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Phase-only Synthesis of Linear Microstrip Patch Antenna Array using Improved Local Search Particle Swarm Optimization

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Abstract

Antenna arrays have been used for various applications in wireless communications, Radar, satellite communications and mobile communications. Low sidelobe antenna arrays are need to be designed for increasing the efficiency of the communication systems. In this paper, an enhanced version of particle swarm optimization (PSO) known as improved local search particle swarm optimization (ILSPSO) is proposed to synthesis of phased antenna arrays. ILSPSO is a modified version of particle swarm optimization (PSO), in which Gaussian distribution is used to enhance the local search of the PSO. ILSPSO is applied to optimize the phase excitations of the individual elements to suppress the side lobe levels of a linear micro strip rectangular patch antenna array (MSRPA). A 20 and 32 element antenna array have been considered to demonstrate the effectiveness of the proposed method. The optimized micro strip antenna is simulated using high frequency structure simulator (HFSS). The synthesis results demonstrate that the ILSPSO outperforms PSO and DE in terms of producing lower PSLL and convergence rate. The flexibility and ease of implementation of the ILSPSO algorithm is obvious from this paper, showing the algorithms usefulness in other array synthesis problems.

Keywords: Phased Antenna array, Peak side lobe level, Particle swarm optimization, Differential Evolution, Gaussian distribution, Micro strip rectangular patch antenna, HFSS.

INTRODUCTION

Low side lobe and high directive antenna array systems are need to be designed for enhancing the effectiveness of the communication systems [1, 2]. These have been used for different applications in satellite communication, Radars, wireless communications, mobile communications systems respectively. Systems need to maintain low side lobe levels for interference less communications systems. Side lobe levels are the major concern in design of highly efficient antenna array systems. In transmission mode, energy wasted through the side lobe levels in unwanted directions where as in reception mode unwanted signals are entered into our own communication system through the side lobe levels. So it is required to develop antenna arrays with low side lobes for better communication.

The radiation pattern of the antenna array is depends on the amplitude & phase excitation of the antenna elements, positions of the antenna elements and the radiation pattern of the individual antenna element. So, controlling the side lobe levels of the radiation pattern can be achieved by optimizing the position between the elements, amplitude and phase weights of the antenna elements. Design of aperiodic antenna arrays is more complex in practical. So in this work, the author focuses on more phased only synthesis.

Phased antenna array synthesis has been studied over the last few decades. Several evolutionary algorithms such as genetic algorithm (GA) [3-10], simulated annealing [11], particle swarm optimization (PSO) [12-14], ant colony optimization (ACO) [15-16], Invasive weed optimization (IWO) [17-18], cat swarm optimization (CSO) [19-20] and differential evolution (DE) [21, 22] and etc. have been successfully applied to antenna array synthesis problems. GA and PSO have been extensively used for antenna array problems. But PSO has its own disadvantages. It has been trapped in local optima while solving complex multimodal problems.

In order to overcome the above mentioned problems, a novel improved local search particle swarm optimization algorithm (ILSPSO) is proposed in this paper to solve antenna array synthesis problems. The Gaussian distribution [24] is adopted to enhance the local convergence. In this paper micro strip rectangular patch antenna is used as the antenna element. The micro strip rectangular patch antenna is simulated using HFSS. The simulation results for the return loss and gain are recorded.

In this work, the proposed ILSPSO along with PSO and DE have been applied to optimize the phase excitations of the individual elements of linear MSRPA array to minimize the peak sidelobe level. The paper is organized as follows. The detail description of the ILSPSO algorithm is discussed in Section 2. In Section 3, brief description of the micro strip rectangular patch antenna with HFSS simulated results are discussed. The linear antenna array factor and the problem formulation are discussed in Section 4. Numerical illustrations are illustrated in Section 5. Finally the conclusions are discussed in Section 6.

PARTICLE SWARM OPTIMIZATION (PSO)

The Particle swarm optimization (PSO) [23], a simple and robust stochastic evolutionary algorithm. It has been applied for solving various optimization problems in electromagnetic applications since last 10 years. It has been developed by Eberhart and Kennedy in 1995 who obtained motivation from the migration and aggregation of bird flock when they seek for food. PSO is simple to understand and implement compared to other stochastic algorithms. PSO algorithm explores the search path according to the velocity and current position of particle which changes according to its own best position and other particles best position. PSO have been shown superior performance over traditional DE and genetic algorithm (GA) in many applications in terms of convergence time, memory occupation and has less parameters to adjust.

A swarm of particles P is randomly initialized in a pre-defined search space. Initialize the velocities for each particle. Each row of the position matrix swarm represents a possible solution. In each generation, each particle is updated by the velocity of that particle. The velocity of the particle is changed according to the two best values known as personal best position (P_{best}) and global best position (G_{best}).The personal best position of the i^{th} particle is represented as $P_{besti} = (P_{besti1}, P_{besti2}, \dots \dots P_{bestiD})$, the global best position vector defines the position in the solution space at which the best fitness value was achieved by all particles, and is defined as $G_{besti} = (G_{besti1}, G_{besti2}, \dots \dots G_{bestiD})$

The particle velocity and position are updated by the following equations [23]

$$V_t = \omega V_{t-1} + c_1 r_1 (P_{t-1} - X_{t-1}) + c_2 r_2 (G_{t-1} - X_{t-1}) \quad (1)$$

$$X_t = X_{t-1} + V_t \quad (2)$$

Where ω is a inertial weight (0.9), r_1 and r_2 are the random numbers in the interval 0 and 1. The parameters c_1 and $c_2$specifies the relative weight of the pbest versus and gbest and both the values are chosen as 2.

Improved local search particle swarm optimization (ILSPSO)

The main disadvantage of the PSO is that it traps in local optima while solving complex multimodal problems because of poor local search capabilities. To enhance the local search capabilities Gaussian distribution with mean zero and standard distribution of 1 is adopted while updating the G_{best}. The mechanism is that, after updating the G_{best} in PSO, 'M' number of particles are generated around the G_{best} using the Gaussian distribution to enhance the local search capabilities. Update the new G_{best} after producing 'M' number of particles around the G_{best}[27].

$$New\ G_{best} = G_{best} + Gaussian\ Distribution(0,1) \quad (3)$$

The flow chart of ILSPSO is shown in Fig. 1.

