SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 7, No. 2, November 2010, 141-148

UDK: 621.396.677.3:004.021

Side Lobe Reduction of a Concentric Circular Antenna Array using Genetic Algorithm

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Abstract: A concentric circular antenna array (CCAA) consists of elements positioned on the periphery of imaginary circles on a plane having a common centre and different radii. The simplest way to feed the elements of such an array is to use uniform excitation. However, with a non-uniform excitation profile, considerable reduction of the side lobe level (SLL) may be achieved at the cost of the added complexity. The difference of SLLs (with respect to the uniform excitation case) becomes even more prominent when the beamwidth of the antenna needs to be kept fixed. In this paper, we formulate the task of designing a non-uniformly excited CCAA as a constrained optimization problem and use genetic algorithm (GA) to solve the same. The goal is to determine an optimum set of weights for antenna elements which provides a radiation pattern with maximum SLL reduction with the constraint of a fixed beamwidth.

Keywords: Concentric circular antenna array, Genetic algorithm, Side lobe, Beamwidth.

1 Introduction

An antenna array consists of multiple stationary antenna elements, which are often fed coherently. Antenna arrays are extensively used in mobile and wireless communication systems to improve the system performance by increasing channel capacity, spectrum efficiency, extending coverage area, tailoring beam shape etc. [1]. However arbitrary array design may lead to increment in pollution of the electromagnetic environment [2,3]. The increasing electromagnetic pollution has prompted the study of array pattern nulling techniques i.e., to suppress the side lobe level (SLL) while preserving the beamwidth.

Among the different types of antenna arrays, concentric circular antenna array (CCAA) [4,5] has become very popular in cellular mobile applications.

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Thus, design and performance evaluation of CCAA is of considerable interest. In this paper, we assume non-uniform current excitation weights for CCAA having uniform element separation and minimize the SLL with the constraint of a fixed beam width. Although many excellent analytical techniques exist for synthesizing low side lobe amplitude tapers for arrays, due to the wide variety of parameters involved in the optimization process, genetic algorithm (GA) is preferred [6,7].

The rest of the paper is arranged as follows: In Section 2, the general design equations for the non-uniformly excited CCAA are stated. Then, in Section 3, we introduce GA for solving the cost function obtained in Section 2. Numerical results are presented in Section 4 and finally the paper concludes with a summary of the work in Section 5.

2 Design Equation

Geometrical configuration is a key factor in the design process of an antenna array. For CCAA, the elements are arranged in such a way that all antenna elements are placed in multiple concentric circular rings, which differ in radii and in number of elements. Fig. 1 shows the general configuration of CCAA with M concentric circular rings, where the m-th ($m = 1, 2,\ldots, M$) ring has a radius r_m and the corresponding number of elements is N_m. If all the elements (in all the rings) are assumed to be isotopic sources, then the radiation pattern of this array can be written in terms of its array factor only.

Referring to Fig.1, the array factor, $AF(\varphi, I)$, for the CCAA in x-y plane may be written as

$$AF(\varphi, I) = \sum_{m=1}^{M}\sum_{i=1}^{N_m} I_{mi} \exp\left[j\left(Kr_m \sin\theta \cos(\varphi - \varphi_{mi}) + \alpha_{mi}\right)\right] \tag{1}$$

where, I_{mi} denotes current excitation of the i-th element of the m-th ring, $K = 2\pi/\lambda$; λ being the signal wavelength, and θ and φ symbolize the zenith angle from the positive z axis and the azimuth angle from the positive x axis to the orthogonal projection of the observation point respectively. It may be noted that if the elevation angle is assumed to be 90 degree i.e. $\theta = 90°$ then (1) may be written as a periodic function of φ with a period of 2π radians.

The angle φ_{mi} is nothing but element to element angular separation measured from the positive x-axis. As the elements in each ring are assumed to be uniformly distributed, we have:

$$\varphi_{mi} = 2\pi\left(\frac{i-1}{N_m}\right); \quad m = 1,\ldots,M\ ,\ i = 1,\ldots,N_m\,. \tag{2}$$

