Low Side Lobe Level Linear Array Optimization using Evolutionary Algorithms: A Review

Jaspreet Kaur[1], Dr. Sonia Goyal[2]
[1]*Department of Electronics and Communication Engineering, Punjabi University, Patiala, India*
[2]*Department of Electronics and Communication Engineering, Punjabi University, Patiala, India*
[1]jaspreetchahal34@gmail.com
[2]goyalsonia_82@yahoo.co.in

***Abstract*− Antenna array is an assembly of radiating elements that are arranged in space and can be utilized to deliver a directional radiation pattern that could not possible with single antenna. In antenna arrays the side lobe level is the major problem which causes wastage of energy. To increased transmission efficiency as well as to prevent the interference, minimization of SLL is one of the basic requirements in the array system design. Aimed at this problem various optimization evolutionary algorithms are exploited such as genetic algorithm, invasive weeds optimization algorithm, ant colony algorithm, flower pollination algorithm, particle swarm optimization and hybrid adaptive genetic algorithm etc. based on metrics such as side lobe level (SLL), directivity, final accuracy, convergence speed, and robustness.**

***Keywords*: Micro- strip linear antenna array, Side lobe level, null depth, evolutionary algorithms.**

I. INTRODUCTION

An antenna is a metallic device which converts electronic signals to radio waves and vice versa, efficiently with less amount of loss of signals and now with constantly progressive technology. Antenna plays an efficient role in wireless communication for short and long distance communication [1]. Micro strip patch antenna was first proposed in 1970's and after that micro strip antenna technology became the most fast developing area. A micro strip patch antenna consists of a conducting patch on one side of a dielectric substrate and a ground plane on opposite side. In the course of the most recent decade, Micro strip patch antennas have become one of the most famous antennas and they are often used as array elements because they have numerous advantages over other type of antennas such as low profile, inexpensive, light weight, planar design and easy integration with microwave integrated circuits [1]. Also it has some demerits for example low efficiency, low gain, narrow bandwidth, surface wave excitation etc. They have widely employed for the regular citizens and military applications for instance, radio-frequency identification (RFID), broadcast radio, mobile systems, satellite based navigation system or GPS, multiple-input multiple-output systems, vehicle collision avoidance system, satellite communications, direction founding, radar system, remote sensing, rocket detection and so on.

Linear antenna array – An antenna array consists of multiple fixed antenna elements, which are arranged in such a way that the effective radiation pattern of array is reinforced in desired direction and smothered from undesired direction [2]. In today era of science and technology, antenna arrays are preferred in on several occasions because the use of a single element has numerous limitations regarding directivity and bandwidth. The total field of antenna array is calculated by a vector addition of individual element´s radiated field. An extensive study about linear array synthesis concluded that, side lobe level reduction and null placement can be produced either by optimizing the excitation phase and amplitude or by optimizing the inter-element spacing. Nature inspired algorithms have contains great development in many electromagnetic era where the optimization of several parameters is nonlinear and complex. By proper adjustment of cost function or fitness function and optimizing parameters any issue related to linear array radiation Pattern could be resolved. Various nature inspired evolutionary optimization algorithms such as genetic algorithm (GA), particle swarm optimization algorithm (PSO), ant colony algorithm (ACO), invasive weeds algorithm, flower pollination algorithm, cuckoo search algorithm, cat swarm algorithm, differential search algorithm, Taguchi's algorithm, and grey wolf optimization algorithm have been successfully applied for linear array optimization. Antenna array have several configurations such as linear, circular, rectangular, spherical etc. the geometry of an antenna array impacts on its radiation pattern. In linear configuration the radiating elements are arranged uniformly in a straight line [3].

