Sidelobe Reduction in Linear and Planar Array Antenna

Using the Genetic Algorithm

Ali Abdulhadi Noaman

Dr. Abdul Kareem S. Abdallah   Dr. Ramzy S. Ali

Dept .of Electrical Engineering, University of Basra, Basra, Iraq

Abstract

This paper describes the problem of minimizing the sidelobe levels in the radiation pattern of antenna arrays by using the genetic algorithm. Two types of genetic algorithms representation are used here: binary and continuous genetic algorithms depending on the nature of the problem at hand. Adaptive genetic algorithm which is a special type of genetic algorithm is used in this work. The obtained results explain the capability of this approach to obtain the desired sidelobe level.

تقليل قيمة الفصوص الجانبية لأشعاع الهوائيات المصفوفية بأستخدام الخوارزميات الجينية

علي عبد الهادي نعمان

د. عبد الكريم سوادي عبد الله   د. رمزي سالم علي

كلية الهندسة ــ جامعة البصرة

الخلاصة: يوضح هذا البحث كيفية خفض الفصوص الجانبيه التي تظهر في نموذج الأشعاع للهوائيات المصفوفيه عن طريق أستخدام الخوارزميات الجينيه. لقد أستخدم في هذا البحث نوعين من أنواع الخوارزميات الجينيه: الخوارزميات الثانيه والمستمره وذلك أعتمادا" على طبيعة المسأله المتناوله. الخوارزميات الجينية المتكيفة وهو نوع خاص من الخوارزميات الجينية أستخدم في هذا البحث. تبين النتائج مقدرة هذة الطريقة المقترحة للحصول على التصميم المرغوب به من حيث قيمة الفصوص الجانبية.

Keywords: genetic algorithms, linear array antenna, planar array antenna.

1. Introduction

The sidelobe has an important effect on the performance of different communication systems, for example in the satellite communication system, antennas are used to receive signals transmitted from a satellite. One type of satellite antenna is the antenna array. Figure (1) shows the geometry of two types of array antenna: linear and planar array antenna. The array antenna pattern has a main beam and many sidelobes as shown in Figure (2). The main beam points into space in the direction of the satellite and has a high gain to amplify the weak signals, while sidelobes have a

low gain and point in various directions other than main beam. The problem with the sidelobe is that strong undesirable signals may enter them and drown out the weaker desired signal entering the main beam. The satellite signal is extremely weak because it travels along distance and the satellite transmits a low power [1]. If a cellular phone close to the satellite antenna operates at the same frequency as the satellite signal, the phone signal could enter a sidelobe of the satellite antenna and interfere with its desired signal. Another example is for transmit antennas communicating classified information; sidelobes represent security vulnerability, as unintended receiver may pick up the classified communication. Thus, it is necessary to maximize the main beam gain while minimizing the sidelobe gain [1].

Numerous classical methods have been proposed over the years to reduce the SLL value such as binomial, and Dolph-Tsehebyseheff. While they could reduce the SLL to the desired level, they exhibit many practical disadvantages such as the wide variations between the amplitudes of the different elements of an array, and the large beamwidths. This may be a problem in array beamformer hardware implementation. The GA can be used to achieve the desired SLL and in the same time controlling the value of beamwidth of the main beam. It can be also to treat some complicated problem such as arbitrary geometric layout.

The problem of array antennas sidelobe level (SLL) has been considered in the specialized literature [2-4]. This paper explains how the designers could design an array antenna with a minimum sidelobe level by using a simple and flexible genetic algorithm (GA). Two types of genetic algorithms are used in this work: binary GA, where the variables are represented by ones and zeros, and the real GA where the variables are represented by real values without any coding process [1]. The genetic algorithm method used in this work is different from the algorithms used in [2-4]. Adaptive Genetic Algorithm (AGA) is used in this work. AGAs are GAs whose parameters, such as the crossing over probability, or the mutation probability is varied while the genetic algorithm is running [1]. A simple variant could be the following: The mutation rate can be changed according to changes in the population; the longer the population does not improve, the higher the mutation rate is chosen. Vice versa, it is decreased again as soon as an improvement of the population occurs. The results show the capability of this method to solve the problem of minimizing the value of sidelobe level in array radiation pattern by optimizing different types of design variables such as excitation coefficients, elements spacings.

The paper is presented as follows. The genetic algorithm is briefly explained in section 2. In addition, the representation scheme and the fitness function are also explained in this section. In section 3, the optimization procedure is discussed. The numerical results are explained in section 4. Finally, conclusions are given in section 5.

2. Genetic Algorithm

The genetic algorithm is an optimization and search technique based on the principles of genetics and natural selection .The genetic algorithm consists of three operators [5]: reproduction, crossover, and mutation. The method was developed by John Holland (1975) and popularized by one of his students, David Goldberg [6].

The main advantages of the *GA* are [7]: the ability to manipulate many parameters simultaneously, the good performance in the problems for which the fitness landscape is complex-ones where the fitness function is discontinuous, noisy, changes over time, or has many local optima. Figure (3) shows the flow chart of adaptive *GA*. In this algorithm, the parameters such as the crossing over probability or the mutation probability are varied while the genetic algorithm is running to achieve the best results with compared the standard genetic algorithms.

2.1 Representation

The most common representation in a *GA* is binary. However, the continuous *GA* is more suitable for the problems with real or complex variables. In this paper we choosed the binary *GA* for the array layout optimization problem because it is suitable for this kind of problems.

Each gene in the chromosome was represented by characters belonging to an alphabet *{0, 1}*. The chromosome in this case consists of binary strings, with one bit per antenna array element. Elements that are "on" are represented by a "*1*"and elements that are "off" are represented by "*0*".

Then, if we have *N* elements linear array antenna, then a chromosome is a vector X consisting of N genes C_i.

$$X= (C_1, C_2, \dots\dots, C_N) \qquad (1)$$

$$C_i \in \{0,1\}$$

For the other problems such as optimization elements excitations or finding the optimal distances between the array elements, a continuous *GA* was used because it is more precise, requiring less storage and it is faster than the binary *GA*. For an array antenna with N elements, then the chromosome will have N variables (an N-dimensional optimization problem) given by $p_1, p_2, \dots, p_N$ and the chromosome is written as

$$x= [p1, p2, p3, \dots\dots, pN] \qquad (2)$$

In this case, the variable values are represented as floating-point numbers. These variables may be represented the excitation of the array elements or the distances between the elements, depending on the problem at hand.