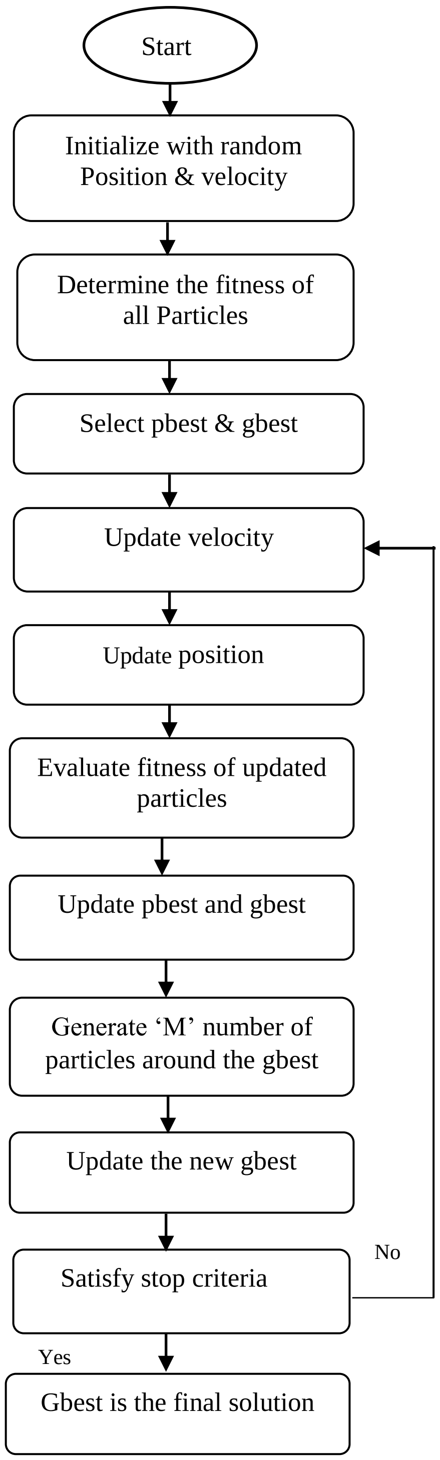

Figure 1. Flow chart of the ILSPSO.

MICRO STRIP RECTANGULAR PATCH ANTENNA (MSRPA)

Microstrip antennas [2,25] are also called patch antennas as they are manufactured by photoetching the radiating elements on the dielectric substrate. The radiating element may be a rectangular, circular, or any other configuration. A rectangular patch antenna is a commonly used Microstrip antenna because of many reasons like compact size, low weight and can be easily printed on printed circuit board as a result the array made of these elements would be occupying less space compared to the 3-D antennas like dipole, horn antenna etc. A rectangular patch antenna consists of a patch on one side and the ground plane on the other side of the dielectric substrate with the ground plane having the same dimensions of that of the substrate. In the design of rectangular patch antenna we have employed the substrate Rogers RT/Duroid 5880 with relative permittivity (ε_r) 2.2 and thickness (**T**) 1.588 mm with the type of feed being Co-axial, matching the 50 ohm impedance. The Schematic diagram of a coaxial probe fed rectangular Microstrip patch antenna is shown in Fig. 2. The antenna is designed at 2.4GHz. The design equations of the rectangular micro strip patch antenna is given below.

Free Space Wavelength:

$$\lambda_0 = \frac{C_0}{f_0} \tag{4}$$

where 'C_0' represents velocity of light in vacuum and 'f_0' represents the resonant frequency

Width of the patch:

$$W_p = \frac{C_0}{2f_0}\sqrt{\frac{2}{(1+\varepsilon_r)}} \tag{5}$$

Effective Dielectric constant :

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{T}{W_p}\right]^{\frac{-1}{2}} \tag{6}$$

Extra Length of the Patch due to fringing:

$$\Delta L_p = 0.412h\frac{(\varepsilon_{eff}+0.3)\left(\frac{W_p}{T}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W_p}{T}+0.8\right)} \tag{7}$$

Length of the Patch:

$$L_p = \frac{C_0}{2f_0\sqrt{\varepsilon_{eff}}} - 2\Delta L_p \tag{8}$$

Impedance of the Patch:

$$Z_p = 90\frac{{\varepsilon_r}^2}{\varepsilon_r-1}\left(\frac{L_p}{W_p}\right)^2 \tag{9}$$

Width of the Ground:

$$W_g = W_p + 6T \tag{10}$$

Length of the Ground:

$$L_g = L_p + 6T \tag{11}$$

Feed position (X_f,Y_f):

$$Z_0 = \sqrt{50 * Z_p} \tag{12}$$

$$Y_0 = \frac{1}{\pi}\cos^{-1}\sqrt{\frac{50}{Z_0}}$$

$$Y_f = Y_0 - \Delta L_p$$

$$X_f = \frac{W_p}{2}$$

The rectangular micro strip patch antenna is simulated using HFSS. The simulated return loss is shown in Fig. 3. The obtained return loss at operating frequency 2.4GHz is - 17dB. The three dimensional radiation pattern is shown in Fig. 4. The maximum gain of the antenna is 7.76dB. The radiation pattern at Ø = 0^0 plane is shown in Fig. 5.

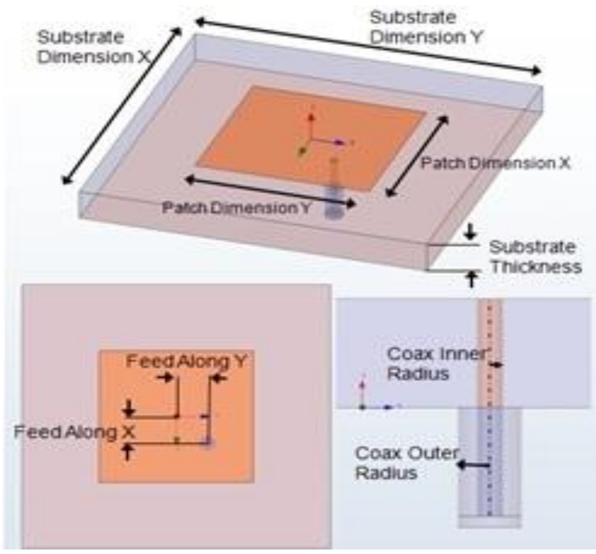

Figure 2. Schematic diagram of a coaxial probe fed rectangular Microstrip patch antenna.

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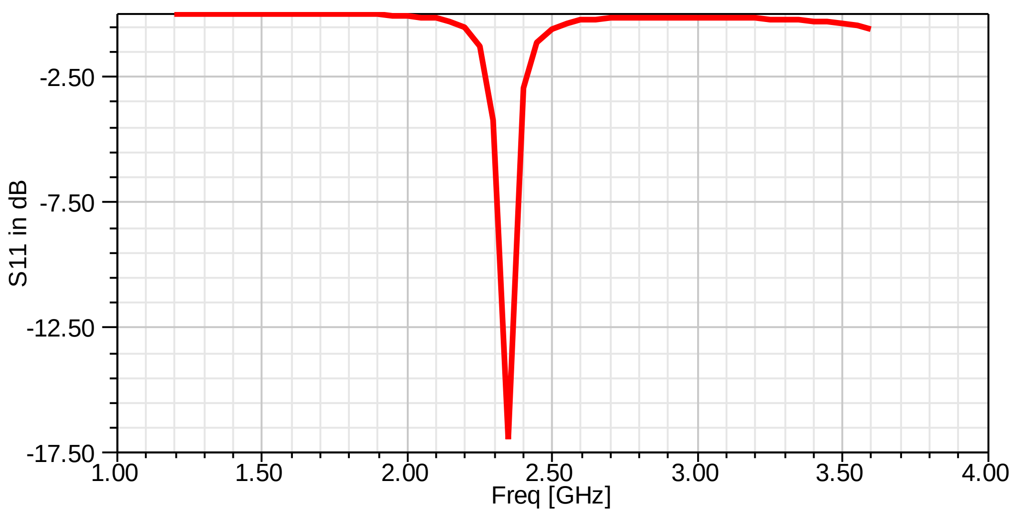

Figure 3. Return loss (S11) of the coaxial probe fed rectangular Microstrip patch antenna at 2.4GHz.

