Journal of Scientific & Industrial Research
Vol. 80, March 2021, pp. 255-259

Evolutionary Computing Tools based Design of Elliptical Antenna Array for Amplitude-Position Technique

B S S V Ramesh Babu[1,2], P S R Chowdary[2]* and Satyasis Mishra[1]

[1]Department of ECE, Centurion University of Technology and Management, Odisha, India

[2]Department of ECE, Raghu Institute of Technology, Visakhapatnam, India

Received 18 September 2020; revised 20 October 2020; accepted 05 January 2021

The work presented in this paper refers to synthesis of elliptical antenna array for a desired radiation pattern in which the SLL is optimized using evolutionary computation algorithms like Accelerated Particle Swarm Optimization (APSO), Flower Pollination (FPA) and Antlion Optimization (ALO) algorithms. The amplitude-position technique of synthesis is used in which both amplitude and angular positions of the element on the circumference of the ellipse are determined using the evolutionary computing algorithms. The simulation-based experimentation is carried out for elliptical array of 12 and 20 elements arranged aperiodically with non-uniform amplitude distribution. The Simulations are performed in MATLAB 2019 and SLL are obtained from the corresponding radiation pattern for analysis.

Keywords: ALO, APSO, EAA, FPA, Side Lobe Level

Introduction

Antenna arrays are of different configurations and geometry are designed and installed to meet the radiation characteristics desired by several wireless applications.[1–5] These antenna arrays are preferred over single element configuration as they are capable of producing the desired radiation patterns. The array geometry can be of any shape, However, Classified as linear and planar. In circular planar array, the elements are arranged to form a circle. Similarly, when they are arranged in the circumference of the ellipse, they are considered as elliptical array. Typical elliptical array antenna has several steering parameters like current excitation (I), inter-element spacing (d) or angular position (Φ) and phase of current excitation. In addition, the EAA also has an additional geometrical parameter known as Eccentricity. Eccentricity of an ellipse (e) is defined as the ratio of distance from the center of foci point to the distance from the center of vertices.[5–9]

$$e = \sqrt{(1 - \frac{a^2}{b^2})} \quad \dots (1)$$

This factor is not present in circular array antenna. Eccentricity is inversely proportional to the distance between the array elements. In this work, the parameters like I and Φ are optimized to suppress the SLL. The objective is to control the beam width and fix it unaltered to the magnitude of EAA with uniform distribution while bringing down the SLL to much lower value as possible.

Problem Formulation

The geometry of the N elements EAA is as shown in Fig 1, in which a & b are semi major and semi minor axis. The array factor formulation of EAA has been modified by Dib and given as.[10]

$$AF(\theta, \emptyset) = \sum_{n=1}^{N} I_n e^{j\alpha_n} e^{jk\rho_n sin\theta \cos[\emptyset - \emptyset_n]} \quad \dots (2)$$

In this equation, N indicates the number of elements. Here, I_n and $\alpha_n$are the excitation current amplitude and phase of n^{th} element respectively. These are termed as the design parameters and used to control the radiation pattern. The phase contributes to the control of the beam position and steering which is given as

$$\propto_n = -k\rho_n \sin(\theta_0) \cos(\emptyset_0 - \emptyset_n) \quad \dots (3)$$

Here, k represents the propagation constant,ρ_n represents the radial distance of n^{th} element which is measured considering origin as the reference. Similarly, corresponding angular position is computed using the following relation

*Author for Correspondence
E-mail: satishchowdary@ieee.org

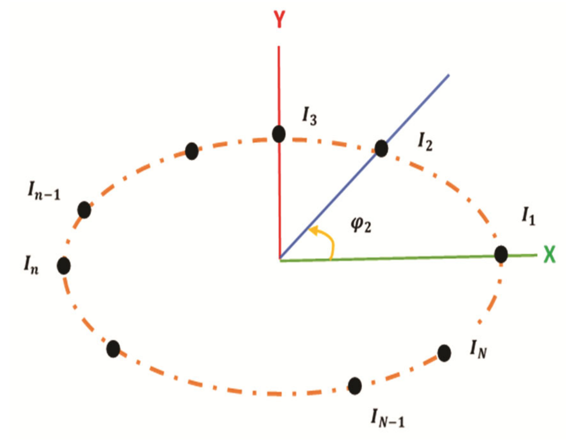

Fig. 1 — Geometry of an EAA

$$\emptyset_n = \frac{2\pi(n-1)}{N} \quad \dots (4)$$

However, these $\emptyset_n$ are optimized using the algorithms.

