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Bio-Inspired Intelligent array for vehicle collision avoidance

A.V.L. Narayana Rao*[1], N. Bala Ankaiah[2] and Dharma Raj Cheruku[3]

ABSTRACT

This paper describes the application of Bio inspired Algorithm in minimizing size and complexity of arrays used for vehicle collision avoidance systems. These are meant for aerospace applications in Particular. Modified form of fire fly algorithm to optimize an intelligent array is introduced here. Process of thinning the array is proposed for minimizing elements number of elements. Since Array uses dipoles in horizontally alignment, it is treated as directive rather than Omni directional. Thus this paper performs towards development of thinned directive array optimization Which roots to the vehicle collision avoidance system. Mutual coupling of the array is also considered and analyzed because it is more effective in aero plane application. Finally, this paper puts path towards utility of Bio informative technology in signal processing and vehicle or transportation systems.

Keywords: Elliptical Array, Thinned Arrays, Fire fly algorithm, Side Lobe Level (SLL), Mutual coupling,

1. INTRODUCTION

Antenna array is the group of elements exited to attain the required radiation pattern in a required direction. Intelligent Antenna is widely useful in sonar, radar, mobile communication and high speed vehicle control applications [1]. An arrangement of the elements as geometry of an ellipse, is called elliptical shaped antenna array [2]. The elliptical shaped array is shown in Fig. 1 where 2m is major axis and 2n is minor axis respectively.

$$E = \sqrt{\left(1 - \frac{m^2}{n^2}\right)} \tag{1}$$

Elliptical configuration is defined by parameter, 'eccentricity' (E). It is given by the equation (1). In which Side lobe Level can be decreased effectively to improve performance of the antenna. The antenna Performance depends upon excitation of the elements, position, radiation mechanism and mutual inductance [3]. One of such controlling methods is thinning of the array.

During Thinning process some of the active elements are switched 'off'. A dummy load is connected or open circuited to create required amplitude density. The Purpose of thinning is to produced low side lobes [4].various thinning methods are available to reduce SLL [5, 6] out of which, the spastically thinned array by the proposed optimization technique is used in this paper [7]. The Optimization technique used is needed to reduce mutual coupling between the elements. This process improves performance of the array by increasing battery life [8]. The Proposed bio algorithm and Firefly Algorithm are discussed in the section 2.0[9].

In the section 3.0, Elliptical directive antenna [10] is formulated. Simulation results are developed using MATLAB for array pattern, directivity and proposed algorithm objective function optimization. Section 4.0 is the conclusion of this work.

*[1] Dept. of ECE, SSNCET, Ongole, AP, India, 2C S I R, Bangalore, India, *Email: narayanaavlrao@gmail.com*

[3] Dept. of ECE, GIT, GITAM University, Visakhapatnam, AP, India, *Emails: bala.nunna8@gmail.com, dharmarajc@yahoo.com*

2. FIREFLY ALGORITHM

Thinning and placement optimization are often done via genetic algorithm, like Firefly algorithm (FFA), particle swarm optimization, differential evolution, etc [1]. In this paper firefly algorithm (modified) is used to minimize SLL. The algorithm uses N, D vectors as the swarm and dimensional vectors of the population of each generation. Each swarm is represented by two vectors of real numbers I = [I1, I2, I3………IN], in the range [0.1] and d = [d1, d2, d3………dN] in the range[o.5λ,1λ]. Light intensity and the value of the fitness function are in proportional i.e. I(s) α f(s).

Light intensity given by equation (2) $I(r) = I_0 e -^{-\gamma r^2}$ (2)

Attractiveness is given by equation (3) $\beta(r) = \beta_0 e -^{-\gamma r^2}$ (3)

Here Io and γ are symbols of light intensity and absorption coefficient respectively. which can be taken as constant. The fireflies given in the equation (4):

$$X_i = \beta_0 * \exp\left(-\rho\delta_{ij}^2\right) * \left(X_1 - X_k\right) + \alpha_0 * \left(rand - 1/2\right) \quad (4)$$

present position of the kth firefly is denoted by first term . The attraction towards the more attractive firefly is given by the second term. In the third term α_0 is parameter of randomization. The step size is controlled between 0 and 1. Brightness and attractiveness of each firefly are estimated for each iteration. These values are used to update the positions of the fireflies. After the completion of sufficient iterations, all fireflies converge to the best possible position. The Array factor of elliptical antenna is given by equation (5)

$$A_F\left(\theta,\varnothing\right) = \Sigma_{n-1}^{N} I_n \exp\left(j\left[k\sin(\theta)\left(a\cos\left(\varnothing_n\right)\cos(\varnothing) + b\sin\left(\varnothing_n\right)\sin(\varnothing)\right) + \alpha_n\right]\right) \quad (5)$$

where

$$k = \frac{2\pi}{\lambda}, \varnothing_n = \frac{2\pi(n-1)}{N} \quad (6)$$

Normalized power of the array is given by equation (7)

$$P(\theta) = 20\log_{10}\left[\frac{\left|A_F(\theta)\right|}{\left\|A_F(\theta)\right|\max\right|}\right] \quad (7)$$

