International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-5, June 2019

Synthesis of Circular Array Antenna for Side Lobe Level and Beam Steering Control Using Social Group Optimization Algorithm

Abdul Rahiman Sheik, Kalva Sri Rama Krishna

Abstract*: In this paper, the design of circular array using novel evolutionary computing tools is dealt with side lobe level (SLL) reduction as main objective. Further, the beam is scanned (steering) to certain angle considering the same objectives and constraints. The Social Group Optimization algorithm (SGOA) is used to design the array and compared with the another evolutionary computing tool known as the Real Coded Genetic Algorithm (RCGA) and conventional uniform design with major concern being not to do performance evaluation with but to elevate that the performance of the novel SGOA is at par with RCGA. The analysis is carried out using the produced radiation patterns for two different lengths of the array.

***Index Terms*: SLL, SGOA, RCGA.**

I. INTRODUCTION

Antennas with high directivity are the basic requirement of many wireless and mobile applications. These applications need the antenna for detecting the radio signal spatially. It is evident from the basic literature that single element antenna is not capable of rendering the required directivity for such applications. For large directivity, similar antenna are grouped into a geometrical configuration to form an array. Such array configuration not only provides the advantage of high directivity but also capable of steering the beam, locating the nulls and controlling the BW of the radiation pattern. One such geometry which is very popular in the recent times is circular array geometry. Circular geometry array has the inherent property of scanning to any angle with much change in the remaining part of the radiation pattern. The other advantage provided by this circular array geometry is that they tender less reaction to the mutual coupling which is often a major problem in practical antenna arrays. This is due to the circular geometry that doesn't possess any end elements like linear or other planar arrays. Some important applications of circular arrays are ground penetrating radars for geo-physical applications and ground water table identification, space and underwater navigation, and RADAR applications [1-5]. Hence it can be considered that an active work on circular arrays is in progress in the current scenario of research in electromagnetics.

Conventional synthesis techniques are available in the literature which are applied to linear array synthesis and extended to circular arrays with certain modifications. However, these techniques have complexed computational steps and complicated mathematics associated with it. In order to overcome the complications, many evolutionary computational techniques are proposed for circular array synthesis. The GA [1, 2], PSO [3], DE [4], Cuckoo Search [5] and Flower Pollination Algorithm [6, 7] have been successfully applied for circular array synthesis. The circular array synthesis process reported so far involved in finding proper element current excitation amplitude or position or both to obtain the desired radiation pattern. In this paper, one such attempt to determine the current excitation amplitudes with the objective of reducing the SLL with no other constraints is presented along with beam scanning features. Later, the problem is formulated as a multi-objective problem by including the BW constraint. It is shown that a relatively low SLL can be achieved with BW as that of uniform circular array (UCA).

Further, the paper is organised as follows. The problem formulation is given in Section 2, and the description and implementation of the algorithm are given in Section 3. The results and discussion is presented in Section 4. Overall conclusions are given in Section 5.

II. PROBLEM FORMULATION

A. Fitness Formulation

Give us a chance to think about that the isotropic components of the cluster are circulated along the outline of the hover of sweep "r" as appeared in Figure 1.

The target of the present issue is to find fitting arrangement of excitation amplitudes and interelement dividing for the components in the exhibit. Consequently, the definition of cluster factor for such a course of action ought to have extent of non-uniform amplitude and non-uniform spacing dissemination. As needs be, the exhibit factor of the geometry is given as fig.1

Manuscript published on 30 June 2019.
***** Correspondence Author (s)
Abdul Rahiman Sheik*, Research Scholar, Dept. of ECE, University College of Engineering & Technology, Acharya Nagarjuna University, Guntur. Associate Professor, Dept of ECE, NRI Institute of Technology, Pothavarappadu, A.P, India
Dr. Kalva Sri Rama Krishna, Professor & Head of the Department, ECE Department, V R Siddhartha Engineering College, Vijayawada, A.P.,India

