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Optimization Of Linear Antenna Array Using Firefly Algorithm

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Abstract

Electromagnetic problems are becoming exceedingly complex due to the new requirements and limitation enforced by the highly evolving system of wireless communications. Antenna array is the most important aspect to improve the communication process. The Parametric optimization methods like Taguchi's Optimization Method (TM), Particle swarm optimization (PSO), Self-Adaptive Differential Evolution (SADE), Firefly algorithm (FA) are the centre of attention in range of optimization problems. In this paper, amplitude excitation of array element is controlled by addressing FA to solve the problem of linear antenna array synthesis. Our results are also compared with PSO, TM and SADE which clearly indicates that firefly algorithm provides significant enhancements than existing met-heuristic algorithm for desired shaped pattern. The effectiveness of FA for linear antenna array is revealed by way of numerical results.

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1. Introduction

Wireless communication has enjoyed unstable enlargement over the past few decades. The wireless communication technology has grown by leaps and bounds and has become part and parcel of our daily life. In the present time, electromagnetic problems are becoming exceedingly complex due to the new requirements and limitation enforced by the highly evolving system of wireless communications. Antennas are the integral part of all the communication technologies. Also, the radiation pattern of antenna array is achieved by controlling main lobe width and enhancing the gain value to be maximum and reducing the SLL to minimal. In linear antenna array, the spacing between the isotropic elements of array is identical. From the previous studies, different stochastic methods have been employed to overcome the different antenna design problems. Algorithms like PSO [1, 2], SADE [3] and Taguchi's methods [4, 5] have been in use to find phase and magnitude of excitation currents of the array elements. Earlier, Liu et al. in [6] recommended a new technique for the synthesis of linear array with shaped power pattern. Panduro [7] has designed non-uniform linear phased arrays using genetic algorithms to provide maximum interference reduction capability in a wireless communication system. In this paper, newly developed FA algorithm [8-10] is used for synthesis of linear antenna array by controlling the elements excitation in order to minimize the SLL where HPBW and FNBW of the pattern are kept within specified constraints. The result obtained by the FA techniques seems to be superior to other techniques in terms of finding optimum solutions for the desired beam patterns of linear antenna array. This survey implies that the Firefly algorithm provides considerable enhancements than existing met-heuristic algorithm for desired radiation pattern with reducing SLL and nulls**.**

2. Problem Formulation

An antenna array is said to be linear if all the elements of the antenna are spaced at an equal distances *d* (that is d in the spacing between adjutant antenna is a constant) along a straight line [11]. In this problem, for a 2*N*-element symmetrical array placed on the *x*-axis shown in Figure 1, the array factor (AF) can be written as:

$$AF(\phi) = 2\sum_{n=1}^{N} A_n \cos[kx_n \sin(\phi) + \varphi] \quad (1)$$

Clearly as can be observed from above equations AF depends upon three parameters: the Amplitudes, the phases, and positions of the elements. In this work, FA is used to design linear antennas by optimizing amplitude excitation of array element.

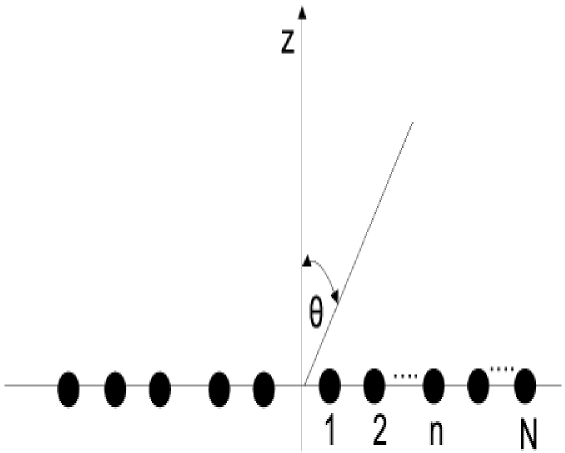

Figure 1. Geometry of 2*N*-element symmetric linear array placed along the *x*-axis.

