Journal of Modern Researches on Electronic Defense Systems

Receive: 15 November 2022 Accept: 9 January 2023

Using Non-Uniform Distribution of Elements with Different Excitation Amplitutes as an Effective Method to Reduce the Maximum Sidelobe of Circular Array Antennas

Amirhosein Zanganeh[1*], Hamidreza Dalili Oskouei[2], Morteza Mohammadi Shirkolaei[3]

[1] Instructor, Faculty of Computer, Shahid Sattari Aeronautical University, Tehran, Iran.
[2]Associate Professor of Electrical Engineering, Shahid Sattari Aeronautical University, Tehran, Iran.
[3]Assistant Professor of Electrical Engineering, Shahid Sattari Aeronautical University, Tehran, Iran.

Abstract – *The Concentric Circular Array Antennas (CCAAs) are made up of elements that are distributed on different concentric circular areas with different radiuses. In this paper we determine the non-uniform distribution of elements excitation amplitude and their positions, in order to achieve more reduction in sidelobe level and beam width. The difference of side lobe levels becomes more important when the beam width of the antenna needs to be kept fixed. The sidelobe level reduction is proposed as an optimization problem and a Genetic Algorithm (GA) is used to handle the large mass of parameters that associate with each other. In this article, experiments have been performed for 3 different cases. In the first case, it is assumed that 18 elements have been distributed on 3 centered rings, and in second case we assumed that 24 elements have been distributed on 7 non-uniform distribution centered rings and in third case 30 elements are distributed on 6 non-uniform distribution centered rings. Based on the results obtained, for first case the proposed method represents -1.89 dB reductions, for second case the proposed method represents -8.16 dB reduction, and for third case also the first sidelobe level -0.44 dB Reduced. The results showed that the design of the non-uniform distribution of elements with non-uniform excitation amplitude for CCAAs, decreased significantly the sidelobe level and beam width.*

Keywords: Maximum 6 keywords, Times new roman 10pt italic, first word in each keyword capitalized, written in alphabetical order, Separated by commas

1. Introduction

An antenna array consists of multiple stationary antenna elements, which are typically fed coherently. Recently various application of antenna array has been investigated in order to improve the performance of mobile and wireless communication system by using efficient spectrum utilization, increasing channel capacity, extending coverage area, tailoring beam shape etc [1], [2]. Antenna array have been devoted considerable interest in different application like radar systems, audio systems, biologic drugs and communication systems. However, arbitrary array design may lead to increment in pollution of the electromagnetic environment and more importantly, wastage of precious power, which proves fetal for power- limited battery-driven wireless devices.

Antenna array have several advantages including the flexibility in array pattern synthesis, design both in narrowband and broadband beam-forming, and the ability of all-azimuth scan. Among the different types of antenna arrays CCAA have become most popular. Hence, design and performance evaluation of CCAA is of considerable interest. Synthesis methods are concerned with suppressing the SLL while preserving the gain of the main beam [3].

In general, several parameters must be considered in design of an antenna array in order to enhance its efficiency, such as antenna gain, sidelobe level, beam width, radiation pattern, antenna size, etc. Ignoring sidelobe will reduce the efficiency and performance of the antenna. Therefore, finding the best set of distances between elements and elements excitation amplitude is proposed as an optimization problem, which is solved by the GA.

Mandal et al. [4] carried out a study for maximum side lobe level reduction of three-ring concentric circular antenna array using a novel practice swarm algorithm. They showed that among all the designs, the three-ring structure containing

Corresponding email: zangane.amirhosein@ssau.ac.ir

(N_1=4, N_2=6, N_3=8) result in the optimal design owing to the highest SLL reduction. Reyna and co-authors [5] used the genetic algorithm for optimal design of steerable concentric rings array for low side lobe level. They reported a considerable reduction of side lobe level of ≤28 dB with respect to the conventional case progressive phase excitation. Then Mandal et al. [6] used different evolutionary optimization techniques to finding the maximum SLL reduction. Real coded GA (RGA), canonical PSO (CPSO), craziness based PSO(CARPSO), and hybrid evolutionary programming (HEP) were used. They concluded that HEP leads to the maximum reduction in SLL, about -31.86 dB. The genetic algorithm has been used by Haupt et al. [7] to reduce the sidelobe level in CCAAs. The PSO algorithm has been applied by Mandal et al. [8] and Pathak et al. [9] to determine the best set of excitation amplitude of elements for highest reduction in sidelobe level. Efficient techniques for reducing the sidelobe level have been studied by Dessouky et al. [10]. Also, Pal et al. [11] have tried to determine the best excitation amplitude of elements to achieve the highest reduction in the sidelobe level.