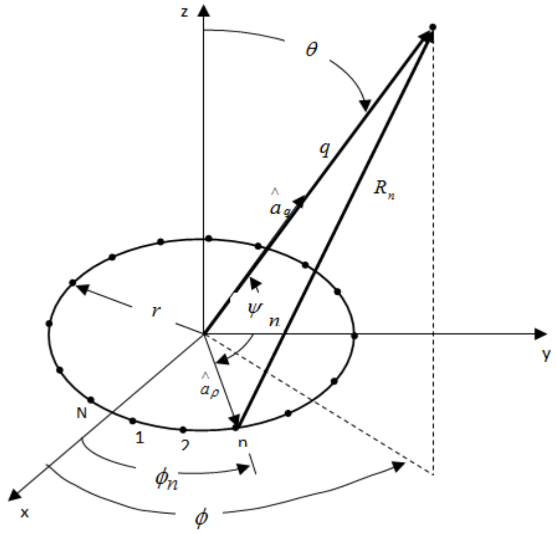

Fig.1: Geometrical configuration of circular array

$$SLL_{diff} = SLL_{Uni} - \max[\ |AF(\theta)|_{-90}^{\theta_0 - \frac{BW_{obt}}{2}},|AF(\theta)|_{\theta_0+\frac{BW_{obt}}{2}}^{90^0}\ ] \quad -(1)$$

$$BW_{diff} = |\ BW_{Uni} - BW_{obt}\ | \quad -(2)$$

$$f_1 = SLL_{diff} \qquad if\ SLL_{diff} > 0$$
$$= 0 \qquad otherwise \quad -(3)$$

$$f_2 = SLL_{diff} \qquad if\ SLL_{diff} > 0$$
$$= 0 \qquad otherwise \quad -(4)$$

$$f = c_1 f_1 + c_2 f_2 \quad -(5)$$

Where

SLL_{diff} is the difference between desired SLL (SLL_{des}) and obtained SLL (SLL_{obt})

BW_{diff} is the difference between desired Beam Width (BW_{Uni}) and obtained Beam Width (BW_{obt})

In the above equations f1 is a function for SLL reduction and f_2 is a function which controls the BW of the array. The overall fitness f value calculated by adding of f1 and f_2. Where c_1 and c_2 are constant biasing weighting quotients such that

$$c_1 + c_2 = 1 \quad -(6)$$

However, in the current work no biasing is applied and the objectives are provided with equal weight, hence c_1 and c_2 each is taken as 0.5.

B. Array Factor Formulation

The structure of the circular array lies on the XY planar surface as given in the Fig. (1). the array factor of the array is

$$AF(\phi) = \sum_{n=1}^{N} I_n \exp(j(kr\cos(\phi - \phi_n) + \beta_n)) \quad -(7)$$

Where,

n is element number

I_n amplitude of source current of n^{th} element

N is total number of elements in the array

β_n is the phase of the source current of n^{th} element

$$kr = \frac{2\pi r}{\lambda} = \sum_{i=1}^{N} d_i \quad -(8)$$

$$\phi_n = \frac{2\pi}{kr}\sum_{i=1}^{n} d_i \quad -(9)$$

The pattern of the radiation of the array is obtained from product of antenna element factor and the corresponding antenna array factor. As the elements in the array are isotropic in nature the element factor is considered as '1'. Hence, the array factor completely delineates the radiation pattern of the array.

It can be understood from the (7) that the array factor is a function of element current excitation amplitude, its corresponding phase, and inter-element spacing. Modifying these parameters the corresponding radiation pattern can be controlled. Basing on this, in brief, the design problem can be described as determining proper array configuration that produces the desired radiation pattern.In amplitude only technique the array configuration is solely defined by the amplitudes of the element's current excitation which is also known as non-uniform amplitude distribution.

