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ARTICLE

ON INFLUENCE OF TURNING THE KOCH FRACTAL DIPOLE ARMS ON ITS BASE FREQUENCY AND BANDWIDTH

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ABSTRACT

A dipole wire antenna of the Koch is considered. The antenna represents a wire dipole symmetrical with respect to the point of feeding. Arms of the dipole have the geometry of Koch prefractal. A family of antennas is singled out, in which the antennas differ from each other by an angle of arms turning. Antennas having the geometry of the first two iterations of a Koch curve are chosen for the analysis. Dipoles based on the Koch pre-fractals of the first two iterations having different wire thicknesses obtained by rotating one of the arms around a given coordinate axis is considered. Graphs depicting dependence of the base frequency and bandwidth for the frequency on angles of rotation around the axes are presented. Rotations of the dipole arms by small angles do not exert influence on the frequency and bandwidth. However, in the case of large angles of the arms rotation, the values of base frequency increase and bandwidth reduce significantly.

KEY WORDS
Koch antenna, base frequency, bandwidth, arms rotation, influence of turning.

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INTRODUCTION

A classical symmetric electric dipole containing two identical arms fed in the middle represents one of the most well explored objects in the theory of antennas [1]. There exist various methods of improvement of electrodynamic characteristics of such dipoles [2]. For example, the improvements can come from varying an angle between the arms and obtaining the so-called V-shaped antennas [3] as well as from mutual influence of radiation originating from the arms on each other. Another method of improvement of the symmetric dipole's characteristics is related to placing the arms in an antisymmetric manner. The method was applied in [4] for improving several resonance characteristics of the classical Koch and quadratic Koch fractal dipole antenna; the study also compared the obtained antennas with each other. A dual-band dipole antenna with asymmetric arms was presented in [5] for WLAN applications.

For improving the electrodynamic characteristics of dipoles, modification of the ratio of sizes (areas) of the dipole's arms is also utilized. For example, study [6] considered a dipole antenna consisting of two printed strips of unequal lengths and presented graphs for reflection coefficients and radiation patterns of the proposed antenna. The wide operating band is obtained at the fundamental and second resonances of the rod dipole by using manipulations related to changing the feed [7]. A balanced-to-unbalanced transformer or balun is also often used [8]. The study [9] considered a printed dipole antenna with a microstrip balun and demonstrated an influence of sizes of the balun on return loss. In the study [10], inductive load was added for reducing the base frequency.

Multiple folded arms are can also used. The studies [11, 12] considered antennas consisting of an axially symmetric array of four and six conductor arms forming a spherically shaped structure and demonstrated influence of increase in the number of arms on quality factor and bandwidth.

For reducing the sizes of the dipoles, one can alter topology of the arms, so that the electric length of the antenna increases, while radius of the sphere covering the dipole remains unchanged. For that purpose, one can roll the arms into a helix [13, 14] or perform various fractal transformations [15]. In this regard, the following antennas can be specified: an antenna which is based on the Koch curve [16, 17], Minkowski curve [18, 19], Sierpinski carpet [20, 21], a rounded fractal antenna [22, 23] and complex fractal combinations [24-26].

Characteristics of the dipole can be further improved by rotating its arms in space with respect to each other. For example, properties of the Koch dipole during rotating the arms in one plane (in the antenna's plane) were studied in [27]. In the present study, we analyze the effect of rotation of the Koch dipole's arms around its axes on base frequency and bandwidth. We investigate changes in such basic properties of the antenna as base frequency and bandwidth on angles of rotation around the axes. As a result, we present graphs and draw the relevant conclusions.

STATEMENT OF THE PROBLEM

The first fractal antenna, whose electromagnetic and directional properties were studied most completely and extensively, was the antenna based on the pre-fractal Koch curve. When constructing a Koch line, the initial interval of length L_0, referred to as an initiator of the fractal, is split into three equal parts. The central part is replaced with an equilateral triangle having sides of length L_0/3. As a result, there appears a broken line consisting of four links; each of the links has length L_0/3 [Fig. 1]. The process is carried out for each segment of the broken line.