Misra et al. [12] Distributed the array antenna elements normally and at equal intervals on 5 concentric loops and then turned off or on the optimal number of elements on each loop to further reduce the area of the side lobes. They were finally able to achieve a maximum reduction of -30.15 dB at the lubrication level for 72 elements distributed on 5 loops with First Null Beam Width = 43.20.

In this paper, the highest reduction in sidelobe level and the main beam width are found by optimizing the elements excitation amplitude, the elements position, ring quantity and rings radiuses in CCAA. There are Nelements on M rings with the radius of $r_1, r_2 \ldots r_m$. The obtained radiation pattern, sidelobe level and the beam width on concentric circles according to non-uniform distribution of elements and amplitudes are presented. Then, the results will be compared with Ref, [6]. Based on the present results, the proposed method causes the highest reduction in sidelobe level on concentric circles for the minimum beam width.

2. Methodology

According to Figure 1, N isotropic elements with distances of d_m are assumed to be in x-y plane and they are located on M concentric rings with radiuses of r_m. Regarding isotropy assumption for the elements, it can be denoted that the distribution pattern of this array of antennas can be expressed by its array factor as:

$$AF = \sum_{m=1}^{M} \sum_{i=1}^{N_m} I_{mi} \, exp\big(j(kr_m \sin\theta \cos(\phi - \phi_{mi}) + \alpha_{mi})\big) \quad (1)$$

$$\phi_{mi} = \frac{2\pi((i-1)}{N_m} \quad (2)$$

$$\alpha_{mi} = -kr_m \cos(\phi_0 - \phi_{mi}) \quad (3)$$

$$k\, r_m = \frac{2\pi r_m}{\lambda} = \sum_{i=1}^{N} d_{mi} \quad (4)$$

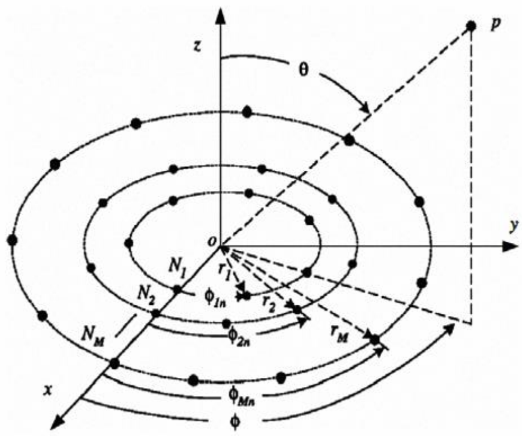

Figure 1. The structure of CCAA with M rings and N elements [13].

In Eq. (3), ϕ_0 is the angle of the main beam, d_{m_i} is the distance between i^{th} and $(i+1)^{th}$ element of m^{th} ring of the array antenna and I_{m_i} stands for the excitation amplitude of i^{th} element of m^{th} ring.

Phase difference between the elements is equal to the constant value of $\frac{2\pi a}{\lambda}$ and $\theta = 90^\circ$, ϕ is the collision angle of the beam with x-y plane and λ is the wave length of the beam. Our intention is to find the best set of elements positions and their excitation amplitude on M concentric circles with the radiuses of r_m.

In this paper, as mentioned earlier, finding the best set of elements position and their excitation amplitude can be proposed as an optimization method. Thus, a target function must be defined to tackle the problem by means of a GA, so that the algorithm could result in the optimal solution.

3. The Used Target Function

To define the target function, we consider the following parameters: ϕ_0 is the angle in which the maximum emission is obtained, and ϕ varies in the range of $[-\pi, \pi]$. θ_{msl} is the angle in which the first sidelobe is formed and it is the largest sidelobe as well. $BWFN_{desired}$ is the maximum beam width that is assumed to be equal to 50 as a constant value and the $BWFN(I_{m_i}, d_{m_i})$ is the first null beam width. Thus, the target function can be described as follows [14]:

$$f_1 = \frac{\left|AF(\theta_{msl1}, I_{m_i}, d_{m_i})\right|}{AF(\theta_{msl1}, I_{m_i}, d_{m_i})} + \left|BWFN_{desired} - BWFN(I_{m_i}, d_{m_i})\right| \quad (5)$$

According to the defined target function, the best set of I_{m_i} and d_{m_i} is achieved when f_1 is in its minimum value.

