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The Optimum Design of Scanned Linear Antenna Array Using Sine Cosine Optimization Algorithm

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ABSTRACT: In this article, the side lobe level (SLL) of the radiation pattern is reduced, and the first null beam width (FNBW) is kept constant by synthesizing symmetric scanning Linear Antenna Arrays (LAA), which is done by considering excitation amplitude as the optimization parameter. A Sine cosine algorithm (SCA) is used to achieve this objective. Three different case studies are illustrated in this article to show the effectiveness of SCA in LAA optimization. The results obtained show that the SCA algorithm performs better than Firefly Algorithm (FA), Symbiotic Organisms Search (SOS), and hybrid optimization algorithm based on Grasshopper Optimization Algorithm (GOA) and Antlion Optimization (ALO).

Keywords: linear antenna array, sine cosine algorithm, side lobe level, scanned antenna array.

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1. INTRODUCTION

In modern wireless applications, including radio, television, mobile, and satellites, the antenna is important. [1]. The main advantage of an antenna array over a single antenna is the ability to direct the main lobe without requiring the mechanical movement of the array [2]. Antenna arrays can take any geometry, such as linear, circular, planar, ...etc. The linear antenna array is the simplest and most popular array form, which will be considered in this paper. Controlling various radiation properties, such as pattern main beam width, minimum possible Side Lobe Level (SLL), directiv-ity, etc., can enhance the performance of the system.

Nonetheless, there is a trade-off between these variables [3]. Using steering LAA enhances the reliability and speed of mobile networks while increasing efficiency. In a steering LAA, the phases of the signals that reach the antenna elements are gradu-ally changed, allowing the radiation pattern's direction to be controlled corresponding-ly [4]. Radiation patterners with narrower beam widths and lower SLL are directed to the position of the user to prevent interference from other users and, as a result, im-prove the network's mobile coverage.

Evolutionary algorithms (EAs), which are search and optimization techniques, have been used successfully in single and multi-objective optimization problems with many constraints and nonlinear processes. Recently, several well-known evolutionary optimization techniques, such as Antlion Optimization (ALO) algorithm [5], Firefly Algorithm (FA) [6], genetic algorithm (GA) [7], particle swarm optimization (PSO) [8], Symbiotic Organisms Search (SOS) [9], central force optimization (CFO) [10], differ-ential evolution (DE) [11], gravitational search algorithm (GSA) [12], ant colony optimization (ACO) [13], Taguchi method [14], and many algorithms have been suc-cessfully used for the design of LAA due to their simplicity and robustness.

In this article, the Sine Cosine Algorithm (SCA) [15] is applied to design symmetric scanning Linear Antenna Arrays (LAA) to have an optimal side lobe level for a fixed major lobe beam width. To explain the effectiveness of the SCA algorithm, three case studies (each with different scan angles) of the design problem have been pre-sented. The results obtained from the suggested algorithm demonstrate that is better than Firefly Algorithm (FA), Symbiotic Organisms Search (SOS), and hybrid optimi-zation algorithm based on Grasshopper Optimization Algorithm (GOA) [16] and Ant-lion Optimization (ALO) [16]. This is due to its acceptable execution time and high efficiency compared to various well-known optimization techniques in the literature, and there are just a few control variables that need to be adjusted [17].

The rest of this article is structured as follows: Section 2 describes the geometry for the scanned LAA. Section 3 presents the SCA algorithm. The results with their expla-nation are introduced in Section 4. The effect parameter ‘a’ of SCA is discussed in Section 5. Section 6 concludes the paper.

