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Performance of Nature Inspired Algorithm in Linear antenna array Optimization

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ABSTRACT

In this paper, the synthesis of linear antenna arrays (LAA) is considered using single variable method like amplitude-only (Amp-Only). It involves in determining the suitable values of amplitudes of current coefficients which provide desired radiation patterns. The technique is considered as simple because it uses only one design variable such as amplitude. Depending on the number of elements in the array the vector amplitude distribution matrix size varied. The synthesis method of determining appropriate amplitudes of excitation uses social group optimization (SGOA) as the tool. The algorithm belongs to the class of nature inspire metaheuristic algorithms. The simulations are carried out in Matlab and results are presented for analysis.

Keywords: Linear antenna array, amplitude only, synthesis, SGOA

I. INTRODUCTION

The antenna arrays are excellent radiating systems. They are considered as highly directive antennas. Directivity of an antenna has a direct impact on the physical dimensions of it. Whereas the physical dimensions are function of operating wavelength, for example the height of the antenna is half-wavelength. This is evident from mathematical relations and from the existing literature in this field. However, they considered to be highly complex as they need typical computational procedures. In order to overcome these disadvantages, many evolutionary techniques have evolved to solve these synthesis problems. Some of the meta-heuristic algorithms namely Genetic-Algorithm, Particle-Swarm-Optimization, Firefly Algorithm, Differential Evolution, Cat Swarm Optimization and social group optimization are very popular in array design.

A thorough mathematical analysis of different types of array geometries and array synthesis techniques is provided in [1, 2]. Uniformly excited arrays and nonuniformly excited array characteristics are studied and their synthesis techniques are presented.

It is explained in [3] that in defence radars, there exist several situations where beam shapes are required to be altered in quick succession. Accordingly, this is possible only by phase control for a fixed amplitude distribution and such requirements can be met by phased array antennas where the phase distribution exhibits a full control on the radiation beams. The general goal in array design is to produce a particular class of radiation patterns, to reduce sidelobe levels, to maximize the directivity, and to synthesize an array with a relatively broad frequency band, or to achieve some combinations of these. Steinberg [4] derived a formula for beam steering angle, and signal bandwidth.

A mathematical theory is proposed for linear array synthesis [5, 6] to achieve a radiation pattern with nulls located in the desired direction. The formulation involves simple modification to the expression for radiation intensity in Linear Arrays that is suitable for controlling its directive properties. The array factor formulation represents a polynomial of certain order say N-1 with same number of complex roots. Basing on this the array factor is represented as a product of these roots. Another method for the synthesis of antenna arrays with patterns consisting of low sidelobe levels and small first nulls [7-12] is proposed by Taylor which was vastly applied to continuous sources.
D. G. Kurup et al. [13] carried out array synthesis using the Differential Evolution Algorithm (DEA) on LA which are arranged with non-uniform space-function and similar phases as well as non-uniform space-function and non-uniform phase distribution which is known to be position-phase technique. C. Salvatore et al. [14] proposed a procedure based on adaptive GA that allows real time control of the receiver's performance by acting on descritized phase coefficients of the array elements. Tian et al. [39], proposed the application of GA to the linear array synthesis problem with a different strategy while Khodier et al. [15] described a synthesis technique for LA with objectives like minimum SLL and null control applying Particle Swarm Optimization (PSO).
In this work, the single variable technique is considered for designing the LAA in two different objectives using the recently proposed social group optimization algorithm. Further, the paper is organized in six Sections. The formulation of LAA and the fitness [16, 17] are given in Section 2 and 3. Following this, the implementation of the algorithms and results followed by the overall conclusions are given in Section 4, 5 and 6 respectively.

II. FORMULATION OF THE LINEAR ARRAY

The linear antenna array (LAA) is a famous geometry of antenna arrays. This is due to its simplicity and ease of installation and mounting in the field. The typical geometry of broad side LA is as shown in Fig.1.

