Synthesis of Linear Antenna Arrays using the Differential Evolution Algorithm with Current-Only Adaptive Nulling Technique

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Abstract: *This paper presents an efficient method for the pattern synthesis of linear antenna array based on the differential evolution algorithm. A number of examples are presented to demonstrate the various capabilities of the this method for different number of elements. The main objective of this paper is to achieve a set of current weights in order to steer the nulls in undesired directions (nulling the undesired signals) and steering the main beam towards the desired direction(direction of desired signal) by changing the phase excitation currents. The fitness function is obtained from maximization of error between actual pattern and desired pattern.*

Keywords: Antenna Arrays, Optimization, differential evolution algorithm

1. Introduction

The antenna pattern synthesis is an important issue in the design of antenna array, whether it is traditional antenna, or a new generation of mobile communications in the smart antenna pattern synthesis play an important role[1,2]. Phased array antennas having adaptive nulling capability are often desirable for radar or communications applications [3].

Over the last several decades, there has been significant attention paid to the area of array pattern synthesis. In the last of the decade, antenna synthesis was started depends on Intelligent systems such that genetic algorithm, simulated annealing, modified touring ant colony optimization algorithm, Taguchi's method, and differential evolution algorithm are used in antenna array pattern nulling for linear antenna arrays[4,5,6,7,8,9,10].

Null steering in phase antenna array has received much attention in the literatures in recent years. Generally, there are many techniques to nulling the pattern of linear array. The first technique of null steering by adaptively changing the complex weights (both amplitude and phases of currents) have proved to be slow and ineffective for large arrays. Karaboga [5] modified touring ant colony optimization algorithm and applied to null steering of linear antenna arrays by controlling both the amplitude and phase of the array elements. Hans [7] used full amplitude and phase control to ensure that the synthesized pattern has nulls at the desired directions.

The second technique is based on the phase-only weight control. Chao [6] derived the pattern nulling of a linear antenna array for interference cancellation by phase-only perturbations using memetic algorithm. Mahanti [8] used a real coded genetic algorithm for the design of reconfigurable dual-beam linear isotropic antenna arrays. The only control parameters are used the phases of digital phase shifters. Smida [10] used Taguchi's method for synthesis of linear array antennas by phase-only weight in order to steer the beam towards any desired direction and avoiding interference.

The third technique uses the amplitude only. Tapaswi [4] applied genetic algorithm (GA) to circular array. Single and multiple nulls are imposed by optimizing the current amplitude excitations of each element through GA.

The fourth technique uses of unequal space for the nulling the pattern of linear antenna array. Kurup [9] applied differential evolution algorithm to uniform amplitude arrays with unequal spacing and equal phases (position-only synthesis).

In this paper, differential evolution algorithm is used in the synthesis of linear antenna array, a set of current weights are generated in order to steer the nulls towards undesired direction and then avoiding interference or undesired signals. MATLAB program is used to implement the algorithm. Figure (1) shows an illustration of the desired and interfering angles [10].