2.2 Fitness Function

The fitness of a chromosome belonging to a population is an artificial quantity that characterizes each string. It is used to detect the more promising chromosomes to be investigated. Depending on their fitness, the chromosomes will be chosen probabistically for the reproduction process.

The fitness function that will be used in this article is given by:

$$C=min\ (abs\ (AF\ (\Theta)) \qquad (3)$$

where *AF* represents the array factor of the array antenna, Θ refers to position of the sidelobes. This function will operate only in the sidelobe regions to minimize the sidelobe level by controlling the value of the elevation angle.

3. Optimization procedure

The work can generally be divided into two parts: the first part deals with linear array antenna and the other part deals with planar array antenna. In the case of linear array antenna, the sidelobe optimization problem has been solved by taking three different cases: optimization of elements weights, optimization of elements position and array layout optimization. For the planar array antenna, the excitations and the elements position are considered in the optimization procedure. In this work and since the population size depend on the complexity of the problem, the size of the population is chosen to be *100* individuals since a large population requires much more computational cost, memory and time while the small population will badly lack the diversity required to find the optimal solution for the problem at hand. The first population is chosen randomly and each chromosome is sorted according to its fitness value. After that, the genetic operations such as selection, recombination, and mutation are applied to generate the next population. This process continuing until the solution is converged to the desired sidelobe level.

4. Numerical Results

4.1. Linear Array Antenna

A) elements weights optimization

In the first, an array antenna with one-half wavelength spaced *20* isotropic elements was used and the elements excitations of this array were determined. The array factor of broadside array positioned on the Z-axis can be written as [8]:

$$AF(\theta) = \sum_{n=1}^{N} a_n e^{j(n-1)(kd\cos\theta+\beta)} \qquad (4)$$

where $d=\lambda/2$, $k=2\pi/\lambda$, a_n is the weight of the nth element, θ is the scanning angle from broadside, d is the distance between the two neighboring array elements, and β is the progressive phase excitation between the elements. Random element excitations are used here as shown in Table (1), and Figure (4 a) shows the pattern of this array with sidelobe level (SLL) of -6.769dB. On the other hand, the uniform excitation method results in a SLL equal to -13.4 dB as shown in the same figure. After using GA optimization, the optimum element excitations are also shown in Table (1). The optimum pattern is shown in Figure (4b) with SLL of -19.65 dB which is clearly smaller than that of the random and uniformly excitation array.

As a matter of comparison, let us consider an array of N=10 elements and d=λ/2 symmetrically positioned on the z-axis. The optimum Dolph-Chebyshev current distribution which gives the lowest sidelobe levels for a prescribed beamwidth value among the available practical distributions is considered here for comparison. Assuming the amplitude excitation is symmetrical about the origin, Table (2) shows the Dolph-Chebyshev excitation values along with the optimum excitation values obtained by GA. The optimal pattern found by GA is plotted in Figure (5) along with that of the Dolph-Chebyshev distribution. It is clear that the pattern produced by GA has smaller SLL than that of Dolph-Chebyshev distribution. Moreover, Dolph-Chebyshev method is

only applicable to uniformly spaced array [9] while *GA* can be applied to arbitrary spaced array.

B) Optimization of elements positions

Consider the nonuniformly spaced, linear antenna array depicted in Figure (6). This array is symmetrical about its center, and each element has the same amplitude and phase. The number of elements, not shown in Figure (6) is *20*.The design goal is to find the *20* element-to-element spacings that yield the lowest maximum sidelobe levels relative to the amplitude of the main beam by using the *GA*. Because the array is symmetrical, only *10* spacings need to be found. The equation for the array factor of this antenna array is given by [9]:

$$AF(\theta) = 2\sin(\theta)\sum_{n=1}^{\frac{N}{2}}\cos\left[k\left(\sum_{m=1}^{n}d_m - \frac{d_1}{2}\right)\cos(\theta)\right]$$

(5)

Figure (7a) shows the initial radiation pattern for a *20*-element array with uniform excitation and uniform spacing $(d=\lambda/2)$.The maximum sidelobe level is *-13.21dB*.The optimized radiation pattern is shown in Figure (7b). The element-to-element spacings for this configuration in wavelengths are: *0.6158, 0.5109, 0.3178, 0.3701, 0.3668, 0.2847, 0.3436, 0.4969, 0.3602, and 0.4161*. These values are sorted on the both sides of the array center. The maximum relative sidelobe level is *-21.28 dB*.

Grating Lobe Problem:

For a uniform spacing array antenna, the maximum angle that the array can be scanned from broadside without the appearance of grating lobes in the radiation pattern can be written as [10]:

$$\theta s = sin\text{-}1(\lambda/d - 1) \qquad (6)$$

For linear array antenna with uniform spacing $d=\lambda$, the scan angle is 0° from broadside. If it is desired to get a scan angle of 90° then the resulted pattern will contain grating lobes as shown in Figure (8a). The *GA* will be used here to eliminate the grating lobes in the radiation pattern of uniform excitation linear array antenna with *N=40*. Figure (8b) shows the optimized pattern obtained by *GA* with optimal element-to element spacings. The *GA* clearly reduces the grating lobes, creating a pattern with maximum *SLL* of *-21.31dB*. The optimized array can now be scanned from 0° to 90° without *SLL* rising above *-21.31dB*. The optimal element-to-element spacings sorted on both sides of the array center for this uniform configuration in wavelengths are: *0.99874, 0.81233, 0.087924, 0.16017, 0.61264, 0.36885, 0.27792, 0.39032, 0.076779, 0.44709, 0.52089, 0.23415, 0.27297, 0.52385, 0.43326, 0.21287, 0.44075, 0.52067, 0.081004, and 0.47274*. In another case, the *GA* is used to eliminate the grating lobe that produced when the main beam is shifted by 45° from the broadside. The initial and the optimized radiation patterns are shown in Figure (9). For comparison purpose, *16* elements linear array antenna with a uniform spacing of *0.8* wavelengths steered to 60° that considered in reference [2] is considered here. *SLL* of *-15 dB* is achieved here as shown in Figure (10) with compared to about *-13dB* obtained in reference [2].

