JOURNAL OF ZANKOY SULAIMANI

Part -A- (Pure and Applied Sciences)

VOLUME 25 ISSUE 1 June 2023
ISSN: 1812-4100
www.jzs.univsul.edu.iq

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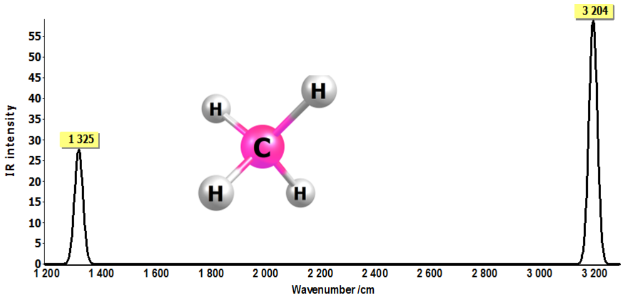

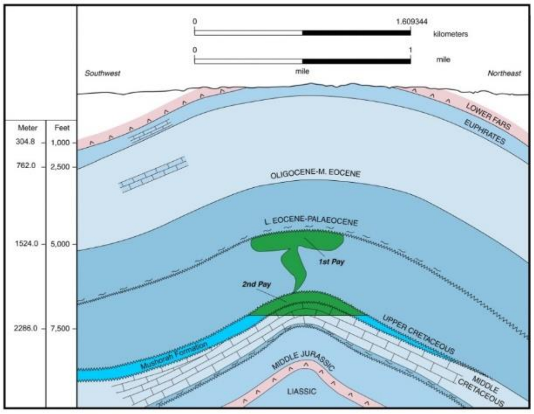

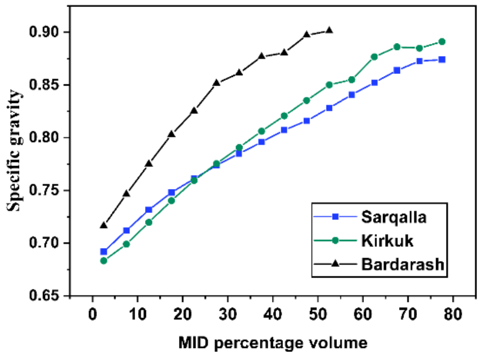

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Journal of Zankoy Sulaimani
Part-A- (Pure and Applied Sciences)
ISSN:1812-4100

Linear 2.4 GHz Array Optimization Using Genetic Algorithm Technique

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Article info

Original: 06/07/2022
Revised: 16/09/2022
Accepted: 09/10/2022
Published online:
20/06/2023

Key Words:
Antenna Array
Uniform Array
Binomial Array
Dolph-Chebyshev Array
Genetic Algorithm
Gain
HPBW
Max. SLL
Number of SLL
And
Radiation Pattern

Abstract

Genetic algorithm (GA) is global numerical optimization approach is based on the genetic recombination and assessment in nature. This kind of optimization can be utilized to optimize the amplitude, phase levels and spacing distribution for the elements of an antenna array to achieve its best performance. In this study the genetic algorithm of the 4NEC2X software has been used to optimize the element spacing ($d = \frac{\lambda}{4}$) of both a uniform and non-uniform (Binomial and Chebyshev) current excitation for 10-element, 2.4 GHz linear broadside dipole antenna arrays. As a consequence, for the above-mentioned array antennas the spacing optimization yielded a notable improve in their directivity and Gain (dBi), such that for the uniform current excitation the gain was reached to 14.8dBi and for both Binomial and Chebyshev non-uniform current excitation the gain increased to 12.57 dBi and 15.04 dBi respectively.

Introduction

In many communication applications, a highly directed array antenna must be designed with high gain and directivity compared to single antennas. In a uniform linear array, all the items are positioned on one line with the same distance between them. In reality, the majority of real-world electromagnetic issues are nonlinear and non-differentiable for which analytical solutions do not exist. These problems lead to employ numerical methods rather than analytical solutions. These approaches do not reveal the global optimal solution to the issue, which is impossible to discover using these methods [1]. Because of this, numerical solvers resort to marching parameters up and down (optimization) until they find the best overall solution.