3. Algorithm Detail and Parametric Arrangement

Firefly algorithm is a comparatively brand new member of swarm brainpower family [8-10]. Swarm intelligence is branch of nature motivated algorithms, which focused on insect behavior in order to grow some meta-heuristics, which can mimic insect's problem solution abilities. Ant colony optimization, particle swarm optimization, Cuckoo optimization etc. are some of the renowned algorithms that mimic insect behavior in problem modeling and result. The fireflies use bioluminescence with different flashing pattern for communication with each other, search for pray and to find mates. To develop a firefly inspired algorithm, some of the uniqueness of fireflies has been idealized [12]. For simplicity, only three idealized rules have been used: 1) All fireflies are unisex so that one firefly will be attracted toward the other fireflies without considering their sex; 2) Attractiveness is proportional to brightness of the fireflies. For any two flashing fireflies, the fireflies with less brightness will move towards the brighter one. Attractiveness is proportional to the intensity of the two fireflies, which decreases with increasing distance between them that means attractiveness is proportional to the brightness. If there are no brighter fireflies than a particular fireflies then this individual fireflies will move randomly in the space; 3) the brightness of a fireflies is determined by the cost function of the problem. For an optimization problem, brightness can simply be proportional to the value of the objective/cost function.

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STEP 1 (Initialization): In present problem [8, 9], first initialize the position of P fireflies in D dimensional search space with in a search margin is given as

$$x_{pd}(0) = rand_{pd}(0,1)\,(x_{pd}^{U} - x_{pd}^{L}) + x_{pd}^{L} \quad (2)$$

$$p = 1, 2, 3 \ldots P; \; d = 1, 2, 3 \ldots D \quad (3)$$

Where x_{pd}^{U} and x_{pd}^{L} indicates the upper and lower limits of the d[th] variable in the population respectively, $rand_{pd}$ (0,1) is a regularly circulated random value within [0,1].

STEP 2 (Compute the brightness or light intensity of firefly): Calculate the intensity I of firefly at exacting place x can be taken as for maximization problem and minimization problem in x correspondingly

$$I(x) \propto f(x) \quad (4)$$

$$I(x) \propto 1/f(x) \quad (5)$$

STEP 3 (compute current global best and Rank the fireflies): Ranking of firefly depends on their brightness in present generation. Current global best(g_{BEST}) allocate the location of the brightest firefly in population and corresponding intensity as best fitness value at present generation.

STEP 4 (Update of the location of the fireflies through their movements): In this, each firefly tends to move in the direction of another firefly with bright light intensity and update the position of next iteration of algorithm. The attraction of a firefly is evaluated by the light intensity that depends on encoded cost function. Also the locality of both the fireflies i.e. moving and brighter firefly rely on attraction between them.

The attraction within the fireflies i.e. p and k in the D dimensional search space given by

$$x_p = x_p + \beta_0 e^{-\gamma r^2} pk(\, x_p - x_k \,) + \alpha\varepsilon_p \quad (6)$$

where the different parameters of the above equation like ε_p is a vector of random numbers calculated from Gaussian distribution , α is a randomization parameter, γ is light absorption coefficient for given medium and attraction among the fireflies is given by product of β_0 and $e^{-\gamma r^2} pk$. Cartesian distance for β_0 attraction is given by r = 0 and is calculated by

$$r_{pk} = \| x_p - x_k \| = \sqrt{\sum_{d=1}^{D} (x_{p,d} - x_{k,d})^2} \quad (7)$$

In this algorithm fireflies change their locality according to eq. (6) while the brightest firefly is holed at the current generation on a fixed location. Hence,(g_{BEST}) solution is slowly updated in the successive iteration algorithm.

STEP 5: Repeat steps from 2 to 4 until the iterations numbers are not completed .this will give the best firefly (g_{BEST})locality for the global solution and corresponding brightness of firefly gives the most favorable fitness value of the objective function using firefly algorithm.

