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Design of Concentric Circular Antenna Array using Biogeography Based Optimization

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Abstract: Biogeography based optimization (BBO) is a novel stochastic force based on the science of biogeography. Biogeography is the schoolwork of geographical allotment of biological organisms. BBO make use of migration operator to share information between the problem solutions. The problem solutions are called as habitats and sharing of features is called migration. In this paper, BBO algorithm is developed to optimize the current excitations of concentric circular antenna arrays (CCAA). CCAA has several interesting features that make it crucial in mobile and communication applications. In this paper, a uniform arrangement of elements where the inter-element spacing is kept half a wavelength has been considered. The goal of the optimization is to reduce the side lobe levels and the primary lobe beam width as much as possible.
Keywords: Arrays, optimization, concentric antenna arrays, biogeography based optimization.

I. Introduction

Circular antenna arrays have considerable interest in a numerous applications which comprise sonar, radar, and mobile and commercial satellite communications systems [1–4]. A circular array is an arrangement of a number of elements, usually omni directional, arranged on a circle [1] and can be employed for beam forming in the azimuth plane such as at the base stations of the mobile radio communications system [2-4]. Due to their ability to perform the scan in all directions without a considerable change in the beam pattern and provide 360^0 azimuth coverage, circular arrays have become popular in recent years over other array. Moreover, circular arrays are less sensitive to mutual coupling as compared to linear and rectangular arrays since these do not have edge elements [1]. Concentric circular antenna array (CCAA) that contains many concentric circular rings of different radii and number of elements has a number of advantages including the flexibility in array pattern synthesis and design both in narrowband and broadband beam forming applications [2-4]. CCAA is also employed in direction of arrival (DOA) applications since it gives almost invariant azimuth angle coverage. Hence the synthesis of the circular arrays is under active research by many groups. Genetic Algorithm (GA) has been used in [5] to optimize the element placement in CCAA. Particle Swarm Optimization (PSO) [6] has been applied for the optimized synthesis of thinned CCAA. Efficient side lobe reduction techniques have been discussed in [3]. PSO has also been used for obtaining flat-top beam pattern of CCAA [7]. Null synthesis of CCAA has been performed using hybrid Ant Colonial method [8].

In this paper, biogeography-based optimization (BBO) is applied for the optimization of CCAA. BBO is a new evolutionary technique introduced in [10]. Since inception it has been applied for the optimization of variety of antennas. It has been applied for the design of linear antenna arrays for obtaining the maximum SLL reduction and null placement in desired directions in [11]. Results obtained using BBO for the linear arrays are encouraging. The BBO method produced a lower value of SLL and better null placement as compared to PSO [12].BBO has also been used for the optimization of Yagi-Uda [13]. Circular and concentric antenna arrays have been designed using BBO [14-15]. The BBO method has also been utilized for the thinning of linear and planar arrays [16-17]. The BBO method has been also applied in other areas, such as the power flow problem [18], optimization of gear trains [19]. The aim of this paper is to present the optimization of CCAA using BBO for reducing the maximum SLL and at the same time keeping the first null beamwidth (FNBW) as small as possible. This is achieved by optimizing the amplitude excitations of each ring of concentric arrays. Two examples of of the design problem have been used to illustrate the application of the algorithm and the results have been compared with the previous published results.
The rest of the paper is organized as follows: Section II discusses the geometry and general design for the CCAA. In Section III Biogeography theory is explained and in section IV, the BBO algorithm is discussed. Section V presents design examples and the results and in Section VI conclusions are presented.