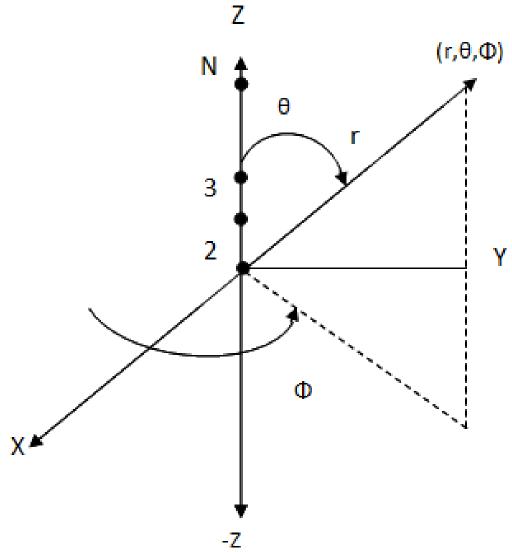

Fig.1: Geometry of broadside LAA

The array factor (AF) of LAA is given as

$$E(\theta)=\sum_{n=1}^{N} A_n \exp[j(n-1)(kd\cos\theta+\beta)] \tag{1}$$

Here,

A_n = n^{th} elements current excitation
d = Inter-element distance
θ = Plane wave look angle
λ = wavelength
$\beta = -kd\cos\theta_d$

The corresponding far-field pattern is formulated from the above expression as

$$P(\theta)=20\log_{10}\left[\frac{|E(\theta)|}{|E(\theta)|_{max}}\right] \tag{2}$$

This expression is essential when power distribution characteristics are needed to study.

III. FITNESS FORMULATION

The formulation of fitness function incorporates the objective of SLL reduction and BW control. The radiation pattern is the distribution computed AF values for every interval of azimuthal angle (θ) over a range of -90⁰ to 90⁰. Hence the fitness is formulated as a function of AF values in order to obtain the desired patterns.

$$SLL_{diff} = SLL_{des} - \max[\,|\mathrm{AF}(\theta)|\,|_{-90}^{\theta_0 - \frac{BW_{obt}}{2}}\,] \quad -(3)$$

$$\mathrm{BW}_{diff} = |\,\mathrm{BW}_{Cheb} - \mathrm{BW}_{obt}\,| \quad -(4)$$

$$f_1 = SLL_{diff} \qquad if\ SLL_{diff} > 0$$
$$= 0 \qquad otherwise \quad -(5)$$

$$f_2 = SLL_{diff} \qquad if\ SLL_{diff} > 0$$
$$= 0 \qquad otherwise \quad -(6)$$

$$f = c_1 f_1 + c_2 f_2 \quad -(7)$$

Here the term, SLL_{diff} refers to the difference between the desired SLL (SLL_{des}) and the obtained SLL (SLL_{obt}). Similarly, the term BW_{diff} is the difference between the desired Chebyshev beam width (BW_{Cheb}) and the obtained beam width (BW_{obt})

IV. SOCIAL GROUP OPTIMIZATION ALGORITHM

The structure of the SGOA is briefly divided into two phases like [9, 17]

a) Improvement phase

b) Acquisition phase

Further, to get acquainted with the approach SGOA, let us first interact the concept of individual and population as

Individual $I_j = [I_{j1}, I_{j2}, \ldots\ldots I_{jn}]$

And population P= $[I_1, I_2, \ldots\ldots I_j \ldots\ldots I_N]$

Here n is the dimension of the problem and 'N' is refers to the number of individuals.

Constituting the population. This can be even considered as population size.

4.1 Improvement phase:

In the improvement phase, initially the best individual with the best solution in the group is chosen and every individual improve is personal traits with inspiration from the group best individual which in other words called as updating one's own capability. This is mathematically interpreted as

I_j(t+1)=C*I_j(t) +r*[$gbest_j$(t)-I_j(t)]

Here t is the iteration member and accordingly I_j(t+1) is the new j^{th} individual trait and I_j(t) is the old j^{th} individual trait. C is a selfintrospection parameter which lies between 0 and 1.

Similarly, r is a random number obtained through a uniform random variable.

