CONTROL OF GRATING LOBES IN PHASED ARRAYS USING GENETIC ALGORITHMS

Mahmoud M. Dawoud

Professor, Electrical Engineering Department, KFUPM, Dhahran 31261
Email: mmdawoud@kfupm.edu.sa

ABSTRACT

Grating lobes appear in the radiation patterns of antenna arrays when the separation between the elements approaches or exceeds one wavelength. Such arrays are used in many modern communication systems such as the base stations of mobile networks. The concept of adaptive arrays and smart antennas is based on the characteristics of such phased arrays. These grating lobes are undesirable because they lead to reduced antenna gain and high interference levels compared to the desired signal. In this work, we demonstrate the possibility of reducing the level of these grating lobes by means of locating some array nulls within the grating lobe spatial directions. This will eventually lead to increased antenna gain and reduced interference level. The relocation of the array nulls within the spatial range of the grating lobe is achieved by using genetic algorithms. These algorithms have been successfully used in solving electromagnetic problems and in particular, the design of antenna arrays.

The results of this work demonstrate the capability of controlling the overall signal level in the undesirable directions in space, and hence help in the development of smaller and more reliable antenna systems that can be used in modern communication systems.

Keywords: *Antennas, Antenna Arrays, Null Steering, Grating lobes, Communication Systems, Genetic algorithms.*

الملخص :

تظهر الاشعاعات الغير رئيسية في حزمة الاشعاع لمصفوفات الهوائيات عندما تقترب المسافة بين وحدات الهوائيات من طول الموجة. وتستخدم هذه المصفوفات في العديد من نظم الاتصالات الحديثة ومنها وحدات الارسال في شبكات الهاتف الجوال. وكذلك تعتمد فكرة المصفوفات المتكيفة والهوائيات الذكية على خواص هذه المصفوفات الطورية. ولذلك تعتبر الاشعاعات الغير رئيسية غير مرغوب فيها لما تؤدي إليه من التداخل بين الاشارات المختلفة. ونعرض في هذا البحث إمكانية تقليل مستوى هذه الأشعاعات الغير رئيسية بواسطة توجية أصفار المصفوفة إلى اتجاهات هذه الاشعاعات. ويؤدي ذلك إلى زيادة معدل كسب مصفوفة الهوائيات ويقلل من مستوى تداخل الإشارات. وقد تم الحصول على تلك النتائج المرغوبة بواسطة الخوارزميات الجينية.

وتبين نتائج هذا البحث مدى التحكم في قوة الإشارات في الأتجاهات الغير مرغوب فيها. كما تؤدي هذه النتائج إلى تصميم مصفوفات هوائيات صغيرة الحجم ذات قدرة كسب عالية مناسبة لنظم الاتصالات الحديثة.

1. INTRODUCTION

The concept of phased arrays [Balanis, 1997] has been widely used in the design of transmitting and receiving antennas for modern communication systems and radars. The main beam of the array is scanned electronically to the desired signal direction by means of individual phase shifters incorporated in the feed network of the array elements. Phased and adaptive arrays have recently received considerable attention due to their importance in radar and communication systems. These arrays are systems where the spatial distribution of the radiated or received electromagnetic waves are electronically adjusted to enhance desired signals and/or suppress interference, noise and jamming signals. Several techniques have been suggested for the realisation of such arrays. The rapid development in electronic devices and integrated circuits made improvements and adoption of new techniques in this field possible.

In the last three decades, an enormous growth and progress has occurred in the adaptive array systems. This progress encompasses several areas including side lobe cancellers, fully adaptive arrays, and super resolution. The side lobe canceller (SLC), was the first adaptive array system that incorporated the key capability for automatic interference nulling [Howells, 1965]. It grew out of experimental research applied to a real-world radar antenna jamming problem.

Early work concerning the processing of array outputs concentrated on the achievements of a desirable directional array pattern. Attention later shifted to the problem of obtaining an improvement of the SNR (signal-to-noise ratio). These techniques were utilised in radar and sonar signal reception.

