Journal of Engineering Science and Technology
Vol. 16, No. 5 (2021) 4138 - 4148

NOVEL TECHNIQUES OF ELLIPTICAL ARRAY OPTIMIZATION USING GRASSHOPPER ALGORITHM

SURAYA MUBEEN*, CH. SUDHAMANI, K. BHARATH KUMAR, SURESH

Department of Electronics and Communication
Engineering, CMR Technical Campus, Hyderabad, India
*Corresponding Author: suraya418@gmail.com

Abstract

Elliptical antenna array (EA) is one of the preferred geometries with excellent control on the radiation pattern significantly better than circular array. In this paper, efficient optimization of the EA with good number of examples is presented with the objective of SLL suppression along with the beam width (BW) using novel grasshopper optimization algorithm (GOA). The synthesis techniques like amplitude only (Amp-only) and Amplitude position (Amp-Ph) are compared in EA design with emphasis to the objective. The results are compared with ant lion optimization algorithm (ALO) and uniform distribution. The performance of the GOA is evaluated while comparing with the so far available best results with the modified/corrected array factor of the EA.

Keywords: Amplitude position technique, Elliptical antenna array, Grasshopper algorithm (GOA).

1. Introduction

Antenna array configurations are used because of their obvious advantages of enhanced directivity, gain and capability to steer the beam to desired directions with no mechanical effort are taken from reference [1]. Considering these advantages, the arrays are used in many wireless communication applications which includes mobile and other commercial and defense systems. Every application has its own specification in terms of either desired radiation pattern and properties or desired physical parameters of the radiation system. Accordingly, several geometries of antenna arrays are proposed to meet the requirements in terms of decorum and radiation characteristics. Fundamentally, the antenna arrays can be one, two- and three-dimensional geometry. In one and two dimensional, the array can be linear and planar respectively. The planar arrays configuration can be geometrically circular, rectangular, hexagonal, elliptical etc., these planar arrays have advantage of better performance over linear arrays in terms excellent control on the radiation patterns. Generally, the linear arrays in which all the elements are arranged on a straight line have poor freedom of steering the beam which is restricted to only one plane of angle. As a result, reflections have to be arranged to have the beam steered to desired direction, which makes the radiation system bulky and complex. It is not so in the ease of planar arrays. The planar arrays have the capability to steer the beam to any desired direction [2-4]. Among several planar array geometry, the best are circular antenna arrays and the elliptical antenna arrays. Conceptually, the circular geometry also belongs to the class of ellipse with the corresponding eccentricity approaching zero.

Besides this, the elliptical array geometry has more flexibility over circular array as the geometry does not demand for strict e=0. Moreover, it is also important to note that, for elliptical arrays the number of controlling parameters are more. In addition to inter element spacing, excitation amplitudes of current and their phase angle, the EA has other design parameters like semi-major axis (a), semi-minor axis (b) and eccentricity (e). however, the eccentricity is computed from a and b values. Generally, either amplitudes or phases or the inter element spacings for ‘a’ fixed ‘e’ of each element in the array are determined to obtain desired radiation pattern in the case of single variable optimization. Also, it is possible to go with a multiple variable optimization strategy in which two or more design parameters of the EA are determined to obtain the desired radiation pattern.

The design of EA is much complex phenomenon when compared with CA. However, because of the efficiency of producing desired pattern and ease of installation of EA can be performed using novel evolutionary computing Tools (ECT). The ECT is not a novice when it comes to concept of application to electromagnetics and antenna design. However, the techniques and strategies in ECT are ever growing and always it is possible to find a development right from the genetic algorithm to latest ant-lion algorithm.

Earlier the particle swarm optimization along with fuzzy logic is used to design EA with reduced SLL and optimal BW [5]. Similarly, PSD is also used for thinning of EA is reported in [6]. While the strategy of aging ladders and challengers equipped PSO is used in [7]. Another version known as wavelet mutation based PSO [8] is used to design EA suing amplitude only technique which is later enhanced to multiple ring EA using simplex-PSO [9]. In addition to the above, other ECT like differential evolution [10] symbiotic algorithm [11], backtracking search [12] and ALO [13] are also applied to synthesize EA for SLL suppression.

