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Design and Simulation of Linear Array Antenna Using Koch Dipole Fractal Antenna Elements for Communication Systems Applications

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Abstract

In this paper, the fractal concept has been used in the linear array antenna design to obtain multiband operation. The fractal linear array antenna has been designed at a frequency of 750 MHz with equal spacing and uniform amplitude distribution of the elements array. 1st iteration quadratic Koch curve dipole fractal element is used in design of the array. The proposed antenna array design, analysis and characterization had been performed using the Method of Moment (MoM) technique. The radiation pattern, side lobe level (SLL), directivity (D), and input impedance of the proposed antenna are described and simulated using 4NEC2 software package and MATLAB programming language version 7.6.

Keywords: Koch curve, multi-band antenna, dipole antenna, quadratic Koch curve, linear array antenna.

تصميم ومحاكاة مصفوفة هوائيات خطية باستخدام عناصر جزئية لهوائي كوخ ثنائي القطب لتطبيقات انظمة الاتصالات

الخلاصة

تم في هذا البحث استخدام فكرة الهندسة الجزئية في تصميم المصفوفات الخطية للهوائيات وذلك للحصول على هوائيات تعمل على اكثر من تردد. تم تصميم مصفوفة الهوائيات الجزئية الخطية عند التردد التصميمي 750 MHz مع تغذية ومسافات متساوية لعناصر المصفوفه.
تم استخدام التكرار الاول لعناصر جزئية ثنائية القطب من نوع منحني كوخ مربع الشكل في تصميم مصفوفة الهوائيات. ان تصميم وتحليل مصفوفة الهوائيات المقترحه انجزت باستخدام تقنية العزوم (MoM). تم محاكاة ووصف نمط الشعاع، مستوى الفصوص الجانبية (SLL)، التوجيهية (D)، وممانعة الدخول لمصفوفة الهوائيات باستخدام اللغة البرمجية MATLAB النسخة 7.6 والبرنامج 4NEC2.

1. Introduction

A wide variety of applications of fractals can be found in many branches of science and engineering. One such area is fractal electrodynsamics. Fractal geometry can be combined with the electromagnetic theory for the purpose of investigating a new class of radiation, propagation and scattering problems [1].

One of the most promising areas of fractal electrodynamics research is in its application to antenna theory and design. There are a variety of approaches that have been developed over the years, which can be utilized to achieve one or more of these design objectives pertaining to size, gain, efficiency and bandwidth. Unique properties of fractals can be exploited to develop a new class of antenna element designs that are multi-band, compact in size and can possess several highly desirable properties,

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including multi-band performance, low side lobe levels, and their ability to develop rapid beam forming algorithms based on the recursive nature of fractals [2].

Fractal shapes radiate signals at multiple frequency bands, occupy space more efficiently and offer design solutions meeting the requirements for antennas in future wireless devices such as cell phones and other wireless mobile devices such as laptops on wireless local area networks (LANs) [1].

In many applications it is necessary to design antennas with very directive characteristics (very high gains) to meet the demands of long distance communication; this can be accomplished by antenna array [3]. The increasing range of wireless telecommunication services and related applications is driving the attention to the design of multi-frequency (multiservice) and small antennas. This can be achieved through the use of fractal concepts in the design and analysis of arrays by either analyzing the array using fractal theory or by placing elements in fractal arrangement or considering them both [4]. Fractal arrangement of array elements can produce a thinned array and can achieve multi-band performance.

2. Linear Array Antenna

An array is usually comprised of identical elements positioned in a regular geometrical arrangement. A linear array of isotropic elements N, uniformly spaced, a distance d apart along the z-axis, is shown in Figure (1) [5].

The array factor corresponding to this linear array may be expressed in the form [3]

$$AF(y)=\begin{cases} a_0+2\sum_{n=1}^{N} a_n \cos(ny) & \text{For } (2N+1) \text{ elements} \\ 2\sum_{n=1}^{N} a_n \cos\left(\left(\frac{2n-1}{2}\right)y\right) & \text{For } (2N) \text{ elements} \end{cases} \quad .....(1)$$

where

$y = kd\cos(q) + a$ = Phase delay

$AF(y) =$ The array factor

$d =$ Spacing between adjacent elements in the array

$a =$ The progressive phase shift between elements

$k = \frac{2p}{l} =$ The wave number

$q =$ Elevation angle

3. Quadratic Koch Curve Fractal Element

In this paper, the quadratic Koch curve is taken as an example of fractal element antenna that has multi-band characteristics [6].

