RESEARCH ARTICLE

Design of Uniform and Nonuniform Circular Arrays Comparison with FFA and RLS

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Abstract: Multiple antennas can be arranged in various geometrical configurations to form antenna array with high directive radiation pattern. Linear antennas are limited in their steering capability. The circular arrays are more popular in recent years over other array geometries because they have the capability to perform the scan in all the directions and considerable change in the beam pattern which provide 3600 total coverage. Circular arrays are less sensitive to mutual coupling as compared to linear and rectangular arrays since they do not have edge elements. They can be used for beam forming in the azimuth plane for example at the base stations of the mobile radio communication systems as the components for signal processing. FFA design method of circular apertures for narrow beam width and low side lobes has been reported by Taylor. It includes the development of continuous circular aperture distributions, which contain only two independent parameters, A & $\bar{n}$, where A is related to the design of side lobe level and $\bar{n}$ is a number controlling the degree of uniformity of the side lobes.
Keywords: Uniform Circular array; RLS; FFA.

1. Introduction

The genetic has been employed to determine an optimum set of amplitude excitations and antenna element separations, which provide a radiation pattern with maximum side lobe level reduction coupled with the constraint of a fixed beam width.Chatterjee[1] deteremined the Scannable circular arrays by comparing three population based optimization algorithms - PSO, GA, and Differential Evolution (DE). These algorithms are compared on a single representation of the design problem by optimizing amplitude excitations and phase perturbations. Mandal *et al*[2] designed a non uniform circular antenna array with optimum side lobe level reduction. The Particle Swarm Optimization (PSO) method is used in the optimization process. The method of PSO is used to determine an optimum set of weights and antenna element separations that provide a radiation pattern with maximum side lobe level reduction with the constraint of a fixed major lobe beam width. An ecologically inspired optimization algorithm, called Invasive Weed Optimization (IWO) algorithm, has been employed for the design of non uniform circular arrays. The obtained patterns are compared with the patterns of classical IWO and three other state-of-the-art stochastic algorithms, GA, PSO, and DE. The results obtained with IWO shows better optimized performance with respect to SLL, directivity and null control in a scanning range of 0^0 to 360^0.However, synthesis of non uniform circular array using Firefly Algorithm (FFA), Bat and Cuckoo Search (CS) algorithms to minimize the side lobe level with beam width constraint has not been reported so far.

FFA is employed to design non uniform circular arrays to generate patterns with minimum side lobe level for a specific first null beam width[3]. Two other swarm based approaches, Bat and CS algorithms are also used to design the

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same array and consequent array patterns are compared with conventional uniform circular array.

2. Design Formulation in Circular Array

The elements are non uniformly spaced on a circle of radius r in the Y-Z plane. The elements are assumed to be isotropic sources which is used to determine the factors in an arrat. The geometry of an N element circular array is described in **Figure 1.**

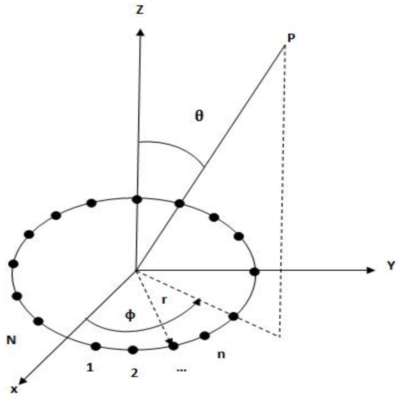

Figure 1. Geometry of isotropic Circular Array

The array factor in the Y-Z plane can be written as

$$A_F(\theta) = \sum_{n=1}^{N} \exp\left[jka\cos(\theta - \phi_n + \alpha_n)\right] \qquad (1)$$

Where,

$$ka = \sum_{i=1}^{N} d_i \qquad (2)$$

$$\emptyset_n = \frac{2\pi \sum_{i=1}^{n} d_i}{\sum_{i=1}^{N} d_i} \qquad (3)$$

$$\alpha_n = -ka\cos(\theta_0 - \emptyset_n) \qquad (4)$$

$A = [A_1, A_2 ----, A_n ---- A_N]$, A_n represents the excitation amplitude of the n-th element of the array, $d = [d_1, d_2 d_n ---- d_{N+1}],]$, d_n represents the distance from element n to $(n+1)$. Excitation current phases are fixed at $0°$.

