Fractal Koch Dipole Antenna

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الخلاصة:

تعتبر هندسة الكسوريات ذات فائدة كبيرة في التصميم الهندسي للهوائيات بشكل عام ولهوائي ثنائي القطب بشكل خاص. إن الاستفادة التي يمكن تحقيقها من استخدام نموذج كوخ كثنائي قطب هو تقليل الارتفاع لهوائي ثنائي القطب الكلاسيكي عند التردد الرنيني.

تم إجراء الحسابات لهوائي ثنائي القطب بالاعتماد على أساسيات الهندسة الكسورية وأظهرت النتائج انه بالإمكان تقليل الارتفاع الكلي لهذا الهوائي كما أظهرت تحسنا في خصائص الموائمة الممثلة بعامل الانتقائية (SWR) ، أما الاتجاهية ومعامل الكسب فقد بقيت ثابتة إلى حد ما.

Abstract:

It is well established that fractal geometry is of benefit in the design of antennas in general and dipole antenna in particular. The benefit of using fractal Koch as a dipole antenna is to miniaturize the total height of the classical antenna at resonance.

Calculations based on fractal geometry are made for the classical dipole antenna. Results indicate that it is feasible to reduce the total height of the classical dipole and improve the matching properties represented by (SWR) ratio, while the gain and directivity remain slightly constant.

1. Introduction:

Fractal is a term coined by Mandelbrot in 1975 while studying irregular shapes [1]. Fractal objects have two common properties: **self-similarity** that means the object has many copies of itself at several scales, and **fractal dimension**, which represents the space-filling properties of the object [2,3].

Fractals have wide varying applications. As far as the technological applications of fractals are concerned the field of antennas has witnessed a surge of activity in the last few years.

In this area, the most important fractal application is fractal antenna design. Fractal antennas are very useful tools to solve two of the limitations of classical antennas, the single band performance and the dependence of antenna's size on the operating frequency [4].

The first scientist to work in this field was Cohen, N. at Boston University. He published his first article " Fractal Antennas " on 15August 1995 [5]. Few months later, Puente, C. at University of Catalonia, Barcelona in Spain published papers about fractal antennas [6,7]. Fractal electrodynamics is a research area connecting the fractal geometry and electromagnetic theory, the term was coined by Jaggard, D.L. [8].

In this study, we start with a dipole antenna that is resonant at 1900 MHz as a zero iteration of Koch model. It is known from previous studies in this field if the height of the antenna is held constant, the resonant frequency decreases as the number of iteration increases and If the resonant frequency is held fixed, miniaturization of antenna height is possible.

However, most of previous studies dealing with the investigation of the possibility of height reduction as a result of Koch fractalization of the classical dipole antenna used very small radius which make the designed antenna impractical. Also, the previous studies did not investigate the radiation pattern of the fractalized dipole and hence did not make clear suggestion as regard the areas of application. Besides, no mention of antenna gain was made in previous studies.

To this end, the present work has been performed to address these issues. The rest of the paper is organized as follows. In section (2) a

description of the main ideas and tools of the computer simulation techniques are given.
Section (3) describes the algorithm for the generation of the Koch fractal that will be used in the present work. Section (4) presents the result obtained in the present work. Finally, the main conclusions are presented in section (5).

2. Computer Simulation Technique.

Method of Moments is a numerical method for solving integral equations. The general form of this equation is [9]:

$$\int I(z')K(z,z')dz' = -E^{i}(z) \quad \ldots\ldots\ldots\ldots(1)$$

The kernel K(z, ź) depends on the specific integral equation formula. The procedure of moments' method is, reducing this integral equation to a system of linear algebraic equations in terms of the unknown current I(ź). Most electromagnetic radiation problems are expressed as integral equations with a source term on the right hand side and the unknown within the integral.
Total sharing of the electric field over the wire volume is :-

$$\vec{E}_z = \frac{1}{j\omega\varepsilon_0}\iiint\left[\frac{\partial^2\psi(z,z')}{\partial z^2} + \beta^2\psi(z,z')\right]Jdv' \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$\beta^2 = \omega^2\mu_0\varepsilon_0$
$\psi(z,z')$ is the free space green function [10]

If we assume the conductivity is infinity, then the current is confined to the surface of the wire and by considering the distribution of the current as uniform with respect to (φ), then equation (2) is reduced to a line integral of current [11].

$$\vec{E}_z = \frac{1}{j\omega\varepsilon_0}\int_{-L/2}^{L/2}\left[\frac{\partial^2\psi(z,z')}{\partial z^2} + \beta^2\psi(z,z')\right]I(z')dz' \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where: L is the wire length.

