International Journal of Electronics and Telecommunication Systems
Volume1, Issue 04 2025

A Comparative Analysis of Evolutionary Algorithms for Synthesis of Scanned Linear Array of Mutually Coupled Parallel Dipole Antennas

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Research Article

Date of Submission: 20-11-2025 **Date of Acceptance: 22-12-2025** **Date of Publication: 23-01-2026**

Abstract—In order to synthesize a scanned linear array of evenly spaced parallel half wavelength dipole antennas, this work compares three evolutionary algorithms: the Backtracking Search Algorithm, the Cuckoo Search Algorithm, and the Artificial Bee Colony Algorithms. In this case, the broad null depth, reflection coefficient, and side lobe level of the antenna are taken into account for algorithm comparison. Additionally, statistical metrics are compared, including the mean, standard deviation, and greatest fitness value of the fitness values derived from algorithms. In order to produce radiation patterns, the mutual coupling between the antenna components is taken into account. The induced Electro-Motive Force technique is used to compute both the mutual and self-impedances. This study presents two distinct cases to verify the efficacy of the used method. This method may be used for different array geometries even though it is applied to a linear array of dipole antennas.

Keywords—Inverse rapid Fourier transform, evolutionary algorithms, antenna arrays, comparative analysis, and scanning

INTRODUCTION

Antenna arrays are widely used in both commercial and military applications due to their benefits [1], which include guiding the primary beam and creating excellent directivity. The linear antenna array, which generates a sufficiently narrow beam and a broad null depth at the necessary angles, is one of the most often used antenna array shapes. The literature has covered a number of antenna array synthesis methods that address different design characteristics, such as null placements [2–8].

In addition to the aforementioned benefits, the antenna array's null steering [2–5] characteristic is used in several applications to reduce signal-to-noise ratio deterioration due to interference in radar and other communication systems. Priority is given to null placements in the discussion of adaptive nulling utilizing just phase with a genetic algorithm [2], different null control techniques [3], and their effects on antenna design. The significance of null placement in radiation patterns is further shown by null synthesis by phase control for antenna arrays [4] and pattern nulling via perturbation of phases [5]. Since mutual coupling is crucial to the deterioration of radiation patterns, antenna array synthesis techniques have focused on including this

Particle Swarm Optimization (PSO) vs Genetic Algorithms (GA) for phased array synthesis [7], Mutual Coupling in Phased Arrays [8], and design of phase-differentiated reconfigurable array antennas with a minimal value of the dynamic range ratio [6] are examples of coupling in several dimensions.

The authors of this study have taken into consideration the incorporation of nulls in certain directions throughout the radiation pattern creation process. Each element in a phased array is supplied coherently at a constant scan angle, and the phase shifters in each element assist in scanning the beam in the necessary directions. The input impedance of an array member differs from its impedance value when the same element is detached due to mutual coupling effects. Furthermore, the array's scan angle affects this variation in impedance values. Unwanted radiation patterns are produced by these impedance discrepancies. This leads to significant phase errors that reduce the angle of arrival estimates for direction finding in small arrays, and it also impacts the side lobe level (SLL) for larger arrays. It is a challenging challenge to guide the array radiation pattern while including mutual coupling. Antenna array synthesis in the presence of mutual coupling has been documented in the literature review [9–13].

A brief examination of the arrays' synthesis reveals the support that evolutionary methods generated in them. By creating the existing distributions, these evolutionary algorithms have been instrumental in producing the intended radiation patterns. Below are quotes from a few of the algorithms. P. Civicioglu [14–15] has effectively used the Backtracking Search method (BSA), a novel population-based evolutionary method, to numerical optimization issues. The technique of looking for cuckoo birds to deposit their eggs in a suitable host bird nest is the basis of the Cuckoo Search algorithm (CS), which has been explored in [16–19]. The Artificial Bee Colony (ABC) method has been published in [20–22]. It is based on a unique intelligent handling with honeybee swarms. These methods were selected for this article because they have previously been successful in solving several optimization issues.