A global optimization techniques basing on the Darwinian hypothesis of evolution by natural selection and evaluation known as Genetic algorithm (GA) has numerous benefits over standard numerical optimization methods, such as the flexibility to employ either continuous or discrete parameters, search through a broad sample of the solution space, and manage a high number of variables.

The first introduction of GA was on 1975 by Holland and their practical applications to problems were performed by Goldberg in the late 80s and early 90s [2]. The first usage of GA within electromagnetic has been most often to antenna array design like thinning beam forming and side lobe minimization. In recent years GA, have spread to use to the design of a single antenna for the parameters optimization such as bandwidth, efficiency, size, gain and radiation pattern [3]. On 1997 [4] used genetic algorithms to describe and design four different wire antennas, named loaded monopole radiating at 1.6 GHz and the second one was array of seven elements while the last two were modified Yagis, one of which is intended to cover a wide frequency range and the other was for a high gain operating at 235 MHz and 432 MHz respectively. [5] has recently compiled a large lot of work on antenna design using genetic algorithm. The same genetic algorithm was also used by [6] to design a twisted Yagis antenna to make it an attractive alternative to the helical antenna .Genetic algorithm have proven their usefulness in both the areas of array thinning and array synthesis delivering outcomes that perform vast efforts to enhance the array design. A hemispherical radiation pattern antenna creation is a very unique application of GA [7, 8].

In the present work, the genetic algorithm of 4NEC2X software optimization will be used to optimize the spacing between the elements of a 10-element, 2.4 GHz uniform and non-uniform excitations arrays as an effect to enhance their directivity and the gain.

Genetic Algorithm

Based on natural processes such as genetic recombination and evolution, genetic algorithms provide "global" numerical optimization. Genes are the binary sequences encoded by the algorithms. Natural selection, mating, and mutation all play a role in determining the best possible solution for a given problem. Many other optimization issues may be solved using these techniques, but only lately they have been used to improve electromagnetics difficulties. In the field of electromagnetics, gradient-based algorithms have long been employed to discover the best solution, involving the calculation of derivatives [9].

Genetic algorithms are distinct from more regular optimization and search processes in the four ways [10]:

1. The parameters themselves are not used by genetic algorithms; rather, a coding of the parameter set is used.
2. A population of points, rather than a single point, is searched using a genetic algorithm.
3. Genetic algorithms employ objective function information, not any derivative or auxiliary information.
4. Genetic algorithms employ probabilistic transition rules, not deterministic rules.

One may summarize the most essential GA parameters by looking at the [2]:

1. Type of crossover and rate of crossover.
2. The kind of mutation and the frequency of mutation.
3. Size of the population.
4. Selection method.
5. There have been a total of how many generations.

The genetic algorithm (GA) utilized in 4NEC2X is based on real-world values. Selection, crossover and mutation-techniques, N-point Blend simulated binary crossover, and random Gaussian or non-uniform mutation need extra time to optimize before the algorithm can begin. A chromosome is formed by a set of variables known as a gens, each of which has a minimum and maximum value. These user-selected upper and lower bounds establish the boundaries of the search-space. Typically, these boundaries are defined in accordance with physical constraints, such as available space, maximum length, or spacing; nevertheless, establishing a range that is too broad may cause the system to slow down [11].

Design and Simulation Results

In this work some basic radiation characteristics for a uniform and non-uniform linear 10 element dipole antenna array has been analyzed through the optimization of the spacing between the elements by using 4NEC2X software Genetic Algorithm for a uniform array, Dolph Chebyshev and Binomial non-uniform excitation arrays. The length (L) and the wire radius (R) of the array elements of half wavelength dipole antenna has been calculated from the equations below [12, 13].

$$L = 0.475\,\lambda \;= \frac{143}{\text{f(MHz)}}\ (m)\ \ldots\ldots\ldots\ldots(1)$$

$$R = \frac{D}{2} = 0.001\,\lambda\ \ldots\ldots..\ldots\ldots\ldots\ldots\ldots.(2)$$

$$\lambda = \frac{c}{f}\quad \ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots(3)$$

Where D is the wire diameter of the elements, c is the speed of light and λ, f are the wavelength and frequency of the operating wave.

