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# SYNTHESIS OF LINEAR ANTENNA ARRAY USING FIREFLY ALGORITHM

Kamaldeep Kaur, Dr. Vijay Kumar Banga

**Abstract**— Antenna array is the most important aspect to improve the communication process. The objective of this paper are to minimize the maximum side lobe level (SLL) and perform null steering for linear antenna arrays by controlling different parameters of the array elements (phase, position and amplitude). The Nature inspired optimization methods like Taguchi's Optimization Method (TM), Self-Adaptive Differential Evolution (SADE), Firefly algorithm (FA) are the centre of attention in range of optimization problems. In this paper, phase excitation of array element is controlled by addressing FA to solve the problem of linear antenna array. Our results are also compared with TM and SADE which clearly indicates that firefly algorithm provides considerable enhancements than existing met-heuristic algorithm for desired shaped pattern. The effectiveness of FA for linear antenna array is exposed by means of numerical results.

**Index Terms**— Firefly algorithm (FA), Self-Adaptive Differential Evolution (SADE), Side lobe level (SLL), Taguchi's Optimization Method(TM).

## 1 INTRODUCTION

Various geometrical configuration have been proposed since last decade which were provided with different parameters like phase, excitation current and there relative magnitudes of radiating elements [1], [2]. The radiation characteristics of the antenna array depend on these input parameters. An antenna array can be designed to produce almost any arbitrary prearranged pattern by controlling these parameters. For this reason, antenna arrays find application in RADAR, SONAR and wireless communication systems [3], [4]. The antenna is the basic part or the back bone of the wireless communication. It is mainly used as device to transmit and receive signal. To get better facility from this device it is necessary to modify or synthesize the geometric configuration or the other parameter of the device. This modification of the parameter of the antenna for getting our desired requirement is known as antenna synthesis. The synthesis of antenna array aims at obtaining a physical structure whose radiation pattern is close to the preferred radiation pattern. In Antenna array shapes and patterns are controlled by keeping five aspects in coordination and these are the geometrical configuration, spacing between elements, excitation Amplitude, excitation phase and relative pattern of the individual elements. Antenna array is synthesized according to requirement of high gain for the main beam and highly directional antenna. In linear antenna array isotropic elements are aligned linearly and spacing between them is identical. Earlier, Liu et al. in [5] recommended a new technique for the synthesis of linear array with shaped power pattern. Panduro in [6] has designed non-uniform linear phased arrays using genetic algorithms to provide maximum interference reduction capability in a wireless communication system. Basu and Mahanti in [7] have used artificial bees colony (ABC) optimization and firefly algorithm (FA) for the synthesis of scanned and broadside linear array antenna. The main objective of their work is to compute the radiation pattern with minimum side lobe level (SLL) for specified half power beam width (HPBW) and first null beam width (FNBW). Results show that FA performs better than the SADE for linear antenna array. In this paper, newly developed FA algorithm [8], [9], [10] is used for synthesis of linear antenna array by controlling the elements excitation in order to minimize the SLL and Nulls. 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 analysis implies that the Firefly algorithm provides extensive enhancements than existing met-heuristic algorithm for desired radiation pattern with reducing Side Lobe Level and Nulls.

• Kamaldeep Kaur is currently pursuing master's degree program in Amritsar college of Engg. And Tech., Amritsar, Punjab, India. E-mail: deep.chahal4@gmail.com
• Dr. Vijay Kumar Banga, HOD of ECE deptt .in Amritsar college of Engg. And Tech., Amritsar, Punjab, India. E-mail: vijaykumarbanga@gmail.com

## 2 PROBLEM FORMULATIONS

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:

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

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

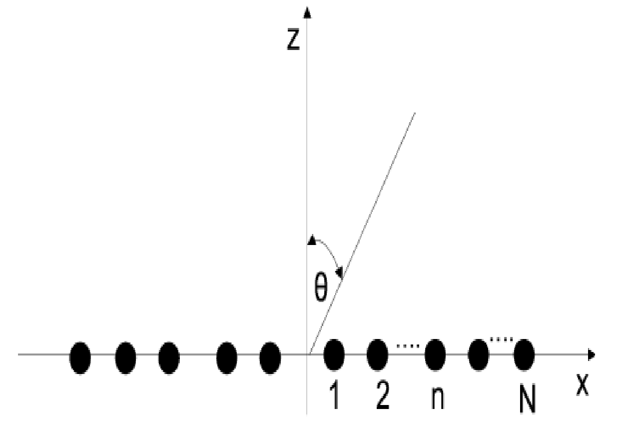


Figure1: Geometry of 2*N*-element symmetric linear array placed along the *x*-axis.