And Cost function / fitness function given by equation (8)

$$f(\bar{\rho}) = \max_{\theta\in S}\left|\frac{A_F^{\bar{\rho}}(\theta)}{A_F^{\bar{\rho}}(\theta_0)}\right| \quad (8)$$

where the span of angle θ is *S* without considering the main lobe. The parameter vector $(\bar{\rho})$ for element positions and position-amplitudes is given by the equation (9)

$$\bar{p} = \{d_n, I_n\}, 0 \le n \le (N-1) \quad (9)$$

Algorithm:

Step 1: Define Fitness function:

Step 2: Generate 'N' firefly population initially.

Step 3: Define the absorption coefficient of the light

Step 4: if It equals 1, then

Step 5: *for* k = 1: N

for l = 1: k

if($I_l > I_k$)

Move firefly k towards l in d-dimension;

Else

k^{th} Firefly moves randomly

End if

Brightness depends on distance r, hence evaluate new solutions using fitness function. Now, intensity light of can be updated since brightness is treated as attractiveness.

End for l

End for k

Step 6: Find the Local best by ranking Fireflies.

Step 7: if It < Max It, then

Step 8: Stop and Post process results and visualization

Otherwise It = It + 1 and repeat steps 5, 6.

2.1. Proposed Algorithm

The proposed algorithm given here finds displacements between the elements for better SLL. Which is the modified form of FireFly Algorithm with Gaussian Distribution function (GD_FFA). In FFA Flies moves in the space for optimization with pre defined step randomly. In the proposed algorithm all flies are made to move in similar manner and the step value is assigned by Gaussian. At the end of the each iteration, error between best value and fitness function is corrected with a random number given by the Gaussian. Thus iterations required for convergence are minimized.

Modified FireFly Algorithm (GD_FFA):

Step 1: Input data of elliptical array parameters (Eccentricity, HPBW) and Firefly parameters,

Define objective function:

$$f\left(\bar{\rho}\right) = \max_{\theta \in S} \left| \frac{A_F^{\bar{\rho}}\left(\theta\right)}{A_F^{\bar{\rho}}\left(\theta_0\right)} \right| \quad (11)$$

Step 2: Generate initial population (N) of fireflies

$$x_{id} = \left[x_{i1}, x_{i2}, ..., x_{id}\right] (12)$$

Step 3: I_i (Light intensity) at x_k is defined by Objective function $f(x_k)$. Determine γ (light absorption Coefficient)

Step 4: **if It equals1,then**

Step 5: *for* k=1:N

for l=1:k

if($I_j > I_i$)

Move firefly k towards l in d-dimension; $X_k = \beta_0 * \exp\left(-\rho\delta_{kl}^2\right) * \left(X_1 - X_k\right) + \alpha_0 * \left(rand - 1/2\right)$

Else Firefly i can be moved towards best solution.

end if

Attractiveness can be varied along with the distance r= via , using objective function new solutions can be evaluated and light intensity can be Updated.

end for l

end for k

Step 6: Find the Local best by ranking the fireflies

Step 7: Define the normal distribution

Step 8: For i = 1: N, Now, a random number from normal distribution can be applied in the equation

$\rho = f\left(x/\mu,\delta\right) = \frac{1}{\delta\sqrt{2\pi}} e \frac{-\left(x-\mu\right)^2}{2\delta^2}$ best solution and fitness of fire fly k is x = $f(g_{best})$-$f(x_k)$

Update of x is given by $x_k = x_k + \alpha * (1 - \rho) * \text{rand}\ (\ )$

Step 9: Evaluate new solution for new_cost (k)

Step 10: If((new_cost (i)<cost function (k))&(new_cost(i)< least _cost for the iteration (i)))