4. The Proposed Algorithm

The main purpose of this paper is to design a CCAA with non-uniform element distribution on external surfaces regarding the limitation of the maximum beam width with the aim of succeeding the highest reduction in the sidelobe level. To this end, we have used a population-based stochastic procedure denominated genetic algorithm.

The GA is essentially a probabilistic search algorithm which is built based on the concept of assessment and natural selection. In each generation, an initial population of possible solutions is produced from members called chromosomes. Each chromosome is evaluated by a function called Fitness that is usually the cost function or objective optimal function of the problem. Then, a number of the best chromosomes are elected in the next step based on Fitness function. This technique helps to keep the finest members in each generation.

To generate new Childs, some solutions remain unchanged and some of them pass to the next step with Crossover and Mutation operations from the chosen solutions in the previous step. Thus, some of the best solutions generate new solutions. This procedure leads to evolution of the members. Therefore, the search space will evolve in the direction of optimizing the solution.

In this algorithm, the Crossover operation has the exploratory property and it can search the spaces between parents by big jumps to discover new areas. But the Mutation operation has the extension property and it can make small random changes to extend discovered areas. Figure 2 shows the implementation of the components of the genetic algorithm that is described earlier as:

1) The Function of Initial Population: This function produces the initial population in a uniform and random form.

2) Evaluation Functions: At each stage, this function iterates all the solutions using a fitness function or Fitness is evaluated. Then some of best hypothesis using a likelihood function are selected and they form new population.

3) Operations of Crossover and Mutation functions: Some of these selected solutions are used in their current state, and the others are utilized to make Childs by using genetic operations such as Crossover and Mutation.

4) Stopping Criteria: The algorithm continues until the generation counter reaches the maximum number of generations or the best evaluation function value does not change.

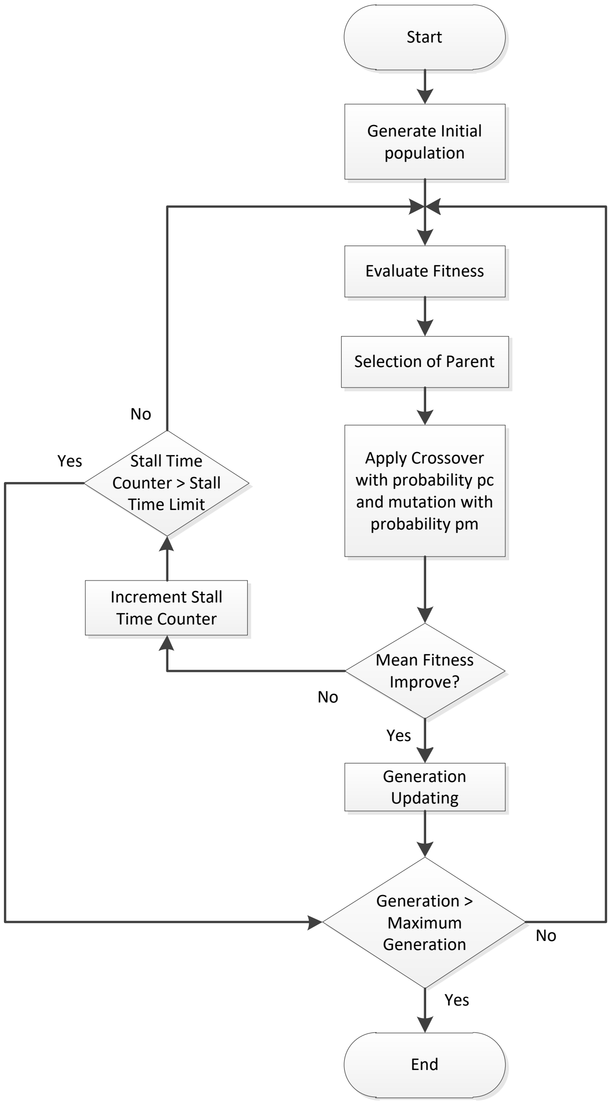

Figure 2. The GA flowchart [15].

5. Results

In this section, the proposed method for non-uniform distribution of array antenna elements with non-uniform excitation amplitude is implemented. It is assumed the concentric rings radiuses to vary using the GA algorithm, and the results have been compared with the results of previous studies [1] for designing a CCAA. For all cases, the angle in which the maximum emission occurs, ($\phi_0 = 0^{\circ}$) is assumed to be equal to zero.

