# Investigation of the Characteristics of the Radiation of the Microstrip Antenna Based on the Fractal Approach

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***Abstract*—The study of the influence of geometrical factors on the characteristics of the antenna radiation. The offer to use the fractal approach to the creation of microstrip antennas. The implementation of the calculation of the radiation pattern of the antenna, and computer modeling, the comparison and analysis of results.**

## I. Introduction

In today's world of wireless technology the telecommunication systems require compact antennas. This requires the following basic requirements: small dimensions, the radiation pattern requirements, polarization, and frequency.

Microstrip antennas are small dimensions, which are used for communication of standards GSM, Wi-Fi, GPS, Wi-Max, GLONASS.

Requirements for radiation pattern include the desired shape of the antenna radiation.

Particularly, narrow directivity pattern with high gain is created by microstrip antenna arrays or antenna with different dielectric layers.

Polarization requirements are performed due to slots, truncation angles and by using special tuning stub in microstrip antenna.

Frequency requirements include providing broadband, simultaneous operation in several frequency bands, the introduction of slots, shorting pins, cutouts. Frequency requirements also include the ability to change the resonant frequency due to the geometry of the microstrip antenna.

The Introduction into the fractal microstrip antenna is used to create multi-band antennas [1]. The advantage of the fractal approach is the simple algorithm for forming the antenna geometry [2].

The main problem of the simple microstrip antenna is a low gain (5-6 dB) and one pronounced resonance, which are limit the use of microstrip antenna simultaneously in several frequency ranges. Linear polarization does not allow us to use simple microstrip antenna in satellite communication systems.

Actually in this moment it is the antenna with a high gain, having multi-band characteristics and required type of polarization. These characteristics are determined in the proposed approach by the geometrical parameters of the antenna [3].

## II. Microstrip antenna based on the fractal approach

The Microstrip antenna based on the fractal approach is presented on the Fig.1, 2.

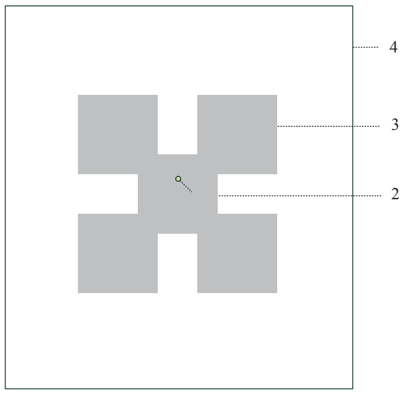


Fig. 1. Fractal microstrip antenna. Top view

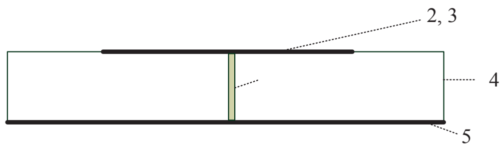


Fig. 2. Fractal microstrip antenna. Side view

The microstrip antenna consists of coaxial feeder supply 1 connected to the central part 2, which are located at the corners of the peripheral elements 3 and are arranged on the dielectric substrate 4 with a metal screen 5 on the opposite side. Feeder is offset by a distance 1/6 the length of the radiator on the radiator edge of the center [4].

The Analysis of the radiation characteristics of the fractal antenna has various forms of the fractal generator: square (Fig. 3), round (Fig. 4) and triangular (Fig. 5) revealed a similar set of characteristics of radiation, in particular radiation pattern (Fig. 6, Fig. 7, and Fig. 8).