The aim of antenna array geometry synthesis is to decide the physical design of the array that produces a desired radiation pattern. In the recent periods researchers pay more attention on the methods to extend the scanning range. It is realized that the phased array with 3dB beam width elements can extend a scanning range. Mutual coupling between array elements is another necessary factor for scanning, due to that strong coupling is maintained between array elements .The quality of phased array scanning performance, such as gain, directivity and side lobe level etc. can be enhanced by production of mutual coupling energy. The exact controls over phase and amplitude excitations of array elements are necessary for suitable scanning side lobe level. In [3] the micro strip phased array with eight elements and sixteen elements was proposed. The investigation by researchers is in progress for mutual coupling effects and peak SLL at many angles. An optimum compromise must be necessary between the low side lobe level and beam width of array , because in linear array while suppressed the side lobe level the beam width of radiation pattern gets increased and vice versa [4].

II. PROBLEM FORMULATION

The geometry of a simplest uniform linear antenna array with 2N elements placed in straight line or around ring as shown in Fig 1, where, d is the distance between elements. The array factor of an antenna array is independent of the antenna type and is defined as the product of element factor and spacing factor [3]. The calculation of such array factor for any antenna array geometry has a great importance in determining its radiation characteristics and many other electromagnetic properties of it. Let us suppose Elements of the linear array are isotropic in nature with element wise uniform radiation pattern for all azimuth and elevation angles [3]. But these elements present the variety of patterns when packed as an array.

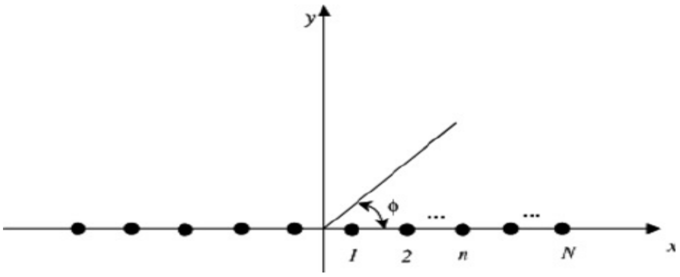

Fig.1. Symmetric 2N linear antenna array geometry [2]

Array factor of linear antenna array with 2N geometry is calculated with the equation (1) given below:

$$E(\theta) = 2\sum_{n=1}^{N} A_n \cos[kd\cos(\theta) + \varphi_n] \tag{1}$$

Where, N = Number of array elements

$E(\theta)$= array factor of antenna array

A_n = magnitude excitation of n^{th} element on either side of array

D = location of the n^{th} element from array centre

φ_n = phase of the n^{th} array element

Now if we consider that the elements have uniform amplitude and phase excitations means have φ_n = 0. Therefore, array factor equation becomes shown below in equation (2):

$$E(\theta) = 2\sum_{n=1}^{N} A_n \cos[kd\cos(\theta)] \tag{2}$$

The normalized array factor can be calculated with equation (3):

$$E(\theta)_{norm} = \frac{|E(\theta)|}{|E(\theta)|_{max}} \tag{3}$$

The normalized form of the equation (1) is given as in dB in equation (4):

$$E(\theta)_{norm}dB = 20 * log_{10}(E(\theta)_{norm}) \tag{4}$$

In linear antenna arrays, proper placement of antennas elements is very essential. If the antennas are set excessively too close to each other, it calls to mutual coupling effects. Then, if the antennas put too far away, it prompts grating lobes [3]. There, to overcome this optimization problem, the following conditions must be satisfied:

(i) $X_m - x_n > 0.25$

(ii) Min{x_m} > 0.125; m = 1, 2, . . . , N. m ≠ n where, x_n is the antenna position adjacent to the antenna position x_m and {x_m} is the set of all antenna positions [5].

III. LOW SIDE LOBE LEVEL IN LINEAR ANTENNA ARRAY

Side lobes can be defined as an extra or unwanted lobes (maxima in other direction then main beam) exterior of the main beam in the linear array radiation pattern, which cause wastage of energy outside the main beam [4]. Due to the effect of side lobes, interference arrives at the transmitting antenna as well at receiving antenna which increases the noise level at receiver side. In the recent decade of communication systems to improve the transmission efficiency, side lobe level reduction in antenna array radiation pattern becomes the more attractive and important issue. The SSL suppression mostly depends on either element position or excitation amplitude weights. Therefore, an efficient antenna array design with low side lobe can determine by proper adjustment of array element spacing and optimum weights [5].