III. CIRCULAR ARRY SYNTHESIS USING SGOA

Social Group Optimization Algorithm [8, 9] is novel metaheuristic population based algorithm inspired by the soial behaviour of the society. The people belonging to a society have some features and interests in common and some completely conflicting. They often express these features basing on the prevailing conditions around them. Some time they encounter some complex issues which have to be solved. On the line of solving these problems they may apply their inherent skills or may share the experiences of the other fellow human beings in the society. This is called group knowledge sharing. Individual efforts to solve the problem are often considered as the local search technique while the group activity may be referred as the global search. The SGOA process of problem solving is divided in to two parts. The first part consists of the 'improving phase'; the second part consists of the 'acquiring phase'. During the former phase, the knowledge source is the most knowledgeable person of the society or group. This is given as the following expression.

$$Inew_{ij} = c * Iold_{ij} + r * (gbest(j) - Iold_{ij}) \quad -(10)$$

During the later stage there is mutual interaction that helps to improve the solution. This mutual interaction is randomly performed. Finally, the individual with wide knowledge is emerges as the best in that iteration. The implementation of these algorithms is specific to the synthesis process as the array factors of both linear and circular array are similarly a function of amplitude (I), inter element spacing (d) and element excitation phase (Ø).

IV. RESULTS AND DISCUSSIONS

The simulation experiment is divided in to three cases. First and second cases use amplitude only technique to synthesize circular arrays that produce a lower SLL of -25dB consistently over any value of n when main beam is positioned at 0^0 and 15^0 respectively. The simulation work is divided in to two cases as follows.

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A. Case-1:

In case-1, the results in terms of radiation pattern plots along with their corresponding element amplitude distribution plot is given for n=40 and 80. In this case, the corresponding position of the main beam is at 00. Fig.2 through Fig.5 refer to the results pertaining to this case.

The radiation pattern plots for n=40 and 80 are given in Fig.2 and Fig.4 with the reduced SLL to -25dB consistently. This shows the efficiency of the algorithm.

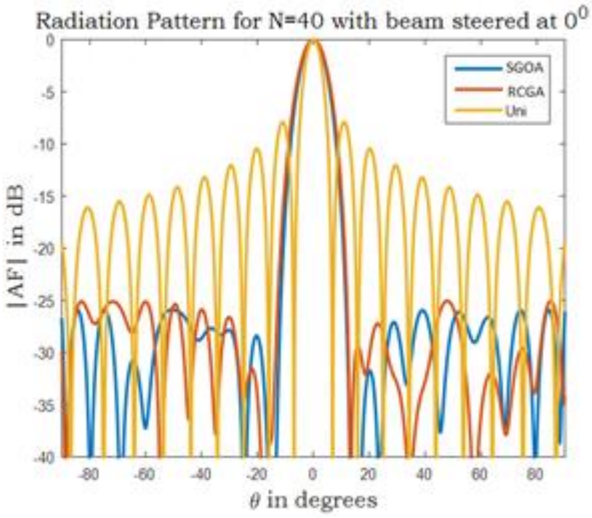

Fig.2: Radiation pattern for n-40 while beam positioned at 0^0.

