Franklin Monopole Antenna with Different Iteration Fractal Elements

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***Abstract* — In this study a possibility of antenna implementation with elements in shape of fractal curves that form different iterations has been considered. The Franklin antenna as a monopole is the root form in which the main arms are replaced with shapes of first and/or second iteration Koch curves. An optimization, using the design of experiment theory has been made in order to discover the optimal dimensions of the different antenna structures from matching at chosen frequency perspective. The results from simulations with different parameters, such as antenna gain, HPBW, frequency bandwidth, common dimensions etc. have been compared.**

Keywords—Fractal Antenna; Koch's curve; Diferent Iteration Shapes; Matching Optimization; Design of Experiment;

I. Introduction

Nowadays different approaches to implement antennas with varied parameters and characteristics have been examined. There are many options in this aspect, one of which is to use the so-called fractal antennas in order to achieve beneficial improvements, such as multiband features, decreased dimensions, bigger bandwidth, and others [1][2][3].

It is attractive to include fractal elements in the structure of more complex antennas, such as antenna arrays [4][5], and observe the overall behavior. In this study a linear antenna array with series excitation, better known with the popular name Franklin Antenna, has been chosen for making research of its parameters and characteristics in the case of replaced dipole elements with fractal structures. A good shape for this purpose has the Koch's curve [6] as it is possible to replace different elements with shapes from different iteration. It is possible also to achieve axial radiation, instead of omnidirectional, with excitation of individual element with the appropriate phase of the wave. This can be done with the help of adjusting the phasing stubs that separate the elements.

In this article the results from simulations of antennas with different combination types of fractal elements have been presented. For further experimental research the antennas' matching is optimized in advance to ISM frequency of 433.92 MHz but the attained results can be applied for other frequencies due to the principle of electromagnetic similarity. Also, the antennas are observed as planar structures in order to make possible their accomplishment in printed circuit board (PSB) and/or other planar implementations.

II. Issue Description

A. *Fractal Franklin antenna structures*

The main Franklin antenna consists of several radiating dipole elements, separated with phasing stubs. An overview of the antenna can be seen on Fig. 1.

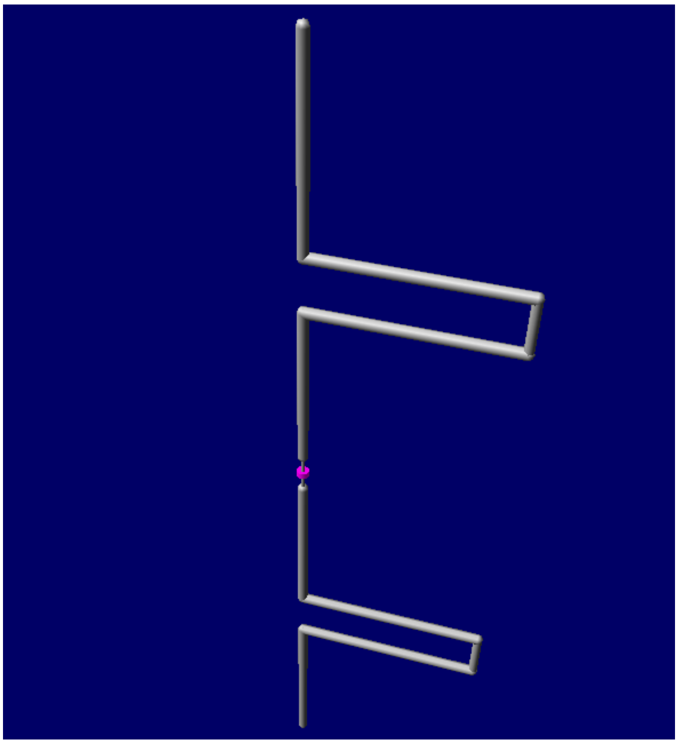

Fig. 1. Overview of a linear antenna array with series excitation (Franklin antenna)

In case of axial radiation pattern the antenna has two maximums of the radiation pattern in direction of the two arms of the antenna. If the antenna is fulfilled as a monopole antenna, as shown on Fig.2, the maximum of the radiation pattern is one. This type of structure is called with code name ’00’ for easier recognition further in the article.

