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Research paper

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

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Abstract

Multiple antennas can be arranged in various geometrical configurations to form an antenna array with high directive radiation pattern. Linear antennas are limited in their steering capability. The circular arrays have become popular in recent years over other array geometries because they have the capability to perform the scan in all the directions without a considerable change in the beam pattern and provide 3600 azimuth coverage. Circular arrays which are used for design is compared to linear and rectangular arrays as they does 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 and , where A is related to the design of side lobe level, is a number controlling the degree of uniformity of the side lobes. A radiation pattern is expressed in the integral form. They are compared with a line source and circular aperture.

Keywords: *Uniform-Circular array,RLS,FFA,Array*

1. Introduction

Real-coded Genetic Algorithm (GA) has been employed to determine an optimum set of amplitude excitations and antenna elements, which provides a radiation pattern of maximum side lobe level reduction for a fixed beam width.
Chatterjee [1] designed Scannable circular arrays by comparing three population based optimization algorithms – Particle swarm optimization, GA and Differential Evolution. 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 00 to 3600.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 same array and consequent array patterns are compared with conventional uniform circular array.

2. Design Formulation of 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 so that the radiation pattern of the array can be described by its array factor. The geometry of an N element circular antenna has been shown in Fig.1.1.

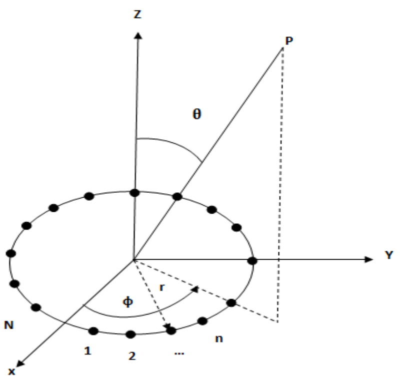

Fig. 1.1: Typical Geometry of isotropic Circular Array

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

$$A_F(\theta) = \sum_{n=1}^{N} \exp\,[jkacos(\Theta - \phi_n + \alpha_n)] \qquad (2.1)$$

Where,

$$ka = \sum_{i=1}^{N} d_i \quad (2.2)$$

$$\emptyset_n = \frac{2\pi \sum_{i=1}^{N} d_i}{\sum_{i=1}^{N} d_i} \quad (2.3)$$

$$\alpha_n = -ka\cos(\theta_0 - \emptyset_n) \quad (2.4)$$

$A = [A_1, A_{2----}, A_n - - - - A_N]$, A_n represents the excitation amplitude of the n-th element of the array, $d = [d_1, d_2 d_n - - - - dN+1], dn$ 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

$$P(\theta) = 20\log_{10}\left[\frac{|A_F(\Theta)|}{|A_F(\Theta)|_{max}}\right] \quad (2.5)$$

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

$$D = \frac{4\pi |A_F(\theta_s, \phi_s)|^2}{\int_0^{2\pi}\int_0^{\pi} |A_F(\theta, \phi)|^2 \sin\theta \, d\theta \, d\phi} \quad (2.6)$$

Here, (θ_s, ϕ_s) = Steering angle.

3. Fitness Function

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

$$Fitness = Max_{\theta \epsilon S} \left|\frac{P(\theta)}{P(\theta_0)}\right| \; F \le \; F_u \quad (2.7)$$

Here S is the space scanned by the angle θ excluding the main lobe. F is the 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 a 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 are separately presented as Objective-1(4.4.1) and Objective-2(4.4.2) as follows.

4.1. Side Lobe Level Optimization

As discussed above, 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 the 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, 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). The implementation of the FFA for circular arrays is as similar as that of the linear array synthesis which is discussed in the previous Chapter.
In this Section, the simulation-based experimentation for circular arrays is carried out with several numbers of elements ranging from N=10 to 40 with an interval of 10.