IV. OPTIMIZATION OF LINEAR ARRAY USING EVOLUTIONARY ALGORITHMS

The mathematical optimization and linear programming techniques often fails on large scale practical problems, Therefore to overcome these issues, many researchers have introduces evolutionary/stochastic algorithms to explore the optimum standard for array system or for optimum radiation pattern design. These algorithms are widely used because they provide better solution for large problems close to ideal solutions, less time computation, and also easy to implement on PC's. Frequently used nature inspired evolutionary algorithms are genetic algorithm, invasive weed optimization (IWO) [2], particle swarm optimization algorithm (PSO), flower pollination algorithm (FPA) [4], ant colony algorithm (ACO), simulated annealing, and cat swarm optimization [3] etc. These algorithms are easy to use and give optimum global solutions for some practical engineering problems. Now let us discuss one by one and determine the better one.

A. Classical particle swarm optimization(PSO)

Through many evolutionary algorithms, PSO is widely used algorithm due to its optimization simplicity and faster convergence rate. Here, in this article, the classical particle swarm algorithm is used to synthesize the non-uniformly excited linear arrays. Suppose elements of linear array are isotropic in nature and placed with uniform inter-element spacing [1]. The proposed method eliminates the randomness of defining search space for CSO algorithm. So here, Taylor distribution is utilized to define the range of excited amplitudes, in which CPSO algorithm searches for optimal value of amplitude by testing at even or odd numbered linear array, with the aim of obtaining low side lobe level. Consider the excitation amplitudes of each element are optimization parameters [1]. The fitness function for proposed optimization problem is shown in equation (5).

$$f = SLL|_{desired} - max\left\{20\log\left|\frac{AF(\theta)}{AF(\theta)_{max}}\right|\right\} \quad (5)$$

Here, $AF(\theta)$ is the array factor of linear array, $AF(\theta)_{max}$ is the maximum array factor in particular elevation angle. suppose θ = 90° in current problem. The side lobe region is defined as in equation (6)

$$SLL = max(|AF(\theta)|)_{\theta\in\theta_{SLL}};\ \theta = [0,\theta_{FNL}] \cup [\theta_{FNR}, 180] \quad (6)$$

Where, $\theta_{FNR}$and $\theta_{FNL}$are first right and left nulls around main beam, and are shown in equation (7) below

$$\theta_{FNR} = 90 - \left|\frac{BW}{2}\right|,\ \theta_{FNL} = 90 + \left|\frac{BW}{2}\right| \quad (7)$$

In the proposed algorithm the no. of particle are set to 25. Termination criteria for optimization process is reached when fitness function becomes zero, the classical PSO checks the fitness function for each iteration and updates the position and velocity. From figure it is concluded that for 20-element array with λ/2 interelement spacing, desired SLL -22Db is achieved.

TABLE 1: PARAMETRIC COMPARISON OF DIFFERENT ARRAY CONFIGURATIONS USING THE PROPOSED METHOD

No of elements	SLL	FNBW
12	-28.5	28
16	-22.4	17.6
20	-21.15	11.1

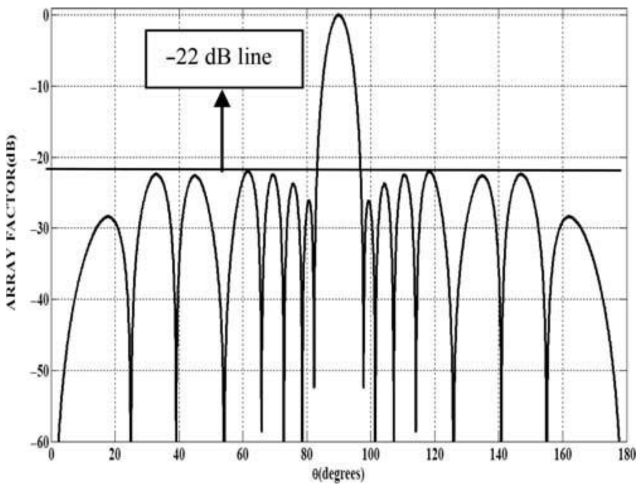

Fig.2. Array factor of a 20-element array using CPSO for -22DB SLL

The proposed methods are efficient as SLL minimization is obtained in almost any case. TABLE 2 represents the SLL and FNBW values for different array configuration. CPSO converges at around 13 generations than GA which converges around 21 generations.