It is possible to mention that the ECT has been a sobriquet of synthesis techniques of EA. It is also evident that every new algorithm may or may not have a significant impact on the final objective. But typically has its own search strategy effecting the computational time. Hence, always there is a need to check the efficiency of novel ECT, compare with existing algorithm and quote the redoubt ableness.

In this paper, both the single and multi-variable optimization strategies are used to design the EA with reduced side lobe level (SLL) and fixed beam width (BW). In the first case, amplitude only technique is employed, in which the remaining parameters are fixed to definite values. In the second case, both amplitude and phase (or angular position) are determined for each element of the array. In either case, the design parameters are obtained using grasshopper algorithm.

2. Array Factor of Elliptical Array

2.1. Geometry of elliptical antenna array

An EAA belongs to the class of planar arrays in which all the elements are arranged on the circumference of the ellipse as shown in Fig. 1.

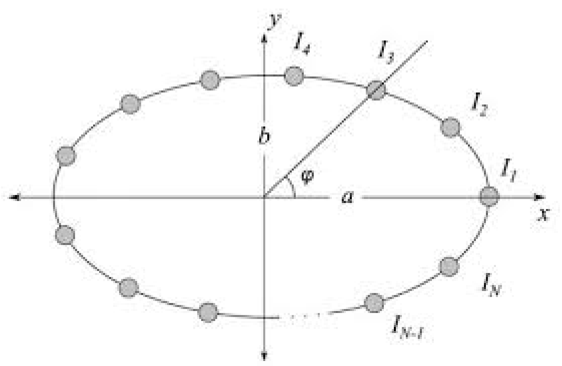

Fig. 1. Geometry of EAA.

The geometry is typically defined using three different geometrical parameters known as eccentricity (e), semi-major and semi-minor axis given as 'a' and 'b' respectively. The value of 'e' can be as low as '0' and as high as '∞'. As 'e' approaches '0', it takes the shape of a circle, while it appears more and more hyperbolic for larger values. However, the geometry to look like ellipse, the corresponding 'e' should be around '0.5'. in this work, e = 0.5 and the corresponding a varies depending up on the number of elements like (0.5, 1.15, 1.5) for 8, 12 and 20 element EAA respectively.

The array factor of the EAA used in this work is directly taken from [dib-2019] without giving much privilege to the discussion on the validity of earlier formulations of the same. The final AF formulation of the EAA is given as [13].

$$AF(\theta,\phi) = \sum_{n=1}^{N} A_n e^{(j\rho_n \sin\theta \cos(\phi-\phi_n)+j\alpha_n)} \quad (1)$$

Here, the current excitation amplitude is 'A_n' and excitation phase α_n is given as,

$$\alpha_n = -\beta\rho_n \sin(\theta_0)\cos(\phi - \phi_n) \quad (2)$$

While $\theta_0 = 90^0$ and $\phi_0 = 0^0$ such that the major lobe is oriented towards positive X-axis. Also, n is the element number, while 'N' refers to the total number of elements in EAA. Similarly, the position of the element on the plane is given as,

$$x_n = \rho_n \cos\phi_n, y_n = \rho_n \sin\phi_n, z_n = 0$$

where,

$$\rho_n = \frac{a*b}{\sqrt{(b\cos\phi_n)^2 + (a\sin\phi_n)^2}} \quad (3)$$

$$e = \sqrt{1 - \frac{b^2}{a^2}} \quad (4)$$

And,

$$\phi_n = \frac{2\pi(n-1)}{N} \quad (5)$$

2.2. Fitness formulation

The fitness formulation should necessarily induct the objectives of the work in terms of SLL and BW. Accordingly, the formulation is given as,

$$SLL_{(d)} = \left|SLL_{(des)} - SLL_{(obj)}\right| \quad (6)$$

$$BW_{(d)} = \left|BW_{(des)} - BW_{(obj)}\right| \quad (7)$$

The final fitness is calculated as follows

$$F = r_1 * SLL_{(d)} + r_2 * BW_{(d)} \quad (8)$$

Here r_1 and r_2 are biasing factors. However, in this work $r_1 = r_2 = 1$ in order to represent no biasing. Also, $SLL_{(des)}$ and $SLL_{(obj)}$ are desired and obtained SLL. Similarly, $BW_{(des)}$ and $BW_{(obj)}$ are desired and obtained BW.