The major area of interest in phased and adaptive arrays is their application to problems arising in radar and communication systems, where interference suppression is required. Another example of application is that of direction finding in severe interference environment [Berni, 1975, Davis et al, 1976]. The main aim of designing an adaptive array is to steer the main beam towards a desired signal and/or steer the array pattern nulls towards the interference or undesired signals.

Null steering in adaptive arrays has been achieved using several techniques. The most versatile technique is the control of both amplitudes and phases of the array elements, as shown in the linear antenna array geometry of Figure (1). A second technique for null steering is achieved through controlling only the phases of the array elements, which is an attractive solution, since in a phased array the required controls are available at no extra cost. Thus in order to minimise complexity and cost, the phase only method is used to control the null steering arrays [Baird and Raswieler,1976, Steyskal et al, 1986, Shore and Steyskal, 1982, Steyskal, 1982].

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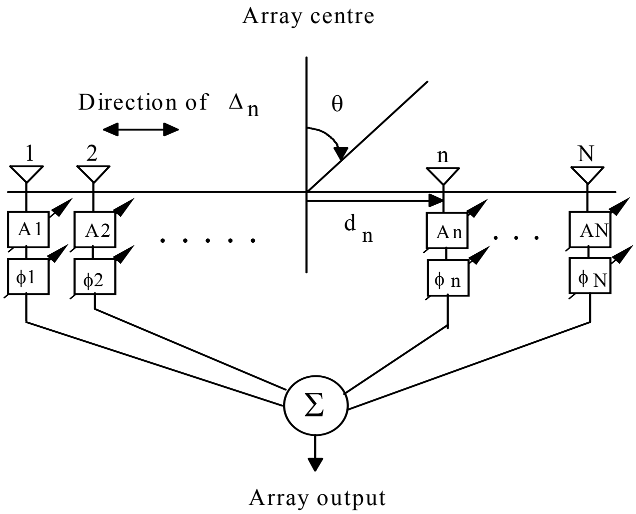

Figure (1) The linear array geometry

Partially adaptive arrays can be designed by controlling only a limited number of array elements, which results in reducing the number of degrees of freedom. This is an attractive solution for large arrays when dealing with a small number of nulls [Chapman, 1986, Morgan, 1986, El-Azhary et al, 1988].

Null steering is also possible by controlling the amplitudes only, which overcomes some of the limitations of phase only method while simplifying the adaptive system. The phase shifters are used solely for steering the main beam towards the desired signal. Null steering without using the phase shifters is done by forcing the zeros of the array factor to form in conjugate pairs on the unit circle in the complex plane [Vu, 1984, 1984, 1986].

The process of null steering can be carried out by controlling the element positions in the array [Dawoud and Ismail, 1990, 1991]. In this way, the amplitudes and phases of the element currents are used only for controlling the pattern structure and directing the main beam for maximum signal reception. This method starts from a given original pattern $F_o(u)$, with the desired main beam and side lobe envelope, corresponding to a given element coefficients $\{a_n\}$ and initial inter-element equal spacing d_o. These element positions are then perturbed such that the perturbed pattern has nulls at the desired directions, where their locations are known in advance. This technique allows the independent steering of the main beam and the nulls to arbitrary independent directions and greatly simplifies the feed network for the adaptive array. This technique is also capable of obtaining side lobe cancellation and wide band signal rejection.

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The concept of phased and adaptive antenna arrays are utilised in smart antenna systems. Such antennas received considerable attention in wireless and modern communications systems. The concept of adaptive antennas can be utilized in order to extend the coverage area of the cell, reduce the power requirements, increase the network capacity, achieve smart hand-over, and improve the communication between the base station and the mobile unit. The incorporation of the adaptive antenna concepts in the design of smart antennas will make it possible to have fewer base stations to cover larger areas with improved trunking efficiency. On the other hand, they require more expensive hardware and possibly need large arrays. The desirable characteristics of adaptive antennas, which are exploited in the design of smart antennas, are main beam scanning and null steering [Dawoud, 1999].

