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Elliptical antenna array pattern synthesis with fixed side lobe level and suitable main Lobe beam width by genetic algorithm

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Abstract: In this paper, the design of uniform elliptical array (UEA) with optimum side lobe level reduction is presented. Multi-lobe pattern and adaptive nulling of the pattern is achieved by the control of the antenna elements phases in different states. This method is based on genetic algorithm (GA). The method of genetic algorithm is used to determine an optimum set of array factor cost that provide a radiation pattern with maximum side lobe level reduction with constraint of a suitable main lobe beamwidth. The results show that synthesis of the uniform elliptical antenna array by using GA method provide a side lobe level reduction and main lobe beamwidth better than circular antenna array obtained by using IWO (Invasive Weeds Optimization) and also optimized elliptical antenna array by using EPL (The Excitations Of Elements Phases at Eccentricity Low Level).

Keywords: SLL, Directivity, Beam Width, AF

1. Introduction

Usually the radiation pattern of a single element is relatively wide and each element provides low values of directivity. Antenna arrays increase the directivity without enlarging the size of single elements. Antenna arrays have been widely used in different applications are radar, sonar, and communications and as they are useful in high power transmission, reduced power consumption and enhanced spectral efficiency [18]. Array antennas have a structure with many radiation parameters that all of them must be optimized for best transmission condition, generally, they can be controlled and optimized by adjusting several array elements, such as the spacing between them, their excitation coefficients, their relative phase, the geometrical configuration of the overall arrays (linear, circular, elliptical, and so on) and also relative pattern of the individual elements array properties that can be controlled and optimized include directivity and gain, side lobe level (SLL), half-power beamwidth and other components that we can point to them [1]. To provide the desired pattern of antenna arrays and reducing interference from the side lobes of the antenna, we need a method which can improve the radiation parameters values, Therefore global optimization tools are good options to solve these problems. There are different global optimization methods such as genetic algorithm (GA), Invasive weed optimization (IWO) simulated annealing (SA) [7,16,17-20]. The behavior of the elements in an array antenna is described in some of the other applications of soft computing tools which are discussed in [16]. In this paper, we have presented an idea to optimize ten elements elliptical array with one main-lobe with (GA). If we want to explain about proposed method, we must point to ellipse geometry and also to the radiation parameters, why the ellipse with low level of eccentricity can increase the directivity by the reduction the main lobe beamwidth, so that decreasing the eccentricity value is the first step of optimization. The ellipse geometry which effects on antenna pattern are analyzed in section 2. There is a problem in reducing eccentricity cost and which is enhancing the side lobe level and the reason of undesired side lobe level is equal amounts of power and large quantities of antenna function sigma. When the cost of the array factor is large, all of the isotropic sources radiate the high level of power and this case leads to interference therefore we used the genetic algorithm to solve this disadvantage. The method of genetic algorithm generally based on controlling the factor of array value. We select array factor as algorithm cost function and phases of antenna elements are genes, so we find different values for the arrayfactor in the successive iterations and finally we choose the lowest costs of it, because the large size of array factor isn't suitable for synthesis the radiation pattern and makes distortion. now we have two values, first is the cost of array factor after optimization and another is set of phases which have been selected by genetic algorithm and we help to improve the array pattern via choosing them as the location of the antenna elements. The final part of synthesis is consist of selecting the elements phases on ellipse and radiation parameters computing, because we must understand which state can be presented to compare with another optimized structures.

2. Elliptical Antenna Array Function

Consider an elliptical antenna array of N elements non-uniformly spaced on a ellipse in the x-y plan (Fig. 1).

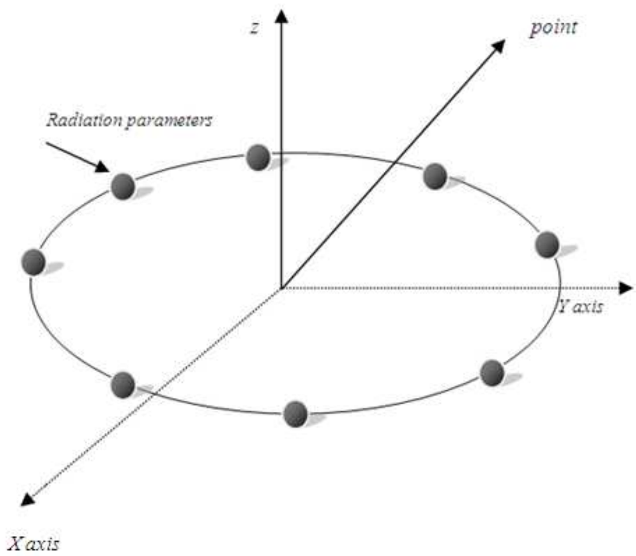

Figure 1.*Geometry of elliptical antenna array*

Array is taken to be isotropic sources, so the radiation pattern of this array can be described by its array factor. In the *x-y* plane, the array far field function for the Elliptical array shown in Fig. 1 is:

$$E(r,\phi,\theta) = \sum_{n=1}^{N} a_n \frac{e^{-j\beta R_n}}{R_n} \quad (1)$$

$$R_n = r - \sin\theta \left(x \cos\phi_n \; a_x + y \sin\phi_n \; a_y\right) \quad (2)$$

If the center of an ellipse is located at the origin on the *x-y* plane, then the parametric equation of ellipse in the rectangular coordinate system is given by

$$\begin{cases} x = a \cos\varphi \\ y = b \sin\varphi \end{cases} \quad 0 \le \varphi \le 2\pi \quad (3)$$

Where the a and b are the semi-major axis and semi-minor axis, respectively, and φ is angle between positive section of x-axis and a point (x,y) of the ellipse in x-y plane, Also the ellipse eccentricity e can be defined as:

$$e = \frac{c}{a} = \sqrt{1 - \frac{b^2}{a^2}} \qquad c = \sqrt{a^2 + b^2} \quad (4)$$

c is the half of the distance between two focuses, thus for an elliptical N-element array with its center in origin of x-y plane, we have:

$$R_n = r - \sin\theta \left(a \cos\phi \cos\phi_n \; a_x + b \sin\phi \sin\phi_n \; a_y\right) \quad (5)$$

Where:

$$\phi_n = \frac{2\pi(n-1)}{N} \quad (6)$$

is the angle in the x-y plane between the x-axis and the nth element. Thus, the array factor can be written with this form [1].

$$E(r,\phi,\theta) = \frac{e^{-j\beta r}}{r} \sum_{n=1}^{N} a_n \, e^{j\beta \sin\theta (a\cos\phi\cos\phi_n + b\sin\phi\sin\phi_n)} \quad (7)$$

$$E(r,\phi,\theta) = \frac{e^{-j\beta r}}{r} \left[AF(\theta,\phi)\right] \quad (8)$$

$$AF(\phi,\theta) = \sum_{n=1}^{N} I_n \, e^{j\beta \sin\theta (a\cos\phi\cos\phi_n + b\sin\phi\sin\phi_n + \alpha_n)} \qquad a_n = I_n e^{j\alpha_n} \quad (9)$$

In the above equations, In and αn represent the excitation amplitude and phase of the *n-th* element.

3. Eccentricity Influences on Elliptical Antenna Array Pattern

We can't ignore the geometric parameters of ellipse because they are very effective, therefore these parameters must be considered in analyzing results. To introduce the eccentricity influences on the antenna pattern, we will explain about two radiation features of antenna, first is directivity and second is SLL, highest directivity can increase the signal power at the desired point of transmission and reduces nulls distances between the radiated signals of Antenna elements, also good amount of this cause can provide a suitable beamwidth for main pattern. The side lobes levels must be very lower than main beam signal amount, because highest level of these patterns can make waveform and can be cause of interference. The important point is relation between these factors and eccentricity. When we increase amount of eccentricity, the side lobe level will be reduced, but decreasing side lobe level will enhance the width of main pan and reduces the directivity, the reason for increasing the main pattern beamwidth is mutual coupling effects. The distances between the array components will be reduced when we increase the eccentricity value, this geometric parameter decreasing can help to increase the mutual coupling effects on the antenna pattern, because mutual coupling has direct relation with distances between the elements and under such circumstance, the isotropic antennas reinforce each other better than other situations.

