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Design of non-uniform circular antenna arrays for side lobe reduction using the method of genetic algorithms

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Abstract

A design problem of non-uniform circular antenna arrays for maximal side lobe level reduction with the constraint of a fixed beam width is dealt with. This problem is modeled as a simple optimization problem. The method of genetic algorithms is used to determine an optimum a set of weights and antenna element separations that provide a radiation pattern with maximal side lobe level reduction with the constraint of a fixed beam width. The effectiveness of genetic algorithms for the design of non-uniform circular arrays is shown by means of experimental results. Experimental results reveal that design of non-uniform circular antenna arrays using the method of genetic algorithms provides a considerable side lobe level reduction with respect to the uniform case.

Keywords: Non-uniform circular arrays; Genetic algorithms; Side lobe level; Main beam width; Radiation pattern

1. Introduction

The design of circular antenna arrays finds application in areas as mobile and wireless communications systems. Generally speaking, the problem of designing antenna arrays is characterized by different and conflicting requirements (beam width, side lobe level, directivity, noise sensitivity, robustness) to be satisfied. In this paper a design criterion is considered to evaluate the performance of antenna arrays: the criterion of minimum side lobe level at a fixed main beam width. In this case, the antenna array design problem consists of finding weights and antenna element separations that provide a radiation pattern with maximal side lobe level reduction. Due to the great variety of parameters involved, optimization techniques such as genetic algorithms (GA) [1] are very appropriate tools to search for the best antenna models. GA techniques are becoming widely used to solve electromagnetic problems due to their robustness, wide range of applications and readiness in their implementation. GA techniques [2–8] have been fairly successful at designing linear antenna arrays. However, array configurations in which the elements are placed in a circular ring are of great interest. They have applications in radio direction finding, air and space navigation, radar, and other systems. In this paper, we apply GA techniques to the design of circular antenna arrays design of non-uniform circular antenna arrays to be a problem optimizing a single objective function, i.e., the minimization of the side lobe level at a fixed main beam width. The purpose and contribution of this paper is to present a model of problem that includes design of non-uniform circular antenna arrays for side lobe level reduction using the method of genetic algorithms. The remainder of the paper

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is organized as follows. Section 2 states the antenna array design problem we are dealing with. Then, a description of the used algorithm is presented in Section 3. Following this description the experimental setup and results are presented in Section 4. Finally, the summary and conclusions of this work along with some future line of research are presented in Section 5.

2. Problem statement

Consider a circular antenna array of N antenna elements non-uniformly spaced on a circle of radius a in the x–y plane. If the elements in the circular antenna array are taken to be isotropic sources, the radiation pattern of this array can be described by its array factor [9]. The array factor for the circular array in the x–y plane (Fig. 1) is given by [10]

$$\mathrm{AF}(\theta, \mathbf{I}, \mathbf{dm}) = \sum_{n=1}^{N} I_n \exp(jka\cos(\theta - \phi_n) + \alpha_n), \tag{1}$$

where

$$ka = \sum_{i=1}^{N} \mathrm{dm}_i, \tag{2}$$

$$\phi_n = \left(2\pi \sum_{i=1}^{n} \mathrm{dm}_i\right) \Big/ \left(\sum_{i=1}^{N} \mathrm{dm}_i\right), \tag{3}$$

$$\alpha_n = -ka\cos(\theta_0 - \phi_n). \tag{4}$$

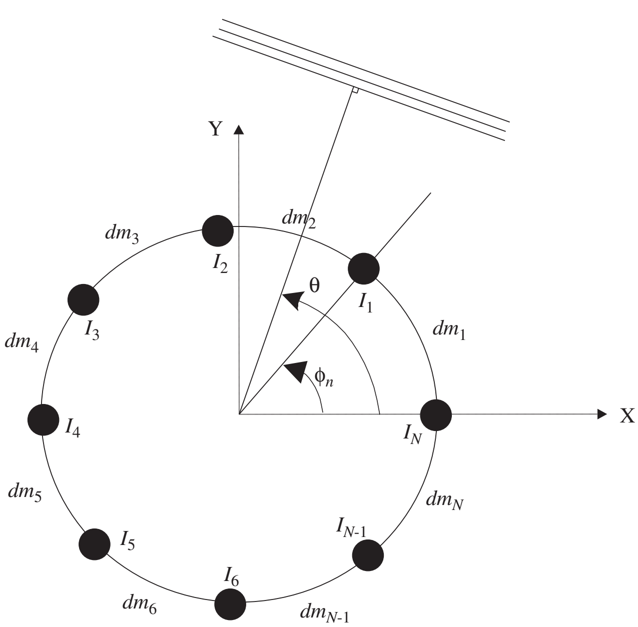

Fig. 1. Geometry and notations used for non-uniform circular antenna array.