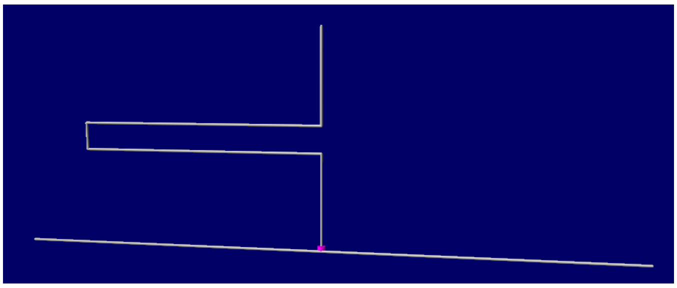

Fig. 2. Franklin antenna monopole (Type code 00)

Fig. 3 and Fig. 4 show the observed antennas with substituted elements with fractal structures.

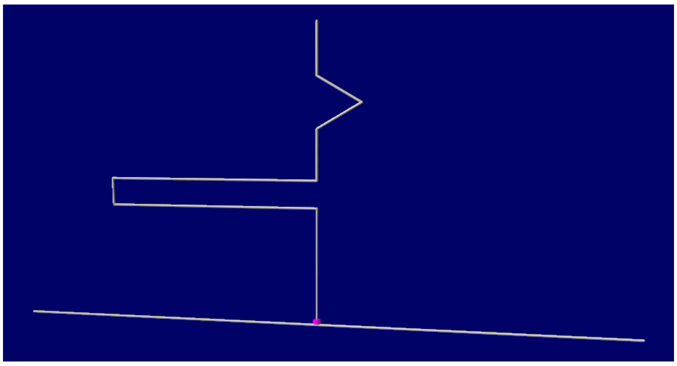

Fig. 3. Antenna with elements from zero and first iteration (code name 01)

The structure on Fig. 3 contains one straight element, which can be observed as a zero iteration of a Koch’s curve and one element from first iteration (structure code name ‘01’).

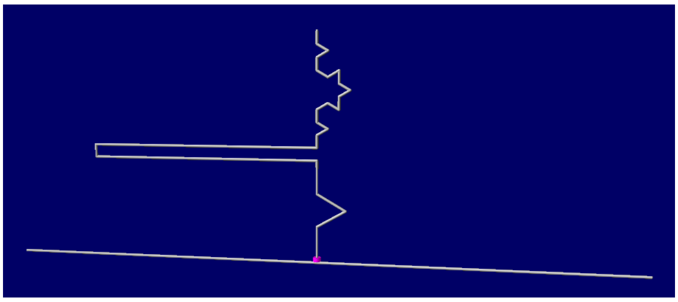

Fig. 4. Antenna with elements from first and second iteration (code name 12)

The structure on Fig. 4 contains one element from first and one from second iteration of Koch’s curve and has a code name ‘12’.

B. Matching the antennas

The antenna structures shown in Fig. 2, Fig. 3 and Fig. 4 need to be matched on the same frequency in order to compare their parameters and characteristics. Such optimization can be achieved with the help of the design of experiment theory. This analytical description can present the behavior of a given parameter in relation to the factors from which it depends. In this case the factors ***x1*** and ***x2*** are the dimensions of the different fractal elements, represented by coefficients ***k11*** and ***k12***. It is necessary to conduct full factorial experiment type 3^2, in which two factors are varied on three levels and the parameter against which the optimization is made has been read. In this case it is appropriate for the parameter ***Y*** to be the antenna matching represented by the standing wave ratio (SWR) at 433.92 MHz. Based on the data generated in nine attempts in a planned experiment type 3^2 this analytical dependence has the form [7]:

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

The coefficients ***b***, where ***i,k = 1,2***, are defined according to the following laws:

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

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

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

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

Fig. 5 shows the structures of the observed antennas with marked dimensions for better illustration. In fact, the optimization through the described above planned experiment has been made on the coefficients ***k11*** and ***k12***, which represent the relative segment length of the fractal elements referred to the quarter wavelength ***λ/4***.