We consider symmetric dipoles based on the Koch pre-fractal (DBKP) of the first two orders. The zeroth order DBKP coinciding with the ordinary dipole is shown in [Fig. 1(a)], the first order DBKP is shown in [Fig. 1(b)] and the second order DBKP is shown in [Fig. 1(c)]. The feed point for all the dipoles is located exactly in the middle.

We assume that initially the antenna lies in the plane {z=0}. We rotate the right arm in space relative to the starting position [Fig. 2]. Moreover, we consider three sub-problems, each of which represents rotation around a particular axis [Fig. 2(a)-(c)].

We seek base frequency and bandwidth (S_11<-10 dB) of the obtained new dipoles by rotating an arm. It should be noted that rotation around the x-axis does not influence electromagnetic characteristics in vicinity of the base frequency. A difference shows up only at higher frequencies in vicinity of the second resonance. The same conclusion regarding comparison of the symmetric and antisymmetric dipoles was drawn in [4]. Therefore, we will hereafter explore only rotations around the y-axis and z-axis.

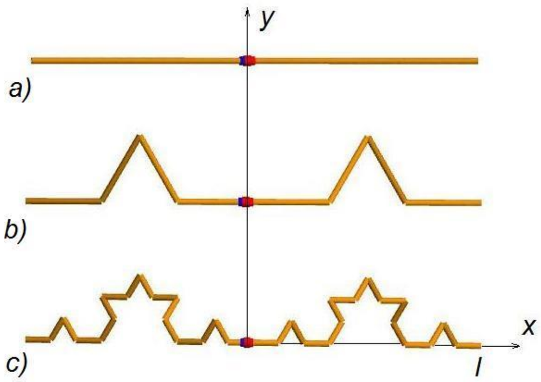

Fig. 1: Symmetric Koch fractal dipole. Arm length l=7.5 cm, wire radius r=1 mm. a) zeroth-order dipole (ordinary dipole); b) first-order dipole; c) second-order dipole.

Calculations in the present work were carried out using the FEKO software. In all cases, length of the segment partitions was selected to be five times greater than radius. It was assumed that the wire was made of copper of a circular cross-section. Main calculations were conducted for wires having radiuses equal to r=1.0 mm, r=1.5 mm and r=2.0 mm.

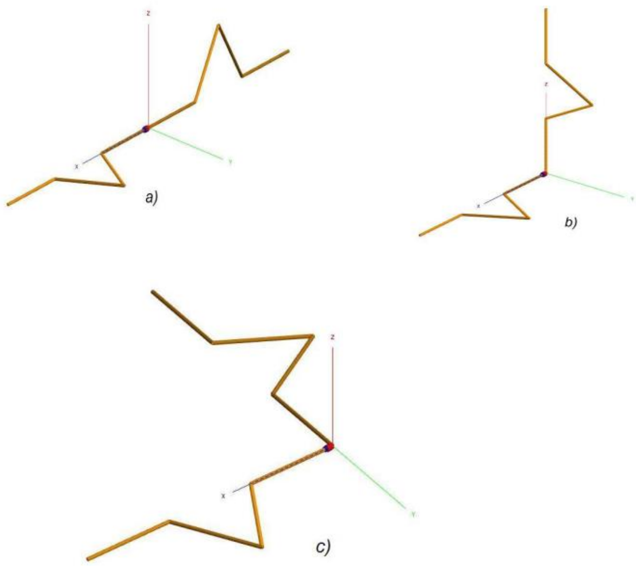

Fig. 2: Options for rotation of an arm around the axes: a) rotation around the x-axis (twisting); b) rotation around the y-axis; c) rotation around the z-axis.

For numerical implementation, we perform cycles with angle steps equal to 1-2 degrees. For determining the resonance angles with high accuracy, we decrease the angle step size to 0.01 degrees and frequency step size to 10 kHz.

BASE FREQUENCY OF THE DIPOLE

One of the main advantages of the fractal antenna is the increase of its electrical length, while its linear dimensions remain unchanged. For example, length of the Koch curve L_m increases for every new m-th iteration in line with formula [28]

$$L_m = \left(\frac{\;}{\;}\right) \quad L_0 , \qquad (1)$$

where L_0 is length of the initial curve. This reduces base frequency f_m while maintaining the linear dimension l unchanged.