2. LINER ANTENNA ARRAY (LAA

According to recent developments, the utilization of industrial UAVs, basically referred as drones, has increased in various applications, including This study considers a general configuration of LAA with 2N (even) elements dis-tributed symmetrically on both the positive and negative sides of the x-axis, as shown in Figure 1. Symmetric scanning LAAs are created to reduce the SLL of the radiation pattern. The optimization parameter that is taken into consideration is excitation amplitudes. The principal lobe of scanned array antennas is directed in a particular direction, allowing them to be used in several applications, including mo-bile and cellular communications. This is accomplished by introducing a progressive phase shift into the feeding currents [13]. Accordingly, the AF equation for an N-element scanning antenna array that has a spacing of ($\lambda/2$) between consecutive elements can be expressed as follows [13]:

$$AF\ (\theta) = \sum_{n=1}^{N} I_n exp(j\pi(n-1)\ [cos\ (\Theta)\ - cos(\Theta_d)] \qquad (1)$$

Where θ is the azimuth angle, Θ_d and I_n are the steering angle of the main lobe and the excitation amplitude of nthelement, respectively.

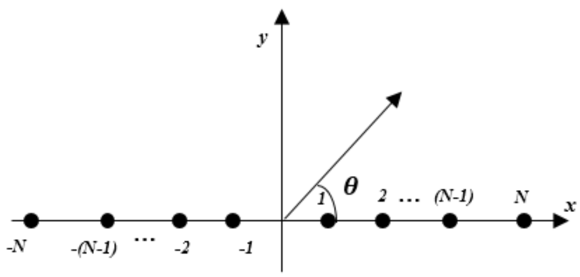


FIGURE 1. Geometry of 2N elements symmetric LAA

The main goal is to apply the SCA algorithm by using the fitness function expressed in Eq. (2) to determine the optimal design of scanned LAA to produce the required radiation pattern with the lowest side lobe levels.

$$Fitness\ function = min\left(max\left(20log\frac{(AF\ (\Phi)|}{max\,(AF\ (\theta)|}\right)\right] \qquad (2)$$

Where [0, Φ] denotes the area of the side lobe that is dependent on the number of elements. In this study, the chosen values are [0,15∘]∪[41∘,180∘],[0,38∘]∪[52∘,180∘], and [0, 58∘]∪[65∘, 180∘] for the corresponding numbers 20, 26, 30 and 40 elements and the steering angle of the main lobe 30∘, 45∘, and 60∘**,** respectively

3. SINE COSINE ALGORITHM (SCA)

Seyedali Mirjalili introduced the SCA algorithm in 2016 [15] as a new population-based optimization algorithm for resolving optimization problems. This algorithm generates a set of solutions at random to begin the search process and enables them to oscillate towards or outwards the best solution using the principle of trigonometric sine and cosine functions. The following equations are used to update the solutions in SCA:

$$X_i^{g+1} = X_i^g + r_1 \sin(r_2) \times \left|r_3 P_i^g - X_i^g\right| \qquad (3)$$

$$X_i^{g+1} = X_i^g + r_1 \cos(r_2) \times \left|r_3 P_i^g - X_i^g\right| \qquad (4)$$

Typically, the two functions mentioned above (Eq. (3) and (4)) are combined into one function, as in equation (5):

$$X_i^{g+1} = \begin{cases} X_i^g + r_1 \times \sin(r_2) \times \left| r_3 P_i^t - X_i^g \right|, r_4 < 0.5 \\ X_i^g + r_1 \times \cos(r_2) \times \left| r_3 P_i^g - X_i^g \right|, r_5 \geq 0.5 \end{cases} \quad (5)$$

Where, X_i^g and X_i^{g+1} represents the i^{th} position of the current solution at generation or iteration g and g+1, respectively. The parameters r_1, r_2, r_3 *and* r_4 represents random numbers, P_i^g the fittest solution in i^{th} location in the solution set.

The parameter r1 declines linearly from a fixed constant (a) to 0 [15] in order to balance diversification and intensification search behaviours. The following equation is used to update it:

$$r_1 = a - a \times \frac{g}{G} \quad (6)$$

Where g is the current generation, G is the maximum number of generations, and a is a constant. The parameter r2 is used to find the direction of the movement of the destination. Also, the parameter r3 provides a random weight for the Pi, and the r4 parameter. The r4 is used to alternate between the sine and cosine functions. The selected range for the SCA tuning parameters is shown in Table 1. The flowchart of the SCA Algorithm is illustrated in Figure 2.

