Modified Minkowski Fractal Yagi-Uda Antenna

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***Abstract*— An elaborated Yagi-Uda antenna operating in the 800-960 MHz frequency band is proposed and examined in this paper. Performance enhancement – wideband and multiband performance – comes through usage of modification of Minkowski fractals – combination of first and second order of fractal. The SWR, antenna gain, F/B ratio and radiation pattern are simulated and compared with these of classic Yagi-Uda antenna. Real model is also assembled and SWR was measured and compared with simulated.**

Keywords—fractal antennna, Yagi-Uda antenna, multiband, Minkowski curve.

I. Introduction

Antennas in modern communications have to match so many challenges – wideband and multiband performance, small size, simple structure etc. That explains interest of many researchers on fractal shaped antennas in recent years [1-6].

Yagi antenna arrays have simple structure and relatively high gain [1] but in other hand they have limited frequency bandwidth. Usage of fractal antenna elements in Yagi-Uda antennas could lead to wideband and multiband performance. In other hand the analysis and optimization of fractal antennas are very complicated [2], because after every adjustment of the length or width of one of the elements or the distances between elements the optimization has to start almost from the beginning.

In our previous works [7-9] have been presented our studies on fractal antennas - studies on different types of fractal antennas and antennas designed with fractal modifications. Fractal modification allows achievement of wideband performance [9]. Despite the Koch curve is most used in wired fractal antenna design in this paper is proposed and analyzed a five element Yagi-Uda antenna based on Minkowski fractal. This approach represents a wideband and multiband performance and relatively small size. The main antenna parameters - radiation pattern, SWR, antenna gain and front-to-back (F/B) ratio were simulated in comparison with these of conventional Yagi-Uda antenna optimized in the same frequency band.

II. Minkowski Fractal

Minkowski fractal was first introduced by Herman Minkowski in 1885.

Similarly to the antennas which are structured according to most used in antenna design Koch's curve, the antennas shaped as Minkowski curve also use iterations. Despite of the Koch's curve, which has got triangular geometry, the Minkowski geometry is based on a square, in one specific case rectangular, generator structure. In Figure 1 are shown the initiator and the first two iterations. The initiator is considered to be a straight line. The first iteration is formed as the initiator is divided into three parts with equal length and the middle one is replaced by a square (rectangle).

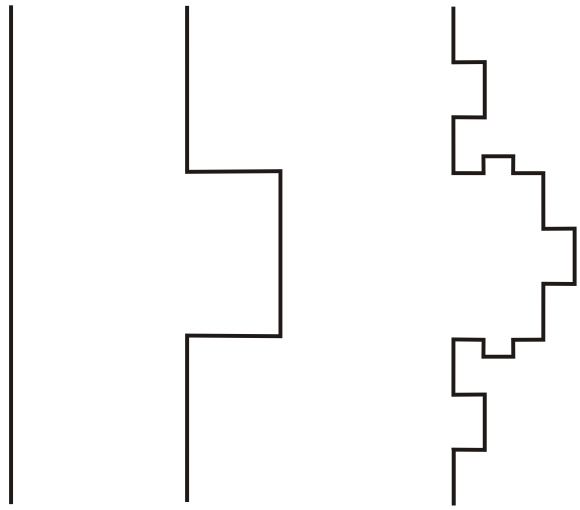

Fig. 1. Minkowski curve – initiator, first and second iteration.

Second iteration is obtained as for every line of the first one is performed described above procedure.

The first iteration increases antenna gain but the next iterations do not improve significantly the antenna gain, they only broaden the frequency bandwidth and the antenna itself becomes more compact but also more complicated for manufacturing.

Therefore in this work, the combination of first and second iteration has been used – only central element of first iteration is developed to the second – Fig. 2. Unlike classical Minkovski curve the lengths of elements in fractals of proposed antenna are different but the symmetry is preserved. That gives possibility wider antenna bandwidth to be achieved with relatively simpler antenna shape and relatively compact antenna size.

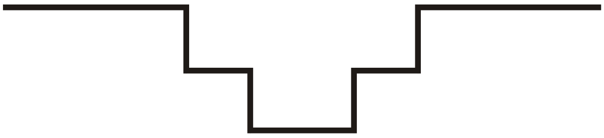

Fig. 2. Proposed modified fractal shape.