$\mathbf{I} = [I_1, I_2, \ldots, I_N]$, I_n represents the excitation of the nth element of the array, $\mathbf{dm} = [\mathrm{dm}_1, \mathrm{dm}_2, \ldots, \mathrm{dm}_N]$, dm_n represents the distance from element n to element $n+1$, $k = 2\pi/\lambda$ is the phase constant, θ is the angle of incidence of a plane wave, λ is the signal wavelength and θ_0 is the maximum radiation angle.

We now need to formulate the objective function we want to minimize. Let us introduce first a couple of definitions for the radiation pattern. Let θ_0 be the angle where global maximum is attained in $\theta = [-\pi, \pi]$. Let θ_{msl} be the angle where the maximum side lobe is attained, and BWFN the beam width where first nulls are attained. Based on these definitions the objective function can be written as:

$$f_1 = |\mathrm{AF}(\theta_{\mathrm{msl}}, \mathbf{I}, \mathbf{dm})| / |\mathrm{AF}(\theta_0, \mathbf{I}, \mathbf{dm})| + |\mathrm{BWFN}_{\mathrm{desired}} - \mathrm{BWFN}(\mathbf{I}, \mathbf{dm})|$$

Thus the optimization task is then the minimization of f_1. This problem can be defined as

$$\begin{array}{ll} \text{Minimize} & f_1 \\ \text{subject to} & \mathrm{dm} \in \mathbf{D}, \mathbf{I} \in \boldsymbol{\Lambda}, \end{array}$$

where $\mathbf{D} = [0, 2\lambda)^N$ is imposed to take the physical size of the antenna array into account; $\boldsymbol{\Lambda} = [W_{\min}, W_{\max}]^N$ is the range of the current amplitude coefficients imposed for practical implementation of the attenuators.

The next section presents the method we use to obtain the design of non-uniform circular antenna arrays for side lobe reduction.

3. The proposed algorithm

The main purpose of this study is to design a low side lobe radiation pattern for non-uniform circular antenna arrays with the constraint of a fixed beam width. For this purpose, we propose, to use a population-based stochastic procedure denominated genetic algorithm [11]. We chose this algorithm for its easiness of implementation. The procedure for used GA technique (Fig. 2) is described as follows.

The function *generate initial population* randomly and uniformly generates a set of individuals.

The main idea in *classify individuals* is to rank the individuals according to their fitness values.

A *selection scheme combining fitness ranking and elitist selection* [11] is implemented instead of a common weighted roulette wheel selection.

The function *update population* assigns ranks to individuals in the population generated by the union of parents and children. This is in order to hold the best individuals in each generation. Rahmat-Samii et al. [1] explain the procedures involved at each step of this algorithm in detail. The individual representations as well as the crossover and mutation operators are explained in the following subsections.

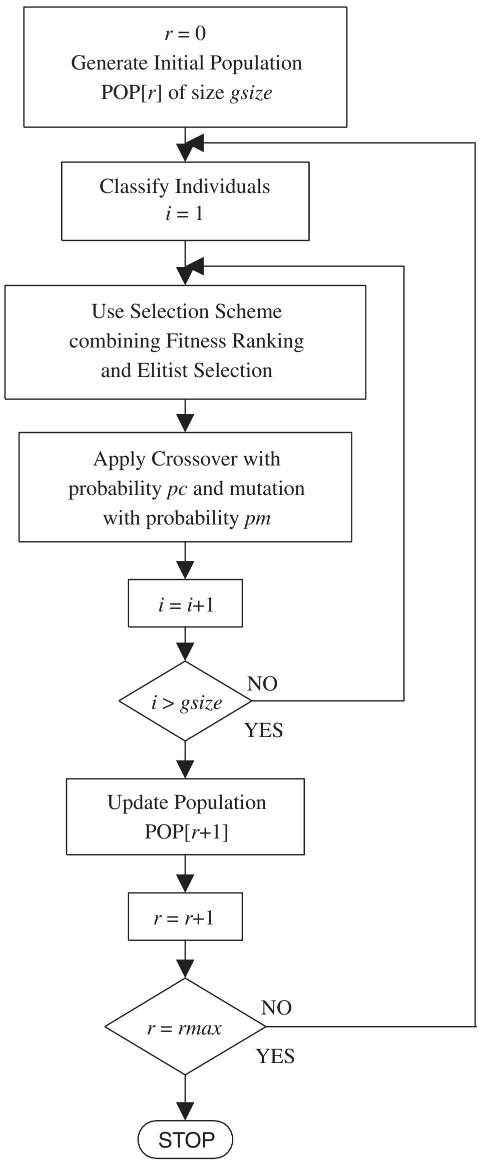

Fig. 2. Flow chart for the evolutionary optimization algorithm.