Figure (2) contains the first three iterations in the construction of the quadratic Koch curve. This curve is generated by repeatedly replacing each line segment, composed of four quarters, with the generator consisting of eight pieces, each one quarter long [7]. Each smaller segment of the curve is an exact replica of the whole curve. There are eight such segments making up the curve, each one represents a one-quarter reduction of the original curve. Different from Euclidean geometries, fractal geometries are characterized by their non-integer dimensions.

Fractal dimension contains information about the self-similarity and the space-filling properties of any fractal structures [8]. The fractal similarity dimension (FD) is defined as [7]:

$$FD = \frac{\log(N)}{\log(1/e)} = \frac{\log(8)}{\log(4)} = 1.5 \qquad (2)$$

Where N is the total number of distinct copies, and $(1/e)$ is the reduction factor value which means how will be the length of the new side with respect to the original side length.

4. Mathematical Modeling

The numerical simulations of the antenna system are carried out via the method of moments. Numerical modeling commercial software 4NEC2 is used in all simulations. The NEC is a computer code based on the method of moment for analyzing the electromagnetic response of an arbitrary structures consisting of wires or surfaces, such as Hilbert and Koch curves. The modeling process is simply done by dividing all straight wires into short segments where the current in one segment is considered constant along the length of the short segment. It is important to make each wire segment as short as possible without violation of maximum segment length to radius ratio computational restrictions. In NEC, to modeling a wire structures, the segments should follows the paths of conductor as closely as possible [9].

5. Proposed Linear Array Antenna Design

The linear array antenna with equal spacing between array elements has been modeled, analyzed, and its performance has been evaluated using the commercially available software 4NEC2, where the first iteration quadratic Koch fractal antenna is used as an array element. The Method of Moment (MoM) is used to calculate the input impedance of each element in the proposed array. MATLAB programming language (version 7.6) is used to calculate the radiation pattern and radiation properties at each operating frequency. The layout of this antenna array with respect to the coordinate system is shown in Figure (3).

The linear array consist of four fractal antenna elements, as shown in Figure (3) and designed at a frequency 750 MHz (λ_0 = 40 cm), with quarter-wavelength (d = $\lambda_0/4$) spacing between adjacent array elements with progressive phase shift between elements (α) equal to zero. The total element length is equal to $\lambda_0/2$ (20cm).
Each array element is fed at its center point with uniform amplitude feeding coefficients. The array structure in three dimensions is shown in Figure (4).

6. Computer Simulation Results

The real and imaginary parts of the input impedance of this array antenna are illustrated in Table (1).

It is clear from Table (1) that the proposed linear array antenna possesses many resonant frequencies some of which has high resistance more than 50 Ohm.

The radiation patterns at these resonant frequencies have been demonstrated as in Figure (5), while the results of the radiation properties (D, SLL) are listed in Table (2).

7. Conclusions

From the figures and tables, the following points can be noticed:

1. Number of resulting resonant frequencies is much greater than the number of resonant frequencies of the fractal element, where some of these resonant frequencies are close to each other. These resonant frequencies when added to the element design frequency (750MHz in our case) yielding a new group of resonant

frequencies that are also close to each other.

2. Multiple groups of resonant frequencies are appears to be approximately the same from the radiation pattern and input impedance point of view.
   These groups are clearly noticed in table (1) with different colors.
3. The best field pattern is obtained when the resonant frequencies are approximately (0.6 to 3.2) times the element design frequency.
4. SLL is reduced when the resonant frequencies are less than the array design frequency since the distance between array elements will be less than one wavelength, while the SLL is increased when the resonant frequency becomes higher than the array design frequency since the distance between array elements will be higher than one wavelength.