Fitness Function

Following fitness function is used for synthesis of elliptical antenna array. In fitness function cost with respect to the desired SLL and BW is computed with the objective to suppress SLL while the corresponding uniform BW is the constraint. The fitness function used for 12 element EAA is

f1=10-abs (max (slll, sllr)) … (5)

f2=abs (42.2-fnbw) … (6)

where slll and sllr are sidelobe levels of left and right side of the main beam respectively and fnbw is the first null beam width. Similarly, for 20 element EAA it is given as

f1=12-abs (max (slll, sllr)) … (7)

f2=abs (30.2-fnbw) … (8)

and finally, fitness is calculated as

fitness=f1+f2 … (9)

Algorithms

Antlion Optimization

The ALO algorithm is a natural inspired algorithm.[11] It has two phases, known as larvae and adult stages. The antlion basically digs a pit in the form of a circle and hide itself under the bottom most layer and covers itself with sand and when the pray is found, it binds the edge of the pray by throwing sand on it and does not allow it to move out. The random walk is chosen for modelling ants' movement as follows:

$$X = \sum_{n=1}^{N} 2(r_n(t) - 1) > 0.5 \quad \dots (10)$$

where, n calculates the cumulative sum and r denotes the maximum number of iterations for a random walk of a stochastic function.

$$r(t) = \begin{cases} 1\ if\ rand\ > 0 \\ 0\ if\ rand\ <= 0 \end{cases} \quad \dots (11)$$

where, t shows the step of random walk and rand is a random number generated with uniform distribution in the interval of [0, 1].

Flower Pollination Algorithm

The FPA was proposed by Yang.[12] It is greatly inspired by the flower pollination mechanism which is responsible for the reproduction in flowering plants. Pollination is classified into self-pollination and cross pollination. Basing on certain rules, the pollination process takes place. When the pollination takes place over long distances using insects and other biotic means, it is referred as biotic global pollination. If it takes place through abiotic means over a short range within the same flower or the same plant then it considered as abiotic local pollination. This way local and global search are accomplished. It is possible to switch between the search criteria using switching parameter known as 'p', the two phases of updating the current position are given as

$$X_i(c+1) = X_i(c) + L(X_i(c) - X^*) \quad \dots (12)$$

$$X_i(c+1) = X_i(c) + \varepsilon\,(X_l(c) - X_m(c)) \quad \dots (13)$$

Here, $X_i(t)$ the i[th] pollen at iteration c while L refers to Levy flight based distribution. Similarly, X is an individual representing pollen while l and m are indices of these individuals in the population. Further,∈ is a random number.

Accelerated Particle Swarm Optimisation Algorithm

APSO[14] is another version of PSO.[13] Unlike conventional PSO, in APSO it is proposed to use only global best based search operation. In PSO, both pbest and gbest are used whereas APSO only gbest. The gbest is the position of the best value with respect to the entire swarm over every iteration, the velocity vector is given as

$$V_i(t+1) = V_i(t) + \propto r_1[g_{best} - X_i(t)] + \beta r_2[p_{ibest} - X_i(t)] \quad \dots (14)$$

Here, Xi is the ithelement and t represents the iteration number. Also,r_1 and r_2 are the two random numbers. Moreover,V_i is the velocity vector and α, β are the accelerating parameters. In this we use only g_{best} and the simplified equation is

$$V_i(t+1) = V_i(t) + \propto \in_n + \beta[g_{best} - X_i(t)] \quad \ldots (15)$$