B. *Modified invasive weeds optimization(MIWO)*

IWO is a new method compared to genetic algorithm and some other evolutionary algorithms, and the modified IWO is a modified version of standard IWO [2]. In this paper, the synthesis of linear array antenna is done using modified invasive weeds algorithm. The synthesis issue in this work is to find the amplitude excitation of the antenna array elements that are desirable to provide radiation pattern with minimum side lobe level and symmetrical wide nulls in both sides of main beam and with an acceptable DRR value. This modified version of IWO is also utilized to design time modulated linear array with a tradeoff between low SLL and FNBW [2].

In this work, Three examples are used to clarify the performance of the modified IWO for linear array synthesis, where the no. of antennas are taken as 12, 16, and 20 and for uniform inter-element space of d=λ/2, with taken into account the dynamic range ratio (DRR) [2]. In order to show the performance of this proposed algorithm, obtained results are compared to a similar work using particle swarm optimization. The required fitness function for this method is shown below.

$$cost_1 = Abs\left[\prod_{m=1}^{M} AF(\theta = null_m)/\left(AF(\theta_0)\right)\right] \tag{8}$$

Where M is the maximum number of nulls positions for every side, and $AF(\theta_0)$ is the maximum value of array pattern achieved in direction of major beam. Here, number of nulls depends upon the number of antenna array elements and the position of nulls. To reduce the DRR, cost function is:

$$DRR = Max\left[\frac{I_{n+1}}{I_n}\right] \tag{9}$$

The proposed method controls only the amplitude weights of the linear array elements. The amplitude of each element can vary from 0 to 1. The scanning angle is set at 90°, the standard deviation is 0.05, probability of mutation p_m is 0.8, and number of iteration is 50 are fixed for proposed method. Table 2 shows the comparative performance of MIWO and PSO (without DRR constraints) to the uniform distribution for each example.

TABLE 2: SYNTHESIS AND EXCITATION RESULT OF LINEAR ARRAY USING MIWO

Number of elements	**12**	**16**	**20**
Nulls depth in dB (MIWO)	-64.83	-59.15	-55.86
Nulls depth in dB (PSO)	-41.78	-53.04	-45.56
SLL in dB (MIWO)	-26.52	-25.96	-17.25
SLL in dB (PSO)	-21.15	-19.07	-19.19
Optimal current excitation	0.9888 0.9175 0.5767 0.4580 0.1458	0.7969 0.8970 0.5425 0.5355 0.3551	0.8431 0.9320 0.4787 0.9065 0.4507 0.2601
DRR	3.14	1.93	12.01

Therefore, the algorithm gives satisfied outcomes in comparison to some results in literature. Because when we use a mutation to find the standard deviation, the search space will be more enhance, restricting falling in local minimum and the convergence will be fast.

C. *Cat swarm optimization*

Cat swarm optimization is a nature inspired stochastic type algorithms. Here it is used to design a linear antenna array having micro strip patch elements [3]. For the practical implementation of any antenna, the parameter consideration is very essential. The excitation of each antenna element and uniform or non-uniform inter-element spacing are optimized by CSO, including phase excitation is null. The cost function to keep the low side lobe level is defined. The suitable results are got by an extensive MATLAB based computation using cat swarm optimization algorithm are approved through the computer simulation tech.-microwave studio (CST-MWS) software which mimics the practical environment[3]. The proposed micro strip antenna resonated at 5.85 GHz frequency. Here, three examples are considered to evaluate the performance of cat swarm optimization algorithm 12, 16, and 20 elements linear array. In this paper, CSO optimizes non-uniform amplitude excitation and uniform inter-element spacing for linear array. The array factor for the desired direction is characterized by equation (10).