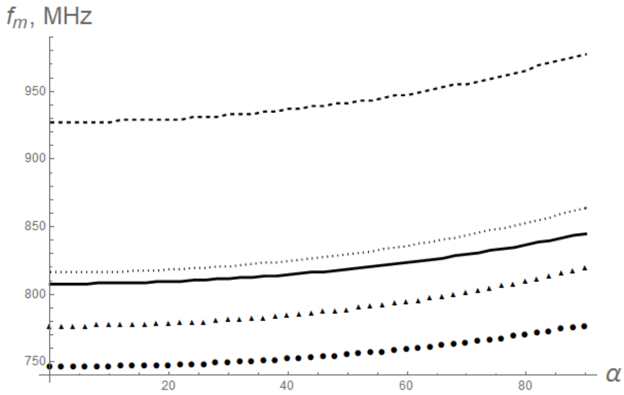

Fig. 3: Dependence of f_m on α. The solid line corresponds to r=1.0 mm and the DBKP of the 1st order; the dotted line – r=2.0 mm and the DBKP of the 1st order; circles – r=1.0 mm and the DBKP of the 2nd order; triangles – r=2.0 mm the DBKP of the 2nd order. The dashed line – the ordinary dipole with r=1.0 mm. l = 7.5 cm.

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Graphs presented in [Fig. 3 and 4] serve as a proof for this particular statement. Here, the dashed lines in the figures correspond to the ordinary dipole (DBKP of the zeroth order); the continuous lines corresponds to the DBKP of the 1st order, and the circles correspond to the DBKP of the second order. These three graphs are drawn for the wire of radius r=1 mm. It can be seen that base frequency of the dipoles decreases with increase in electrical length of the arms. For example, for symmetric position of the arms, f_0 decreases from 927 MHz corresponding to the ordinary dipole to 746 MHz corresponding to the 2nd order DBKP.

Rotation of an arm of the ordinary dipole having radius r=1 mm around the y-axis in the interval of α∈(0^∘,90^∘) leads to a monotonic increase in base frequency f_0 from 927 MHz to 977 MHz. For the 1st order DBKP, variation of base frequency occurs in the range from 808 MHz to 845 MHz, while for the 2nd order DBKP, variation occurs in the range from 746 MHz to 776 MHz. Thus, increase in the angle α leads to a continuous increase in base frequencies for all types of the considered dipoles [Fig. 3]. At increasing the dipole geometry's complexity, difference between the values of f_m at α=0^∘ and α=90^∘ becomes smaller. For the classical dipole, the frequency f_m decreases by 50 MHz; for the 1st order DBKP, the difference decreases and makes 37 MHz; for the 2nd order DBKP, the difference drops even further and makes 30 MHz.

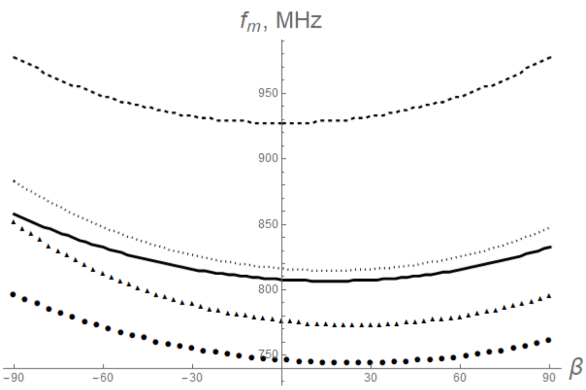

Fig. 4: Dependence of f_m on β. The solid line corresponds to r=1.0 mm and the DBKP of the 1st order; the dotted line – r=2.0 mm and the DBKP of the 1st order; circles – r=1.0 mm and the DBKP of the 2nd order; triangles – r=2.0 mm the DBKP of the 2nd order. The dashed line – the ordinary dipole with r=1.0 mm. l = 7.5 cm.