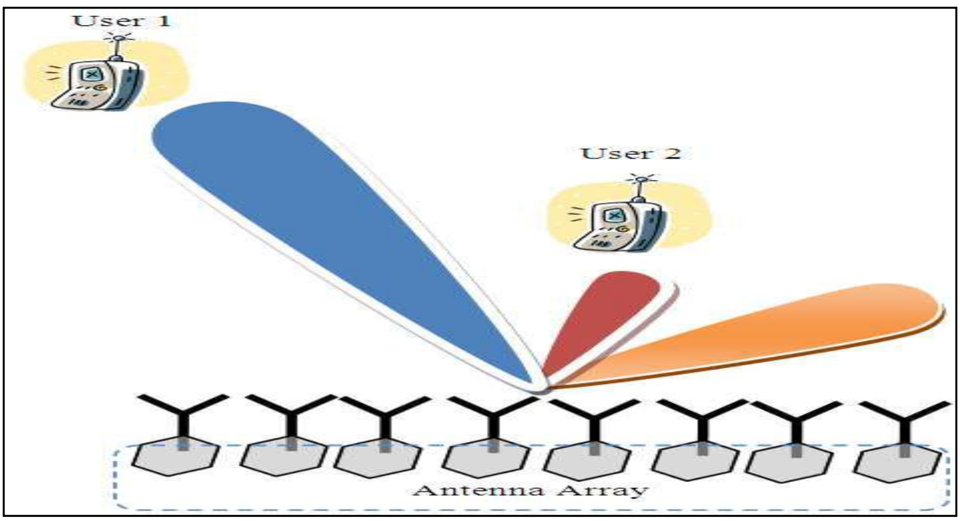

Figure (1) Radiation pattern for desired and interfering angles [10]

2. Design of a Linear Antenna Array

The problem of array pattern synthesis can be stated as follows: Which has N equally spaced elements along the x-axis as shown in figure (2). The element spacing is half-wavelength and it is desired to find a set of weights (current distribution for elements) ,and the excitations of array elements are symmetric. Such that the output pattern (Fout(θ)) as the same as the desired pattern Fdes(θ). The array pattern (AF) is given by[11,12]:

$$AF(\theta) = \sum_{n=0}^{N-1} I_n e^{jn\psi} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where:

$\psi = \beta d \cos\theta + \alpha$

$\beta = 2\pi/\lambda$ = wave number (phase constant).

λ is the wavelength.

d is the distance between elements.

α Phase excitation current.

I_n are weights of DE (represented current distribution).

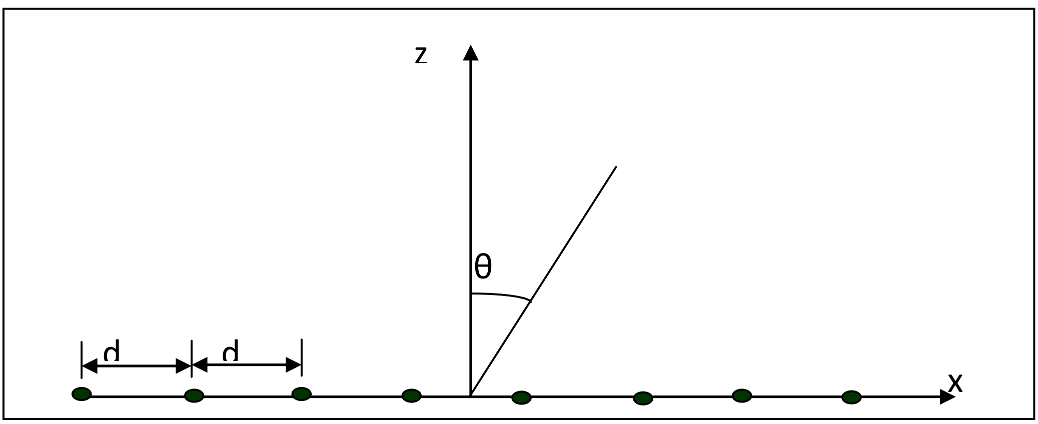

Figure (2) the geometry of N elements symmetric linear antenna array

Equation (1) represents a mathematical description of the antenna radiation pattern and can be used by optimization algorithms.

3. Differential Evolution Algorithm (DEA)

The differential evolution algorithm is a population based on an algorithm like genetic algorithms using the similar operators: crossover, mutation and selection. The main difference in constructing better solutions is that of genetic algorithms rely on crossover while differential evolution algorithm relies on mutation operation. In other words, differential algorithm is a variant of genetic algorithm (GA), which attempts to replace the crossover operator in GA by a special type of differential operator for reproducing offspring in the next generation. DE is a combination of original GA, evolutionary programming and evolutionary strategies[13,14].

The differential evolution algorithm uses mutation operation as a search mechanism and selection operation to direct the search toward the prospective regions in the search space. The differential evolution algorithm also uses a non-uniform crossover[13]. Among these methods (mentioned in section 1) evolutionary algorithms may be one of the most successful methods and have been successfully applied to antenna array synthesis problems [15].