II. Concentric Circular Antenna Design

In CCAA, the elements are arranged in such a manner that all antenna elements are positioned in multiple concentric circular rings, which vary in radii and in number of elements. Fig. 1 shows the general configuration of CCAA with M concentric circular rings, where the m^{th} (m = 1, 2,…, M) ring has a radius r_m and the corresponding number of elements is N_m. Assuming that all the elements (in all the rings) are isotopic sources, then the radiation pattern of this array can be written in terms of its array factor only. The array factor (AF) is given by:

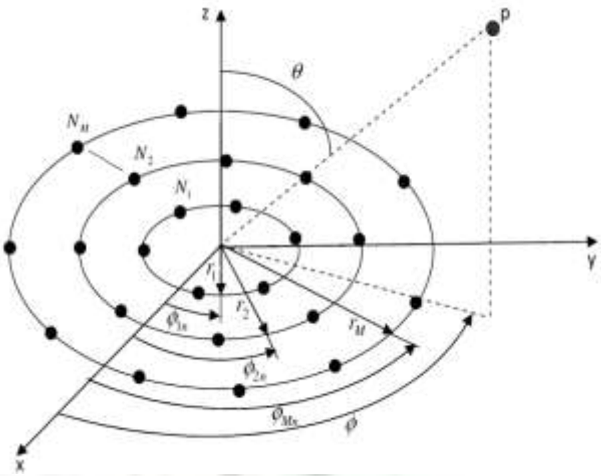

Fig. 1: Concentric Circular Antenna Array

$$AF(\phi, I) = \sum_{m=1}^{M} \sum_{n=1}^{N_m} I_{mn} \exp[\, j(kr_m \sin\theta(\cos(\phi - \phi_{mn}) + \alpha_{mn})] \qquad (1)$$

where,

k_w is the wave number = $2\pi / \lambda_w$,

λ_w is the signal wavelength,

r_m is the radius of the mth ring = $N_m d_m / 2\pi$,

d_m = inter element arc spacing of the m^{th} ring

$\phi_{mn} = 2\pi(n-1) / N_m$ is the angular position of the n^{th} element of the m^{th} ring,

I_{mn} is the current excitation of the n^{th} element of the m^{th} ring ,

ϕ and θ are the azimuth and zenith angle respectively ,

$\alpha_{mn} = -k_w r_m \cos(\phi_0 - \phi_{mn})$ is the residual phase,

ϕ_0 is the value of ϕ where main beam is to be directed.

For a $\lambda_w/2$ UCCAA we will have element increment $n_i = N_{m+1} - N_m = 6$, normalized ring-radial separation $t_m = 0.4775\ \lambda_w$ and normalized inter element arc spacing $d_m = 0.5\ \lambda_w$. The total number of elements in the array will be $N_t = MN_1 + \sum_{m=1}^{M-1} 6m$

III. Biogeography Theory

Biogeography is the study of distribution of biodiversity over space and time. The science of biogeography was sown by naturalists like Alfred Wallace and Charles Darwin. Till 1967, biogeography was mainly a descriptive study. But the work carried out by R. MacAurthur and E. Wilson changed this perception. They were able to construct a mathematical model for biogeography and made it feasible to predict the number of species in a habitat.

In the science of biogeography, a habitat is an ecological area that is inhabited by a particular plant or animal species and which is geographically isolated from other habitats. Each habitat is classified by Habitat Suitability Index (HSI). Areas or habitats which are well suited as living places for biological species have high HSI while habitats that are not good have low HSI. The value of HSI depends upon many features of habitat like rainfall, temperature, diversity of vegetation, land area, safety and security. If each of the features is assigned a value, HSI is a function of these values. Each of these features that characterize habitability is known as Suitability Index Variables (SIV). SIVs are the independent variables while HSI are the dependent variables.

Habitats with high HSI have large population, high emigration rate μ, simply by virtue of large number of species that migrate to other habitats. The immigration rate λ is low for these habitats as these are already saturated with species. On the other hand, habitats with low HSI have high immigration rate λ, low emigration rate μ because of sparse population.

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The value of HSI of low HSI habitat may increase with the influx of species from other habitats as suitability of a habitat is function of its biological diversity. But if HSI does not increase and remains low, species in that habitat go extinct and this leads to additional immigration. For sake of simplicity, it is safe to assume a linear relationship between a habitat HSI and its immigration and emigration rate and also that the rates are same for all the habitats. The immigration and emigration rate depends upon the number of species in the habitats. These relationships are shown in Fig. 2.