Moreover, array patterns have been effectively synthesized using the Inverse Fast Fourier Transform (IFFT) connection between the array factor and element excitations to expedite the synthesis process [23–25]. [23] describes the combination of GA with Fast Fourier transform (FFT) for array synthesis. Faslow SLL synthesis for larger sized planar array antennas employing successive FFTs of Array Factor [24], low side lobe pattern synthesis employing iterative Fourier techniques are detailed in [25].The element pattern of the dipole antenna is given by the equation below:

$$\frac{\pi}{2}\cos(-u)$$

In this paper, the aim is to obtain the optimum set of current amplitude distribution using the algorithms (BSA, CS and $EP(u) = \frac{}{\sqrt{1-u^2}}$ (2)

ABC) that will satisfy the goal. In addition to it, the performance of these algorithms based on the antenna and when the dipole antenna axis is along *x*-axis then *u* is given by:

radiation pattern parameters as well as the statistical parameters are compared. Self-impedances and mutual

$$u = \sin\theta\cos\phi \quad (3)$$

impedances are calculated by induced Electro-Motive Force (EMF) method. Mutual coupling matrix is first calculated and then stored in a mat file. To calculate the voltage distribution across each antenna, the program calls this mat file at every iteration and multiplies it with current excitation distribution along with a constant scan angle. This method along with calculation of array factor by means of IFFT reduces the computational time to a great extent. In addition to the above, effort is taken to make sure that there exists a better level of matching between the antenna and the corresponding feed network is available by minimizing maximum reflection coefficient to a value nearby to the specified.

I. APPROACH

A linear antenna array constructed of parallel half-wavelength thin dipole antennas with uniform spacing *d* between the elements is considered along the *y*-axis. Elements are placed side-by-side as shown in Fig. 1. Using pattern multiplication, the free space far-field pattern of an array constructed of similar elements is the product of the element pattern and the pattern of an array of isotropic point sources. This linear organized array of dipoles is located in free space. The implications of ground plane are not taken into Here, the element pattern of horizontal half wavelength

dipole antenna is assumed omnidirectional in *y*-*z* plane ($\phi = 90^0$ plane), i.e. $EP(u) = 1$.

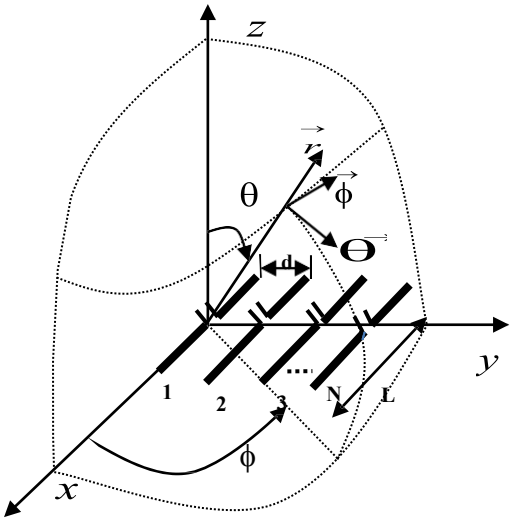


Fig.1. Figure of linear array of x-directed parallel half-wave length center - fed dipole antennas along y-axis.

The voltage across the *n*-th dipole [1, 13] is given by:

consideration.