Parameter	Population	Iterations	r2	r3	r4	a
Value	50	150-1000	[0,2π]	[0,2]	[0,1]	0.15-2

FIGURE 2. The range specified for SCA tuning parameters

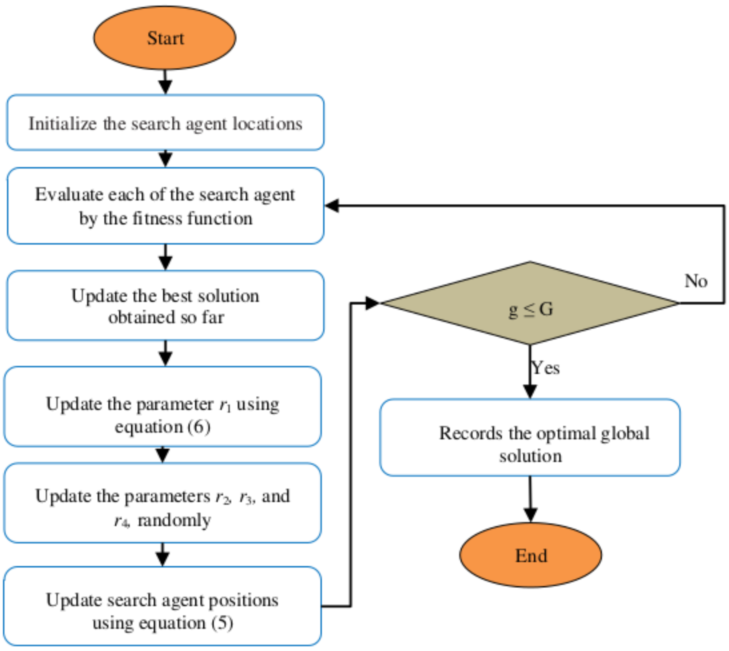


FIGURE 3. Flowchart of the SCA Algorithm

4. RESULTS AND DISCUSSIONS

In this study, three different LAA configurations are optimized with different main lobe's steering angles (N = 20 with Θ_d = 30∘, N = 26 with Θ_d =45, N = 30 with Θ_d =60∘) to show how the proposed algorithm works. All of the case studies use the suggested SCA to optimize the excitation amplitude to reduce the side lobe level in comparison to the result of the SOS [9], FA [6], Hybrid [16], and ALO [16]. In all cases, 50 population size and 1000 generations are employed.

4.1 CASE STUDY 1: 20 ELEMENTS LAA WITH Ø_D = 30○

The first case study illustrates the synthesis of the 20-element array with Θ_d = 30○ for minimize SLL. The optimal element amplitudes, first null beam width (FNBW), and peak SLL obtained from the SCA algorithm are shown in Table 2, along with conventional array, SOS [9], Hybrid [16], ALO [16], and FA [6] techniques. Figure 3 shows the array pattern produced using the SCA algorithm beside SOS and Hybrid algorithms. The convergence curve over 1000 iterations is shown in Figure 4.

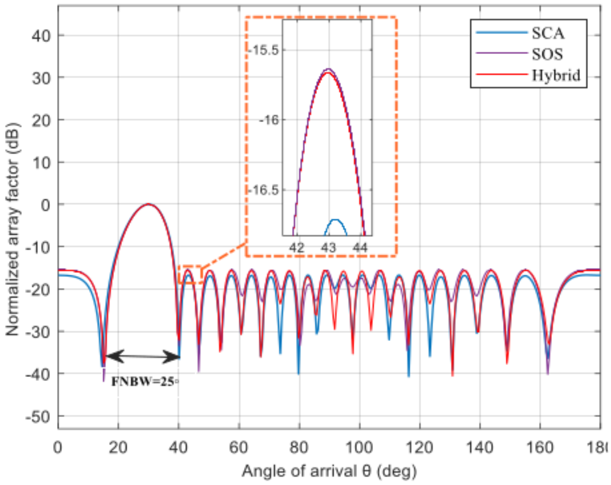


FIGURE 4. The radiation pattern obtained with Ø_d= 30○, N=20

The peak SLL of the suggested SCA algorithm has been minimized to -16.7dB by about 3.52 dB, 1.11 dB, 1.25 dB, 1.06 dB, and 1.04 dB as compared to the conventional array, FA, ALO, SOS, and Hybrid algorithms, respectively. It can be observed from Table 3 that the Standard deviation (SD) for this algorithm is lower than the SD for Hybrid, ALO, SOS, and FA, which demonstrates the accuracy and robustness of the suggested techniques.