Here, $\in_n$is a random number for a range (0,1) and the position is updated as

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad \ldots (16)$$

Results and Discussion

The results pertaining to the synthesis of the EAA are presented in this Section. Two examples namely a 12 element EAA and a 20 element EAA are considered for synthesis. The angular positions of the elements and their corresponding amplitudes current excitation are determined using ALO, FPA and APSO and compared with those of uniform distribution. However, the respective beam-width in both the examples is considered as the constraint which is fixed to the beam-width of the uniform distribution in which all the elements are excited uniformly along with their corresponding angular position. In all the two examples, the corresponding design variables are the coefficients to be determined as a part of implementation of the algorithms for synthesis of EAA. Hence the number of design variables is twice the number of elements which corresponds to the sum of number of amplitude levels and the angular positions. Which means, for an N element EAA, the number of design variables to be determined in Amplitude-Position technique is 2*N. Though this common to all the three algorithms employed, the respective algorithm specific and general parameters are not similar. For example, the initial population considered was 30, 50, and 30 for ALO, FPA and APSO respectively. The values of parameters of elliptical geometry like a ande are predefined and fixed. However, they vary with the number of elements in the array. In this work, the value of a takes 0.5, 1.15 and 1.6 respectively for 8, 12 and 20 element EAA while the eccentricity is 0.5 in order to emphasize perfect ellipse. With uniform distribution, the elements of the array uniformly excited without any biasing and placed periodically on the circumference of the ellipse. Under such uniform distribution the corresponding SLL and BW of 8 element EAA is −7.75 dB and 98.8^o , while they are −2.95 dB and 42.2^o for 12 element EAA. Similarly, for 20 element EAA the uniform distribution reported a SLL of −6.87 dB and 32.2^o of BW.

Example 1: 12 Element Elliptical Antenna Array

In this instance, consider a 12 element EAA synthesis using the multi-variable technique known as amplitude-position technique. The ALO, FPA and APSO are used for the implementation of the technique. Every algorithm runs for 50 unbiased times and finally the best among the 50 trials is chosen as the result. In this case, the eccentricity is defined as 0.5. The most suitable amplitudes and angular positions that give the minimal SLL as determined by the algorithms are presented in Table 1. The Fig 2(a) indicates the radiation pattern obtained using ALO while Fig 2(b) shows the pattern obtained using FPA and Fig 2(c)has the pattern obtained using APSO algorithm. There is a considerable decrease in the SLL while the corresponding BW is the constraint. The improvement was around 150% in term of reduction in the SLL. Using ALO, the SLL reported to be −7.61 dB which is 4.7 dB less than the uniform distribution while in the case of FPA and APSO, the reduction in the SLL was 4.4 dB and 4.55 dB respectively.

Example 2: 20 Element EAA

The optimized amplitudes and angular positions determined for 20 elements EAA are populated in Table 2 for all the three algorithms. The most effective amplitudes and angular positions that give the minimal SLL are considered among 50 trials. The SLL along the BW can be read directly from the

Table 1 — 12 element EAA

N=12, FNBW=42.2^0	Normalized Amplitudes ($I_1, I_2, \ldots, I_{12}$)	Angular Positions ($\Phi_1, \Phi_2, \ldots, \Phi_{12}$) in degrees	SLL (dB)
ALO	0.93,0.93,0.91,0.91,0.30,0.96,0.99,0.90,0.55, 0.84,0.05,1.0	14.61,72.06,90.66,101.22,164.13,168.88,198.04,257.80,270.79,270.79,324.62,350.80,360	−7.61
FPA	0.81,0.39,1.00,0.36,0.77,0.55,0.32,0.79,0.56, 0.26,0.01,0.64	15.49,54.62,89.10,121.05,163.20,192.84,228.66.265.60,279.48,303.19,336.57,344.91,360	−7.40
APSO	0.93,0.15,0.77,0.31,0.56,0.11,0.49,0.37,0.52, 0.89,0.69,1.00	11.66,46.12,72.99,93.74,94.47,104.90,163.64,191.33,212.79,266.99,287.90,340.36,360	−7.55