4. Proposed Technique

An iteration of the classical DE algorithm consists of the four basic steps initialization of a population of search variable vectors, mutation, crossover or recombination, and finally selection. The last three steps are repeated generation after generation until a stopping criterion is satisfied. The steps for the design of nulling the pattern of linear antenna array, using DE, can be summarized as follows [14]:

Step 1: Initialization

A chromosome (a string of solutions) is composed of genes (current weights). In this problem, a set of chromosomes is generated randomly. The initial step may be to generate a collection of random matrix vectors (M_{nm}), n =1,2,3,…,N, m =1,2,3,…,C. where N is the number of genes (number of elements), and C is the number of chromosomes.

Step 2: Mutation

Add the weighted difference of any two of the parameter to the third vector to form a donor vector.

$$Donar \quad vector \quad M_{i+2,j} = M_{i+2,j} + F * \left(M_{i,j} - M_{i+1,j}\right) \quad \ldots \ldots \ldots \ldots (2)$$

The scaling factor F scales the difference of two vectors and adds it to the third one, which can range from 0 to 2 [13,14].

Step 3: Evaluation

Evaluate each chromosome's fitness. For every chromosome, its fitness value is calculated. Check every chromosome's fitness value one by one. Compared with the present best fitness value, if one chromosome can give better fitness, it will renew the values of the defined vector and variable with this chromosome and its fitness value.

Otherwise, keep their values unchanged. The error between the array outputs and the desired pattern is used as objective function.

$$error = \left(F_{out} - F_{des}\right)^2 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3)$$

And then the fitness function is

$$\max = \frac{1}{error} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (4)$$

The block diagram of the DE design for nulling the pattern of linear antenna array optimization is illustrated in figure (3).