The values of emigration and immigration rates are given as:

$$\lambda = I\left(1-\frac{k}{n}\right) \tag{2}$$

$$\mu = \frac{E}{n} \tag{3}$$

where I is the maximum possible immigration rate; E is the maximum possible emigration rate; k is the number of species of the k-th individual and n is the number of species.

IV. Biogeography Based Optimization

BBO is a novel population-based global optimization algorithm stimulated by the science of biogeography. The candidate solutions for a problem are considered as habitats. Each solution is associated with the fitness which is analogous to HSI of a habitat. A good solution is analogous to a habitat with high HSI and a poor solution represents a habitat with a low HSI. Good solutions share their features with poor solutions by means of migration. Good solutions have more resistance to change than poor solutions. On the other hand, poor solutions are more dynamic and accept a lot of new features from good solutions.

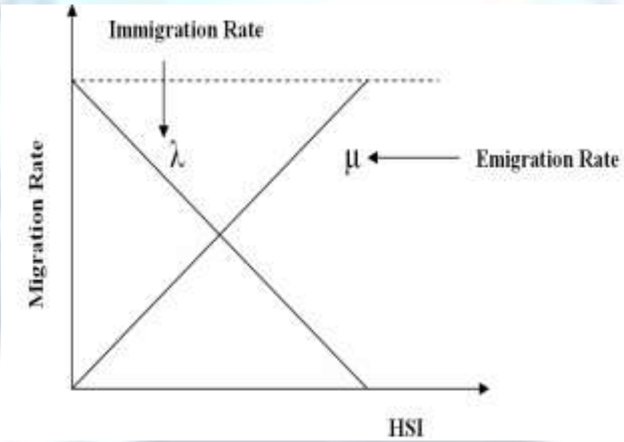

Fig. 2: Habitat Migration Rate vs. Habitat Suitability Index

Consider a global optimization problem and population of possible solutions. In an N–dimensional optimization problem, a habitat is a 1X N_{var} array. Each solution is represented by N-dimensional integer vector as $[SIV_{1 \ldots\ldots,}\ SIV_{Nvar}]$. In BBO, a SIV is a solution feature corresponding to "gene" while habitat is similar to "chromosome" in other population-based optimization algorithm like GA. The variable values or SIVs in the habitat are represented as floating numbers. The set of all such vectors is the search space from which the optimum solutions are to be found. The value of HSI of a habitat is value of objective function associated with that solution. The value of HSI is found by evaluating the cost of function at the variables $[SIV_{1,\ \ldots\ldots}SIV_{Nvar}]$. Therefore,

$$\text{HSI}=\text{f (Habitat)} = \text{f } (SIV_{1\ \ldots}SIV_{Nvar}) \tag{4}$$

These solutions are made to share features among themselves by applying migration operator. For each SIV, in each solution, it is decided probabilistically whether or not to immigrate. If immigration is selected for a given solution feature, the emigrating habitat is selected for a given solution probabilistically using roulette wheel normalized by μ. The mutation operator is probabilistically applied to the habitat which tends to increase the biological diversity of the population. The mutation rate m is inversely proportional to the solution probability which is given by:

```
Create a random set of habitats (population) H1, H2,….. Hn ;
Calculate SI values;
While the halting criterion is not satisfied do
    Compute immigration rate λ and emigration rate μ for each habitat based on SI;
    For each habitat (solution)
        For each SIV (solution feature)
            Select habitat Hi with probability α λi;
            If Hi is selected then
                Select Hj with probability α μj;
                If Hj is selected then
                    Hi (SIV) ← Hj (SIV);
                End if
            End if
            Select Hi (SIV) based on mutation probability mi;
             If Hi (SIV) is selected then
                Replace Hi (SIV) with randomly generated SIV;
             End if
        Next for
        Recalculate SI values;
    Next for
End while
```

Fig. 3: BBO algorithm

$$m = m_{\max}\left(1 - \frac{P}{P_{\max}}\right) \qquad (5)$$

where, m_{max} is a user-defined parameter.