C) Optimization of array layout

A number of applications require a narrow scanned beam, but not commensurably high antenna gain. Since the array beamwidth is related to the largest

dimension of the aperture, it is possible to remove many of the elements (or to "thin") an array without significantly changing its beamwidth. The array gain will be reduced in approximate proportion to the fraction of elements removed, because the gain is related directly to the area of the illuminated aperture. This procedure can make it possible to build a highly directive array with reduced gain for a fraction of the cost of a filled array. The cost is further reduced by exciting the array with a uniform illumination, thus saving the cost of a complex power divider network [10].

Typical applications for thinned arrays include satellite receiving antennas that operate against a jamming environment, where the uplink power is adequate in terms of signal-to-noise ratio in the absence of jamming. For this case, antenna gain is of secondary value; only sidelobe suppression or adaptive nulling can counter the jammer noise, and a narrow main beam can discriminate against jammers very near to the main beam. A second application often satisfied by thinned arrays is ground-based high-frequency radars, in which the received signal is dominated by clutter and atmospheric noise. Here again, the emphasis is on processing and array gain is of secondary value to the system. A third application and one of the most significant, is the design of interferometer arrays for radio astronomy. Here the resolution is paramount, while gain is compensated by increased integration time. For applications such as these, the goal of the antenna system is to produce high resolution, so the array should be large, but not necessarily high gain [10].

An array antenna of *50* elements with one –half wavelength spaced is considered here. Figure (11a) shows the radiation pattern of this array with maximum *SLL* of *-13.27dB*. The optimization goal is reducing the sidelobe level by the thinning the array antenna (optimally removing some elements from the array antenna). Figure (11b) shows that the value of maximum *SLL* became *-20 dB* after the optimization process in which 52 % of the elements were removed from the array antenna. The final optimal array layout is:

[01001001010010101101101110110101011010101001001000], where *1*'s belongs to the existence of the elements, while *0*'s denote the removed elements.

4.2 *Planar array antenna*

The linear array only controls the pattern in one plane; it depends on the element pattern to control the beam in the other plane. Planar arrays as shown in Fig. 4.b can control the beam shape in both planes and form pencil beams. The array factor for the planar array can be written as [8]:

$$AF(\theta) = \sum_{n=1}^{N} I_{In} \sum_{m=1}^{M} I_{ml} e^{j(m-1)(kd_x \sin\theta\cos\phi + \beta_x)} e^{j(n-1)(kd_y \sin\theta\sin\phi + \beta_y)}$$

(7)

where I_{ml} and I_{In} are the mth and n^{th} elements excitation coefficients along x-axis and y-axis respectively, d_x and d_y are the spacings between elements along the x-axis and y-axis respectively, β_x and β_y are the progressive phase shifts between the elements along the x-axis and y-axis respectively.

In matrix form

$$AF = S_{xm}S_{yn} \qquad (8)$$

where

$$S_{yn} = \sum_{n=1}^{N} I_{1n} e^{j(n-1)(kdx \sin \theta \sin \phi + By)} \qquad (9\text{-}a)$$

$$S_{xm} = \sum_{m=1}^{M} I_{m1} e^{j(m-1)(kdx \sin \theta \cos \phi + Bx)} \qquad (9\text{-}b)$$

For the case of (10x10) planar array antenna with equal amplitude and phase excitations and nonuniformly elements spacings, as shown by Table (3), the goal from using the GA is to find the optimal element-to-element spacings (in wavelength) to reduce the sidelobe level in the radiation pattern. Figure (12a) shows the initial pattern with sidelobe level of -6.721 dB, Figure (12b) shows the optimized pattern with maximum SLL of -16.87 dB. The two Figures display the corresponding two-dimensional elevation patterns with cuts at $\Phi = 90^{\circ}$ (y-z plane). The optimal spacings (in wavelength) are also listed in Table (3).

5. Conclusion

The obtained results demonstrated that GA is an effective and flexible method for array antenna sidelobe level control. A powerful optimization method results from the adaptive nature of the optimization method that was used in this work. All the design cases were considered in this work which explains the ability of this method. The different optimization cases studied in this paper and the quality of optimization obtained results explain the affectivity of the optimization method considered in this work are compared with the methods that were used in other papers in this field.

References

[1] Randy L.Haupt, Sue Ellen Haupt, Practical Genetic Algorithms, 2nd edition John Wiley & Sons, Inc., 2004.

[2] Matthew G. Bray, et.al, "Optimization of Thinned Aperodic Linear Phased Array Using Genetic Algorithms to Reduce Grating Lobes during Scanning". IEEE Trans. Antennas and Propagat. Vol. 50, NO. 12, pp. 1732-1740, 2002.

[3] Keen-Keong Yan and Yilong Lu, "Sidelobe Reduction in Array- Pattern Synthesis Using Genetic Algorithm". IEEE Trans. Antennas and Propagation, Vol. 45, NO. 7, pp.1117-1122, July 1997.

[4] D. J. O'Neill, "Elements Placements in Thinned Arrays Using Genetic Algorithms", IEEE Int. conf. Oceans 94 Osates, Vol. II, NO.9, pp.301-306, 1994.

[5] Hartmut Pohlheim, "Evolutionary Algorithms: overview; Methods and Operators", pp.1-51, version 3.7(November 2005), http://www.geatbx.com.

[6] Mitchell Melanie, An Introduction to Genetic Algorithms, 1996 Massachusetts Institute of Technology.

[7] M. Melanie, An Introduction to Genetic Algorithms, MIT Press, Massachusetts, 1999.

[8] Constatine A. Balanis, Antenna theory analysis and design, 2nd edition, John Wiley & Sons, Inc, 1997.

[9] Lal Chand Godara, Handbook of antennas in wireless communications, CRC Press LLC, 2002.