We can set the quantity ($\bar{E}_z$) in equation (2) as the scattered field ($\bar{E}_z^s$) that is radiated by the equivalent current I(z'). There is also the incident field ($\bar{E}_z^i$)

at the surface of a perfectly conducting wire, and the sum of the scattered and incident fields must be zero, i.e., $\vec{E}_z^s = -\vec{E}_z^i$

Thus, equation (2) becomes:

$$\frac{1}{j\omega\varepsilon_0}\int_{-L/2}^{L/2} I(z')\left[\frac{\partial^2\psi(z,z')}{\partial z^2}+\beta^2\psi(z,z')\right]dz' = -\vec{E}_z^i(z) \;\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

This equation was derived by Pocklington [9] and it is equivalent to equation (1). The expansion functions are a stair step approximation to the current distribution on the wire.

$$\int_{-L/2}^{L/2} I(z')K(z_m,z')dz' \approx I_1 f(z_m,z_1') + I_2 f(z_m,z_2') + \ldots + I_n f(z_m,z_n') + \ldots + I_N f(z_m,z_N') \approx -E_z^i(z_m)$$

$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (5)

The physical interpretation of this equation is illustrated in figure (3)

From the computed currents we can calculate the radiation pattern of the simulated antenna by using the standard far field approximations [11,12]:

$\vec{E} = -j\omega\vec{A}$ ………………….(6)

$\vec{H} = \frac{j\omega}{\eta}\times\vec{A}$ ………………….(7)

where $\eta = \sqrt{\frac{\mu}{\varepsilon}}$ ……………….(8)

$$A(r) = \frac{\mu}{4\pi}\frac{e^{-j\beta r}}{r}\int_s J(r)e^{-j\beta r}ds \;\ldots\ldots\ldots(9)$$

3. <u>Fractal generation</u>:

For the Koch fractal, the generator is a straight segment that has been broken into three pieces of equal size. The middle one is removed and replaced by two segments equal in size to the removed one, these two segments are fit into the gap in an equilaterally triangular fashion [13,14] as shown in figure (1).

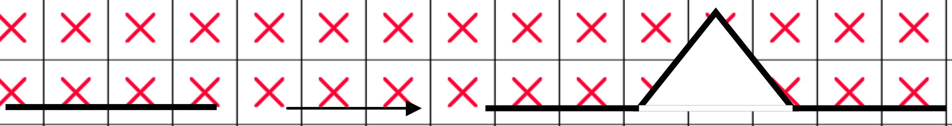


Figure (1): Koch generator

The total length of the generator is one third longer than it has previously. If the process is carried out for an infinite numbers of times, Koch model will have an infinite length while the height will not change [15,16]. The total length of Koch model is given by [17] and is given by:

$L_{Koch} = h(4/3)^n$ ……… (10)

where h is the height of the starting generator and n is the number of iterations. This algorithm has been translated into a computer program written in FORTRAN 90.

4. <u>Results:</u>

The initial height of the dipole is chosen to be (7.5 cm) and its diameter (0.5 mm) and connected to 50 Ω coaxial cable. These dimensions make the dipole resonant at 1900 MHz, which make it applicable in the wireless communication band.

To make all fractal Koch iterations resonant at the same frequency, scaling each iteration is required. The relative height and length of the dipole and the three iterations of fractal Koch fractal is given in table (1):

Table (1): Relative height and length of Koch fractal

Iteration	Height (cm)	Length (cm)
0	7.5	7.5
1	6.47	8.63
2	6.12	10.83
3	6	14.28

The following figure shows the relative heights of Koch dipole for different iterations, w