As in other population-based optimization algorithms, elitism is introduced so that the best solutions are retained in the population from one generation to the next. The algorithms for BBO is shown in Fig. 3

Mutation and migration operators in BBO are similar to GA and PSO and therefore, it is also applicable to same type of problems as GA and PSO are used for. BBO is different in some respects with the other global optimization techniques e.g. as compared with GA it does not involve reproduction and it keeps the solution set while moving from one iteration to the next [10].

V. Design Examples

In this section, the BBO algorithm is applied to different CCAAs. The goal of synthesis of the antenna in this section is to determine a CCAA for having the radiation pattern with the minimum SLL and narrow FNBW. This is done by manipulating the excitation currents of the elements of each ring. It is assumed that the current excitations for elements of same ring are equal. The fitness function to achieve the desired pattern using BBO is given by:

$$Fitness = a * SLL + b * FNBW \qquad (6)$$

The optimization problem can be summarized as the minimization of fitness function to obtain a set of element current excitations $[I_1, I_2, ...I_m]$. The values of the element amplitudes are allowed to vary between [0, 1]. The main lobe is steered at θ_0 =0. After many runs of the optimization, the following parameters that yield satisfactory results are chosen for the BBO algorithm as follows:

- Number of habitats or population : NP =70
- Number of generations =60
- Habitat modification probability=1
- Mutation probability: m_{max}=.005
- Elitism parameter p =2
- Maximum Emigration and Immigration Rate= 1
- a=1 and b=2

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In the first example, a CCAA with eleven rings (M=11) and no. of elements in first ring equal to five (N_1=5) is optimized for the above given objective. The results of optimization are shown in Table 1 together with the results of uniform excited array. The results show that for a nominal increase of FNBW of 1^0, the SLL of the BBO optimized antenna has improved by about -15 dB as compared to uniform excited array. The radiation pattern of BBO optimized array is shown in Fig. 4**.**

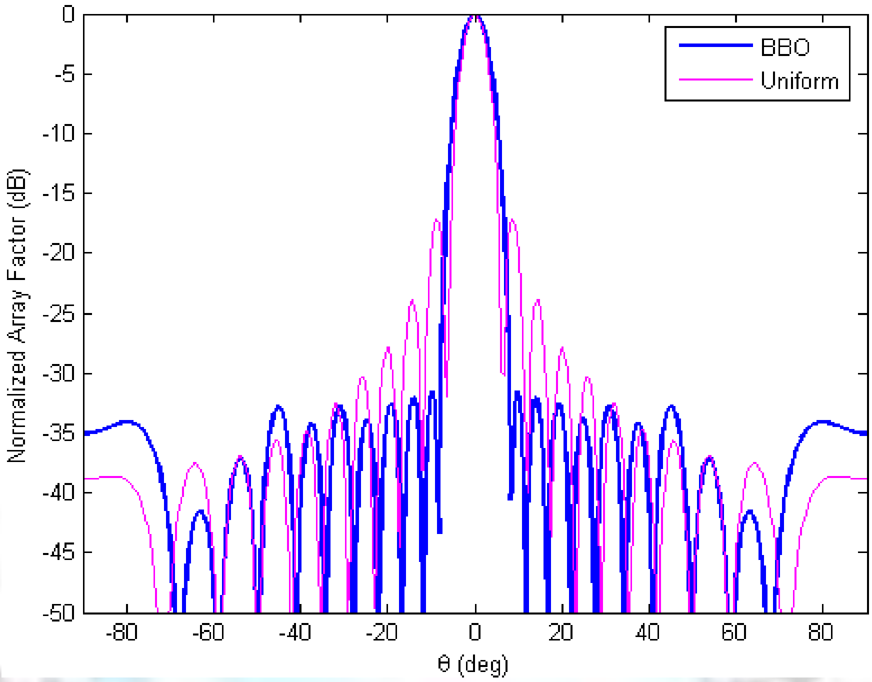

Fig. 4 Radiation pattern of CCAA with N_1 = 5 and M = 11

Table 1: Current excitations of CCAA with (N_1=5 and M=11)