4.2 Knowledge Acquisition Phase:

In this phase, the knowledge is acquired by the individual from another individual of the same group of society. Here the individual who is acquiescent should be inferior to the acquiesce. However, the *gbest* remains the more knowledgeable and also participate in transferring certain traits to every individual in the acquisition phase. Considering the above, the corresponding mathematical interpretation of the behaviour of an individual in this phase can be given as

I_j(t+1)=I_j(t)+r_1*(I_j(t)-I_k(t))+r_2(gbest(t)-I_j(t)) if f(I_j(t))<f(I_k(t))

I_j(t+1) =I_j(t)+r_1*(I_k(t)-I_j(t))+r_2(gbest(t)-I_j(t)) else

where

Here I_j and I_k are two randomly selected j^{th} and k^{th} individuals. The r_1 and r_2 are two random numbers taken from U (0,1).

Also, the fitness of the k^{th} individual is represented by f(I_k(t)).

V. RESULTS AND DISCUSSIONS

The simulation based results are taken for two different cases. The first case involves in employing SGOA to produce patterns which are similar and comptetive to the uniform LAA. In the second case, it involves in employing the SGOA to obtain patterns which are comptetively good in terms of conventional technique like Chebyshev methods.

5.1 Case-1:

The uniform LAA have specific SLL and BW. They are usually considered as their high values which keep degrading in terms of radiation. This often leads to interference. Hence it is required to suppress the SLL with control on the BW is of high priority. In this Case, the SGOA is applied to determine the coefficients of current excitations using Amp-Only method to produce radiation patterns with SLL less than the corresponding ULA.

The optimized radiation patterns obtained using the SGOA are presented in Fig.2 through Fig.5 for N=8 to 48. The corresponding SLL and the BW are listed in Table 1.