Table 1. *Eccentricity influences on mutual coupling (MC) between array elements 1 and 8*

	mutual coupling	*eccentricity*	
DistancesBetweenelements	*1.8-2.3j*	*0.455*	*40cm*
DistancesBetweenelements	*-2.8-0.7j*	9.99×10^{-4}	*44cm*

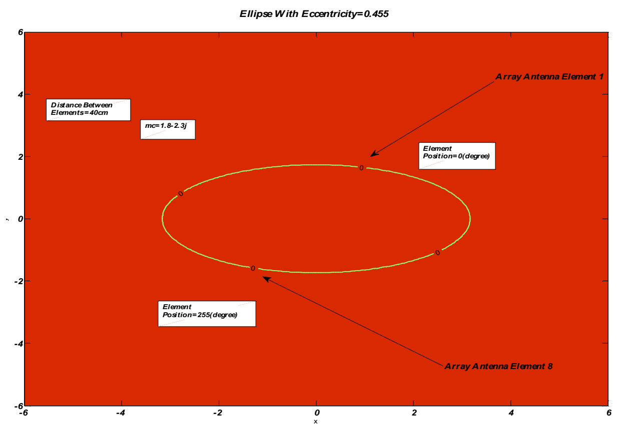

Figure.2. *Ellipse with e=0.455*

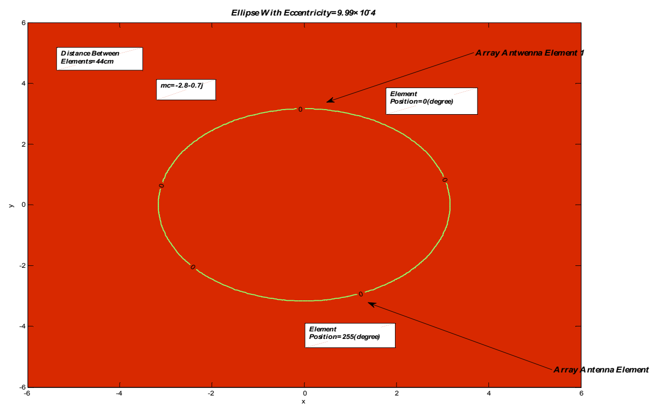

Figure.3. *Ellipse with* $e=9.99\times10^{-4}$

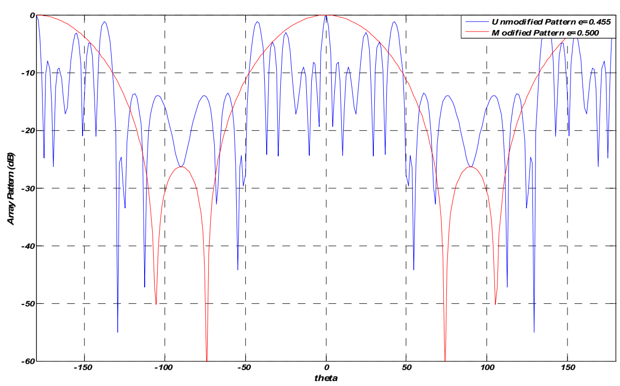

Figure. 4. *Unmodified and modified antenna pattern by eccentricity value excitements*

Table 2. *Information about antenna pattern*

Eccentricity	*Directivity*	*BeamWidth*	*SLL*
0.455	*14.6dB*	*8.4°*	*-1.12dB*
0.500	*10.4dB*	*150°*	*-26.5dB*

3.1. The Excitements of the Elements Phases at Eccentricity High Level (EPH Method)

Now we have decided to concentrate on the main objective of optimization. The increase of eccentricity is a reason for negative changes at radiation power, however another element that we have to focus on it is isotropic antenna phase, elements phases are places that isotropic Antenna located in them on the ellipse, we want to investigate about phase changes, and then analyze its results. There are two methods for this investigation, first is EPH solution and another is EPL analyzing that we prefer second rout for synthesis but we have to explain about both of them. What is EPH, because of the increasing beamwith of the main lobe and large size of AF amount, make changes in the eccentricity value can't consider as a good offer for optimization, so we must follow EPH method, thismethod is based on the changes in elements phases. To use this method we provide a specific value for the eccentricity and then should choose the different phases to the array elements randomly.