Table 2 — 20 element Elliptical Antenna Array

N=20, FNBW=30.2^0	Normalized Amplitudes ($I_1, I_{2,\ldots}\ I_{20}$)	Angular Positions ($\Phi_1, \Phi_{2,\ldots..}, \Phi_{20}$) in degrees	SLL (dB)
ALO	0.98,0.01,0.20,0.48,0.37,0.97,0.56,0.54,0.07,0.10,0.70,0.99,0.02,0.33,1.00,0.99,0.55,0.11,0.59,0.97	2.73,17.04,44.52,60.03,74.88,84.61,86.98,114.56,140.33,161.21,174.59,192.34,210.78,242.84,261.67,273.67,294.23,316.81,346.46,359.86,360	−9.88
FPA	0.81,0.52,0.29,0.31,0.77,0.82,0.98,0.15,0.98,0.98,0.44,0.23,0.41,1.00,0.05,0.73,0.69,0.15,0.81,0.10	0.02,14.74,49.13,61.06,76.08,91.14,106.52,139.87,173.23,184.33,196.44,217.19,249.19,260.01,262.56,277.98,290.01,322.89,340.47,342.55,360	−9.27
APSO	0.98,0.23,0.63,0.26,1.00,0.84,0.18,1.00,1.00,0.18,0.23,0.59,0.8,3,0.93,0.70,0.04,0.01,0.06,0.37,0.70	4.11,39.87,72.31,86.07,87.,51,100.22,137.29,173.56,184.81,190.02,217.58,254.41,264.98,273.73,289.43,293.32,296.10,336.32, 352.67,355.58,360	−10.30

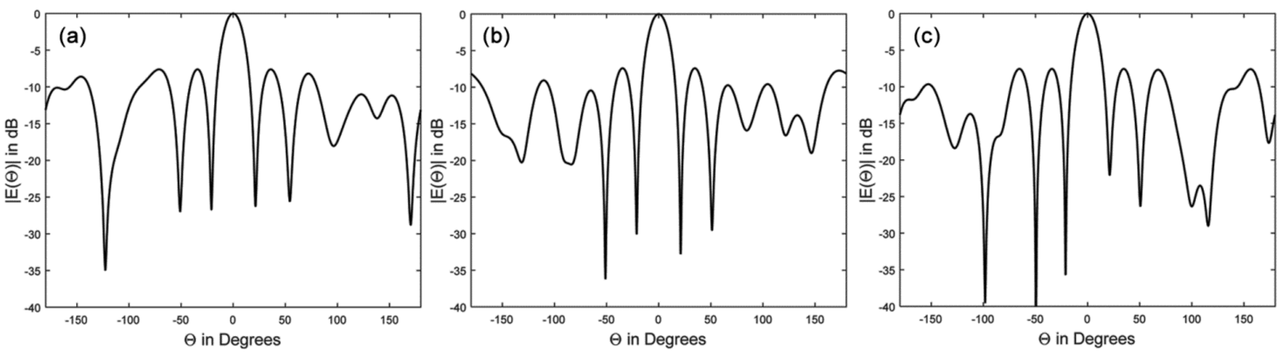

Fig.2 — Radiation Pattern of 12 element EAA obtained using (a) ALO,

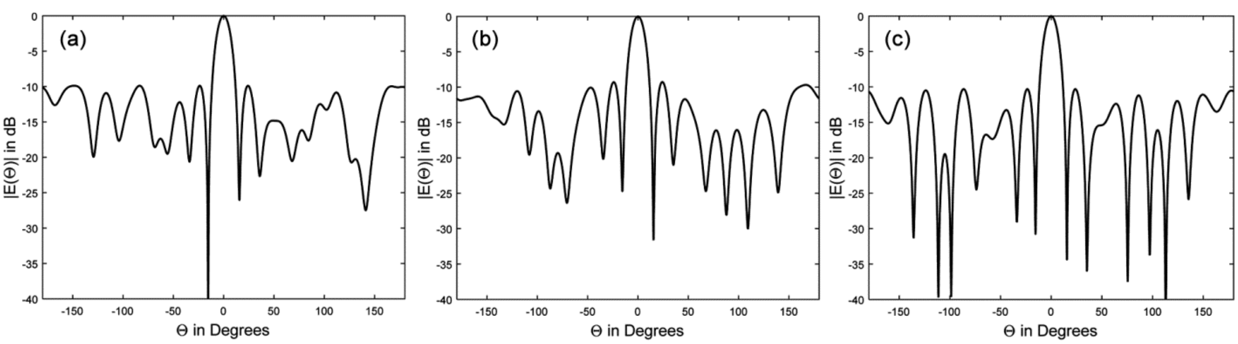

Fig.3 — Radiation Pattern of 20 element EAA obtained using (a) ALO, (b) FPA and (c) APSO