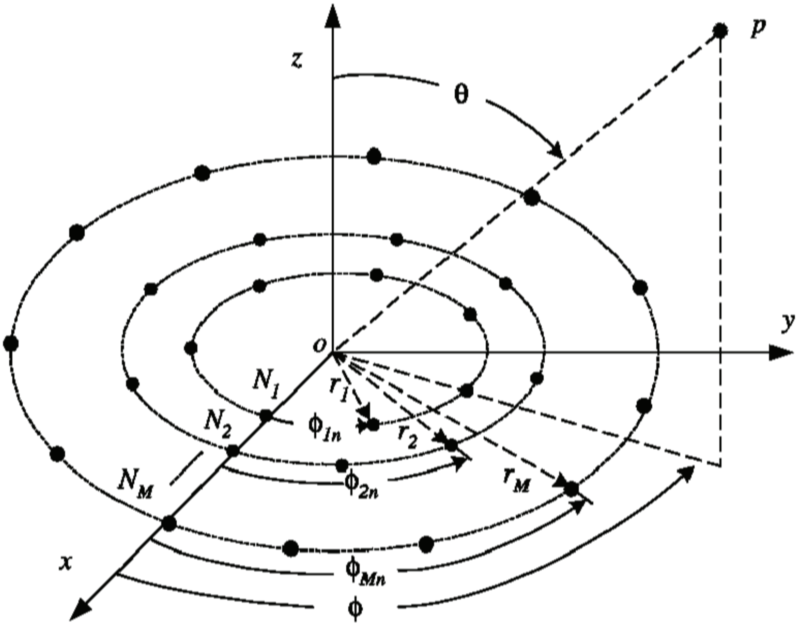

Fig. 1 – *Concentric circular antenna array* (CCAA).

The residual phase term α_{mi} is a function of angular separation φ_{mi} and ring radius r_m

$$\alpha_{mi} = -Kr_m \cos(\varphi_0 - \varphi_{mi})\,;\; m = 1,\ldots,M\;,\; i = 1,\ldots,N_m\,, \tag{3}$$

where φ_0 is the value of φ where peak of the main lobe is obtained.

After defining the array factor, the next step in the design process is to formulate the objective function which is to be minimized. The objective function may be written as

$$\begin{aligned} f_1 = W_1 \times \left|AF(\varphi_{msl}, I_{mi})\right| / \left|AF(\varphi_0, I_{mi})\right| + \\ + W_2 \times \left|BWFN_{computed} - BWFN(I_{mi} = 1)\right|, \end{aligned} \tag{4}$$

where, *BWFN* is an abbreviated form of first null beamwidth, or, in simple terms, angular width between the first nulls on either side of the main beam. Thus, $BWFN_{computed}$ and $BWFN(I_{mi} = 1)$ basically refer to the computed first null beamwidth in radian for the non-uniform excitation case and for uniform excitation respectively. The misfitness (f_1) is computed only if $BWFN_{computed} < BWFN(I_{mi} = 1)$ and corresponding solution of current excitation weights is retained in the active population (otherwise discarded). Further, W_1 and W_2 are the weighting factors, φ_0 is the angle where highest maximum of central lobe is attained in $\varphi \in [-\pi, \pi]$, and φ_{msl} is the angle where the maximum sidelobe $AF(\varphi_{msl}, I_{mi})$ is attained. The weights W_1 and W_2 are chosen in such a way that optimization of SLL remains more dominant than optimization of $BWFN$ and f_1 never becomes negative. Minimization of f_1 means maximum reductions of SLL and lesser $BWFN_{computed}$ as compared to $BWFN(I_{mi} = 1)$. The GA technique employed for optimizing the current excitation weights resulting in the minimization of f_1 and hence reduction in both SLL and BWFN are described in the next section.

3 Implementation

The main purpose of this study is to design a low side lobe radiation pattern for non-uniformly excited concentric circular antenna arrays with the constraint of a fixed beam width. For this purpose, we propose to use the GA technique [8, 9]. We chose this algorithm for its ease of implementation and implemented the same with Matlab$^{\text{TM}}$ v.7.1.

A Genetic algorithm is mainly a probabilistic search algorithm based on the principles and concept of natural selection and evolution. At each generation it maintains a population of individuals where each individual is a coded form of a possible solution of the problem at hand and called chromosome. Each chromosome is evaluated by a function known as fitness function, which is usually the cost function or the objective function of the corresponding optimization problem. Next, new population is generated from the present one through selection, crossover and mutation operations. Purpose of selection mechanism is to select more fit individuals (parents) for crossover and mutation. Crossover causes the exchange of Genetic materials between the parents to form offspring, whereas mutation incorporates new Genetic material in the offspring.

Implementations of above-mentioned components for the proposed Genetic algorithms given in Fig. 2 are as follows:

- ***Population*****:** Initial population is generated randomly and uniformly.
- ***Crossover*****:** We have used standard simple single point crossover for our purpose. For implementation we have used a crossover probability of 70%.
- ***Mutation*****:** For mutation operation we have utilized adaptive algorithm implemented via inbuilt function `mutationadaptfeasible`, which is available in standard simulation package Matlab.