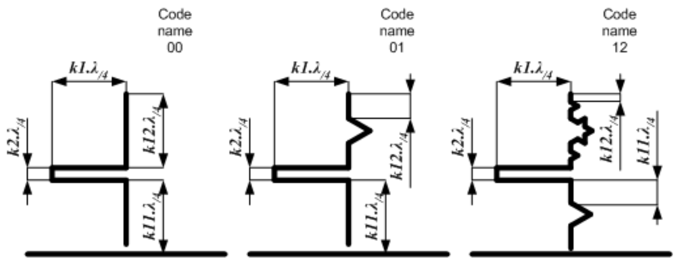

Fig. 5. Dimensions of antenna structures

III. Results

A. Matching optimization

By means of previous basic tests and taking into account that the length of the individual radiating elements should be in the order of $\lambda_{/4}$ the values for the variation of the coefficients ***k11*** and ***k12*** into the factor space are defined in advance. The exact values vs. coded values of ***x1*** and ***x2*** are given in Table I.

TABLE I. FACTOR VARIATION LEVELS

Code Variation Level	Antenna code name 00		Antenna code name 01		Antenna code name 12	
	k11	*k12*	*k11*	*k12*	*k11*	*k12*
+1	0,40	0,40	0,48	0,22	0,132	0,050
0	0,38	0,38	0,45	0,20	0,131	0,049
-1	0,36	0,36	0,42	0,18	0,130	0,048

In Table II are given the values for the optimization parameter (in this case SWR) for the nine different samples of each antenna structure.

TABLE II. EXPERIMENTAL MATCHING VALUES

N	Coded Place in factorial space		SWR		
	k11	*k12*	*Antenna code name 00*	*Antenna code name 01*	*Antenna code name 12*
1	+1	+1	1,57	2,41	1,25
2	+1	0	1,31	1,26	1,11
3	+1	-1	1,09	1,75	1,08
4	0	+1	1,31	1,86	1,20
5	0	0	1,09	1,10	1,06
6	0	-1	1,12	2,40	1,11
7	-1	+1	1,10	1,41	1,18
8	-1	0	1,11	1,49	1,09
9	-1	-1	1,36	3,23	1,16

Through the data from Table II the models according to (1) are estimated. The coefficients of these estimations are given in Table III.

TABLE III. COEFICIENTS FOR THE PLANNED EXPERIMENT'S MODELS

	Antenna code name 00	Antenna code name 01	Antenna code name 12
b_0	1,11444	1,19111	1,07222
b_1	0,06833	-0,28333	0,04667
b_2	0,06667	-0,11833	0,00167
b_{12}	0,18500	0,62000	0,03750
b_{11}	0,08833	0,89333	0,07667
b_{22}	0,08333	0,13833	0,02167

On Fig. 6, Fig. 7 and Fig. 8 is presented the overview of the parameter behavior, estimated with MatLab [8] in the considered factor space for each type antenna structure.

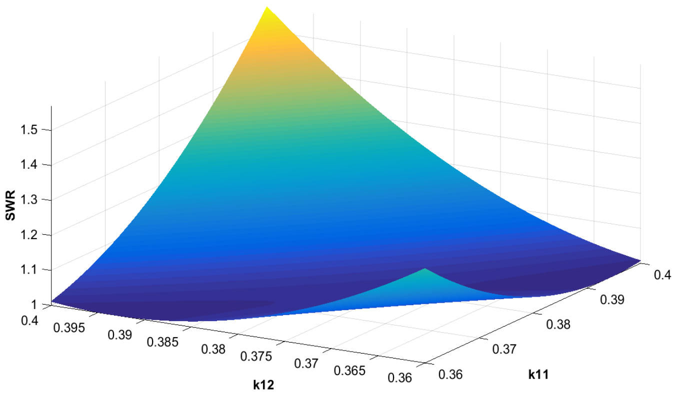

Fig. 6. Model for antenna code 00

Based on the behavior of parameter in the factorial space the optimal points have been found. This defines the values for coefficients ***k11*** and ***k12*** for each antenna structure.