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Radius r of the wire also affects resonance frequency. Values of f_m increase with increase of r. For the 1st order DBKP having an arm of length l=7.5 cm, for a change in radius from 0.5 mm to 2.0 mm, one can obtain the following relation expressed using dimensionless variables:

$$f_1(d) \approx f_1(0.5) + 12(d - 0.5)^{0.7} = 800.5 + 12(d - 0.5)^{0.7}, \quad (2)$$

where r is expressed in mm while the resulting value of f_1 is expressed in MHz. For the 2nd order DBKP, the dependence takes the form

$$f_2(d) \approx f_2(0.5) + 42(d - 0.5)^{0.8} = 721.1 + 42(d - 0.5)^{0.8}. \quad (3)$$

Comparison of the formulas (2) and (3) with each other shows that increase of r leads to a significant increase of f_m for pre-fractals of higher orders. This be confirmed by analyzing the distances between the solid line and the dotted line (for r=1 mm) and the distances between circle signs and triangle signs (for r=2 mm) in [Fig. 3] and [Fig. 4].

In rotating the arm around the z-axis, a change in f_m follows a slightly more different pattern. For the 1st order DBKP, rotation by a negative angle (β<0) significantly increases base frequency from 808 MHz to 858 MHz. At the same time, rotation by a positive angle, at first, slightly reduces f_m down to the minimum value f_m≈807 MHz at 10^∘<β<22^∘. A further increase in the angle β leads to increase in base frequency up to the value f_m≈833 MHz at β=90^∘.

A quite similar pattern is also observed for the 2nd order DBKP. In this case, the minimum value of base frequency is achieved at the angle values in the range 12^∘<β<36^∘; at β=0^∘, the values decrease from 746 MHz to 744 MHz.

As a result of analysis of the base frequency values f_m, it can be concluded that rotations of the dipole arms by small angles do not exert influence on the frequency. However, in the case of large angles of the arms rotation, the values of base frequency f_m increase significantly. For a more complete understanding of the dependence of frequency on angles of rotation, you can use regression analysis on a number of other parameters [29, 30].

DIPOLE BANDWIDTH

We assume that the frequency range near the base frequency f_m, in which S_11<-10 dB, is, indeed, the bandwidth BW. In rotation around the y-axis by small angles (α<40^∘), width of the frequency range for the ordinary dipole behaves differently than for the DBKP. For the ordinary dipole, bandwidth increases with increase in the rotation angle from 86 MHz to 93.3 MHz at α≈64^∘, then decreases again and reaches its initial value at α=90^∘. For the DBKP, values of BW always decrease with increase in α [Fig. 5] and β [Fig. 6].

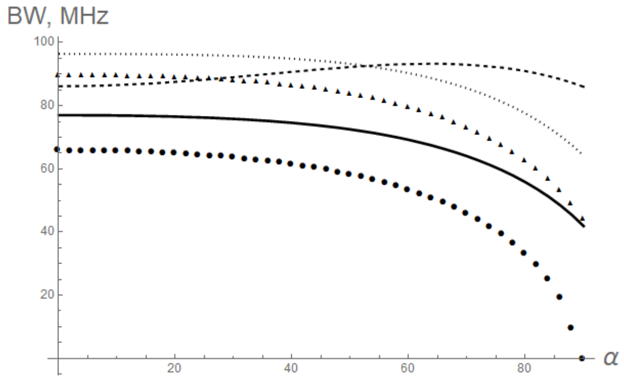

Fig. 5: Dependence of BW on the rotation angle α of the arm around the y-axis relative to the normal dipole. The solid line corresponds to r=1.0 mm and the DBKP of the 1st order; the dotted line – r=2.0 mm and the DBKP of the 1st order; circles – r=1.0 mm and the DBKP of the 2nd order; triangles – r=2.0 mm and the DBKP of the 2nd order. The dashed line – the ordinary dipole with r=1.0 mm. l = 7.5 cm.

Narrowing of the frequency range is insignificant for small angles of rotation (α<40^∘) around the y-axis. For example, for the 1st order DBKP, the value decreases from 77 MHz to 74.5 MHz for r=1.0 mm, and from 96.5 MHz to 95 MHz for r=2.0 mm. For the 2nd order DBKP, dispersion of the intervals becomes slightly more discernible at r=1.0 mm with the values decreasing from 66 MHz to 61.5 MHz; at r=2.0 mm, the values decrease from 90 MHz to 86.5 MHz.