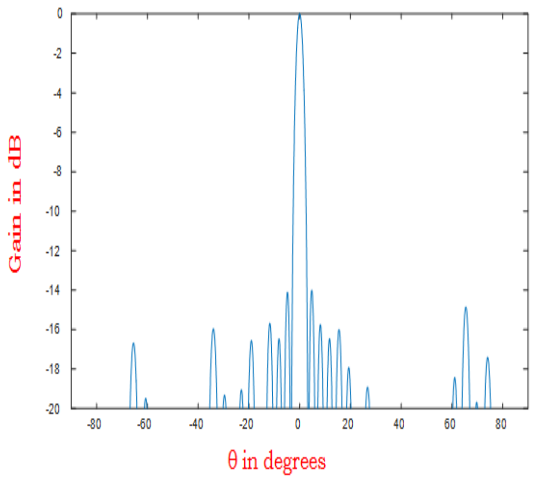

Fig.1.2: Radiation Pattern of Circular Array with 10 elements

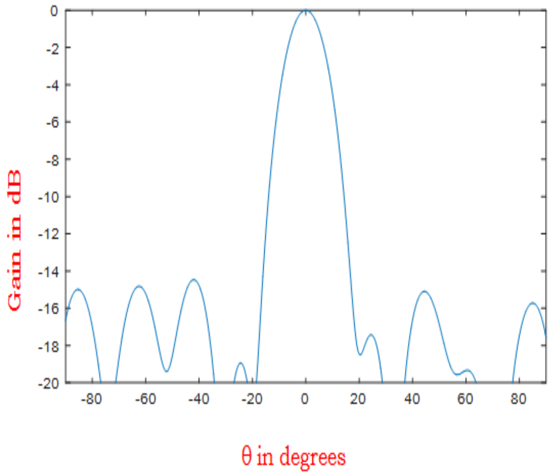

Fig.1.3: Radiation Pattern of Circular Array with 20 elements

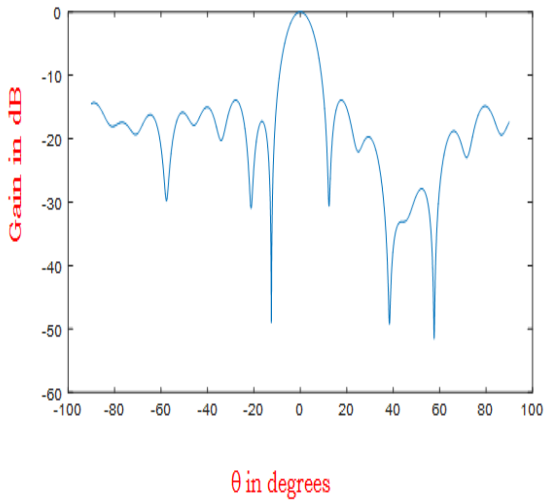

Fig.1.4: Radiation Pattern of Circular Array with 30 elements

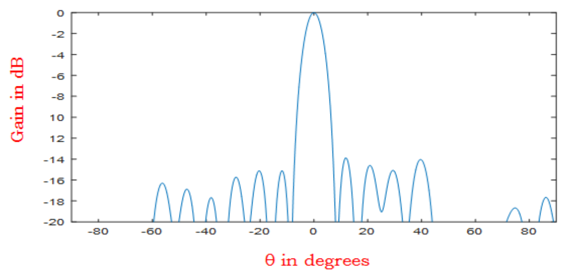

Fig.1.5: Radiation Pattern of Circular Array with 40 elements

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.1.1 for comparison. It is observed that N increases, Beam width decreases , SLL is also decreased. 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 in Figure 1.2 to 1.5 and shown in table 1.1

Table 1.1: Beam width and Side Lobe level Variations for number of Elements

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

4.2. Beamforming Optimization

It is evident from the preliminary literature survey that the array antenna works for the wireless applications should have the capability to accept as well reject the signals in multiple directions along with the several constraints imposed in terms of SLL and beam width. Considering this, an experimental framework has been designed that Hansen [4] the study of circular array capability in beam forming with constraints using an evolutionary algorithm like FFA. The following table describes the simulation-based experimentation framework 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, the 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 is designed contains weights that provide a radiation pattern with maximum SLL. 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 the design of non-uniform circular antenna array provides a considerable side lobe level reduction with respect to the uniform case.