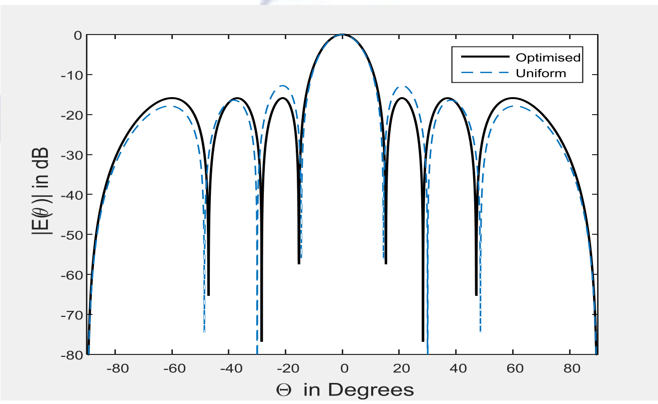

Fig 2 (a): Optimised RP of 8 element LA

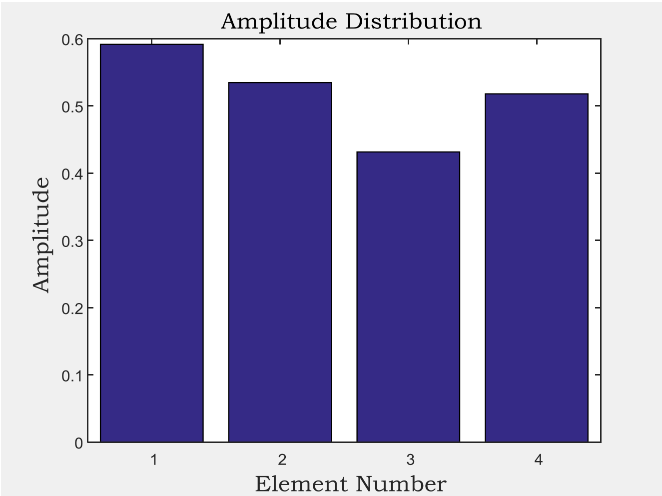

Fig.2(b): Amplitudes of optimized 8 element LA in case 1.2

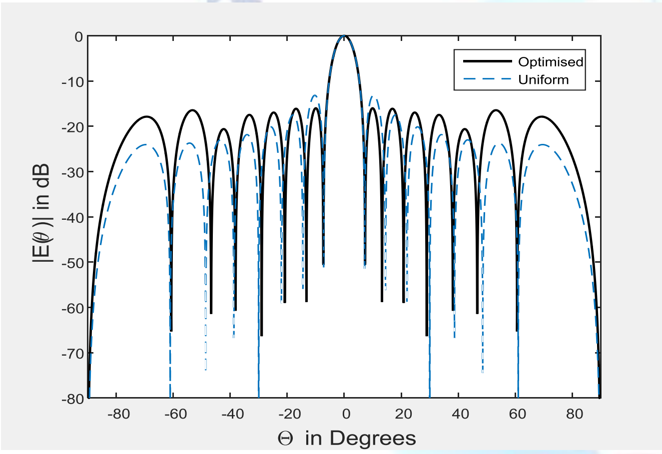

Fig.3(a): Optimised RP of 16 element LA

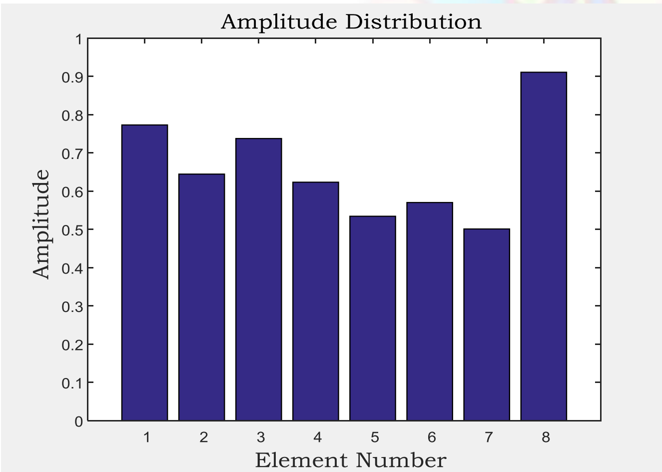

Fig.3(b): Amplitudes of optimized 16 element LA

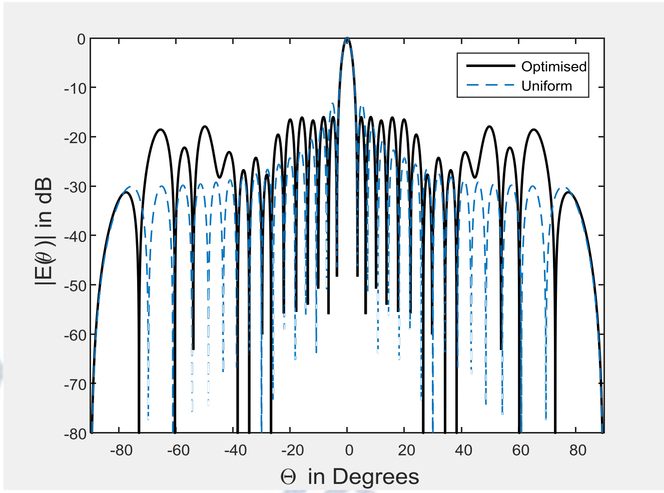

Fig.4(a): Optimised RP of 32 element LA

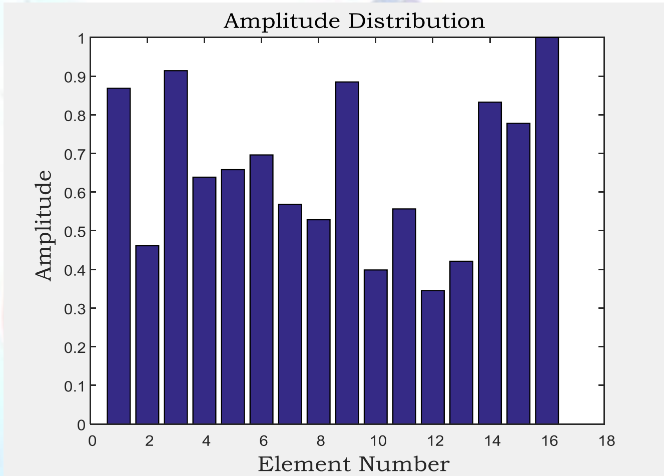

Fig.4(b): Amplitudes of optimized 32 element LA

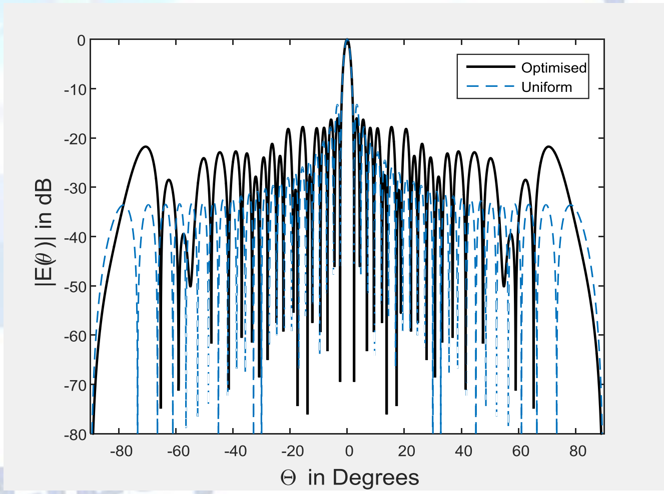

Fig.5(a): Optimised RP of 48 element LA

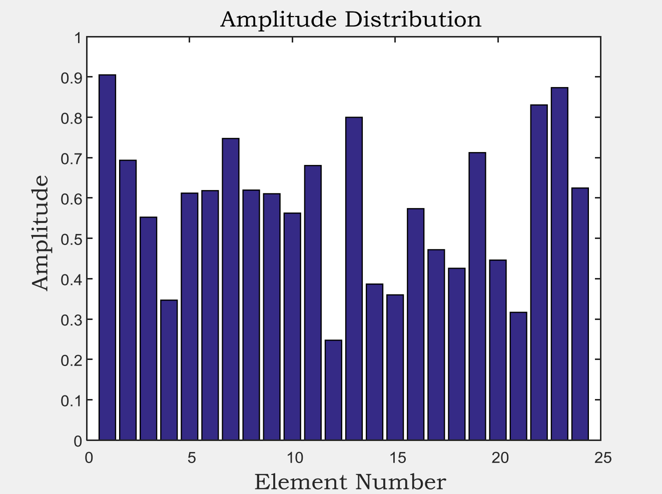

Fig.5(b): Amplitudes of optimized 48 element LA

Table 2: SLL and BW

S.No	elements	SLL (dB)	BW (degrees)
1	8	-15.902	29.2
2	16	-16.0017	14.7
3	32	-15.9955	7.3
4	48	-16.0081	5

5.2 Case-2:

In this case, the conventional numerical technique known as Chebyshev polynomial method is used to synthesize non-uniform LAA for of N=8,16,32, and 48. The objective of the synthesis is to produce a SLL of -30dB. The radiation patterns are as shown in Fig.3.24(a) through Fig.3.34(a). The corresponding amplitude distributions are given in the respective bar graphs as shown in Fig.6 to Fig.9. The corresponding beamwidth for every value of N in the LAA is listed in Table.2.