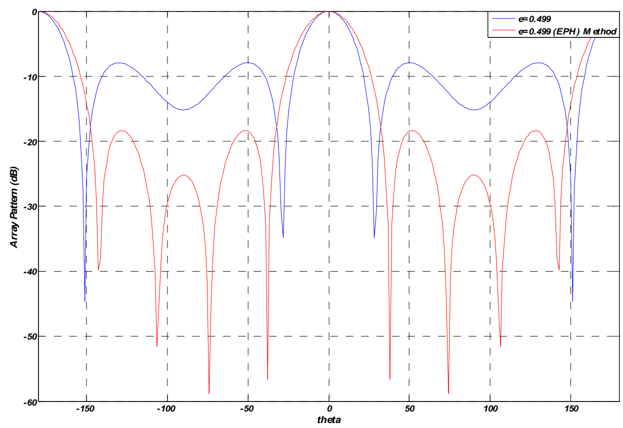

Figure. 5. *Compare between the unmodified pattern and modified pattern by EPH method*

Table4. *Element phases e=0.499*

Phases	*Unmodified Pattern*	*(EPH) Method*
$\phi_1 = \phi_{-1}$	*0°*	*0°*
$\phi_2 = \phi_{-2}$	*36°*	*180°*
$\phi_3 = \phi_{-3}$	*72°*	*120°*
$\phi_4 = \phi_{-4}$	*108°*	*36°*
$\phi_5 = \phi_{-5}$	*144°*	*120°*

Table5. *Information about antenna pattern parameters*

Method	*Directivity*	*BeamWidth*	*SLL*
EPH	*11.3dB*	*76°*	*-18.3dB*
-------	*11.5dB*	*56°*	*-8dB*

3.2. The Excitements of the Elements Phases at Eccentricity Low Level (EPL Method)

Other method for optimizing the elliptical antenna array is EPL. In this way, we will make changes in the elements phases when the eccentricity amount is low, we found that only the side lobes low level don't have the best condition to send waves, so we want to find a good way for optimization with a complete structure. This structure ongh to provide the best values of theradiationparameters to reduce interference in transmission, the reasons which cause this method appropriate are the width of main lobe at eccentricity low level and SLL reduction by making the changes in element phases, therefore we combined these methods together and introduced a new method with the name of EPL [13].

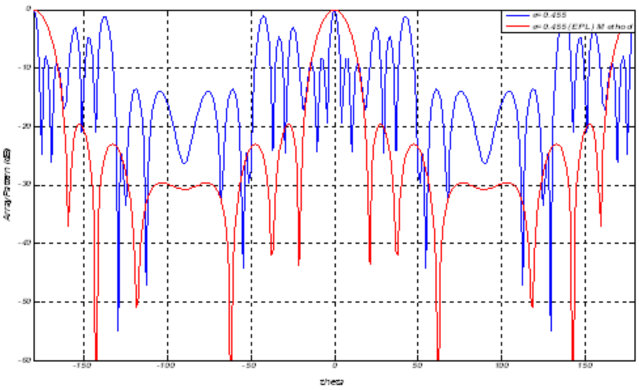

Figure.6 *compare between the unmodified pattern and modified pattern by EPL method*

Table6. *Element phases e=0.455*

Phases	*Unmodified Pattern*	*(EPL) Method*
$\phi_1 = \phi_{-1}$	*0°*	*0°*
$\phi_2 = \phi_{-2}$	*36°*	*162.1622°*
$\phi_3 = \phi_{-3}$	*72°*	*174.9271°*
$\phi_4 = \phi_{-4}$	*108°*	*191.8772°*
$\phi_5 = \phi_{-5}$	*144°*	*188.4817°*

Table7. *Information about antenna pattern parameters*

Method	*Directivity*	*BeamWidth*	*SLL*
EPL	*12.5dB*	*39°*	*-19.5dB*
-------	*14.6dB*	*8.4°*	*-1.12dB*

4. Genetic Algorithm

Genetic algorithm is an iterative stochastic optimizer that works on the concept of the survival of the fittest, motivated by Darwin, and uses methods based on the principle of natural genetics and natural selection to construct search and optimization procedures that best satisfies a predefined goal [21]. Genetic algorithms search about the solution space of a function through the use of simulated evolution, i.e., the survival of the fittest strategy. In general, the fittest individuals of any population who tend to reproduce and survive to the next generation, so improving a successive generation. However, inferior individuals can, by chance, survive and also reproduce. Genetic algorithm has been show to solve linear and nonlinear problem by exploring all regions of the state space exponentially exploiting promising areas through mutation, crossover, and selection operation applied to individuals in the population [16]. Genetic algorithms use principles ofnatural evolution. And there are five important features of (GA) as follow:

4.1. Encoding

Encoding is thepossible solution for problem that is considered as individuals in a population. If the solutions can be divided into a series of small steps (building blocks), then these steps are presented by genes and a series of genes (a chromosome) will encode the whole solution. This way for different solution of a problem are presented in (GA) as a chromosomes of individuals.