In the first case, it is assumed that 18 elements have been distributed on 3 centered rings, and in second case we assumed that 24 elements have been distributed on 7 non-uniform distribution centered rings and in third case 30 elements are distributed on 6 non-uniform distribution centered rings.

A. Case One: Number of elements=18 , Radiuses =[1 2 3]

In figure 3, the radiation pattern of non-uniform distribution with non-uniform excitation amplitude is shown on CCAA. According to figure 3, the proposed method represents -1.89 dB reductions in the first sidelobe level and 60.4 degrees reduction in beam width compared to that of reported in Mandal et al. [1]. Based on these results, the first state clearly shows its superiority over the previous study.

B. Case Two: Number of elements=24 , Radiuses =[1 2 3 4 5 6 8]

Similar to Figure 3, Figure 4, also shows the radiation pattern of CCAA that its elements have non-uniform excitation amplitude with non-uniform distribution of elements position. Based on the provided results, the proposed method represents -8.16 dB reduction in the first sidelobe level and 51.92 degrees reduction in beam width. In this case, we can likewise observe the superiority of the propose method over the previous study.

C. Case Three: Number of elements=30 , Radiuses =[1 2 3 4 5 6]

The radiation pattern of CCAA with 30 elements that have non-uiform excitation amplitude with non-uniform distribution of elements position is shown in figure 5. Here also -0.44 dB reduction in the first sidelob level and 51.66 degrees reduction in beam width is observed.

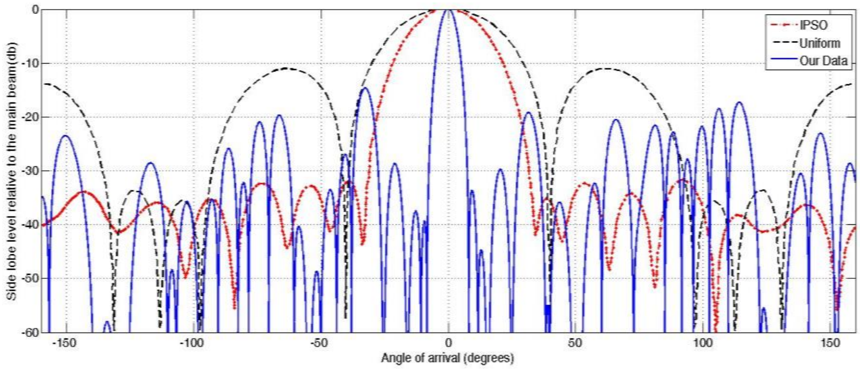

Figure 3. Radiation pattern and the position of CCAA elements (the 1^{th} state)

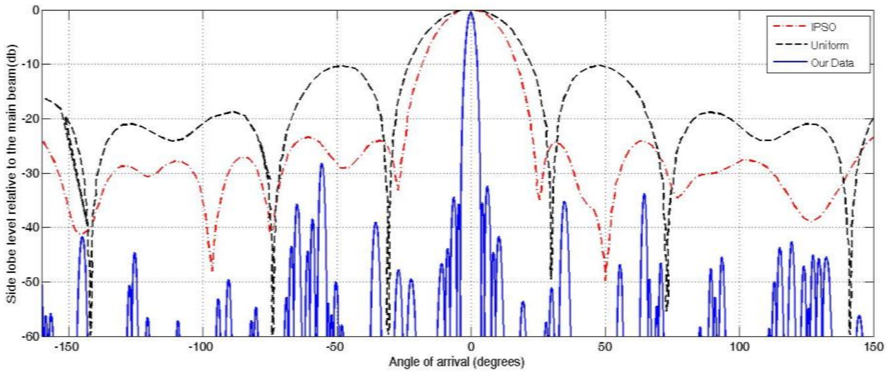

Figure 4. Radiation pattern and the position of CCAA elements (the 2^th state)

