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Circular Array Antenna Optimization with Scanned and Unscanned Beams using Novel Particle Swarm Optimization

KEYWORDS: Circular array, particle swarm optimization, scanned and unscanned, sidelobe level, evolutionary algorithms

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ABSTRACT *Sidelobe level suppression is a typical circular array (CA) optimization problem. Many conventional techniques are proposed in the due course of time which are computationally complexed and time consuming. As an alternative, several evolutionary and heuristics approaches have evolved for solving such problems. In this paper, a novel accelerated particle swarm optimization (APSO) is considered for solving circular array optimization problem. The APSO is implemented for CA synthesis with the objective of SLL suppression. The objective is achieved under scanned and unscanned beam conditions. A very low SLL of -25dB is observed when the main beam positioned at 00,150 and 300 . In all the cases the efficiency of the APSO is evaluated by the comparing the generated radiation patterns with those obtained from uniform CA.*

INTRODUCTION

An Antenna by its basic operation can be defined as an electromagnetic radiator, interceptor, sensor, transducer or an impedance matching device [1]. It is the most important block of all communications, radar and in bio-medical systems. It is obvious that the gain of a single antenna element is not sufficient for most applications [2]. Increasing the gain and directivity involves in increasing the physical length of the antenna. This makes the antenna more bulky forfeiting the ease of installation. Under this circumstance use of arrays provide the solution. An Array is a collection of well versed elements (antenna). It is a geometrical configuration of antenna elements grouped in such a way as to direct radiated power towards particular angular direction in space there by increasing the directivity and decreasing the beam width. Many traditional computational techniques [3] are used for array synthesis. Most of the techniques have failed in handling the array synthesis problems efficiently due to computational limitations. Hence, many evolutionary and heuristic approaches like genetic algorithm (GA) [4,5], particle swarm optimization (PSO) [6], teaching learning based optimization (TLBO)[7] and flower pollination [8] etc. are proposed.

In practice, there are many types of array geometries like linear, circular, planar and cylindrical. The classification is based on the geometrical structure and the dimension. Among all these array geometries, circular arrays have evolved as very good candidates with wide applications in wireless communications in the recent times.

It is evident from the literature that the radiation characteristics of an antenna array depends on some input parameters like the element current excitation magnitude, phase of excitation, the geometrical configuration of the array and the spacing between the array elements. These parameters should be modified in order to control the radiation characteristics of an array.

In this paper, certain emphasis is given to circular array synthesis with the constraint of SLL to -25dB by modifying the amplitudes of current excitation of each element. According to the literature this is termed as amplitude only technique. In the present work Accelerated PSO is employed for the circular array synthesis. APSO is another flavor of PSO proposed by Xin She Yang, which is proven to be very efficient in solving multi-modal problems in many disciplines.

The rest of the paper is organized as follows. A brief introduction to the APSO is given in Section II. Implementation is mentioned in Section III. Results pertaining to the objective are presented in Section IV. Overall conclusion of the work is discussed in Section V.

PARTICLE SWARM OPTIMIZATION

Kennedy and Eberhart have applied this PSO as a novel method of optimization on Neural Networks. Prior to this Craig Reynolds has demonstrated and programmatically realised the behavior of flock of birds [4]. This is made possible considering some characteristic rules of the flock like continuous monitoring and updating one's velocity with its neighborhood, and always keep the direction steered towards the center of the flock while avoiding collisions.

In its basic form this PSO is characterized by stochastic search, population based search and adaptive nature with its neighbors. Being population based search algorithm it holds the capability of global search and scattering local searches. Its iterative evolution allows its particles to adaptively relocate with the knowledge as well as experience of its neighbor.

The PSo in its simplistic form is a simulation of the social behavior of birds in a flock. Every bird is a particle in hyper-dimensional search space. Also every particle has some socio-psychological nature by which it tries to enhance its scope of other particles.

In PSO the swarm is a collection of particles in motion. And every particle concerns a potential solution. The solution approaches the desired value as the particle moves with its knowledge of personal experience as well as global.

To accomplish for this it has 2 parameters

$x_i(t)$=i^{th} particle position at time slot 't'.

$v_i(t)$=i^{th} particle velocity at time slot 't'.