III. ANTENNA DESIGN

The proposed five-element fractal Yagi antenna (Fig. 3) has a plane structure (the fractal elements are in one plane) in order to save space and for easy of manufacturing. The physical dimensions of the antenna elements in millimeters achieved after optimization are specified in Table 1, where the small letters from *a* to *e* designate the fractal segments, without digit for dipole element, with 0 for reflector and with 1, 2, 3 for 1st, 2nd and 3rd directors, the capital letters D_0 and D_1, D_2 and D_3 designate the distance between driving element and reflector, driving element and 1st director, 1st and 2nd director and 2nd and 3rd director respectively (Fig. 3). Wire diameter is 2.76 mm.

The simulation and optimization of the antenna are performed with 4nec2 moments-method software [10] for 800-960 MHz frequency band with 120 segments per half-wave length of antenna elements. In optimization weighting factors for SWR 80% and for antenna gain 20 % are used.

The optimization algorithm is as follow:

1. Driven element is designed as its electrical length is equal to length of driven element of classical Yagi antenna;
2. Fractal segments of driven element are optimized;
3. Reflector is designed as in step 1;
4. Fractal segments of reflector and its distance from driven element are optimized;
5. The two-element antenna is optimized;
6. 1st director is designed as in step 1;
7. Fractal segments of 1st director and its distance from driven element are optimized;
8. The three-element antenna is optimized;
9. 2nd director is designed as in step 1;
10. Fractal segments of 2nd director and its distance from 1st director are optimized;
11. The four-element antenna is optimized;
12. 3rd director is designed as in step 1;
13. Fractal segments of 3rd director and its distance from 2nd director are optimized;
14. The five-element antenna is optimized.

TABLE 1. ANTENNA ELEMENTS DIMENSION

a	***b***	***c***	***d***	***e***	***r***
51	3.5	14	8	19	1.38
a_0	b_0	c_0	d_0	e_0	D_0
27	20	31	15	22	31
a_1	b_1	c_1	d_1	e_1	D_1
34	13	14.5	12	20	36.6
a_2	b_2	c_2	d_2	e_2	D_2
35	12	13	12	20	53
a_3	b_3	c_3	d_3	e_3	D_3
40	5	9	9	20	85.5

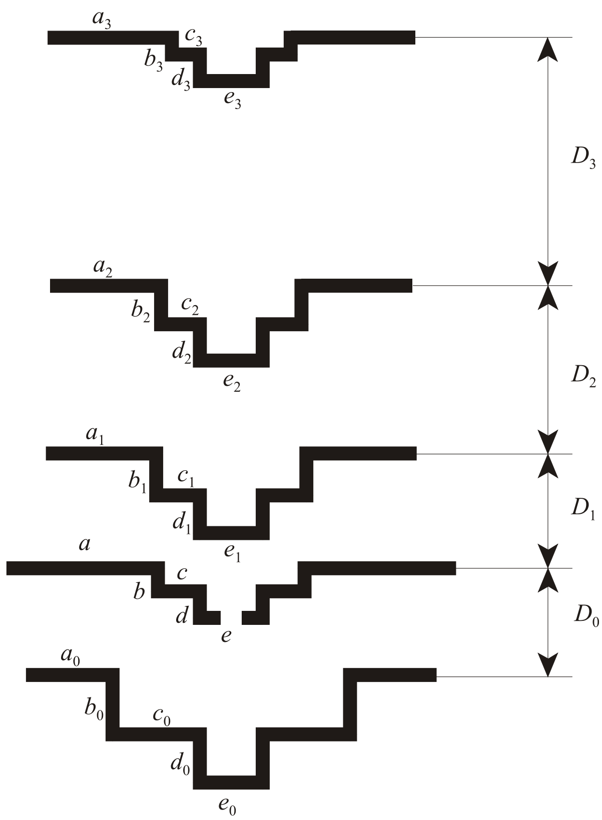

Fig. 3. Proposed modified fractal antenna design.

A real antenna model based on simulation results is prepared of copper plane lines. The lines width is 5.5 mm, as the equal wave impedance of wires in simulated model and plane lines in real one to be achieved (Fig. 4).

