Research of a Fractal Microstrip Antenna Based on the Modified Minkowski Curve of the Second Iteration

M M Smirnova¹, L G Statsenko², Yu V Mirgorodskaya⁴, N A Klescheva³, M V Bernavskaya⁴,⁵

¹Senior lector, Department of Electronics, Telecommunications, and Instrumental Engineering, Far Eastern Federal University, p. Ajaks, 10., o. Russkij, Vladivostok, 690922, Russian Federation
²Professor, Department of Electronics, Telecommunications, and Instrumental Engineering, Far Eastern Federal University, p. Ajaks, 10., o. Russkij, Vladivostok, 690922, Russian Federation
³Professor, Department of General and experimental physics, Far Eastern Federal University, p. Ajaks, 10., o. Russkij, Vladivostok, 690922, Russian Federation
⁴Master degree student, Department of Electronics, Telecommunications, and Instrumental Engineering, Far Eastern Federal University, p. Ajaks, 10., o. Russkij, Vladivostok, 690922, Russian Federation
⁵Assistant Professor, Foreign Languages department, Peter the Great Saint-Petersburg Polytechnic University, ul. Politechnicheskaja, 29, Sankt-Peterburg, 195251, Russian Federation

E-mail: smirnova.mmi@dvfu.ru

Abstract. Evolving telecommunications systems require modern antennas with improved performance. The creation of miniature antennas with a high gain, multi-band properties and defined polarization is an urgent task. New challenges in the reception and emission of electromagnetic waves are being solved in different ways. The use of fractals in the construction of antennas is becoming widespread. This article presents the results of a study of fractal microstrip antenna of the second iteration based on the Minkowski geometry. The main parameters such as the reflection coefficient, directivity and efficiency are described. Resonance frequencies and directional patterns at these frequencies as well as bandwidths are shown. Conclusions concerning the possibility of using this type of antenna in various applications are drawn.

1. Introduction
The use of the fractal concept in the design of antenna devices becomes more relevant every year. It allows to fill the antenna space more efficiently and becomes a powerful and promising tool for achieving multi-band properties [1]. The number of foreign and russian studies on the development of new designs of fractal antennas is increasing every year. [2]. This caused by the fact that the theory of fractal antennas is in the stage of formation, and the absence of strict formulas and dependencies forces us to predominantly use modeling and conduct experiments. [3].
Fractal antennas have two important properties - self-similarity and space filling. [4]. These properties help improve antenna performance, size and weight. Benefits of fractal antennas [5] are as follows: miniaturization (in most cases, the dimensions of the antenna are reduced with each iteration); improved input impedance; broadband (each fractal iteration applied to the antenna canvas expands its frequency band); multi-frequency (continuous operation in a wide frequency range). Disadvantages of technology are decrease in the gain; complexity of design; limited number of numerical methods used for analysis; the benefits of using a fractal structure begin to diminish after the first few iterations. The aim of this work is to study a fractal microstrip antenna based on the Minkowski geometry.

2. Justification of the choice of fractal geometry

Minkowski fractal geometry was chosen because it is poorly studied. It is rarely used in antenna design and it can also be used to create many variations and modifications of the fractal curve. In the classical version, the Minkowski curve is a bipolar jump, however a symmetric version of the Minkowski curve is more widely used. During the construction of symmetric version meanders, decreasing with each iteration are formed. (figure 1). This modification is called a fractal rectangular curve (FRC) [6].

The application of this curve to a rectangular antenna patch usually leads to an increase in overall dimensions, therefore, a modification of the Minkowski fractal was chosen. It makes possible to achieve greater miniaturization as new elements are not completed to the original canvas, but are cut out of it. (figure 2).

3. Research of a fractal microstrip antenna

The study of a fractal microstrip antenna based on the Minkowski curve of the second iteration (figure 3) was carried out by numerical simulation in the Ansys HFSS program. Coordinate basic origin is at the geometric center of the antenna patch.

The dimensions of a rectangular microstrip antenna to which the fractal geometry is applied are presented in Table 1.
Table 1. Dimensions of the original rectangular microstrip antenna.

| Characteristic                              | Value (mm) |
|--------------------------------------------|------------|
| Substrate width Ws                         | 60         |
| Substrate length Ls                        | 70         |
| Patch width Wp                             | 32         |
| Patch length Lp                            | 40         |
| Coaxial feeder inner conductor radius      | 0.47       |
| Coaxial feeder outer conductor radius      | 1.6        |
| Supply line length                         | 20         |

Calculation of the coordinates of the power connection point shows that it should be located at the
distance of about one third of the plate width from its edge [7]. The resulting value is adjusted
experimentally within small limits otherwise, as shown by a number of experiments carried out, the
agreement will be severely violated. We will consider three options for connecting the power supply at
relative distance of 0.28, 0.33, 0.38 from the edge of the plate.