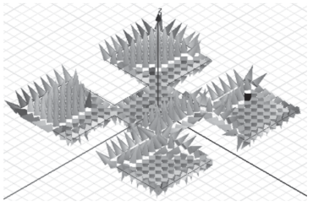

Fig. 3. Distribution of electromagnetic field in the rectangular patch

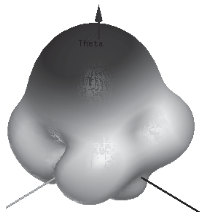

Fig. 6. Radiation pattern of the rectangular patch

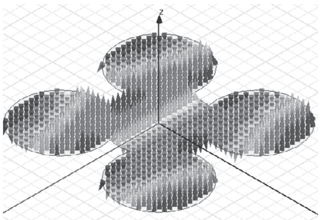

Fig. 4. Distribution of the electromagnetic field in the circular patch

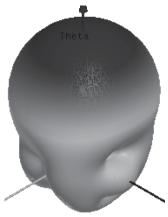

Fig. 7. Radiation pattern of the circular patch

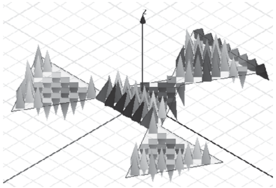

Fig. 5. Distribution of the electromagnetic field in the triangular patch

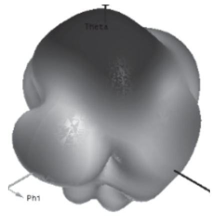

Fig. 8. Radiation pattern of the triangular patch

Designed antennas allow us to design antennas with a pre-predictable results.

These directional diagrams show an increase in the gain of a microstrip antenna to 11dB.

The method of calculating the fractal antenna pattern based on the calculation of the radiation pattern of circular antenna arrays. Four emitter fractal antennas are on a ring with a radius $r = \frac{d}{\sqrt{2}}$ of the central - in the center of the ring (Fig. 9).

The Equation for directional pattern of the fractal antenna is determined as the product of a multiplayer in the radiation pattern of the lattice, created by one transmitter.

$$f(\theta,\varphi) = F_0(\theta,\varphi) \cdot F_p(\theta,\varphi)$$

When the distance between peripheral elements is in the range of $0.5\lambda \le d \le \lambda$ peripheral elements are electrically connected via the central elements.

The Fractal antenna is compared with a similar array of 2x2 increased gain (Fig. 10).

The Radiation pattern of the fractal antenna constructed using the proposed formulas (Fig. 9) corresponds to radiation pattern obtained by a computer simulation (Fig. 14).

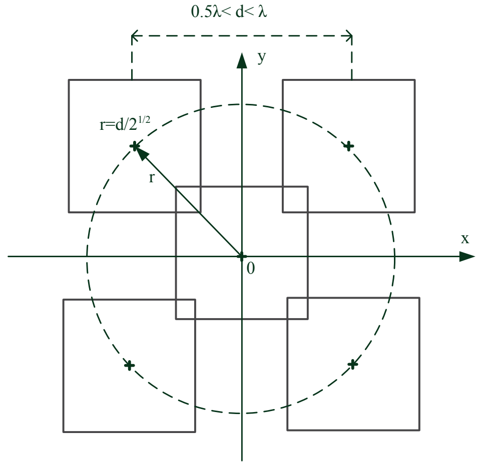


Fig. 9. View of fractal antenna, based on the approach of circular antenna arrays

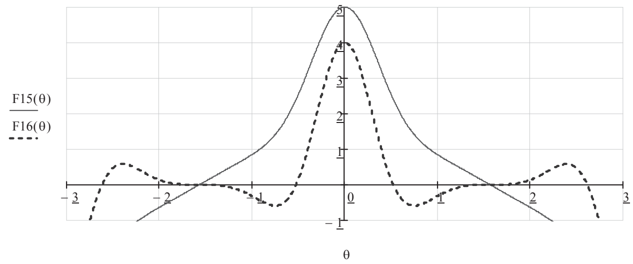


Fig. 10. Normalized radiation pattern of fractal antenna and antenna array 2x2

Discussed patch antennas are fractal antennas of the first iteration. Peripheral elements are the similar to the central element with the scale, determined to the ratio between the size of the peripheral elements to the size of a central element. Fractal antenna of the second iteration is shown on Fig. 11.

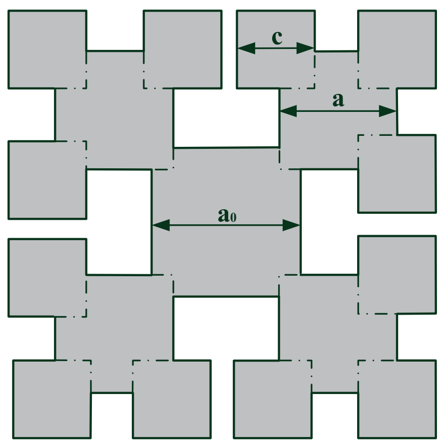


Fig. 11. Fractal antenna of the second iteration

Thus, three peripheral element is added to the each peripheral element last iteration. The total number of peripheral elements of the second iteration is 12.