In a particular iteration the position is updated as

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad - (1)$$

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It can be understood from above expression that the velocity updates the position with the knowledge of globally exchanged information. With respect to the methodology adopted in updating velocity there are many flavors of PSO as Individual Best PSO, Global best PSO and Local Best PSO.

In Individual Best PSO methhod the velocity is updated with the knowledge of only its personal best as follows

$$v_i(t+1) = v_i(t) + \rho\,(x_{i(pbest)} - x_i(t)) \qquad -(2)$$

where as in Global Best PSO the velocity is updated with including the knowledge of the best particle's position in the flock.

$$v_i(t+1) = v_i(t) + \rho_1(x_{i(pbest)} - x_i(t)) + \rho_2(x_{gbest} - x_i(t)) \qquad -(3)$$

In local best the updating process is similar to that of Global best where x_{gbest} is replaced with x_{lbest} which is local best of the particle.

$$v_i(t+1) = v_i(t) + \rho_1(x_{i(pbest)} - x_i(t)) + \rho_2(x_{lbest} - x_i(t)) \qquad -(4)$$

Where as in APSO only the global best is used [9,10] in updating process rather than complexed equation involving local best. This is demonstrated in the following equation.

$$v_i(t+1) = v_i(t) + \alpha\varepsilon_n + \beta\,(g^* - x_i(t)) \qquad -(5)$$

ARRAY FACTOR FORMULATION OF CIRCULAR ARRAY ANTENNA

The geometry of the circular array antenna is as given in the Fig.1. The array factor formulation is the vital part of the simulation experiment carried in this paper. The radiation pattern is plotted using the array factor values obtained using this array factor. The radiation pattern is used to evaluate the SLL for the non uniform current excitation coefficients distribution given by the algorithm. The corresponding array factor expression is given as [1]

$$AF(\phi) = \sum_{n=1}^{N} I_n.\exp(j.(kr.\cos(\phi - \phi_n) + \beta_n)) \qquad -(6)$$

Where

n is element number

N is number elements in the array

I_n is the current excitation of the nth element

β_n is the phase excitation of the nth element

the 'kr' and ϕ_n are given as

$$kr = \frac{2\pi r}{\lambda} = \sum_{i=1}^{N} d_i \qquad -(7)$$

$$\phi_n = \frac{2\pi}{kr}\sum_{i=1}^{n} d_i \qquad -(8)$$

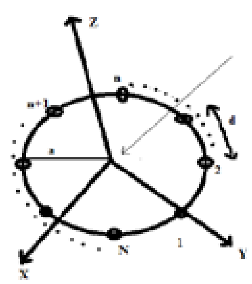

Figure 1: Geometry of Circular Array

The fitness is evaluated using the following expression

fitval=min[max(AF(SL))]

fitness= 25+fitval -(9)

where SL is sidelobes. The expression explains that the optimization problem is the minimization of maximum sidelobes that are directly read from the magnitudes of the AF obtained using the eq.(6).

RESULTS

The objective of the work is to attain a SLL of -25dB in non-uniform CA with amplitude only technique using APSO. The simulation experiment is carried with the following data

Number of elements (N)=30

Initial population (pop)= 100

The simulation is carried out as three cases. The first case is to obtain the desired SLL when the main beam is positioned at 0^0. Case-2 involves in obtaining the same SLL when the main beam is steered to 15^0. Similar to case-2 the same SLL is achieved in case-3 but with main beam positioned at 30^0 this time. For all the cases the corresponding the radiation patterns and the convergence plots are presented.

Case-1: Main beam at 0^0 (Unscanned)