4. Simulation Results and Discussion

This section deals with application of FA for minimizing SLL of arrays by optimizing element positions, current excitations and phases of elements. The objective is to have an antenna which has radiation pattern with minimum possible SLL. The fitness function used to achieve the desired antenna can be written as:

$$Fitness = \min(\max\{20\log|AF(\phi)|\}$$

Subject to $\phi_{SLL} \in \{[0^0, \phi_1] \& [\phi_2, 180^0]\}$ (8)

Where, ϕ_{SLL} is the angular space outside the main lobe. This function will minimize the side lobes in the antenna array radiation pattern. The following FA parameters are used:

- Number of fireflies or population=20
- Iterations or Generations =400
- Attractiveness $\beta_{0=}$0.20
- Absorption coefficient γ=0.25

For optimizing amplitude, parameters x_n, φ_n are fixed where φ_n is taken as zero and the spacing between the adjacent elements is taken as $\lambda/2$, n=1, .N. Due to even symmetry the position of first element is assumed to be at $x_{1=}$ $\lambda/4$.

4.1 LAA Optimization 10 Elements

For the first example, a 10-element linear antenna is considered. The number of element amplitudes to be optimized is five due to symmetry. It took only 20 seconds to run this optimization. The values of the amplitude are decreasing from the centre of the array to the edges. The maximum SLL obtained using FA is -26.72 dB while those obtained by SADE (Dib *et al.*,2010) TM (Dib *et al.*,2010), PSO (Khodier and Aqeel, 2009)[13] are -24.81 dB, -24.41 dB,-24.62 dB and that of uniform array is -13 dB. Hence, the FA optimized array offers reduced SLL as compared to other techniques. The smooth amplitude distribution makes it feasible to use power dividers. However, the beam width of FA obtained antenna is slightly more than the PSO antenna array. But it is well known fact that if SLL decreases the beam width will increase (Balanis, 1997) [14]. Figure 4 shows the convergence of the fitness function versus the iteration number. The normalized results from the optimization are given in Table 1**.**

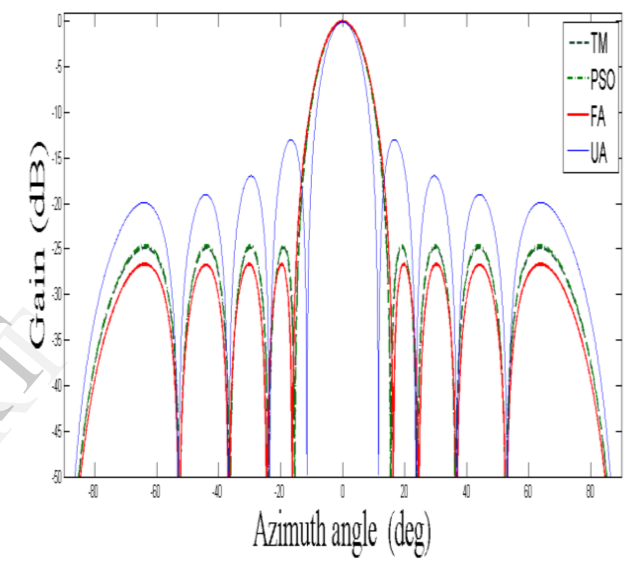

Figure 2. Radiation pattern of 10 elements $\lambda/2$ spaced array optimized with FA with respect to amplitude.

Table 1. 2*N* = 10 elements optimized using FA with respect to amplitudes constraint compared with TM, SADE, PSO method (the values are normalized)

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I_N				
N	**TM**	**SADE**	**PSO**	**FA**
1	1.000	1.000	1.0000	1.0000
2	0.8999	.9028	0.9010	0.8913
3	0.7228	.7277	0.7255	0.7036
4	0.5077	.5153	0.5120	0.4787
5	0.3994	.4158	0.4088	0.3397
SLL (dB)	**-24.88**	**-24.41**	**-24.67**	**-26.72**