Im **[Uniform]**	1 1 1 1 1 1 1 1 1 1 1	**SLL**= -17.6 dB **FNBW**= 14^0
Im **[BBO]**	1.0000 1.0000 1.0000 0.7923 0.8313 .5669 0.5946 0.4417 0.3310 0.2534 0.4333	**SLL**= -32.5 dB **FNBW**=15^0

In the second example, a CCAA with nine rings (M=9) and eight elements in the first ring (N_1=8) is optimized for the objective as in previous example. The results of optimization are shown in Table 2 along with the results of uniform excited array. The SLL of the BBO optimized is lower by -8.5 dB as compared to uniform excited array. The price paid for this improvement is an increase of 1.2^0 in FNBW. The radiation pattern for the BBO optimized array and uniform array is shown in Fig. 5. The results of the two cases are also compared with the previous published results of DE [9], PSO [9], IWO [9] and DIWO [9] in Table 3.

Table 2: Current excitations of CCAA with (N_1=8 and M=9)

I_m **[Uniform]**	1 1 1 1 1 1 1 1 1	**SLL**= -17.1 dB **FNBW**=15^0
I_m **[BBO]**	1.0000 0.9458 1.0000 0.5960 0.7072 0.5225 0.5656 0.1768 0.8515	**SLL**= -25.6 dB **FNBW**=16.2^0

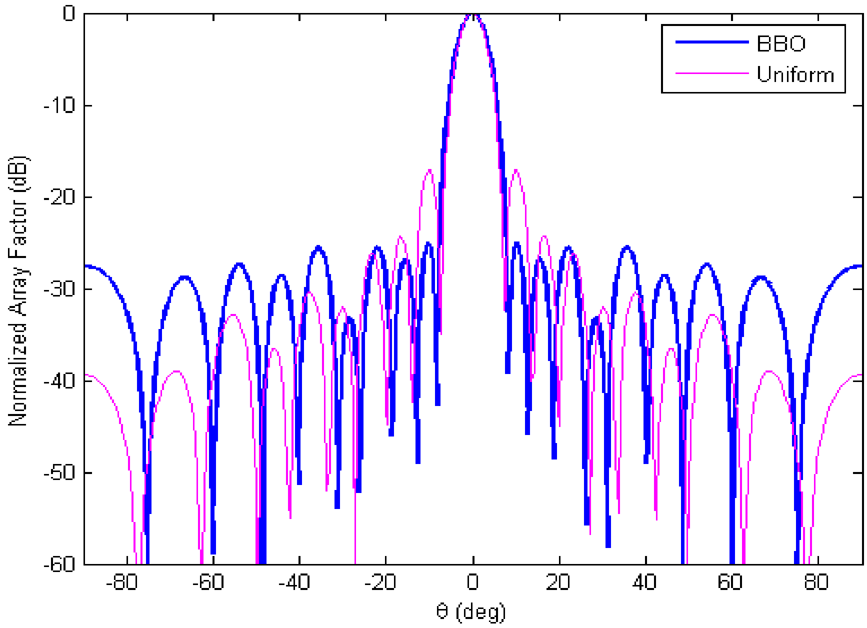

Fig. 5: Radiation pattern of CCAA with N_1 = 8 and M = 9

Table 3: Comparison of Results

		DE[9]	PSO[9]	IWO[9]	DIWO[9]	BBO
Case 1	**FNBW** (deg)	14.28	13.92	13.84	13.81	14
	SLL (dB)	-23.81	-21.08	-23.37	-25.12	-32.15
Case 2	**FNBW** (deg)	16.25	17.45	16.25	16.15	16.2
	SLL (dB)	-23.40	--23.45	-24.63	-26.01	-25.6

VI. Conclusions

This paper presented the design of a non-uniformly excited concentric circular antenna array with uniform spacing between the elements using the BBO technique. The aim is to obtain a concentric antenna array with suppressed sidelobes and thin primary lobe. BBO obtained results which are better than the results of other algorithms like DIWO, PSO, DE and IWO. The chief advantage of the BBO is its simplicity for giving an easy, quick, and efficient resolution of medium and large problems. The BBO method has proved to be a competent algorithm for the antenna optimization problems.

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