a bandwidth of 23.73 GHz (Fig. 11.a) or $\delta f = 1.22$. The use of symmetric non-uniform pattern location of grooves (see Fig. 8.c) led to the extension of bandwidth up to 21.6 GHz (range 6-27.6 GHz) or $\delta f = 1.29$ and a minimum level of RL -42.98 dB at the frequency of 21.6 GHz (Fig. 11.b).

Simultaneous use of bilateral chess template layout to all of the circles divides the total bandwidth into multiple ranges.

From the point of view of obtaining low-level RL, it is quite interesting model shown in Fig. 12. This option is based on the use of the chess pattern of the fractal transformation of the outer ring. The depth of the grooves is 2 mm. This arrangement is characterized by the geometry of the slit outer ring with presence in the field of power port small ledges.



b)

Fig. 11. Examples of estimated bandwidth: a) – according to the schedule VSWR for the model shown in Fig. 8.b; b) – according to the schedule return loss for the model shown in Fig. 8.c

Obtained in this case, the lowest level RL is -44.55 dB. If you leave the depth of grooves 2 mm, but remove ledges near the slit of the outer ring, the bandwidth is 22.3 GHz (from 5.7 to 28 GHz) or $\delta f = 1.32$ and the maximum value of return loss characteristics (RL) equal to -40 dB.

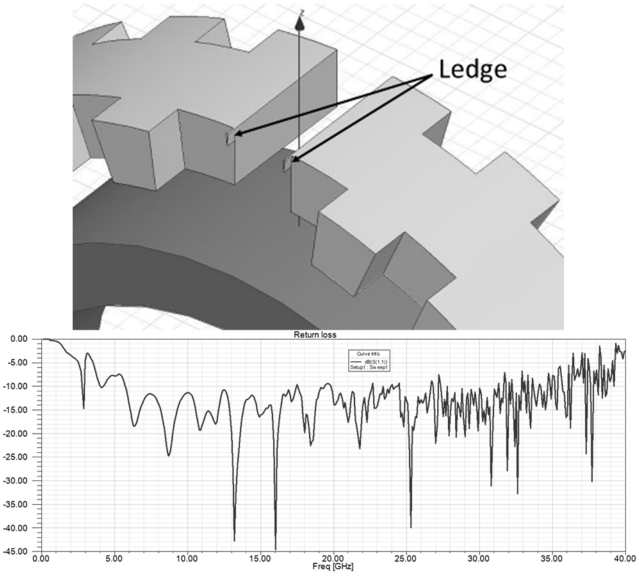


Fig. 12. The model has the lowest level return loss: a) – the shape of the neckline; b) – return loss

A generalization of the analysis of the spatial-frequency characteristics shows that the synthesized quasi-fractal two-ring structure compared to [7] allowed us to obtain efficiency gains ESA. For example, managed to achieve a minimum level of RL - 44.55 dB (in [7] a minimum level of RL amounted to -28 dB), a and also to expand the fractional bandwidth to the values $\delta f = 1.22 \ldots 1.32$ (in [7] obtained $\delta f = 0.645$).

In turn, the assessment of beam pattern synthesized ESA indicates greater its deformation and deviation from same-beam forms on the boundary frequencies of the operating range (Fig. 13 and 14.).

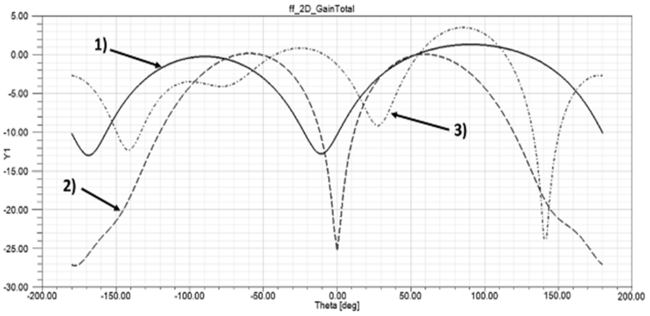
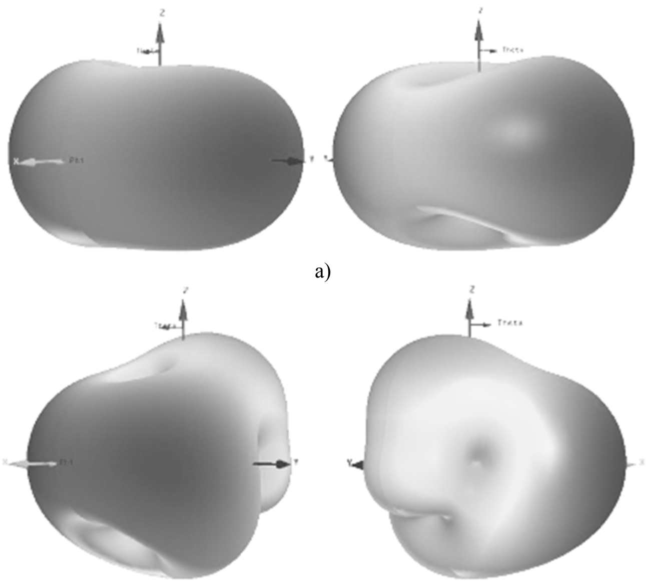


Fig. 13. 2D Beam pattern: 1) – quasi-fractal ring vibrator (see Fig. 1) [7]; 2) – synthesized model with the power port between the rings without cutting the outer ring (see Fig. 4 or 5); 3) – model with a dissection of the outer ring (for example, see Fig. 7-9)


a)

b)

Fig. 14. 3D Beam pattern: a) – antenna in Fig. 1 [7]; b) – the models with split outer ring (for example, see Fig. 7-9)

V. PERSPECTIVES OF FURTHER RESEACH

Further studies of the type proposed two-ring ESA should focus on the optimization of their spatial-frequency characteristics to maximize bandwidth. As priorities, consider the following ways of improving the geometry of the antenna elements:

- chaotic arrangement of the grooves in the end surfaces of the segments with different depth and length along the strips and/or staggered;
- the use of twisted, corrugated and fractal shapes of grooves and wedge-shaped, stepped, triangular, hexagonal, spherical or similar antenna Vivaldi;
- introduction lateral passive segments in the form of templates that were used for the formation of grooves in the end surfaces of the strips, with the implementation of such segments from a metal, dielectric, alternating metal and dielectric;
- filling the space between the rings (totally or partially) by a dielectric (including, with features that change in angular segments for speed and/or gradient law);
- cut in the surfaces of the strips of many slots fractal forms;
- execution of grooves not the entire thickness of the strips or of variable thickness.

Another direction is the combination of the above modifications along with multi-dimensional fractal transform, in particular, on the basis of several different fractals.

Also, in order to create a broadband metamaterials, highly relevant is the development of a Split Ring Resonator (SRR) based on the pair split strips, with end slots. Thus, it is advisable to analyze 3D structures, taking into account the above modifications of the ring components.

VI. CONCLUSIONS

The results of the study indicate the feasibility of using two strip structures for the development of broadband and multi-band ESA. Simplification of the synthesis of their 3D-structures due to the decomposition of the original geometry and multi-dimensional fractal transformation provides the basis for finding the optimal layout geometry of the active ESA and the unit cells of the metamaterial.

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