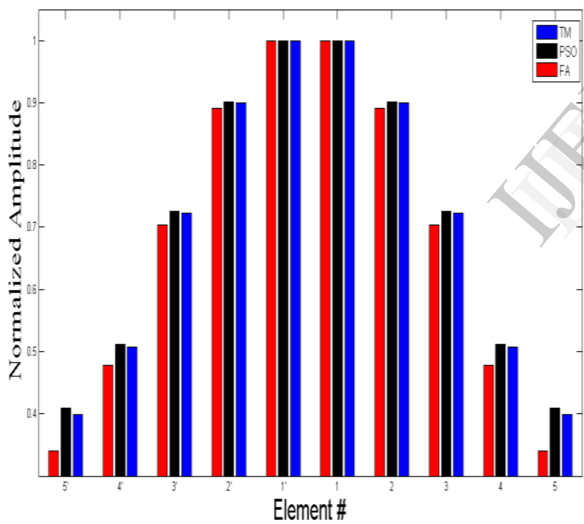

Figure 3. Normalized amplitude distribution ||*In*|| of array elements using FA

The amplitude distributions along the array elements are shown in Figure 2 and Figure 3 shows the normalized amplitude distribution ||*In*||of array elements using FA compared with other Techniques. Also results obtained from other algorithms such as SADE, TM and PSO are also listed for comparison.

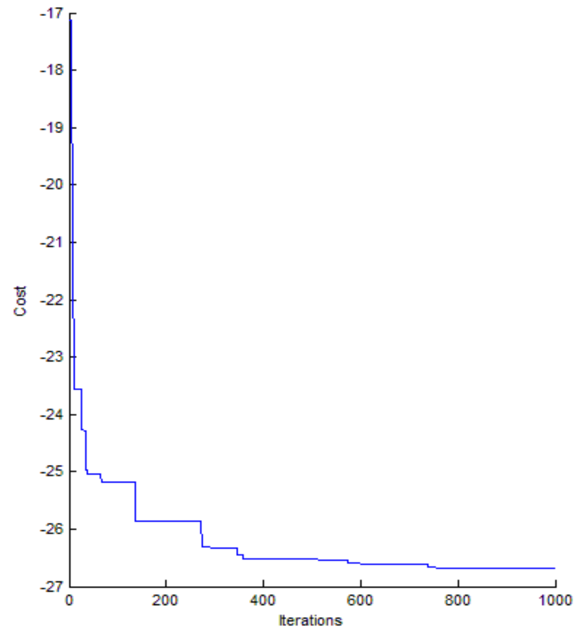

Figure 4. Convergence curves of the fitness value of the 10 elements λ/2 spaced LA.

4.2 LAA Optimization 16 Elements

In this example, a 16-element LAA is optimized using FA method. The best results are listed in Table 2. Figure 5 shows the radiation pattern obtained by FA compared to other methods and Figure 6 shows the normalized amplitude distribution ||*In*||of array elements using FA compared with other Techniques. The maximum SLL obtained using FA method is -33.06 dB, while that obtained using the SADE, PSO, TM and the uniform array is -31.06 dB, -30.7 dB, -31.31 dB, -13.15 dB, respectively. The maximum SLL obtained using FA is less than the uniform one by about 19.91 dB and is also better than the PSO results in [13] by about 2.36 dB.

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Table 2. 2*N* = 16 elements optimized using FA with respect to amplitudes compared with TM, SADE, PSO methods (the values are normalized).

N	TM	SADE	PSO	FA
1	1.0000	1.0000	1.0000	0.9303
2	0.9500	0.9515	0.9521	0.8821
3	0.8575	0.8586	0.8605	0.7936
4	0.7317	0.7333	0.7372	0.6730
5	0.5861	0.5889	0.5940	0.5361
6	0.4381	0.4404	0.4465	0.3956
7	0.2988	0.3020	0.3079	0.2661
8	0.2552	0.2616	0.2724	0.2180
SLL (dB)	**-31.31**	**-31.06**	**-30.70**	**-33.06**