$$AF(\theta) = 2\sum_{n-1}^{M} I_n \cos\left[\left(\frac{2n-1}{2}\right) kdcos\theta\right] \tag{10}$$

Where, θ is elevation angle, d is inter-element spacing, 2M is sum of elements in array, and k is propagation constant. The cost function for side lobe level minimization can be defined by equation (11);

$$CF = |AF(\theta_{msl}, I_n)|/|AF(\theta_0, I_n)| \quad (11)$$

Where, θ_0 is the angle of elevation plane for maximum radiation pattern, θ_{msl} is angle of elevation for low SLL. A simple micro-strip patch antenna is simulated in CST and it is designed to work at 5.85GHz resonant frequency with 335MHz bandwidth. Normal FR-4 epoxy is used as a substrate material having thickness 1.6mm and relative permittivity of 4.4 and other design parameters. TABLE 3 shows that, for optimal non-uniformly excited amplitudes and uniformly spaced symmetric 12-, 16-, and 20-elements linear arrays, side lobe level minimizes up to -37.91 dB, -39.97dB, -41.72 dB, respectively.

TABLE 3: OPTIMAL INTER-ELEMENT SPACING, OPTIMAL SLL, AND FNBW FOR THREE LINEAR ARRAYS FOR MICRO STRIP PATCH ANTENNA ELEMENT

No. of elements	Inter –element spacing (λ)	SLL (dB)	FNBW (deg.)
12	0.8565	-37.91	19.8000
16	0.8883	-39.97	15.1200
20	0.9084	-41.72	11.8800

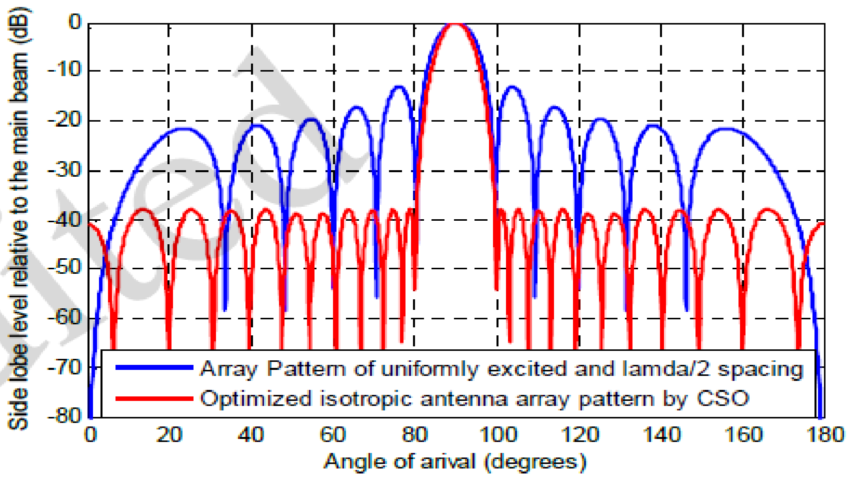

Fig. 3. Optimal radiation pattern obtained by utilizing CSO for 12- element linear array of microstrip patch antrennaelements.

D. Flower pollination algorithm

This is a latest nature inspired evolutionary algorithm which is proposed for the optimization of linear antenna array [4]. It was introduced by Xin-She Yung in 2012. Flower pollination algorithm is applied first time to linear antenna array to determine optimized antenna element positions to reduce the side lobe level, and to adjust nulls in specified direction. In paper [4] the implementation of FPA is initialized with the terms of objective function and initialization of the population of flowers with random solutions. There are two design examples are considered A & B, suppose in case A the optimized antenna element positions are determined to reduce the peak SLL in the desired spatial region, and in examples B determine the optimized antenna element positions in order to reduce SLL and place deep nulls in the specified direction. The flower pollination algorithm is derived on MATLAB and executed 15 times.