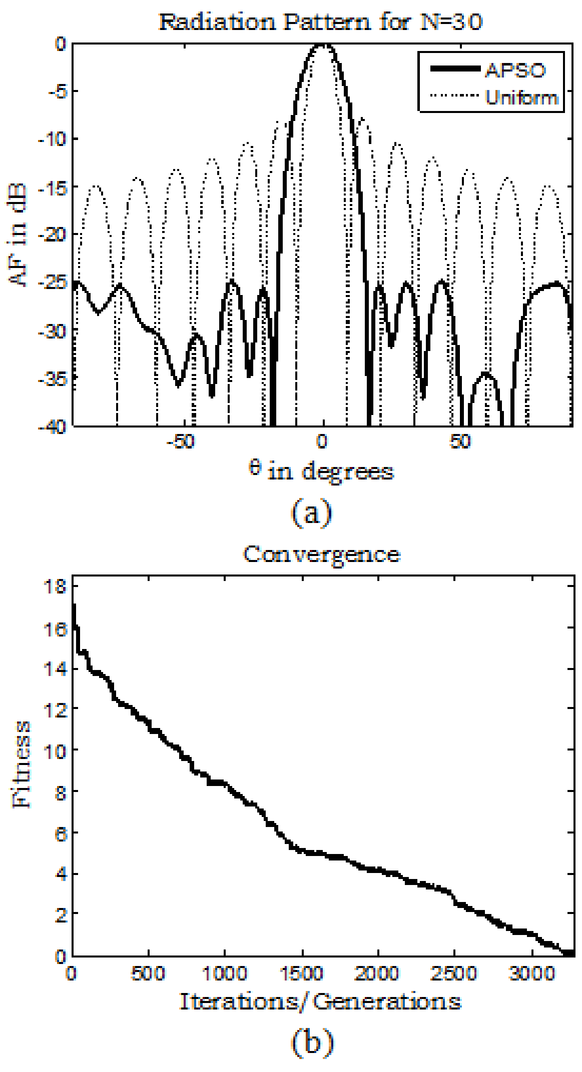

Figure 2: Output plots for N=30 and unscanned conditions (a) Radiation pattern (b) Convergence plot.

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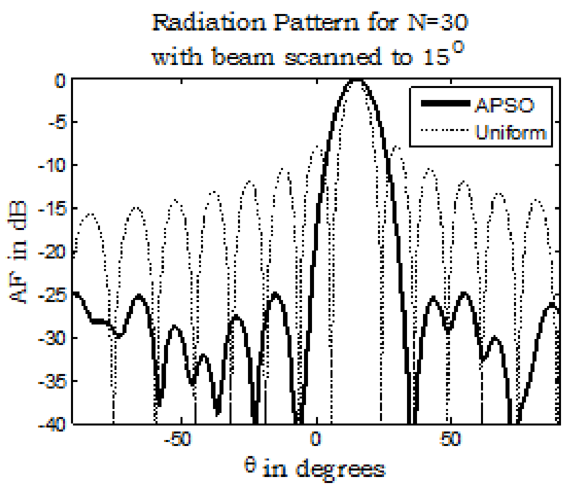
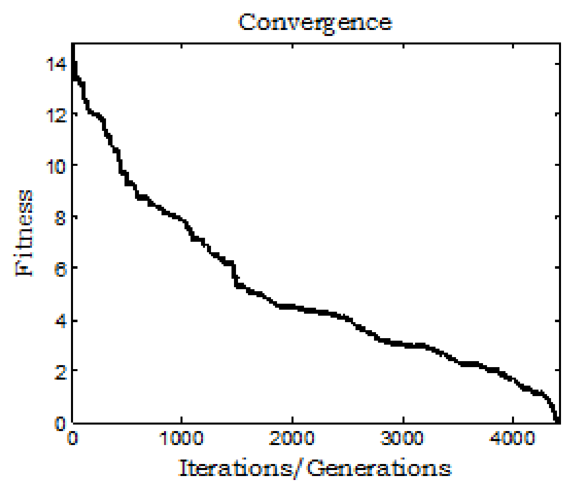
A relatively low SLL of -25dB can observed from Fig.2. The dotted plot refers to uniform CA in which all the elements in the array are uniformly excited. The solid line refers to the non uniformly excited array in which the element excitation is obtained from APSO algorithm with respect to the objective. From the convergence plto it can be read that the algorithm consumed more than 3000 generations to converge. The convergence point in this problem is zero, as the fitness is the difference between the desired SLL and obtained best individual's SLL.

Case-2: Main beam at 15^0 (Scanned)

In this case, the main beam is steered to 15^0 and the same objective is achieved as shown in the Fig.3(a). It can be learned from the convergence plot given in Fig.3(b) that the number of iterations consumed in this case is more than that of case-2. This is due to beam steering.