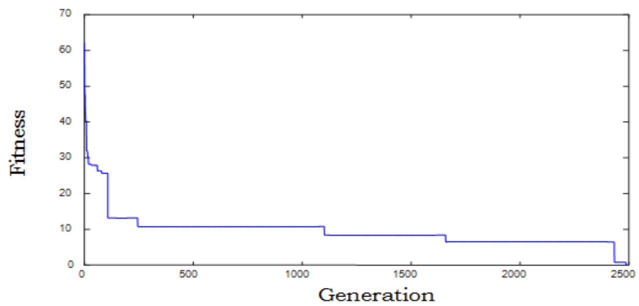

Fig.1.6 (a): Convergence Plot for RLS

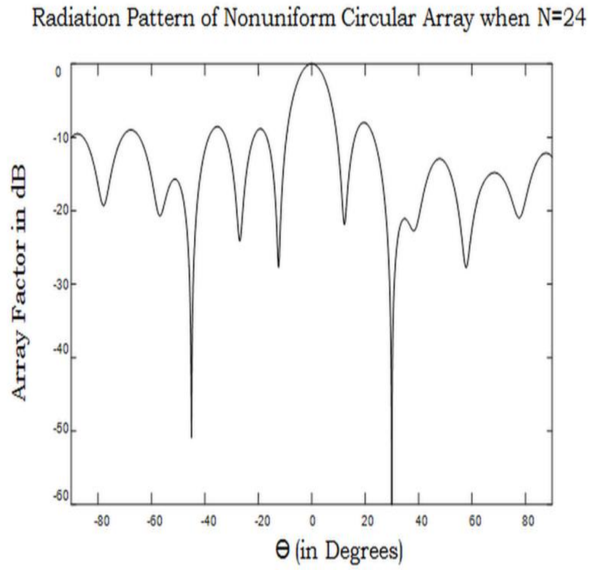

Fig .1.6(b): Radiation Pattern Plots for RLS

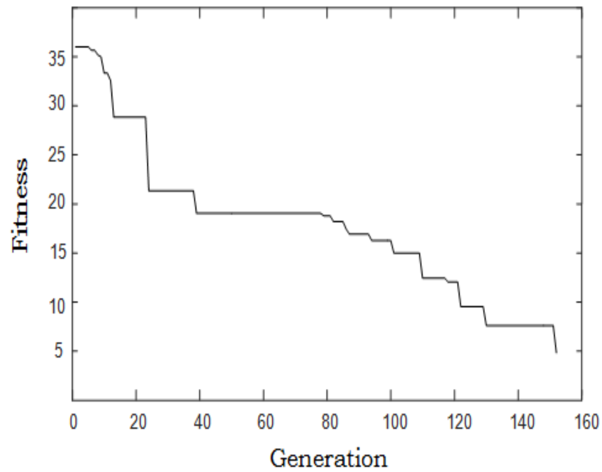

Fig.1.6 (c): Convergence Plot for FFA

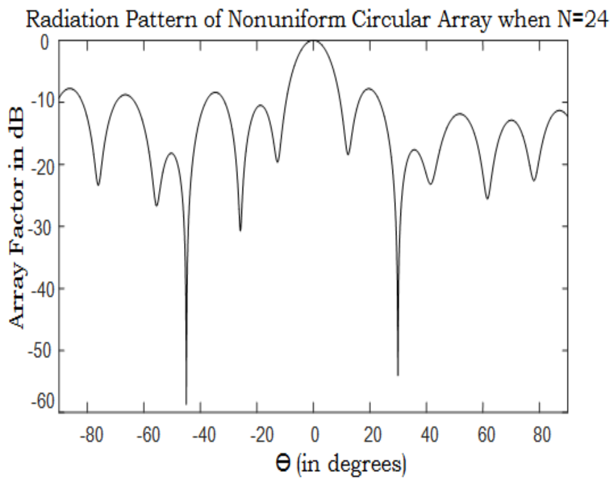

Fig.1.6(d): Radiation Pattern Plots for FFA

Fig.1.6 Convergence and Radiation pattern plots for Case-1a using (a-b) RLS and (c-d) FFA

Fig .1.6 (b) and (d) shows the radiation pattern of a non-uniform circular array for RLS and FFA algorithms are shown and their convergence plots are shown in fig .1.6 (a) and (c). The 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° and 30°.

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°,15°and 30°. Fig.1.7 (b-d) shows the radiation pattern of non-uniform circular array for RLS and FFA algorithms are shown and their convergence plots are shown in Fig 1.7 (a-c).