3.1. First power supply position
At the first feed point with the coordinate (0, 30), nine resonant frequencies are observed and the
directional patterns are shown in figure 4.

![Figure 4. Fractal microstrip antenna based on the Minkowski curve of the second iteration.](image-url)
The radiation patterns at the resonant frequencies of 5.2 GHz and 6.75 GHz are the most useful from the point of view of possible practical application. It should also be noted that with this version of the antenna, matching is observed in a wide frequency band of 15.41-16.43 GHz, the bandwidth in this case is 1020 MHz.

At two resonant frequencies from the range 15.7 GHz and 16.25 GHz, the radiation patterns are almost identical, they have two significant maxima, but at the same time a significant level of side lobes.

Table 2 shows the characteristics of the simulated Minkowski fractal antenna of the second iteration with the first power supply position.

An increase in the number of resonant frequencies is observed with increasing to the second iteration of the fractal applied to the antenna. At 5.2 GHz, the radiation pattern is almost omnidirectional and has the lowest gain of 3.9 dB. At 6.75 GHz, the antenna exhibits the highest gain of 12 dB, and the radiation pattern has one significant maximum. A wider bandwidth of 1020 MHz was obtained in comparison with the antenna of the first iteration. This bandwidth contains two resonant frequencies 15.70 and 16.25 GHz. The relative bandwidth reaches 6.5%, which is a good result for the class of microstrip antennas.

Table 2. Characteristics of the simulated fractal Minkowski antenna of the second iteration with the first power supply position.

| Resonant frequency (GHz) | Bandwidth (GHz) | Relative bandwidth (%) | S11 (dB) | Gain (dB) | Directivity (dB) | Efficiency (%) |
|--------------------------|----------------|------------------------|----------|-----------|-----------------|---------------|
| 5.200                    | 5.16-5.23      | 1.3                    | -17.9    | 3.9       | 4.4             | 88.7          |
| 6.725                    | 6.67-6.75      | 1.2                    | -12.8    | 12.0      | 12.9            | 80.0          |
| 8.150                    | 8.11-8.18      | 0.9                    | -24.4    | 4.6       | 5.8             | 76.1          |
| 11.575                   | 11.49-11.67    | 1.6                    | -17.6    | 10.0      | 10.5            | 89.3          |
| 12.400                   | 12.37-12.45    | 0.6                    | -10.3    | 8.5       | 9.0             | 89.2          |
| 13.100                   | 12.94-13.21    | 2.1                    | -19.6    | 6.6       | 7.0             | 91.9          |
| 15.025                   | 14.85-15.25    | 2.7                    | -27.7    | 8.3       | 8.6             | 93.2          |
| 15.700                   | 15.41-16.43    | 6.5                    | -24.0    | 10.6      | 10.9            | 95.0          |
| 16.250                   | 15.41-16.43    | 6.3                    | -16.7    | 10.7      | 10.9            | 94.7          |

3.2. Second power supply position

In this case, power is supplied at a point with coordinates (0; 23) mm. The number of resonant frequencies has increased by one compared to the first power position and is equal to ten.

It should be noted that with a change in the power supply position, most of the resonances shifted to the lower frequencies band. The difference between the corresponding resonant frequencies is 25-125 MHz. The types of antenna radiation patterns with the second power supply position are identical to the case of the first considered power point (figure 4), therefore they are not shown separately. In addition, a new resonant frequency of 7.32 GHz has appeared, the radiation pattern of which has one significant maximum (figure 5). At 5.175 GHz, the antenna radiation is almost omnidirectional, as in the first power position at 5.2 GHz.
Table 3 shows the characteristics of the Minkowski fractal antenna of the second iteration with the second power supply position at resonant frequencies.

The number of resonant frequencies increased to ten with the second method of the antenna power of the second iteration. At 5.175 GHz, the antenna radiation is almost omnidirectional and has the lowest gain of 4 dB.

The antenna radiation patterns at 6.70 and 7.32 GHz have one pronounced maximum, and the antenna achieves high gains of 11.8 and 10.7 dB, respectively.