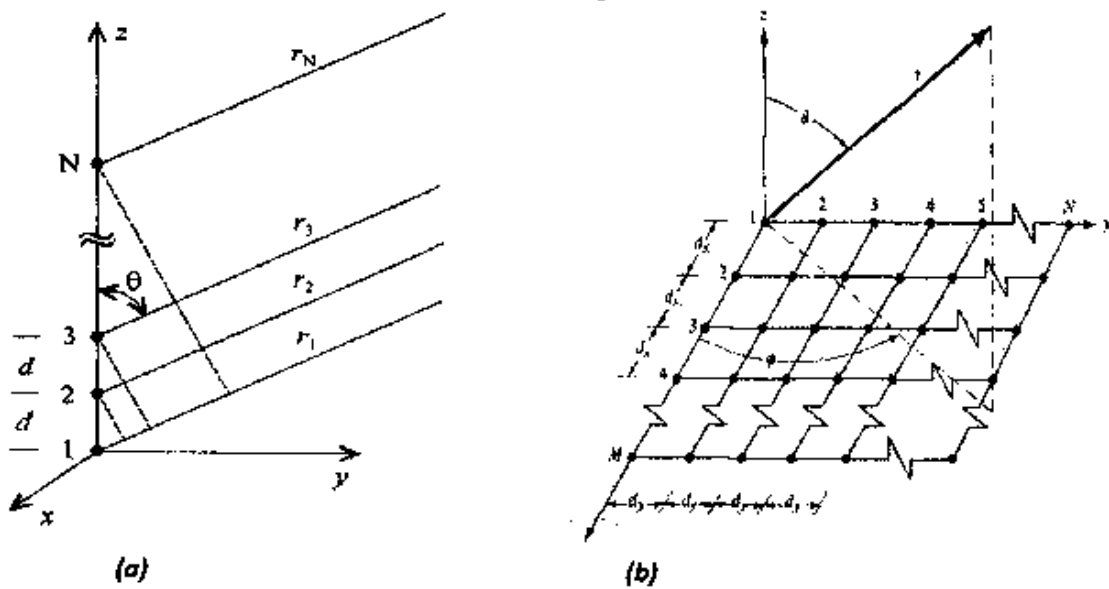[10] Robert J. Mailloux, Phased Array Antenna Handbook, Second Edition. Norwood: ARTECH HOUSE, INC., 2005.

Figure (1): Geometries of array antennas
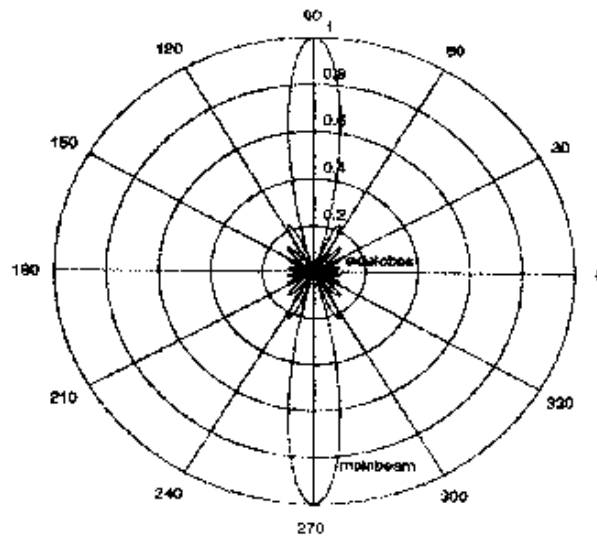
(a) Linear array antenna
(b) planar array antenna

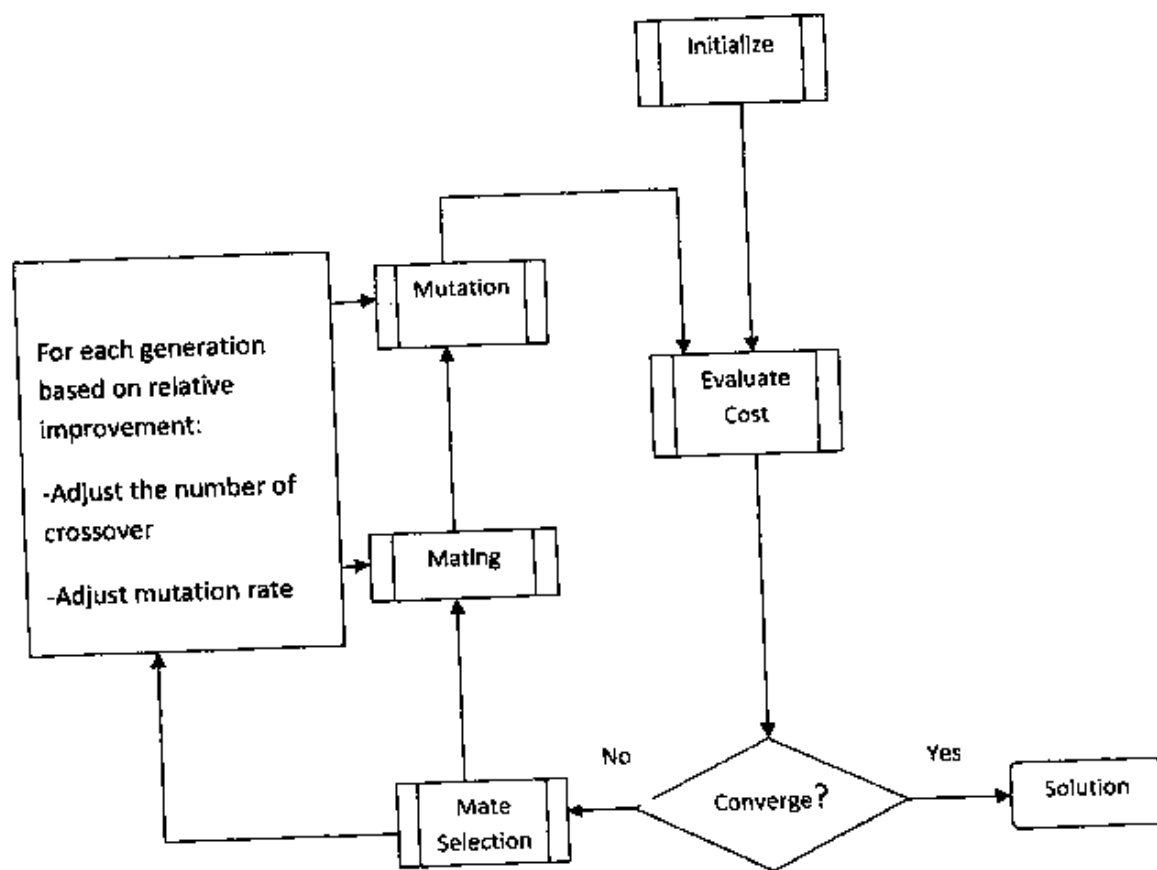**Figure (2): Plot of an antenna polar pattern that shows the mainbeam and sidelobes**

