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Printed Circular Antenna Array for Reduce SLL and High Directivity Using Cuckoo Search Algorithm

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Abstract

This paper presents the synthesis and optimization of printed circular antenna array using the Cuckoo Search Algorithm (CSA). The CSA is a simple and effective global optimization algorithm which can be used to solve linear and non-linear problems. It has been applied to solve a wide variety of optimization problems. In our case, it is used to find the optimum weights of amplitudes and phases of complex feeding currents of a uniform printed circular antenna array. The goal to be achieved is a directional radiation pattern. To study the effect of these optimizations, a Gaussian centered at 90° is considered in our simulations. The obtained results are promising in terms of reduced Side Lobe Level (SLL) and directional factor array.

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Keywords: Printed circular antenna array, CSA, Optimization.

1. Introduction

Micro-strip patches have been widely studied and are popular through a lot of works in electromagnetic applications and antenna design. One of the major advantages of micro-strip antennas is the simplicity of fabrication especially for arrays construction [1]. Arrays antennas is also a field of importance because of the ability of arrays to perform beam scanning with enhanced gain and directivity [2]. The potential advantage of the use of arrays is the control of the major lobe direction and Side Lobe Level (SLL) of radiation pattern by a relevant calculation of the excitation currents (magnitude and phase) and by the position of array elements.

The pattern array synthesis consists in looking to the best setting of excitation currents to reach a desired radiation pattern. Various analytical and numerical techniques have been developed to meet this challenge [3].

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Conventional antenna array synthesis techniques such as Binomiale, Chebyscheff, Taylor and Hansen distributions [4, 5, 6, and 7] have often been used but are limited and are not efficient because they often fall to local minima and are unable to find a global solution [8].

The CSA used in this study overcomes this problem. Synthesis of printed circular antenna array feed parameters is presented. Optimum weights (amplitudes and phases) of complex currents have been calculated. In order to evaluate the improvements on radiation patterns, a Gaussian centered at 90° is considered in our simulations. Major lobe control direction and SLL diminution have been obtained and will be presented.

2. Array Factor of a Printed Circular Antennas Array

We consider a circular network consisting of n radiating elements, as shown in Fig.1. The radiating elements are placed on a circle of radius a. The electric field created by the array antenna at an observation point P is the sum of all the contributions of the radiating elements.

The array factor (AF) is given by the following equation [9]:

$$AF = \sum_{i=1}^n I_i e^{j(ka \sin \theta \cos(\varphi - \varphi_i) + \beta_i)} \tag{1}$$

Where i is the element number, n is the number of elements in the array, I_i and β_i are the current and the phase excitation of the i^{th} element respectively.

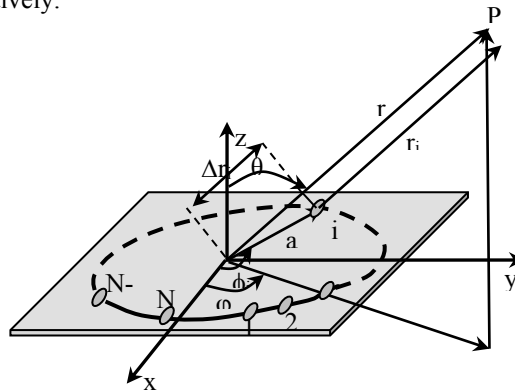


Fig.1. Structure of printed circular antennas array

3. Optimization Problem of Circular Antennas Array

We consider the circular antennas array of Fig. 2, its radiation factor is given by equation (1). In order to obtain a directional radiation pattern with reduced SLL, the parameters I_i and β_i should be optimized.

The minimum value of 'a' radius of the circle on which the radiating elements are placed must ensure that the mutual effect is zero or negligible. Generally the minimum spacing d_{min} is equal to $0,25 \lambda$ [10].

The distance between two successive elements as shown in the figure is given by:

$$d_i = 2r \sin \frac{\alpha_i}{2} \tag{2}$$

Where α_i equal to:

$$\alpha_i = 2 \arcsin \frac{d_i}{2r} \tag{3}$$

On the other hand for $d_i = d_{min}$, the spacing between two elements so that one can neglect the mutual effect, the minimal angle will be:

$$\alpha_{min} = 2 \arcsin \frac{d_{min}}{2r} \tag{4}$$

From the previous equation, the number of antennas to be placed on the circle of radius a is:

$$n = \frac{2\pi}{\alpha_{\min}} \tag{5}$$

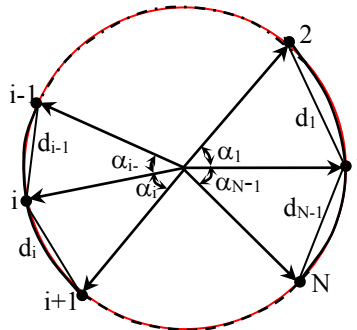


Fig.2. Structure of circular antennas array

4. Cuckoo Research Algorithm

The CSA is a metaheuristic algorithm proposed by Xin-She Yang and Suash Deb [11-12]. The Cuckoo Research is inspired from the parasitic behaviors of cuckoos and the mechanism of the levy flight. Where, solution are represented by eggs in host’s nests and the cuckoo eggs represent the new solutions, the aim is to use the new and potentially better solutions (cuckoos) to replace the not-so-good solutions in the nests. The CSA is based on three idealized rules [11]:

1. Each cuckoo lays one egg at a time, and dumps it in a randomly chosen nest;
2. The best nests with high quality of eggs (solutions) will carry over to the next generations;
3. The number of available host nests is fixed, and a host can discover an alien egg with probability $P_a \in [0, 1]$. In this case, the host bird can either throw the egg away or abandon the nest to build a completely new nest in a new location.

The third assumptions can be approximated as the fraction P_a of the n nests is replaced by new nests (new random solutions). The quality or fitness of a solution can be defined in a similar way to the fitness function in genetic algorithms [11].

The basic steps of the CSA can be summarized as follows:

1. Set the initial value of the nest size of the host, the probability and maximum number of iterations.
2. Set $t = 0$. {Counter Initialization}.
3. For $i = 1$ to n , do (n : number of nest : Population size) :
4. Initialize a population of n host $X_i^{(t)}$ (solution)
5. Evaluate the fitness function of: $f = (X_i^{(t)})$
6. Generate a new solution $X_i^{(t+1)}$ by Levy flight (i is chosen randomly)
7. Evaluate the fitness function of a solution $X_i^{(t+1)}$
8. Choose a nest among n (say j) randomly;
9. if $f = (X_i^{(t)}) > f = (X_j^{(t)})$, Replace j by the new solution i
10. Si $(f(x_i^{(t+1)})) > (f(x_j^{(t)}))$ so: we go directly to step (11)
11. Abandon a fraction P_a Of worse nests.
12. build new ones at new locations via Lévy flights
13. Keep the best solutions
14. Rank the solutions and find the current best
15. Set $t = t + 1$. (Increasing iteration counter)
16. Go to Step 6 redo up. {Starting Criteria}
17. Results and visualisation

5. Simulation Results

To study the effects of these variables for an optimum design, a MATLAB code has been developed using Eq. 1 and AF is observed as a function of various control parameters.

To serve as a reference, array factor have been calculated for several cases of elements number n whilst keeping the spacing between two consecutive elements as $\lambda/2$, the excitation amplitudes of all elements equal to 1 and their excitation phases equal to zero. The results are normalized with respect to the maximum value of main lobe and are plotted in Fig. 3. As expected, an increase in n decreases the half power beam width (HPBW), while its effect on SLL is negligible. So for narrow beam width, as it is required in target localization system, the number of elements should be quite high.

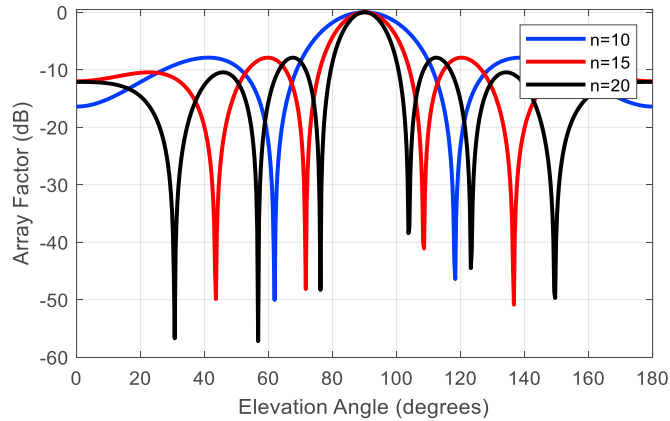


Fig. 3. Array Factor of printed circular array as a function of elevation angle θ and number of elements n without optimization

Simulation results are divided into three cases in order to illustrate the effectiveness of the proposed algorithm. Case 1: excitation amplitude has been optimized keeping excitation phase equal to zero (Fig. 4), Case 2: excitation phase has been optimized keeping excitation amplitude equal to 1 (Fig. 5), Case 3: excitation amplitude and phase have been optimized (Fig. 6).