Step 11: Firefly can be moved towards k Local best

end if

end for i

Step 12: **if It < Max It, then**

Step 13: Stop and Post process results and visualization

Otherwise It = It + 1 and **repeat steps 5, 6.**

3. DIRECTIVE ELLIPTICAL ANTENNA

The figure1 shows elliptical array. Array factor of the antenna is given by the equation

$$A_F\left(\theta,\varnothing\right) = \sum_{n-1}^{N} I_0 \exp\left(j\left[k\sin\left(\theta\right)\left(a\cos\left(\varnothing_n\right)\cos\left(\varnothing\right) + b\sin\left(\varnothing_n\right)\sin\left(\varnothing\right)\right) + \alpha_0\right]\right)$$

Where I_0 is the amplitude when excited and α_o is the phase of the o^{th} element = elevation angle from z axis: $ø_n$ is the azimuth angle measured from the x-axis for n^{th} element: 2m, 2n are major and minor axis respectively: E = Eccentricity

which is 0.48 in the proposed array:

$$\alpha_n = -k\sin\left(\theta_0\right)\left(a\cos\left(\varnothing_n\right)\cos\left(\phi_0\right) + b\sin\left(\varnothing_n\right)\sin\left(\phi_0\right)\right) \quad (13)$$

If the elements used in the array are dipoles in horizontal alignment, its pattern function is as below

Pattern function is given by $f\left(\varnothing\right) = \frac{\cos\left(\pi/2a\cos\left(\phi\right)\right)}{b\sin\phi} b\sin\left(\frac{\pi}{2}\sin\varnothing\right)$

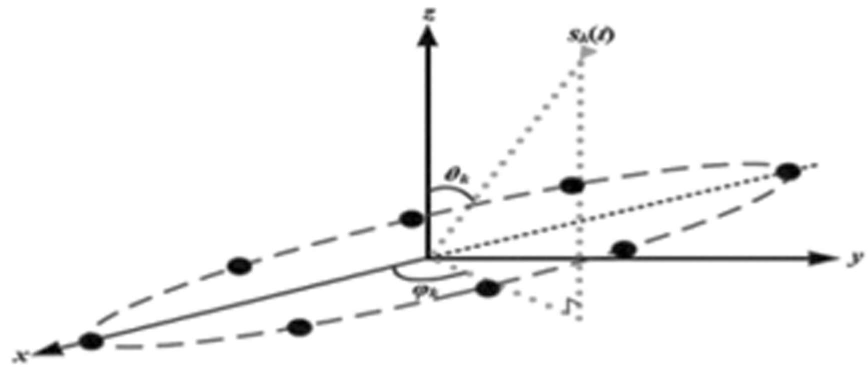

Figure 1: The ellipse-antenna geometry in 2D-plane

4. RESULTS

Simulation results are obtained using MATLAB7.0. The result uses MSWORD as well for comparing real and imaginary parts of mutual coupling values graphically. Three sections of results are given below in this work.

4.1. Thinned and Elliptical arrays

Optimized results of the thinned elliptical array with Firefly algorithm hybrid with Gaussian distribution are shown in Figures 2-9. In which Array Factor, the polar pattern for number of the elements 40,100 are

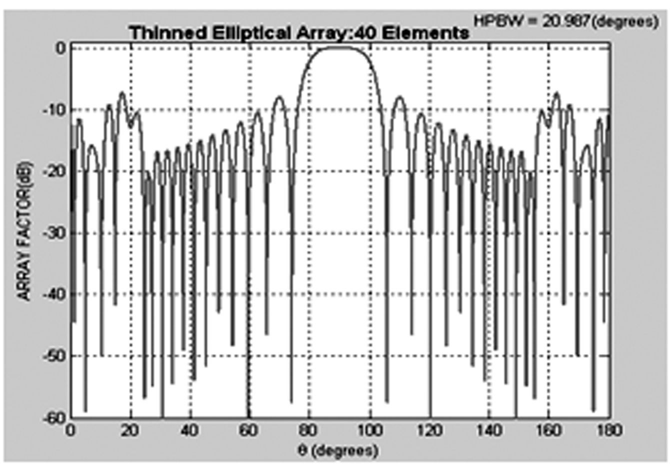

Figure 2: Thinned Elliptical Array with the GD_FFA (N=40)