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Table (1) Input impedance for the right hand side of the proposed antenna array

f (MHz)	Z_1 (Ω)	Z_2 (Ω)
445	5.47-j58.5	87.53+j4.57
467	64.14+j2.2455	49.1-j55
500	77.5+31.9	85.52-j0.71
1280	90.78-j0.34	76.2-j23.2
1294	96.7+j22.6	84.87-j0.28
1988	117-j27.9	83.96+j0.56
2016	132.8+j0.027	90.1+j33.4
2352	529.4+j0.544	183-j722
2700	178-j26.7	149.7-j0.37
2726	194-j0.7	164+j24.9
2950	526.8+j0.134	565+j70.3
2972	550-j53.7	607.9-j0.39

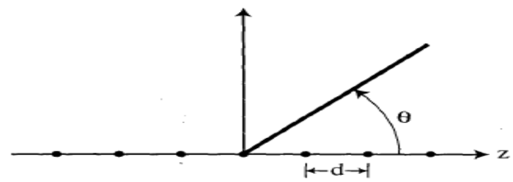


Figure (1) Linear array geometry of uniformly spaced isotropic sources [5]

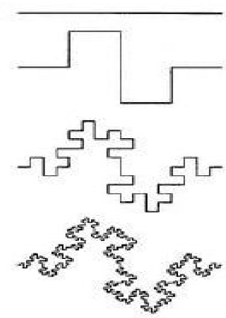
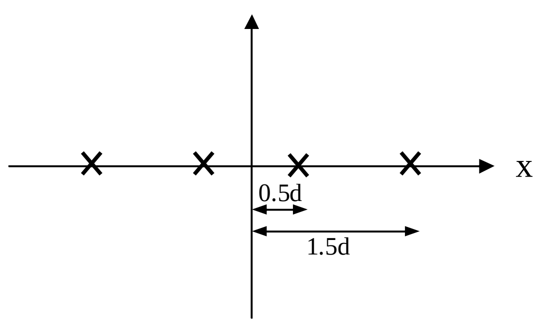


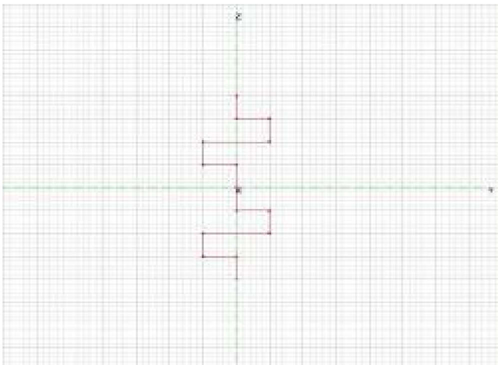
Figure (2) First three iterations of the construction of the quadratic Koch curve [7]

Table (2) Radiation properties of the proposed antenna array

f (MHz)	D (dB)	SLL (dB)
445	4.52	-14.34
467	4.69	-12.84
500	5.04	-12.17
1280	8.29	-4.36
1294	7.95	-3.62
1988	10.39	-6.86
2016	10.43	-6.8
2352	10.63	-6.16
2700	8.55	-1.33
2726	8.09	-0.8698
2950	8.55	-3.08
2972	8.63	-3.42



a) Element configuration



b) Array configuration

Figure (3) Proposed linear array antenna geometry

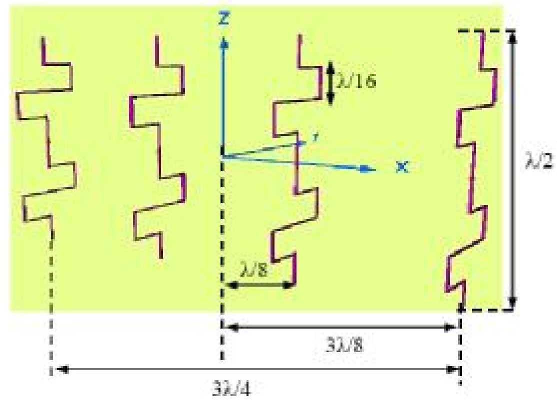
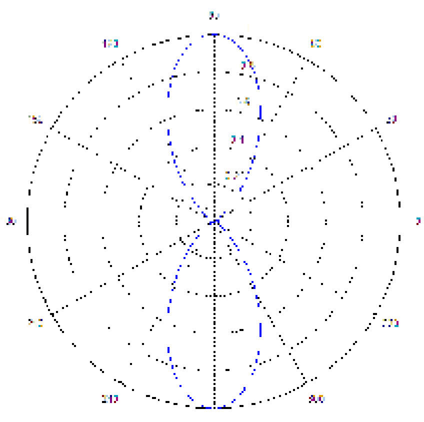
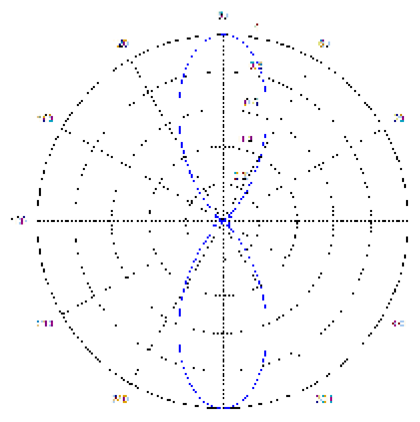