Peripheral elements of the second iteration is cross with increasing this ratio. The high value of gain at the first iteration is achieved in that the peripheral and the central elements are the same as one half wavelength.

The gain of the fractal antenna is not increased with increasing the number of iterations. This fact is due to geometrical parameters. The size of elements should be decreased on each next iteration. The elements on the first, second and next iteration are not the same to each other and are not the same to one half wavelength.

Analysis of the results showed that:

1) Proposed fractal approach for the design of microstrip antennas on the basis of the central (fractal generator) and four peripheral elements (with a variable scaling factor), located at the corners of the central element, made in a single metal layer, providing electrical communication between elements on a dielectric substrate with a metal shield allows to create the antenna with a higher gain;
2) The results of the method of calculating the fractal antenna pattern based on the calculation of the circular antenna arrays is equal to the results of a computer model of the fractal antenna in Ansoft HFSS software package;

Frequency characteristic of the fractal antennas doesn't depend on the fractal shapes (square, circular and triangular) and corresponds to the fundamental mode of radiation equal to one-half wavelength.

Frequency characteristic of fractal antenna with different shapes has three resonance frequencies.

Analysis of the electromagnetic field shown that the first resonance frequency is the same to the half wavelength.

The half wavelength fits into each of the five elements of the fractal antenna. This fact provides gain at the first resonant frequency about 11dB.

The second resonance frequency fits only into peripheral elements, whereas the central element is not emitting on this frequency.

The radiation pattern on the second radiation frequency has a gap in the central region and the resulting gain about 6,1dB (Fig. 12).

Radiation pattern at the second resonant frequency is a four-view that allows using the antenna to measure the angle of drift and ground speed (Fig. 13).

The requirement for a four-directional pattern is necessary to continuously determine the velocity, direction and current position of the aircraft's location.

Half wavelength fits on the third resonant frequency in the central element, wherein the peripheral elements in two half wavelength (Fig. 14).

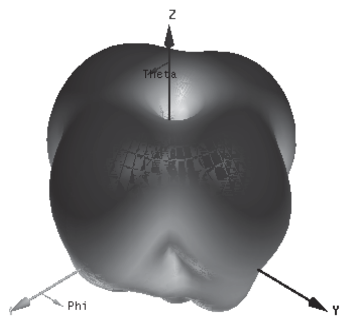


Fig. 12. Radiation pattern on the second radiation frequency (in dB)

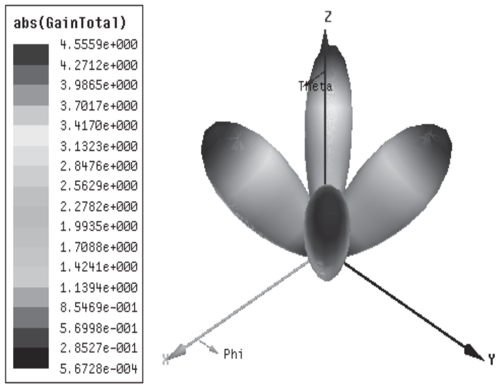


Fig. 13. The radiation pattern on the second radiation frequency

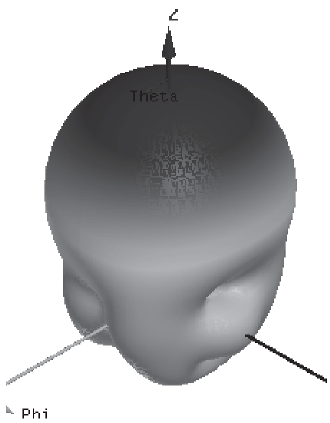


Fig. 14. The radiation pattern on the first radiation frequency of the rectangular based fractal antenna

## III. CONTROL OF RESONANT FREQUENCIES

The actual task for fractal antennas is the ability to control the frequency characteristic and radiation pattern, as well as obtaining dependencies, allowing to set frequency characteristics and to vary the gain depending on the geometrical parameters [5].