The free space far-field pattern

$FP(u)$ in vertical plane (*y*- $V_n = Z_{nn}I_n + \sum Z_{nm}I_m$

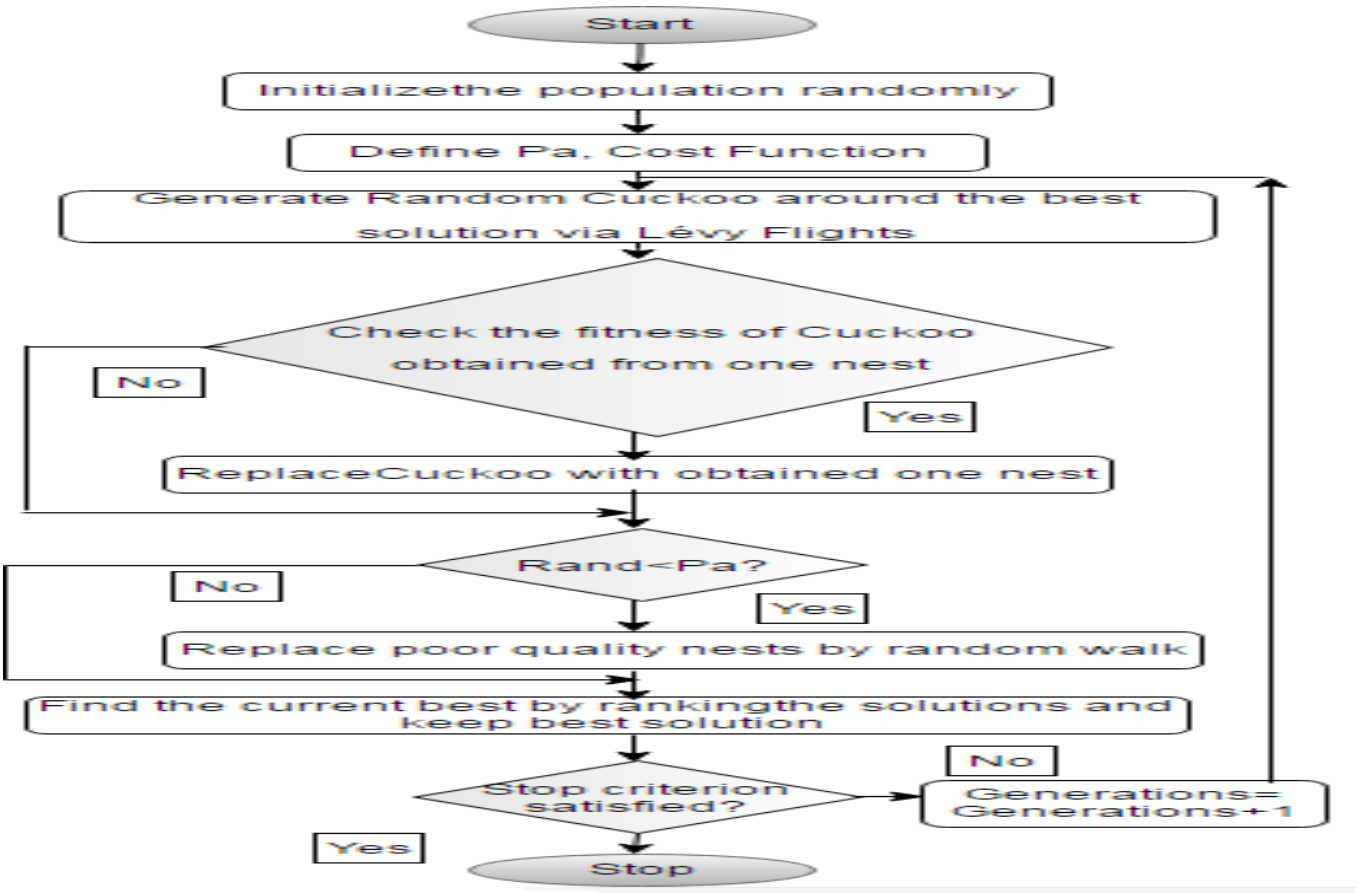
where Z_{nn} is the self-impedance of dipole n and Z_{nm} is the mutual impedance between dipoles n and m. The active scan where n refers to the element number, j is the imaginary quantity, d is the inter element spacing which is taken as 0.5λ, $k=2\pi/\lambda$ is the wave number, λ *is the* wavelength, $u=sin\theta$, θ In the end, the maximum active scan impedance $\left(Z^{A}\right.$ $_{n,\max}$ calculated among all elements.

being the polar angle of far-field measured from *z*-axis (-90° to +90°), $u_n = -(n-1)kdu_0$ = progressive phase, $u_0 = \sin\theta_0$ is the scan angle, I_n is the amplitude (current) of the n-th element, N is the total number of elements, $AF(u)$ is the array factor and $EP(u)$ is the element pattern of each *x*-directed horizontal half-wave length dipole antenna.The voltage reflection coefficient is a parameter that describes the effect of impedance discontinuity or mismatch in the network. It is the ratio of the reflected voltage to that of the forward voltage. Assuming that the characteristic impedance (Z_o) of the network that feeds is equal to 50 ohms, the maximum reflection coefficient (RC_{max}) at the input of n-th dipole antenna [1] is given by

$$RC_{\max} = \left| \frac{Z_n^A\big|_{\max} - Z_o}{Z_n^A\big|_{\max} + Z_o} \right|$$

