Synthesis of Quasi-Fractal Ring Antennas

Ihor Sliusar, Larisa Degtyareva
Department of Computer Engineering
Poltava National Technical Y. Kondratyuk University
Poltava, Ukraine
islyusar2007@ukr.net, ladegt12@gmail.com

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

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

***Abstract* — The article considers the variants of models quasi-fractal antennas. Their synthesis suggested the vector description of the fractal transformation of individual segments of the primary geometric shape. The combination of the decomposition of the geometric shape and multi-dimensional fractal approach allows to simplify the synthesis of fractal 3D structures and/or to use several types of fractals, including with a different number of iterations. This approach allows achieving broadband and multi-band antenna systems. Thus the influence of the segmentation level and the power scheme on the spatial-frequency characteristics of the antenna. Due to the complexity of describing the interaction of the antennas of non-Euclidean geometry with radio waves for their synthesis and analysis taken methods of numerical simulation. Evaluation and comparison of antennas held by the following characteristics: amplitude-frequency response, beam pattern and voltage standing wave ratio.**

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

I. Introduction

Current trends of minimization of telecommunications facilities require the implementation of combined compact integrated antennas, which have respective levels broadband and multi-band [1].

Analysis of technical solutions, allowing to provide conformity to the specified requirements, shows that they basically boil down to the use of electrically small antennas [2]; introduction of the geometry of fractals [3]; introduction of elements based on dielectric resonator antennas (DRA) [4-6]; formation of multi-element gratings; implementation of combinations of these design approaches.

One of variants of such integration may be the use of various modifications of the antenna elements based on simple geometric shapes, e.g., square, rhombus, triangle or circle. Among them, the largest increase has a ring structure.

In this case the physics of operation of such antenna – the bigger the space is covered, the higher the gain, which it is provided. The bandwidth of such structures is several times wider than that of a conventional dipole. However, in comparison, they have a high input impedance.

In turn, the application of the fractal approach allows to some extent to resolve this issue, as well as to expand the bandwidth and to create multiple resonant frequencies. In addition, in recent years many works discuss quasi-fractal structure. As you know [7], the term «quasi-fractal» describes antennas that do not have a strictly defined progression of the frequency of occurrence of items at each change in scale, or they are incomplete (inexact) similarity of the structure and its elements. In general, the range of such antennas is constantly expanding.

As a result, it is advisable to evaluate antenna solutions, where the geometry of the annular emitter is described by the fractal (quasi-fractal).

II. Analysis of Recent Studies and Publications, Which Discuss The Problem

Systematization of existing sources related to this issue can provide some generalized areas of research.

Traditionally, the ring structure is the basis for the improvement of classical antennas and arrays on their basis (framework, logo-periodic, etc.) [7, 8].

Another direction involves the implementation of fractal approach for the formation of the antenna by scaling the complex antenna elements at the base of the circle [9, 10].

In this sense, we should also remember the antenna based on the classic geometric fractals which are inscribed in a circle, for example: the Koch snowflake. Usually, these fractals, which are used in antenna technology, as the initiator used a straight line.

The most promising looks to integrate several antenna technologies and solutions with ring structures. Thus, in [7, 11-14] proposed quasi-fractal dielectric resonator antenna (DRA) based on simple geometric shapes. As feed they used classic ring vibrator (i.e., a fractal approach is used not only in the geometry of the hemispherical dielectric components).

Overall, the analysis of existing antenna solutions shows that in theoretical terms, yet insufficiently studied antenna based on fractal ring structures, including, in case of simultaneous use of several types of fractals. All this testifies to the relevance of research.

978-1-7281-4184-8/19/$31.00 ©2019 IEEE

III. The Aim of Research

Thus, the aim of this work is to increase the efficiency of antenna systems based on ring structures using a fractal approach.

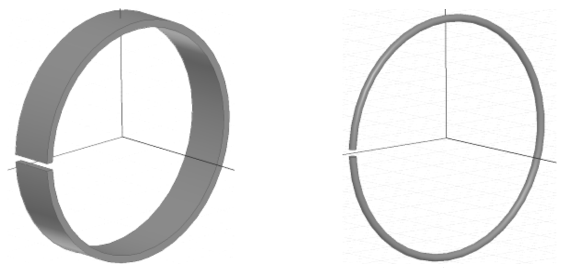
IV. The Main Results of the Study

To address the main objectives of the research proposed to combine the decomposition of the initial geometric shapes and multi-dimensional fractal transformation. This allows to simplify the synthesis of fractal 3D-structures and/or to use several types of fractals, including with a different number of iterations. The benefits are particularly pronounced for forms of priority which is based on spherical or cylindrical coordinate system.