3.1. Individual representation and decoding

Each individual is in general represented by two vectors of real numbers. One vector of real numbers restricted to be on the range $[W_{\min}, W_{\max}]$, i.e. $\mathbf{I} = [I_1, I_2, \ldots, I_N]$, and another one restrained on the range $[0, 2\lambda]$, i.e. $\mathbf{dm} = [\mathrm{dm}_1, \mathrm{dm}_2, \ldots, \mathrm{dm}_N]$.

3.2. Genetic operators

The genetic operators are standard: the well-known two-point crossover [11] along with a single mutation where a locus is randomly selected and the allele is replaced by a random number uniformly distributed in the restricted range.

The results of using this algorithm for design of non-uniform circular antenna arrays are described in the next section.

4. Experimental setup and results

The method described in the previous section was implemented to study the behavior of the radiation pattern for non-uniform circular antenna arrays. In this case, radiation patterns of the circular arrays with main lobe steered to $\theta_0 = 0$ degrees are considered. Several experiments were carried out with different number of antenna elements ($N = 8, 10, 12$). In the experiments the algorithm parameters, after a trial and error procedure, were set as follows: maximum number of generations rmax=500, population size gsize=50, crossover probability pc = 1.0 and mutation probability pm = 0.1. The obtained results are explained below.

Fig. 3 shows a comparison between the radiation pattern for a uniform circular antenna array ($d = \lambda/2$) and the non-uniform circular antenna array optimized with the use of the genetic algorithm. The behavior shown in Fig. 3 indicates that a uniform circular array has a radiation pattern with −3.6 dB side lobe level for $N = 10$, when the element excitation is of equal amplitude. All side lobes are suppressed to a level less than −11.03 dB as a result of the optimization procedure described in the previous section. In this case, it is observed in Fig. 3 that the method of genetic algorithms provides a maximal side lobe level reduction of 57.49% with respect to the uniform case. Fig. 4 illustrates the case for $N = 12$. For this value of N, the genetic algorithms method generates a set of weights and antenna element separations that provide a radiation pattern with −11.8 dB side lobe level, i.e. a maximal side lobe

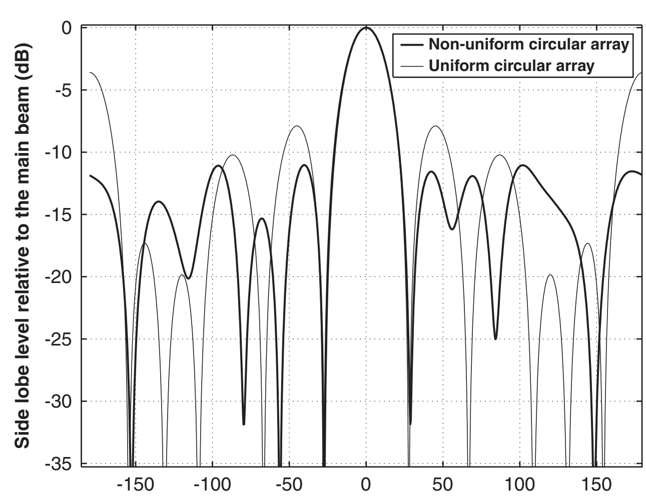

Fig. 3. Comparison between the radiation pattern for a uniform circular antenna array and the non-uniform circular antenna array optimized with the use of the genetic algorithm $N = 10$.