Here 'θ_0' be the angle where global maximum is attained in $\theta = [-\pi, \pi]$.

Normalized power pattern can be expressed as

$$P(\theta) = 20\log_{10}\left|\frac{|A_F(\theta)|}{|A_F(\theta_0)|}\right| \qquad (5)$$

The directivity of a circular array with isotropic elements can be expressed as

$$D = \frac{4\pi |A_F(\theta_s, \phi_s)|^2}{\int_0^{2\pi}\int_0^{\pi} |A_F(\theta, \phi)|^2 \sin\theta \, d\theta \, d\phi} \qquad (6)$$

Here, (θ_s, ϕ_s) = Steering angle.

3. Fitness Function

The uniform circular array has high side lobe geometry (approximately 8 dB below the main lobe). The first and most important parameter in pattern synthesis of antenna array is Side Lobe Level (SLL) that is desired low as possible [4].So, the objective of the work is to minimize the maximum side lobe level in the array pattern by adjusting the amplitudes and positions of different elements while first null beam width (FNBW) is kept within some specified limitsThus the following fitness function is used.

$$\text{Fitness} = \text{Max}_{\theta \in S} \left|\frac{P(\theta)}{P(\theta_0)}\right| \; F \leq F_u \qquad (3.7)$$

Here S is represented as space scanned by angle θ excluding the main lobe. F is first null beam width of the pattern produced by the array considered for optimization. F_u is the resultant values obtained with the uniform circular array.

4. Simulation Results

The results pertaining to the above discussion are presented in this Section. The objective of simulation based experimentation related to synthesis of circular array for SLL optimization and null positioning for beam forming characteristics is divided into two parts. The radiation pattern plots pertaining to both the objectives .

Side lobe level Optimization

The first objective is dedicated to side lobe level optimization in Circular arrays [6]. The extent of side lobe levels (SLL) in circular arrays is a serious problem as in conventional method of uniform distribution leads a very high level of -7dB which is far greater than the required level in wireless communications. Hence it is often required to optimize the SLL in circular arrays. Considering this, the SLL minimization is included as an objective. The problem of SLL minimization in this case is achieved using the novel evolutionary algorithm known as Firefly Algorithm (FFA). In this Section simulation based experimentation for circular arrays is carried out with several number of elements ranging from N=10 to 40 with an interval of 10. It is ensured that all the resultant patterns have produced an SLL less than the conventional case of -7dB. The resultant patterns incorporating this side lobe level are presented from **Figure 2** to 5 and shown in table 1.