The essence of this approach is based on a vector description of the fractal transformation of individual segmented parts of the initial geometric shape. So, for the 3D-figure, this vector may contain four components: the first describes the law of a geometric fractal transformation relative to the coordinate axis 0x, respectively, the second – 0y, the third – 0z, and the fourth – change material characteristics (e.g., permittivity). At the same time, the number of iterations for each of these components may differ. In turn, other geometric segments can be applied (or not applied) are excellent options fractal transformation. To ensure the integrity of synthesized structures it is sometimes necessary to involve overlapping segments.

To understand the process n-dimensional fractal transformations considered in the paper the simplest variant is the synthesis quasi-fractal ring vibrator. In this case, as the initiator of the fractal use arc stands, and as the generator of the fractal use the meander. For the formation of a meander necessary to attract two segments. To simplify the modeling process introduced a number of assumptions.

1. As basic element considers the annular vibrator (Fig. 1.a), which is made of copper. It is a tape with a width of 4.5 mm with a fixed thickness (0.75 mm), which coincides with the diameter of the wire ring vibrator (Fig. 1.b) similar to [7, 11-14]. The external diameter of the synthesized antenna elements does not exceed the outer diameter of the wire ring vibrator (24.4 mm).



a) b)

Fig. 1. Ring vibrator: a) – tape; b) – wire

2. Due to the complexity of describing the interaction of the antennas of non-Euclidean geometry with radio waves for their synthesis and analysis selected methods for the numerical simulation. During the evaluation of the spatial-frequency characteristics of the designed antenna solutions in the range up to 40 GHz are considered such indicators as return loss, beam pattern i voltage standing wave ratio. Although there are several interpretations of the bandwidth, we use the definition of strip by the criterion of return loss [15], for which the module of S_{11}, less than -10 dB.

3. As the main is considered a cylindrical coordinate system. Decomposition of the initial geometric shape provides only the integer value of the angular dimension of the segments (in deg.) according to the expression: $Angle_{seg} = 360 / N$. The number of segments N can be determined Table I. To ensure the integrity of the structure the overlapping segments corresponds to the thickness of the tape ring vibrator (Fig. 1).

TABLE I. The Angular Dimension of the Segments

N	***Angle$_{seg}$* (deg.)**	***N***	***Angle$_{seg}$* (deg.)**	***N***	***Angle$_{seg}$* (deg.)**
1	360	11	32.73	21	17.14
2	180	12	30	22	16.36
3	120	13	27.69	23	15.65
4	90	14	25.71	24	15
5	72	15	24	25	14.4
6	60	16	22.5	26	13.85
7	51.43	17	21.18	27	13.33
8	45	18	20	28	12.86
9	40	19	18.95	29	12.41
10	36	20	18	30	12

4. To power the antenna element scheme is applied without coordination with the resistance, which contains only one port. It can have an arbitrary location.

5. To facilitate comparison with the spatial frequency characteristics of the primary vibrators (Fig. 1, 2) fractal transformation at the level of the first iteration is subject only to the tangential component of the geometric shape (using a cylindrical coordinate system).

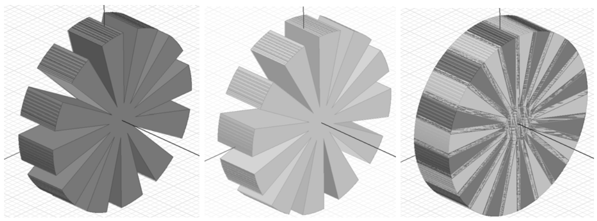


Fig. 2. Segmentation Template

In the future, taking into account the assumptions, one should consider the process of formation quasi-fractal ring vibrator, which contains 24 segments. The angular size of one segment is 15 deg. For clarity, the segments can be divided into even and odd (Fig. 2). The segments have mutually overlapping, which is equal to the thickness of the tape ring vibrator (Fig. 1.a). Formed of the overlapping zones form a pattern for the radial component of the synthesized geometric shapes (Fig. 3). In accordance with the assumptions, it is not subject fractal transformation. Using logical operations of inversion, conjunction, disjunction, and, as a generator of the fractal - the meander, you can create a 24-segment quasi-fractal ring vibrator (Fig. 4). The height of the meander (1.5 mm) is characterized by the distance between external and internal radial components of the vibrator. Accordingly, in Fig. 5 examples of 9-, 15- and 30-segment patterns.

