Amplitude Only Linear Array Synthesis with Desired Nulls Using Evolutionary Computing Technique

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***Abstract* ─** Beamforming is a desirous technique in wireless communication by which the desired signal is filter spatially from the interference environment. In this paper, the Firefly algorithm (FFA) is used to demonstrate such beamforming characteristics in linear arrays using amplitude only technique. The amplitude only technique is effectively employed with the FFA to synthesize the linear arrays with desired radiation characteristics. The generated radiation patterns have single and multiple nulls with no constraint imposed on beam width or side-lobe level. The beam steering characteristics are also studied using the same methodology.

***Index Terms* ─** Beam width, direction of arrival, firefly algorithm, side lobe level.

I. INTRODUCTION

Multiple stationary elements collectively operate as a single element antenna there by concentrating the radiation to one direction which is desirable for many wireless applications. Earlier single element antennas with directivity much less than the required level are used for these applications. Later antenna arrays with excellent directivity characteristics have replaced these single element antennas [1-4].

Radiating elements for modern wireless communications needs to posses certain features like high directivity, good control on side-lobe level (SLL), control on beam width (BW) along with beam steering (BS) capabilities [5,6]. Single element antenna fails to achieve the above, as they exhibit poor directivity and no control on SLL and BW. Also, they require some additional circuitry to control the position of the main beam which makes the system more unwieldy. Moreover, the main problem with single element antenna is that they are highly frequency dependent. Any attempt to enhance the directivity would have a direct impact on the operating frequency of the antenna which is evident from the case of a simple fundamental is $\lambda/2$ (half wave length) dipole. The operating wavelength and the corresponding frequency gets modified when the length of the dipole is increased in order to increase its directivity. Hence, such antennas are not suitable for frequency dedicated applications. Therefore, the solution lies in enhancing the electrical length keeping the physical length constant. This is possible with the concept of antenna array where the electrical length is greater than the physical length of the each individual element constituting the array.

Antenna arrays are capable of controlling radiation pattern for desired main BW, half power BW and SLL with proper modifications of geometrical and electrical properties of the array.

An antenna array synthesis problem refers to determining weights for the geometrical properties like spacing (d) between elements or electrical properties like current excitation and phase excitation to produce desired radiation pattern. The choice of considering number of properties for synthesis depends on the type of synthesis problem. In general, the objectives of array synthesis include either SLL control or BW control or both to effectively produce desired shaped radiation pattern [7-14].

Interference suppression is the other reason for array synthesis which is not possible in the case of single element antennas. This is made possible by controlling the radiation in the unwanted direction and projecting the same in the desired direction. This concept in simple form known as beam-forming. The rejection of the undesired signal is carried out by simply placing the nulls in the direction of arrival (DOA) of the interference signal while the main beam is steered to the DOA of the desired direction.

Many conventional techniques like Schelkunoff and Taylor's methods are proposed to solve the problem of beamforming. Unfortunately these are time consuming

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as well as prone to stick in the local minima. In order to overcome these hurdles, in the recent, past several evolutionary techniques are proposed. These techniques are quite efficient and often express the supremacy over traditional techniques.

In this paper, such an attempt is made by adopting Firefly algorithm (FFA) for such applications. FFA is effectively applied to the problem of null generation in linear arrays under non-beam steering and beam steering conditions. The procedure allows essential implementation of beamforming conditions.

The rest of the paper is organized as follows. Section II is dedicated to description the FFA. Problem statement and its formulation is given in Section III and the corresponding fitness evaluation and formulation is given in Section IV. Implementation of the FFA to the array synthesis problem is explained in Section V. The case wise presentations of results are given in Section VI which is followed by overall conclusion in Section VII.

II. FIREFLY ALGORITHM

FFA is a novel metaheuristic algorithm inspired by the behaviour of fireflies [15]. FFA is proposed by Yang. It is another swarm intelligence based algorithm which is inspired by the behaviour of fireflies and the phenomenon of bioluminescent communication.

The construction of FFA algorithm is based on the following set of rules

1. Fireflies (FF) are unisex and can attract any fellow FF.
2. Attractiveness depends on ones brightness.
3. The brightness or light intensity of a firefly is influenced by the landscape of fitness/cost function.

The structure of the FFA is as mentioned in Fig. 1.