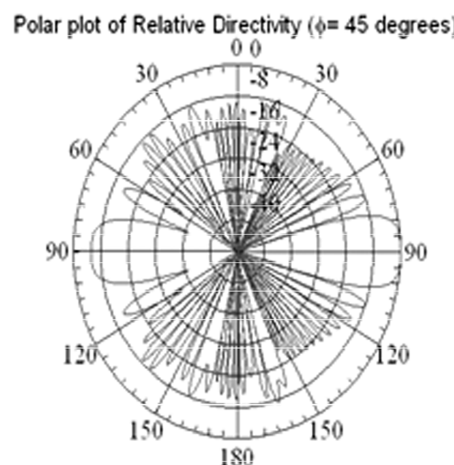

Figure 3: Polar plot _Thinned Elliptical Array: GD_FFA (N=40)

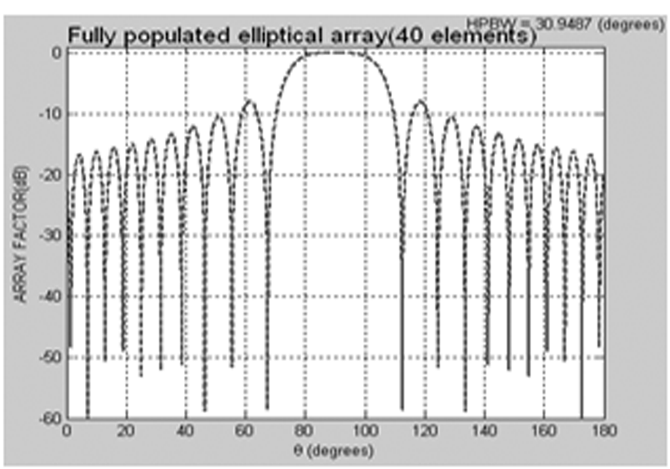

Figure 4: Fully populated Array (N=40)

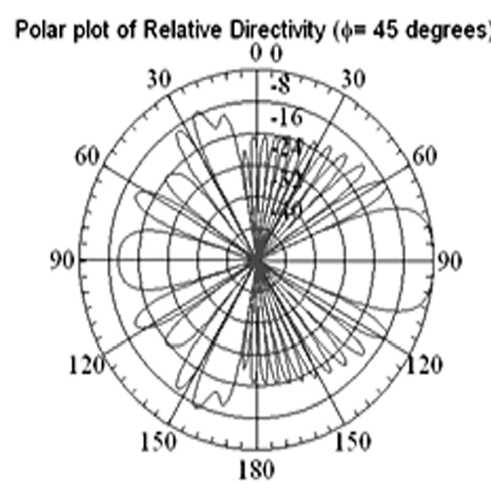

Figure 5: Polar plot Fully populated Array (N=40)

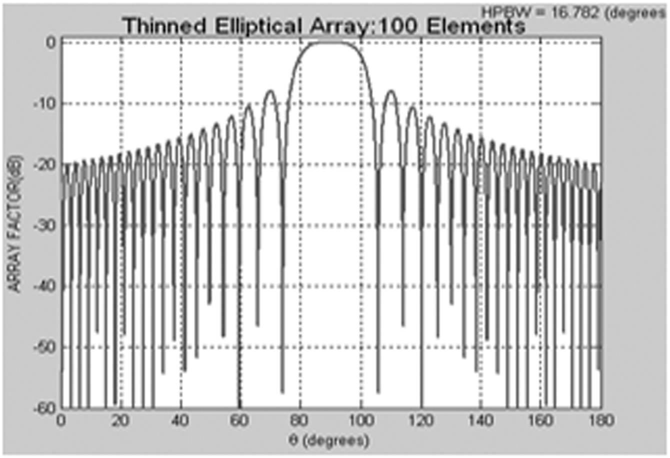

Figure 6: Thinned Array :GD_FFA(N=100)

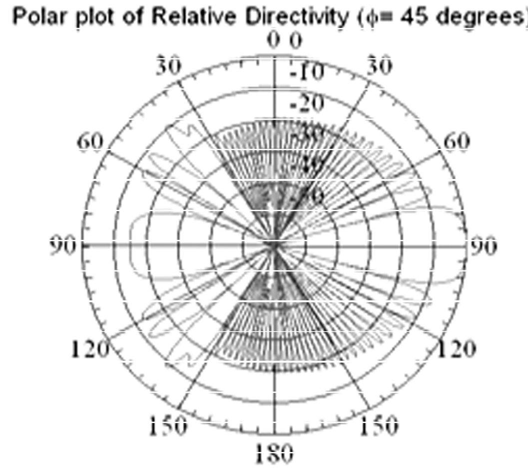

Figure 7: Polar plot Thinned Array :GD_FFA (N=100)