Special attention is given to search for optimal host port power supply. For odd N in the placement of the port corresponds to Fig. 6. For even N, the number of the investigated variants is slightly expanded (Fig. 7).

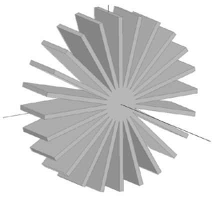


Fig. 3. Template for the radial component

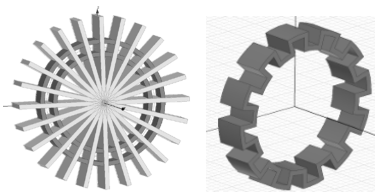


Fig. 4. Synthesis of quasi-fractal ring vibrator (N=24)

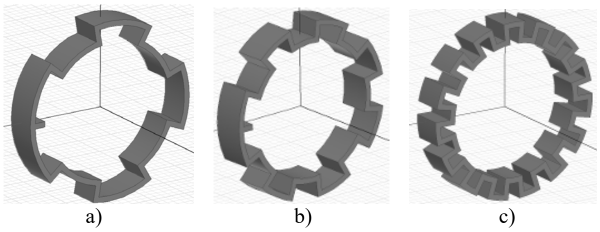


Fig. 5. Template for multi-segment quasi-fractal ring vibrator: a) – N=9; b) – N=15; c) – N=30

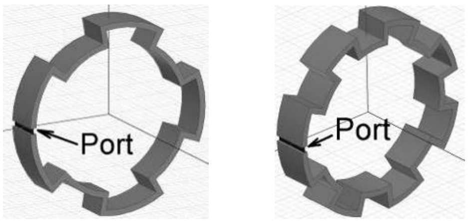


Fig. 6. The placement of the power port with an odd N

In the course of research comparison of primary ring vibrators (see Fig. 1).

Examples are shown in Fig. 8 i 9. As can be seen, the use of tape instead of wire improves performance, but does not meet the requirements for broadband and multi-band supports. On the other hand, the comparison of the ring structures shown in Fig. 1.a and Fig. 4 evidence of the positive effects of the use of fractal approach (see Fig. 9).

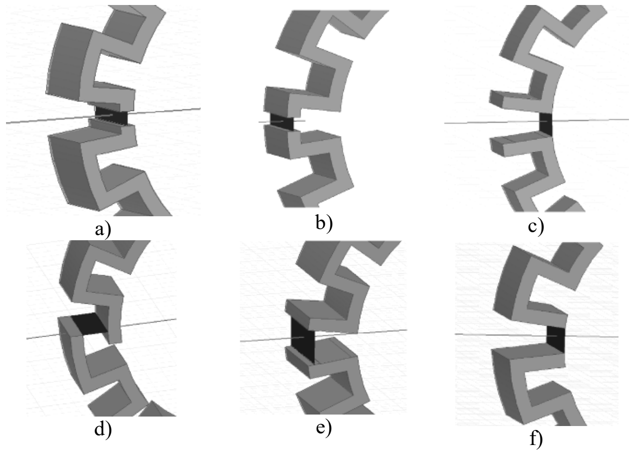


Fig. 7. An example of the placement of the power port for a 30-segment quasi-fractal ring vibrator

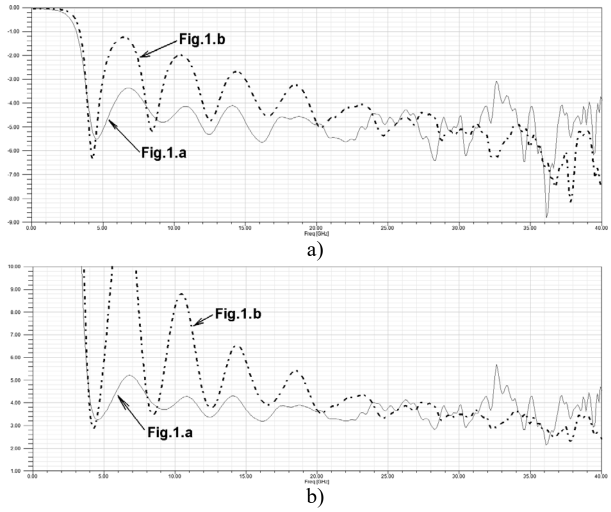


Fig. 8. Comparative evaluation of the frequency characteristics of the basic ring vibrators: a) – return loss; b) – VSWR