In this paper, we demonstrate that the null steering techniques described above, can be used to suppress the side lobe levels and control the radiation pattern of phased arrays. These situations arise when the array element separation is increased so that the main beam is kept narrow or the array gain is maintained at a high level. They also occur in scanned arrays for large scanning angles.

2. GENETIC ALGORITHMS APPLICATION TO NULL STEERING AND PATTERN CONTROL

The genetic algorithm approach is based on the optimisation of the selected set of array parameters in order to precisely locate the required nulls in the directions of interference signals. Pattern control is achieved by specifying the required side lobe level in the directions of grating lobes or relatively high levels.

The perturbation of each array parameter from its original value has been treated as a variable in an optimisation program based on a genetic algorithm. In the basic genetic algorithm each variable is termed a gene and a set of all the problem variables a chromosome, and is described by the following steps:

i) Generate an initial chromosome population of random genes within the variable constraint range.

ii) Evaluate the 'fitness' of the population from the optimisation function F.

iii) If the optimisation function (F) satisfies the design specification then stop otherwise step iv).

iv) Generate a new population from the fittest members of the old population by crossover followed by mutation.

v) repeat step ii).

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In gene crossover a new chromosome is formed by selecting genes (at random) from chromosomes belonging to the previous generation. The probability of a particular chromosome being selected for crossover is determined by its fitness. Mutation is used to introduce gene variation into the population. The genes of each newly formed chromosome may, subject to a probability factor, be altered by a random amount within the constraint range. The optimisation function used for the examples here is given by:

$$F = F(u_s) / \prod_{m=1}^{M} F(u_m) \tag{1}$$

where $F(u_m)$ is the value of the array factor at each of the desired null positions and $F(u_s)$ is the value in the main beam direction. In evaluating (F) the contribution from each $F(u_m)$ was limited to the desired design specification and the optimisation process halted when all nulls were at or bellow this level.

For null steering purposes, the null depth was chosen as -60 dB in the optimisation process. The level was chosen as -15 dB for pattern control and grating lobe suppression. Figure (2-a) shows the array pattern of an 8-element uniform array when one null is imposed at 38^{o}, when the main beam lies in the broadside direction. A scanned 8-element array pattern is shown in Figure (2-b) when the null is imposed in the direction -50^{o}. The element position perturbations for the 8-element arrays are given in Table (1).

3. ARRAY PATTERN CONTROL USING GENETIC ALGORITHMS

Scanning and phased arrays suffer from the appearance of grating lobes and excessively large side lobes for increased scan angles, and when the inter-element spacing is comparable to the wavelength. Null steering techniques, based on the genetic algorithm, have been successfully used to solve this problem and provide array pattern control, by specifying a maximum limit on the array factor in the region of the large unwanted lobes. Figure (3) shows the array pattern of an 8 element uniform array when the main beam is scanned to -60^{o}. The initial pattern has a large back lobe of level -4.5 dB and shown dotted. Using the genetic algorithm, and specifying a level of -15 dB in the directions 55^{o}, 75^{o}, and 90^{o}, it was possible to obtain the controlled solid pattern shown. The array pattern of a 12-element -15 dB Chebyshev pattern, with element separation 0.96 λ, is shown in Figure (4). The back side lobe has a level of -3.75 dB. Applying the pattern control using genetic algorithms, resulted in the solid pattern with the -15 dB level. Figure (5) show an example of a 12 element scanning linear array when the main beam is scanned from -63^{o} to -75^{o}. It is clear that the back lobe increases from -7.7 dB to -0.6 dB. The solid patterns show that this large back lobe can be eliminated and restrict the level to the prescribed -15 dB.

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Table (1) Element position perturbations for the 8-element uniform arrays whose array patterns are given in Figures (2-a,2-b).