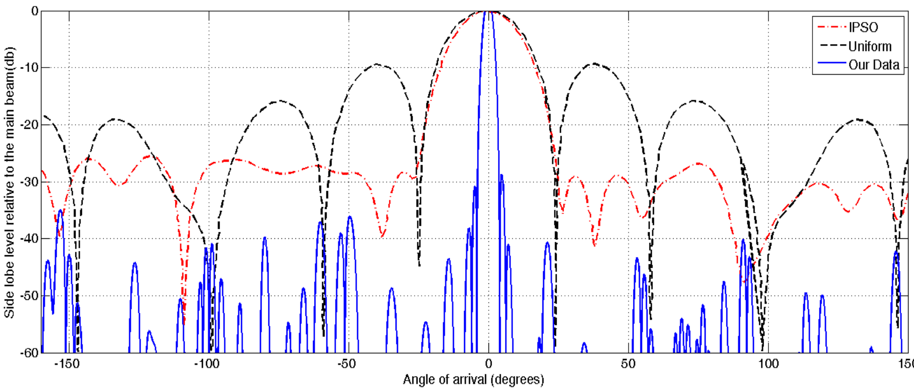

Figure 5. Radiation pattern and the position of CCAA elements (the 3^{th} state).

Table 1. The comparison results of the proposed method and previous works (case 3)

CASE NO.	$(I_{11}, I_{12}, \ldots, I_{mi})$; $(x_{11}, x_{12}, \ldots, x_{mi})$; $(y_{11}, y_{12}, \ldots, y_{mi})$ in λ	SLL (dB)	BWFN (deg)
1	1.4445 2.9833 2.3469 3.7022 1.9843 2.6613 0.3625 0.1485 3.0999 0.9846 1.9643 0.0892 3.1345 3.9808 0.6944 0.5238 1.1932 3.5607 0.5419 -0.4870 0.7996 -0.9758 -1.9214 -1.9883 0.3529 -1.1567 1.2548 1.8148 1.8739 -1.1953 1.6450 -2.3396 2.3676 -2.1424 -2.2838 2.5250 0.8405 -0.8734 0.6005 0.2186 -0.5552 -0.2162 1.9686 -1.6316 -1.5574 -0.8405 0.6990 1.6035 1.1376 -1.8778 -1.8424 2.1000 1.9453 -1.6200	-29.97	16.1
2	1.2912 3.8709 3.1983 0.2913 1.9527 0.6314 0.6725 3.5027 3.6584 2.6347 1.1565 0.2060 1.2770 3.3065 1.2867 1.4042 0.4728 1.0992 1.1756 0.3864 0.3553 0.4039 2.2177 2.5301 -0.9928 1.5408 -1.7325 -0.5536 -1.5224 -1.7284 -0.8778 -1.8358 -2.4341 -2.2500 2.8298 2.8701 3.9972 -1.1533 -3.9142 -3.2141 3.0381 2.9262 -2.0600 -2.4809 -2.3789 1.4951 5.6964 -6.4402 0.1199 1.2751 -0.9992 -1.9219 1.2971 1.0063 -2.8687 2.3727 -1.7536 -1.9843 -0.9962 -2.7861 -0.1504 3.8301 -0.8241 -2.3811 3.9711 -4.0543 -4.5559 4.3411 -4.3978 4.7712 1.8845 4.7460	-16.28	7.66
3	0.6683 2.3255 1.2252 4.3558 1.1517 0.1107 1.8464 0.9552 1.0267 4.4622 2.2313 1.2369 0.1733 3.1617 2.9042 0.3490 0.4333 1.6108 0.8538 0.3649 1.5065 2.5347 5.7361 0.9425 2.3073 3.7323 0.7693 0.8603 0.1612 1.4382 0.1957 0.9096 1.8008 0.4381 -0.1386 1.5147 -1.4834 0.4999 -0.0731 2.9537 -0.8670 0.4326 -2.2187 2.7639 2.9225 0.5727 0.3663 -1.3870 -1.6830 1.3678 3.4700 -3.9988 -3.9149 -3.5435 -1.9597 1.3467 -4.9868 4.9789 3.9541 4.8792 -0.9807 0.4154 -0.8701 -1.9514 1.9952 1.3060 1.3415 1.9365 1.9987 -0.5252 -2.8720 2.9686 -2.0192 1.1665 0.6774 -2.9448 -3.9832 3.7518 -3.6287 3.7589 -1.9897 -0.0969 -0.8206 -3.5276 4.5999 -4.8152 0.3634 -0.4594 3.0602 -3.4919	-28.12	8.1

Table 1 also shows the results of the proposed method and the previous investigation. Here, the radiuss and number of rings are free to change, which is a reason for superioty of this method compared to the previous studies.