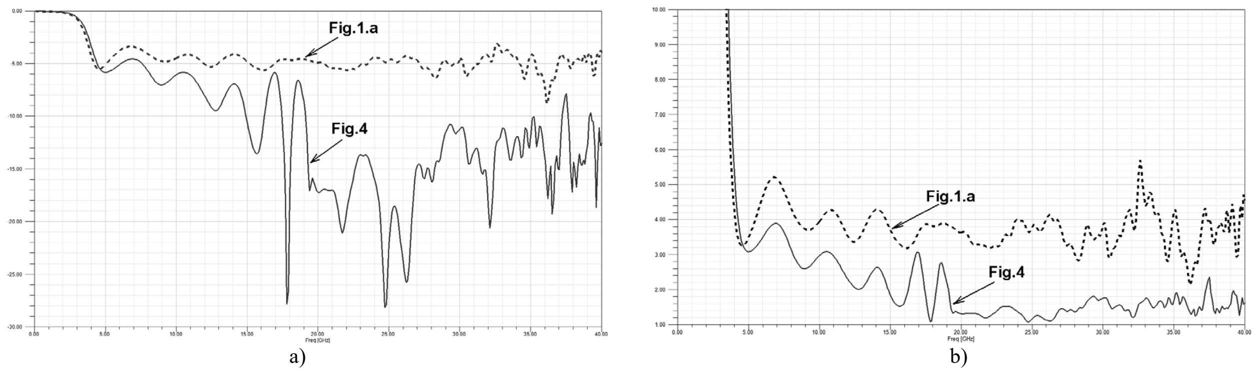


Fig. 9. Comparative evaluation of frequency characteristics of quasi-fractal ring structures: a) – return loss; b) – VSWR

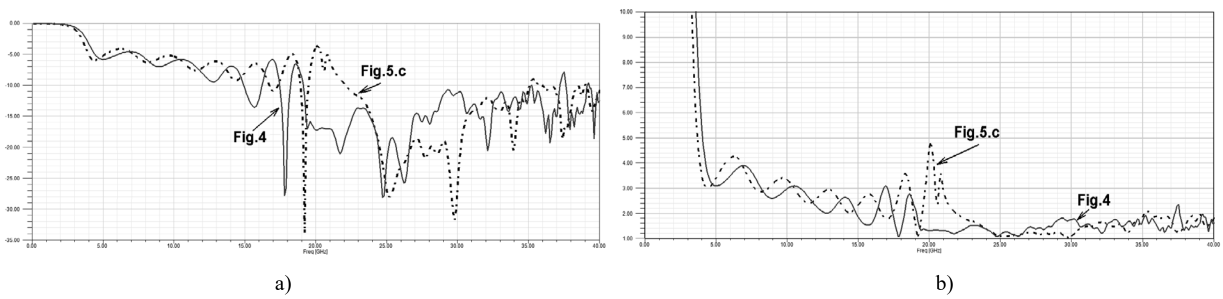


Fig. 10. Comparative evaluation of the frequency characteristics of the synthesized ring structures: a) – return loss; b) – VSWR

The minimum level of the return loss reaches -28 dB, and at frequencies above 17 GHz we have VSWR < 3. Provided that appropriate location of power port (see Fig. 7.f) on the selected criterion, the bandwidth is 18 GHz.

For quality assessment based on spatial-frequency characteristics of the level of segmentation for Fig. 10 shows the pair wise comparison for vibrators with the number of segments 24 and 30, and Fig. 11.a – the beam pattern for the case of $N = 24$.

In turn, given the current capabilities of using additive manufacturing composite antenna systems, the studies made 3D-printing template 24-segment quasi-fractal ring vibrator (Fig. 11.b, c). It can be used for further stages of production.

a) b) c)

Fig. 11. 24-segment quasi-fractal ring vibrator: a) – beam pattern; b) – the template is made on a 3D- printer «Prusa i3» (material – PETG); c) – model after processing

Overall, the results allow drawing the following conclusions.

1. To have pronounced resonances, it is necessary to increase the number of segments in the line of a meander.

2. An even number of segments allows obtaining a more efficient structure than odd.

3. For a pair of number of segments it is better to have the ratio of their number to 4, which allows to observe the full symmetry of the ring shape of the vibrator with respect to all coordinates. In this sense, 24 segment is better than 30 (for example, it gives a wider bandwidth).

4. The maximum bandwidth allows you to power port in a completely remote jumper segment. At the same time, it should be located on the inner radius surface of the meander.