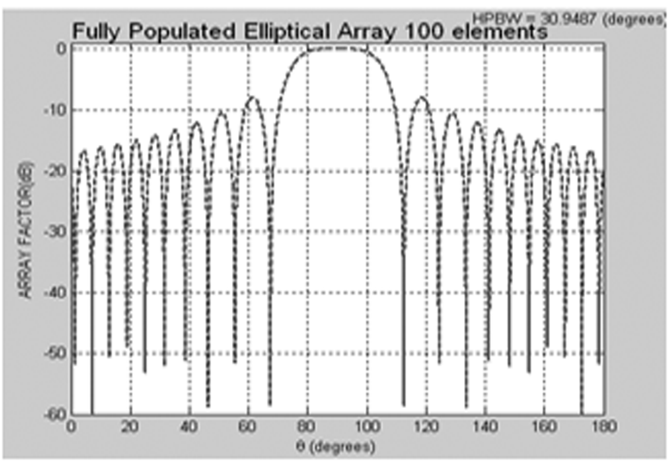

Figure 8: Fully populated Elliptical Array(FPA:N=100)

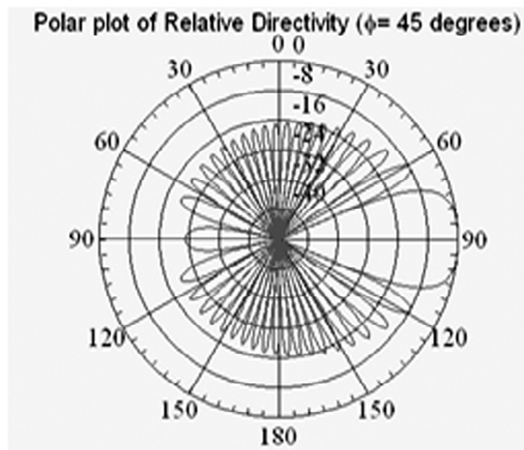

Figure 9: Polar plot Fully populated Array (N=100)

compared. The Array factor for thinned array is nearly same as the fully populated array with number of the elements reduced by nearly 31%.Example is array of 40 elements array equals in patter with 28 element array which is evident from Fig. 2. Hence thinned array has less elements. Polar plots are obtained for Ø = 45^0. Similarly, for N = 100 array, equals with 71 elements. The Beam width for thinned arrays is 35% narrow to the beam width of fully populated arrays. Observe fig 2-9.

4.2. Directivity and Side lobe level (SLL)

The figures 10-13 shows the ability of Gaussian _Distribution FireFly Algorithm in improving main beam parameters like beam width, Side lobe level, directivity and figures 14-20 shows the comparison of GD_FFA with FFA.

Table 1
Radiation parameters of Elliptical Array

No of Elements	*Eccentricity*	*Directivity of elliptical array (dB)*		*SLL (Thinned) dB*	*SLL (FPA) dB*
		Thinned	*Fully populated (FPA)*		
40	0.5	13.885	15.078	6.8	7.0
100	0.5	16.317	17.742	7.5	9.8

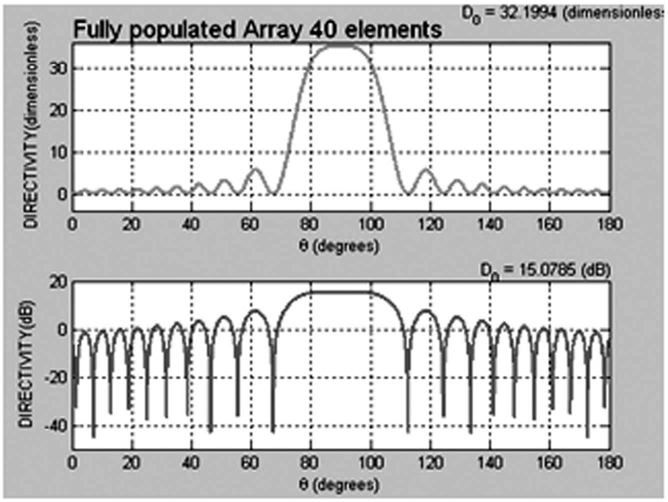

Figure 10: Directivity of FPA (N=40)