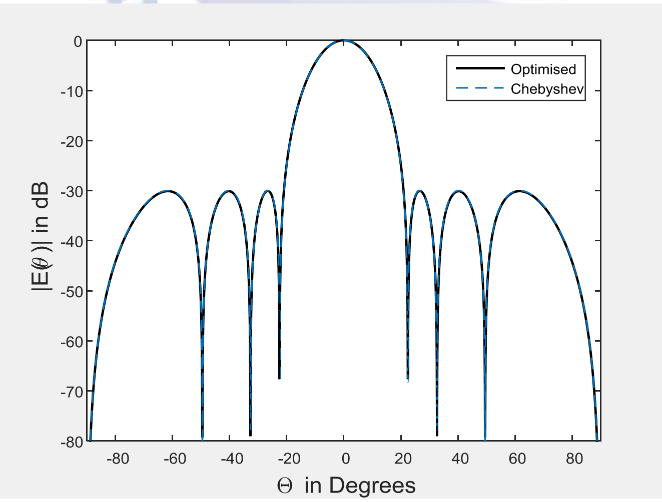

Fig.6(a): Optimised radiation pattern of 8 element LA in case 2

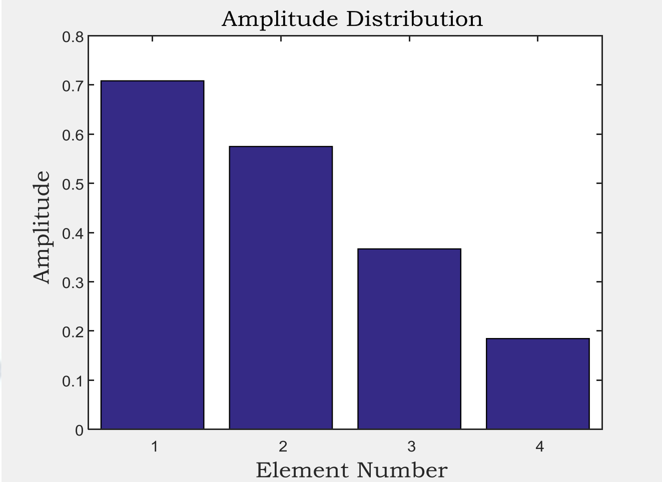

Fig. 6(b): Amplitude distribution of 8 element LA in case 2.2

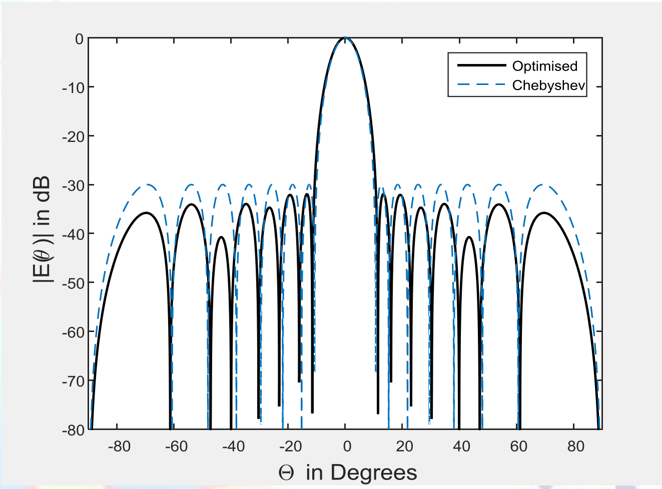

Fig.7(a): Optimised radiation pattern of 16 element LA in case 2

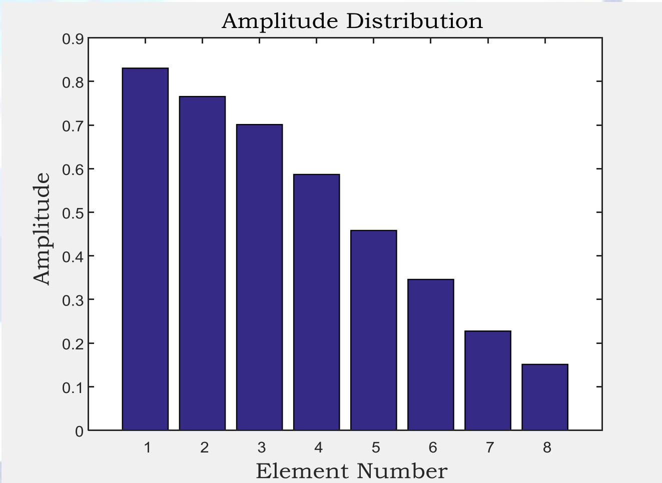

Fig.7(b): Amplitude distribution of 16 element LA in case 2

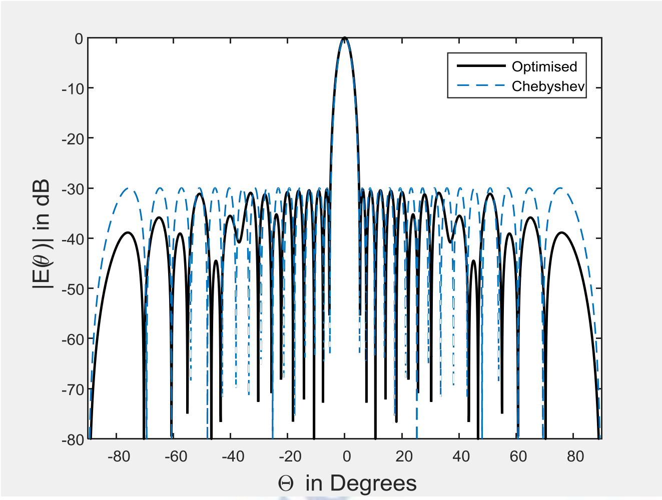

Fig.8(a): Optimised radiation pattern of 32 element LA in case 2

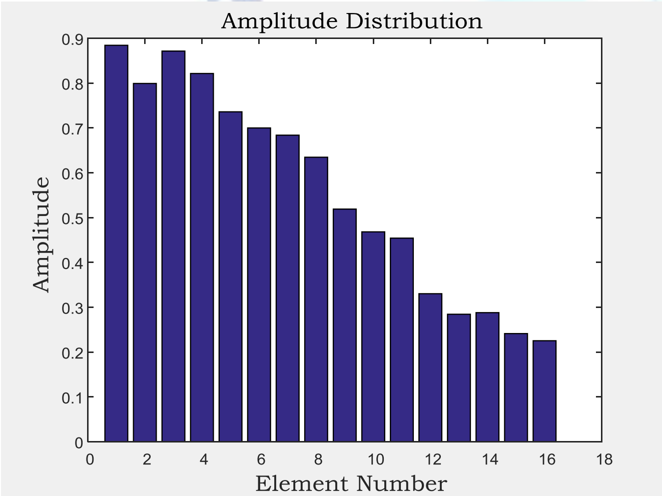

Fig.8(b): Amplitude distribution of 32 element LA in case 2