## 3 Algorithm Detail and Parametric Arrangement

Firefly algorithm is a comparatively brand new member of swarm brainpower family [8], [9], [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.

**CASE 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

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

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

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].

**CASE 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

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

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

**CASE 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.

**CASE 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

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

where the different parameters of the above equation like $\varepsilon_p$ 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 $\beta_0$ and $e^{-\gamma r^2}pk$. Cartesian distance for $\beta_0$attraction is given by r = 0 and is calculated by

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

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.

**CASE 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 the optimization problem is treated by presumptuous that all elements have the same exciting amplitudes and only phase control is allowable. The linear array has 2*N* equally spaced elements with spacing of $\lambda / 2$ .Application of FA for minimizing SLL of arrays by optimizing element phases, current excitations and positions 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:

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

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

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

1. Number of fireflies or population=20
2. Iterations or Generations =400
3. Attractiveness $\beta_0$=0.20
4. Absorption coefficient $\gamma$=0.25

For optimizing Phase, The first element phase is set to $\varphi_1 = 0°$. Initial phase values are uniformly distributed in [0,180°] 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 The 20-Element Uniform Phases Array with Bidirectional Null Steering At 14 And 20.5 Degrees

In this example, a 20-element phase-optimized array patterns shows using FA method. The optimum phase values (in degrees) using TM (Dib *et al.,* 2010), SADE [13] and FA is obtainable and the best results are listed in Table 1. The radiation pattern obtained by FA method compared to other techniques is shown in Figure 2. The maximum SLL obtained using FA method is -13.07 dB and the uniform array is -11.37 dB at the same time the maximum SLL for the optimized array (obtained using both algorithms) is -12.27 and -12.60 dB. Also, the result shows the maximum SLL obtained from FA is -0.8 dB is less than the TM and SADE method in all cases. Hence, the FA optimized array offers reduced SLL as compared to other techniques. But it is well known fact that if SLL decreases the beam width will increase [1] (Balanis, 1997).

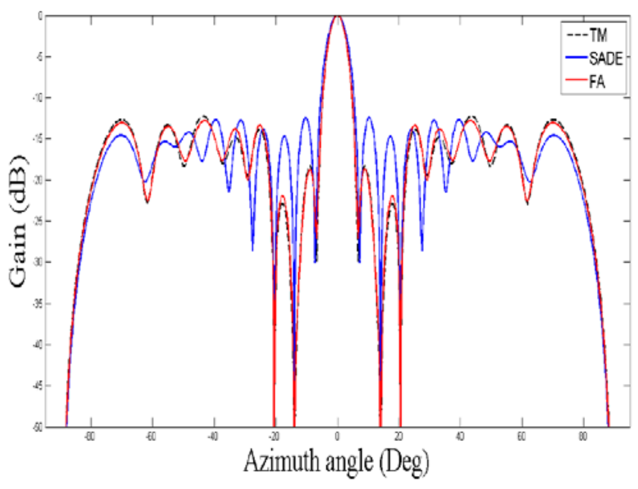


Figure 2: Optimum array patterns of 20 element array by the phase-only synthesis with bidirectional null steering at 14 and 20.5 degrees compared with TM and SADE.

TABLE 1

OPTIMUM PHASE VALUES (DEGREES) FOUND BY FA, TM AND SADE FOR THE 20-ELEMENT UNIFORM AMPLITUDE ARRAY WITH BIDIRECTIONAL NULL STEERING AT 14 AND 20.5 DEGREES.

| | $\varphi_n$ | | |
|---|---|---|---|
| **N** | **TM** | **SADE** | **FA** |
| 1 | 46.607 | -1.000 | 25.3859 |
| 2 | 26.703 | -1.000 | 11.9269 |
| 3 | 33.178 | 0.000 | 13.3920 |
| 4 | 38.478 | -1.000 | 18.3639 |
| 5 | 42.276 | 0.000 | 26.1443 |
| 6 | 53.586 | -1.000 | 36.7091 |
| 7 | 43.362 | -19.125 | 25.1971 |
| 8 | -34.757 | 53.613 | -55.4618 |
| 9 | 112.326 | -7.236 | 93.1825 |
| 10 | 33.945 | -126.688 | 20.3350 |
| **SLL (dB)** | **-12.27** | **-12.60** | **-13.07** |