4.2. Fitness Function

Fitness function can present the main requirements of desired solution of a problem (i.e. cheapest price, shortest route, most compact arrangement). This function calculates and returns the fitness of an individual solution.

4.3. Selection

Selection operator defines the way individuals in the current population are selected for that reproduction. There are many strategies for that (e.g. roulette–wheel, ranked, etc), but usually the individuals which are more fit are selected.

4.4. Crossover

Crossoveroperator defines how chromosomes of parents are mixed in order to obtain genetic codes of their offspring. This operator implements the inheritance property (offspring inherit genes of their parents).

4.5. Mutation

Mutation operator creates random changes in genetic codes of the offspring. This operator is needed to bring some random diversity into the genetic code. In some cases GA cannot find the optimal solution without mutation operator (local maximum problem). We consider an elliptical array antenna of 10 isotropic antennas symmetrically that is 0.5λ apart with its center at the origin in order to generate broadside symmetric pattern in azimuth plane and the excitation amplitude distribution is uniform. In this paper, one idea has been presented and that is reducing array factor amount to decrease the interference with desired SLL of -15 or below. We know that the phases are effective elements of the antenna array mathematically function and the goal method is decreasing this function cost via definite algorithm,so we covert the phases values to the binary numbers and put them in the optimizing cycle to improve the beam steering by using desired algorithm.The application of the genetic algorithm is choosing the best particles after different iterations to reduce the global function cost. The structure of our method is based on the general behavior of the GA to synthesis the multi beam patterns , in other word the cost of the antenna array factor will be reduced in the normal mathematically process which is consist of two steps. The first step is selecting the initial antenna particle positions as the algorithm genes and presenting them to algorithm structure for optimizing the array function value,which has been selected as algorithm cost function. The second section is choosing the suitable trend of elements phases for side lobe level reduction, hence after first step, algorithm will provide various amounts of the genes which we convert to the decimal numbers again and put them in the antenna array function argument as radiator components locals,if these values can decrease quantity of the antenna function and also side lobe level, they will be selected as antenna elements phases and also If they don't have ability to receive the proposed idea, we operate the desired flowchart again, so the optimization has been shared to two parts, minimizing the array factor cost and then using the special technique to radiator components arrangement. This part is done to reduce SLL and main beamwidth when there is no coupling between the antenna elements. For this optimization, GA is run independently with fixed number of generation, the size of population is same as antenna array elements number and selection operator used in GA is uniform ranking with probability of 0.13 for selecting the best individuals.

4.6. Optimization Results

In this case, we want to minimize the array factor amount, first we reduce the eccentricity cost and then we optimize the cost function, this method will be operated in the different iterations with different values forarray factor that we will choose the lowest costs of it. Optimization results include minimized cost of array factor and also elements phases. We can see the amount of the phases in binary and radian mode in table 8, they have been selected by genetic algorithm as positions of the antenna elements. The important issue is the quantity of the array factor which is obtained by elements phases arrangement on the Antenna.

Table8. *Algorithm Genes*

ALGORITHM GENES	*PHASES*
00110000	**0.65°**
00110001	**1.30°**
00111000	**5.84°**
00110110	**3.80°**
00110010	**2.85°**
00101110	**0.72°**
00110111	**0.70°**
00111000	**0.80°**
00110101	**3.56°**
00101110	**2.50°**

Table9. *Different states of elements phase arrangement on ellipse*

State	$\phi_1 = \phi_{-1}$	$\phi_2 = \phi_{-2}$	$\phi_3 = \phi_{-3}$	$\phi_4 = \phi_{-4}$	$\phi_5 = \phi_{-5}$
1	*0.65°*	*1.3°*	*5.84°*	*3.8°*	*2.85°*
2	*0.8°*	*1.3°*	*5.84°*	*3.8°*	*2.5°*
3	*0.8°*	*1.3°*	*5.84°*	*3.6°*	*2.85°*
4	*0.7°*	*1.3°*	*5.84°*	*3.8°*	*2.85°*
5	*0.72°*	*1.3°*	*5.84°*	*3.8°*	*2.85°*
6	*5.84°*	*2.85°*	*1.3°*	*0.72°*	*3.56°*
7	*3.8°*	*5.84°*	*0.8°*	*0.72°*	*2.5°*
8	*2.85°*	*0.8°*	*3.56*	*1.3°*	*0.72°*
9	*1.3°*	*2.85°*	*5.84°*	*0.8°*	*0.72°*
10	*0.8°*	*1.3°*	*2.85°*	*0.7°*	*5.84°*