3. Grans Hopper Optimization Algorithm

The GOA [14] is greatly inspired by the swarming behaviour of GH. The GH have an interesting swarm nature which is considered as a most disgusting and often annoying to the farmer. The GH swarm quickly develops to a large volume crossing the geographical boundaries. Unlike other insects, during the larva stage, they move in large size of groups. While they move, they are responsible for all damage to the farmer as they prey on the plants and all the vegetation. This process continues till they transform into adult just to gain the capability to migrate rapidly to long distance. It is obvious that as swarm size increases the corresponding magnitude of damage would be more serious and severe and most of the time untraversable. In fact, as swarm goes building up in size, the more the need for food and food-seeking capability rises. This outbreak may be so profound and intense at the end. Moreover, it is interesting to note that there are two quite contrary phases of life. The GH behaves during the larval phase, the swarm moves slowly while on the other hand during the adult stage, the swarm accelerates its movement and moves this strange behaviour of the swarm, and its evolution process is modelled as GOA. Like any other algorithm as proposed and structured for modelling and optimization problems, the GOA also performs searching with different strategies. The two search strategies are typically local and global. In this algorithm, they are termed as explore and exploit. In addition to these two strategies, the GHOA inherently possess target seeking tendency by which it is considered as more efficient and effective.

The basic formulation incorporating these characteristics is given as,

$$I_i = (SI)_i + (GF)_i + (WA)_i \tag{9}$$

Here I_i is the ith individual position, $(SI)_i$, $(GF)_i$ and $(WA)_i$ are social, gravitational and wind propelled movements of the ith individual. However, these three have individual descriptions and mathematical expression of their own. The social movement is expressed as social force and strength. Computed using the distance between two GH. Similarly, the GF component is computed using the force (g) which is driving towards the centre of the earth ($\hat{e}_g$). Accordingly, the (WA) component is computed by using drift (u) and direction ($\hat{e}_w$) of wind. Finally, the position of the ith individual is given as

$$I_i = \sum_{\substack{j=1 \\ j \neq i}}^{N} SA\left(\left|X_j - X_i\right|\right) \frac{X_j - X_i}{d_{ij}} - g\hat{e}_g + u\hat{e}_w \tag{10}$$

Here *N* refers to the population size, which counts the number of GHs. However, this Eq. (10) is modified in order to provide adaptability to the handle the optimization problems and is given as follows

$$I_i = c\left[\sum_{\substack{j=1 \\ j \neq i}}^{N} c\,\frac{ub_k - lb_k}{2} SA\left(X_j^k - X_i^k\right) \frac{X_j - X_i}{d_{ij}}\right] + \hat{T}_d \tag{11}$$

Here the term $\hat{T}_d$ indicates the food seeking tendency. Also, the component 'c' serves as an inertial parameter which keeps on decreasing with the progressing iteration.

$$C = C\,\frac{C_{(max)} - C_{(min)}}{t_{max}}\;{}_{max} \tag{12}$$

Also, the upper and lower bounds (ub_k, lb_k) of the kth individual which is the best solution so far are used and multiplied with 'c' in order to deal with repulsion or attraction. The structure of the GHOA is explained in the flow chart given in Fig. 2.

4. Results and Discussion

Simulations pertaining to optimization of EAA are carried out in two cases with three examples. In the first example, an 8 element EAA is considered, while 12 and 20 element EAA is considered in example 2 and example 3 respectively. In the first case, the design of the EAA is carried out using the amplitude only technique in which the amplitudes of current excitation of each element in the array are determined according to the objective. Similarly, in the second case, both the amplitude and phase (angular position) are determined using amplitude-phase (Amp-Ph) technique. For all the example cases, the objective is to suppress the SLL with respect to the SLL of uniform distribution, while keeping BW unaltered. Hence, incorporation of uniform BW (BW of uniform distribution) can be considered as a constraint in the SLL optimization process. In this work, initially in every example, amplitude only technique (Case-1) is employed and later compared with the results of amplitude-phase technique (Case-2). Example-wise results are given in the subsequent discussions.