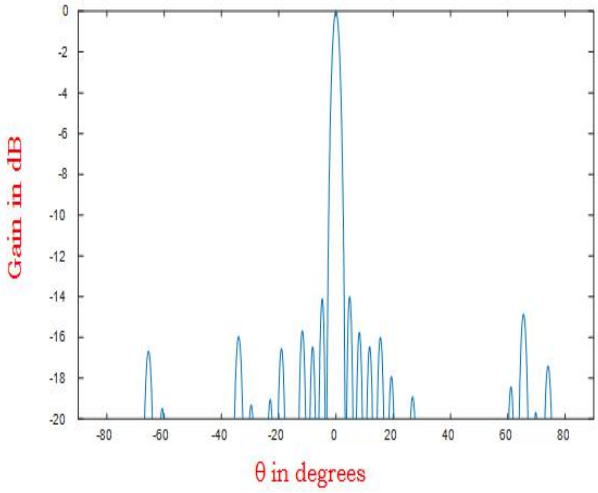

Figure 2. Radiation Pattern of Circular Array with 10 elements

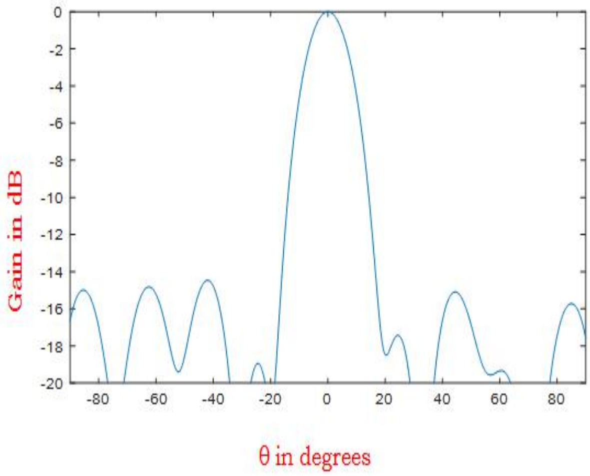

Figure 3. Radiation Pattern of Circular Array with 20 elements

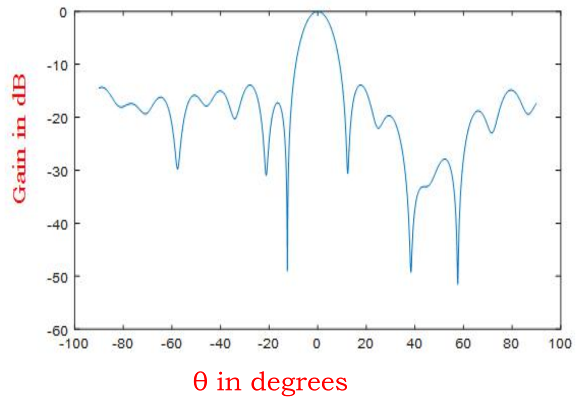

Figure 4. Radiation Pattern of Circular Array with 30 elements

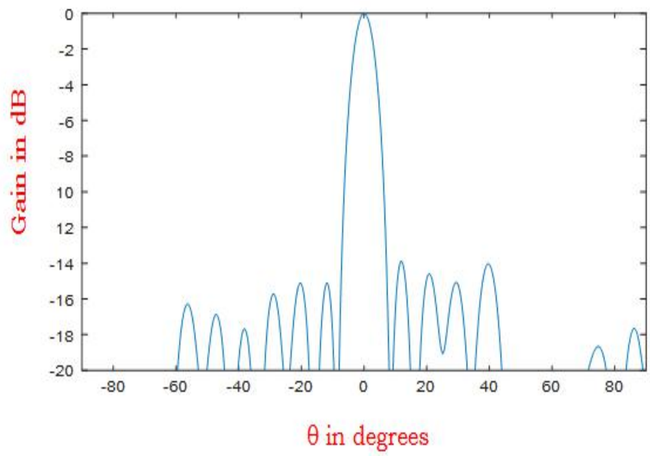

Figure 5. Radiation Pattern of Circular Array with 40 elements

For the above cases discussed for N=10,20----40 which is simulated in MATLAB ,the Side lobe level &Beam width variations are presented in Table 1 for comparison. It is observed that N increases, Beam width decreases , SLL is also decreased.

No of Elements	Beam width in Degrees	Side lobe level in dB
10	40	-15
20	38	-15
30	36	-14
40	35	-14

Table 1. Beam width and Side Lobe level Variations for number of Elements

Beam forming Optimization

It is evident from the preliminary literature survey an array antenna is implemented for wireless applications should have the capability to accept as well reject signals in multiple directions along with the several constraints imposed in terms of SLL and beam width. Considering this, an experimental frame work has been designed that Hansen [5] the study of circular array capability in beam forming with constraints using evolutionary algorithm like FFA. The following table describes the simulation based experimentation frame work employed for this purpose. However, the local search methods like RLS method is also employed and compared with the proposed method in terms of convergence. Several factors like computational time, complexity of the study can be studied using the convergence plots. The same has been performed here in this work and each case illustrated in the tabular form.