Uniform Linear Half Wavelength Dipole Antenna Array (uniform spacing and uniform amplitude excitation)

For the linear broadside dipole array, the elements were arranged parallel to each other along the ordinary z-axis (it has horizontal dipoles with x-axis orientation) as shown in figure (1) below [14].

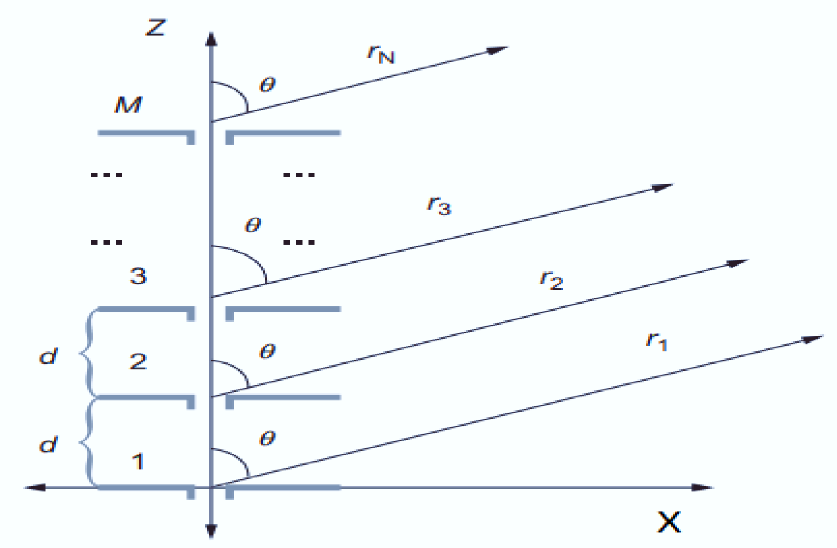

Fig. (1): Schematic diagram of M-element uniform array half wavelength dipole antenna along the ordinary z-axis ***[14]***.

The genetic algorithm of the 4NEC2X software has been used to optimize the spacing between the 10 uniform excitation current elements. Because of the size of the antenna components, the mutual coupling between the elements and to ensure that there are no maxima in the other directions (grating lobes), the separation between the elements should not be equal to multiples of a wavelength $d \neq n\lambda\,, n = 1,2,3 \ldots$ so the initial minimum spacing was set at 0.25 λ This parameter has a physical limits. The widest possible distance between objects is $\leq 2\Delta$ where $\Delta = 0.5\,\lambda$ [15, 16, 17].

After optimization the non-uniform broadside array is produced having spacing (d) s as the following.

d_1=0 λ d_2=0.760λ d_3= 0.755λ d_4=0.703λ d_5=0.584 d_6=0.587λ d_7=0.773λ d_8=0.794λ d_9=0.799λ d_{10}=0.740λ

Table (1) below tabulates some characteristics of this non-uniform spacing array before and after optimization.

Table (1): shows Gain, HPBW, no. of side lobe, max. Side lobe level.

Antenna Characteristics	Before Optimization	After Optimization
Gain (dBi)	10.41	14.8
HPBW (Ver. Plan)	20	8
HPBW (Hor. Plan)	80	80
Max. side lobe level (dBi)	-2.49	0.08
No. of side lobe	6	26

Fig (2) shows the 2D and 3D radiation pattern for uniform spacing before optimization (fig. 2A) and the non-uniform spacing between elements (fig. 2B) by using GA optimization for 10-element uniform excitation.