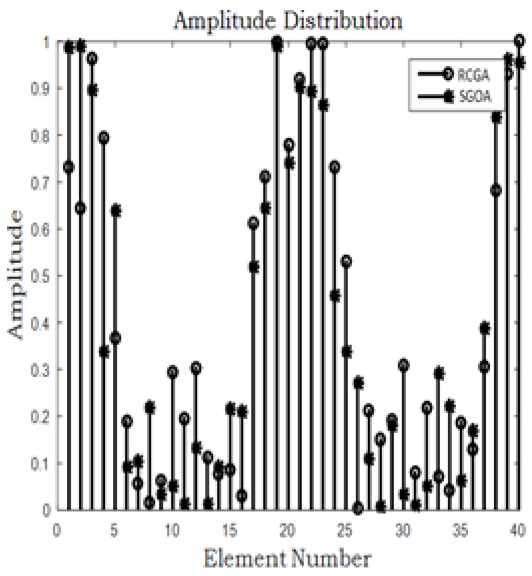

Fig.3: Amplitude distribution of 40 element CA

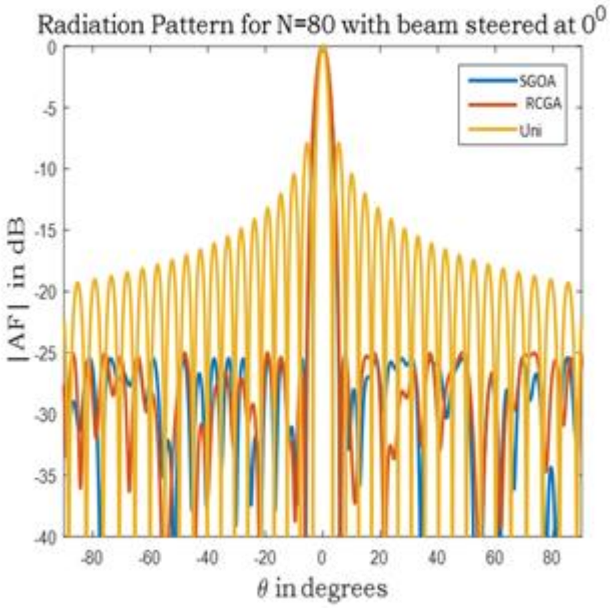

Fig.4: Radiation pattern for n=80 while beam positioned at 0^0.

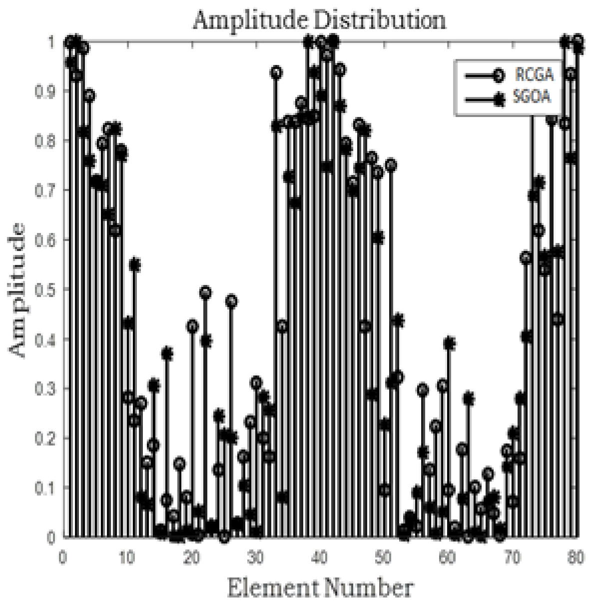

Fig.5: Amplitude distribution of 80 element CA

B. Case-2:

In case-2, the radiation pattern plots along with their corresponding element amplitude distribution plot is given for n=40 and 80 with the corresponding beam steering. In this case, the corresponding position of the main beam is at 150. Fig.6 through Fig.9 refer to the results pertaining to this case. The radiation pattern plots for n=40 and 80 are given in Fig.6 and Fig.8 with the reduced SLL to -25dB consistently. Similarly, the respective non-uniform distribution is presented in Fig.7 and Fig.9.

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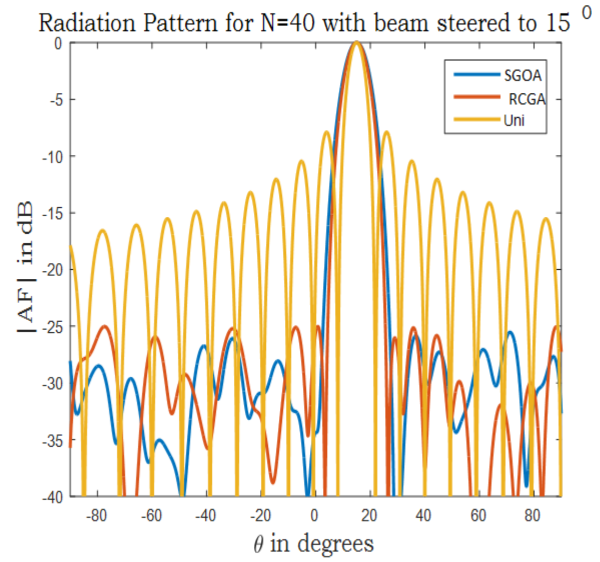

Fig.6: Radiation pattern for n=40 while beam positioned at 15^0.