Case -1a: The Objective is to design the non-uniform circular antenna arrays for maximal side lobe level reduction. The antenna array design problem consists of finding weights that provide a radiation pattern with maximal side lobe level reduction. The effectiveness of Real Coded Genetic Algorithm (RCGA) such as FFA for the design of non uniform circular arrays is shown by means of experimental results. Experimental results reveal that design of non uniform circular antenna array provides a considerable side lobe level reduction with respect to the uniform case.

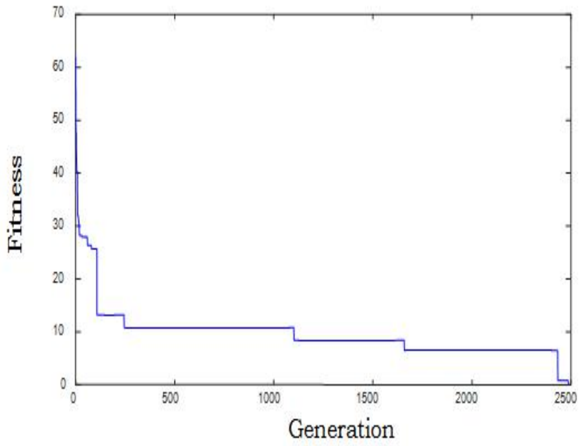

Figure 6a. Convergence Plot for RLS

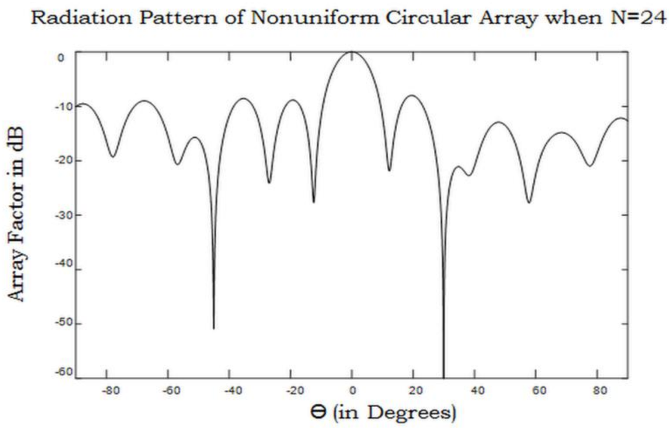

Figure 6b. Radiation Pattern Plots for RLS

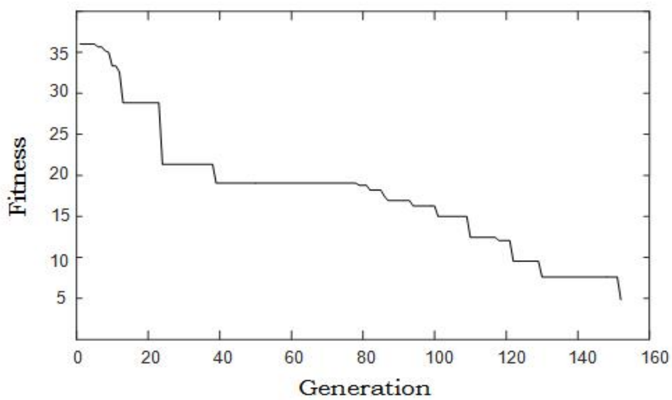

Figure 6c. Convergence Plot for FFA

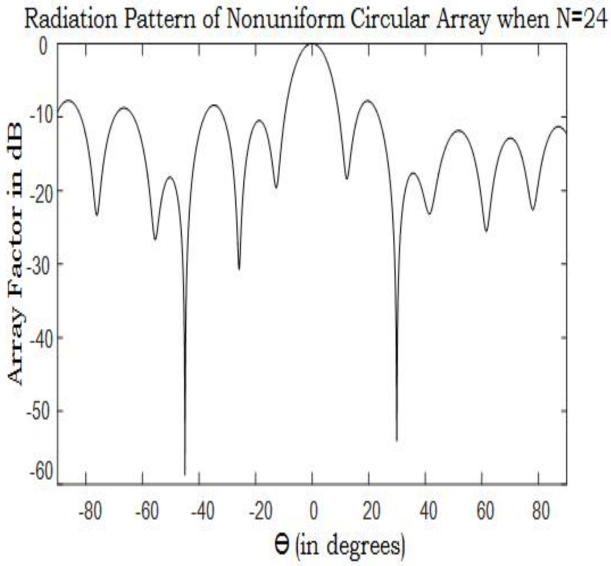

Figure 6d. Radiation Pattern Plots for FFA

Figure 6. Convergence and radiation pattern plots for Case-1a using (a-b) RLS and (c-d) FFA