Table 1. Optimal element amplitudes obtained with (N=20 and Ø_d= 30○) LAAs using the SCA algorithm and compared to other methods

Evolutionary algorithm	Optimized element amplitudes $I_1, I_2, \ldots, I_{20}$	Peak SLL (dB)	FNBW
SCA	1.0000, 0.2760, 0.4123, 0.2976, 0.5385, 0.4721, 0.5947, 0.6386, 0.5094, 0.6917, 0.5002, 0.7120, 0.4426, 0.5985, 0.5217, 0.4476, 0.5832, 0.3241, 0.4439, 0.8145	-16.70	25○
Hybrid [16]	0.8605, 0.3907, 0.3162, 0.4714, 0.3610, 0.4231, 0.5925, 0.5250, 0.4333, 0.3947, 0.6472, 0.6108, 0.4942, 0.4035, 0.4594, 0.4787, 0.3173, 0.4131, 0.2273, 1.0000	-15.66	25○
SOS [9]	1.0000, 0.2762, 0.4499, 0.3040, 0.3787, 0.6113, 0.5305, 0.5042, 0.5554, 0.6113, 0.4950, 0.4909, 0.5940, 0.4393, 0.3429, 0.5587, 0.4266, 0.3142, 0.4099, 0.9092	-15.64	25○
ALO [16]	1.0000, 0.4893, 0.5830, 0.4354, 0.2566, 0.8691, 0.4855, 0.8047, 0.3192, 0.6924, 0.5965, 0.8191, 0.7401, 0.4672, 0.2588, 0.7958, 0.5334, 0.2349, 0.5780, 0.9991	-15.45	25○
FA [6]	0.9804, 0.7662, 0.3690, 0.5529, 0.9071, 0.2019, 0.5196, 0.8449, 0.5094, 0.9805, 0.5142, 0.5387, 0.8027, 0.5540, 0.8808, 0.4037, 0.3321, 0.4655, 0.5034, 0.9460	-15.59	25○
Conv.	1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000, 1.0000	-13.18	25○

4.2 CASE STUDY 2: 26 ELEMENTS LAA WITH Ø_D = 45○

The second case study uses SCA to reduce the peak SLL of 26-element LAA with Θ_d = 45○. Table 4 shows the peak SLL, FNBW, and optimum element amplitudes determined using the suggested algorithm, while Table 5 shows the effectiveness of the SCA over 20 runs. The azimuth radiation pattern along with the SCA algorithm is shown in Figure 5 compared to SOS and Hybrid algorithms. The convergence curve over 1000 iterations is shown in Figure 6.

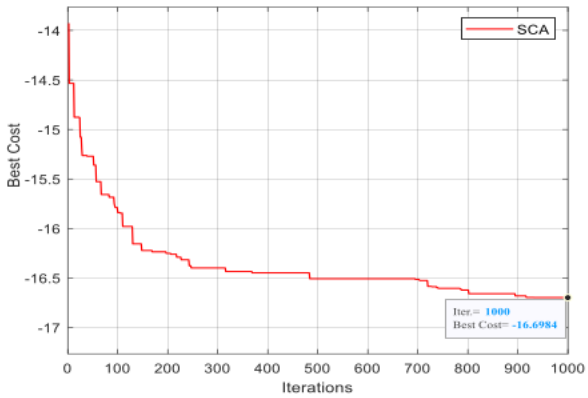


FIGURE 5. **Convergence curve for 20-element SCA-optimized LAA over 1000 iterations**

Table 2. **SCA algorithm effectiveness for (N=20 and Ø_d = 30○) over 20 runs compared to other algorithms.**