The no. of iterations is set to 1000 for each run. The control parameters of FPA process are fixed in order to achieve better quality of solution. However, these parameters are population size (n) = 25, levy- flights step size (β) = 1.5, switching probability (p) = 0.8, and scaling factor (γ) = 0.1with optimum values.

- **Peak SLL Reduction**: First example describes the design of 2N = 10 element array for minimum SLL in the regions, θ = [0°, 74°] and θ = [106°, 180°]. Fitness function for reduction in peak SLL is calculated by equation $Fitness = \min(\max(20 log|A(F(\theta)|\,))$ (12)

  In this paper the fitness function of FPA is calculated for parameter values of linear array are optimized array element locations (x_n), uniform amplitude I_n =1 and phase excitations ψ_n =0. The proposed algorithm gives a peak SLL of -23.45dB which is much better than other Algorithms such as PSO, ACO, and CSO. TABLE 4 shows the different optimized values of peak SLL using various algorithms [4].

TABLE 4: OPTIMIZED PEAK SLL FOR 10 ELEMENT ARRAY

Sr. no.	Approach	Peak SLL in (dB)
1	Conventional Array	-13.22
2	ACO	-22.66
3	PSO	-20.72
4	CSO	-22.89
5	Proposed	-23.45

- **SLL reduction along with null placement:** The fitness function utilized for side lobe reduction as well as for null placement in specified direction is calculated by equation (13).

$$Fitness = \sum_i \frac{1}{\Delta\theta_i} \int_{\theta_{li}}^{\theta_{ui}} |AF(\theta)|^2 d\theta + \sum_k |AF(\theta)|^2 \quad (13)$$

Where, θ_{li} and θ_{ui} are the spatial regions in which SLL is minimized and $\Delta\theta_i = \theta_{ui} - \theta_{li}$. The null direction is define by θ_k. here in equation the first term represent the SLL reduction and the second term utilized for the placement of nulls in specified direction. Presently , the second method illustrates the synthesis of 28 element linear antenna array for create low SLL in the regions θ = [0° , 84°] and θ = [96° , 180°] alongside null placement at θ = 55°, 57.5°, 60°, 120°, 122.5° and 125°. The result obtained by this method using FPA illustrates that placement of deep nulls as -95.12 dB deep in desired directions. The table 5 shows comparative results of peak SLL and minimum null depth using various algorithms.

TABLE 5: COMPARATIVE ANALYSIS OF PEAK SLL AND MINIMUM NULL DEPTH OBTAINED BY SEVERAL ALGORITHMS FOR 28 ELEMENT ARRAY

Method	PSO	ACO	CSO	Proposed FPA
Minimum null depth (in Db)	-50	~-50	-65	-89.42
Peak SLL (in dB)	-13.22	-15	-12.78	-20.46

It is observed from table 5, the minimum depth produced by using FPA is −89.42dB, which is 39dB lower than PSO (Christodoulou 2005) and ACO. The obtained peak SLL using FPA is around 7.23dB lower than conventional array and PSO algorithms, approx. 5.46 dB lower than ACO optimized array, and about 7.67 lower than CSO optimized array. There are many other examples should be illustrated for 32 element array or more than that. FPA have some disadvantages as compared to PSO that, it consumes much computational time than PSO.

V. OVERALL ANALYSIS AND COMPARISON OF SLL REDUCTION ALGORITHMS

The side lobe level minimization algorithm should be picked with proper awareness as indicated by various system requirements. In this paper we have concentrated some nature inspired evolutionary algorithms. Each algorithm has its own particular merits, demerits and properties. We have reviewed some side lobe level suppression algorithms are classical particle swarm algorithm [1], modified invasive weeds optimization algorithm [2], cat swarm optimization [3], and flower pollination algorithm [4]. TABLE 6 shows parameter values acc. to algorithms. Cat swarm optimization provides better SLL reduction as compared to other algorithms and Flower pollination have minimum null depth is -89.42dB.