II. Overview of BSA, CS and ABC

BSA proposed by P. Civicioglu [14-15], is an evolutionary algorithm which for generating a trial population uses a strategy that contains two new operators' crossover and mutation. The strategy for controlling the amplitude of the search-direction matrix and search-space boundaries increases honey bee foraging behavior as proposed in [20-22] has parameters, namely, colony size NP (employed bees+ onlooker bees) and the number of food source (FS). In our case, FS is set as half of the colony size (NP/2). A food source is considered as a potential solution for the problem case that needs to be optimized. Another control parameter is "limit". A food source is deemed to be discarded by the employed bee if its solution for the problem does not find any improvement within the set limits and this ends up in the employed bee allied with that corresponding food source becoming a scout. Flow charts of all the evolutionary algorithms are shown in Fig.2 to Fig.4. Details of the above three algorithms are available in the articles [14-22].



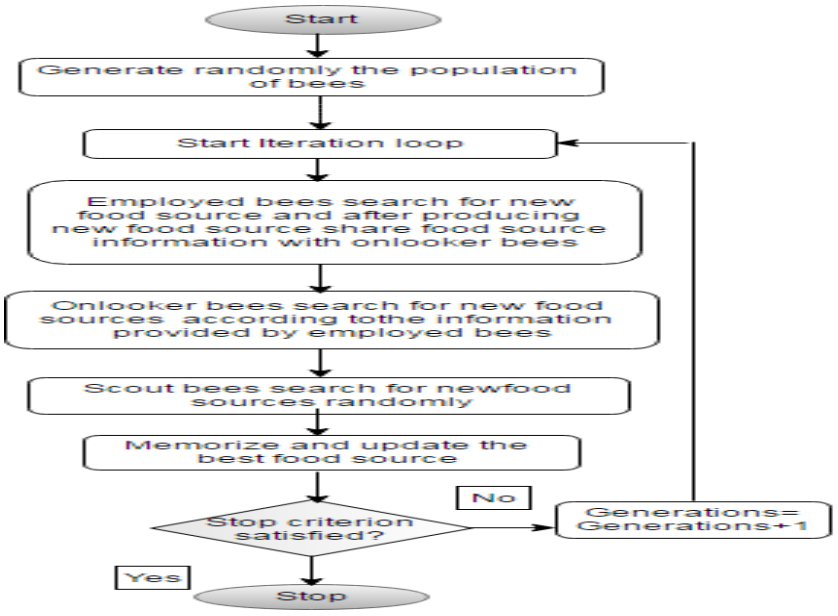


Fig. 3. Flow chart of CS algorithm.

SIMULATED RESULTS

Linear array of 26 and 100 parallel half-wave length antennas which are center-fed and uniformly spaced with an interval of 0.5λ are considered along the y-axis in order to generate scanned far-field patterns in vertical plane (y-z plane). The excitation current amplitude distributions that are obtained using the algorithms is asymmetric. Each dipole's diameter is set to be 0.006λ and the current distribution on each of the antenna array elements is assumed to be a sinusoidal one. The length-to-width ratio is 83.33, which likely resembles a very thin sized dipole. Across each dipole in an array, because of mutual coupling effects, the active impedance varies with the beam scan angle. A 4096-point IFFT is used to speed up the process in these simulations.

The details of tuning parameters of all the evolutionary algorithms used in the problem are shown in the Table I For the purpose of comparison, the value of k_1, k_2 and k_3 or each of the optimization algorithms are chosen to get the best possible desired results from same fitness function. All the internal parameters are tuned by linear variation in between their minimum and maximum values or by trial and error method and then assigned a suitable value to the parameters for obtaining the scanned far-field pattern including the effects of mutual coupling with desired values.For example 1: For the comparison performance of the used algorithms in terms of different antenna parameters as well as statistical parameters and for generation of power pattern, all the algorithms are run 20 times with 2000 iterations each and with a population size of 60. One best scoring individual is generated after every run and a global best individual is considered as the best one out of such twenty best scoring individuals. A set of 26 current amplitude values is obtained by all the optimization techniques. Mean as well as the standard deviation of twenty best fitness values are calculated.

Simulations are done using Matlab software. The processing time that is involved in these simulations is measured with a PC with Intel core2 duo processor of clock frequency 2.93 GHz and 4 GB of RAM. Table II shows the obtained results using BSA, CS and ABC algorithms. Fig.5 shows the normalized current amplitude distribution. Fig.6 shows the normalized power pattern in dB scanned at u=0.3 using BSA, CS and ABC. Fig.7 shows global best fitness value versus iterations.