Evolutionary algorithm	Best SLL (dB)	Mean(dB)	Worst SLL (dB)	SD (dB)
SCA	-16.70	-16.63	-16.50	0.0471
ALO [16]	-15.45	-15.30	-15.14	0.0859
Hybrid [16]	-15.66	-15.56	-15.40	0.0674
SOS [9]	-15.64	-16.04	-	0.1038
FA [6]	-15.59	-15.43	-	0.1332

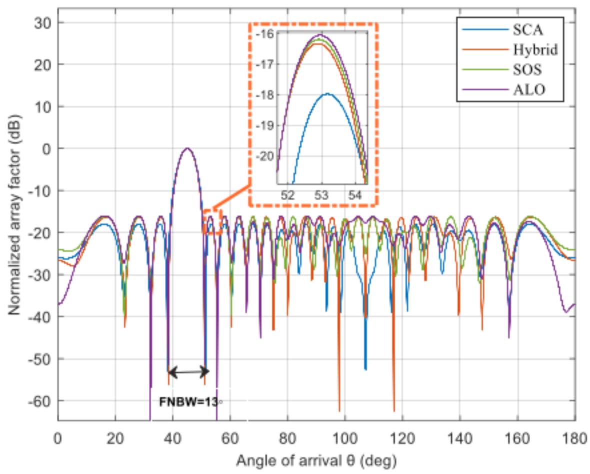


FIGURE 6. **The radiation pattern obtained with Ø_d= 45○, N=26**

According to the results in Table 4, the peak SLL achieved by SCA has been minimized from -13.18 dB to -17.96 dB as compared to the uniform array, which is 2.44 dB, 2.00 dB, 1.87 dB, and 1.73 dB less than FA, ALO, SOS, and Hybrid algorithms, respectively. It is also observed from Table 4 that the FNBW for all algorithms maintained constant.

Table 3. Optimal element amplitudes obtained with (N=26 and Ø_d = 45○) LAAs using the SCA algorithm and compared to other methods

Evolutionary algorithm	Optimized element amplitudes $I_1, I_2, \ldots, I_{26}$	Peak SLL (dB)	FNBW
SCA	1.0000, 0.4677, 0.2577, 0.5632, 0.3470, 0.3525, 0.5107, 0.6772, 0.5295, 0.6340, 0.4619, 0.6728, 0.6227, 0.5677, 0.5690, 0.8123, 0.5362, 0.4292, 0.4769, 0.5183, 0.6707, 0.2039, 0.4677, 0.3104, 0.4615, 0.6696	-18.05	13○
Hybrid [16]	0.9777, 0.3424, 0.5421, 0.0849, 0.2830, 0.5290, 0.5246, 0.4015, 0.4598, 0.5848, 0.3557, 0.5388, 0.5393, 0.5852, 0.3864, 0.6349, 0.4756, 0.5046, 0.3672, 0.4508, 0.3547, 0.3458, 0.5698, 0.2367, 0.2848, 1.0000	-16.32	13○
SOS [9]	1.0000, 0.2314, 0.4243, 0.4349, 0.3933, 0.4423, 0.4890, 0.3892, 0.5260, 0.5470, 0.3889, 0.8891, 0.4148, 0.5557, 0.4317, 0.7241, 0.4748, 0.3302, 0.7278, 0.5896, 0.2174, 0.5061, 0.1908, 0.4341, 0.6199, 0.9584	-16.18	13○
ALO [16]	0.9845, 0.9246, 0.0105, 0.6751, 0.6270, 0.0630, 0.6520, 0.5410, 0.5882, 0.7589, 0.4931, 0.6906, 0.8221, 0.4432, 0.5654, 0.6296, 0.6533, 0.5303, 0.4111, 0.7564, 0.3702, 0.7454, 0.0055, 0.7433, 0.3655, 1.0000	-16.05	13○
FA [6]	1.000, 0.7242, 0.5590, 0.4483, 0.7197, 0.3194, 0.7075, 0.6203, 0.5399, 0.8630, 0.6732, 0.7158, 0.8349, 0.7795, 0.4271, 0.7953, 0.7136, 0.6301, 0.6267, 0.6301, 0.7473, 0.0601, 0.7387, 0.5984, 0.7782, 0.9975	-15.61	13○
Conv.	1.0000, 1.0000	-13.22	13○