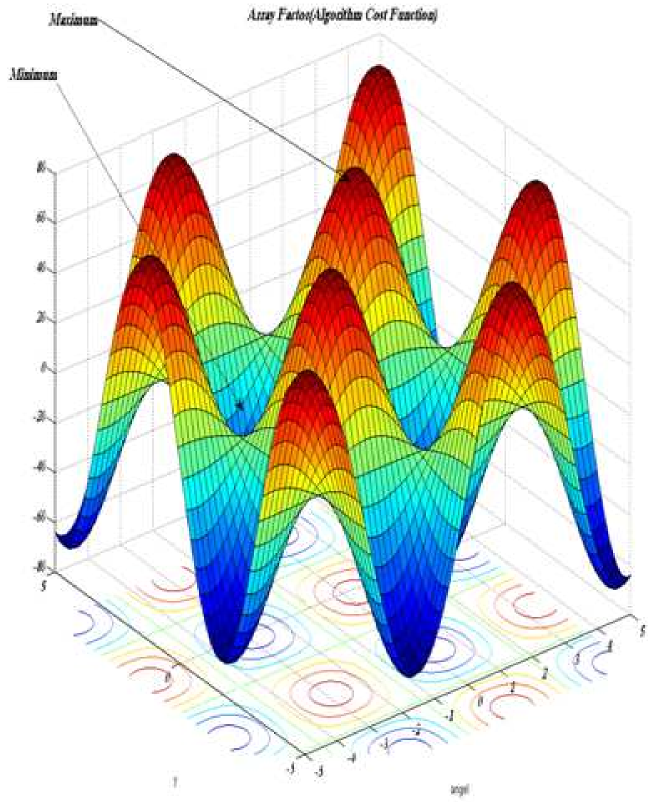

Figure. 7. *Algorithm Cost Function Value plot*

Table 10. *AF Amount in different states of elements phases placing e≈0*

State	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
AF	***38***	***20***	***25***	***36***	***34***	***30***	***54***	***74***	***52***	***55***

There are six states of array factor cost in the section 4.1 that can provide best condition for elliptical array pattern so we will select them as desired antenna array signal situations without interference to find optimized pattern. next section as final part of synthesis is consist of mutual coupling computing and choose the best state with low coupling between the elements for comparing with other optimized structures.

5. Numerical Results

To illustrate the performance of the proposed method for synthesis of the elliptical array antenna pattern some examples of uniform excited elliptical array with N=10 and also one-half wavelength spaced isotropic elements were performed. The results of steering beam in the direction of desired signal without waveform are presented in figure 8 and also table 12 shows the information about signals radiation parameters values.

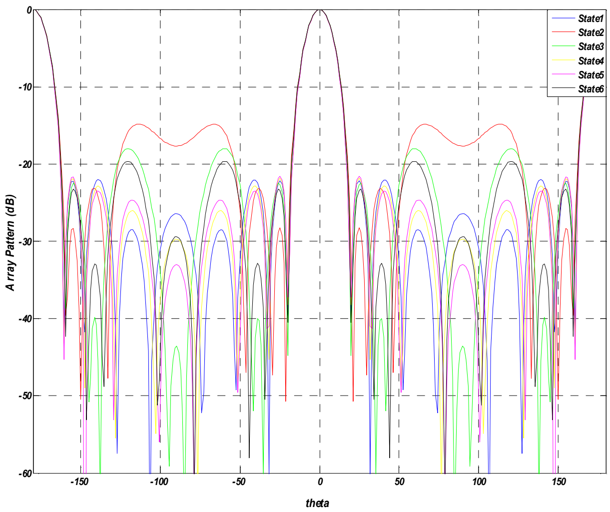

Figure.8. *Modified elliptical antenna patterns by(GA) state 1-6 e≈0* φ_0*=90*

The figures show the ability of genetic algorithm to improve the elliptical antenna array pattern with good radiation parameter values such as directivity, side lobe level and main pattern beamwidth but one of them is right to introduce as optimized signal, so we have presented Table 11 and 12 to choose the best state. Table 11 doesn't include all of the coupling impedances between the array components because we just wanted to present some of them to show the GA method effect on the mutual coupling influence reduction.