### 4.2 Optimize 20-Element Uniform Amplitude Array Element Phases ($\varphi_n$)

We set $\varphi_n$ = 1 and the spaces between elements is $\lambda/2$ as the uniform array. The first element phase is set to $\varphi_1 = 0°$. Initial phase values are uniformly distributed in [0,180°]. Table 2 shows the corresponding phase values obtained by TM, SADE and FA. Figure 3 shows the optimum array patterns for the phase optimized 20 elements LA compared with TM and SADE. The maximum SLL obtained using FA method is -18.42 dB, while that obtained using the SADE (Dib *et al.,* 2010), TM [13], and Uniform array is –16.24 dB, -16.24 dB, and -13.19 dB, respectively. Figure 4 shows Stem plot for the phase-optimized 20 elements linear antenna array compared with TM and SADE and results shows superiority of FA over other techniques.This shows that the maximum side lobe reduction is improved by 2.18 dB which is slightly better than previous techniques.

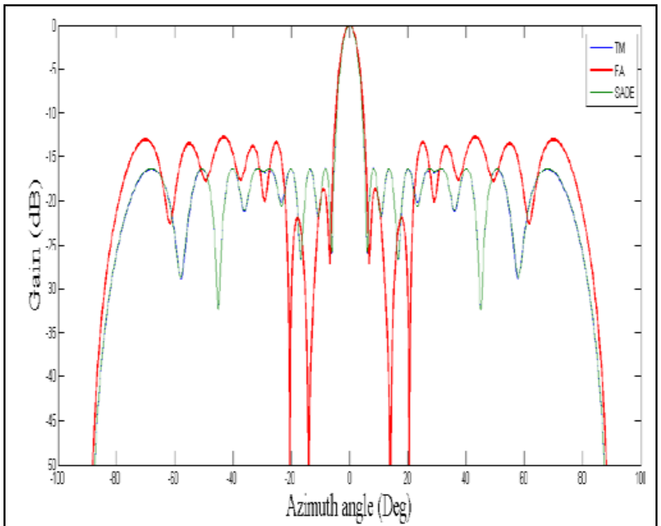

Figure 3: Optimum array pattern for the phase-optimized 20 elements LA, compared with TM and SADE.

TABLE 2

Optimum phase values (degrees) found by TM and SADE for the 20-element uniform amplitude array

| $\varphi_n$ | | | |
|---|---|---|---|
| **n** | **TM** | **SADE** | **FA** |
| 1 | 34.296 | -8.216 | -3.0849 |
| 2 | 28.558 | -1.345 | -8.5961 |
| 3 | 25.851 | 1.475 | -12.7952 |
| 4 | 27.328 | 0.023 | -11.6217 |
| 5 | 20.520 | 5.39 | -1.7889 |
| 6 | 25.816 | 0.71 | 14.7851 |
| 7 | -18.624 | 46.728 | -5.6794 |
| 8 | 85.245 | -58.136 | -69.3511 |
| 9 | 44.900 | -18.198 | 1.2100 |
| 10 | 28.062 | -1.904 | -36.0929 |
| **SLL(dB)** | **-16.24** | **-16.24** | **-18.42** |

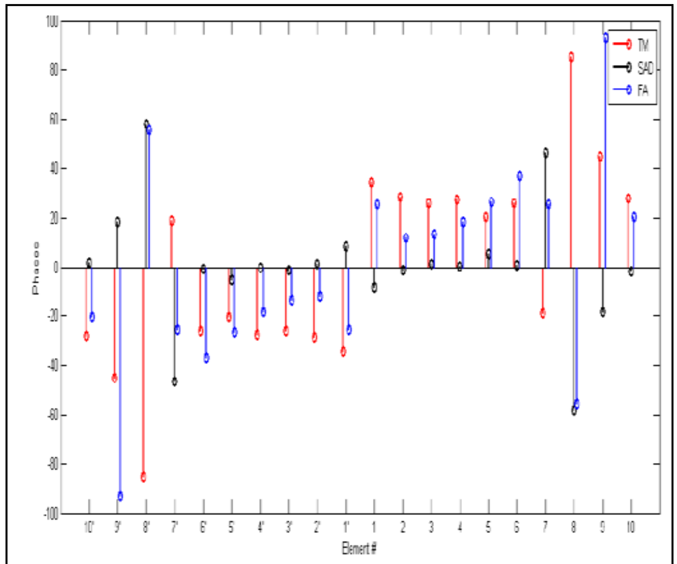

Figure 4: Stem plot for the phase-optimized 20 elements LA, compared with TM and SADE.