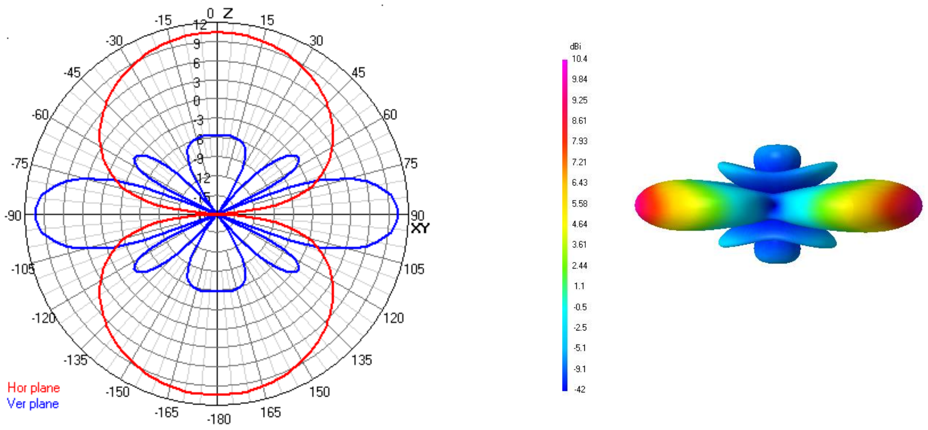

Fig. (2A): 2D and 3D radiation pattern of the uniform space and uniform excitation for half wavelength dipole array before optimization.

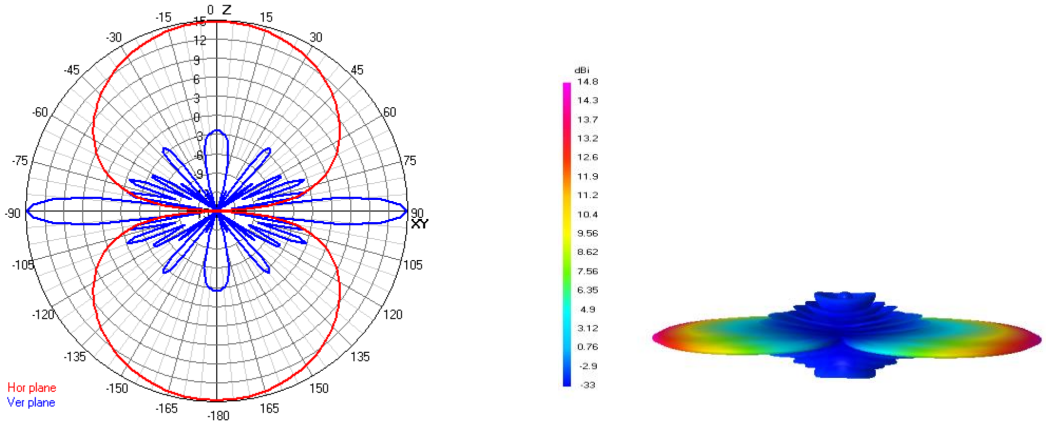

Fig. (2B): optimizing 2D and 3D radiation patterns of a half wavelength dipole array with non-uniform spacing and uniform excitation.

Non-Uniform Excitation Half Wavelength Dipole Antenna Array:

In this section GA was used to optimize the spacing for two different non-uniform current excitations i.e. Binomial and Dolph-Tschebyscheff excitations making use of references [18, 19] respectively.

Binomial Excitation:

The previous 10-element uniform spacing operating at 2.4 GHz was excited with the binomial coefficients. Binomial array excitation coefficients determined by writing the function $(1+x)^{m-1}$ in a series, using the binomial expansion, as shown in [18, 20].

$$(1+x)^{m-1} = 1 + (m-1)x + \frac{(m-1)(m-2)}{2!}\,x^2 + \frac{(m-1)(m-2)(m-3)}{3!}\,x^3 + \cdots \qquad \ldots\ldots(4)$$

The series expansion's positive coefficients for various m values are:
m = 1 1
m = 2 1 1
m = 3 1 2 1
m = 4 1 3 3 1
m = 5 1 4 6 4 1
m = 6 1 5 10 10 5 1
m = 7 1 6 15 20 15 6 1
m = 8 1 7 21 35 35 21 7 1
m = 9 1 8 28 56 70 56 28 8 1
m = 10 1 9 36 84 126 126 84 36 9 1

The number of elements in the array is represented by the value of m, and the relative amplitudes of those elements are represented by the coefficients of the expansion. Binomial arrays get their name from the fact that their coefficients are derived by binomial series expansion.
The optimized spacing using genetic algorithm of 4NEC2X software got the following values.