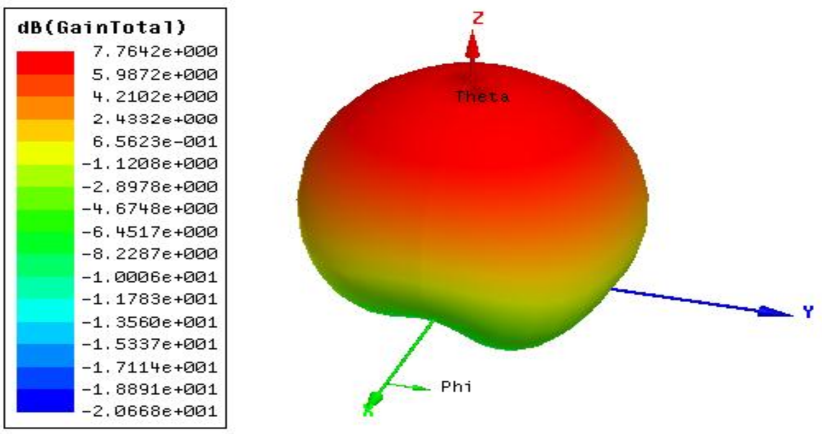

Figure 4. Gain of the coaxial probe fed rectangular Microstrip patch antenna at 2.4GHz.

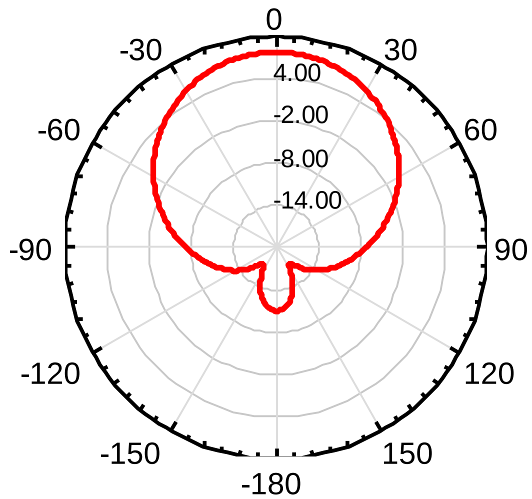

Figure 5. Radiation pattern at $Ø = 0^0$

PROBLEM FORMULATION FOR MINIMIZING THE SIDE LOBE LEVELS

The geometry of 2N element uniformly placed symmetric linear antenna array along x axis shown in Fig. 6 is considered.

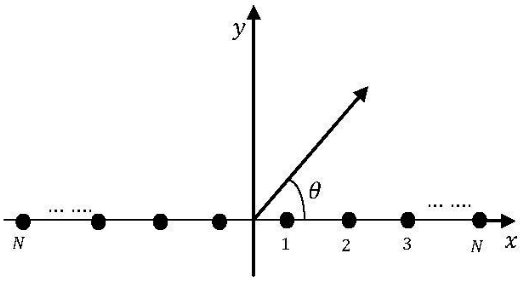

Figure 6. Schematic diagram of 2N-element linear antenna array.

The array factor of the linear antenna array [1,26] is

$$AF(\theta) = \sum_{n=1}^{2N} I_n \cos[kx_n \cos(\theta) + \varphi_n] \quad (13)$$

Where $k = 2\pi/\lambda$, I_n , φ_n and x_n are the excitation amplitude, phase and position of element n respectively.

The main aim of this paper is to minimize the peak side lobe level by employing non uniform phase excitations to individual elements of the antenna array, i.e., by varying φ_n . For that, the fitness function [10, 15] is formulated as

$$Fitness = max\left(\frac{AF(\theta)}{AF_{max}}\right) \quad (14)$$

where AF_{max} is the main beam peak and the fitness is valid in the side lobe region of θ.

NUMERICAL ILLUSTRATIONS: 20 AND 32 ELEMENT MSRPA ARRAYS

Two examples have been selected to illustrate the method of ILSPSO, PSO and DE to optimize the phase excitations of individual elements for minimum side lobe level. The ILSPSO, PSO and DE algorithm's parameters are given in Table 1. A -20dB Taylor window profile has been considered during simulation. To obtain the mean performance, all the algorithms are performed for 50 runs. All the simulations are performed using MATLAB and HFSS.

Table 1. ILSPSO, PSO and DE initial parameters.

ILSPSO		PSO		DE	
Parameters	**Values**	**Parameters**	**Values**	**Parameters**	**Values**
Number of particles	50	**Number of particles**	50	**Number of particles**	50
Number of generations	500	**Number of generations**	500	**Number of generations**	500
c_1	2	c_1	2	**SF**	0.9
c_2	2	c_2	2	**CR**	0.5
ω	Linearly varies from 0.9- 0.4	ω	0.9	-	-
M	20	-	-	-	-

20 element phased MSRPA array

The first example illustrates the synthesis of 20 element rectangular micro strip patch antenna array for minimum PSLL in the side lobe region. The optimized phase excitations and their performance metrics are given Table 2.The produced radiation pattern using ILSPSO, PSO and DE are shown in Fig. 7. It can be seen that the ILSPSO yields lower PSLL compared to PSO and DE. ILSPSO produces PSLL of -21.66dB, PSO produces PSLL of -20.65dB and DE produces PSLL of -20.67dB. PSO and DE produces similar PSLL. The convergence plots for the 20 element phased micro strip rectangular patch antenna array using ILSPSO, PSO and DE is shown in Fig. 8. It can be observed from Fig. 8 that, ILSPSO shown superiority over PSO and DE in terms of low fitness value. The obtained phase excitations using ILSPSO, PSO and DE are shown in Figs. 9, 10, 11 respectively. Also ILSPSO converges faster than PSO and DE. The variation of the first null beam width versus generations using ILSPSO, PSO and DE are shown in Figs. 12,13 and 14 respectively.