Table 4. SCA algorithm effectiveness for (N=26 and Ø_d = 45○) over 20 runs compared to other algorithms

Evolutionary algorithm	Best SLL (dB)	Mean(dB)	Worst SLL (dB)	SD (dB)
SCA	-18.05	-17.99	-17.93	0.0573
ALO [16]	-16.05	-15.90	-15.76	0.0943
Hybrid [16]	-16.32	-16.21	-16.11	0.0911
SOS [9]	-16.18	-15.84	-	0.0930
FA [6]	-15.61	-15.82	-	0.1184

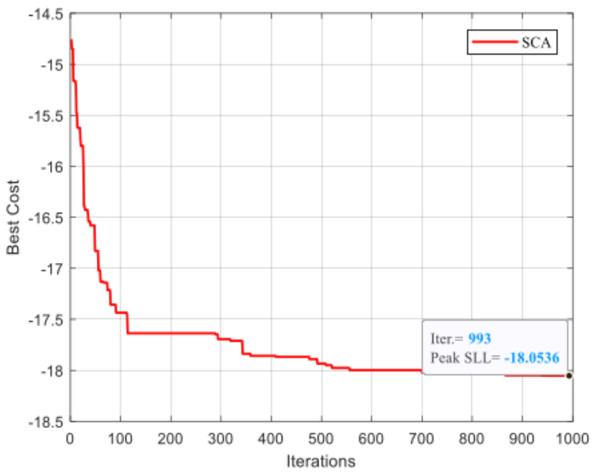


FIGURE 7. Convergence curve for 26-element SCA-optimized LAA over 1000 iterations

4.3 CASE STUDY 3: 30 ELEMENTS LAA WITH Ø_D = 60○

In this case, the optimum excitation amplitude for 30 elements and 60○ scanned LAA obtained and tabulated in Table 6, with Peak SLL and FNBW for the SCA algorithm. This table demonstrates that the SCA algorithm outperforms other methods considerably. The azimuth radiation pattern and the convergence curve along with the SCA algorithm is shown in Figure 7 and 8, respectively. While Table 7 shows the effectiveness of the SCA over 20 runs.

Table 5. Optimal element amplitudes obtained with (N=30 and Ø_d = 60○) LAAs using SCA algorithm and compared to other methods

Evolutionaryalgorithm	Optimized element amplitudes $I_1, I_2, \ldots, I_{30}$	Peak SLL (dB)	FNBW
SCA	0.9897, 0.4624, 0.1580, 0.3478, 0.3486, 0.2591, 0.5198, 0.5018, 0.4885, 0.5101, 0.6641, 0.5252, 0.5595, 0.5786, 0.6234, 0.5115, 0.5406, 0.6200, 0.5150, 0.3568, 0.6000, 0.5028, 0.2902, 0.5674, 0.4192, 0.5451, 0.1918, 0.4242, 0.3971, 0.7614	-18.14	9○
Hybrid [16]	0.7668, 0.3184, 0.2907, 0.3373, 0.2029, 0.3096, 0.2510, 0.4666, 0.3332, 0.2843, 0.2275, 0.5557, 0.4165, 0.4146, 0.3572, 0.4841, 0.4154, 0.2713, 0.2931, 0.4726, 0.5228, 0.2981, 0.2830, 0.3537, 0.3229, 0.2353, 0.3448, 0.1407, 0.2381, 1.0000	-16.20	8.96○
SOS [9]	1.0000, 0.9219, 0.4011, 0.1512, 0.6258, 0.0149, 0.7433, 0.5357, 0.4412, 0.8182, 0.3055, 0.5388, 0.8813, 0.5962, 0.4734, 0.8110, 0.3965, 0.6665, 0.3149, 0.7865, 0.6591, 0.4047, 0.3755, 0.5224, 0.5257, 0.5935, 0.2734, 0.3698, 0.6766, 0.9982	-15.93	9○
ALO [16]	0.9380, 0.5472, 0.4980, 0.4647, 0.4777, 0.0382, 0.4824, 0.7979, 0.3462, 0.4455, 0.6926, 0.3170, 0.6597, 0.6022, 0.7500, 0.1379, 0.8532, 0.5132, 0.7009, 0.1911, 0.7336, 0.7231, 0.0303, 0.6409, 0.5290, 0.3575, 0.3012, 0.2129, 0.7843, 1.0000	-15.94	9○
FA [6]	0.9957, 0.6844, 0.6299, 0.0499, 0.1793, 0.7345, 0.4852, 0.6181, 0.3336, 0.6318, 0.6364, 0.3934, 0.4918, 0.7724, 0.6454, 0.4840, 0.7396, 0.7441, 0.5279, 0.4501, 0.8221, 0.5290, 0.4582, 0.4190, 0.4868, 0.2416, 0.8668, 0.6361, 0.2969, 0.9993	15.97	9.08○
Conv.	1.0000, 1.0000	-13.21	8.52○