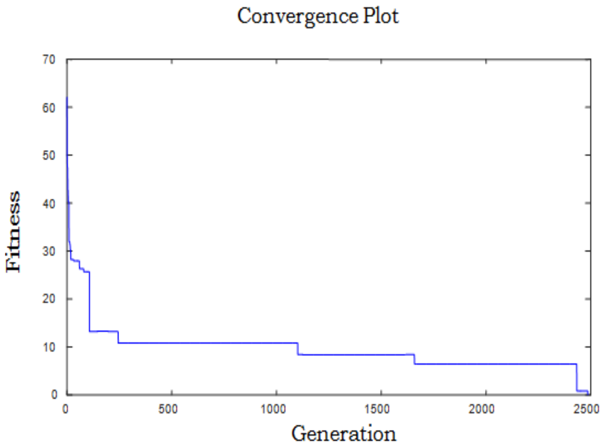

Fig.1.7 (a): Convergence Plot for RLS

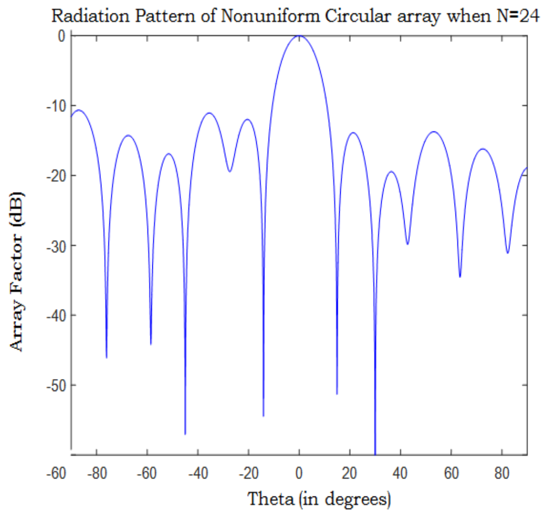

Fig.1.7(b): Radiation Pattern Plot for RLS

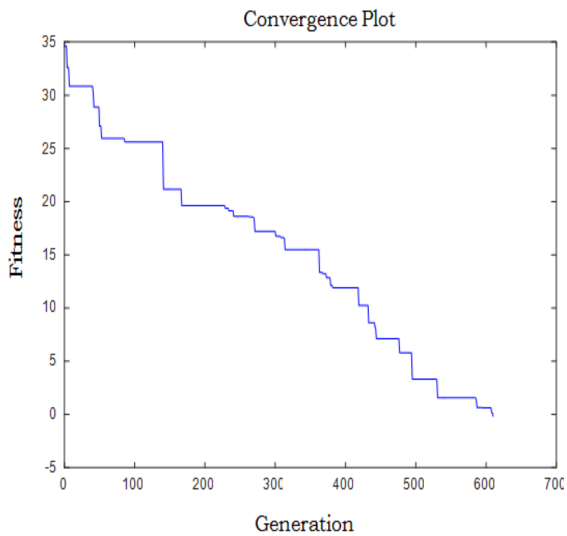

Fig.1.7(c): Convergence Plot for FFA

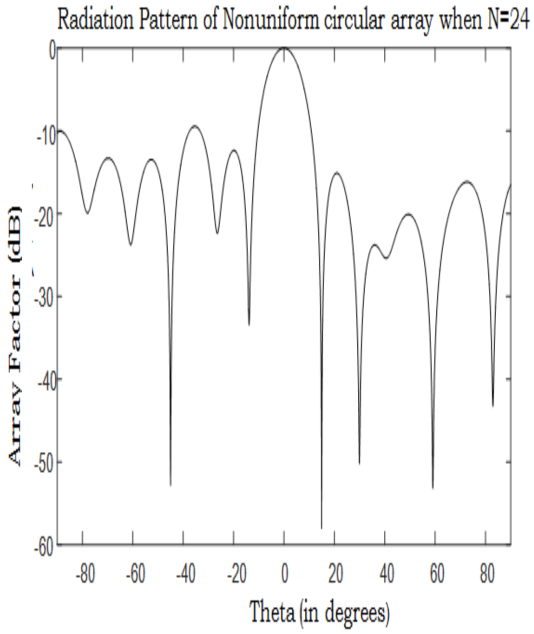

Fig.1.7 (d): Radiation Pattern Plot for FFA

Fig.1.7 Convergence and Radiation Pattern for Case-1b: (a-b) RLS and (c-d) FFA.
From the radiation pattern plots we can observe that there is a large reduction in SLL at various null positions found at -13dB for a non-uniform circular array.

Case-2a: The radiation pattern of a non-uniform circular array is as shown in Fig.1.8, and corresponding convergence plot is shown in fig a -15dB side lobe level less than a uniform circular array and corresponding beam width is 25°.