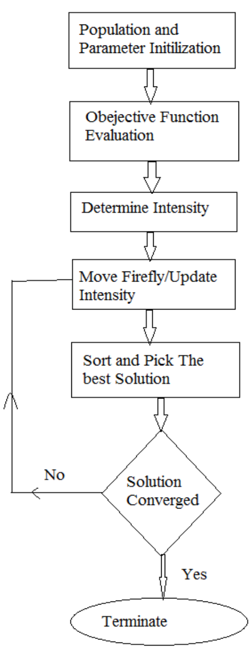

Fig. 1. Flow chart of FFA.

III. FORMULATION OF THE DESIGN PROBLEM

The geometry of the linear array with centre feed and symmetric distribution on either sides of the feed point is as shown in Fig. 2.

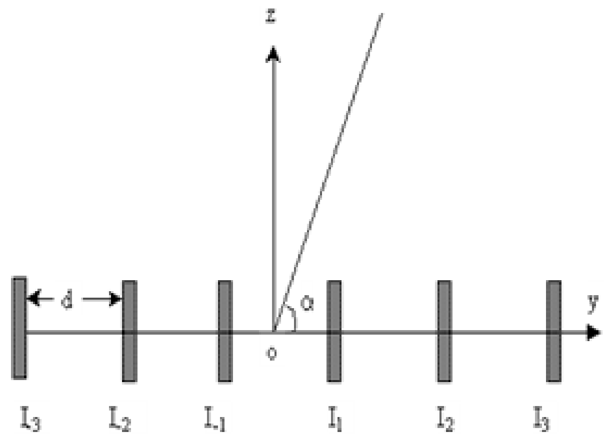

Fig. 2. Geometry of the linear array with symmetric distribution.

The number of elements in the array is given as N=2n and are oriented along X-axis along a straight line to depict a simple line array. Each element in the array is an antenna which is characterized by three parameters and are given as current excitation (I), phase of current excitation ($\o_n$) and spacing (d_{en}). The corresponding array factor that is used to draw the radiation pattern of the LA is a function of these three parameters. However, in this work it is already mentioned that the adopted technique is amplitude only. Hence, the remaining parameters, i.e., d and $\o_n$ are uniform and are assigned with values (0.5λ and 0^0 respectively). Accordingly, the array factor is simplified and given as:

$$AF(\theta) = 2\sum_{n=0}^{N-1} I_n \cos[\pi \cos\theta + \phi], \tag{1}$$

where I_n is the nth element current excitation and θ is look angle.

IV. FORMULATION OF FITNESS FUNCTION

The Fitness Function formulation is according to the objective of the proposed work. Accordingly, is given as follows:

$$f = 60dB + E(\theta_{null}) \quad \text{if} \quad |E(\theta_{null})| < 60$$
$$= 0 \quad \text{Otherwise,}$$

where θ_{null} - null position in degrees, $E(\theta_{null})$ is the corresponding E-field magnitude at the desired null position and desired null depth of ‘60’ is simply considered as the fitness value of the corresponding individual.

V. ARRAY DESIGN USING FIREFLY ALGORITHM

The implementation of the algorithm for the array design problem is explained in several steps as discussed below.

A. Population initialization

Like any other population based algorithm, the FFA also starts with initialization of random population in terms of P fireflies (FF) in a K dimensional search space. Each FF corresponds to a solution in the domain of search. Improvement in the solution is obvious with every progressive iteration. Implementation of the FFA for LA synthesis refers to interpretation of each FF as a vector of coefficients for the amplitudes of excitation of a LA. This is represented as:

$$x_i = [x_1, x_2, x_3 .... x_K]. \quad (2)$$

The corresponding population matrix is given as:

$$X = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ x_P \end{bmatrix} = \begin{bmatrix} x_{11}\ x_{12} .... x_{1K} \\ x_{21}\ x_{22} .... x_{2K} \\ . \ . \ . \ . \ . \ . \ . \\ . \ . \ . \ . \ . \ . \ . \\ x_{P1}\ x_{P2} .... x_{PK} \end{bmatrix}. \quad (3)$$

The upper and lower bounds of the search variable is (x_{min}, x_{max}).