### 4.3 Optimize 32-Element Uniform Amplitude Array Element Phases ($\varphi_n$)

In this example, a 32-element phase-optimized array patterns shows using FA method. The optimum phase values (in degrees) using Taguchi's method(TM), SADE (Dib *et al.*, 2010) [13] and FA are obtainable and the best results are listed in Table 3. The number of element amplitudes to be optimized is 16 due to symmetry. It took only 20 seconds to run this optimization.

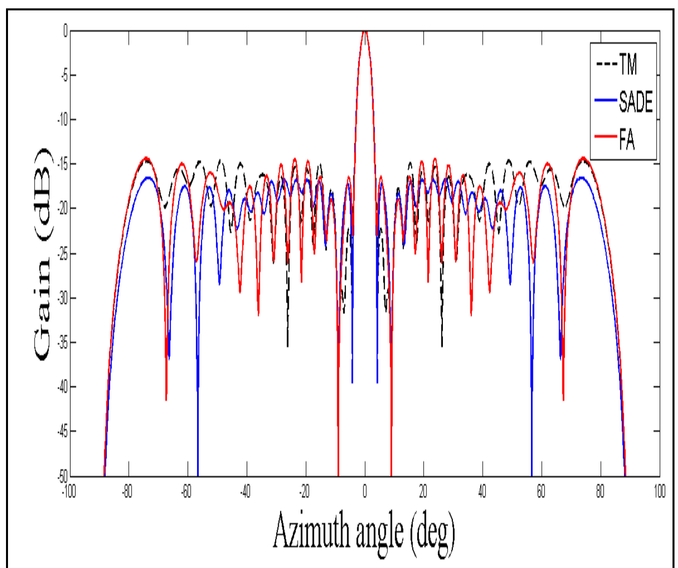

Figure 4: Optimum array pattern of 32 element array by the phase-only synthesis with unidirectional null steering.

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The values of the amplitude are decreasing from the centre of the array to the edges. Radiation pattern obtained by FA method compared to other Techniques are shown in Figure 4. The maximum SLL obtained using FA method is -19.06 dB while using Taguchi's null value is -14.6792 dB, SADE is -16.73 dB and uniform array is -13.24 dB . Hence, the FA optimized array offers reduced SLL as compared to other techniques. But it is well known fact that if SLL decreases the beam width will increase (Balanis, 1997) [1].

TABLE 3

OPTIMUM PHASE VALUES (DEGREES) FOUND BY TAGUCHI'S METHOD AND SADE FOR THE 32-ELEMENT UNIFORM AMPLITUDE ARRAY WITH UNIDIRECTIONAL NULL STEERING

| | $\varphi_n$ | | |
|---|---|---|---|
| N | TM | SADE | FA |
| 1 | 97.008 | 0.468 | -14.3199 |
| 2 | 89.395 | -1.000 | 14.3869 |
| 3 | 84.816 | -1.000 | -14.5202 |
| 4 | 89.771 | -1.127 | -11.5955 |
| 5 | 89.476 | 0.000 | 9.2805 |
| 6 | 85.127 | -4.170 | -13.5805 |
| 7 | 93.879 | -1.000 | -3.8908 |
| 8 | 90.626 | -1.000 | -22.3140 |
| 9 | 90.311 | 0.000 | -19.1019 |
| 10 | 73.426 | 0.000 | -17.0609 |
| 11. | 179.009 | 28.288 | -46.1303 |
| 12 | 73.499 | 0.678 | -8.2024 |
| 13 | -22.226 | 83.517 | -167.7976 |
| 14 | 127.411 | -95.316 | 6.3216 |
| 15 | 83.729 | -32.137 | 3.7668 |
| 16 | 121.048 | 0.000 | -22.2180 |
| **SLL(dB)** | **-14.6792** | **-16.73** | **-19.06** |

### 4.4 Optimize 40-Element Uniform Amplitude Array Element Phases ($\varphi_n$)

Figure 5 shows the results for the case of 40 elements array. The optimum phase values (in degrees) obtained using Taguchi's method, SADE [13-14] and FA are listed in Table 4. The maximum SLL for FA method is -16.96 dB while the maximum SLL for the Taguchi's optimized array with null steering is -16.26 dB and for the SADE is -15.23 dB. It is worth mentioning that the maximum SLL for the uniform array is -13.24 dB. The result shows that there is optimum reduction in the SLL by using FA technique compared with other met-heuristic techniques.