Table 6. SCA algorithm effectiveness for (N=30 and Ø_d = 60○) over 20 runs compared to other algorithms

Evolutionary algorithm	Best SLL (dB)	Mean(dB)	Worst SLL (dB)	SD (dB)
SCA	-18.14	-18.01	-17.93	0.0341
ALO [16]	-15.94	-15.80	-15.66	0.0865
Hybrid [16]	-16.19	-16.06	-15.96	0.0501
SOS [9]	-15.45	-15.93	-	0.0470
FA [6]	-15.38	-15.97	-	0.0686

5. EFFECT OF VARIATION PARAMETER "A" FOR SCA

While keeping all other parameters fixed, the value of "a" is changed to 0.15, 0.5, and 2. Table 8 shows the fitness values for a variant of "a". For all design case stud-ies, the best average outcomes are obtained with "a" set to 0.15. The box-and-whisker plot of 20, 26, and 30 elements LAA in 20 independent runs are shown in Figures 9, 10, and 11, respectively.

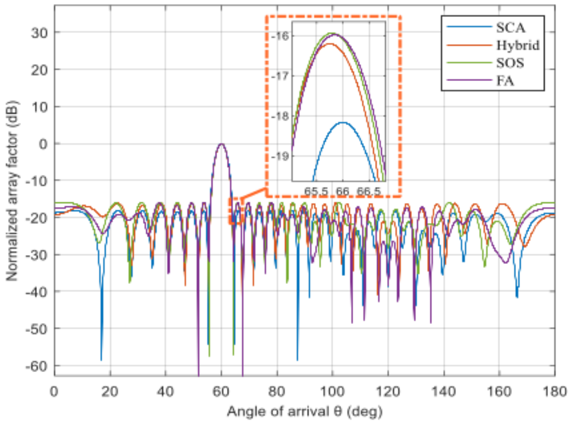


FIGURE 8. **The radiation pattern obtained with Ø_d= 60○, N=30**

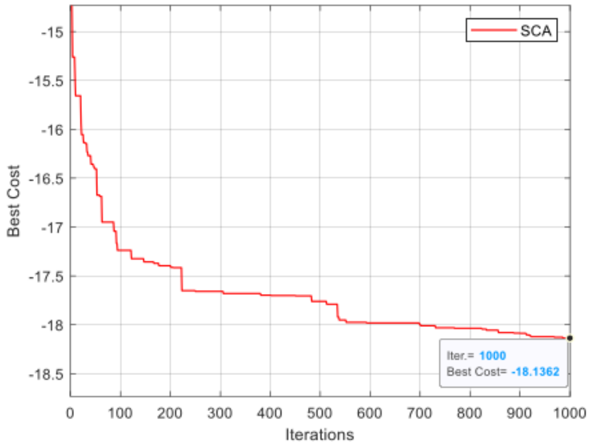


FIGURE 9. **Convergence curve for 30-element SCA-optimized LAA over 1000 iterations**

Table 7. **The optimal fitness function value, as determined by the SCA technique, for the design examples in Section 4 in response to a change in parameter "a"**