B.FF evaluation

FF evaluation refers to evaluation of the fitness for the corresponding amplitude distribution:

$$I_{i\,=}\ \text{ObjFunc}\ (x_i).$$

C. Attractiveness, distance and displacement

The calculation of the attractiveness of a FF is given by [15]:

$$\beta(r) = \beta_o * \exp(-\gamma r_{ij}^2). \quad (4)$$

Here, r is the distance between any two fireflies, β_o is the initial attractiveness at r=0 and γ is the absorption coefficient which controls the decrease of the light intensity. The distance between any two fireflies i and j at x_i and x_j respectively, can be defined as a Cartesian distance 'r_{ij}' using the following equation [15]:

$$r_{ij} = |x_i - x_j| = \sqrt{\sum_{k=1}^{n} (x_{ij} - x_{jk})^2}\ . \quad (5)$$

The displacement of a firefly 'i' which is attracted by a more attractive (i.e., brighter) firefly 'j' is given by the following equation [15]:

$$x_i = x_i + \beta_o * \exp(-\gamma r_{ij}^2) * (x_j - x_i) + \alpha * (\text{rand} - 1/2). \quad (6)$$

The parameters used in the proposed FFA are shown in Table 1.

Table 1: Parameter used in the proposed FFA

Description	Parameter	Typical Value
Maximum attractiveness	β_0	1
Time varying algorithm parameter initial value	α	0.25
Absorption coefficient	γ	1
Swarm size	P	30
Number of iterations	Iter	250

VI. RESULTS AND DISCUSSION

The entire simulation based experimentation is divided in to four cases. Description of the problem statement and the corresponding radiation pattern plots are given case-wise in the following discussion. In every case the results are compared with those obtained using Genetic Algorithm. From Case 1 to Case 2, the number of desired nulls are incremented from 1 to 3. Whereas, in Case 4, the Case 3 objectives are repeated but, with the main beam steered in order to serve for DOA of 30^0. The last case significantly refers to the study of receiving a desired signal of interest, which is in the direction of $\Theta=30^0$ while the interference signals are in the direction of 20^0, 40^0 and 60^0.

The corresponding amplitude distribution for both GA and FFA are given in the respective column of Table 2 case-wise. In addition to the amplitude distribution, the computational time for each simulation based experimentation is also recorded in order to analyse the performance of the FFA when compared with GA.

A. Case-1

In this, a simple linear array is synthesised with desired nulls at one position, i.e., at 20^0. Due to the inherent symmetry, a similar null appears on the other side of the pattern at -20^0 also. The radiation pattern obtained for the amplitude distribution determined by the FFA is presented in the Fig. 3. A null at 20^0 with null depth of less than -80 dB can be observed.

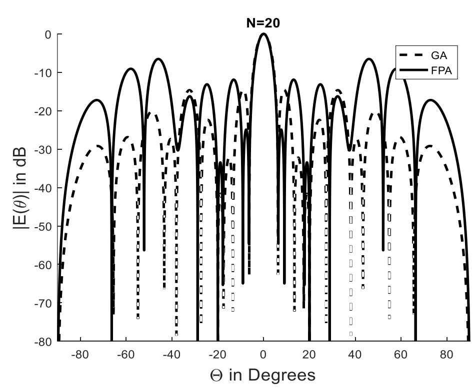

Fig. 3. Radiation pattern with null 20^0.

B. Case-2

In this case, multiple nulls are considered. The objective of this case involves in positioning the second null at 40^0 in addition to the earlier existing null. The validation and the effectiveness of the algorithm is evident with this kind of effort to generate the null which doesn't appear in the previous case protecting the existing null. The corresponding radiation pattern is as shown in the Fig. 4. The amplitude distribution is as mentioned in the Table 2. It is evident from the radiation pattern presented in Fig. 3 that, the magnitude of E-field at $\Theta=40^0$ is well above -30 dB, while the magnitude of E-field at the corresponding $\Theta=40^0$ is well below -80 dB.

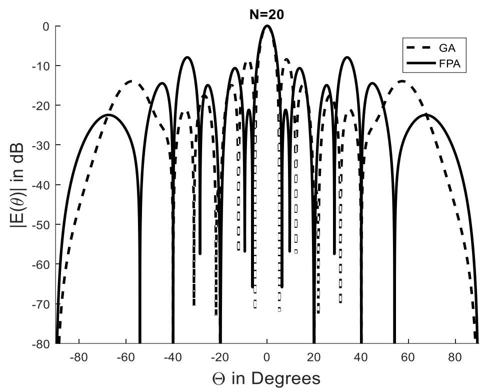

Fig. 4. Radiation pattern with nulls at 20^0 and 40^0.