TABLE 4

Optimum phase values (degrees) found by Taguchi's method, SADE and FA for the 40-element uniform amplitude array with unidirectional null steering

| | $\varphi_n$ | | |
|---|---|---|---|
| N | TM | SADE | FA |
| 1 | 63.935 | -2.152 | 5.6597 |
| 2 | 52.596 | -4.772 | -2.1080 |
| 3 | 62.808 | -1.000 | -6.6206 |
| 4 | 55.933 | 6.145 | 2.3816 |
| 5 | 73.719 | -1.000 | -10.8026 |
| 6 | 81.473 | -1.000 | 8.9062 |
| 7 | 86.684 | -9.465 | 3.8632 |
| 8 | 55.439 | -1.000 | 5.6608 |
| 9 | 19.538 | -1.000 | 3.0174 |
| 10 | 23.263 | -5.280 | -3.8398 |
| 11. | 59.938 | 0.000 | 13.7358 |
| 12 | 77.890 | 0.000 | 15.5993 |
| 13 | 62.579 | -1.000 | 15.0307 |
| 14 | 56.510 | -1.000 | 14.8010 |
| 15 | 66.814 | 12.082 | -11.0146 |
| 16 | 112.846 | 20.134 | -90.9484 |
| 17 | -30.596 | 131.145 | -5.4055 |
| 18 | 118.459 | 55.280 | 119.6962 |
| 19 | 60.524 | 0.000 | -26.1121 |
| 20 | 40.272 | -27.990 | 14.5506 |
| **SLL(dB)** | **-16.26** | **-15.23** | **-16.96** |

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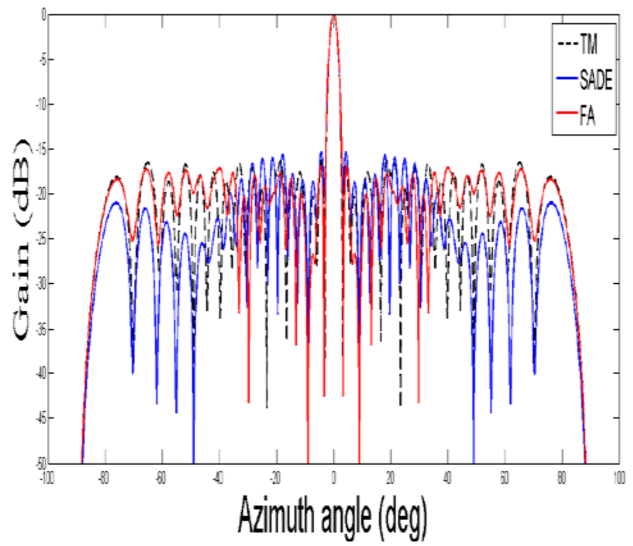


Figure 5: Optimum array patterns of 40 element array by the phase-only synthesis with unidirectional null steering.

## 5 Conclusion

The firefly algorithm (FA) is a met-heuristic algorithm, inspired by the flashing behavior of fireflies. The primary purpose for a firefly's flash is to act as a signal system to attract other fireflies. In this paper, the firefly algrithm is projected for solving a realistic problem of linear antenna array by re-optimizes only the Phase excitation of the remaining elements to improve the orignal pattern of the antenna array. The comparison of FA with other techniques like TM, SADE showed the superiority of FA in terms of both efficiency and success rate.This paper shows various phase current exciation results which gives better performance. It reduceses the value of SSL and Nulls compared with other techniques. Overall the FA is found to be very appropriate 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 the enhancement of the present algorithm using different phase values and exploring design of other array geometries using FA technique.

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**Kamaldeep Kaur** is pursuing M. Tech in Electronics and Communication Engineering from Amritsar College of Engineering & Technology and currently working as a Assistant Professor in Adesh Institute of Engineering and Technology, Faridkot. She did her B.Tech degree in Electronics and Communication Engineering from Amritsar College of Engineering & Technology, Amritsar, Punjab, India. Her area of interest is Antenna array.

**Dr. Vijay Kumar Banga** is working as a Professor and Head of the Department of Electronics & Communication Engineering, Amritsar College of Engineering and Technology, Amritsar, Punjab, India. He obtained his B. E (Electronics and Instrumentation Engineering) from Punjabi University, Patiala, Punjab, India, M. Tech (Electronics and Instrumentation) from Panjab University, Chandigarh, India and Ph.D. in Electronics (Artificial Intelligence) from Thapar University, Patiala., India. Presently, he has 13 years of research and UG & PG teaching experience. He has 45 research papers to his credit in various international journals and conferences. He is member of Board of Studies in Electronics and Communication Engineering of Punjab Technical University, Jalandhar, Punjab, India.