$d_1=0\lambda$ $d_2=0.394\lambda$ $d_3= 0.202\lambda$ $d_4=0.791\lambda$ $d_5=0.742\lambda$ $d_6=0.827\lambda$ $d_7=0.782\lambda$ $d_8=0.781\lambda$ $d_9=0.941\lambda$ $d_{10}=0.313\lambda$

The table (2) below tabulates some characteristics along with their optimized values and before optimization.

Table (2): shows Gain, HPBW, no. of side lobe, max. Side lobe level before and After Optimization using GA optimization for 10-element Binomial excitation.

Antenna Characteristics	Before Optimization	After Optimization
Gain (dBi)	7.41	12.57
HPBW (Ver. Plan)	40	12
HPBW (Hor. Plan)	80	80
Max. side lobe level (dBi)	-∞	-5.28

No. of side lobe	0	6

The Figure no. 3A shows its 2D and 3D radiation pattern for equal spacing and varying levels of excitation, and figure no. 3B shows its 2D and 3D radiation pattern of the non-uniform spacing and non-uniform excitation half wavelength dipole Binomial array.

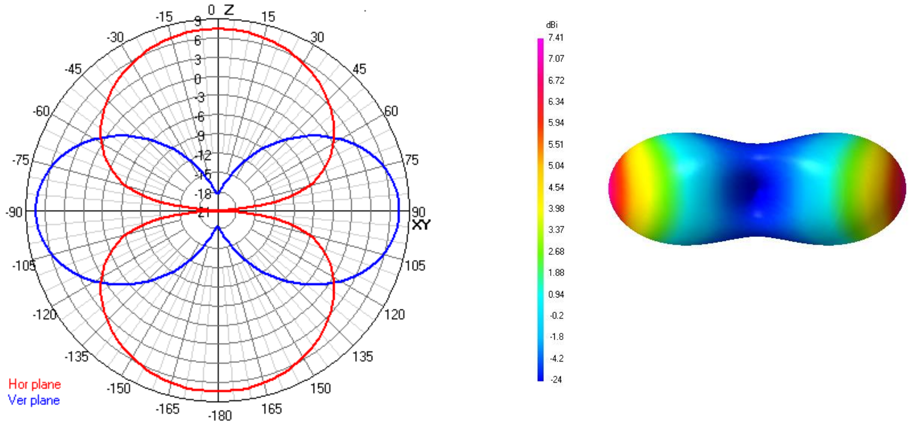

Fig. (3A):2D and 3D radiation pattern of the equal spacing and varying levels of excitation half wavelength dipole Binomial array.

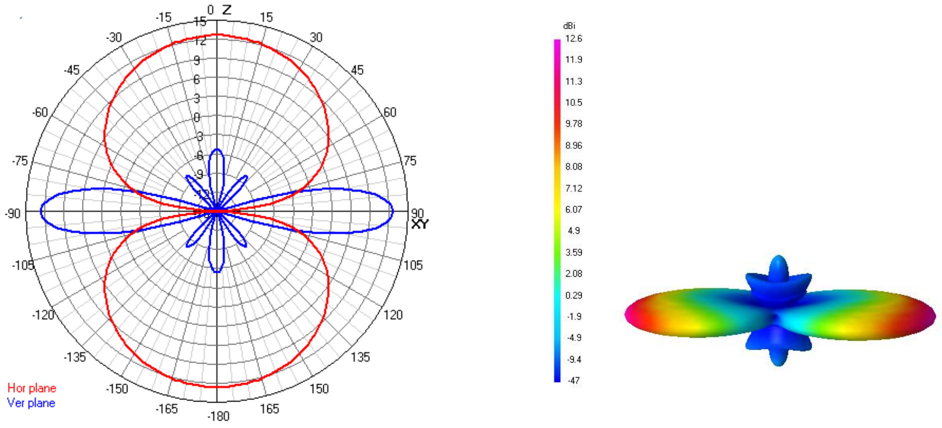

Fig. (3B): Non-uniform spacing and non-uniform excitation half wavelength dipole Binomial array optimized radiation pattern in 2D and 3D.