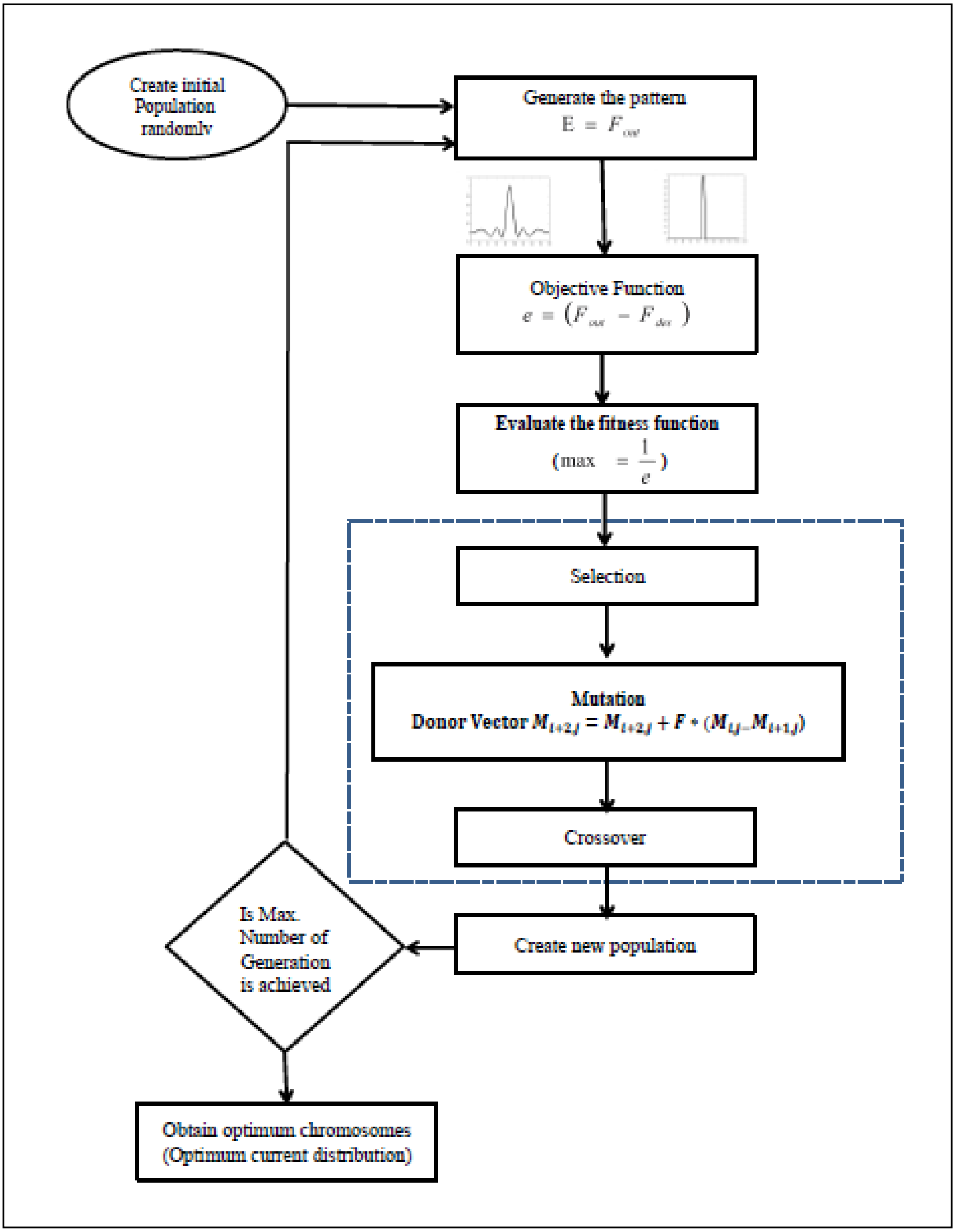

Figure (2) Flow chart of the DE model for the pattern synthesis of linear antenna array

5. Simulation Results

A number of examples are presented to demonstrate the various capabilities of the this method

Example 1: design of linear antenna array using DE with number of elements is equal to 8. Figure(4) shows the relative pattern of linear antenna array with 3 nulls at angles (20^o, 40^o, and 60^o) and the main beam at angle 80^o. Table(1) shows the current distrbution for half elements of linear antenna array that gives three nulls at angles (20^o, 40^o, and 60^o) and the main beam at angle 80^o.

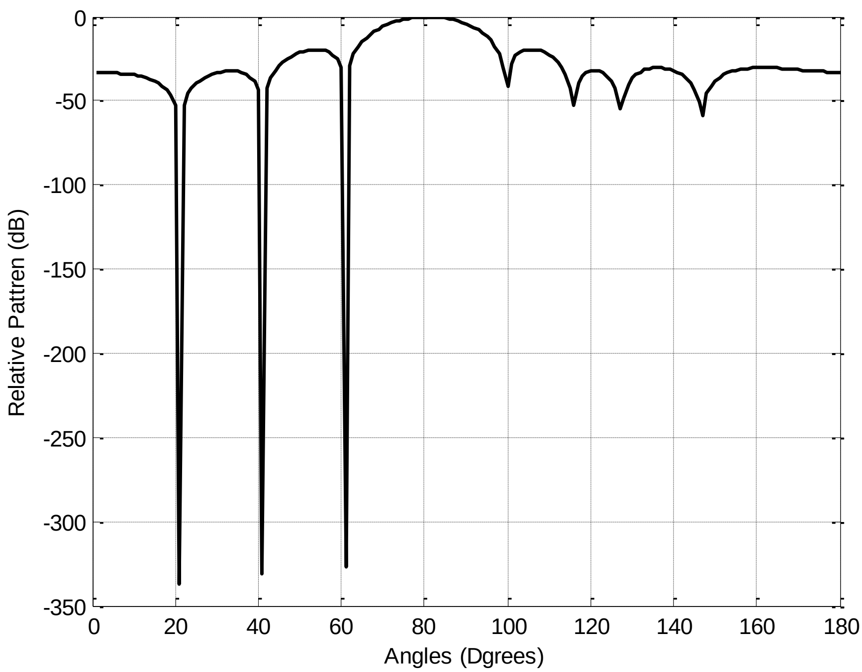

Figure (4) Relative pattern of linear antenna array with N=8, SLL = -20dB, and with 3 nulls