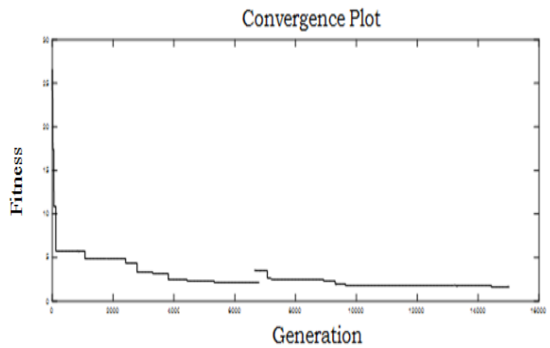

Fig.1.8 (a): Convergence Plot for RLS

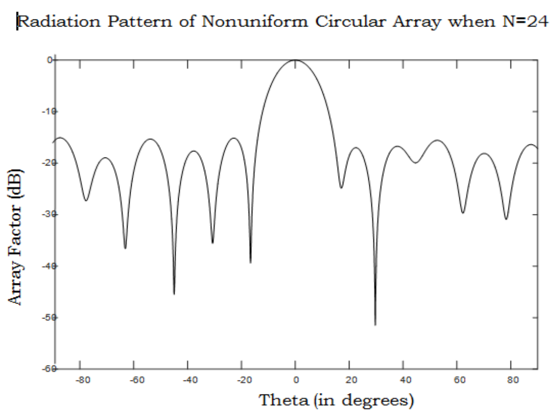

Fig.1.8 (b): Radiation Pattern Plots for RLS

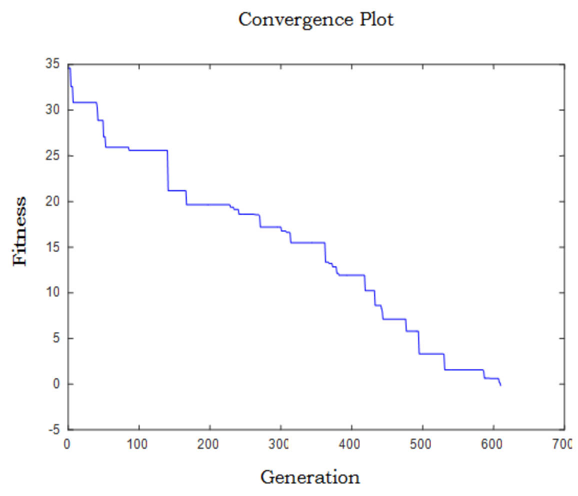

Fig.1.8 (c): Convergence Plot for FFA

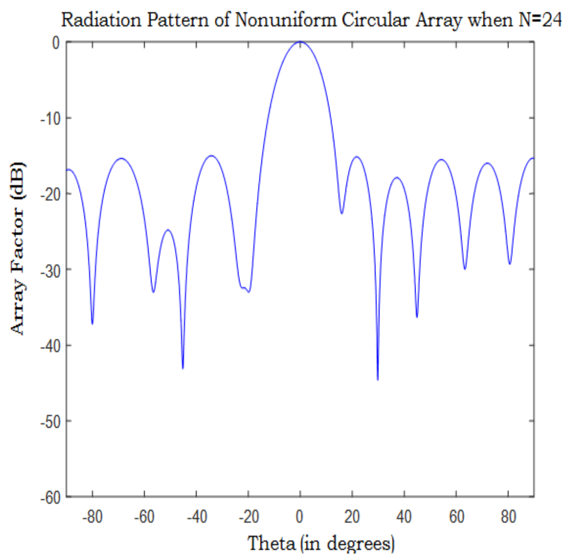

Fig .1.8 (d): Radiation Pattern Plots for FFA

Fig.1.8 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 Fig.1.9,and corresponding convergence plot is shown in Fig (a) has -15dB side lobe level less than uniform circular array and corresponding beam width is 40°