Figure 6b and 6d shows the radiation pattern of non uniform circular array for RLS and FFA algorithms are shown and their convergence plots are shown in **Figure 6**a and c. Total number of elements is taken as the 24 in this case and simulations carried out separately for RLS and FFA algorithms. The null positions found at the -45^0 and 30^0.

Case-1b : In this case the total number of elements is taken as the 24 in this case and simulations are performed in MATLAB separately for RLS and FFA algorithms. The null positions are found at -45^0,15^0 and 30^0. **Figure 7**b-d shows the radiation pattern of non uniform circular array[68] for RLS and FFA algorithms are shown and their convergence plots are shown in **Figure 7**a-c.

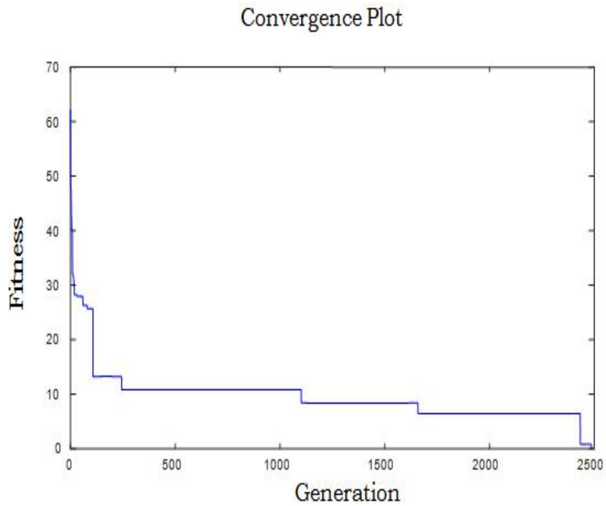

Figure 7a. Convergence Plot for RLS

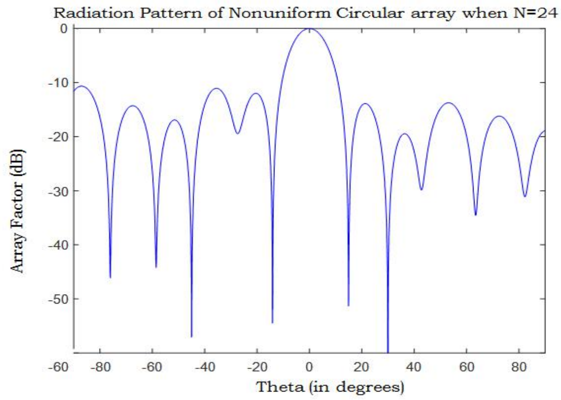

Figure 7b. Radiation Pattern Plot for RLS

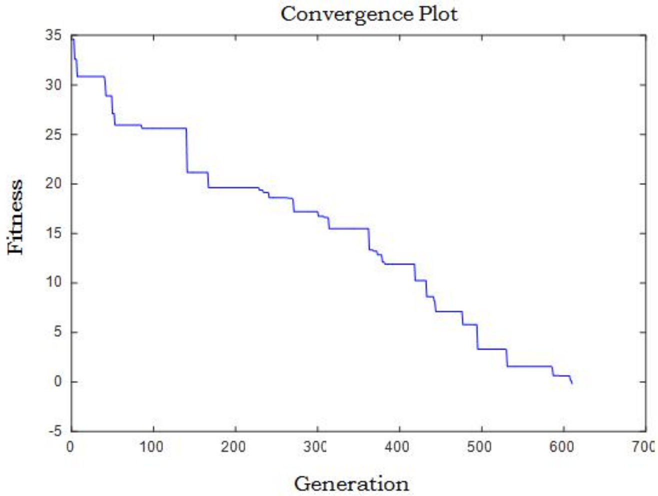

Figure 7c. Convergence Plot for FFA

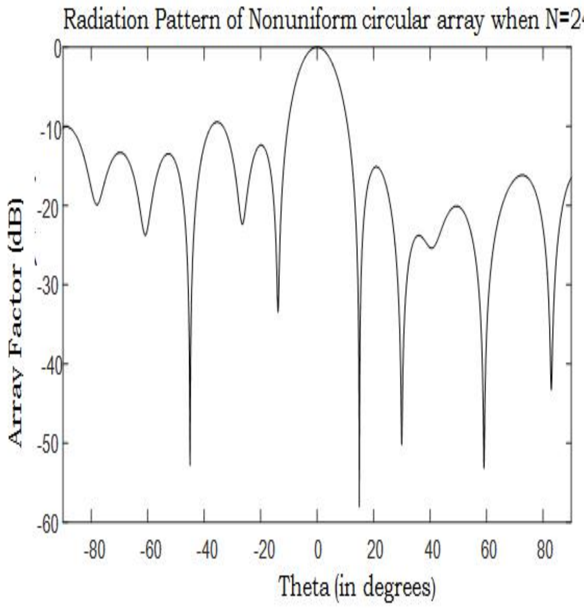

Figure 7d. Radiation Pattern Plot for FFA

Figure 7. Convergence and radiation pattern plots for Case-1a using (a-b) RLS and (c-d) FFA

From the radiation pattern plots we can observe that there is an large reduction in SLL at various null positions found at -13dB for non uniform circular array.

Case-2a The radiation pattern of nonuniform circular arrayis as shown in **Figure 8**, and corresponding convergence plot is shown in figure a -15dB side lobe level less than uniform circular array and corresponding beam width is 25°.