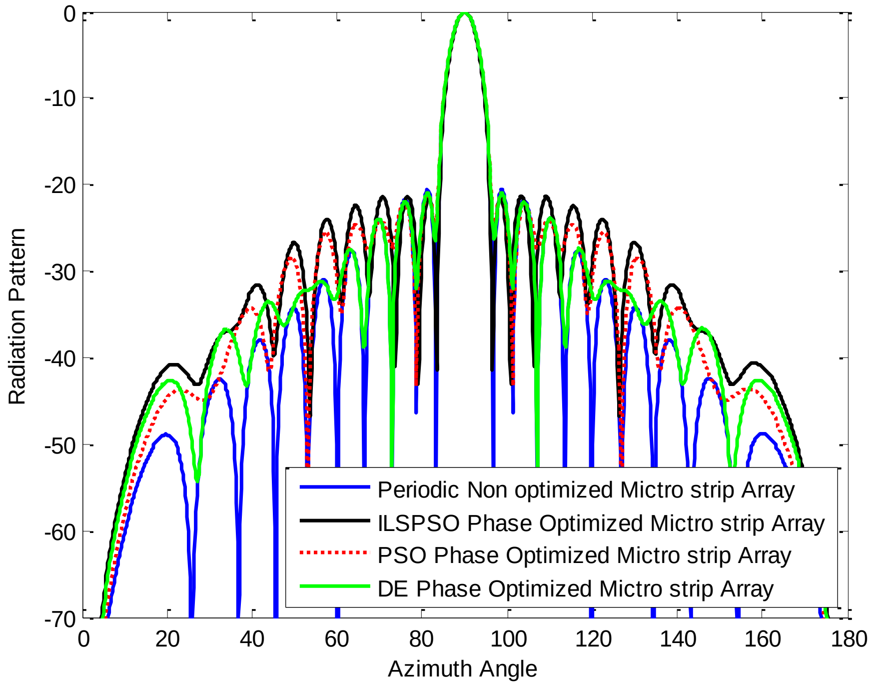

Figure 7. Radiation pattern of the ILSPSO, PSO and optimized 20 element phased MSRPA array along with the periodic phased MSRPA array.

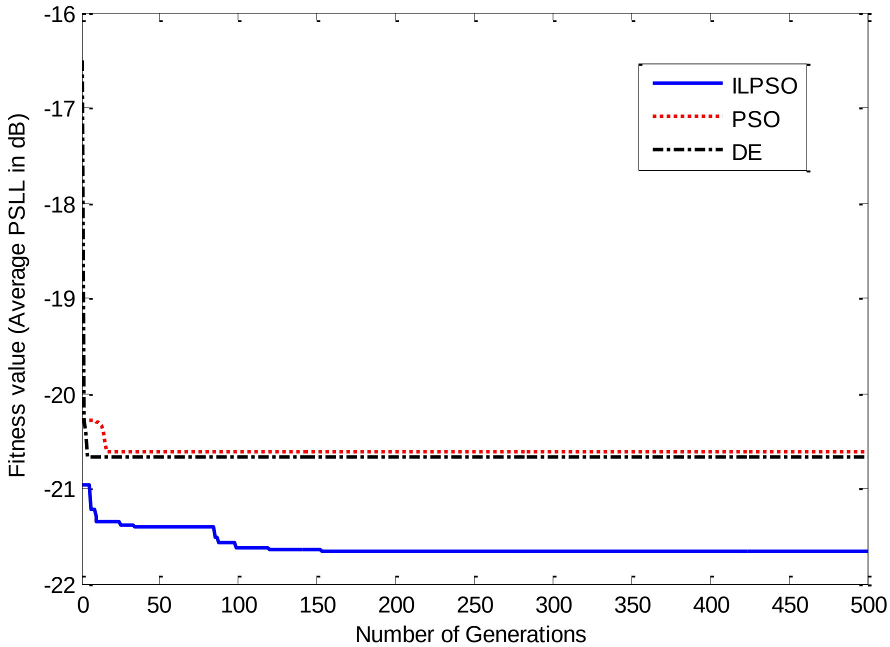

Figure 8. ILSPSO, PSO and DE convergence plots for the synthesis of the 20 element phased MSRPA array.

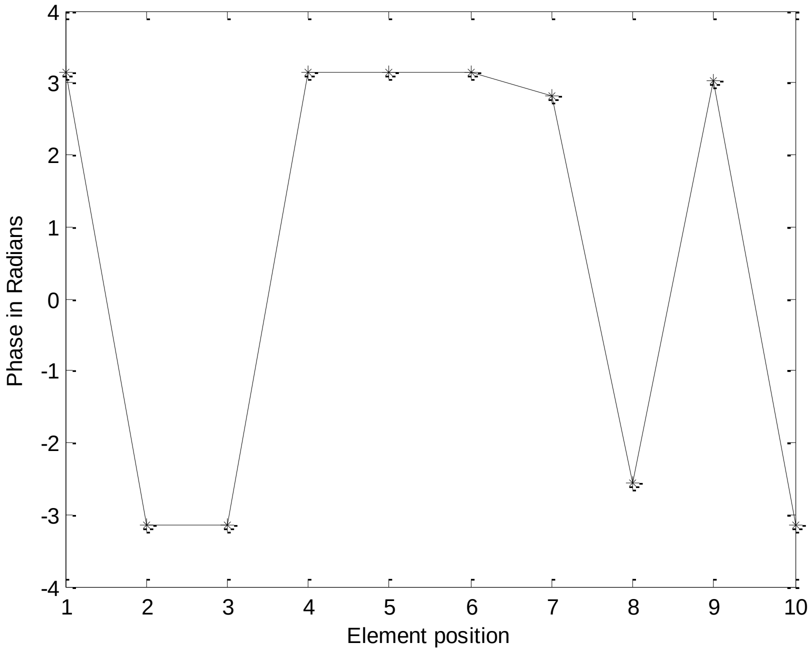

Figure 9. Phase excitations of the antenna elements (in radians) of the 20 element phased MSRPA array using ILSPSO

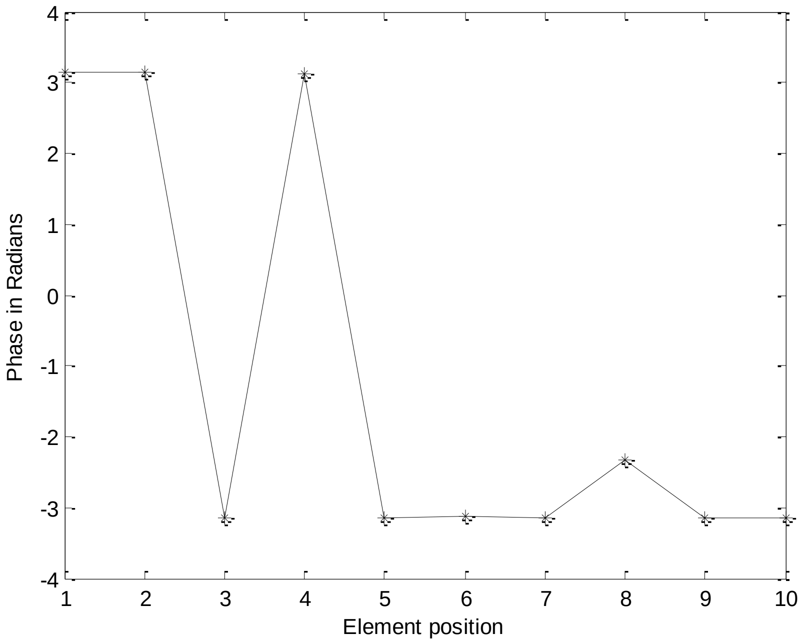

Figure 10. Phase excitations of the antenna elements (in radians) of the 20 element phased MSRPA array using PSO