After passing the value α=40^∘, the BW values decrease more significantly. For example, for the 1st order DBKP, the interval width decreases (at α→90^∘) down to 42 MHz and 64 MHz for r=1.0 mm and r=2.0 mm, respectively. For the 2nd-order DBKP, the interval width decreases down to 0 MHz and 44 MHz for the same values of r, respectively.

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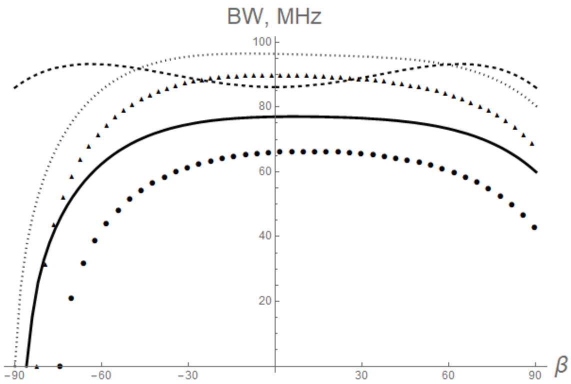

Fig. 6: Dependence of BW on the rotation angle β of the arm around the z-axis relative to the normal dipole. The solid line corresponds to r=1.0 mm and the DBKP of the 1st order; the dotted line – r=2.0 mm and the DBKP of the 1st order; circles – r=1.0 mm and the DBKP of the 2nd order; triangles – r=2.0 mm and the DBKP of the 2nd order. The dashed line – the ordinary dipole with r=1.0 mm. l = 7.5 cm.

In rotation around the z-axis, the bandwidth behavior remains identical to that observed in rotation around the y-axis. The BW values slightly decrease in rotation by a small angle. Decrease in BW becomes significant with a further increase in the angle β.

Let us consider a change for the 1st order DBKP. A dipole having radius 1 mm does not have a bandwidth at the angles β<-86^∘. If β∈(-28^∘,50^∘), slight variations are observed in the bandwidth: BW∈(75 MHz, 77 MHz). For a dipole having r=2 mm, the bandwidth disappears only at β=-90^∘. An approximate 2 MHz-spread of the maximum bandwidth BW∈(94.3 MHz, 96.4 MHz) occurs at nearly the same values of the angle β∈(-32^∘,50^∘).

For the 2nd order DBKP, the pattern is very similar. The critical angle β, below which "the antenna does not work", is approximately -74^∘ for a wire of radius r=1 mm and -82^∘ for a wire of radius r=2 mm. Small variations in bandwidth occur within the interval BW∈(62 MHz, 64 MHz) at β∈(-18^∘,43^∘) and within the interval BW∈(88 MHz, 90 MHz) at β∈(-27^∘,45^∘).

Thus, small rotations around the y-axis within the angle range α<40^∘ slightly reduce the bandwidth. Rotations around the z-axis in the range -20^∘<β<40^∘ reduce BW by no more than 2 MHz. In large angle rotations, the bandwidth reduces significantly.

CONCLUSION

Rotations of the arms around their own axis (the x-axis) do not exert any influence on electromagnetic characteristics in vicinity of the base. The main effects occur in rotation around the axis of the feed line (y-axis) as well as in the antenna's plane (z-axis). Rotations of the dipole arms by small angles around the y-axis and the z-axis do not affect the resonance frequency. In the case of large angle rotations of the arms, the resonance frequency values increase significantly. Small rotations around the y-axis by the angle within the range α<40^∘ reduce slightly the bandwidth. Rotations around the z-axis by the angle in the range -20^∘<β<40^∘ reduce the bandwidth by no more than 2 MHz. At larger angles of rotation, the bandwidth becomes significantly narrower. It should be noted that rotation around the z-axis can be considered as more advantageous because it is carried out in the plane of the antenna, and rotations around the z-axis can be generalized to the case of the micro strip antennas.

In most cases, the turns of the antennae leads to a slight increase in the values of the base frequency and a decrease in the bandwidth. However, turning the arms at small angles does not significantly change the frequency and bandwidth. This fact can be useful if other electrodynamic characteristics when turning will improve.

CONFLICT OF INTEREST

There is no conflict of interest.

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FINANCIAL DISCLOSURE

None

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