Fractal Designed Antennas Matching

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Abstract – **This study describes an experimental research of a fractal designed antenna matching. Several antenna prototypes shaped as Koch's curves have been made for the performing of measurements. The optimal dimensions and the value of the antenna input reactance have been specified using the theory of planned experiment.**

Keywords – **Fractal Antennas, Koch's curve, Antenna Matching.**

I. Introduction

The Fractals are geometric objects that are not subject to ordinary rules of Euclidean geometry. Despite of their widespread deployment in nature, they receive serious scientific attention in the last quarter of last century (Benoit Mandelbrot introduced the concept of fractal in 1975). The Fractal has a number of interesting characteristics, among which the self-similarity and infinite particularity that is independent of scale and diverse spatial dimension. It is these interesting features of the fractal shaped antenna systems that lead to the interesting features of the antennas themselves. Multi-band reception / transmission are a direct consequence of self-similarity and the variable spatial dimension determines the decreasing physical size of antennas. The listed accents determine the interest of many authors in this subject [1] [2] [3] [4]. It would be of practical interest to determine the possibility of using such antenna systems in contemporary radio apparatus, and for the purpose parameters such as resonant frequencies, input impedance, etc. should be evaluated. The objective of this work is to explore the input impedance and the impedance matching of fractal antenna.

II. Description of the Problem

A. Theoretical basis

The Koch's curve is one of the most typical representatives of the so-called deterministic fractals. It is obtained by a recursive process, using a generator that replaces the base of each iteration. The generator and the base are shown in Figure 1 and curves of the first three iterations - in Figure 2.

Fig. 1. Base and Generator of Koch's Curve Fractal

The fractal dimension is **ln 4 / ln 3 ≈ 1.26**. The base of the Koch's curve is a straight line, which then allows the comparison of the experimental data with those for the quarter-wave dipole.

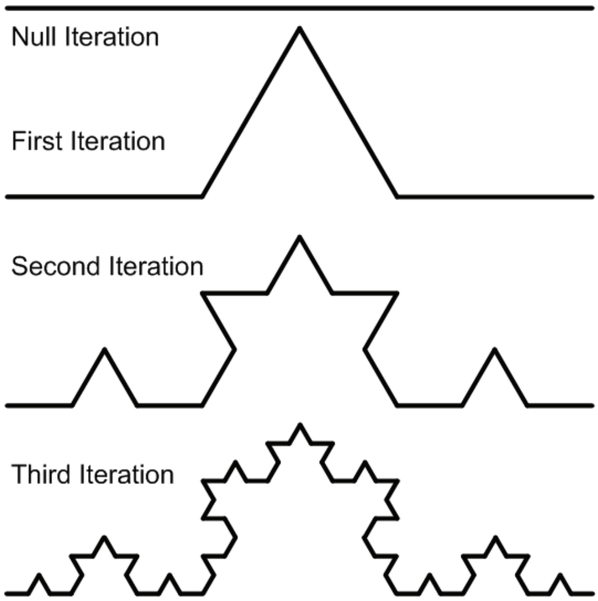

Fig. 2. Koch's Curve Fractal (initial iterations)

B. Experimental

Experimental data were obtained by testing of models of antenna with shape of curve of the first iteration shown in Figure 2. The experiments were made on the stand, whose block diagram is given in Figure 3. Through directional diverter the direct wave is separated from the reflected wave and a scalar analyzer is used to examine the value of the standing wave ratio (SWR). The dipole power occurs through

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capacitive element (capacitor), which serves to compensate the reactive component of its input impedance.

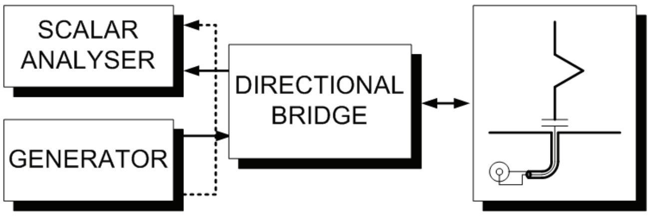

Fig. 3. Experimental Model Diagram

To achieve better matching of the antenna for a given frequency it is necessary to vary the magnitude of the capacitor and the dimension of the radiating element. Such optimization can be done using the theory of planned experiment [5]. The task comes to a full factorial experiment with two factors, ranging on three levels. Nine separate tests should be performed and the alteration of the SWR parameter within the bounds of the factorial space can be defined. This dependence is given by the expression [5]:

$$Y = b_0 + b_1.x_1 + b_2.x_2 + b_{12}.x_1.x_2 + \\ + b_{11}.x_1^2 + b_{22}.x_2^2 , \quad (1)$$

where, by x_1 and x_2 the two factors that determine the alteration of the parameter ***Y*** are denoted. In the present case these are the length ***l*** of one arm of the radiating element and the value of the capacity of the capacitor ***C***, which are presented in Figure 4.