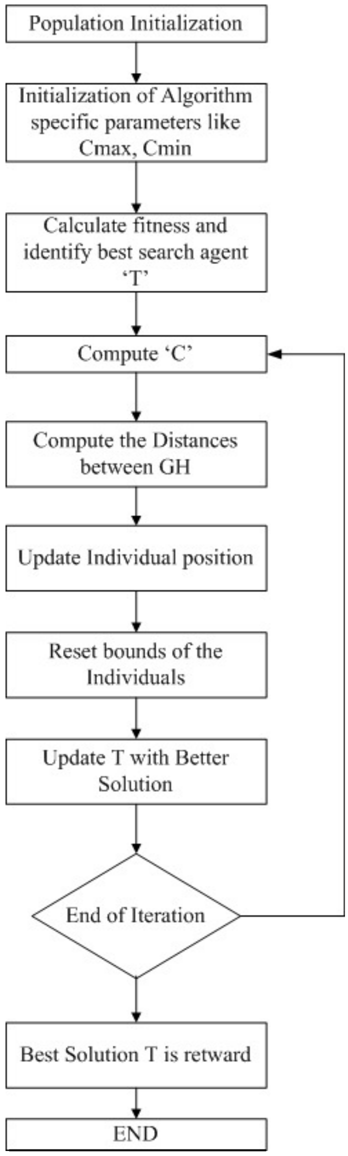

Fig. 2. Structure of GOA.

Case-1: As example-1, an 8-element EA is considered. The uniform amplitude distribution of 8 element EA resulted in a SLL of -7.75dB with the corresponding BW of 102°. The optimum non-uniform amplitude distribution is determined using GOA and compared with the patterns obtained using Ant lion optimization algorithm (ALO). The SLL is reported to be -14.35dB using ALO while the GOA produced patterns have SLL as low as -14.57dB as shown in Fig. 3. In both the cases, the corresponding BW is fixed to the BW of uniform distribution. Similarly, 12 element EA is considered as example-2 and the corresponding uniform distribution produced SLL is -2.75dB. Likewise, in example-1, the optimum non-uniform amplitude distribution is determined using GOA in order to achieve a SLL of -8.1dB which is less than the SLL of -7.9 as determined using ALO. The corresponding radiation patterns of 12 element EA is as shown in Fig. 4. Further, in example-3, a 20 element EA is considered for which the amplitude distribution is determined using GOA and the corresponding radiation pattern is plotted as shown in Fig. 5. The corresponding SLL obtained using GOA is -11.55 dB which is better than the SLL of uniform distribution which is -6.88 dB. The amplitude distribution of all the three examples is given in Table 1.

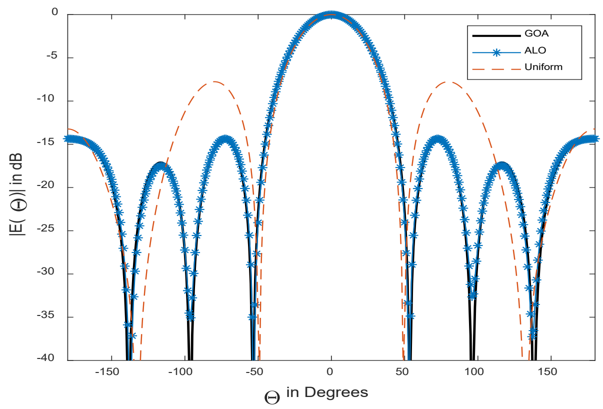

Fig. 3. Radiation pattern of synthesized 8 element EA using Amp-only technique.

Table 1. Amplitude distribution determined using GOA.

Number of Elements	Amplitude Distribution
8	0.542, 0.998, 0.088, 1.0, 0.550, 0.999, 0.084, 0.998
12	0.7414, 0.0011, 0.4022, 0.3325, 0.1560, 0.1599, 1.0000, 0.1607, 0.1641, 0.3332, 0.4106, 0.0006
20	1, 0.54869, 0.49367, 0.14571, 0.26854, 0.46912, 0.36302, 0.0046257, 0.48135. 0.1961, 0.99933, 0.0027855, 0.6607, 0.025609, 0.23107, 0.88636, 0.33892, 0.017579, 0.40131, 0.57411