The control of frequency characteristic and radiation pattern providing due to geometric parameters, such as the ratio between the size peripheral element to the central element a/a_0 (scale coefficient), and the ratio of the distance between the central and peripheral elements of b/b_0 (Fig. 15).

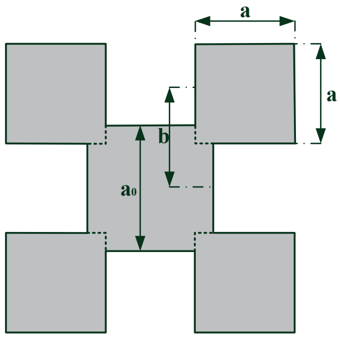


Fig. 15. Fractal antenna with the control geometrical parameters

Maximizing the gain on the first resonant frequency is achieved with a/a_0 = 0,82. Antenna gain decreases on the second and third resonance frequency as the ratio of a/a_0 from 7,5dB to 6dB and 9dB to 4dB.

The Increase of the distance between the central and peripheral antenna elements reduces the gain on the first and third resonance frequencies.

Frequency characteristic depends on the geometric parameters of the antenna via the distribution of the current distribution in the peripheral and central elements of the fractal antenna.

Resonant frequencies are shifted to the lower frequencies if the size of peripheral elements increase. Also, the resonant frequencies are shifted to lower frequencies if the distance between peripheral and central elements increases.

The results allow us to shift the resonance frequency within a range of ± 15% by changing the distance between the peripheral and central elements and peripheral elements size.

An important feature of the developed antenna is the ability to shift of the resonant frequency by changing the geometric characteristics [6].

The first, second and third resonances are shifted to the lower frequencies at the same time with increasing the size of the peripheral elements and the distance between the central and peripheral elements.

The ratio of adjacent resonance frequencies remains constant regardless of the size of peripheral elements.

The following method of setting the required resonance frequency is proposed in this paper:

1) choosing the first resonant frequency which is determined by the resonant frequency of the central element;
2) the second and third resonant frequencies are determined by analytical dependences obtained above;
3) three resonant frequencies can be shifted simultaneously depending on the ratio a/a_0.

## IV. Experimental model

Experimental antenna is measured using a vector network analyzer from Agilent N5230C.

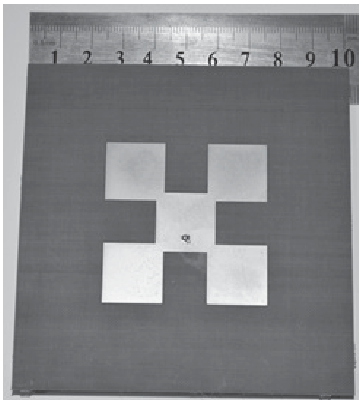

Fig. 16. View of experimental fractal antenna

It was measured the next parameters:

- voltage standing wave ratio (VSWR);
- radiation pattern on the resonant frequencies.

Radiation patterns and resonant frequencies of the experimental sample and the computer model are the same and confirm the results obtained theoretically (Fig. 17, 18, 19).

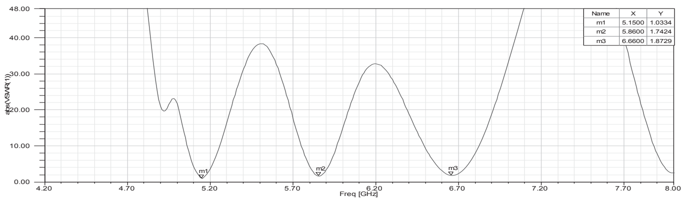


Fig. 17. VSWR of the calculation model of the fractal antenna

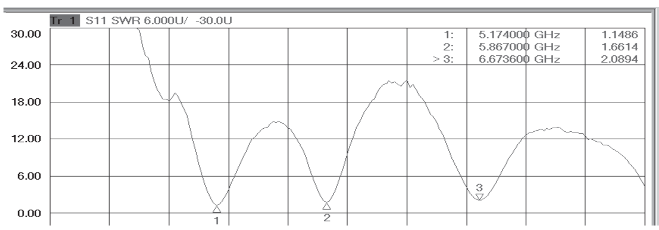


Fig. 18. VSWR of the experimental model of the fractal antenna

The differences in the numerical value of the VSWR experimental sample and the computer model explain the manufacturing error and (Table I).