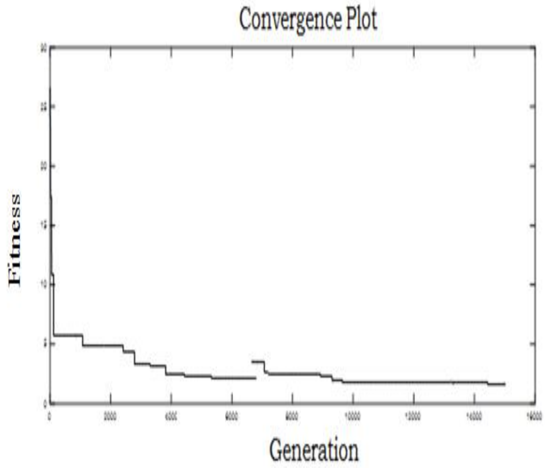

Figure 8a. Convergence Plot for RLS

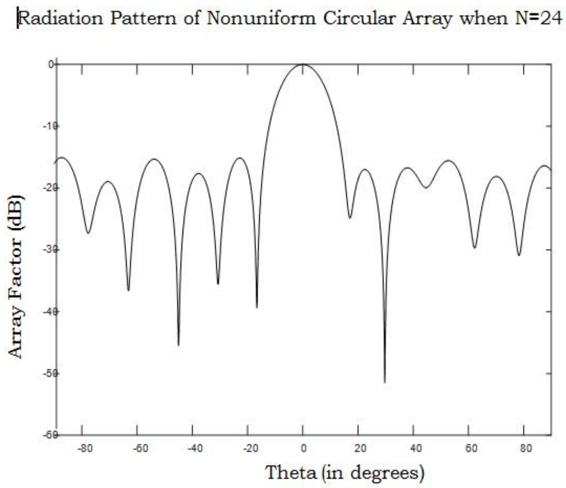

Figure 8b. Radiation Pattern Plots for RLS

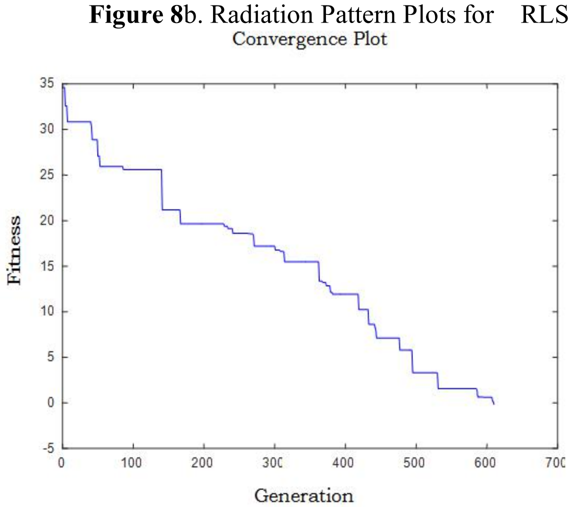

Figure 8c. Convergence Plot for FFA

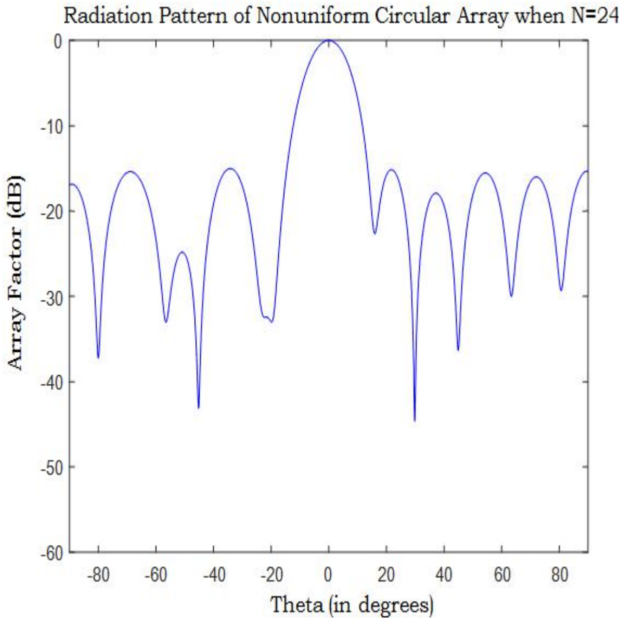

Figure 8d. Radiation Pattern Plots for FFA

Figure 8. Convergence and radiation pattern plots for Case-1b using (a-b) RLS and (c-d) FFA

Case-2b: The radiation pattern of non uniform circular array is as shown in **Figure 9**, and corresponding convergence plot is shown in Figure (a) has -15dB side lobe level less than uniform circular array and corresponding beam width is 40°.