radiation patterns presented in Fig 3(a), 3(b) and 3(c) which are obtained using ALO, FPA and APSO respectively. The corresponding SLL levels read from the patterns are presented in the last column of Table 2. The SLL reported to be -9.88 dB, −9.27 dB and −10.3 dB respectively using ALO, FPA and APSO. Compared to the uniform distribution, the SLL reduced by a maximum of 3.5 dB using APSO while it is around 3dB and 2.4 dB using ALO and FPA respectively.

Conclusions

The synthesis of EAA has been carried out successfully using all the three algorithms with the objective of suppressing the SLL of 12 element and 20 element EAA. The amplitude and position only technique is considered as a multi-variable optimization technique and has been successfully accomplished using ALO, FPA and APSO. Among the three algorithms, APSO expressed its dominance in terms of performance in reducing the SLL by more than 100%. The angular adjustment of the elements on the circumference of the ellipse along with the amplitude distribution certainly added to the performance of the evolutionary computing tools. The technique can be further extended to optimize the current excitation phase of the elements along with the two parameters considered in this paper.

References

1 V S Chakravarthy, P S R Chowdary, S C Satpathy, S K Terlapu & J Anguera, Antenna array synthesis using social group optimization, Springer-Microelectronics, Electromagnetics and Telecommunications (2018) 895–905.

2 C S R Paladuga, CV Vedula, J Anguera, R K Mishra, & A Andujar, Performance of beam width constrained linear array synthesis techniques using novel evolutionary computing tools, Applied Computational Electromagnetics Society Journal (2018) 273–278.

3 M J Ahammed, A Swathi, D Sanku, V Chakravarthy& H Ramesh, Performance of firefly algorithm for null positioning in linear arrays, Springer-Proceedings of 2nd International Conference on Micro-Electronics Electromagnetics and Telecommunications (2018) 383–393.

4 V Chakravarthy, P S R Chowdary, G Panda, J Anguera, A Andújar, & B Majhi, On the linear antenna array synthesis techniques for sum and difference patterns using flower pollination algorithm, Arabian Journal for Science and Engineering (2017), 3965–3977.

5 B S S V. Ramesh Babu, Satyasis Mishra & P S R. Chowdary, Optimal Synthesis of Elliptical Antenna Array, IEEE International Conference on Intelligent Systems and Green Technology (2019).

6 Dib, N, Design of Linear Antenna arrays with Low Side Lobes Level Using Symbiotic Organisms Search. Progress in Electromagnetics Research B (2016), 68, 55–71.

7 Sharaq A., & Dib, N, Design of Linear and Elliptical Antenna Arrays Using Biogeography based Optimization. Arabian J. Sci. Eng., (2013) **39**(4), 2929- 2939.

8 Guney, K., & Durums, A, Elliptical Antenna Array Synthesis Using Backtracking Search Optimization Algorithm. Defense Science Journal,(2016). **66**(3),272–277

9 Amaireh, A., Alzoubi, A., & Dib, N. , Design of Linear Antenna Arrays Using Antlion and Grasshopper Optimization Algorithms. IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT), Amman, Jordan (2017).

10 Nihad Dib, Anas Amaireh & Asem Al- Zoubi., On the Optimal Synthesis of Elliptical Antenna Arrays, International Journal of Electronics. (2018).

11 Mirjalili, S.,The Ant Lion Optimizer. Advances in Engineering Software, (2015)83, 80–98.

12 Yang, X.-S Flower Pollination Algorithm for Global Optimization. Lecture Notes in Computer Science,(2012) 240–249

13 J. Kennedy ; R Eberhart, Particle swarm optimization, International Conference on Neural Networks (1995)

14 Xin-She Yang , Suash Deb & Simon Fong, : Accelerated Particle Swarm Optimization and Support Vector Machine for Business Optimization and Applications in Networked Digital Technologies , Springer-Communications in Computer and Information Science, (2012) 53–66.