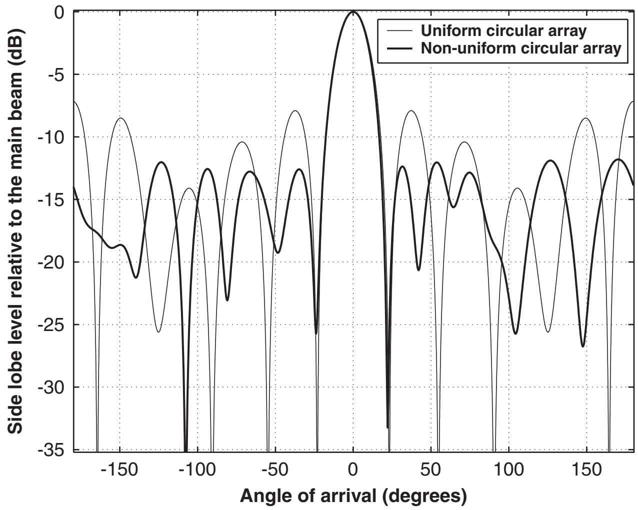

Fig. 4. Radiation pattern for a uniform circular antenna array and the non-uniform circular antenna array optimized with the use of the genetic algorithm ($N = 12$).

level reduction of 41.40% with respect to the uniform case.

Table 1 shows examples of the element distribution and the resulting excitation distribution. In this case, the weightings for the array elements, $I_1, I_2, \ldots, I_N$, are normalized using $\max(I_i) = 1$. Table 1 illustrates that as the number of antenna elements N increases the side lobe level reduction for non-uniform circular antenna arrays is improved.

The effectiveness of the method of genetic algorithms for the design of non-uniform circular antenna arrays is shown by means of experimental results with a set of design options that provide a radiation pattern with radiation characteristics (main beam width and side lobe level) physically attainable.

In this work the coefficients (amplitude excitations) are positive real values, i.e., cophasal excitation. However, the method of genetic algorithms can also be used for complex numbers (phase and amplitude excitations).

From the results shown previously, it is illustrated the application of the method of genetic algorithms to the design of non-uniform circular antenna arrays for side lobe level reduction. This genetic algorithm efficiently computes a set of weights and antenna element separations for non-uniform circular antenna arrays to have a radiation pattern with maximal side lobe level reduction. The antenna array designer will specifies the desired antenna parameters in accordance with the design goal. In this case, the criteria specified will help to select the most appropriate design option. This is in order to meet potentially a reduction of the antenna system cost.

5. Conclusions

This paper illustrates how to model the design of non-uniform circular antenna arrays for maximal side lobe level reduction under the constraint of a fixed beam width. The well-known method of genetic algorithms is proposed as the solution for this problem design. The method of genetic algorithms efficiently computes the design of non-uniform circular antenna arrays to generate a radiation pattern with maximal side lobe level reduction with the constraint of a fixed beam width. Experimental results reveal that design of non-uniform circular antenna arrays using the method of genetic algorithms provides a considerable side lobe level reduction with respect to the uniform case.

Future research will be aimed at dealing with other geometries and constraints. Many different areas of antenna design and analysis require a feasible and versatile procedure, being able to perform array synthesis by tuning antenna characteristics and parameters. Because of the versatility of the method of genetic algorithms it seems a good candidate to face this problem.

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Table 1. Examples of element distributions and the resulting excitation distribution for non-uniform circular antenna arrays obtained by the genetic algorithm for different numbers of antenna elements

N	SLL (dB)	BWFN (deg)	$\text{dm}_1, \text{dm}_2, \text{dm}_3, \text{dm}_4, \ldots, \text{dm}_N$; $I_1, I_2, I_3, I_4, \ldots, I_N$	Aperture
8	−9.811	70.27	$0.1739\lambda, 0.3144\lambda, 0.6620\lambda, 0.7425\lambda, 0.6297\lambda, 0.8969\lambda, 0.4633\lambda, 0.5267\lambda$, 0.3289, 0.2537, 0.7849, 1.0000, 0.9171, 0.5183, 0.6176, 0.4612	4.40λ
10	−11.03	55.85	$0.3641\lambda, 0.4512\lambda, 0.2750\lambda, 1.6373\lambda, 0.6902\lambda, 0.9415\lambda, 0.4657\lambda, 0.2898\lambda, 0.6456\lambda, 0.3282\lambda$, 0.9545, 0.4283, 0.3392, 0.9074, 0.8086, 0.4533, 0.5634, 0.6015, 0.7045, 0.5948	6.08λ
12	−11.80	46.26	$0.4936\lambda, 0.4184\lambda, 1.4474\lambda, 0.7577\lambda, 0.4204\lambda, 0.5784\lambda, 0.4520\lambda, 0.8872\lambda, 0.7514\lambda, 0.4202\lambda, 0.4223\lambda, 0.7234\lambda$, 0.2064, 0.5416, 0.2246, 0.6486, 0.7212 0.7993, 0.5277, 0.3495, 0.5125, 0.4475, 0.5233, 0.8553	7.77λ

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