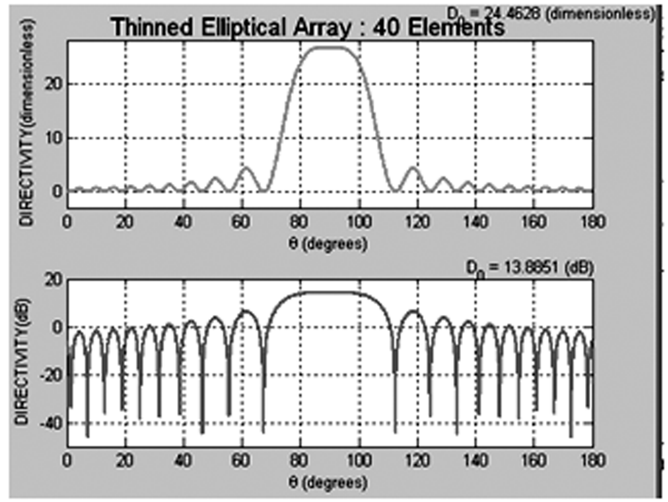

Figure 11: Directivity of Thinned Array : GD_FFA(N=40)

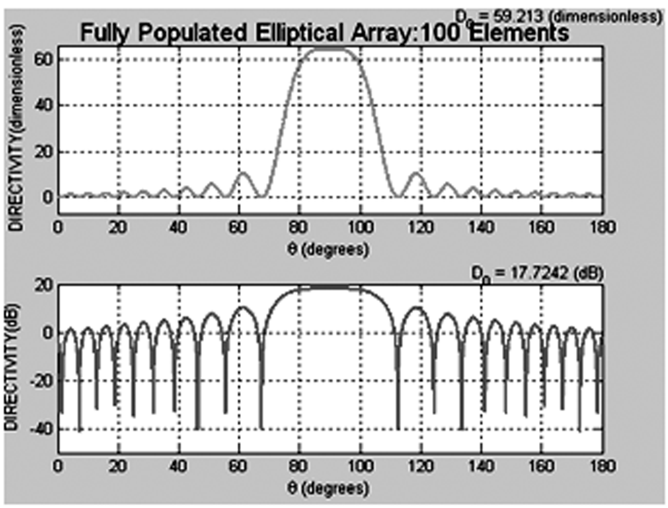

Figure 12: Directivity of FPA (N=100)

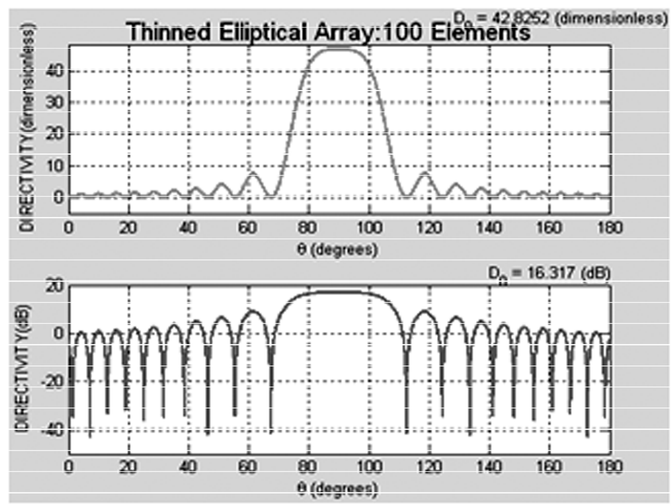

Figure 13: Directivity of Thinned Array :GD_FFA(N=100)

4.3. Proposed and standard firefly algorithm

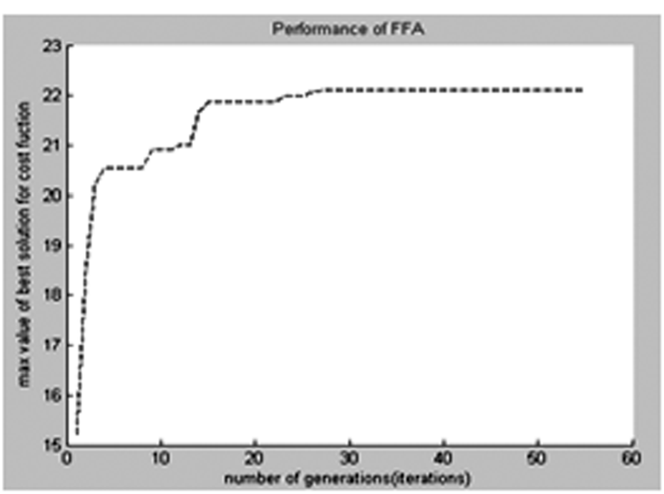

Figure 14: Iterations vs C.F of FPA(N=40)