Table (1) Current distrbution for half elements of linear antenna array with N=8 , SLL=-20dB, and with 3 nulls

Element	1	2	3	4
Current	1	0.95228	0.70303	0.34832

Example 2: design of linear antenna array using DE with number of elements is equal to 8. Figure(5) shows the relative pattern of linear antenna array with 4 nulls at angles (40^o, 88^o, 104^o, and 120^o) and the main beam at angle 60^o. Table(2) shows the current distrbution for half elements of linear antenna array with that gives 4 nulls at angles (40^o, 88^o, 104^o, and 120^o) and the main beam at angle 60^o.

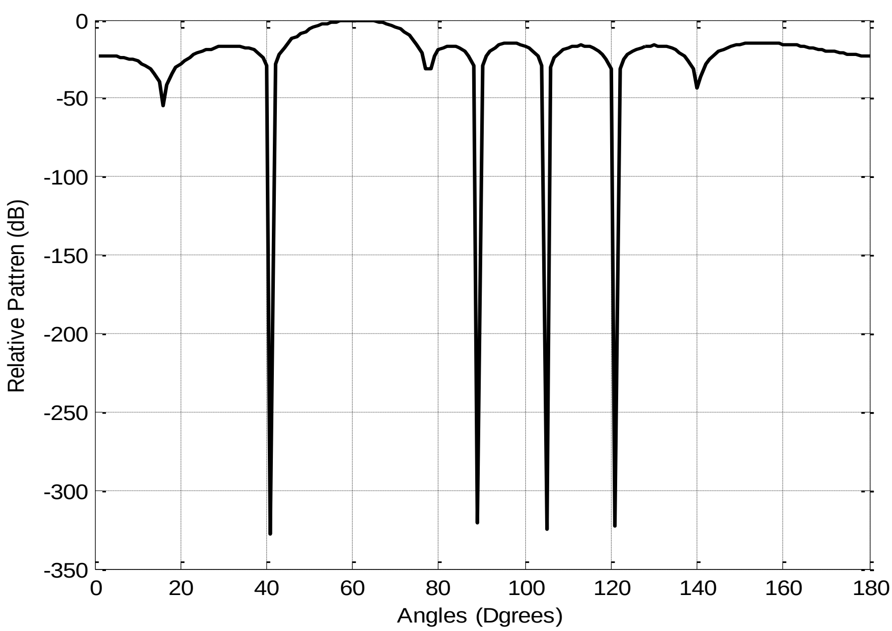

Figure (5) Relative pattern of linear antenna array with N=8, SLL=-18dB, and with 4 nulls

Table (2) Current distribution for half elements of linear antenna array with N=8, SLL=-20dB, and with 4 nulls

Element	1	2	3	4
Current	1	0.81229	0.69067	0.84448

Example 3: design of linear antenna array using DE with number of elements is equal to 8. Figure (6) shows the relative pattern of linear antenna array with 3 nulls at angles (20^o, 80^o,and 110^o) and the main beam at angle 50^o. Table (3) shows the current distrbution for half elements of linear antenna array that gives 3 nulls at angles (20^o, 80^o, and 110^o) and the main beam at angle 50^o.