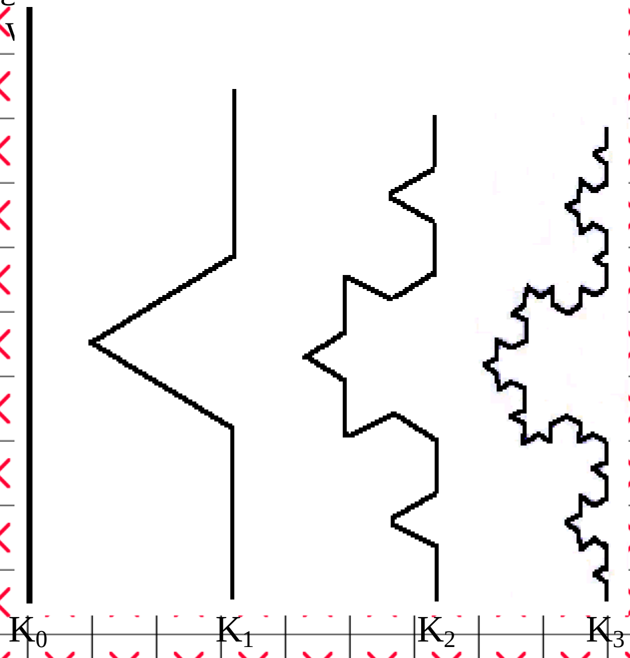


Figure (2): Relative heights of fractal Koch dipole

The following figures represent the standing wave ratio **(SWR)** and Smith chart for fractal Koch iterations which are represented by the symbols K_0, K_1, K_2 and K_3 respectively.