V. Perspectives of Further Reseach

Further research is advisable to send the modeling of 3D-structures, which are based on a combination of several types of fractals; determining dependencies of the spatial-frequency characteristics from the geometry quasi-fractal antennas.

VI. Conclusions

The results confirmed the theoretical statements on the desirability of a broadband and multi-band antenna, based on a fractal approach. Vector representation of the fractal transformation of individual segmented parts of elementary geometric shapes greatly expanding the range of perspective antenna systems with non-Euclidean geometry, and the use of parametric optimization simplifies their practical implementation.

References

[1] D.I. Voskresensky, V.L. Gostyuchin, V.M. Maksimov and L.I. Ponomarev. *Ustrojstva SVCH i antenny [Microwave and antenna devices]*. Moscow, Russia: Radiotechnika, 2006, 376 p. (In Russian).

[2] V.M. Vishnevsky, A.I. Liachov and S.L. Portnoj. *Shirokopolosnye besprovodnye seti peredachi informacii [Broadband wireless communication networks]*. Moscow, Russia: Technosphera, 2005, pp. 524-526. (In Russian).

[3] B. Mandelbrot. *Fɛactals: Forme, Chance and Dimension*. San-Francisco, Freeman, 1977, 365 p.

[4] S.A. Long, M.W. McAllister and L.C. Chen. "The Resonant Cylindrical Dielectric Cavity Antenna." *IEEE Trans Antennas and Propagation*. May 1983, AP-31, pp. 406-412.

[5] M.T. Birand and R.V. Gelsthorpe. "Experirnental Millimetric Array Using Dielectric Resonators Fed by Means of Dielectric Waveguide."– *Electronics Letters*. Sept. 1981, v.17, pp. 633-635.

[6] M. McAllister, S.A. Long and G.L. Conway. "Rectangular Dielectric Resonator Antennas." *Electronic Letters*. March 1983, EL-19, pp. 219-220.

[7] I.I. Sliusar, V.I. Slyusar, Y.V. Polishchuk and E.I. Stas. "Analysis of space-frequency characteristics of a quasi-fractal dra based on a cube and truncated pyramid." *Nauka i studia*. Przemysl, 2018, № 11, pp. 3-12.

[8] V.V. Zimin. "Ring single-wave vibrator", RU Patent No. 2016117783 (A), 10.11.2017. (In Russian).

[9] E.N. Matveev and A.A. Potapov. "Fractal Antennas for the New Class of Radio Systems: Keily Tree and Circular Monopole." *Int. Radar Symp*. (IRS-2009), Hamburg, 2009, pp. 465-468.

[10] D.V. Mayboroda, S.A. Pogarsky, A.V. Poznyakov, V.N. Sukhov and E.V. Shcherbatiuk. "The Quasi-Fractal Microstrip Antenna." in *IEEE 2018 9TH International Conference On Ultrawideband and Ultrashort Impulse Signals (UWBUSIS)*, Odessa, 2018, pp. 349-352.

[11] I.I. Sliusar, V.I. Slyusar, S.V. Voloshko and V.G. Smolyar. "Synthesis of quasi-fractal hemispherical dielectric resonator antennas." in *IEEE 2018 5th International ScientificPractical Conference Problems of Infocommunications. Science and Technology (PIC S&T)*, Kharkov, 2018, pp. 313-316.

[12] O.O. Tahan, I.I. Sliusar, V.I. Slyusar and R.E. Hrebelia. "Quasifractal dielectric resonator antenna based on the symmetric hexagon." *Nauka i studia*. Przemysl, 2018, № 7, pp. 113-123.

[13] A.V. Kolisnyk, V.I. Slyusar, I.I. Sliusar and V.V. Samofal. "Investigation of the overlapping effect of dielectric resonator antennas elements on the basis of a cylinder." *News of Science and Education*. Sheffield, 2018, № 3, pp. 68-74.

[14] V.M.Semenov, I.I. Sliusar and V.I. Slyusar. "Kvazifraktalna dielektrychna rezonatorna antena na osnovi paralelepipeda [The quasi-fractal dielectric resonator antenna based on parallelepiped]." *Systemy upravlinnia, navihatsii ta zviazku*, PoltNTU. Poltava, 2018, № 2, pp. 167-171. . (In Russian).

[15] S.E. Bankov and A.A. Kurushin. *Raschet antenn i SVCH struktur s pomoshchyu HFSS [Calculation of antennas and microwave structures using HFSS Ansoft]*. Moscow, Russia: ZAO NPP "Rodnik", 2009, pp. 207, 208. (In Russian).