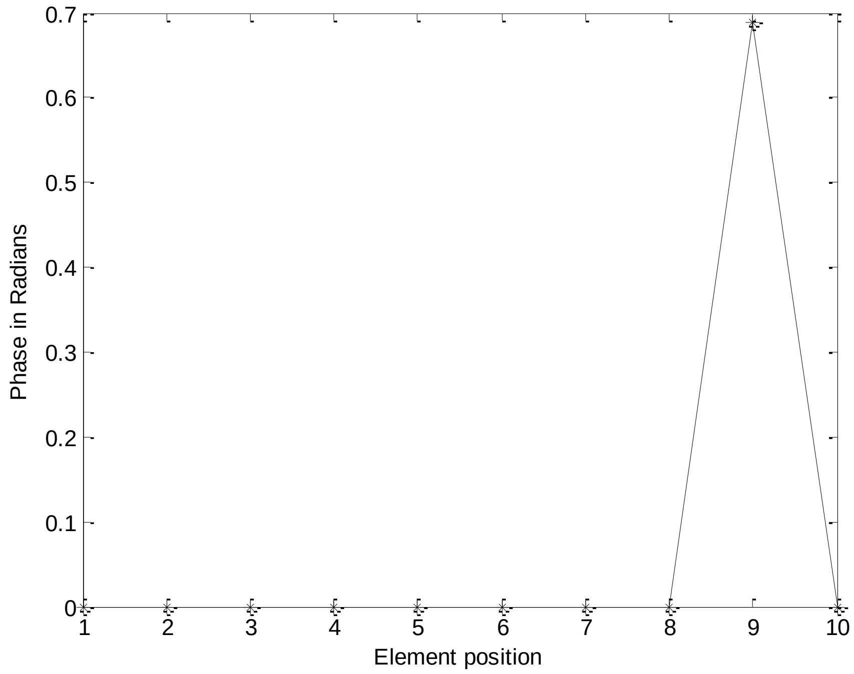

Figure 11. Phase excitations of the antenna elements (in radians) of the 20 element phased MSRPA array using DE

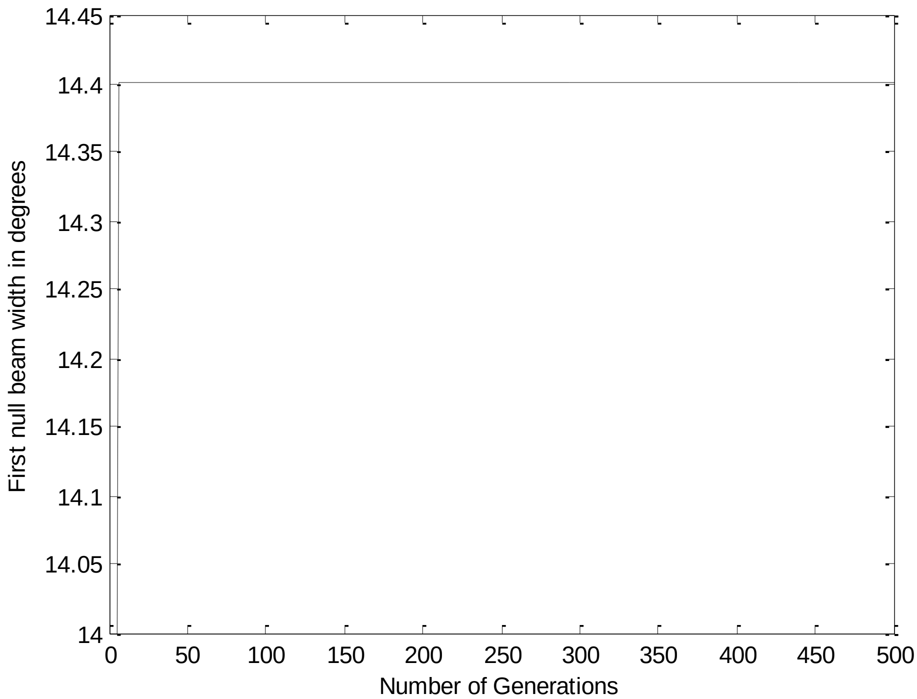

Figure 12. Beamwidth versus number of generations using of the 20 element phased MSRPA array ILSPSO.

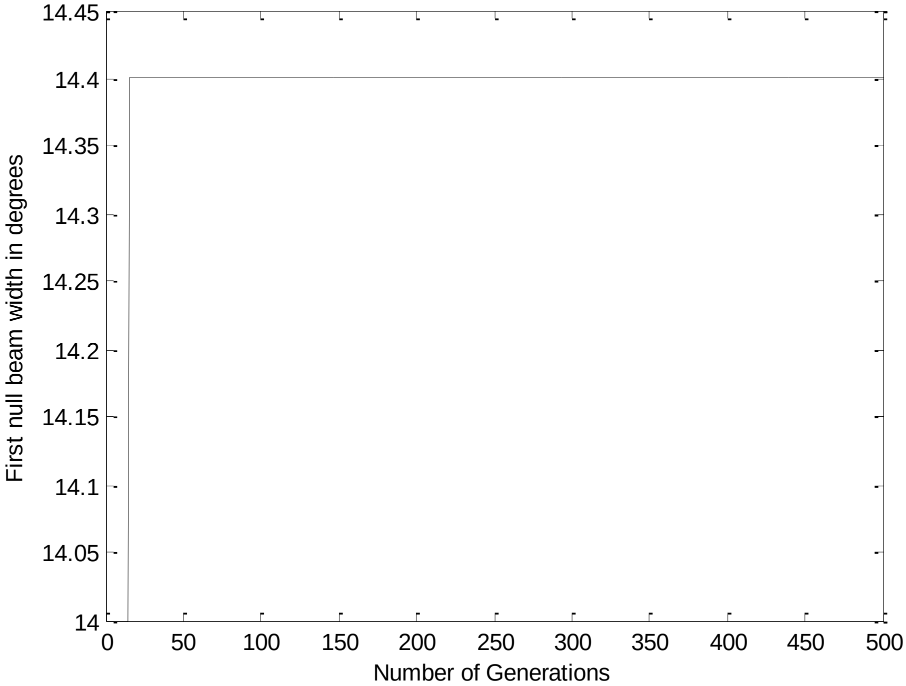

Figure 13. Beamwidth versus number of generations of the 20 element phased MSRPA array using PSO.

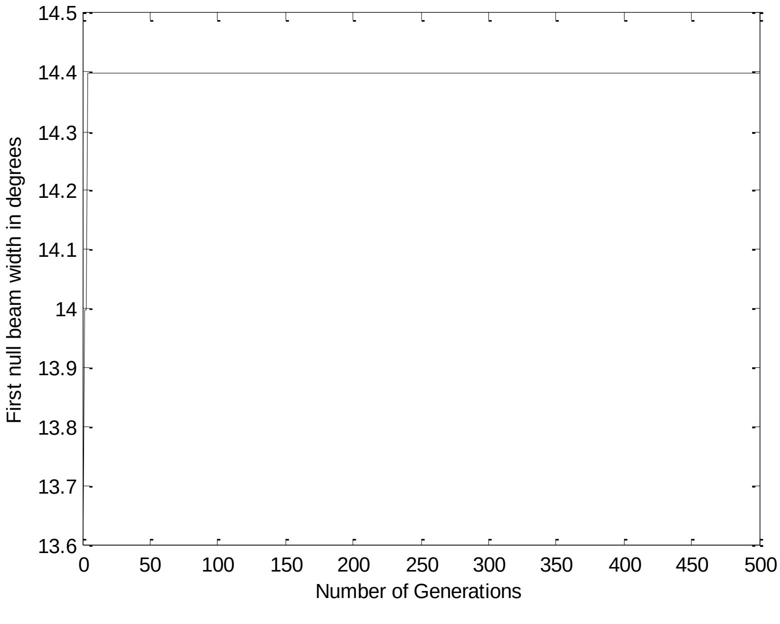

Figure 14. Beamwidth versus number of generations of the 20 element phased MSRPA array using DE.