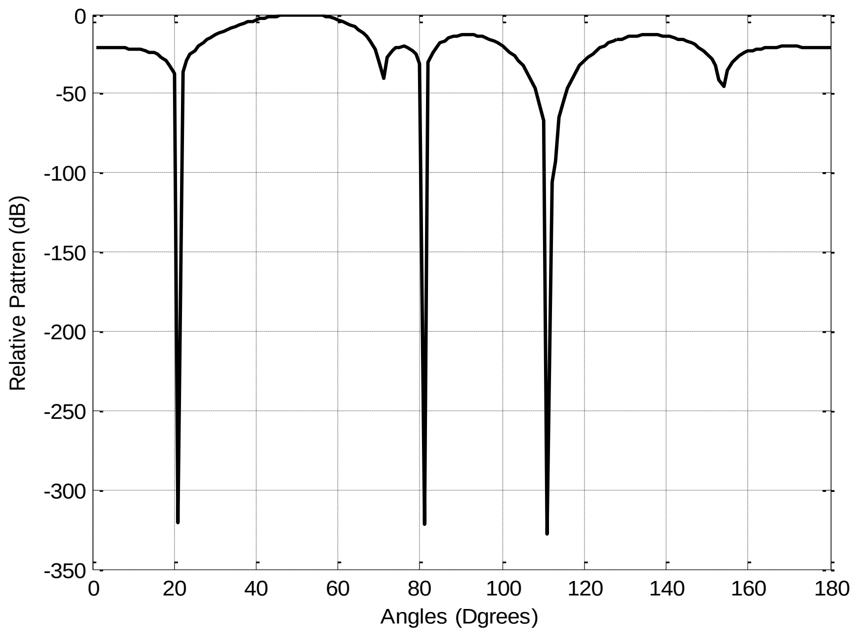

Figure (6) Relative pattern of linear antenna array with N=8, SLL=-20dB, and with 3 nulls

Table (3) current distribution for half elements of linear antenna array with N=8, SLL=-20dB, and with 3 nulls

Element	1	2	3	4
Current	1	0.50078	0.74998	0.46499

<u>Example 4:</u> design of linear antenna array using DE with number of elements is equal to 8. Figure(7) shows the relative pattern of linear antenna array with 6 nulls at angles (25^o,49^o, 60^o, 120^o, 130^o, and 156^o) and the main beam at angle 90^o. Table (4) shows the current distrbution for half elements of linear antenna array that gives 6 nulls at angles (25^o, 49^o, 60^o,120^o, 130^o, and 156^o) and the main beam at angle 90^o.

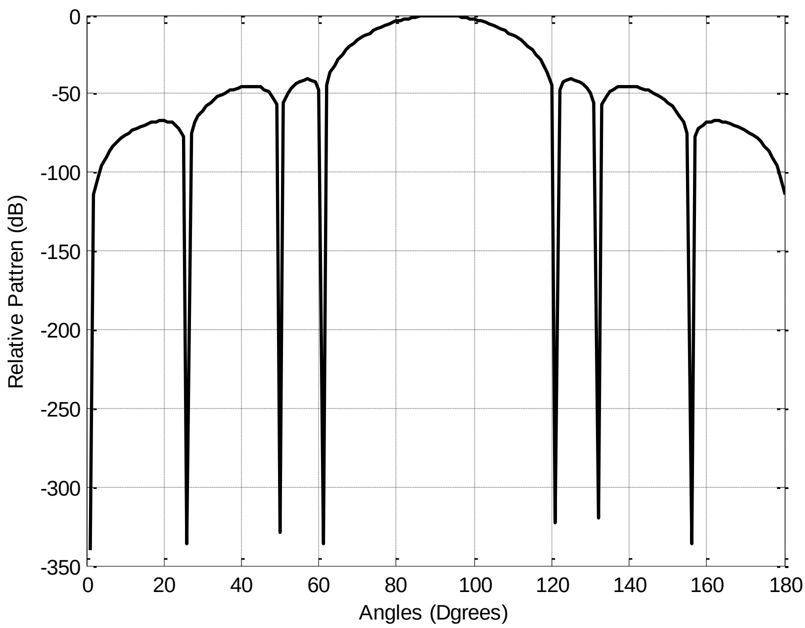

Figure (7) Relative pattern of linear antenna array with N=8, SLL=-40dB, and with 6 nulls

Table (4) Current distribution for half elements of linear antenna array with N=8, SLL=-20dB, and with 6 nulls

Element	1	2	3	4
Current	1	0.72839	0.36673	0.095112

<u>Example 5:</u> design of linear array antenna using DE with number of elements is equal to 10. Figure (8) shows the relative pattern of linear antenna array with one null at angle (30^o) and the main beam at angle 0^o. Table (5) shows the current distrbution for half elements of linear antenna array that gives one null at angle (30^o) and the main beam at angle 0^o.