6. Conclusions

In this paper, we have proposed and applied a method of non-uniform elements distribution that has non-uniform excitation amplitude for CCAAs using the GA algorithm. The objective of this paper is to reduce the maximum sidelobes and the beam width simultaneously. The results clearly show the superiority of the proposed method in reducing the maximum sidelobe level and the beam width, compared to previous studies. Therefore, we recommend using the non-uniform distribution of array antenna elements method with non-uniform excitation amplitude at for CCAA. As a future subject (study), we can focus on the best proportion of number of rings and elements on concentric circular array antennas. Thus, we can determine the optimum number of rings for N elements.

References

[1] M. Zaid, M. R. Islam, M. H. Habaebi, A. Z. Alam, and K. Abdullah, "Optimum concentric circular array antenna with high gain and side lobe reduction at 5.8 GHz," in *IOP Conference Series: Materials Science and Engineering*, 2017, vol. 260, no. 1, p. 012038.

[2] R. L. Haupt and D. H. Werner, *Genetic algorithms in electromagnetics*. John Wiley & Sons, 2007.

[3] Ge Sun, Y Liu, H Li, Shu Liang, Ai Wang, Bo Li, "An Antenna Array Sidelobe Level Reduction Approach through Invasive Weed Optimization", International Journal of Antennas and Propagation, vol. 2018, Article ID 4867851, 16 pages, 2018.

[4] D. Mandal, D. Sadhu, and S. P. Ghoshal, "Thinned concentric circular array antennas synthesis using improved particle swarm optimization," *ACEEE International Journal on Communication (IJCom)*, vol. 2, no. 2, pp. 21–25, 2011.

[5] A. Reyna, M. A. Panduro, D. H. Covarrubias, and A. Mendez, "Design of steerable concentric rings array for low side lobe level," *Scientia Iranica*, vol. 19, no. 3, pp. 727–732, 2012.

[6] D. Mandal, M. A. I. Ansari, R. Kar, and S. P. Ghoshal, "Non-uniform concentric circular antenna array design using IPSO technique for side lobe reduction," *Procedia Technology*, vol. 6, pp. 856–863, 2012.

[7] R. L. Haupt, "Optimized element spacing for low sidelobe concentric ring arrays," *IEEE Transactions on Antennas and Propagation*, vol. 56, no. 1, pp. 266–268, 2008.

[8] D. Mandal, S. P. Ghoshal, and A. K. Bhattacharjee, "Concentric circular antenna array synthesis using Particle Swarm Optimization with Constriction Factor Approach," in *2010 Indian Antenna Week: A Workshop on Advanced Antenna Technology*, 2010, pp. 1–4.

[9] N. N. Pathak, G. K. Mahanti, S. K. Singh, J. K. Mishra, and A. Chakraborty, "Synthesis of thinned planar circular array antennas using modified particle swarm optimization," *Progress In Electromagnetics Research*, vol. 12, pp. 87–97, 2009.

[10] M. I. Dessouky, H. A. Sharshar, and Y. A. Albagory, "Efficient sidelobe reduction technique for small-sized concentric circular arrays," *Progress In Electromagnetics Research*, vol. 65, pp. 187–200, 2006.

[11] S. Pal, A. Basak, S. Das, A. Abraham, and I. Zelinka, "Concentric circular antenna array synthesis using a differential invasive weed optimization algorithm," in *2010 International Conference of Soft Computing and Pattern Recognition*, 2010, pp. 395–400.

[12] B. Misra and G. K. Mahanti, "Side lobe level reduction of thinned concentric elliptical array antenna in vertical and horizontal plane for a desired peak directivity," *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, vol. 34, no. 1, p. e2785, 2021.

[13] N. Dib, "Design of planar concentric circular antenna arrays with reduced side lobe level using symbiotic organisms search," *Neural Computing and Applications*, vol. 30, no. 12, pp. 3859–3868, 2018.

[14] M. A. Panduro, A. L. Mendez, R. Dominguez, and G. Romero, "Design of non-uniform circular antenna arrays for side lobe reduction using the method of genetic algorithms," *AEU-International Journal of Electronics and Communications*, vol. 60, no. 10, pp. 713–717, 2006.

[15] D. Mandal, A. Chandra, P. G. Sakti, and K. A. Bhattacharjee, "Side lobe reduction of a concentric circular antenna array using genetic algorithm," *Serbian Journal of electrical engineering*, vol. 7, no. 2, pp. 141–148, 2010.