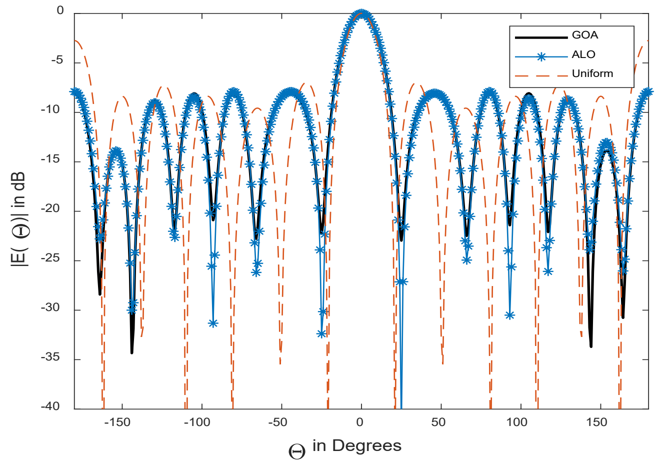

Fig. 4. Radiation pattern of synthesized 12 element EA using Amp-only technique.

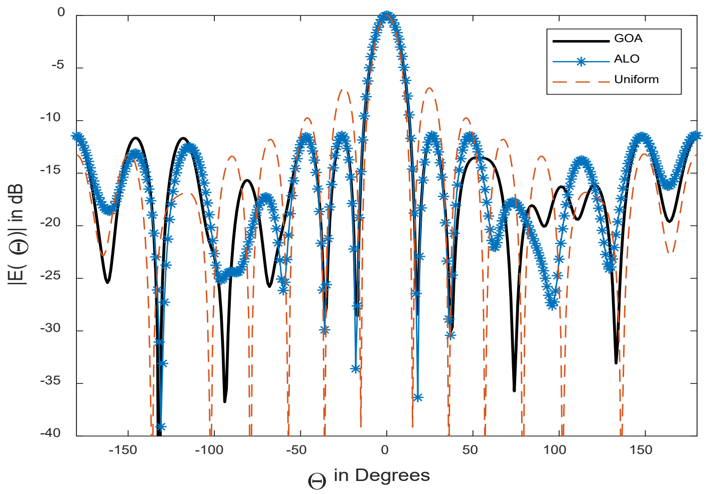

Fig. 5. Radiation pattern of synthesized 20 element EA using Amp-only technique.

Case-2: In this case, all the three example EA design are considered once again, and their side lobe levels are optimized with BW as constraint. However, unlike case-1 here both the amplitude and the corresponding positions of the elements mentioned in terms of θ are determined using GOA. The radiation patterns with optimized SLL for 8, 12 and 20 element EA are presented in Figs. 6 to 8 respectively while the corresponding side lobe levels are -15.08dB, -8.17dB and -11.77dB. Comparatively, these SLL are much lower than the SLL of uniform distribution and better that the Case-1 respectively. The GOA determined distribution of amplitudes and positions are given in Table 2 for all the example EAs.

The SLLs of all the examples for Case-1 and Case-2 are listed in Table 3 from which it is possible to claim the performance of the Amp-Ph technique over the Amp-only technique. There is a certain degree of improvement in the SLL of three example EAs.

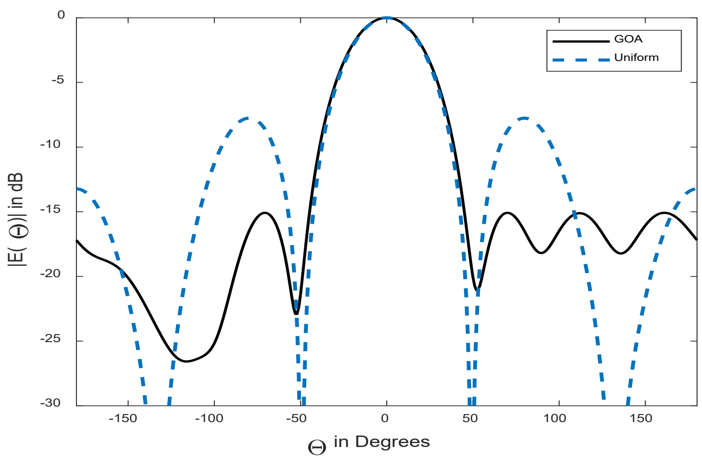

Fig. 6. Radiation pattern of synthesized 8 element EA using Amp-Ph technique.