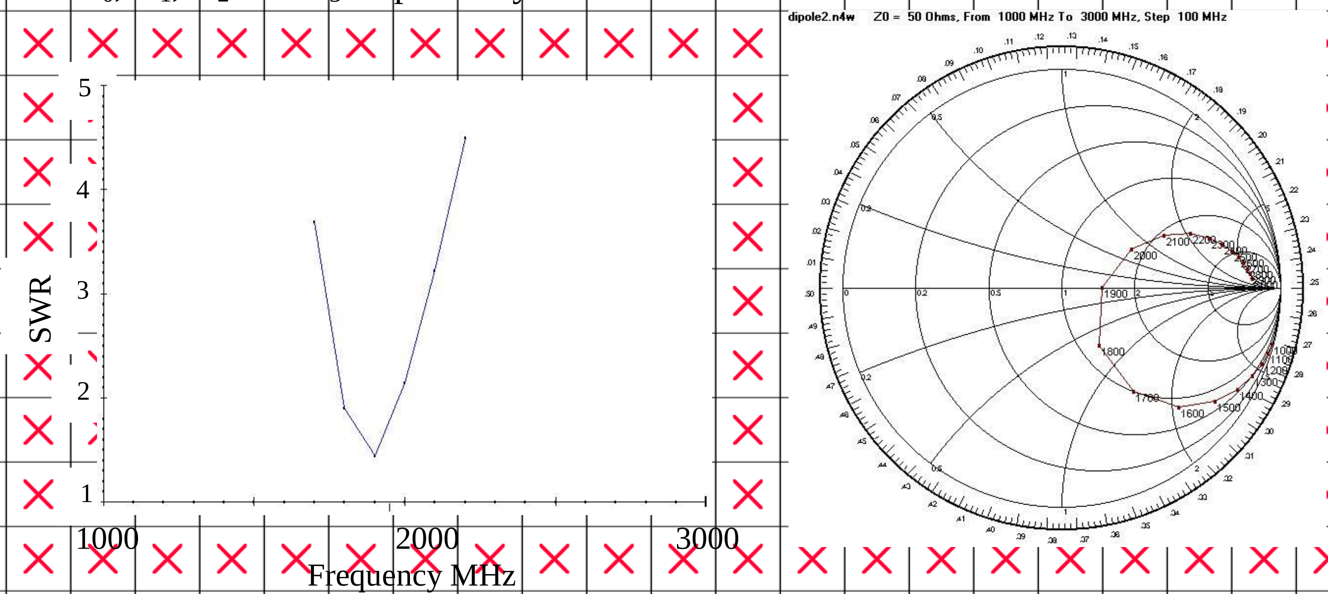


Figure (3): SWR and Smith chart for K_0

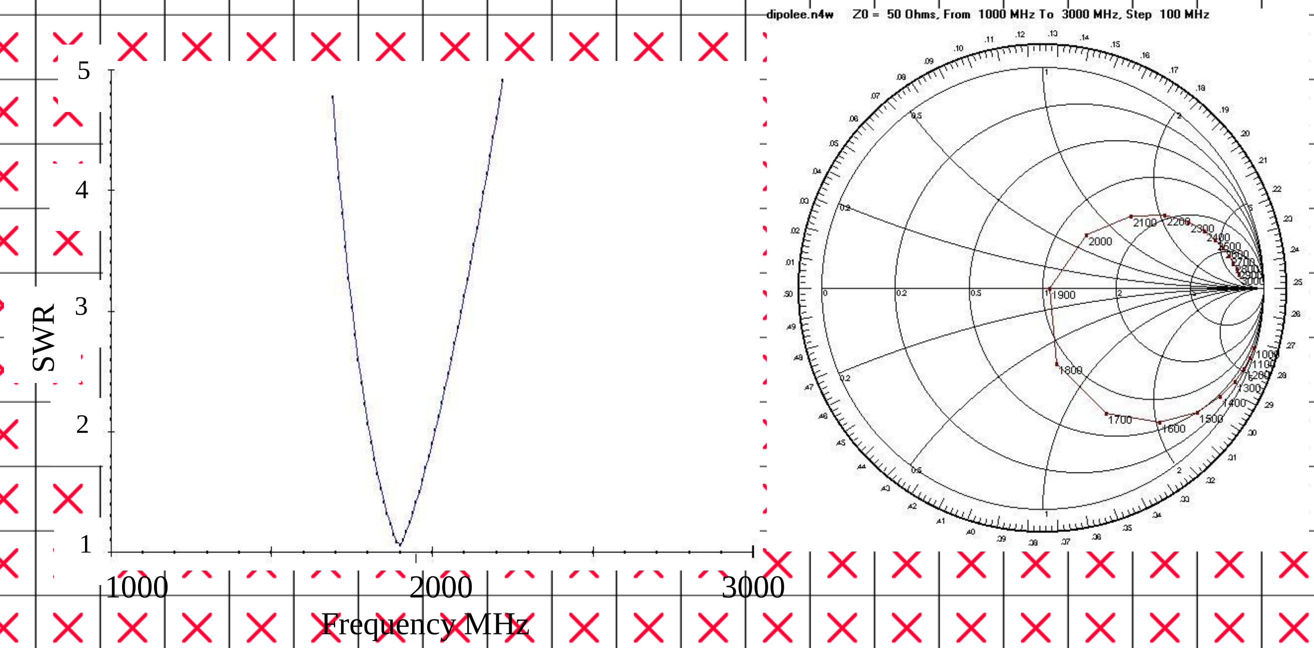