Array #	(1)	(2)
Main beam direction (^{o})	0	20
Direction of null	38	-50
No. of generations	241	99
Δ_1 / λ	-0.0609	0.0228
Δ_2 / λ	0.0578	-0.0258
Δ_3 / λ	-0.0528	0.0237
Δ_4 / λ	-0.0583	-0.0250
Δ_5 / λ	0.0615	0.0238
Δ_6 / λ	0.0456	-0.0217
Δ_7 / λ	-0.0605	0.0228
Δ_8 / λ	0.0591	-0.0230

4. CONCLUSION

The design of adaptive and smart antennas is based on the control of the array pattern such that the main beam is directed towards the desired signal and the nulls are directed to the possible interfering signals. Element position control is attractive because the array currents can be used for shaping the pattern and steering the main beam. A novel procedure, based on genetic algorithms, has been used to provide the array pattern control capability. High side and back lobes can be controlled using this new technique based on genetic algorithms. The results showed that side lobes as high as -.6 dB which appear when the main beam is scanned away from the broadside direction, are reduced to the nominal level of -15 dB of the designed arrays. Single and multiple nulls were also formed in the required interference directions.

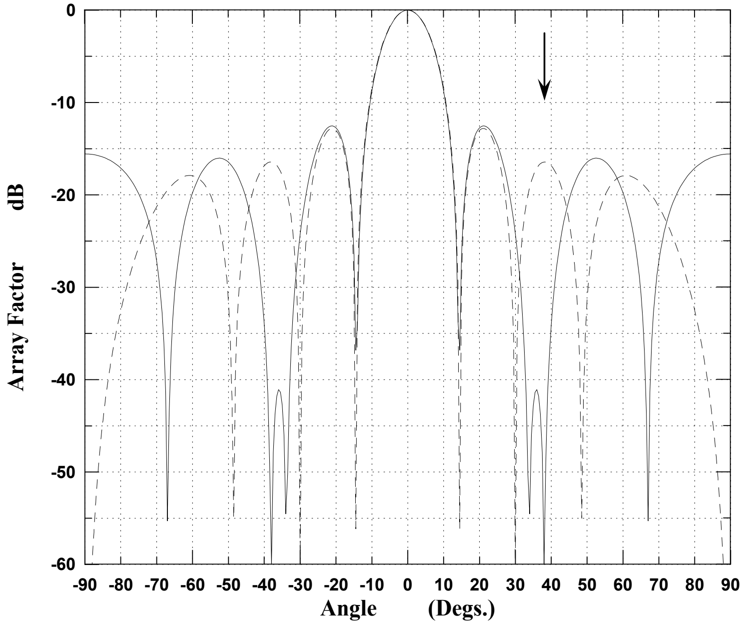

Figure (2-a) Array pattern of an 8 element uniform array with d = 0.5 λ(dashed). The main beam is at $\theta_s = 0^\circ$. One null is imposed at $\theta_m = 38^\circ$ (solid) using genetic algorithms.