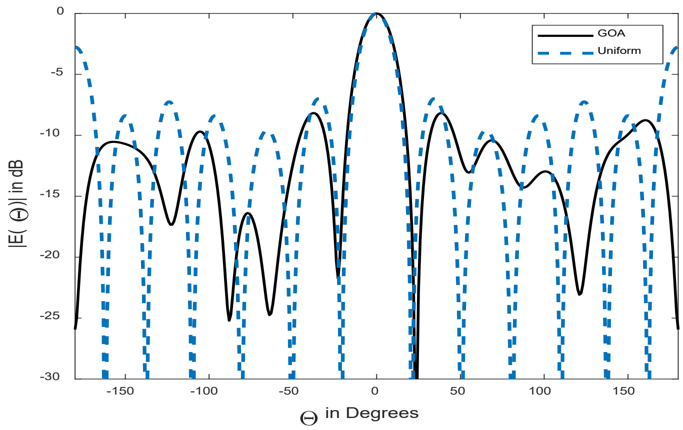

Fig. 7. Radiation pattern of synthesized 12 element EA using Amp-Ph technique.

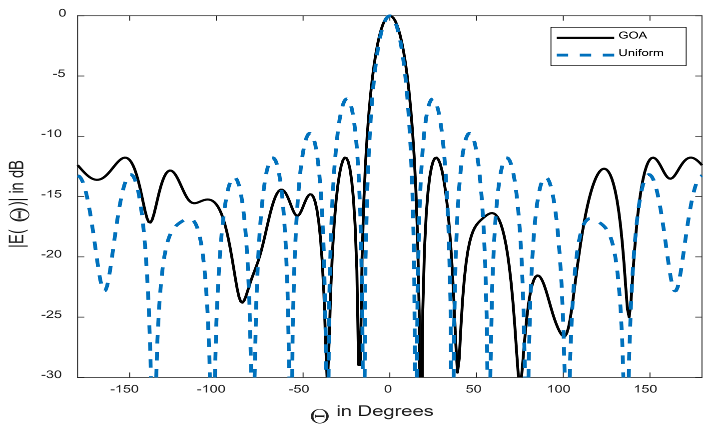

Fig. 8. Radiation pattern of synthesized 20 element EA using Amp-Ph technique.

Table 2. Amplitude and phase distribution determined using GOA.

Number of Elements	Amplitude Distribution	Position (in degrees)
8	0.374, 0.624, 0.315, 0.749, 0.575, 0.711, 0.538, 0.803.	18.84^{o}, 51.44^{o}, 107.84^{o}, 145.22^{o}, 207.51^{o}, 229.52^{o}, 295.45^{o}, 328.28^{o}.
12	0.82615, 0.73395, 0.23335, 0.33337, 0.51076, 0.29671, 0.99626, 0.76092, 0.50491, 0.80817, 0.6649, 0.69227.	15.21189^{0}, 61.34734, 93.38007^{0}, 109.2911^{0}, 159.8515^{0}, 176.0218^{0}, 179.4935^{0}, 227.696^{0}, 261.0544^{0}, 282.3766^{0}, 303.6287^{0}, 356.2936^{0}.
20	0.026958, 0.7522, 0.85277, 0.93275, 0.4043, 0.85894, 0.95323, 0.1872, 0.56659, 0.75467, 0.96618, 0.87294, 0.58088, 0.18783, 0.76375, 0.64873, 0.80409, 0.11076, 0.71824, 0.97891.	0.377348^{0}, 1.463541^{0}, 8.09348^{0}, 39.61646^{0}, 50.1846^{0}, 80.52423^{0}, 111.9932^{0}, 135.0103^{0}, 148.0067^{0}, 168.5402^{0}, 178.9099^{0}, 193.6466^{0}, 212.0583^{0}, 231.9434^{0}, 246.4352^{0}, 266.1761^{0}, 274.0598^{0}, 295.2131^{0}, 323.0689^{0}, 350.6307^{0}.

Table 3. Comparison of SLL.