Figure (3): Flowchart of adaptive genetic algorithm
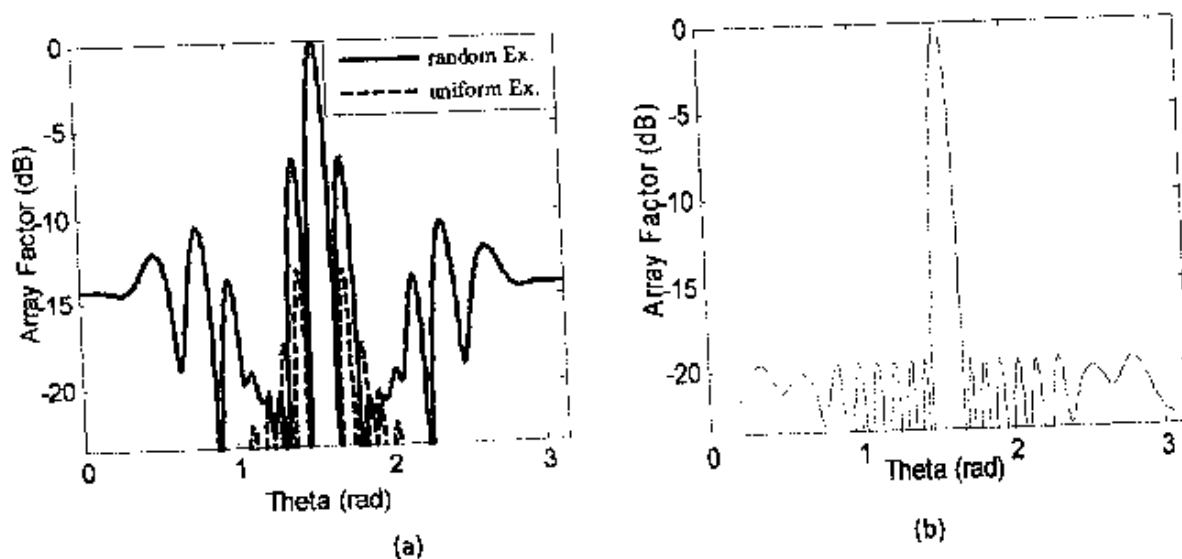

(a)

(b)

Figure (4): Initial and optimized patterns of linear array antenna

(a) with random and uniformly elements excitations
(b) with optimal elements excitations

Table (1): Normalize random and Optimum excitations of N=20, d=λ/2 linear array

n	Random excitations (Volts)	Optimum excitations (Volts)
1	0.005	0.549362
2	0.25	0.542963
3	0.45	0.390515
4	0.3	0.433499
5	0.15	0.749602
6	0.9	0.402159
7	0.25	0.812486
8	0.4	0.869906
9	0.005	0.338223
10	0.3	0.958739
11	0.05	0.59917
12	0.3	1
13	0.05	0.594597
14	0.4	0.616542
15	0.45	0.612159
16	0.15	0.606008
17	1	0.377906
18	0.45	0.431162
19	0.3	0.565449
20	0.5	0.582952

Table (2): Dolph-Chebyshev and Optimum normalized excitations of N=10, d=λ/2 linear array