Dolph- Chebyshev Excitation:

The last part of this work is the spacing optimization of the same original uniform array (d= $\frac{\lambda}{4}$). The Dolph-Chebyshev approach is a compromise between the uniform and binomial methods; the current excitation coefficients for 20 dBi major to minor lobe radiation determined by both methods are equal [19].

The array factor of even and odd numbers of elements in the array with symmetric amplitude excitation is a summation of M or M+1 cosine terms, which is represented by equation 5 and 6 respectively [21]:

$$(AF)_{2M}(even) = \sum_{n=1}^{M} a_n \cos\left[(2n-1)u\right] \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (5)$$

$$(AF)_{2M+1}(odd) = \sum_{n=1}^{M+1} a_n \cos\left[2(n-1)u\right] \ \ldots\ldots\ldots\ldots\ldots\ldots \ (6)$$

$$u = \frac{\pi d}{\lambda}\, cos\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (7)$$

M: element's location is indicated by an integer.

a_n= the array elements' excitation coefficients.

If the array's elements are arranged along the z-axis, then cos u is equivalent to z, and the following terms are connected to the Chebyshev polynomial Tm (z):

m=0 cos (mu) = 1 = $T_o\ (z)$
m=1 cos (mu) = cos (u) = z = $T_1\ (z)$
m=2 cos (mu) = cos (2u) = $2z^2 - 1$ = $T_2\ (z)$
m=3 cos (mu) = cos (3u) = $4z^3 - 3z$ = $T_3\ (z)$

Knowing the preceding two polynomials, one can apply the recursion formula to get a single Chebyshev polynomial. The formula is stated as follows:

$$T_m(z) = 2zT_{(m-1)}(z) - T_{(m-2)}(z) \text{ .... } (8)$$

Dolph Chebyshev excitation coefficients for varying numbers of 10-elements are as follows:

m = 1 1
m = 2 1 1
m = 3 1 1.636 1
m = 4 1 1.736 1.736 1
m = 5 1 1.607 1.929 1.607 1
m = 6 1 1.439 1.855 1.855 1.439 1
m = 7 1 1.276 1.683 1.837 1.683 1.276 1
m = 8 1 1.139 1.507 1.72 1.72 1.507 1.139 1
m = 9 1 1.023 1.355 1.596 1.662 1.596 1.355 1.023 1
m = 10 1 0.926 1.212 1.436 1.558 1.558 1.436 1.212 0.926 1

The coefficients of the current excitation for the major to minor lobe radiation of 20 dBi [19] has been utilized and the optimized spacing between the 10-elements using genetic algorithm was as follows:

$d_1=0\lambda$ $d_2=0.573\lambda$ $d_3= 0.8\lambda$ $d_4=0.824\lambda$ $d_5=0.803\lambda$ $d_6=0.95\lambda$ $d_7=0.823\lambda$ $d_8=0.978\lambda$ $d_9=0.764\lambda$ $d_{10}=0.936\lambda$

The table (3) below tabulates the Gain, HPBW, no. of side lobe, max. Side lobe level after spacing optimization for Dolph- Chebyshev array.

Table (3): shown Gain, HPBW, No. of Side lobe level and Max. Side lobe level before and after spacing optimization.

Antenna Characteristics	Before Optimization	After Optimization
Gain (dBi)	10.3	15.04
HPBW (Ver. Plan)	24	8
HPBW (Hor. Plan)	80	80
Max. side lobe level (dBi)	-8.9	-0.19
No. of side lobe	6	22

Figure No. 4A displays its radiation pattern in 2D and 3D for uniform spacing and non-uniform excitation and figure 4B depicts the radiation pattern of the Dolph- Chebyshev half wavelengths dipole array with non-uniform spacing and non-uniform excitation, (i.e after spacing optimization through GA).