3.3. Third power supply position
Power is supplied at a point with coordinates (0; 16) mm. This antenna configuration has eight resonances. The antenna patterns with the third feed position are shown in figure 5.

Figure 6 shows that the shapes of the radiation patterns for the third power supply method are identical to the previously considered antennas with the first and second power positions. The radiation characteristics of this antenna configuration are summarized in Table 4.
Figure 6. Fractal microstrip antenna based on the Minkowski curve of the second iteration.
Table 4. Characteristics of the simulated fractal Minkowski antenna of the second iteration with the third power supply position.

| Resonant frequency (GHz) | Bandwidth (GHz) | Relative bandwidth (%) | S11 (dB) | Gain (dB) | Directivity (dB) | Efficiency (%) |
|--------------------------|-----------------|------------------------|---------|----------|-----------------|----------------|
| 6,700                    | 6,69-6,71       | 0,3                    | -11,7   | 11,6     | 12,7            | 77,7           |
| 7,325                    | 7,30-7,33       | 0,4                    | -11,7   | 10,7     | 11,8            | 77,1           |
| 8,125                    | 8,11-8,14       | 0,4                    | -13,2   | 4,5      | 5,7             | 76,1           |
| 11,575                   | 11,44-11,65     | 1,8                    | -32,2   | 10,7     | 11,1            | 90,6           |
| 12,175                   | 12,11-12,27     | 1,3                    | -25,7   | 9,6      | 10,1            | 87,6           |
| 13,225                   | 13,09-13,37     | 2,1                    | -15,4   | 8,1      | 8,5             | 92,7           |
| 14,925                   | 14,78-15,07     | 1,9                    | -14,9   | 9,8      | 10,1            | 94,6           |
| 17,150                   | 16,96-17,34     | 2,2                    | -28,4   | 10,9     | 11,1            | 95,0           |

4. Summary
The influence of the fractal geometry of Minkowski on the parameters of microstrip antenna was studied. The research work showed that an increase in the iteration of the applied fractal leads to the appearance of resonances in the band of higher frequencies and an increase in the number of resonant frequencies in general. At higher frequencies smaller elements of the antenna patch are used. They correspond to shorter wavelengths and are formed with each iteration of the fractal. A fractal antenna contains smaller structures as the iteration increases, and the number of resonant frequencies in the high frequency band also increases. Thus, the broadband of fractal antennas is ensured by the fact that the emitting patch works simultaneously both as a whole and as a set of smaller antennas. In addition, as the iteration increases the level of additional maxima and side lobes increases.

The number of resonant frequencies can be influenced by changing the power supply point. The most successful from the point of view of multi-band and broadband were the options for the location of power points at a distance of about one third from the edge of the emitting plate.

Due to their design features fractal antennas can be used to reduce the geometric dimensions of the antenna, increase the bandwidth and increase the number of operating frequencies. Manipulation with the number of iterations and the way the power is applied allows to influence the resonant frequencies of the antenna. It provides a wide range of possibilities - antennas with any resonance structure in a wide range of form factors can be created.

5. References
[1] Mishra G P, Mangaraj B B 2020 Highly compact microstrip patch design based on improved capacitive Minkowski fractal defected ground structure AEU - International Journal of Electronics and Communications 115 153049
[2] Bojkov I V, Ajkashev P V 2018 K voprosu ob analize i sinteze fraktal'nyh antenn Izvestija vysshikh uchebnyh zavedenij. Povolzhskij region. Tehnicheskie nauki 1 (45) 92–110
[3] Bankov S E, Kurushin A A, Razevig V D 2017 Analiz i optimizacija SVCh-struktur s pomosch'ju HFSS (Moscow: SOLON-Press) p 216
[4] Bangi I, Moore Singh J 2019 Minkowski and Koch Curves Based Hybrid Fractal Antenna for Multiband Applications Wireless Personal Communications 108(6) 2435-2448
[5] Potapov A A 2017 Fizicheskie osnovy i principy postroenija fraktal'nyh radarov i fraktal'nyh sensorov: fraktal'nyj analiz i ego primenenie v teorii statisticheskikh reshenij i v statisticheskoj radiotehnike Radioelektronika. Nanosistemy. Informacionnye tehnologii 9(2) 129-138
[6] Sljusar V I 2007 Fraktal'nye antenny Principal'no novyj tip «domanyh» antenn Svjaz' i telekommunikacii 6 82-89
[7] Balanis C A 2016 Antenna Theory: Analysis and Design (4th Edition) John Wiley & Sons p 1095