Figure (4): SWR and Smith chart for K_1

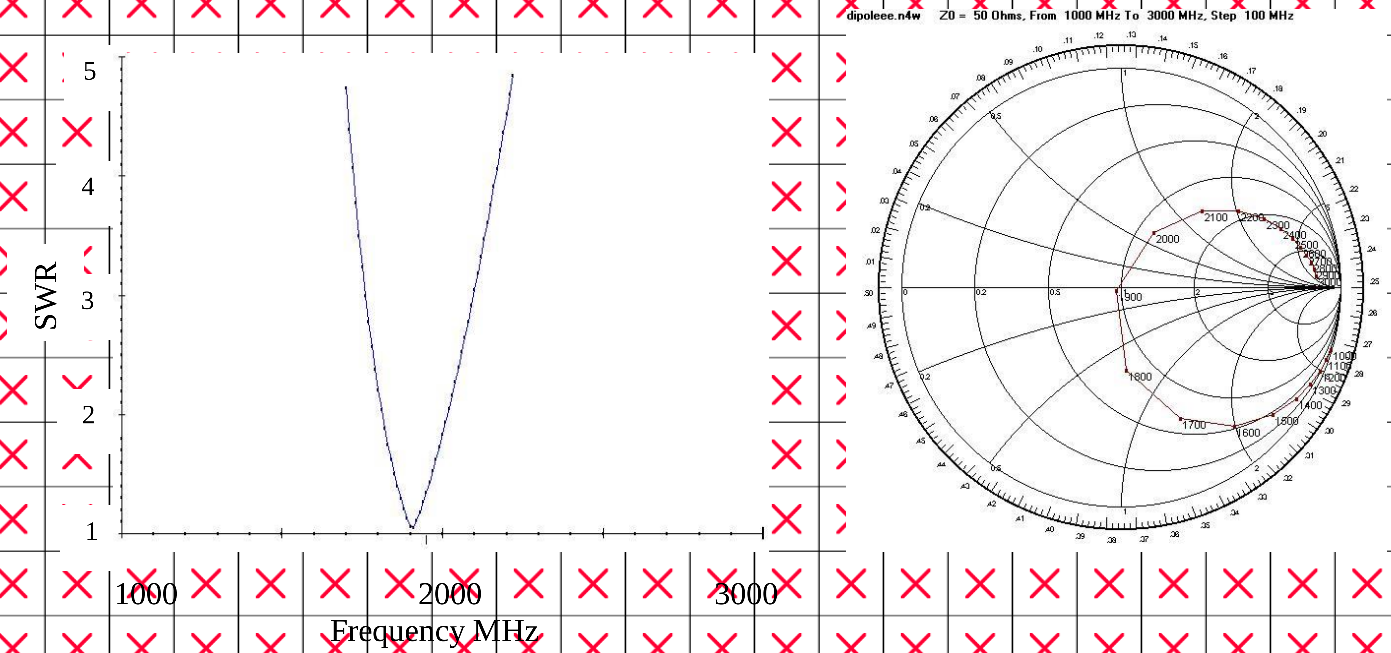
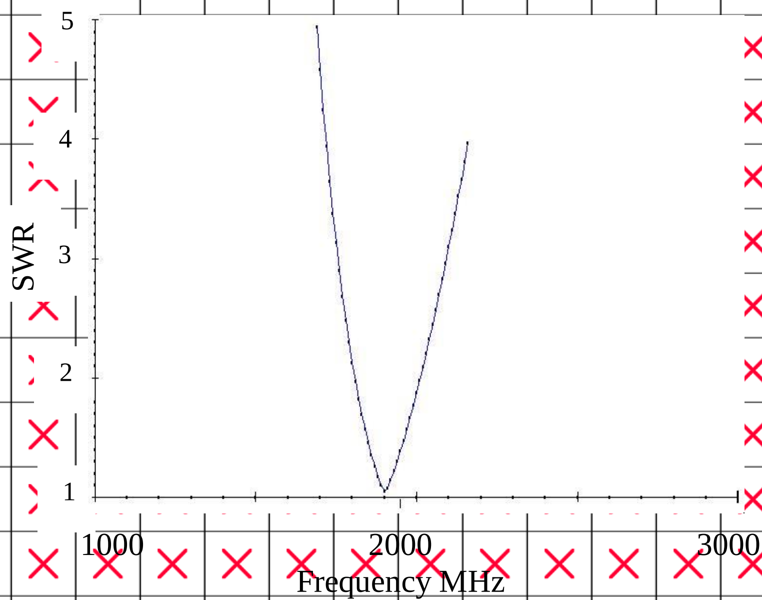