Fitness value for 20 elements in dB for (Case study 1)			
a	0.15	0.5	2
Worst	-16.5012	-16.5585	-16.4041
Best	**-16.7023**	-16.6235	-16.5450
Average	-16.6345	-16.5818	-16.4949
Fitness value for 26 elements in dB for (Case study 2)			
a	0.15	0.5	2
Worst	-17.9342	-17.8570	-17.7011
Best	**-18.0550**	-17.9078	-17.7946
Average	-17.9973	-17.8776	-17.7456
Fitness value for 30 elements in dB for (Case study 3)			
a	0.15	0.5	2
Worst	-17.9296	-17.8685	-17.6778
Best	**-18.1399**	-17.9552	-17.7440
Average	-18.0090	-17.9259	-17.7074

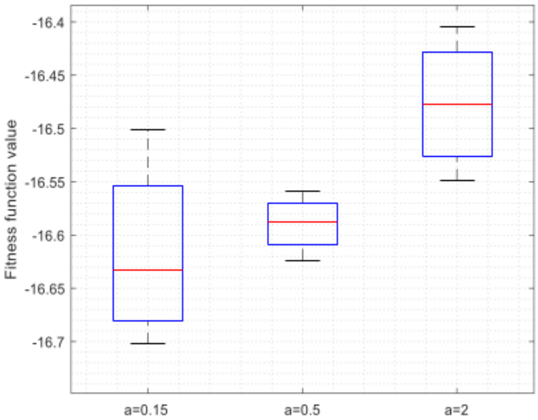
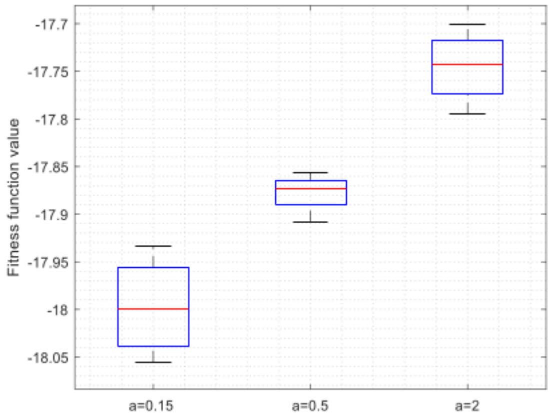


FIGURE 10. **Box-and-whisker plot of Ø_d= 30○, N=20 in 20 runs**



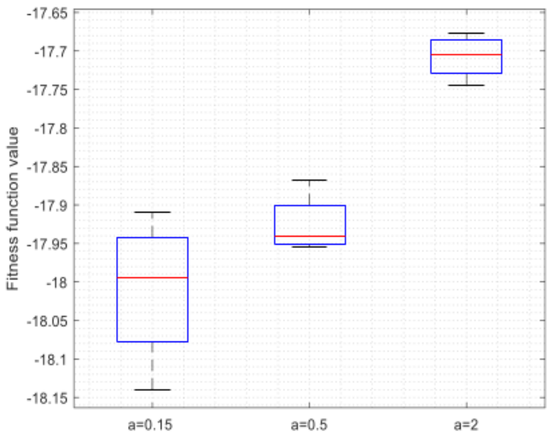


FIGURE 11. **Box-and-whisker plot of Ø_d= 45○, N=26 in 20 runs**

6. CONCLUSION

The above study demonstrates that the widths of the main lobes are inversely proportional to the array length. Moreover, minimized SLL comes at the trade-off of wide FNBW. The SCA algorithm is employed to solve this multi-objective problem, minimizing the side lobe level while maintaining the FNBW constant. In this study, three different LAA configurations are optimized with different main lobe's steering angles (N = 20 with Ø_d = 30∘, N = 26 with Ø_d =45, N = 30 with Ø_d =60∘) in order to show the effectiveness of the suggested algorithm. The excitation amplitude is optimized in each and every case study using the SCA algorithm. The findings demonstrate that the suggested SCA algorithm is very competitive in minimizing the SLL for all case studies compared to other techniques like SOS, FA, ALO, and hybrid optimization algorithms based on GOA and ALO.

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CONFLICTS OF INTEREST

The author declares no conflict of interest.

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