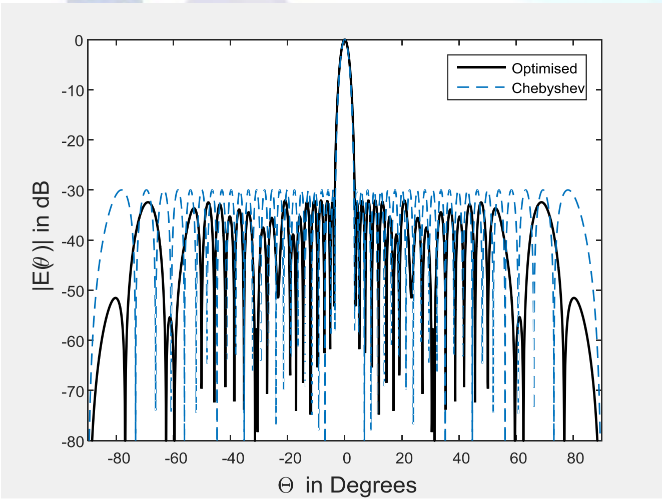

Fig.9(a): Optimised radiation pattern of 48 element LA in case 2

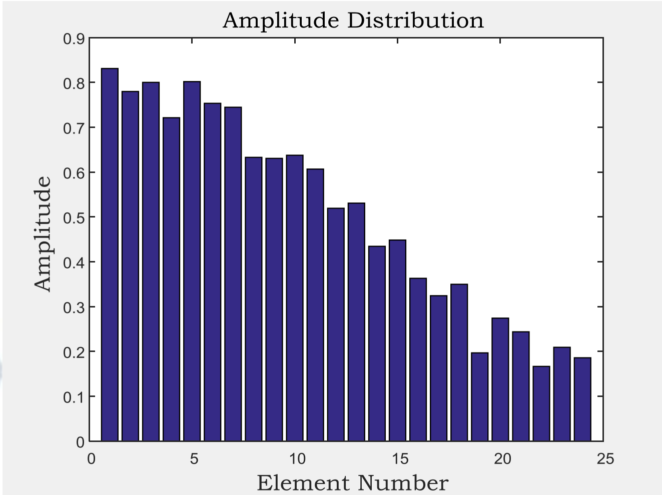

Fig.9(b): Amplitude distribution of 48 element LA in case 2

Table.2: BW of in Case-2 for -30dB

S.No	elements	BW (degrees)
1	8	45
2	16	21.5
3	32	10.5
4	48	7

VI. CONCLUSIONS

The amplitude only technique is implemented for linear array synthesis and compared with uniform and Chebyshev technique. The SGOA algorithm has produced excellent results and appeared to be robust in designing NULA for any number of elements and BW constraint for SLL optimization.

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