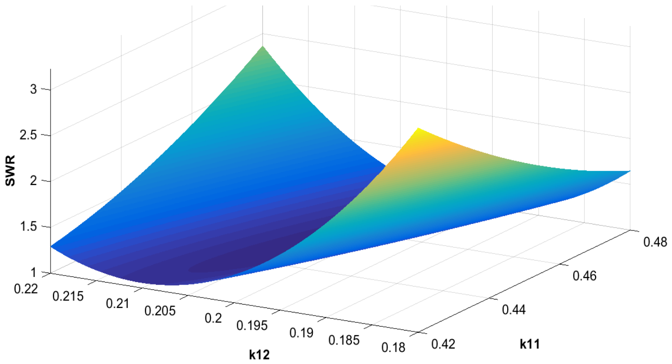

Fig. 7. Model for antenna code 01

The exact values, received through the optimization, are given in Table IV.

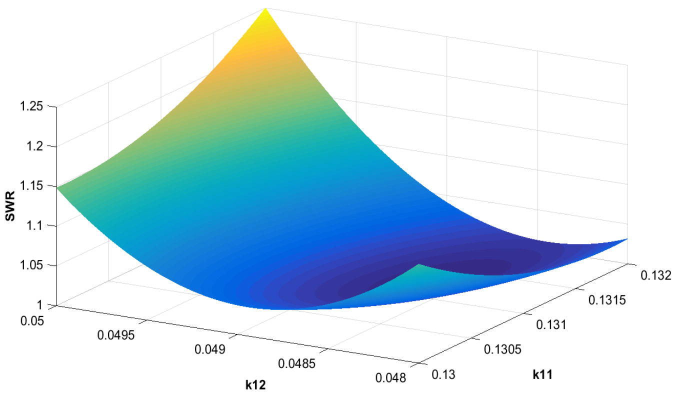

Fig. 8. Model for antenna code 12

Table IV also shows the parameters of the phasing stubs, which are defined again in relative units in reference to the quarter wavelength $\lambda_{/4}$. These are the coefficients ***k1*** and ***k2***, which define the length and the width of the stubs respectively (see Fig. 5). Their values are optimized for the observed frequency too.

TABLE IV. OPTIMISED ANTENNA DIMENSIONS

	Antenna code name 00	Antenna code name 01	Antenna code name 12
k11	0,37912	0,45559	0,13082
k12	0,37912	0,19905	0,04917
k1	0,98273	0,84551	0,91278
k2	0,10904	0,10904	0,05000

B. *Antenna properties*

With the optimized antenna structures a number of simulation has been ran in order to determine the antenna parameters, such as gain, half power beam width (HPBW), frequency bandwidth (BW), dimensions, etc. Table V contains the values of these parameters.

TABLE V. OPTIMISED ANTENNA DIMENSIONS

Values @ 433,92 MHz	Antenna code name 00	Antenna code name 01	Antenna code name 12
SWR, -	1,01	1,11	1,09
BW, % *(@ SWR<2)*	3,11	3,34	2,88
G, dBi	3,67	3,42	3,56
HPBW, deg *(@ -3dB)*	75	75	70
Front to Back, dB	3,38	3,77	3,51
Higth of the Antenna, mm	149,9	200,8	152,9

From the data it is visible, that the antennas have similar behavior, but by increasing the curve grade, the beam width goes narrow. The dimensions of antenna type with code names 00 and 12 are almost equal (the difference is just 3 mm), but the radiation pattern of the second antenna is more focused (75 vs. 70 deg) The frequency bandwidth is also narrower (3,11 vs. 2,88 %). Fig. 9, Fig. 10 and Fig. 11 show the 3D radiation pattern for each antenna.