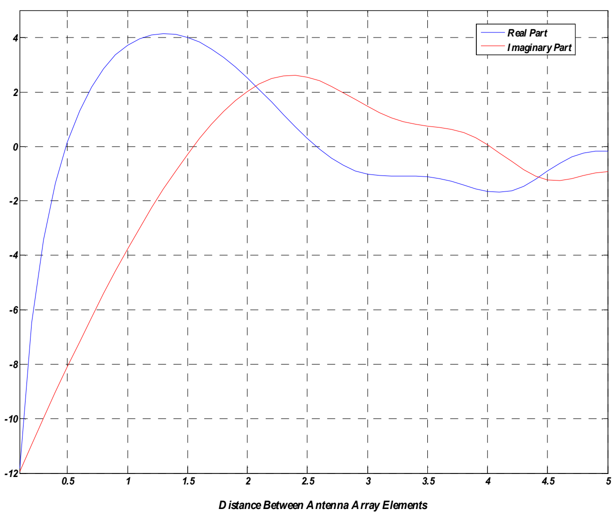

Figure.9. *Mutual Coupling value plot between array elements*

Table 11. *Mutual coupling computing between the array elements*

S	$Z_{4,8}$	$Z_{3,7}$	$Z_{4,6}$	$Z_{5,7}$	$Z_{2,9}$	$Z_{1,8}$
1	3.3+2.2j	2.9-3j	3.7-1.6j	4.2-0.0j	2.6+3j	0.7+4j
2	3.3+2.2j	2.9-3j	3.5-1.5j	3.8-0.0j	2.6+3j	1+3.9j
3	3.2+2.7j	2.9-3j	3.5-1.7j	4.2-0.0j	3+2.8j	1+40j
4	3.3+2.2j	2.9-3j	3.6-1.5j	4.2-0.0j	2.6+3j	0.7+4j
5	3.3+2.2j	2.9-3j	3.6-1.5j	4.2-0.0j	2.6+3j	0.8+4j
6	3.7+1.6j	3.2+2.3j	0.8+4j	4.1-0.0j	3.8-0.7j	3-3j

Table 12. *Different states radiation parameters values*

States	Eccentricity	Directivity	BeamWidth	SLL
1	**9.99×10^{-4}**	**13.02dB**	**38°**	**-22.0dB**
2	9.99×10^{-4}	13.01dB	38°	-14.8dB
3	9.99×10^{-4}	13.01dB	38°	-17.9dB
4	9.99×10^{-4}	13.01dB	38°	-21.8dB
5	9.99×10^{-4}	13.00dB	42°	-21.6dB
6	9.99×10^{-4}	13.01dB	38°	-19.7dB

We analyzed the numerical results from the simulated structure of the antenna pattern and finally we found that the first state is better than the other and we can introduce it as the optimized signal.

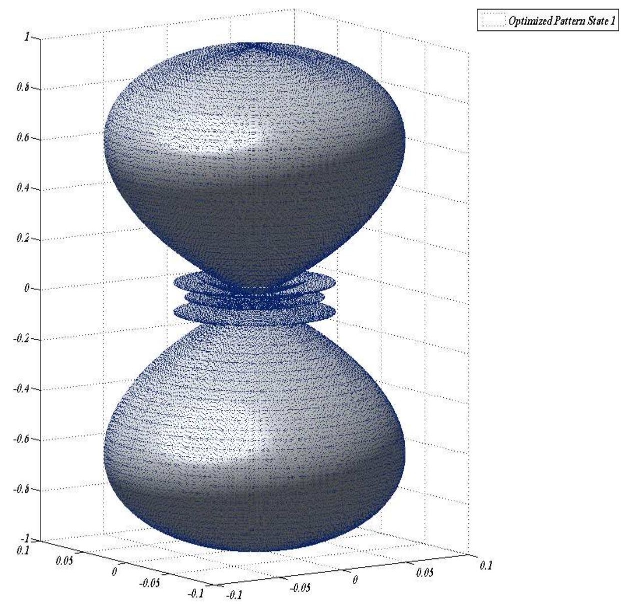

Figure.10. *Optimized Elliptical Antenna Array Pattern State 1* φ_0*=90°*

The elliptical array antenna pattern obtained by using GA will be compared to elliptical array antenna pattern obtained by using EPL method and also optimized circular array pattern by IWO with 10 isotropic array elements. Figure 11 shows the elliptical array pattern obtained by using results in Table 13 for N=10 as compared to that obtained by using other algorithm in[13].