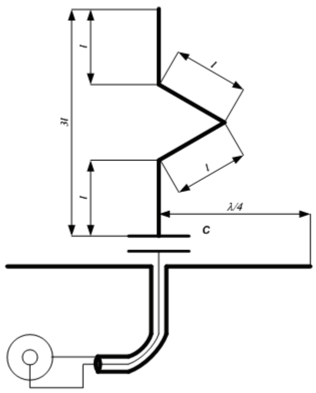

Fig. 4. Prototype dimensions

The figure shows the schematic representation of the experimental prototype. The emitting element is placed on stand, which has a horizontal metal plane made of conductive metallic plate. The dimensions of the plate are chosen to ensure a minimum distance of a quarter of the operating wavelength in all horizontal directions. Thus the antenna system of the type Ground Plane is realized; this system has a corresponding fractal copy as a dipole.

The parameter ***Y*** in formula (1) is the SWR in the supply feeder. The coefficients b, that give the weight of impact of individual factors and combinations of factors are determined by the relations [5]:

$$b_0 = \frac{5}{9}\sum_{j=1}^{9} x_{0j}.\bar{y}_j - \frac{1}{3}\sum_{i=1}^{2}\sum_{j=1}^{9} x_{ij}^{2}.\bar{y}_j , \quad (2)$$

$$b_i = \frac{1}{6}.\sum_{j=1}^{9} x_j.\bar{y}_j , \quad (3)$$

$$b_{ik} = \frac{1}{4}.\sum_{i=1}^{2}.\sum_{j=1}^{9} x_{ij}.x_{kj}.\bar{y}_j , \quad (4)$$

$$b_{ii} = \frac{1}{2}.\sum_{i=1}^{2}\sum_{j=1}^{9} x_{ij}^{2}.y_j - \frac{1}{3}\sum_{j=1}^{9}\bar{y}_j , \quad (5)$$

III. Results

For the purposes of the experiment the resonant frequency of the antenna is considered to be 434 MHz; this frequency is included in one of the ISM bands within the band of decimal waves (UHF). The order of the size of the antenna and the value of the capacity of the capacitor are determined by a rough preliminary experiment. Based on these initial data, the planned levels of ranging of the factors are chosen and the relevant values are listed in Table 1.

Table I

Vary Levels	x_1	x_2
-1	52,5 mm	1,2 pF
0	55,0 mm	2,4 pF
+1	57,5 mm	3,6 pF

Nine experimental tests were performed with different combinations of values for the factors. The values of SWR for each case have been measured. The results are shown in Table 2.

TABLE II

i / j	x_1 / l, mm	x_2 / C, pF	Y_E
1	+1 / 57,5	+1 / 3,6	3,00
2	+1 / 57,5	0 / 2,4	1,46
3	+1 / 57,5	-1 / 1,2	8,25
4	0 / 55,0	+1 / 3,6	1,50
5	0 / 55,0	0 / 2,4	2,40
6	0 / 55,0	-1 / 1,2	15,70
7	-1 / 52,5	+1 / 3,6	3,74
8	-1 / 52,5	0 / 2,4	10,50
9	-1 / 52,5	-1 / 1,2	35,00

From Equations (2), (3), (4) and (5) the coefficients reflecting the influence of individual factors, as well as the combination of them upon the alternating of the parameter ***Y***, can be derived. The concrete values are given in Table 3.

TABLE III

b_0	2,2589
b_1	-8,4517
b_2	-6,0883
b_{12}	6,5025
b_{11}	6,4117
b_{22}	3,7917

From the values of the coefficients it can be noted, that with increasing of the length ***l*** and the value of the capacitor ***C***, the value of SWR decreases. On the other hand there is a straight proportional impact of these factors in the second degree, as that of the value of capacitor ***C*** is twice less than that of the length ***l***. The straight proportional mixed influence, reflected by the coefficient b_{12} is also significant

Using Equation (1) the dependency of the parameter ***Y*** within the factorial space, can be built, which in this case is given by the expression:

$$Y = 2{,}2589 - 8{,}4517.x_1 - 6{,}0883.x_2 + \\ + 6{,}5025.x_1.x_2 + 6{,}4117.x_1^2 + 3{,}7917.x_2^2 . \qquad (6)$$

Figure 5 depicts the dependency (6), obtained using the software MatLab [6].