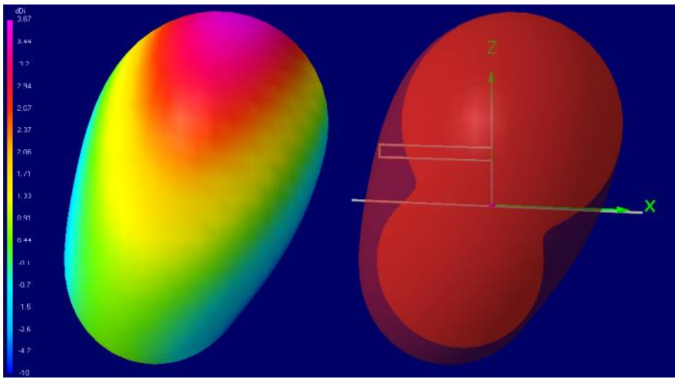

Fig. 9. 3D Radiation pattern for antenna code 00

Antennas with this type of parameters can be used in narrow band frequency communications with applications with high integration grade, such as RFID and Access Control systems. The specific radiation patterns can be useful in case of spot orientated short distance data transfer and to minimize the interference between devices operating at the same frequency in little space area.

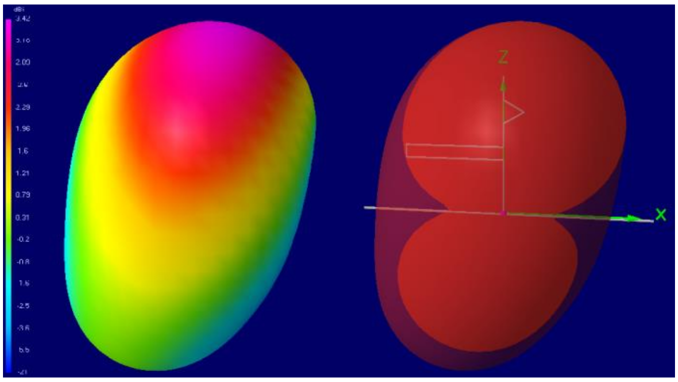

Fig. 10. 3D Radiation pattern for antenna code 01

From fig. 9 – 11 can be seen, that the radiation pattern for the antenna type with code name 01 and 12 have less radiation in the X-Y plane, which is better in case of implementing a spot zone in the direction of Z-axis.

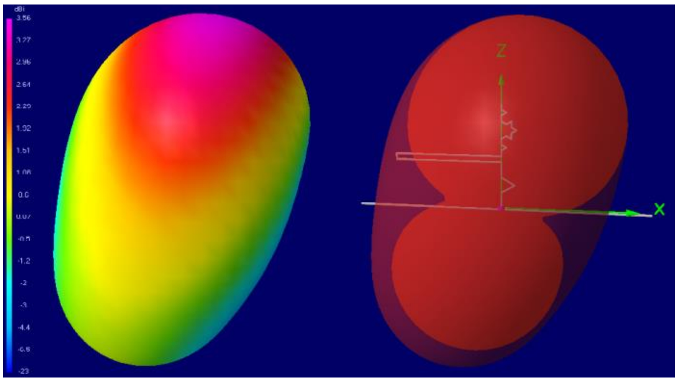

Fig. 11. 3D Radiation pattern for antenna code 12

IV. CONCLUSION

In this study an observation of antennas contained different iteration fractal elements has been made. From the results can be seen, that:

- the proposed structures can be precisely matched and achieved similar results as Gain, HPBW, F/B and dimensions;
- the planar type of this antennas gives the opportunity to implement them in PCB or other flat structures;
- it is appropriate to study furthermore this type of structures in order to achieve other useful parameters.

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