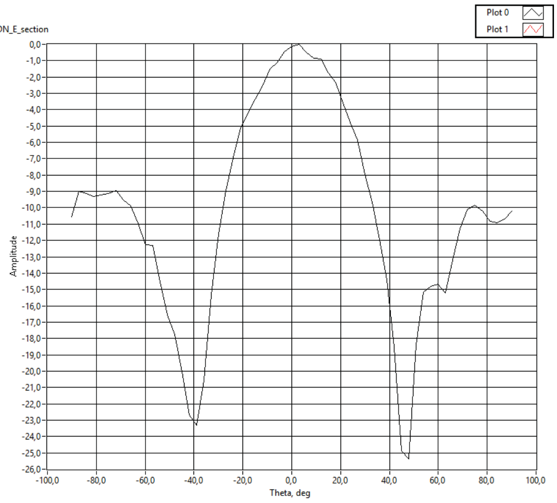


Fig. 19. Radiation pattern of experimental model of the fractal antenna

TABLE I. THE COMPARISON BETWEEN THE CALCULATION AND THE EXPERIMENTAL MODEL

| | Calculation model | Experimental sample |
|---|---|---|
| fr1, GHz | 5,15 | 5,17 |
| VSWR (fr1) | 1,03 | 1,15 |
| fr2, GHz | 5,86 | 5,86 |
| VSWR (fr2) | 1,74 | 1,66 |
| fr3, GHz | 6,66 | 6,67 |
| VSWR (fr3) | 1,87 | 2,09 |

The difference between fractal antenna and antenna array consists of the absence of distribution feeders and couplers.

The central element performs on the fractal antenna the role of the distribution feeder, which provides the power division between the peripheral elements and a role of the radiating element.

The linear polarization is achieved in microstrip antenna array, whereas the fractal antenna provides both linear and circular polarization, depending on the geometrical shape of the radiating elements.

Fractal antenna is multi resonance, unlike the antenna array.

The ratios of the resonant frequencies are determined by geometrical factors such as the distance between central and peripheral elements.

Fractal antenna is not used expensive multilayer structures, compared with the antennas to increase the gain due to dielectric with high dielectric constant.

Compared with the existing antennas, fractal antenna has the following advantages: the three tunable resonant frequencies, enhanced gain relative to the 2x2 antenna arrays, and various type of polarization.

## VII. CONCLUSION

The Opinion sets out the basic results of the thesis, consisting of the following:

1) It is proposed the fractal approach for the design of microstrip antennas on the basis of the central (fractal generator) and four peripheral elements (with a variable scaling factor), located at the corners of the central element, made in a single metal layer, providing electrical communication emitters the dielectric substrate with a metal screen;
2) It is proposed the method for calculating the fractal antenna radiation pattern based on the calculation of the radiation pattern of circular antenna arrays;
3) It is obtained twofold increase of the gain of the fractal antenna compared to the simplest form of the microstrip antenna gain and increased by 25% compared with a similar 4-element antenna array with the same aperture;
4) High value of the gain is achieved by the peripheral and the central elements of a multiple of half wavelength;
5) The calculation of the radiation pattern of the proposed fractal antenna based on a computer model in the software Ansoft HFSS and based on the analytical model of fractal antenna based on the circular antenna arrays showed good agreement with the experimental results produced samples of the proposed antenna type;
6) The investigation of radiation characteristics of fractal antennas with different forms fractal generators of the simplest type (square, round and triangular) found a similar set of antenna radiation characteristics, allowing you to select a separate class of microstrip antennas on the basis of the proposed fractal approach;
7) The type of fractal antenna polarization is determined by the type of resonance, the mutual arrangement of the antenna elements and the shape of the central and peripheral elements, while for the triangular and circular generators are more pronounced in linear polarization;
8) The influence of the geometric parameters of the antenna on its characteristics allows to control the resonant frequency and the shape of the radiation pattern, as well as to design fractal antenna with a pre-predictable results;
9) The increase of the number of iterations does not increase the gain of fractal antennas, since by virtue of their geometric reasons size at each iteration should decrease, making it impossible to fold higher peripheral elements iterations half wavelength.

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