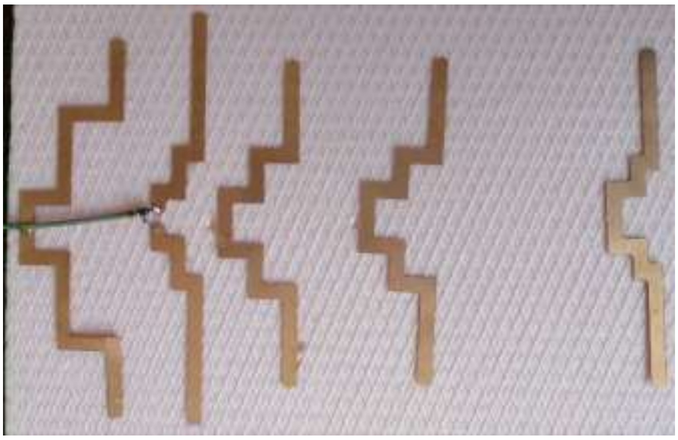

Fig. 4. Experimental model of fractal Yagi antenna.

Simulated and measured SWR of the proposed Modified Minkowski curve Fractal Yagi Antenna are displayed in Fig. 5. It is obvious that the accuracy of the simulation versus that of experimental model is 2,1 %. This could be explained with the usage of plane lines and inaccuracy in preparation of the real model. Fig. 5 shows a operating frequency band from 795 to 960 MHz or bandwidth of 165 MHz (18,9%) for the simulated model and from 807 to 962 MHz or bandwidth of 155 MHz (17,5 %) for the real one and 15,6 % for conventional one (simulated) with the same wire diameter. In interval 981-989 MHz SWR < 2 which gives opportunities with additional adjustment of antenna elements wider operating band to be achieved.

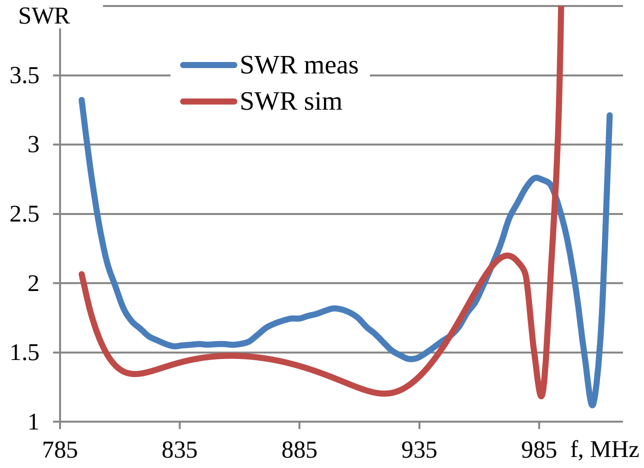

Fig. 5. SWR of experimental and simulated model of fractal Yagi antenna.

Despite of classical Yagi-Uda antenna the proposed Minkowski curve fractal Yagi antenna has also second resonance from 2522 MHz to 2665 MHz – 143 MHz or 5,51 % operating frequency band.

The antenna gain and F/B ratio for the simulated model are given in Fig. 6. The antenna gain is between 7.5 dBi and 9.77 dBi for the whole operating band while for the simulated classical Yagi antenna with straight elements (radiating in free space) is higher as could be expected - between 8.45 dBi and 9.34 dBi. The F/B ratio in the operating frequency band is higher than 12.12 dB while for classical antenna is over 11.68 dB.

The radiation patterns in the H and V plane for frequencies of 795 MHz, 890 MHz and 960 MHz are shown on Fig.7, Fig. 8 and Fig. 9 respectively. For these frequencies the antenna has a pattern similar to that of the classical Yagi-Uda antenna with a gain of 7,87 dBi, 7,96 dBi and 9,71 dBi for three frequencies. The beamwidths at half power for H plane are ±42°, ±40° and ±36.5° respectively and ±29°, ±27° and ±28° for E plane. F/B ratios for these three frequencies are 15,15 dB, 18,83 dB and 12,12 dB respectively.

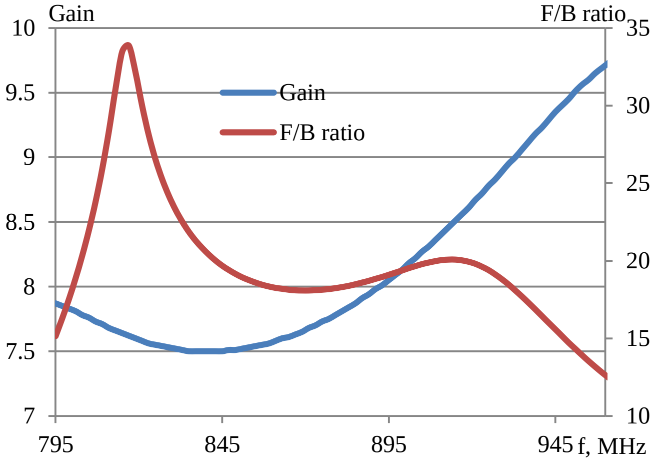

Fig. 6. Gain and F/B ratio of simulated model of fractal Yagi antenna.