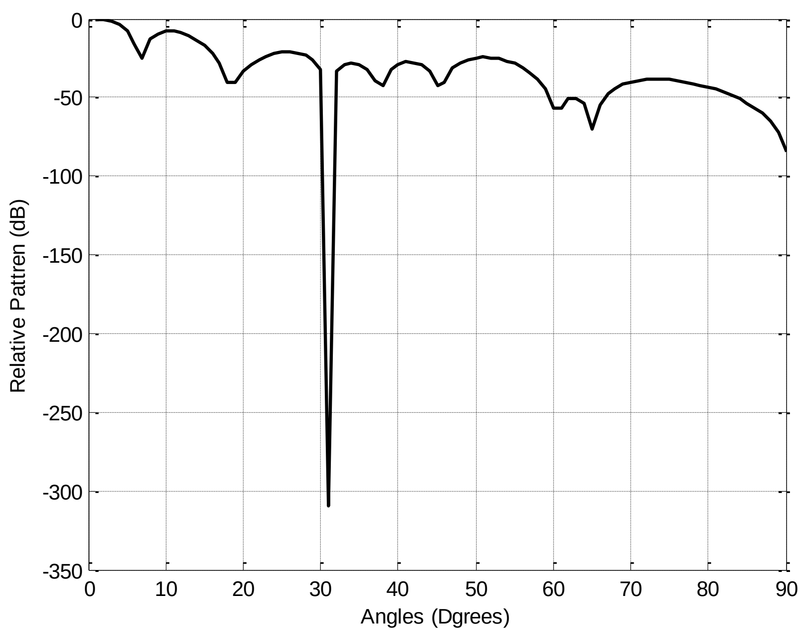

Figure (8) Relative pattern of linear antenna array with N=10, SLL= -15dB and with 1 null

Table(5) Current distrbution for half elements of linear antenna array with N=10 , SLL=-15dB,and with one null

Element	1	2	3	4	5
Current	1	0.8244	0.4361	0.3720	0.2927

<u>**Example 6:**</u> design of linear antenna array using DE with number of elements is equal to 20. Figure (9) shows the relative pattern of linear antenna array with 2 nulls at angles (15^o and 27^o) and the main beam at angle 0^o. Table (6) shows the current distrbution for half elements of linear antenna array that gives 2 nulls at angles (15^o and 27^o) and the main beam at angle 0^o.

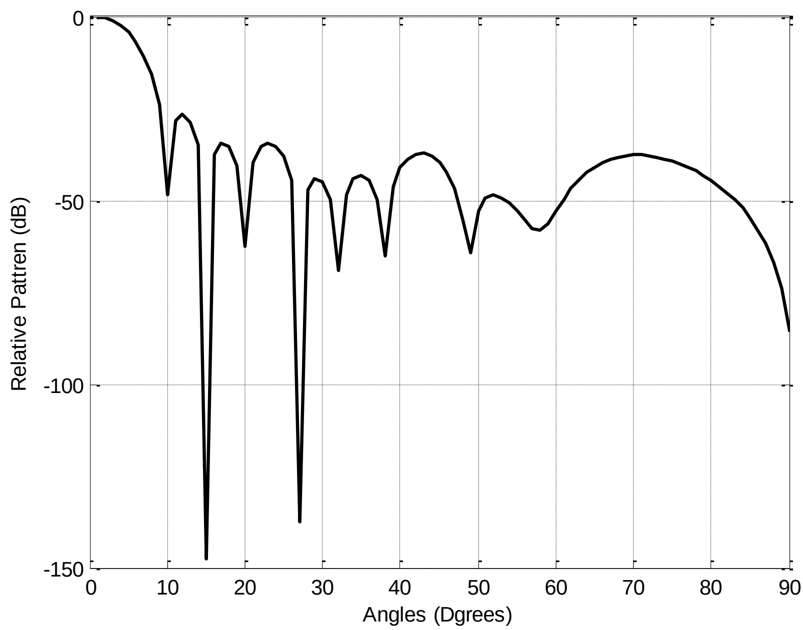

Figure (9) Relative pattern of linear antenna array with N=20, SLL=-28dB, and with 2 nulls