(a)

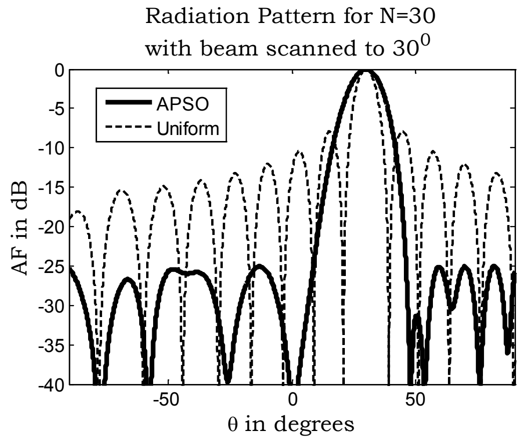


(b)

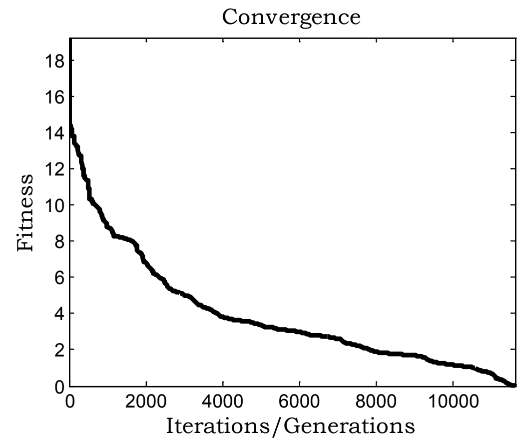
Fig.3: Output plots for N=30 and main beam scanned to 15^0 (a) Radiation pattern (b) Convergence plot.

Case-3: Main beam at 30^0 (Scanned)

In this case, the beam is steered to 30^0 as shown in the Fig.4(a). Also achieving the same objective would validate the implementation of APSO for antenna array applications. Also it is clear from Fig.4(b) that, due to steering to certain angle consumed more number of iterations.



(a)



(b)

Fig.4: Output plots for N=30 and main beam scanned to 30^0 (a) Radiation pattern (b) Convergence plot.

The non-uniform excitation coefficients for current distribution of the circular array obtained using APSO are tabulated in table 1. The first column refers to the distribution when the main beam is positioned at 0^0. The corresponding distribution with respect to case-2 and case-3 are given in second and third columns. This non-uniform distribution can be used to reproduce the radiation pattern plots given in Fig. 2(a), Fig.3(a) and Fig.4(a).

Computational time and the number of generations consumed for each case are given in the table 2. Analysis based on this tabulated data would reveal several interesting points as follows.

i) As the steering angle increases the number of generation to achieve the objective also increases.
ii) With the increase in number of generations the time consumed also increases.

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TABLE – 1

Element Number	Amplitudes obtained using FPA with beam scanned to		
	0^0	15^0	30^0
1	0.7125	0.9264	0.4498
2	0.9388	0.7636	0.9353
3	0.5139	0.8681	0.9995
4	0.4508	0.6649	0.9321
5	0.1496	0.5936	0.6335
6	0.1070	0.1094	0.2111
7	0.0110	0.0137	0.1125
8	0.0314	0.2325	0.0001
9	0.0380	0.1906	0.1526
10	0.0711	0.0703	0.0017
11	0.1452	0.0149	0
12	0.1636	0.0596	0.0074
13	0.3378	0.2602	0.0171
14	0.5149	0.4097	0.3315
15	0.7573	0.4647	0.2121
16	0.6509	0.9977	0.3834
17	0.7688	0.9110	0.7396
18	0.3822	0.8618	0.8403
19	0.3638	0.6307	0.6642
20	0.0679	0.4828	0.3309
21	0.121	0.0279	0.1729
22	0.0068	0.1420	0.0151
23	0.0086	0.1400	0.0004
24	0.1112	0.0470	0.0402
25	0.0193	0.1688	0.0243
26	0.2275	0.0084	0.0039
27	0.2006	0.0243	0.0022
28	0.5456	0.2075	0.2135
29	0.6012	0.2365	0.2781
30	0.9710	0.2513	0.4193

Table-2

Scanning angle	Number of generations	Elapsed time (secs)
0^0	3251	357.46
15^0	4410	1443.86
30^0	11600	3700.79

CONCLUSION

The new version of the PSO known as APSO is efficiently incorporated for antenna array applications. Relatively very low SLL is achieved under both scanned and unscanned conditions. Hence it can be considered that the APSO is validated perfectly for circular array synthesis problems.

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