Table 13. *Comparing between radiation values of the various structure*

Method	Directivity	Beam Width	SLL	eccentricity
GA (UEA)	13.01dB	38°	-22.0dB	e≈0
EPL (UEA)	12.50dB	39°	-19.5dB	0.455
IWO (UCA)	14.40dB	50°	-17.5dB	0

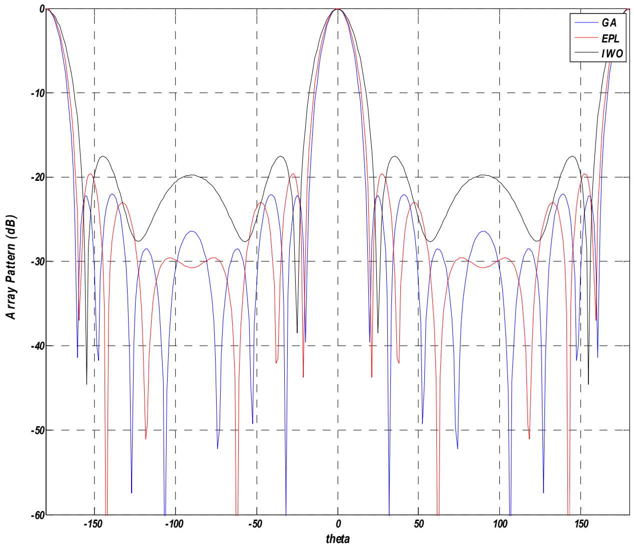

Figure.11. *Radiation pattern for N=10 using the GA results as compared to The EPL and circular array obtained byIWO results from [13] (φ_0=90°)*

It can be seen that using the GA method gives a radiation pattern which is generally better than that obtained from the EPL results. Specifically, all side lobes have levels less than -15 dB. Similarly figure 11 shows the array pattern obtained by using the results in Table 13 for *N=10* as compared to that obtained by using EPL results in [13]. Again, the GA results are, in general, better than the EPL results. Lastly, figure 11 shows the array pattern obtained by using the results in Table 13 for *N*=10 as compared to uniform circular array antenna obtained by using IWO results [13].

6. Conclusions and Discussion

Designing uniform antenna array structure with minimum SLL and maximum Directivity increasing is a challenging optimization problem in computational electromagnetics [7]. In this paper, the GA method was used to adjust elements phases in the elliptical antenna array to obtain better side lobe level with good Directivity suppression. We have presented a pattern synthesis method of uniform elliptical array to provide the suitable signal. Array patterns obtained from GA results are generally better than the other optimized array signal. Now we should pay toAdvantages and disadvantages of the optimized antenna pattern, the advantages of the desired antenna array is the flexible structure, which refers to geometric elements of the ellipse and especially eccentricity, the method of the synthesis will be easy when we focus on the changes of the eccentricity hence the researchers can control the ellipse overall shape and main beam pattern width by this parameter modify, of course we must say that the disadvantage of the offered array will be caused by eccentricity too, hyper excitements of this element can make waveform on the signal steering and finally the method of the optimization will be very hard. At present time, we are investigating the application of the global algorithm method to optimize the pattern of the antenna array especially smart antenna to synthesis the radar cross section propagations.

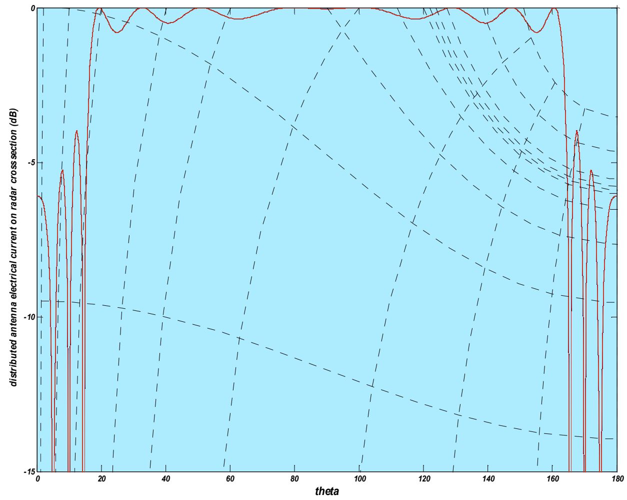

Figure.12. *Plot of Distributed electrical current of elliptical antenna array on the radar cross section indB scale*

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