32 element phased MSRPA array

The second example illustrates the synthesis of 32 element rectangular micro strip patch antenna array for minimum PSLL in the side lobe region. The optimized phase excitations and their performance metrics are given Table 2. The obtained radiation pattern using ILSPSO, PSO and DE are shown in Fig. 15. It can be observed that the ILSPSO produces lower PSLL compared to PSO and DE. ILSPSO produces PSLL of -22.39dB, PSO produces PSLL of -20.53dB and DE produces PSLL of -21.07dB. The convergence plots for the 32 element phased MSRPA array using ILSPSO, PSO and DE are shown in Fig. 16. It can be observed from Fig. 16 that, ILSPSO shown superiority over PSO and DE in terms of low fitness value. The obtained phase excitations using ILSPSO, PSO and DE are shown in Figs. 17, 18, 19 respectively. To compare evolutionary process, ILSPSO converges faster than PSO and DE. The variation of the first null beam width versus generations using ILSPSO, PSO and DE are shown in Figs. 20, 21 and 22 respectively.

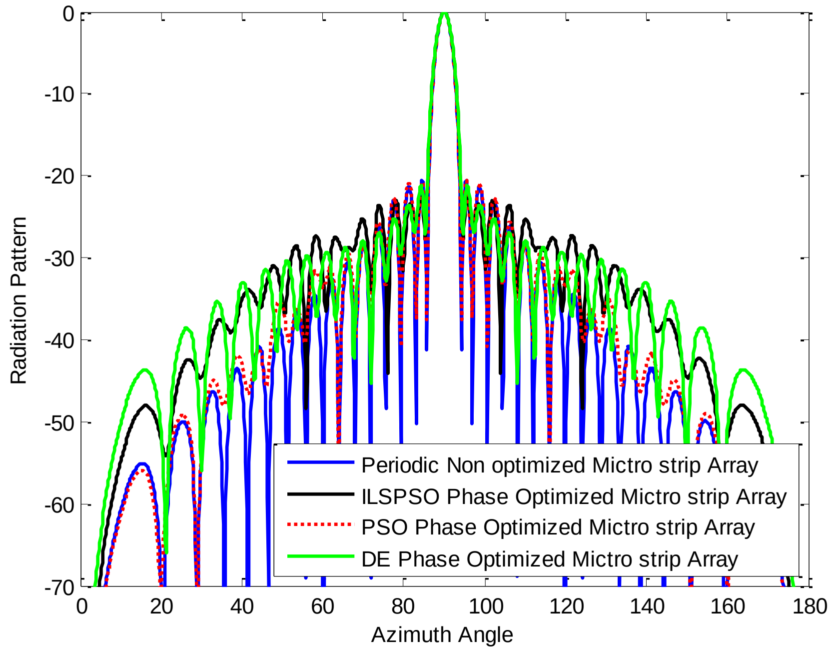

Figure 15. Radiation pattern of the ILSPSO, PSO and optimized 32 element phased MSRPA array along with the periodic phased MSRPA array.

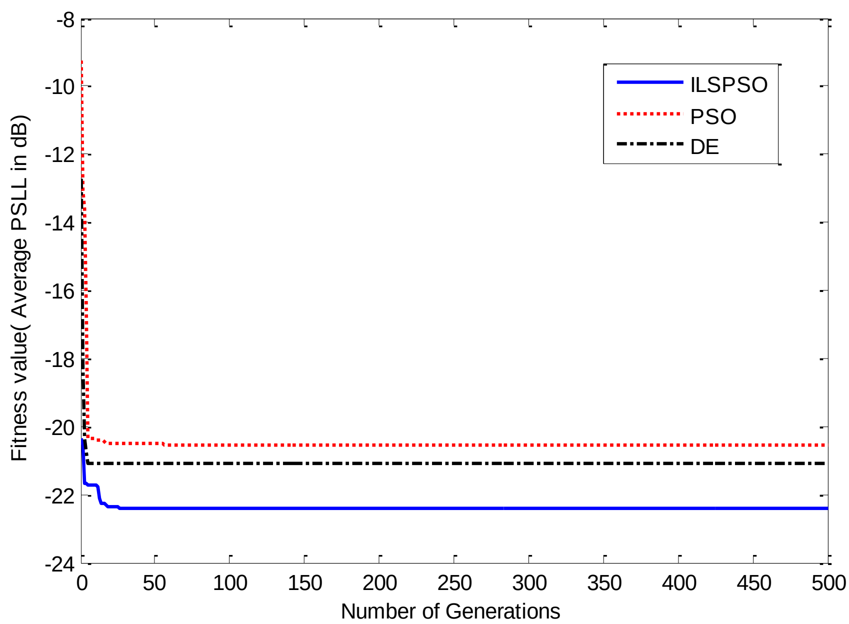

Figure 16. ILSPSO, PSO and DE convergence plots for the synthesis of the 32 element phased MSRPA array.

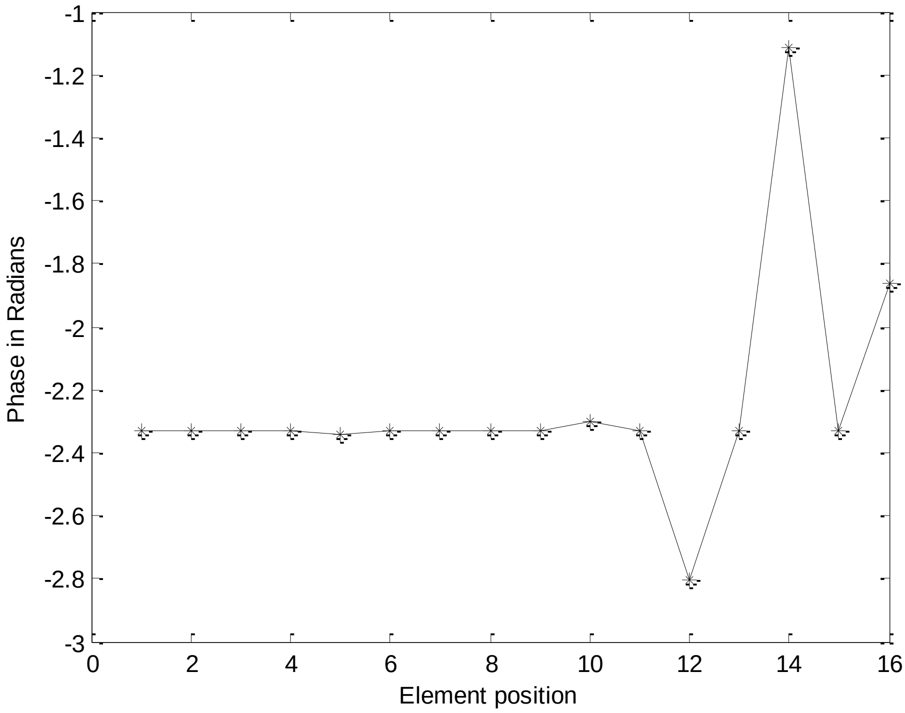

Figure 17. Phase excitations of the antenna elements (in radians) of the 32 element phased MSRPA array using ILSPSO.