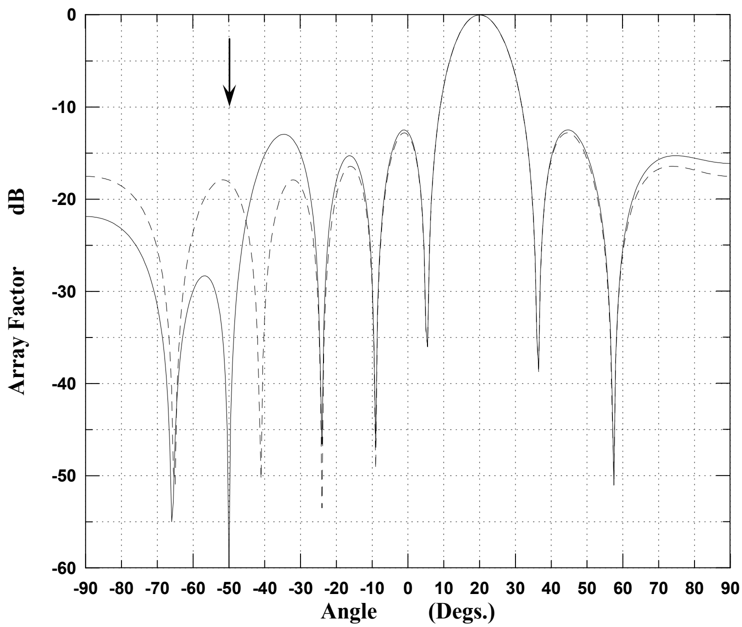

Figure (2-b) Array pattern of an 8 element uniform array with d = 0.5 λ. The main beam is at $\theta_s = 20^\circ$ (dashed). One null is imposed at $\theta_m = -50^\circ$ (solid) using genetic algorithms.

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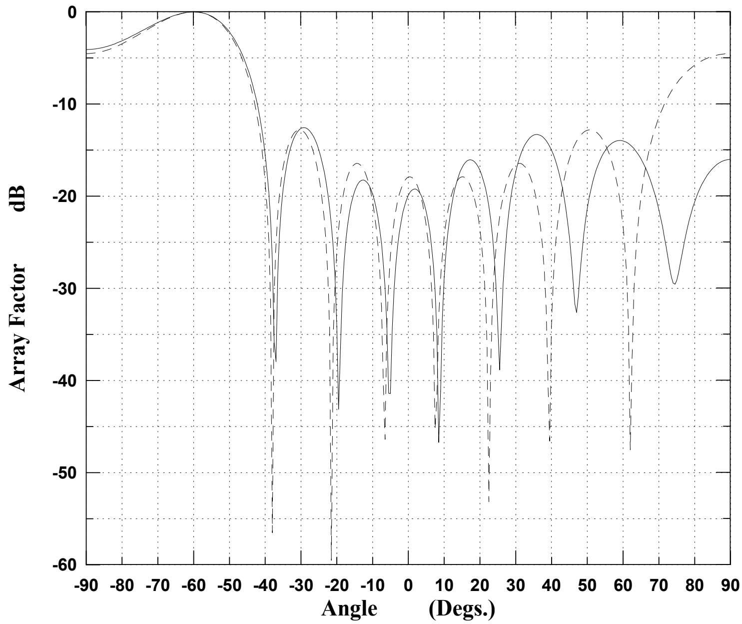

Figure (3) Array pattern of an 8 element uniform array with d = 0.5 λ. The main beam is at θ_s=-60º (dashed). Array pattern is restricted to -15 dB at $\theta_m = 55^\circ, 75^\circ, 90^\circ$ using genetic algorithms (solid)).

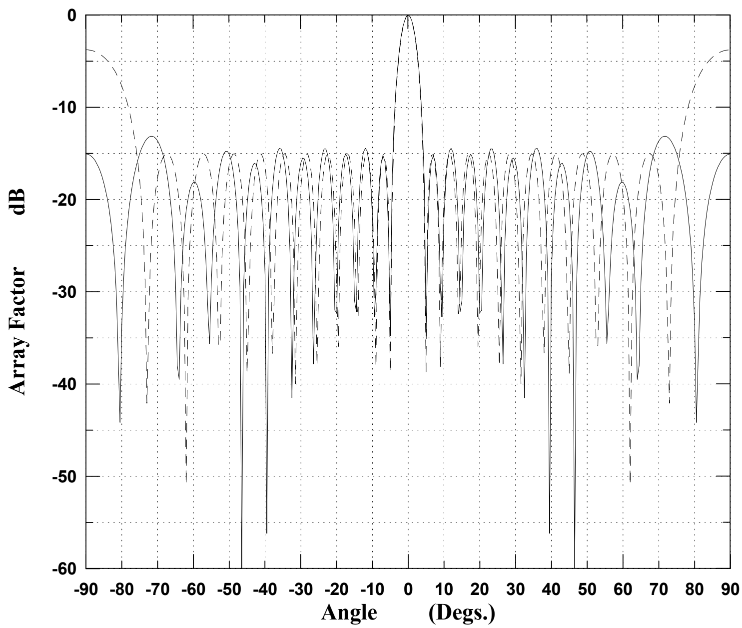

Figure (4) Array pattern of a 12 element 15 dB Chebyshev array with d = 0.96 λ. The main beam is at θ_s=-60º (dashed). Array pattern is restricted to -15 dB at $\theta_m = 50^\circ, 75^\circ, 90^\circ$ using genetic algorithms (solid).