n	Dolph-Chebyshev excitation (Volts)	Optimum excitations (Volts)
1	0.357375	0.234933
2	0.484975	0.430991
3	0.705568	0.654791
4	0.892119	0.88163
5	1	1
6	1	1
7	0.892119	0.88163
8	0.705568	0.654791
9	0.484975	0.430991
10	0.357375	0.234933
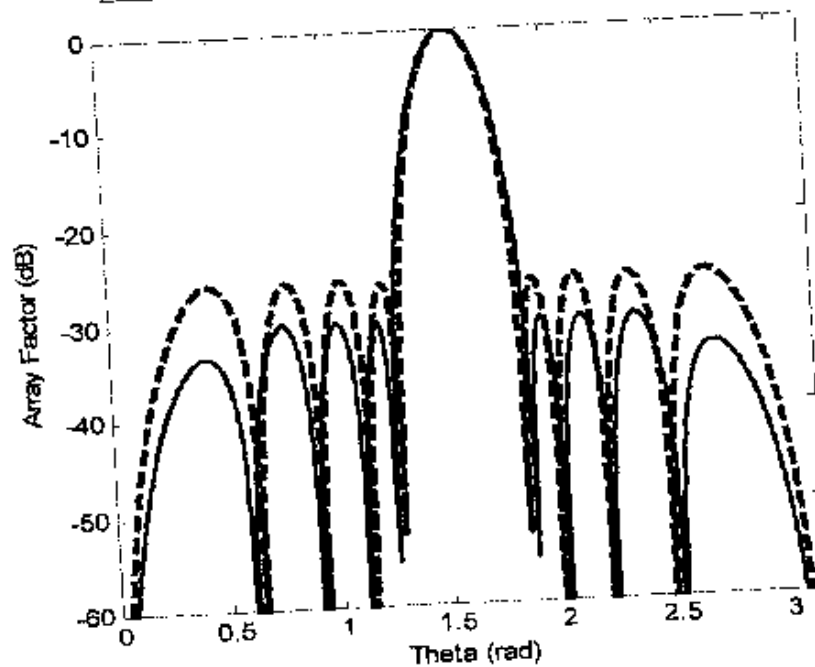
Figure (5): Comparison of patterns of N=10, d=λ/2 linear array with excitations found by GA (solid line) and Dolph-Chebyshev method (dash line)
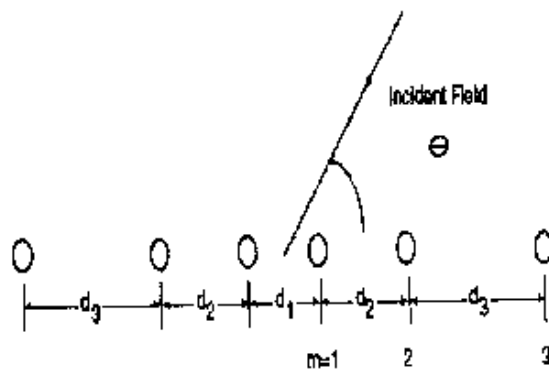
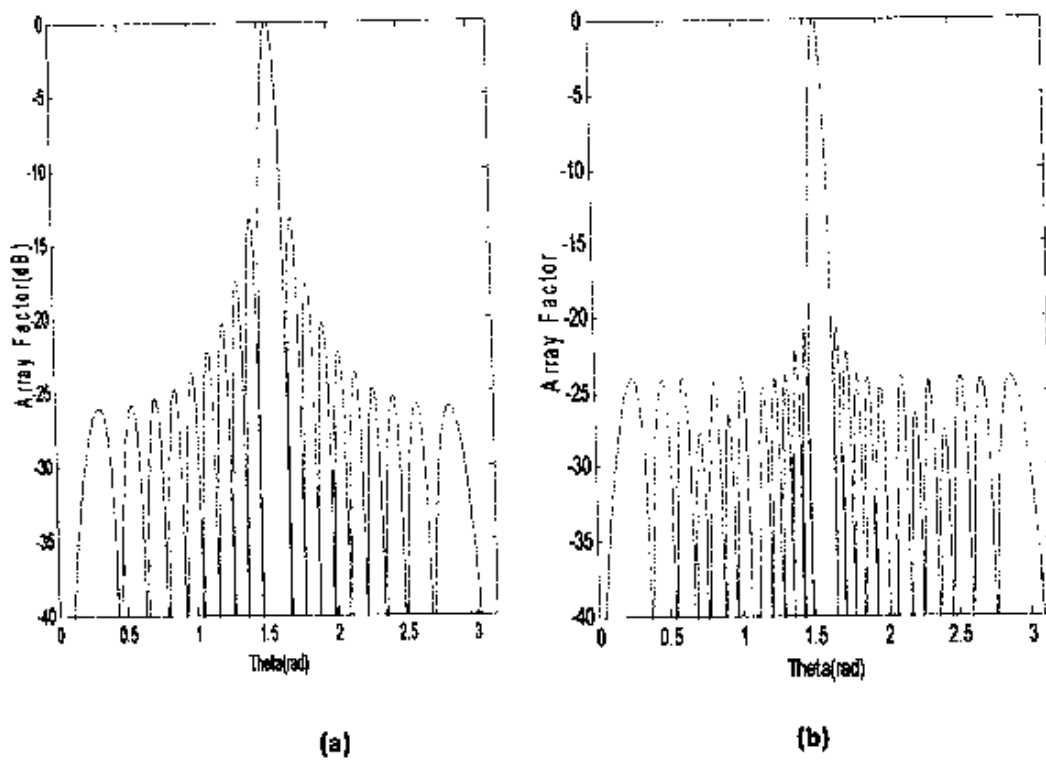**Figure (6): Asymmetrical linear array with nonuniform spacings**

(a)

(b)

Figure (7): Initial and optimized patterns for N=20 linear array with:

(a) spacing of d=λ/2.

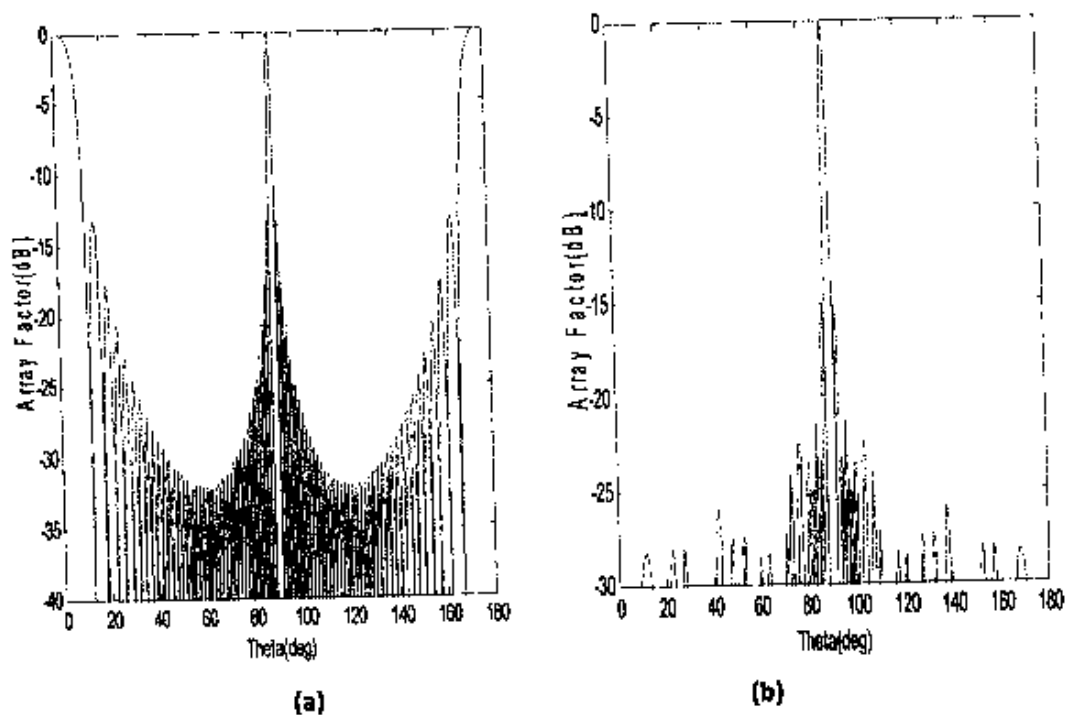**(b) optimized nonuniform spacings**

(a)