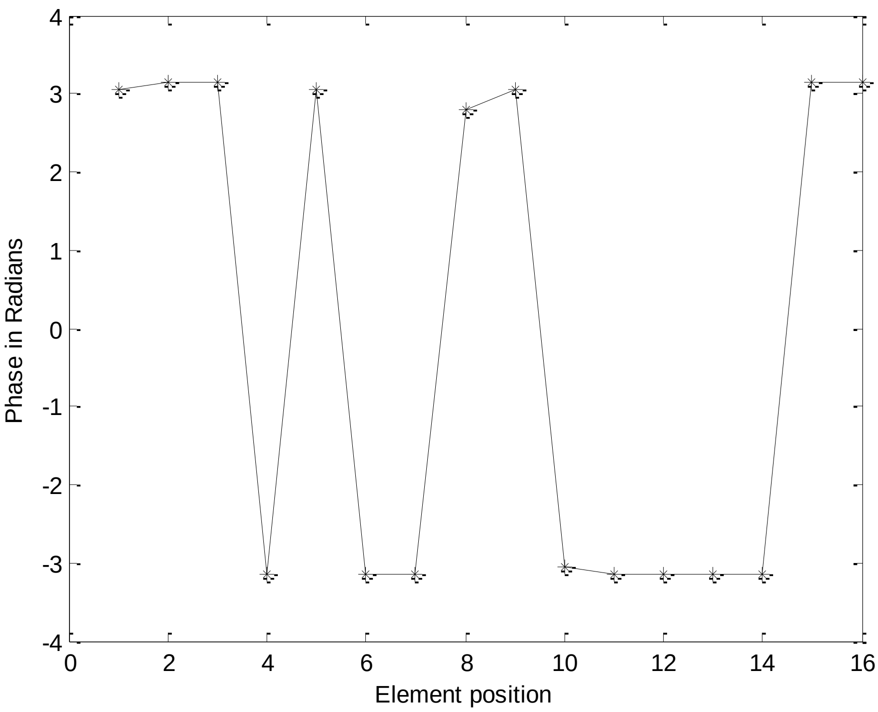

Figure 18. Phase excitations of the antenna elements (in radians) of the 32 element phased MSRPA array using PSO

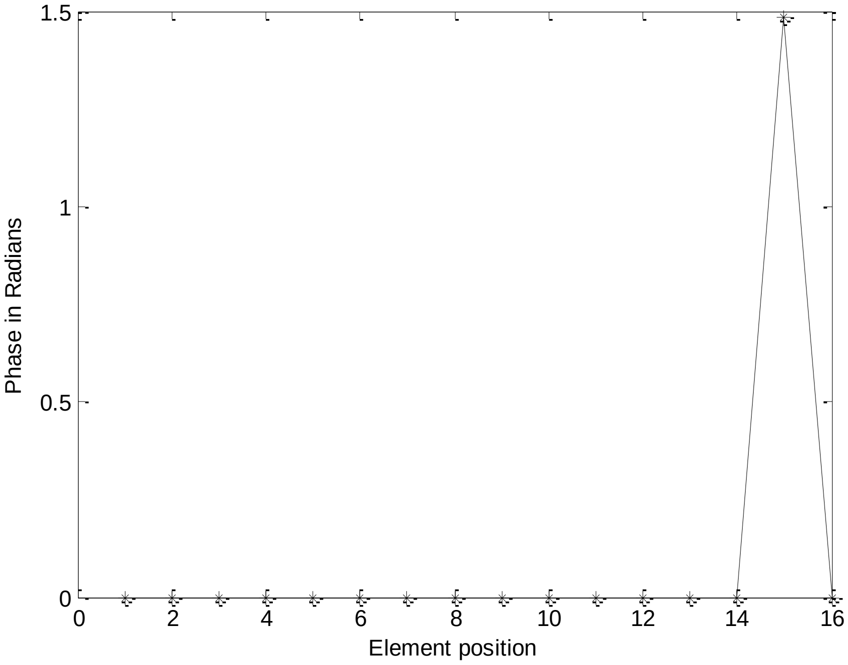

Figure 19. Phase excitations of the antenna elements (in radians) of the 32 element phased MSRPA array using DE.

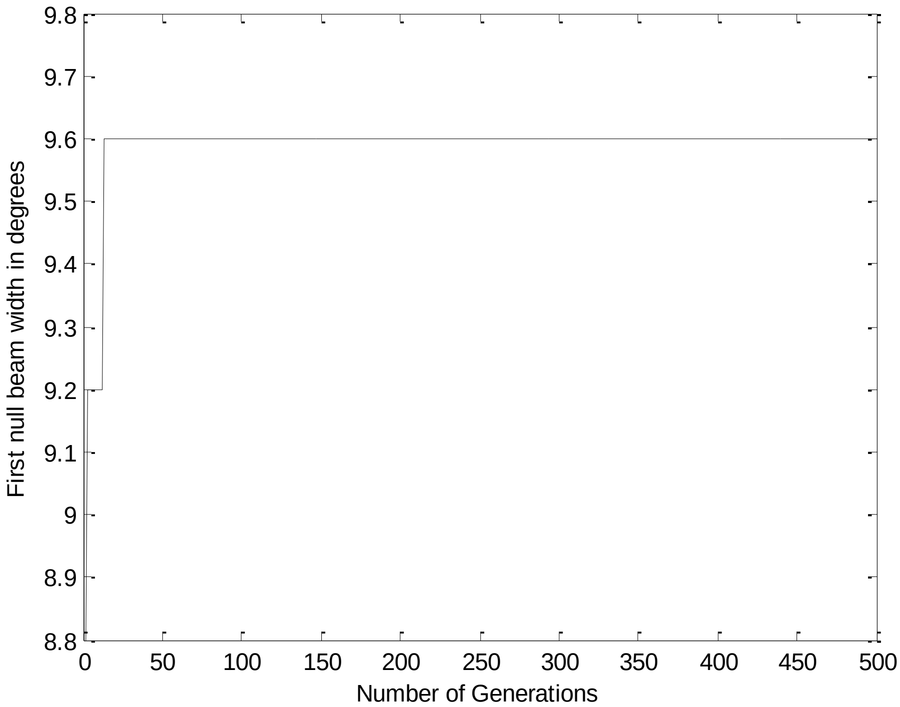

Figure 20. Beamwidth versus number of generations of the 32 element phased MSRPA array using ILSPSO.