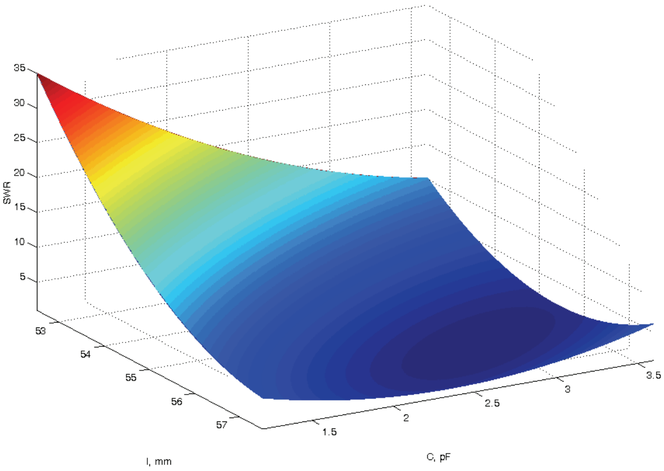

Fig. 5. Model Visualization

Several checks were made of the model (6) for determination the significance of the coefficients and the adequacy of the model. Using the criterion of W. G. Cochran it was proved that all coefficients in the model are significant. Therefore, to assess the adequacy of the model the t-criterion of Student (W. S. Gosset) is applied, with which the ***t*** value was calculated using the formula:

$$t = \frac{|Y_0 - b_0|\sqrt{m}}{\sqrt{\frac{1}{m}.\sum_{j=1}^{m} S_{Y_j}^2}} , \qquad (7)$$

where:

Y_0 – the value of the parameter for null coded values of the factors (sample j=5);

m – number of samples;

S_{Yj} – dispersion of the values of the parameter within the bounds of individual sample.

The values of the parameter of empirical data Y_E and the corresponding values Y_M obtained by model (6) are given in Table IV. In the same table the values of dispersion S_{Yj} of the parameter within the individual sample are presented, which are calculated by the formula:

$$S_{Y_j} = Y_{E_j} - Y_{M_j} . \qquad (8)$$

TABLE IV

j	Y_E	Y_M	S_{Yj}
1	3,00	6,27	-3,27
2	1,46	1,86	-0,46
3	8,25	10,12	-1,87
4	1,50	2,11	-0,61
5	2,40	4,13	-1,73
6	15,70	18,81	-3,11
7	3,74	5,44	-1,7
8	10,50	13,89	-3,39
9	35,00	35,00	0

The values of parameter Y_M are normalized, as it is assumed that its lower level is equal to the lowest possible value of SWR, thus avoiding the irregular values for SWR <1.

The calculated value for the criterion of Student is $t = 0,197$. The verification on inequality $t = 0,197 < t_{0,02;9} = 2,821$ proves that the model (6) is adequate. The value $t_{0,02;9} = 2,821$ is taken from table [5].

The result of performed experiment and the obtained model localize an extremum of the alternation of parameter ***Y***. For values of the factors $x_1 = 0,420$ and $x_2 = 0,445$ that correspond to the length of the one arm of the radiating element $l = 56,05$ ***mm*** and capacity value of the capacitor $C = 2,935$ ***pF*** the minimum for the value of the SWR is obtained at frequency of ***434 MHz***. This means that at these values for the factors, the antenna will have the best emitting properties. Taking into consideration the operating frequency we can find the relative dimensions of the antenna as parts of the operating wavelength. For the length ***l***, the value $l = 0,0811.\ \lambda$ is obtained. In that way the reactive component of the input impedance of the antenna can be determined. Considering that the capacitor is connected in series with the radiating element, then for the resonant frequency of the antenna radiation their reactive components compensate each other. Accordingly, the reactive component of the input impedance is equal to the impedance of the capacitor, but with reverse mark. From the obtained data, it follows that this component has inductive character and a value determined by the dependency:

$$X_a = +j\frac{1}{2\pi fC} = +j124,95\Omega\ . \qquad (9)$$

IV. CONCLUSION

As a result of the performed studies, based on the theory of the planned experiment, an optimization of the dimensions of the fractal antenna is achieved as well as of the capacity of the matching capacitor. A value $0,0811.\lambda$ was determined for the length of one arm of the fractal element. The value $-j124,95\Omega$ was also determined as the impedance for the matching reactive element. The achieved local extremum - minimum of the SWR parameter can be realized with technological feasible values of the factors.

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