For example 2: the procedure that is followed in the above example 1 is utilized here except that the algorithms are run 100 times each with 1500 iterations and with a population size of 30. A set of 100 excitation current amplitude values is obtained by all the optimization techniques. Mean as well as the standard deviation of hundred best fitness values are then calculated.

Simulations are done using Matlab software. The computational time is measured with a PC with Intel(R) Core(TM) i5-4690 processor of clock frequency 3.50 GHz and 4 GB of RAM. Table III shows the obtained results using BSA, CS and ABC algorithms. Fig.8 shows the normalized current amplitude distribution. Fig. 9 shows the normalized power pattern in dB scanned at u=0.45. Fig.10 shows global best fitness value versus iterations.

TABLE I
TUNING PARAMETERS OF ALL THE EVOLUTIONARY ALGORITHMS

Example	**Example1 (26 element)**			**Example2 (100 element)**		
Parameters	**BSA**	**CS**	**ABC**	**BSA**	**CS**	**ABC**
Population size	60	60	60	30	30	30
Iteration	2000	2000	2000	1500	1500	1500
Run number	20	20	20	100	100	100
K_1, K_2, K_3	22,1,8	22,1,8	22,1,8	25,1,10	25,1,10	25,1,10
Dim_Rate	1	—	—	1	—	—
Scale factor	3*randn	—	—	3*randn	—	—
P_a	—	0.25	—	—	0.25	—
Food number	—	—	30	—	—	15

TABLE II
COMPARATIVE OBTAINED RESULTS BY BSA, CS AND ABC FOR EXAMPLE 1

Design Parameters	**Desired Value**	**BSA**	**CS**	**ABC**	**Winner**
Global Best Fitness Value	–	0	0	5.2656	BSA & CS
Standard Deviation	–	6.5037	3.9868	34.2951	CS
Mean	–	5.2497	5.5859	77.3225	BSA

Maximum Active Scan Impedance (Ohm)	–	78.29+ 26.23i	90.02+ 23.67i	85.92+ 10.54i	BSA
Side Lobe Level (dB)	-25	-25.09	-25.01	-24.53	BSA
Maximum Reflection Coefficient	0.33	0.2457	0.3011	0.2678	BSA
Maximum Wide Null Depth in dB (u=0.6606 to 0.8071)	-55	-55.07	-55.28	-54.26	CS
Computation Time (Seconds)	–	8122.55	18973. 83	8447.01	BSA