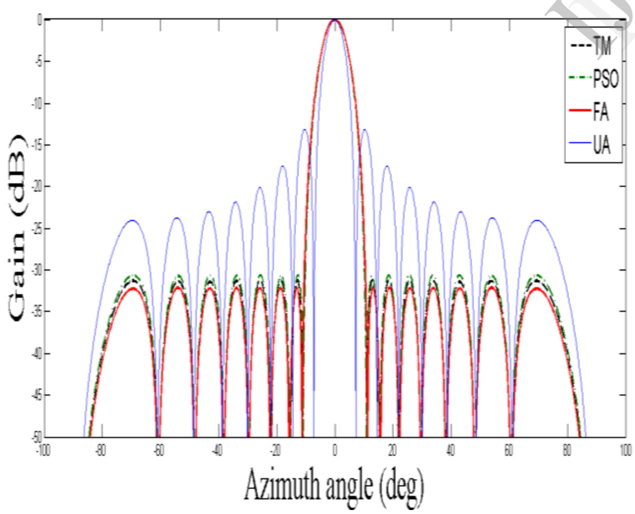

Figure 5. Radiation pattern of 16 elements $\lambda/2$

spaced optimized using FA with respect to amplitudes, compared with conventional array

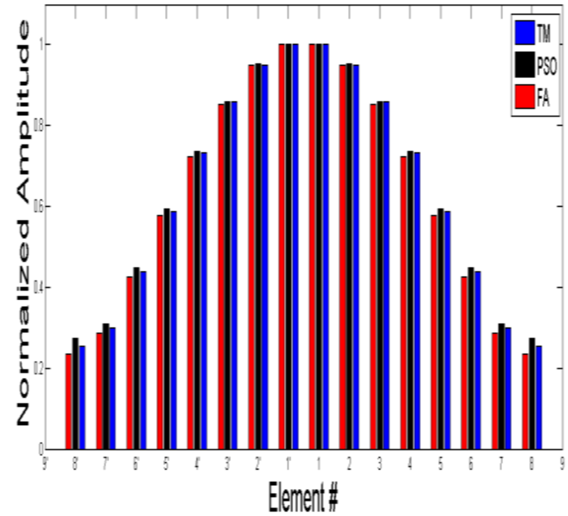

Figure 6. Normalized Amplitude Distribution of 16 Elements Array Using FA Compared With Other Techniques

4.3 LAA Optimization 24 Element

In this example, a 24-element LAA is optimized using FA method. The best results are listed in Table 3. Radiation pattern obtained by FA compared to other process are shown in Figure 7. Figure 8 shows normalized amplitude distribution of 24 element array using FA compared with other techniques**.** The maximum SLL obtained using FA method is -40.12 dB, while that obtained using the SADE (Dib *et al.*,2010), PSO(Khodier and Aqeel, 2009)[13], TM, and Uniform array is -35.21 dB, -34.50 dB, -35.25 dB and -13.95 dB, respectively. Figure 9 shows the convergence of the fitness function versus the iteration number. The maximum SLL obtained using FA is -40.12 dB, while the maximum SLL of the uniform one is -13.95 dB. Alternatively, the maximum SLL obtained through FA is less than the uniform one by about 26.17 dB and is also superior to the other results in [13].

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Table 3. 2*N* = 24 elements optimized using FA with respect to amplitudes constraint compared with TM, SADE, PSO methods (the values are normalized).

n	TM	SADE	PSO	FA
1	1.0000	1.0000	1.0000	0.9884
2	0.9731	0.9747	0.9712	0.9594
3	0.9283	0.9272	0.9226	0.9086
4	0.8585	0.8584	0.8591	0.8234
5	0.7745	0.7735	0.7812	0.7354
6	0.6758	0.6775	0.6807	0.6243
7	0.5772	0.5743	0.5751	0.5206
8	0.4686	0.4712	0.4768	0.4013
9	0.3719	0.3701	0.3793	0.3137
10	0.2764	0.2781	0.2878	0.2127
11	0.1995	0.1972	0.2020	0.1492
12	0.2026	0.2053	0.2167	0.1133
SLL (dB)	**-35.25**	**-35.21**	**-34.50**	**-40.12**