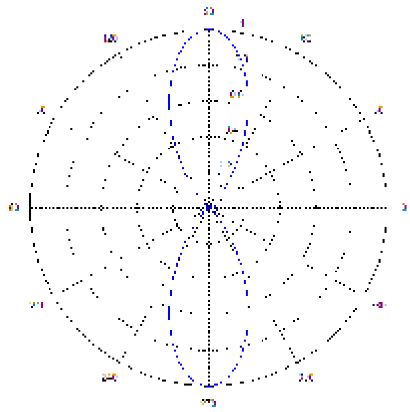
Figure (4) Array structure in 3D view



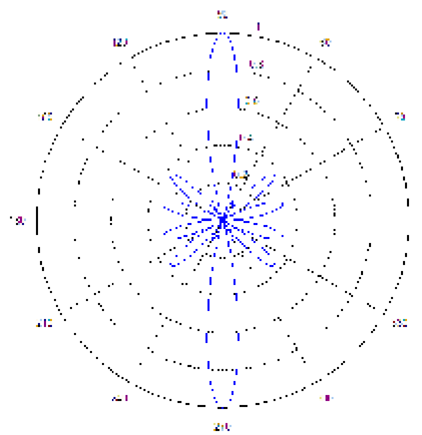
445MHz



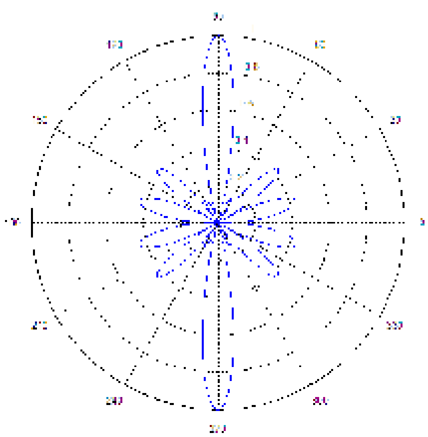
467MHz



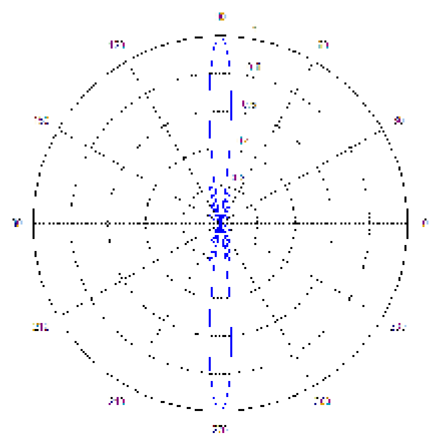
500MHz