Figure (5): SWR and Smith chart for K_2



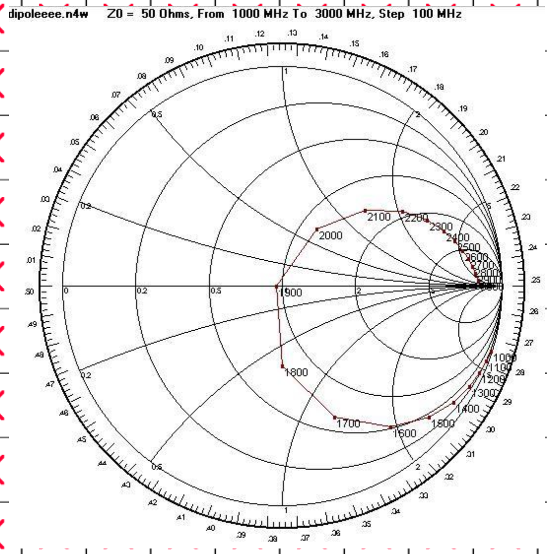
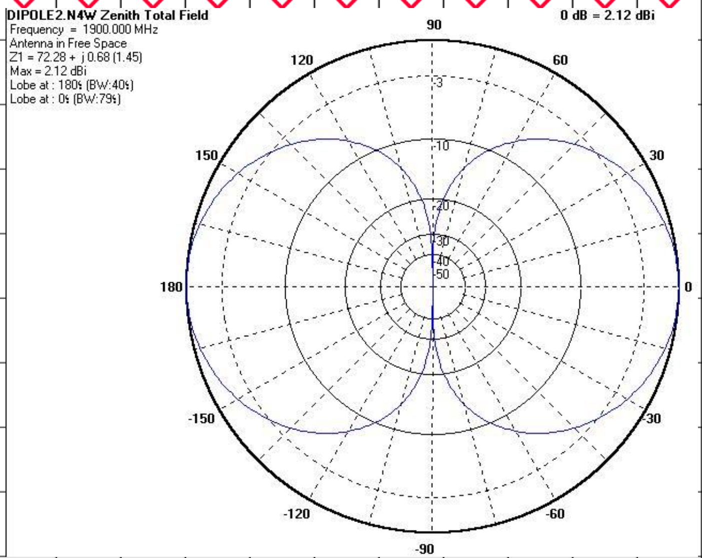
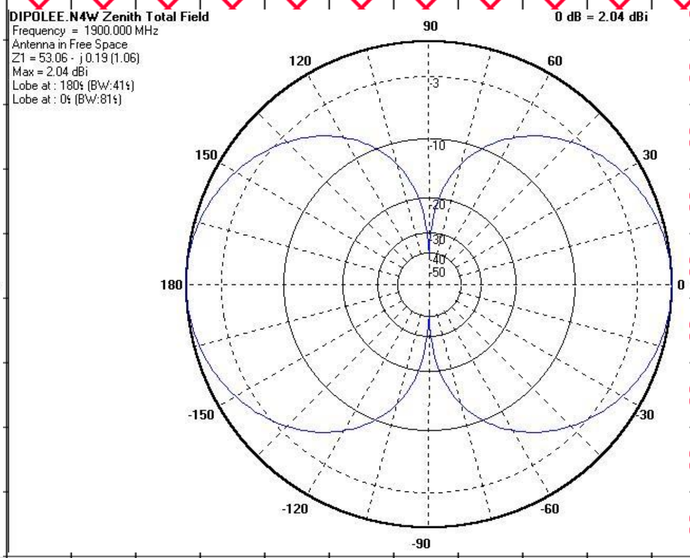


Figure (6): SWR and Smith chart for K_3

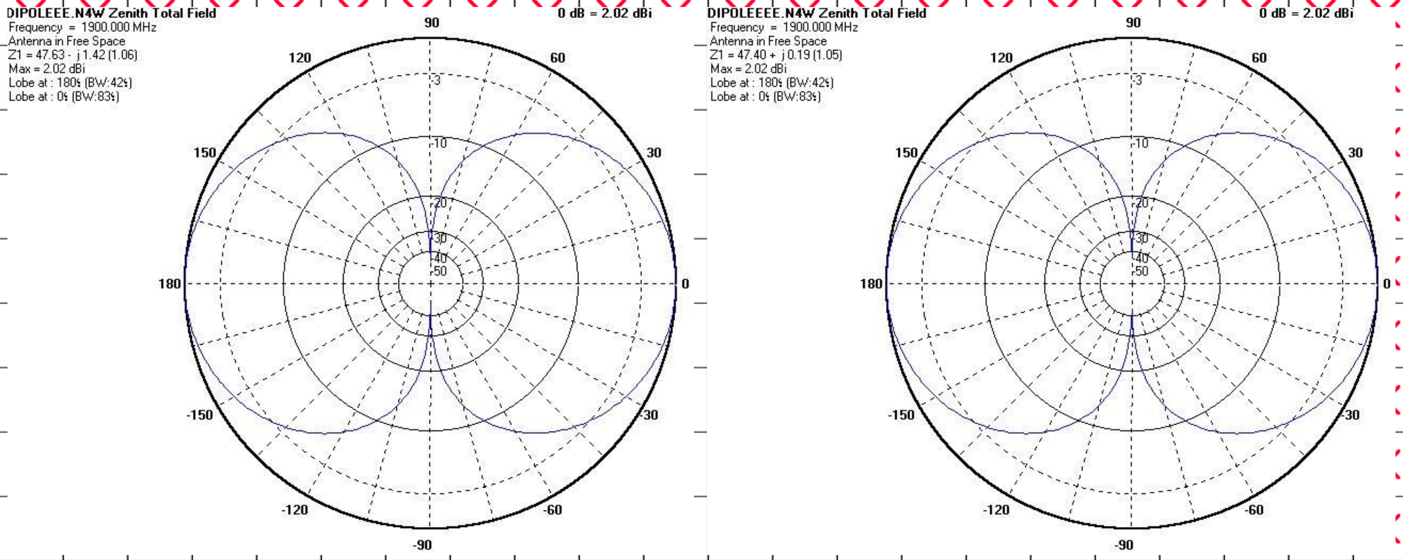
The following figure represent the far field radiation pattern in zenith plane for the three iterations.