(b)

Figure (8): Initial and optimized patterns for N=40 linear array with:

(a) spacing of d=λ

(b) optimized nonuniform spacings

(a)

(b)

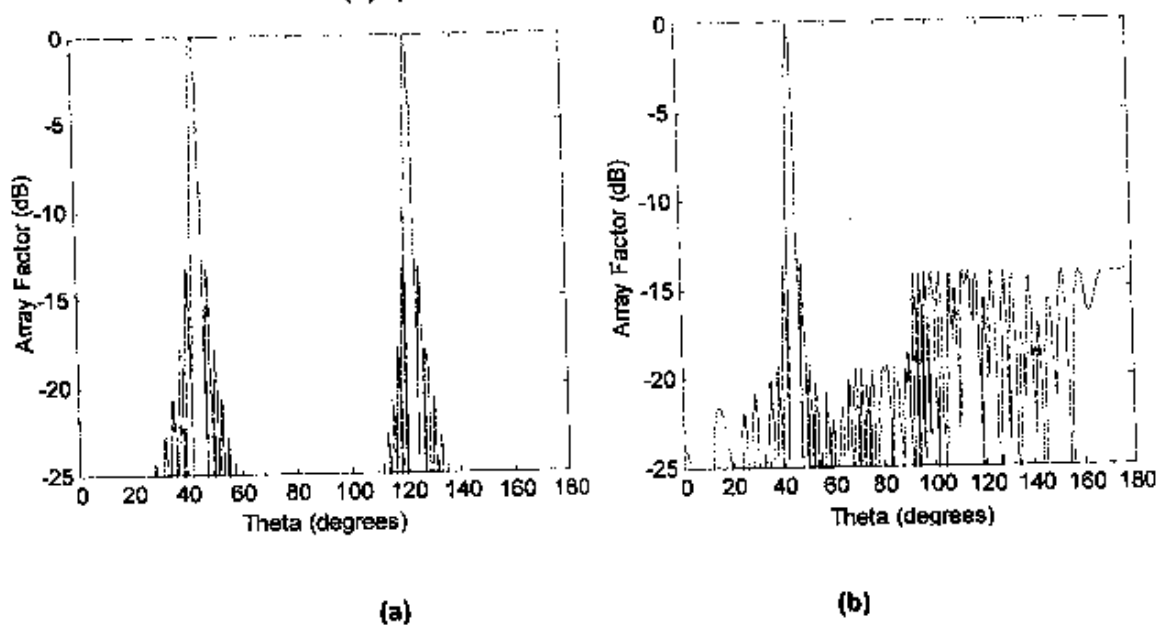*Figure (9): Initial and optimized patterns for N=40 linear arrays with:*
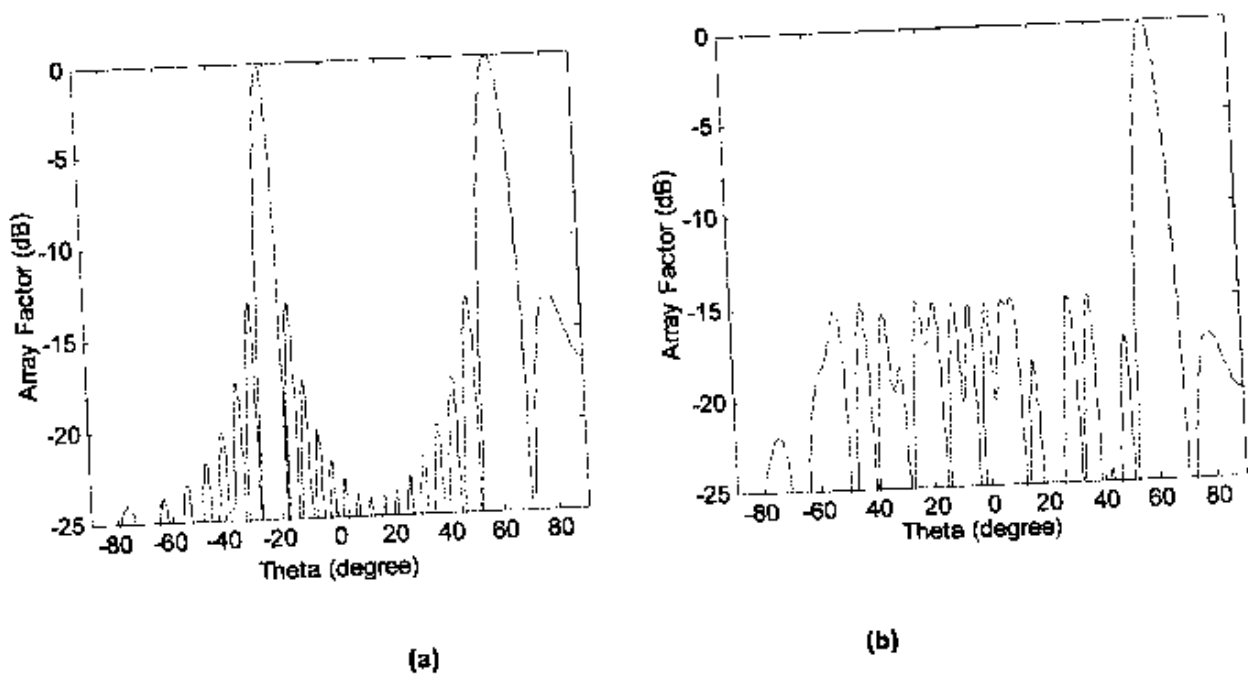
(a) Spacing of d=0.8λ; (b) Optimized nonuniform spacings

(a)   **(b)**

Figure (10): Initial and optimized patterns for N=16 linear arrays with:

(a) Spacing of d=0.8λ

(b) Optimized nonuniform spacings
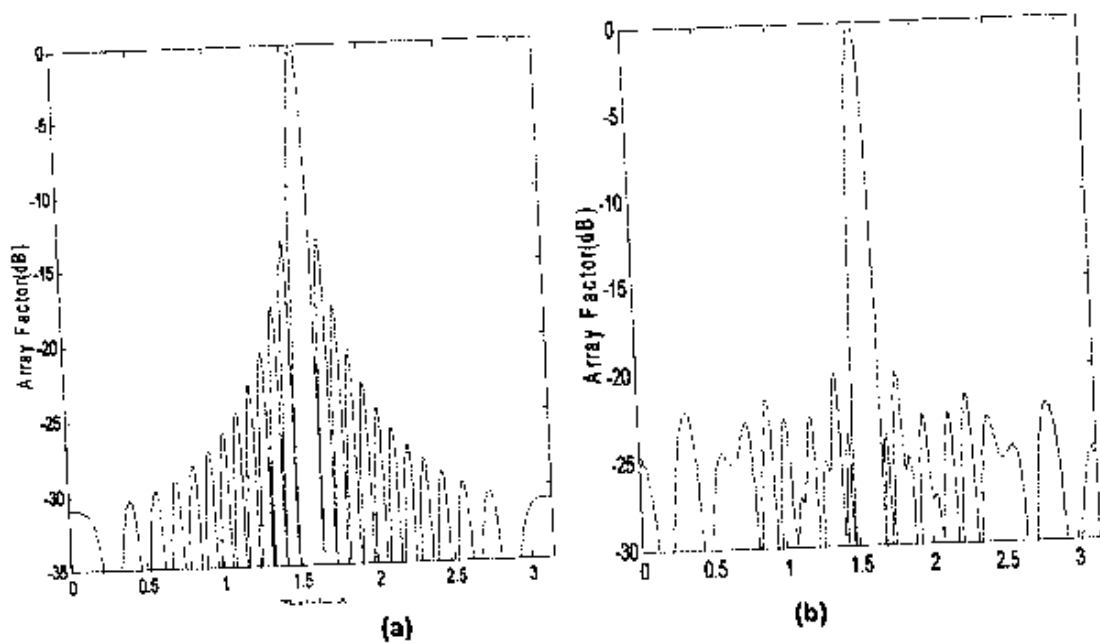

(a)   **(b)**

Figure (11): Initial and optimized patterns for N=50 linear array with d=λ/2

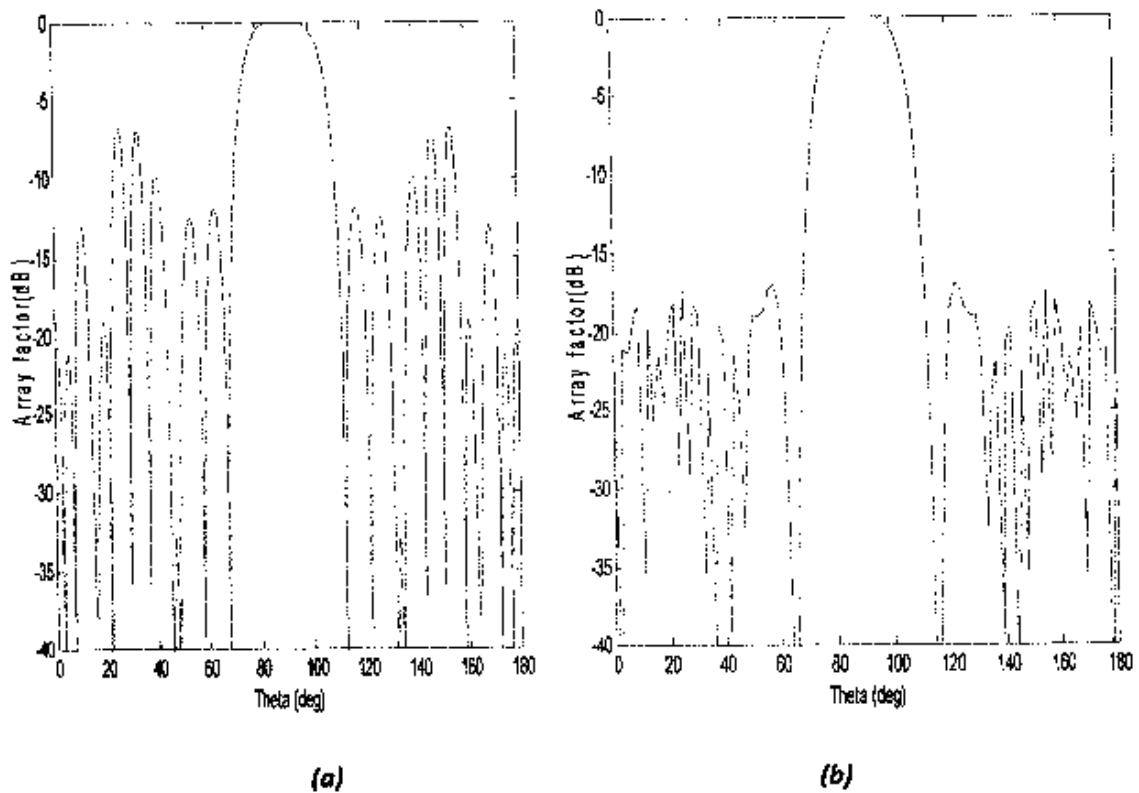*(a) uniform spacing array; (b) optimized thinned linear array*

(a)

(b)

Figure (12): Initial and optimized patterns for (10x10) planar array with:

(a) randomly spacings

(b) optimized nonuniform spacings

Table (3): The random and optimum element spacings (in wavelengths) for a (10x10) planar array

d_x	random	0.4321	0.4562	0.9842	0.7843	0.8833	0.6678	0.9563	0.7754	0.9812
	optimum	0.63793	0.56658	0.84812	0.85543	0.93566	0.92086	0.6067	0.30083	0.52136
d_y	random	0.4321	0.5421	0.6891	0.9641	0.6754	0.9985	0.7743	0.7453	0.4321
	optimum	0.9175	0.669	0.42941	0.95457	0.60898	0.3064	0.48486	0.65298	0.45623