***Stopping criteria*:** The operation will stop when the maximum number of generation is reached and also detects if there is no change in the best fitness value for some time given in seconds (stall time limit). We have used the function `stalltimelimit` for this purpose, which is an inbuilt function of Matlab.

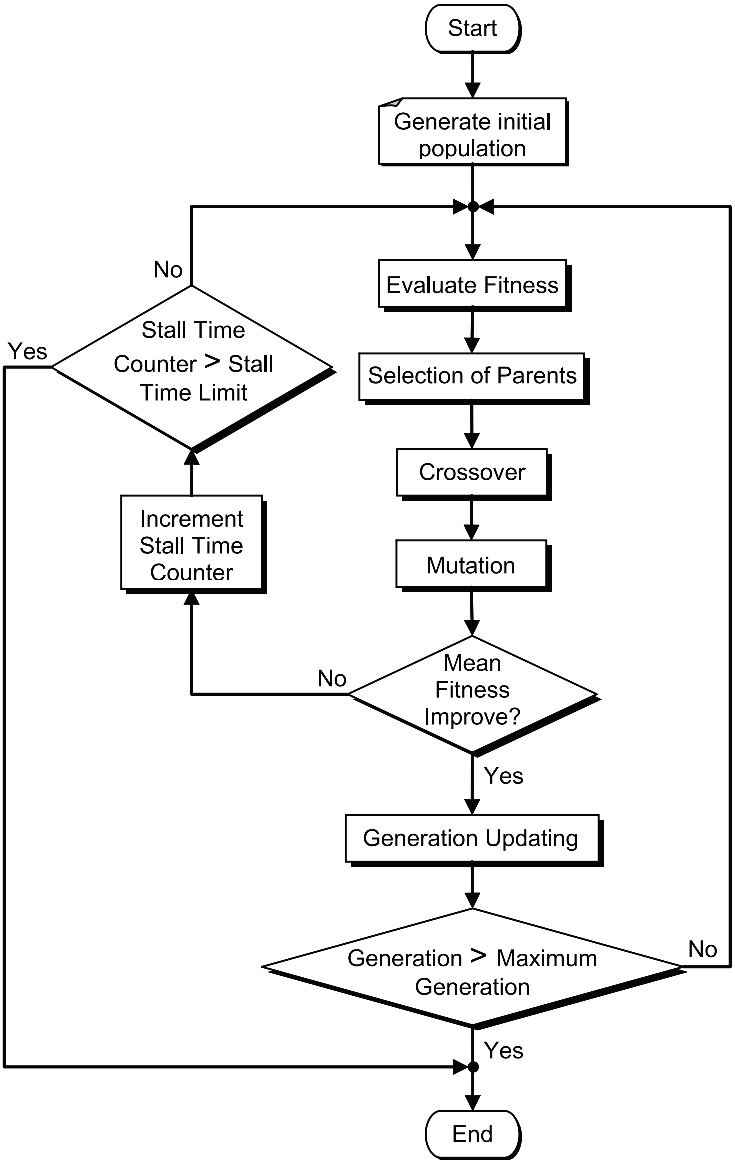

Fig. 2 – *Flow chart of the optimization algorithm.*

4 Experimental Results

The GA algorithm proposed in the previous section is implemented and simulated for a CCAA having 3 circular rings with aperture of 4.4λ, 6.06λ, 9.00λ respectively. The number of elements of the inner most circle (N_1) is 8, for outermost circle (N_3) is 12, whereas the middle circle (N_2) has 10 numbers of elements. Further, we have assumed $\varphi_0 = 0°$ so that the radiation patterns of the CCAA of main lobe starts from $\varphi_0 = 0°$. In this experiment the algorithm parameters are set as follows:

```
Maximum number of generation = 600
Population size = 100
Crossover probability = 0.17
Mutation = Gaussian
Crossover = two point Crossover
Selection = roulette
Stall Time Limit = 100 Second
```

Fig. 3 shows the radiation pattern for a uniformly excited CCAA, it has a radiation pattern with –9.56 dB side lobe level and a BWFN of 54.8°. Fig. 4, on the other hand, shows the radiation pattern of a non-uniformly excited CCAA with uniform spacing between the elements. It has a radiation pattern with –26.15 dB side lobe level. The BWFN is, however, approximately same with the uniform excitation case.