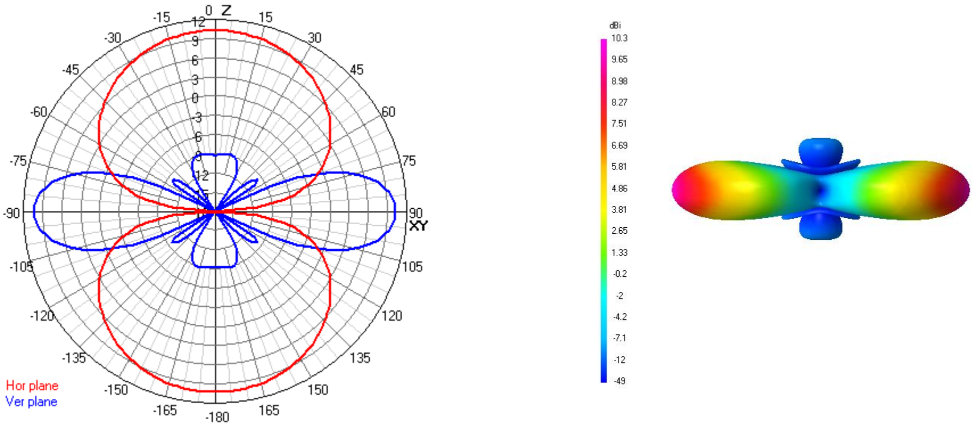

Fig. (4A):2D and 3D radiation pattern of the equal spacing and varying levels of excitation half wavelength dipole Dolph-Chebyshev array.

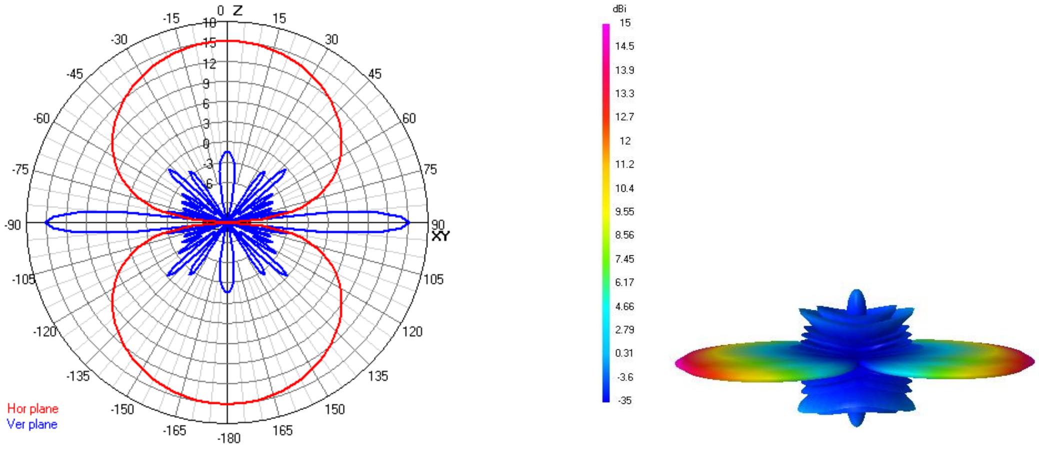

Fig. (4B): Optimized 2D and 3D radiation pattern of non-uniform space and non-uniform excitation half wavelength dipole Chebyshev array.

Conclusions

Genetic algorithm spacing optimization of a 4NEC2X software has been implemented to study the radiation pattern of a 2.4 GHz uniform and non-uniform excitation broadside dipole antenna array. After the accomplishment of the study these conclusions have been achieved:

1- The optimization gave notable rise in the gain (dBi) of the antennas, such that the gain of the uniform spacing and uniform excitation before and after optimization increased from 10.41 dBi to 14.8 dBi respectively.

2- The gain of the non-uniform Binomial and Chebyshev excitations before and after element spacing (d) increased from (7.41 to 12.57) dBi and (10.3 to 15.04) dBi respectively.

3- The HPBW of the uniform, Binomial and Chebyshev excitation decreased from (20 to 8) degree, (40 to 12) degree and (24 to 8) degree respectively which emphasizes an excellent improvement in the directivity of the antennas.

4- The no. of side lobes of uniform, Binomial and Chebyshev excitations before and after optimization increased from (6 to 26), (0 to 6) and (6 to 22) respectively. Fortunately this disadvantage of the optimization yields a decrease in their maximum levels (dBi) by (-2.49 to 0.08), (-∞ to -5.28) and (-8.9 to 0.19) for the above antennas respectively.

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