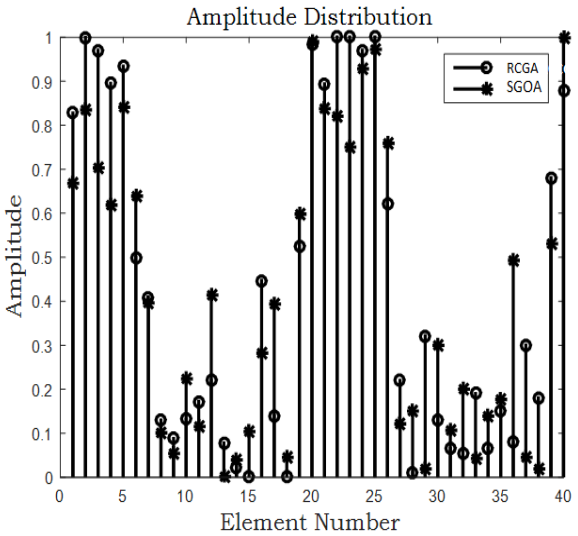

Fig.7: Amplitude distribution of 40 element CA

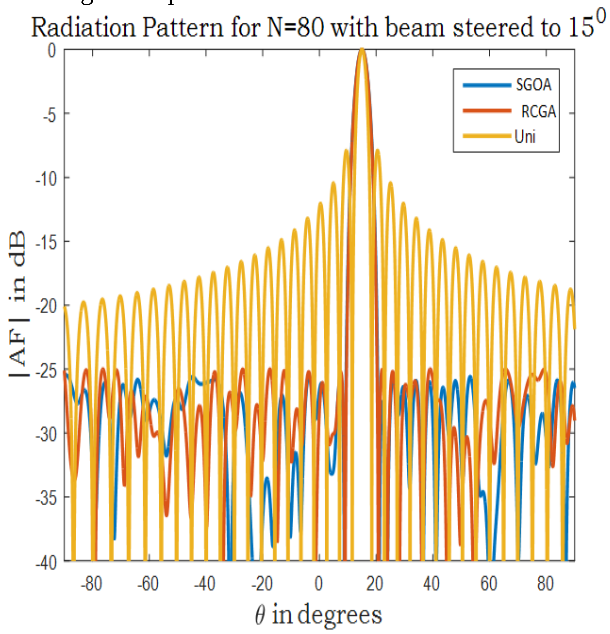

Fig.8: Radiation pattern for n=80 while beam positioned at 15^0.

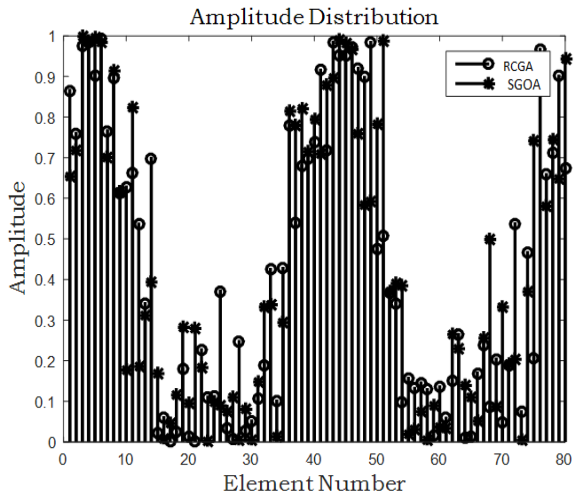

Fig.9: Amplitude distribution of 80 element CA

V. CONCLUSION

The efficient circular array design using non-uniform amplitude distribution technique is presented using the popular Social Group Optimization algorithm. Also, they are compared with the other efficient and renowned algorithm known as the Real Coded Genetic Algorithm. The SGOA has competitively at par with the efficiency of the RCGA. The design problem can be further extended to complex multi modal problem with several constraints on SLL as well as beam width.

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