C. Case-3

This case is similar to Case-2, but with enhanced number of nulls. Keeping the earlier two nulls in their position in the radiation patterns, an extra null is located at 60^0. This further helps in validating the efficiency of the algorithm in positioning the nulls in the desired directions as well as handling multiple nulls. This is demonstrated in Fig. 5, where the arrow marks show the position of the desired three nulls. The amplitude distribution obtained using the FFA is given in Table 2.

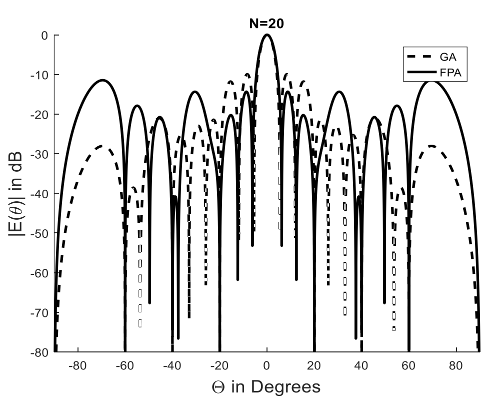

Fig. 5. Radiation pattern with nulls at 20^0, 40^0 and 60^0.

D. Case-4

Beam steering is one of the desired characteristics in beamforming. It is often desired to steer the main beam to the desired direction, which is the DOA of the actual signal. In addition to this, three nulls are also positioned as mentioned in the Case-3 which is considered as the DOA of the interference signals. This is shown in the Fig. 6, where the main beam is steered to an angle of 30^0 which is considered as the DOA of the desired signal. The corresponding amplitude distribution is as given in Table 2.

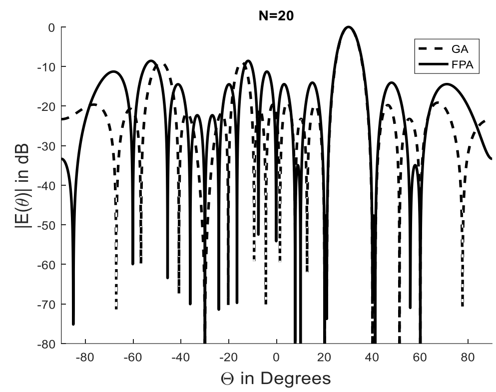

Fig. 6. Radiation pattern with nulls at 20^0, 40^0 and 60^0 with main beam scanned to DOA of 30^0.

Table 2: Amplitude distribution obtained using FFA for different cases

Case #	Algorithm	Normalised Amplitude Distribution	Computational Time (Sec)
1	FPA	0.698, 1, 0.267, 0,0.939, 0.078, 0.404, 0.524, 0, 1	0.56
	GA	0.558, 0.921, 0.714, 0.59, 0.817, 0.928, 0.777, 0.327, 0.402, 0.601	2
2	FPA	0.778, 0.868, 0.567, 0, 0.228, 1, 0.156, 0.211, 0.814, 0.534	1.02
	GA	0.615, 0.148, 0.629, 0.118, 0.898, 0.785, 0.668, 0.801, 0.719, 0.510	12.08
3	FPA	0.443, 0.949, 0.746, 0.519, 0.388, 0.985, 0.571, 0.848, 0.038, 0.622	9.89
	GA	0.625, 0.422, 0.493, 0.368, 0.473, 0.681, 0.737, 0.793, 0.776, 0.178	27.58
4	FPA	0.934, 0.602, 0.608, 0.379, 0.203, 0.860, 0.135, 0.004, 0.911, 0.082	10.08
	GA	0.637, 0.999, 0.33, 0.640, 0.638, 0.139, 0.667, 0.052, 0.265, 0.576	29.58

VII. CONCLUSION

The technique of generating nulls in the desired directions in order to suppress the interference signals is well demonstrated under unscanned and scanned conditions for beamforming characteristics. The novel algorithm has shown its efficiency and simplicity in terms of computation and complexity. When compared with GA, the FFA reported efficient synthesis results in terms of computational time. Instead of number of iterations, performance of the algorithm is evaluated in terms of computational time as the later would be an appropriate scale. Though the GA reported competitive results when compared with the FFA, the consumed time by the GA is at least three times higher than that of FFA. This appears to even worse when the number of elements or the design variable of the problem are considered in large arrays. The technique demonstrated in this paper can easily be extended to any multimodal problems with several constraints.

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