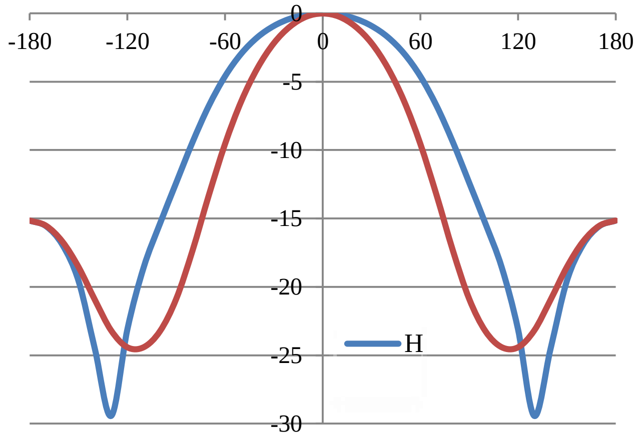

Fig. 7. Simulated radiation pattern of fractal Yagi antenna – H and E plane – 795 MHz.

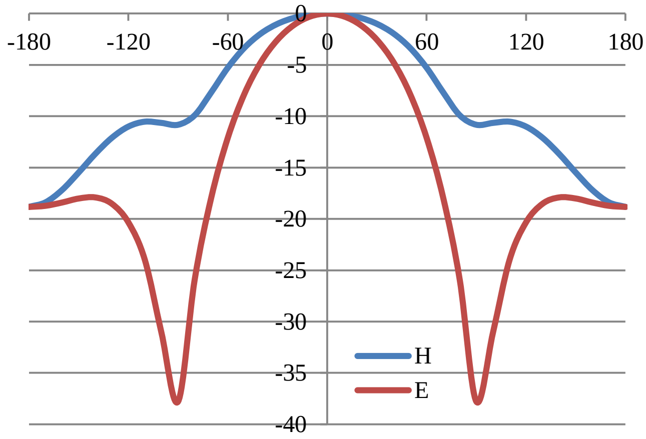

Fig. 8. Simulated radiation pattern of fractal Yagi antenna – H and E plane – 890 MHz.

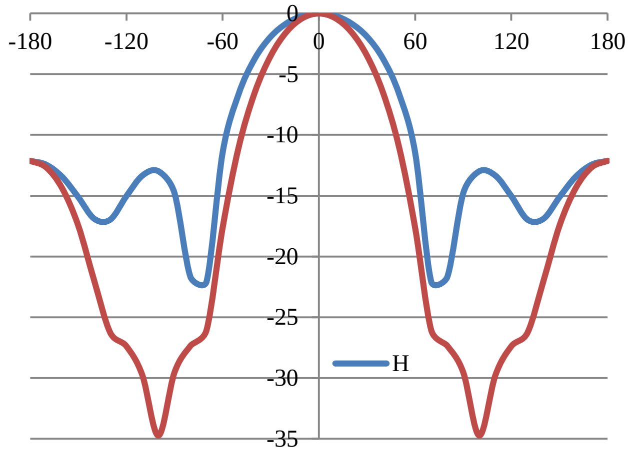

Fig. 9. Simulated radiation pattern of fractal Yagi antenna – H and E plane – 960 MHz.

IV. CONCLUSIONS

A Yagi-Uda antenna with elements shaped as modified Minkowski fractal has been developed and examined in this study. It shows typical fractal antenna and Yagi-Uda antenna features with wideband performance enhanced by some new elements in the design – central element of first order fractal is developed to second order. The second advantage of the fractal Yagi-Uda antenna is the dual-band performance. The Modified Fractal Antenna is also more compact and has very good electrical performance, which makes it a viable option to be used in practical applications. It can be used as standalone antenna for point-to-point and point-to-multipoint applications as well. The innovative approach chosen for the antenna modification can lead to further developments in this still relatively new area of antenna design.

ACKNOWLEDGMENT

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