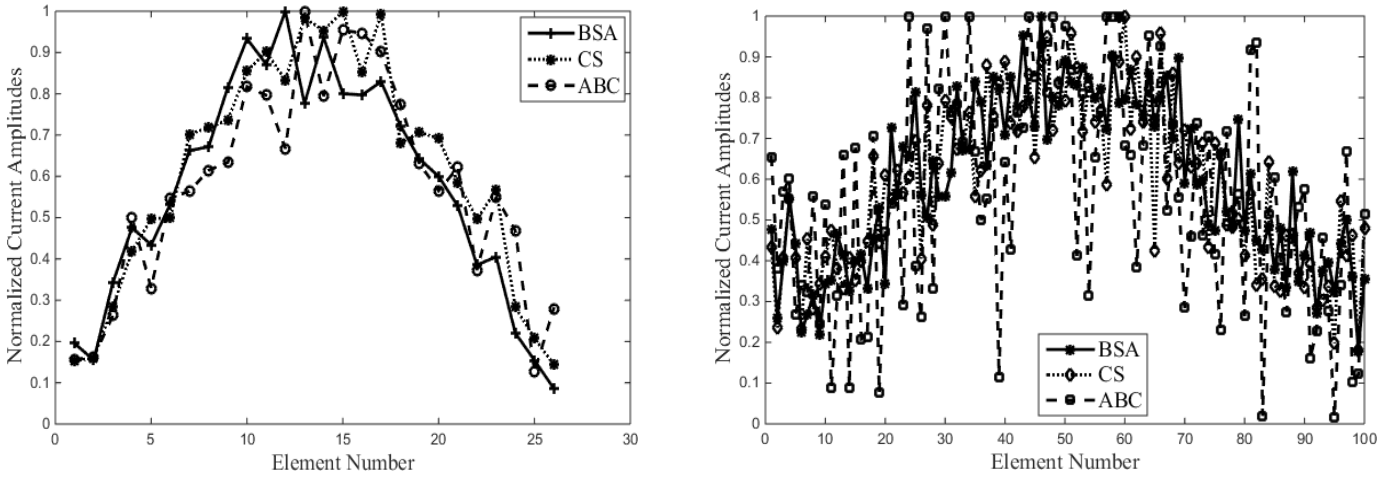


Fig. 5. Normalized current amplitude distribution versus element number for example 1.

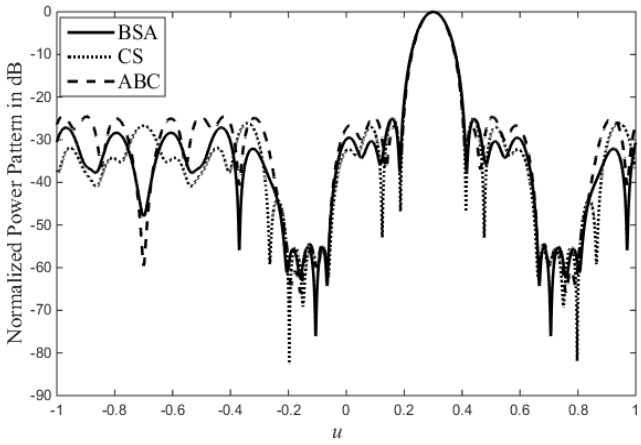


Fig. 6. Normalized power pattern in dB for a linear array of parallel half-wave length dipole antennas scanned at u=0.3 using BSA, CS and ABC with maximum wide null depth of -55dB from u=0.6606 to 0.8071.

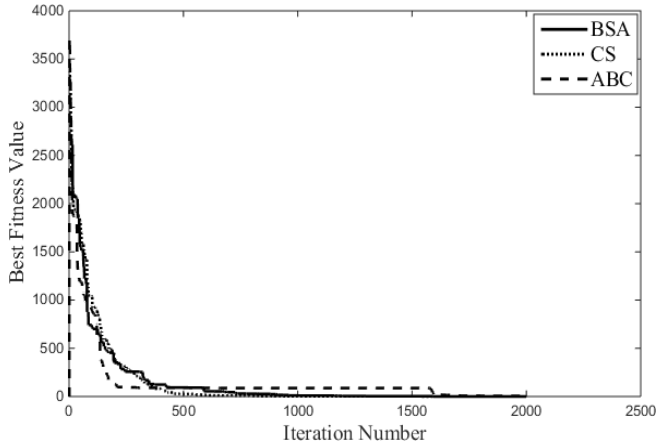


Fig. 7. Global best fitness value versus iteration number obtained by BSA, CS and ABC for generation of power pattern for example 1.
Fig. 8. Normalized current amplitude distribution versus element number for example 2.