Table (6) Current distribution for half elements of linear antenna array with N=20, SLL=-28dB, and with 2 nulls

Element	1	2	3	4	5	6	7	8	9	10
Current	**1**	**0.9748**	**0.92639**	**0.8574**	**0.70219**	**0.6244**	**0.47996**	**0.3607**	**0.236899**	**0.123399**

Table(7) shows the comparison between above examples with respect to number of elements, side lobe level, number of nulls, direction of main beam , null angles, and the depth of the nulls to demonstrate the various capabilities of this method.

Table (7) comparisons between six examples

Example	No. of Elements	SLL (dB)	No. nulls	Main beam angle	Null Angles	The depth of the nulls(dB)
1	8	-20	3	80	20,40, and 60	-330
2	8	-18	4	60	40,88,104, and 120	-326
3	8	-20	3	50	20,80, and 110	-325
4	8	-40	6	90	25,49, 60,120,130 and 156	-335
5	10	-15	1	0	30	-310
6	20	-28	2	0	15, and 27	-150

6. Comparison with Previously Publishing Work

Table (8) shows comparison of results obtained from this method and two other methods (Taguchi's Method [10], and Memetic Algorithms [6]) with respect to the number of nulls, side lobe level, and depth of nulls. It noticed that the number of nulls is greater than two methods and the depth of nulls reaches to -330dB while in other methods reaches to -180 dB.

Table (8) Current distribution for half elements of linear antenna array with N=20 and SLL=-28dB With 2 nulls

Method type	**No. of nulls**	**SLL (dB)**	**Depth of nulls(dB)**
Memetic Algorithms**[6]**	**2**	**-5**	**-180**
Taguchi's Method **[10]**	**2**	**-10 to -15**	**-50**
This paper (differential evolution**)**	**6**	**-15 to -40**	**-330**

7. Conclusions

This paper illustrates the use of global optimization technique based on differential evolution algorithm (DE) for the linear antenna array synthesis to obtain a set of currents weights. These weights were optimized in order to steering the nulls towards undesired directions.

Results show that the amplitudes-only are successfully optimized to obtain the patterns with satisfactory null depth (the depth of the nulls reached to -330dB) and the DE algorithm can suppress multiple interfering signals rather than single interfering signal (the number of nulls are obtained in this paper 1,2,3,4, and 6). DE algorithm can deal with any number of elements (this paper used 8, 10, &20 elements as an example).

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تمثيل مصفوفات الهوائيات الخطية باستخدام خوارزمية التطور التفاضلي وتقنية التصفير التكيفية للتيار فقط.

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المستخلص:

يقدم هذا البحث بطريقة كفوءة لتوليف شكل الإشعاع لمصفوفة هوائيات خطية معتمدا على خوارزمية التطور التفاضلي. في هذا البحث تم عرض عدد من الأمثلة التي توضح القابليات المختلفة لهذه الطريقة لعدد مختلف من العناصر. الهدف الرئيسي من هذا البحث هو انجاز مجموعة من أوزان التيارات لكي تسير الأصفار في اتجاهات الغير المرغوبة (تصفير الإشارات الغير مرغوب بها) وتوجيه الشعاع الرئيسي باتجاه المرغوب به (اتجاه الإشارة المرغوب بها) بواسطة تغيير طور التيارات. تم الحصول على دالة الجودة من تكبير الخطأ بين شكل الإشعاع الحقيقي وشكل الإشعاع المرغوب به.

الكلمات الرئيسية: مصفوفات الهوائيات، الأمثلية، خوارزمية التطور التفاضلي.