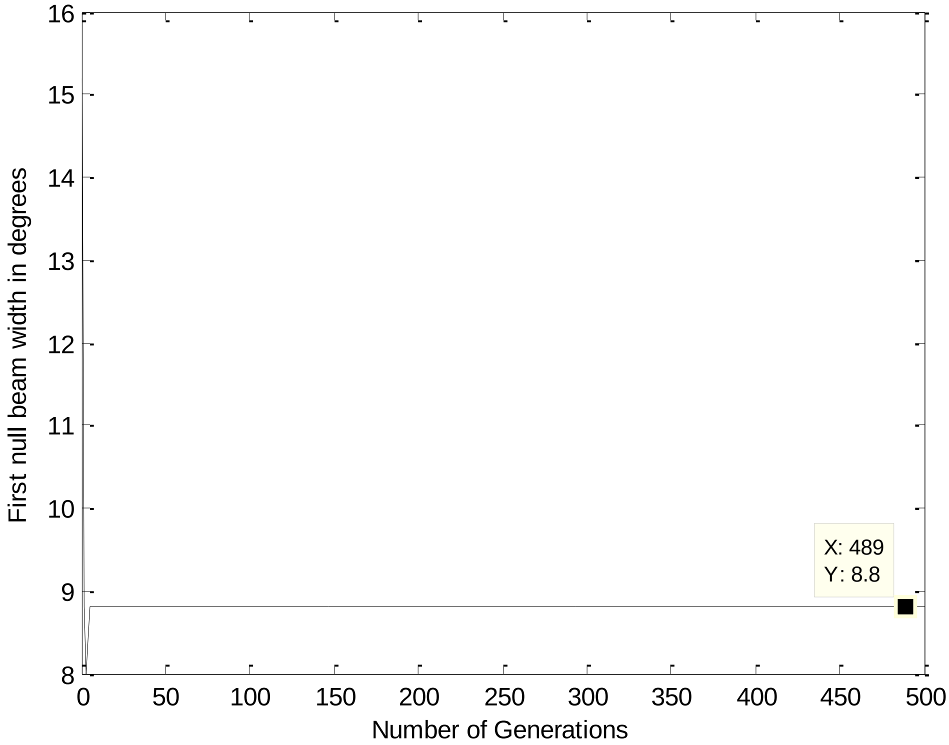

Figure 21. Beamwidth versus number of generations of the 32 element phased MSRPA array using PSO.

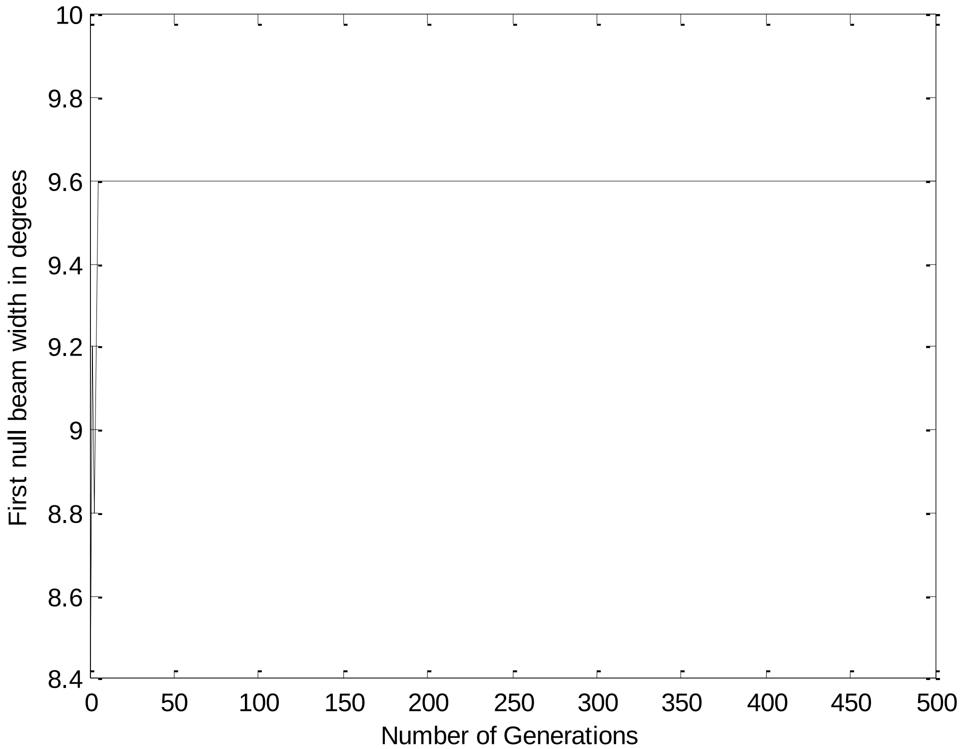

Figure 22. Beamwidth versus number of generations of the 32 element phased MSRPA array using DE.

Table 2. Optimized phase excitations obtained using ILSPSO, PSO and DE and their PSLL's and Beam width for 20 and 32 element MSRPA arrays.

Array Type	Algorithm	Optimized Phases (Since linear antenna array is symmetric, so half of the phases are given below)	PSLL dB	Beam Width Deg.
20 Element Phased MSRPA	**Periodic Array**	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	-13.23	14.4
	ILSPSO	3.1416 -3.1416 -3.1416 3.1416 3.1416 3.1416 2.8244 -2.5616 3.0241 -3.1416	-21.66	14.4
	PSO	3.1416 3.1416 -3.1416 3.1333 -3.1416 -3.1320 -3.1416 -2.3261 -3.1416 -3.1359	-20.65	14.4
	DE	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.6888 0.0000	-20.67	14.4
32 Element Phased MSRPA	**Periodic Array**	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000	-13.23	9.2
	ILSPSO	-2.3289 -2.3289 -2.3289 -2.3289 -2.3450 -2.3289 -2.3289 -2.3289 -2.3289 -2.3024 -2.3289 -2.8057 -2.3289 -1.1133 -2.3289 -1.8646	-22.39	9.6
	PSO	3.0413 3.1401 3.1402 -3.1414 3.0416 -3.1416 -3.1403 2.8054 3.0420 -3.0414 -3.1400-3.1389 -3.1392 -3.1400 3.1402 3.1416	-20.53	8.8
	DE	0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 1.4849 0.0000	-21.07	9.6

CONCLUSION

ILSPSO has been successfully applied for linear phased antenna array synthesis to minimize the peak sidelobe level by optimizing the phase excitations of the elements. Gaussian distribution is adopted to enhance the local and global search capabilities of ILSPSO. ILSPSO is simple like PSO, at the same time it is more robust than the PSO. Minimization of side lobe level of a 20 and 32 element linear MSRPA array is illustrated using ILSPSO, PSO and DE algorithms. The obtained results are compared with PSO and DE optimized synthesized phased arrays. The obtained optimal arrays are simulated through MATLAB and HFSS. Numerical illustrations demonstrate that the ILSPSO method produce significant reduction in peak sidelobe level. Also, ILSPSO converges faster than PSO and DE. These antenna arrays are useful in interference less communications systems. Because of the aforementioned advantages, ILSPSO is also useful in other electromagnetic problems.

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