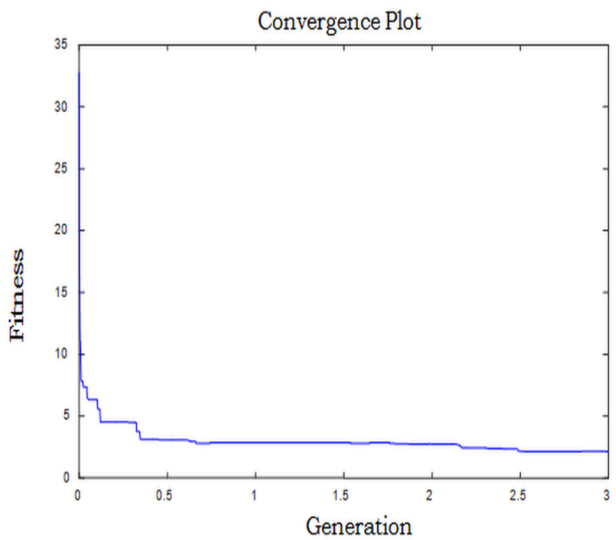

Fig.1.9 (a): Convergence Plot for RLS

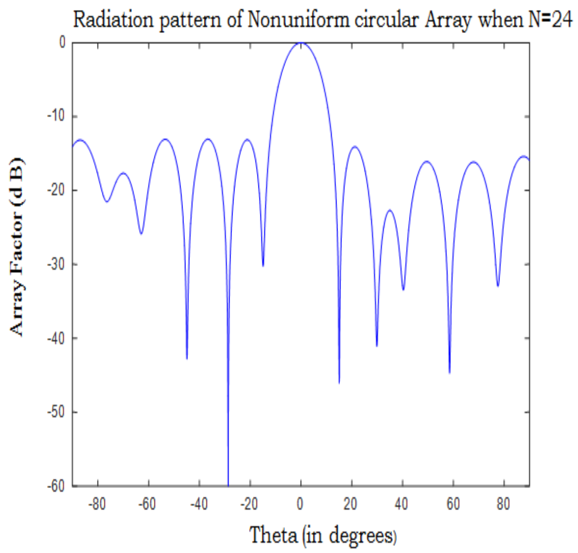

Fig.1.9 (b): Radiation Pattern Plots for RLS

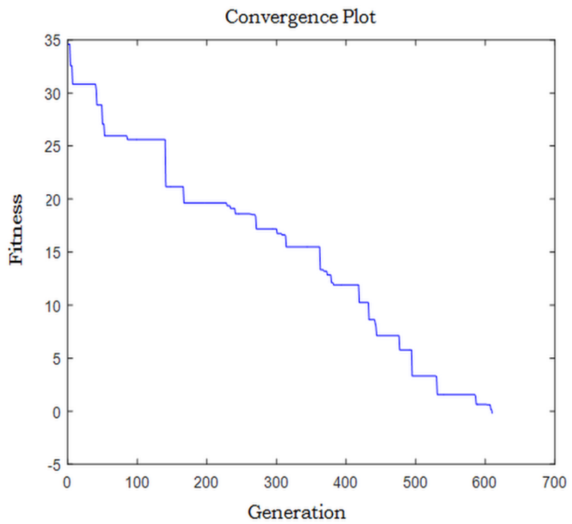

Fig.1.9 (c): Convergence Plot for FFA

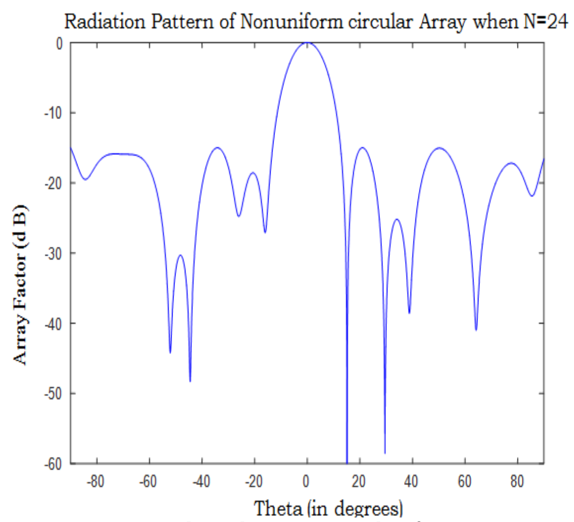

Fig.1.9 (d): Radiation Pattern Plots for FFA

Fig.1.9 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.

Table.1.2: Simulation Based Experimentation for SLL

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	

5.Conclusion

The FFA has emerged as a potential algorithm which is a population-based evolutionary technique in circular array synthesis. The two serious problems in the wireless communications is an 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 is best as they exhibit minimum mathematical complexity.

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