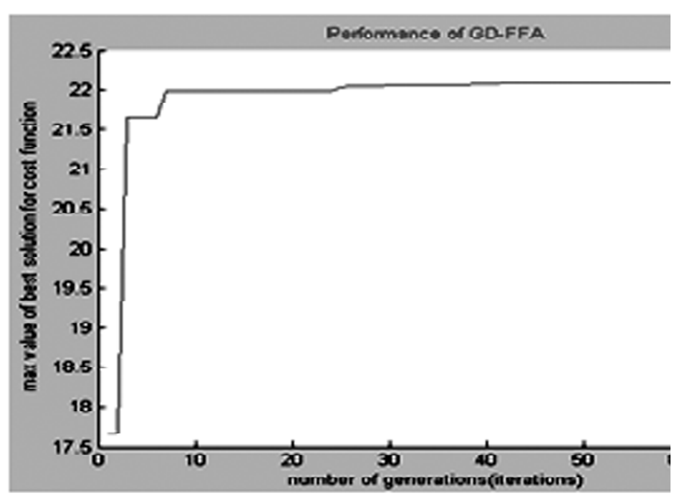

Figure 15: Iterations vs C.F of Thinned Array with GD_FFA(N=40)

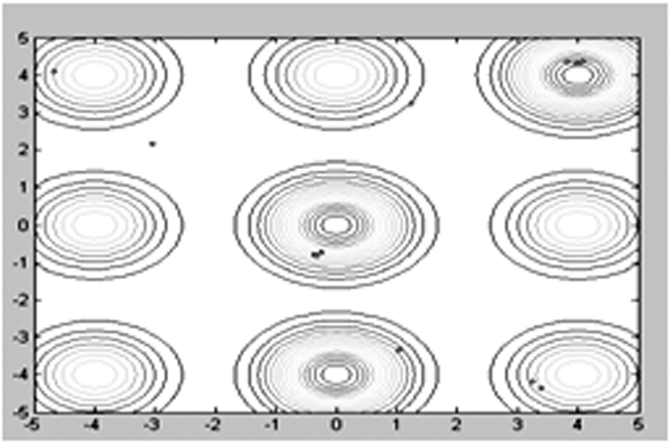

Figure 16: Contours of local best function during FFA

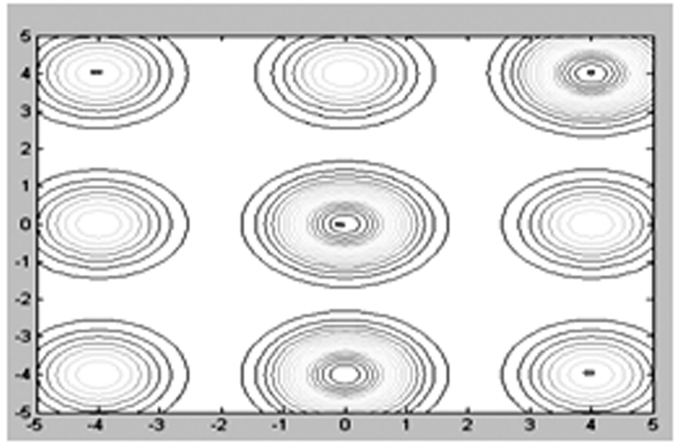

Figure 17: Contours of local best function after FFA

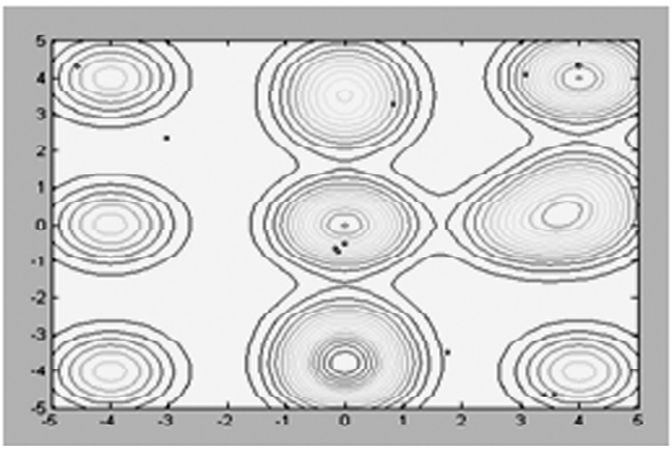

Figure 18: Contours of local best function after optimization: GD_FFA

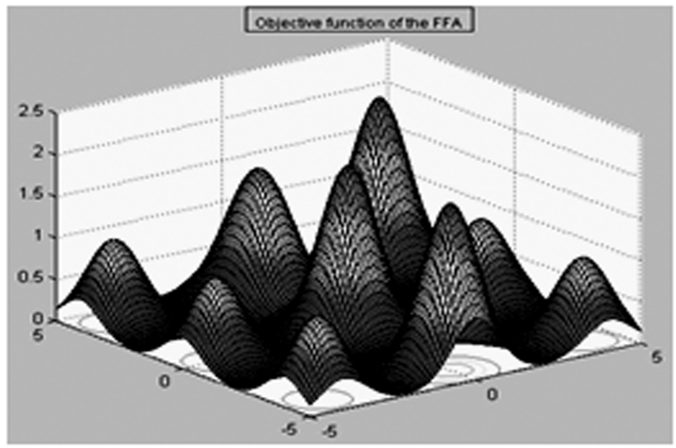

Figure 19: Objective function (local best cost function): FFA

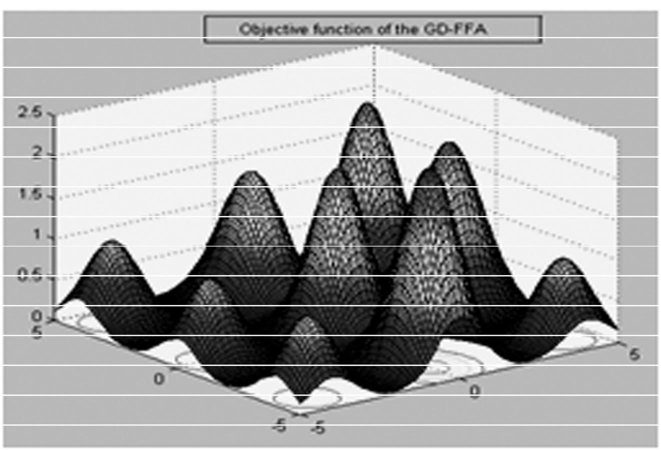

Figure 20: Objective function (local best cost function) : GD_FFA

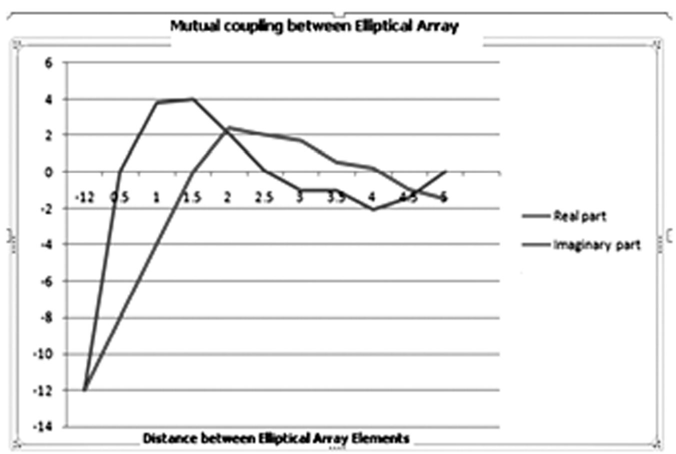

Figure 21: Mutual coupling between the elements of Thinned l Array

4.4. Effect of Mutual coupling in Thinned Elliptical Array

Figure.21 and Table 2 are presented here to show the effect of proposed algorithm on reduction of mutual coupling. Table 2 shows that array has more effect of coupling in iteration 3. It means corresponding inter element spacing coups with coupling.

Table 2
Mutual coupling between the elements of (Thinned) Elliptical Array: N=40

Iteration	Z1,7	Z2,8	Z13,19	Z24,30	Z34,40
1	0.8+3.1J	2.8+1.6j	4.5-0.2j	5.4-1.4j	6.6-2.1j
10	0.8+3.0J	2.4+1.9j	4.3-0.4j	5.2-1.6j	6.5-2.0j
30	1.2+2.8J	2.8+1.6j	3.9-1.2j	4.8-2.1j	6.6-2.1j

5. CONCLUSION

The simulation results give the final conclusions as below:

- Thinning by Gaussian FireFly Algorithm results in 31% of reduction in number of elements and minimum of 35% in beam width than the normal arrays.
- Directivity reduces slightly, but performance is not affected, because Side lobe level decreases.
- The Proposed (GD_FFA) Algorithm leads FFA in convergence speed by 33%.
- Mutual coupling between the elements is more for end elements of major axis either side. Hence optimized coupling is possible with suitable eccentricity.

Final conclusion of this work paves the way for bio inspired algorithm utility in antenna design, particularly in directive antennas of non circular arrays in applications of vehicle collision avoidance.

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