Number of elements	SLL (in dB) for Case-1	SLL (in dB) for Case-2
8	-14.5	-15.08
12	-8.06	-8.17
20	-11.55	-11.77

5. Conclusions

The GOA is successfully applied to EA synthesis problem with SLL optimization and BW constraint. A noticeable improvement in the SLL is evident when the comparison is drawn between the Amp-only (Case-1) and Amp-Ph (Case-2) technique as given in Table 3. It is obvious because, multivariable optimization provides extra degree of freedom during the search for better solution. Here, the inclusion of position of the element on the circumference of ellipse in the Case-2 along with the amplitude of current excitation of each element for optimizing the SLL provided additional advantage in the form of an additional dimension to the search capability. Replacing the isotropic elements with practical antenna elements like dipole in the current problem would be good future work.

References

1. Paladuga, C.S.R.; Vedula, C.V.; Anguera, J.; Mishra, R.K.; and Andújar, A. (2018). Performance of beamwidth constrained linear array synthesis techniques using novel evolutionary computing tools. *Applied Computational Electromagnetic Society Journal*, 33(3), 273-278.
2. Chakravarthy, V.V.S.S.S.; and Rao, P.M. (2015). Amplitude-only null positioning in circular arrays using genetic algorithm. *Proceedings of the IEEE*

International Conference on Electrical, Computer and Communication Technologies. Coimbatore, India, 1-5.

3. Chakravarthy, V.V.S.S.S.; Chowdary, P.S.R.; Panda, G.; Anguera, J.; Andújar, A.; and Majhi, B. (2018). On the linear antenna array synthesis techniques for sum and difference patterns using flower pollination algorithm. *Arabian Journal of Science and Engineering*. 43(8), 3965-3977.
4. Chakravarthy, V.V.S.S.S.; Chowdary, P.S.R.; Satpathy, S.C.; Terlapu, S.K.; and Anguera, J. (2018). Antenna array synthesis using social group optimization. *Proceedings of the International Conference on Microelectronics, Electromagnetics and Telecommunications*. Hyderabad, India, 895-905.
5. Ahmidi, N.; Neyestanak, A.A.L.; and Dawes, R. (2008). Elliptical array antenna design based on particle swarm method using fuzzy decision rules. *Proceedings of the 24th Biennial Symposium on Communications*. Kingston, ON, Canada, 352-355.
6. Bera, R.; Mandal, D.; Kar, R.; and Ghoshal, S.P. (2014). Thinned elliptical cylindrical antenna array synthesis using particle swarm optimization. *International Journal of Electrical, Electronics Science and Engineering*, 8(1), 35-39.
7. Bera, R.; Mandal, D.; Ghoshal, S.P.; and Kar, R. (2016). Optimal design of concentric elliptical array antenna for maximum side-lobe level reduction using particle swarm optimization with aging leader and challengers. *Proceedings of the International Conference on Communication and Signal Processing*. Melmaruvathur, India, 1817-1821.
8. Bera, R.; Mandal, D.; Kar, R.; and Ghoshal, S.P. (2017). Non-uniform single-ring antenna array design using wavelet mutation based novel particle swarm optimization technique. *Computers and Electrical Engineering*, 61(7), 151-172.
9. Bera, R.; Mandal, D.; Kar, R.; and Ghoshal, S.P. (2017). Optimal design of single and multi-ring planar array antenna using simplex-PSO. *IETE Journal of Research*, 63(6), 881-892.
10. Chaitanya, R.K.; Sainath, M.; and Raju, K.V.S. (2016). Reduction of side lobe level for elliptical cylindrical array using particle swarm optimization and differential evolution. *International Journal of Control Theory and Applications*, 10(26), 1-11.
11. Dib, N.I. (2016). Design of linear antenna arrays with low side lobes level using symbiotic organisms search. *Progress in Electromagnetics Research B*, 68, 55-71.
12. Guney, K.; and Durmus, A. (2016). Elliptical antenna array synthesis using backtracking search optimisation algorithm. *Defence Science Journal*, 66(3), 272-277.
13. Dib, N.; Amaireh, A.; and Al-Zoubi, A. (2018). On the optimal synthesis of elliptical antenna arrays. *International Journal of Electronics*.
14. Saremi, S.; Mirjalili, S.; and Lewis, A. (2017). Grasshopper optimisation algorithm: theory and application, *Advances in Engineering Software*, 105, 30-47.