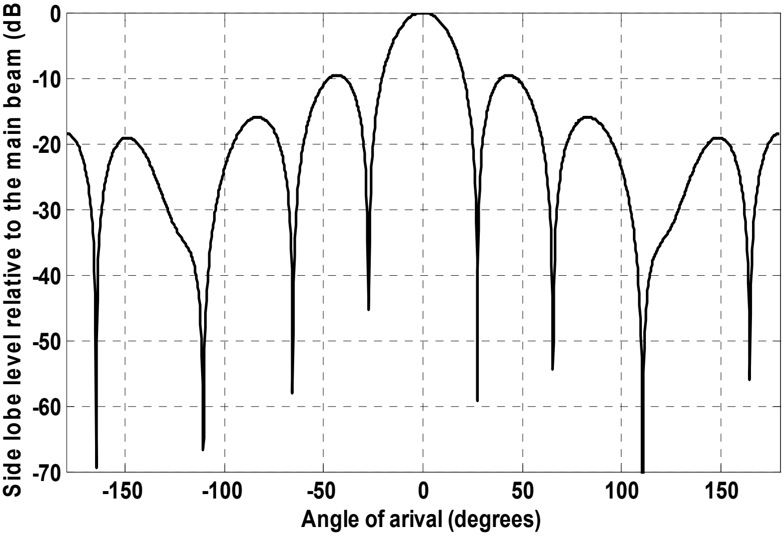

Fig. 3 – *Radiation pattern of an uniformly excited* CCAA.

So it is observed from Figs. 3 and 4 that the method of GA provides massive side lobe level reduction amounting 16.59 dB, compared to the case of uniform excitation.

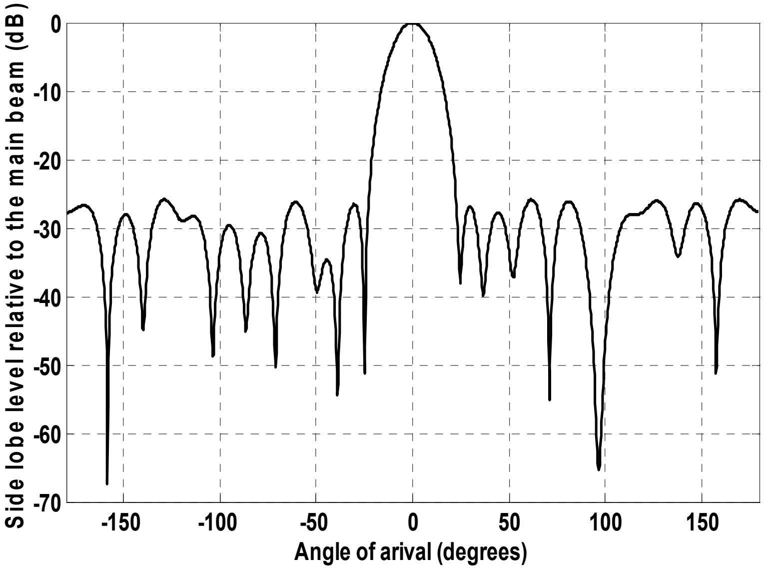

Fig. 4 – *Radiation pattern of a non-uniformly excited* CCAA.

Table 1

Excitation distribution and SLL *for uniformly and non-uniformly excited concentric circular antenna arrays obtained by the genetic algorithm.*

No. of elements	Excitation (uniform/ non-uniform)	Weights for the array elements ($I_{11}, I_{12}, \ldots I_{mi}$)	BWFN (deg)	SLL (dB)
30	uniform	$I_{mi}=1$	54.8	–9.56
30	non-uniform	0.7173 0.3476 0.8193 0.9864 0.7472 0.4022 0.6541 0.8133 0.8206 0.0096 0.2364 0.6728 0.6363 0.7073 0.1668 0.0522 0.7646 0.5785 0.3698 0.4443 0.9648 0.5297 0.4922 0.5270 0.4424 0.4531 0.9853 0.4931 0.4158 0.4287	49.83	–26.15

Table 1 shows the set of current excitation weights (as obtained from the GA based optimization) for all antenna elements of the CCAA used in the

experiment. It may be noted that all the weights are normalized, with a maximum possible value of 1. The table clearly shows huge improvement with non-uniform excitation (SLL of –26.15 dB) when compared to the corresponding uniform excitation (SLL of –9.56 dB) case.

5 Conclusion

The design of non-uniformly excited concentric circular antenna arrays with uniform spacing between the elements has been established using the method of genetic algorithms. This method provides a considerable side lobe level reduction compared to the case of uniform excitation.

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