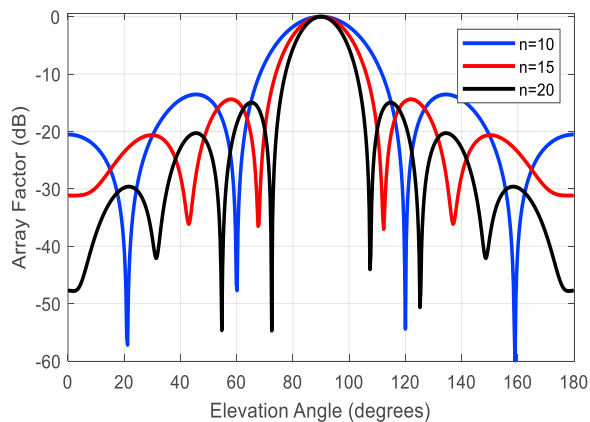


Fig. 4. Array Factor of printed circular array as a function of elevation angle θ and number of elements n with amplitude weights excitation obtained by CSA

All the cases consider uniform inter elements spacing ($d=\lambda/2$) distribution and the aim is to achieve very low SLL as well as high directivity.

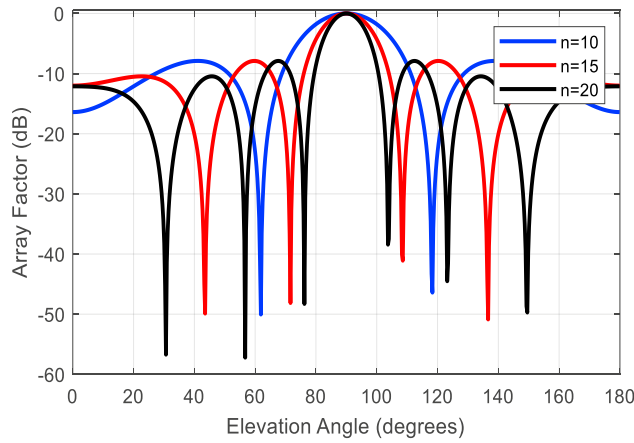


Fig. 5. Array Factor of printed circular array as a function of elevation angle θ and number of elements n with phase weights excitation obtained by CSA

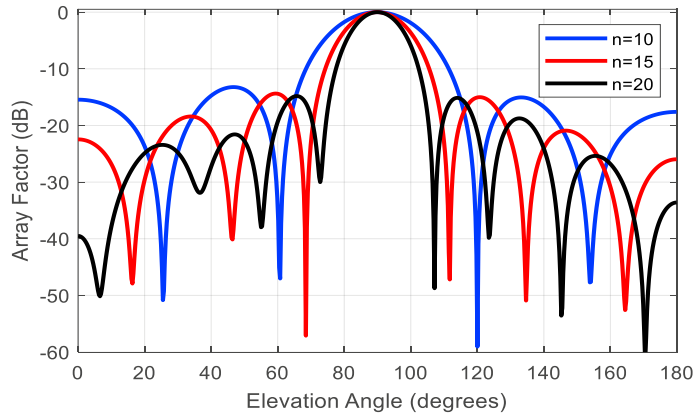


Fig. 6. Array Factor of printed circular array as a function of elevation angle θ and number of elements n with amplitude weights and phase weights excitation obtained by CSA

Table 1. Comparative results of optimized parameters

Number of elements		10	15	20
SLL	Without optimization	8.1975	8.0513	7.9159
	Amplitude and phase are optimized	13.9379	14.6434	15.5554
	Unequal Amplitude	13.7904	14.2789	15.1746
	Unequal Phases	8.1513	8.1513	8.1513
HPBW	Without optimization	25.5242	17.1428	12.9953
	Amplitude and phase are optimized	25.0403	17.1028	12.9953
	Unequal Amplitude	25.5242	19.1129	14.8790
	Unequal Phases	25.4378	17.1428	12.9953

Numerical results of SLL and HPBW are presented in Table 1. It can be observed that appropriate weights can change the overall array pattern and allows the designer to control the array factor and main lobe beam width with reduced SLL. We can notice that SLL reduces considerably as we have more control parameters, i.e., results corresponding to Case 3 are better than Case 1 and 2 and also that the weights of feed amplitudes are more influential than the weights of feed phases.

6. Conclusion

In this work, the CSA has been used for the synthesis and optimization of circular micro-strip antennas array with uniform inter-element spacing. Optimizing the weights of amplitudes and phases of the feeding currents results in reduced SLL and directional array factor for various number of array elements. Based on various simulations using the MATLAB™ environment, the results are satisfying and the algorithm achieves the desired goals with a good convergence.

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