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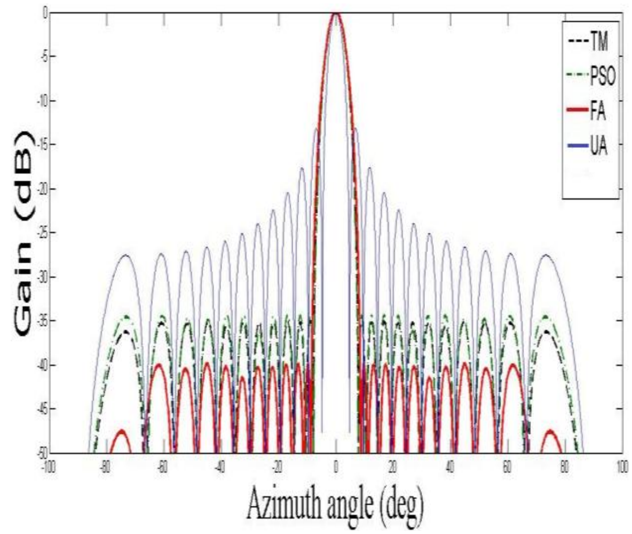

Figure 7. Radiation pattern of 24 element S $\lambda/2$ spaced optimized using FA with respect to amplitudes, compared with conventional array

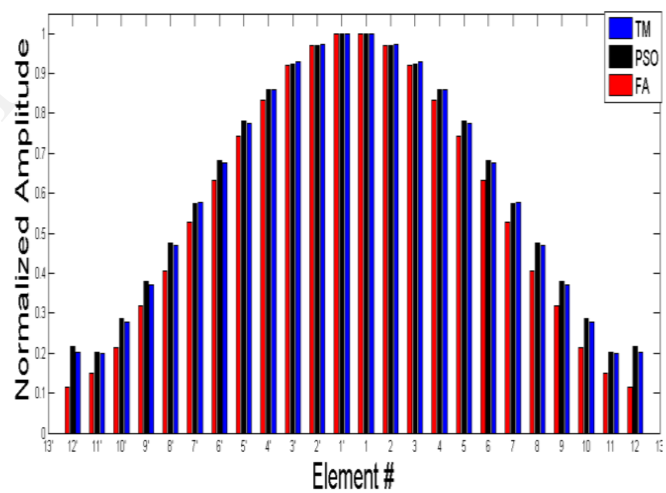

Figure8. Normalized amplitude distribution of 24 Element Array Using FA compared with other Techniques.

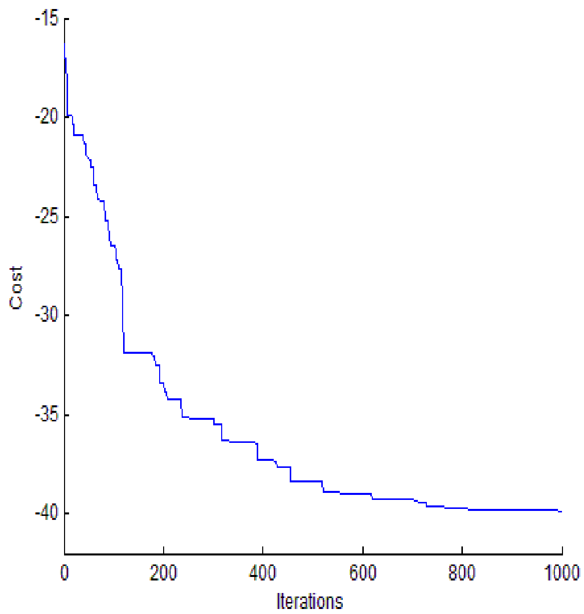

Figure 9. Convergence curves of the fitness value of 24 elements λ/2 spaced LA.

5. Conclusion

It is observed from the above results that a new optimization algorithm was proposed which was inspired by lifestyle of a insect behavior called FireFly algorithm. In this paper, the firefly algrithm is projected for solving a realistic problem of linear antenna array by re-optimizes only the amplitude excitation of the remaining elements to improve the orignal pattern of the antenna array. The comparison of FA with other techniques like PSO, SADE showed the superiority of FA in terms of both efficiency and success rate.FA converged fast in less iterations. Also, it reduceses the value of SSL and Nulls compared with other techniques. Overall the FA is found to be very suitable for null reduction and minimization of SSL and also it obtained global best result compared to other existing optmisation-algorithm–based methods. Future study will focus on exploring the design of other array geometries using FA and enhancement of the present algorithm.

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