K_0



K_1



K_2 K_3

Figure (7): Far field radiation pattern for Koch dipole antenna

The values of (SWR) gain of the Koch dipole antenna are given in Table (2).

Table (2): gain and SWR for Koch fractal antenna in its first three iterations.

Iteration	SWR	Gain (dB_i)
0	1.45	2.12
1	1.06	2.04
2	1.05	2.01
3	1.05	2.02

5. Conclusions:

The result of the present work presented in section (4) lead to the following conclusions:

- The height of fractal Koch dipole is reduced at every iteration, but the benefits of fractal geometry in reducing the height of the antenna became very little at high iterations (after third one) as seen in Table (1).

- The matching properties of the antenna represented by (SWR) was improved because increasing in the number of segments add loads to the end of the antenna which reduce the reactance or the imaginary part in the input impedance of the antenna as shown in Figures 3,4 and 5.

- The gain of fractal Koch is remained slightly constant.

- Far field radiation remains similar in shape as the dipole far field.

References:

[1] Mandelbrot, B.B. (1983), ***The Fractal Geometry of Nature***, Freeman and company, Newyork.

[2] Robert, L.D. (2000),***Fractal Geometry of the Mandelbrot***, http://math.bu.edu/ Dysys/ fracgeom/ fracgeom.html.

[3] Barnsley, M.F. (1993),***Fractals Every Where***, Academic press INC., NewYork.

[4] Shawkat, Z.U. (1994),***On the Dimension of Q-fractals*** , M.Sc. Thesis, University of Baghdad.

[5] Lee, K.F. (1984),***Principles of Antenna Theory***, John Wiley &sons: NY.

[6] Cohen, N. (1995),***Fractal Antennas: part 1***, http://www.fractenna.com/ images/ comm-quarterly-article-3.jpg.

[7] Puente, C. & Claret, J. (1996)***Multiband Properties of a Fractal Tree Antenna Generated by Electrochemical Deposition***, IEEE Electronics letters, vol.32, No.25, pp.2298-2299.

[8] Puente, C. & Romeu, J. (1996),***Perturbation of the Sierpinski Antenna to Allocate Operating Bands***, IEE Electronics letters, vol.32, No.24, pp.2186-2188.

[9] Stutzman, W.L. (1998) ***Antenna Theory and Design***, John Wiley & Sons , 2nd edition.

[10] EdminIster, J.A. (1993) ***Electromagnetics***, McGraw Hill Comp.

[11] Harrington, R.F. (1968) ***Field Computation by Moment Method***, McMillan, NewYork.

[12] Lorrain, P. (1970) ***Electromagnetic Fields and Waves***, W.H. Freeman and Company, Sanfransisco.

[13] Jaggard, D.L. (1990), ***On Fractal Electrodynamics***, In Recent Advances in Electromagnetic theory, H.N.Kritikos, pp.183-224, Springer verlag.

[14] Marten (1995), ***An Introductory Study of Fractal Geometry***, http://www.ea lnet.com/ ealsoft/fracted.htm.

[15] AL Shameri, W.F. (1994), ***Some Results on Fractals***, M.Sc. thesis, Baghdad University.

[16] Shaalan, A.B. (2002***), Simulation of Fractal Antenna Properties Using Fractal Geometry***, Ph.D. thesis, Mustansiriyah University.

[17] Gianvittorio, J. (2000), ***Fractal Antennas: Design***, ***Characterization and Applications***, M.Sc. thesis, University of California, Los Angeles.