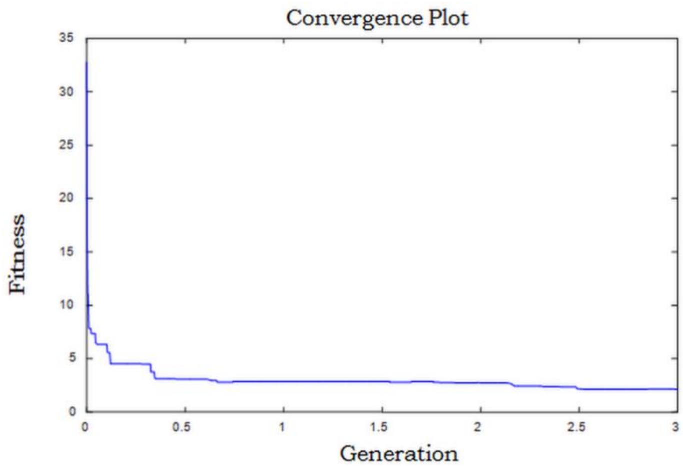

Figure 9a. Convergence Plot for RLS

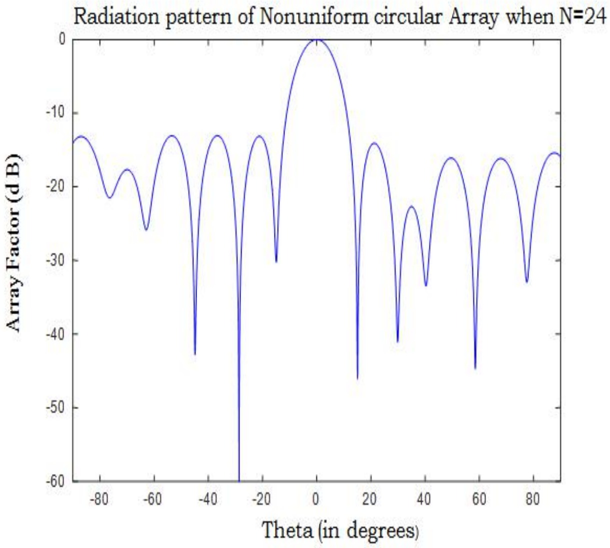

Figure 9b. Radiation Pattern Plots for RLS

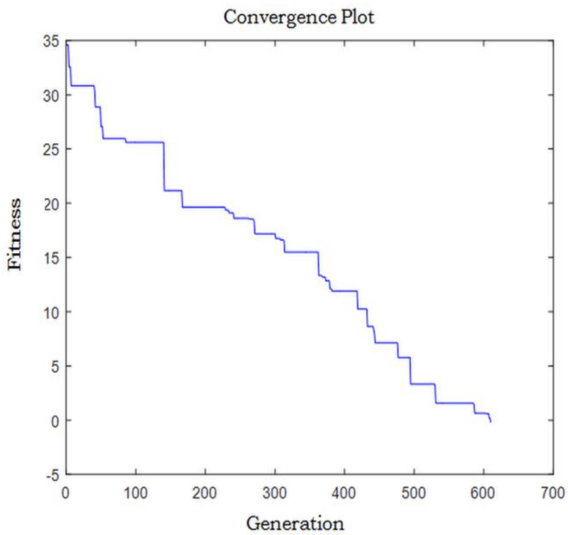

Figure 9c. Convergence Plot for FFA

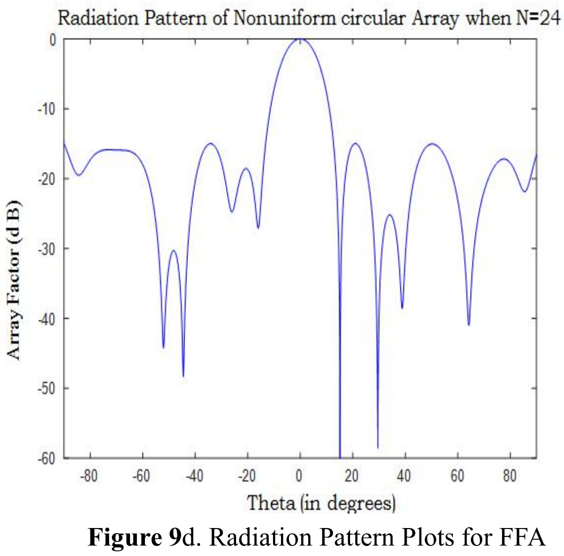

Figure 9d. Radiation Pattern Plots for FFA

Figure 9. Convergence and radiation pattern plots for Case-2a using (a-b) RLS and (c-d) FFA

The above different cases indicates that SLL has been reduced in FFA ,while comparing with RLS algorithm .Hence both SLL and FNBW reduction occurs for non uniform circular antenna arrays.

Position of the Main Beam	Case No	Null Position	Constraint
0^0	1a	-45, 30	No Constraint
	1b	-45, 15, 30	
	2a	-45, 30	-15 dB SLL
	2b	-45, 15, 30	

Table 2. Simulation Based Experimentation for SLL

5. Conclusion

The FFA has emerged as a potential algorithm which is population based evolutionary technique in circular array synthesis. The two serious problems in the wireless communications is adoption of the array systems which are dealt and have shown excellent results when compared with the other conventional uniform distribution and the RLS techniques. Hence it can be concluded that the proposed method of circular array synthesis are best as they exhibit minimum mathematical complexity.

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