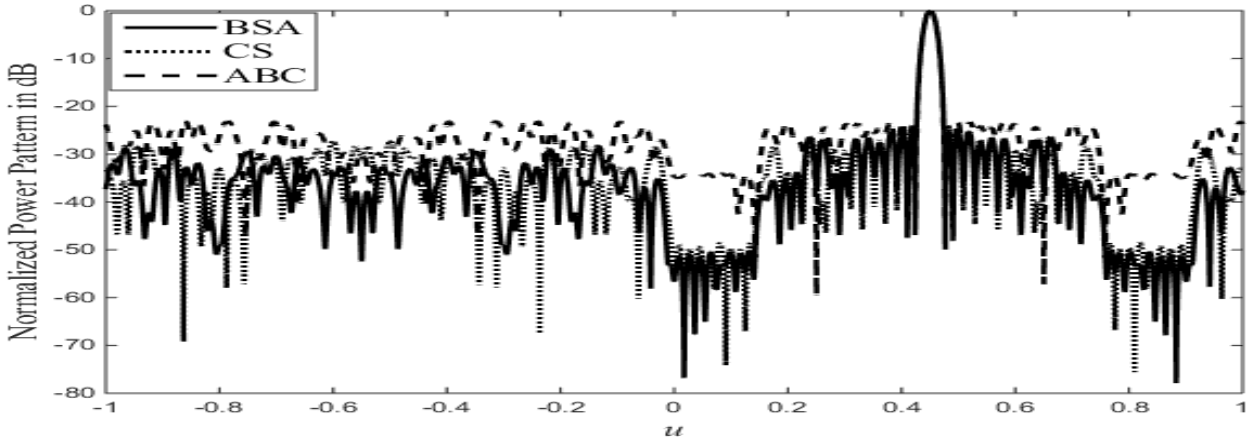


Fig. 9. Normalized power pattern in dB for a linear array of parallel half-wave length dipole antennas scanned at u=0.45 using BSA, CS and ABC with maximum wide null depth of -50dB from u=0.7582 to 0.9048.

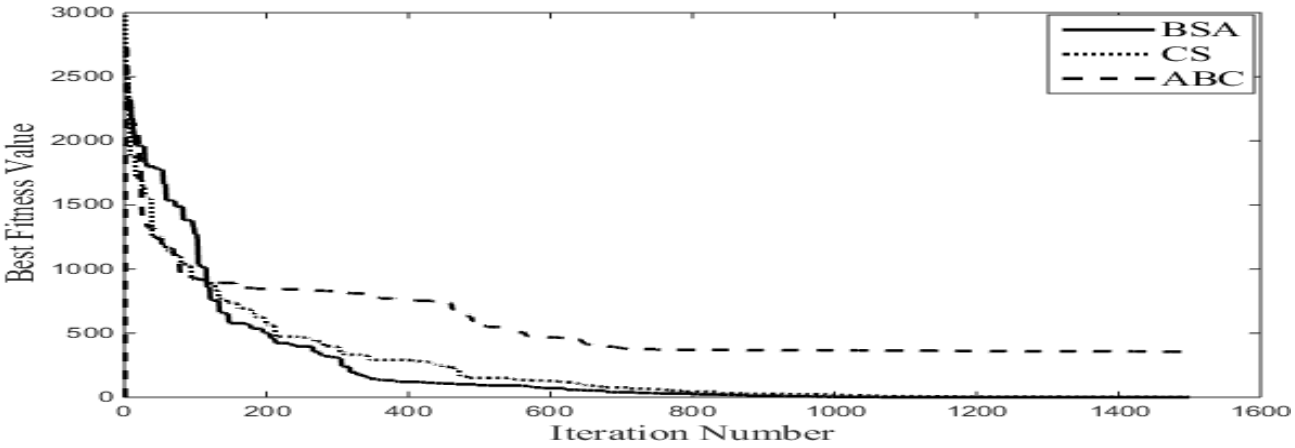


Fig. 10. Global best fitness value versus iteration number obtained by BSA, CS and ABC for generation of power pattern for example 2.

III. CONCLUSIONS

In this work, several evolutionary algorithms were compared in terms of statistical and antenna radiation pattern factors. The methods were evaluated by synthesizing the radiation pattern of a scanned linear array of parallel half-wavelength dipole antennas with a broad null depth in the designated direction, fixed SLL, and maximum reflection coefficient. All of the methods are suitable for power pattern synthesis in the presence of mutual coupling, as shown by the findings of example 1 (lower element). Antenna characteristics like SLL, maximum wide null depth, and maximum reflection coefficient showed extremely near matches between the intended and achieved values. When it came to lowering the peak SLL, BSA and CS performed somewhat better than ABC. Compared to others, CS provided a higher reflection coefficient. ABC was marginally inferior to BSA and CS in terms of maximum broad null depth placement. When it came to statistical parameters, all of the algorithms' performances roughly matched one another. In terms of mean, standard deviation, and global best fitness value, BSA and CS outperformed ABC. The findings obtained from example 2 (upper element) indicate that BSA and CS are more suitable than ABC for the synthesis of power patterns in the presence of mutual coupling. Compared to CS and ABC, BSA yields better results for all antenna characteristics as well as statistical metrics. While BSA is somewhat quicker than ABC, CS's processing time was longer than both. For every array element, the impedance matching criterion was substantially met when the maximum reflection coefficient was low. Overall, it was discovered from the outcomes of both cases that BSA was better than other methods for creating scanning far-field patterns with mutual coupling.

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