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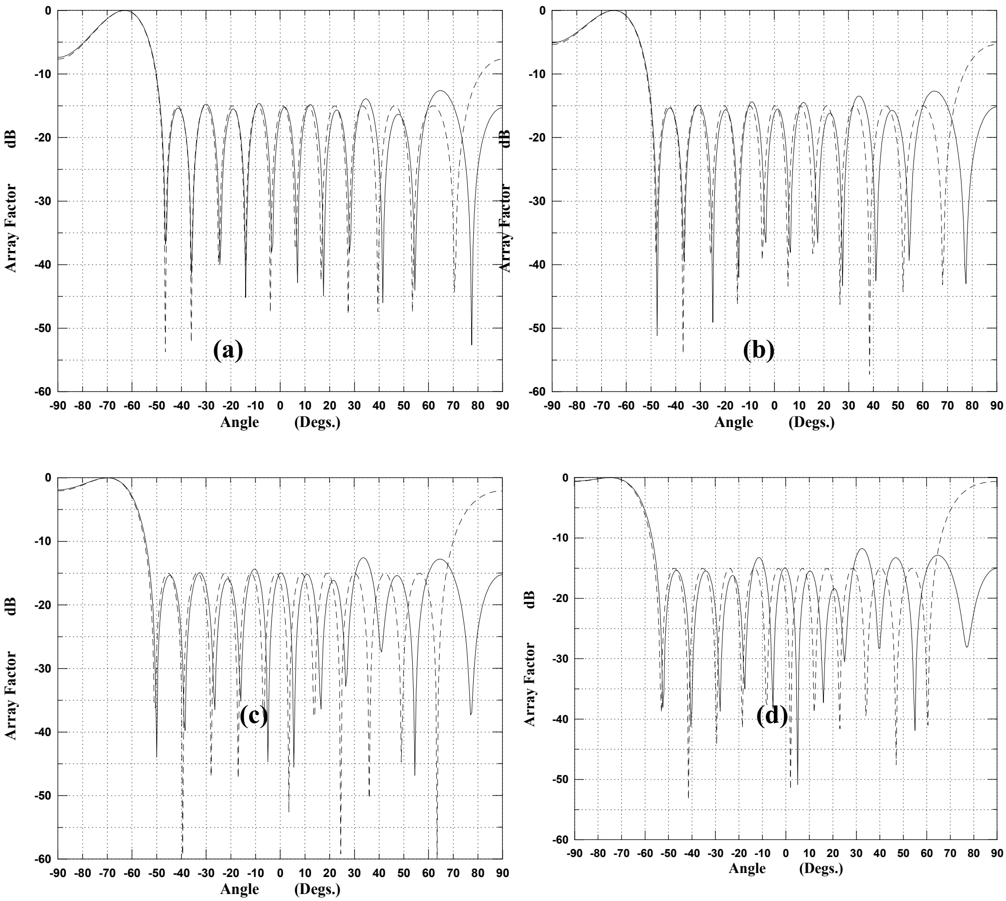

Figure (5) Array pattern of a 12 element 15 dB Chebyshev scanning array with d = 0.5 λ. The main beam is at: (a) $\theta_s = -63^\circ$, (b) $\theta_s = -65^\circ$, (c) $\theta_s = -70^\circ$, and (d) $\theta_s = -75^\circ$ (dashed). Array pattern is restricted to -15 dB at $\theta_m = 50^\circ, 60^\circ, 75^\circ, 90^\circ$ using genetic algorithms (solid).

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