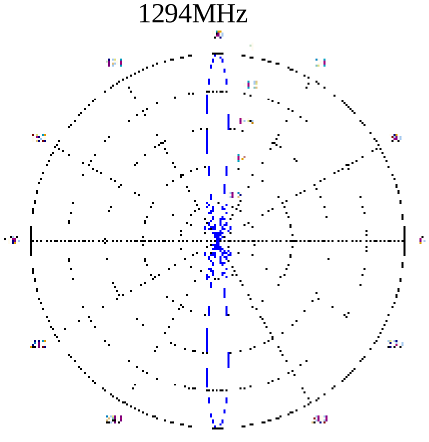
1280MHz



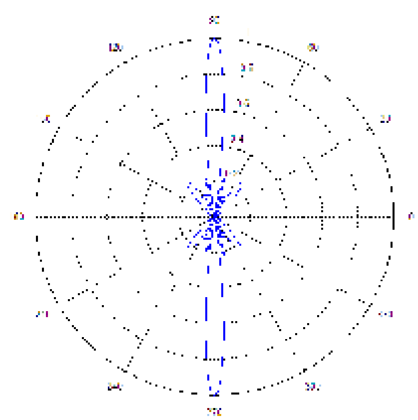
1294MHz



1988MHz



2016MHz



2352MHz

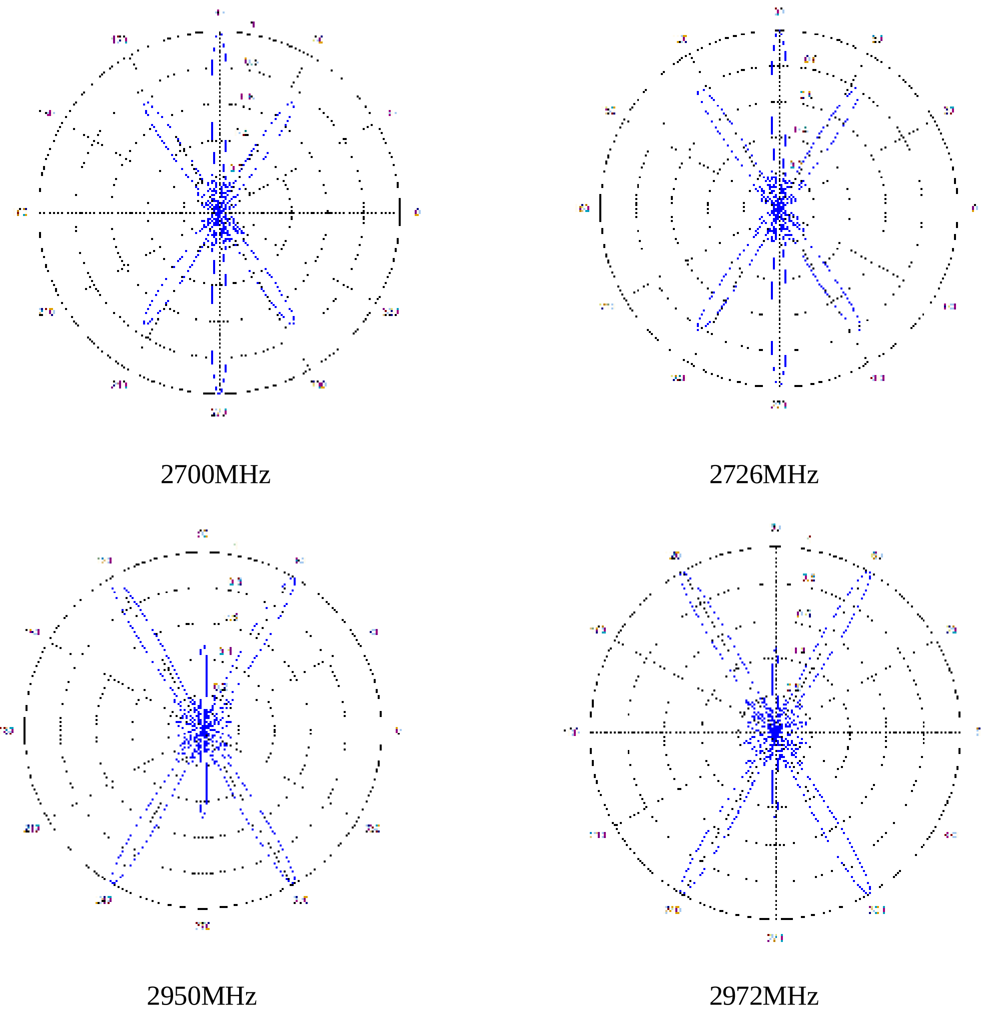


Figure (5) Radiation Pattern of the proposed antenna array at resonant frequencies