TABLE 6: COMPARATIVE ANALYSIS OF EVOLUTIONARY ALGORITHMS FOR SLL, FNBW, AND NULL DEPTH

Algorithm	No. of elements	SLL(dB)	FNBW(degree)	Null depth(dB)
CPSO	12 16 20	-28.5 -22.4 -21.15	28 17.6 11.1	–
MIWO	12 16 20	-26.52 -25.96 -17.25	44.0 33.87 23.38	-64.83 -59.15 -55.86
CSO	12 16 20	-37.91 -39.97 -41.72	19.8000 15.1200 11.8800	–
FPO	10 28	-23.45 -20.46	–	– -89.42

It is concluded from comparison analysis, modified invasive weeds optimization algorithm have better convergence speed, robustness, directivity and have improved results for side lobe level reduction then standard invasive weeds algorithm [2], comprehensive learning PSO(CLPSO), genetic algorithm and PSO. Newly developed flower pollination algorithm also provides better side lobe reduction as well as in terms of placement of strong nulls in required direction [4].

VI. CONCLUSIONS AND FUTURE SCOPE

After reading some research papers and articles it is concluded that the generation of desired radiation pattern of antenna array in specific direction is more challenging requirement, and this requirement is met with the suppression of side lobe level in that direction due to that directivity will be enhanced. Side lobe level and deep nulls are major problems in radiation patterns of antenna array. Now days the researchers pay more attention on improvement of antenna array radiation pattern including non-uniform array structure. The future scope of antenna array synthesis is in various physical applications like in future 5G Samsung smart phones applications and in large communication systems.

REFERENCES

[1] Chatterjee, Soumyo, Sayan Chatterjee, and Dipak Ranjan Poddar. "Synthesis of linear array using Taylor distribution and Particle Swarm Optimisation." *International Journal of Electronics* 102.3 (2015): 514-528.

[2] Kenane, El-Hadi, Farid Djahli, and Christophe Dumond. "A novel Modified Invasive Weeds Optimization for linear array antennas nulls control." *2015 4th International Conference on Electrical Engineering (ICEE)*. IEEE, 2015.

[3] RAM, Gopi, Durbadal MANDAL, Sakti Prasad GHOSHAL, and Rajib KAR. "Optimal array factor radiation pattern synthesis of linear antenna array using cat swarm optimization: validation by EM simulator." (2016).

[4] Prema Saxena and Ashwin Kothar, "Linear Antenna Array Optimization using Flower Pollination Algorithm, " *Saxena and Kothari Springer Plus (2016 5:306).*Ya-Qing Wen, Bling-Zhong Wang, and Xiao Ding, "*A Wide-scanning and low Side lobe Level Micro strip Phased Based on Genetic Algorithm Optimization*, " IEEE Transactions on Antenna and Propagation, vol.64, no. 2, February 2016.

[5] EL Hadi Kenane, Farid Djahli, "Optimum design of non-uniform symmetrical linear antenna arrays using a novel modified invasive weeds optimization" , International Journal of engineering research & technology, Vol. 36, 9-22, 2014.

[6] El-Hadi KENANE, Farid DJAHLI, "A Novel Modified Invasive Weeds Optimization for Linear Array Antennas Nulls Control" , 2015IEEE.

[7] Pappula, Lakshman, and Debalina Ghosh. "Linear antenna array synthesis using cat swarm optimization." *AEU-International Journal of Electronics and Communications* 68.6 (2014): 540-549.

[8] Shi-Wei Qu, Senior Member, IEEE, De-Jan He, Shiwen Yang, "Novel Parasitic Micro Strip Array for Low- Cost Active Phased Array Applications, " IEEE Transactions on Antenna and Propagation, Vol. 62, no. 4, April 2014 1731.

[9] M. Vamshi Krishna, S. Mishra , "Generation of Low Side Lobe Difference Pattern using Nature Inspired Meta heuristic Algorithm, "International Journal of Computer Applications , Vol. 143-No.3, june2016 .

[10] P.V.Florence, G.S.N Raju, "Synthesis of Linear Antenna Array using Accelerated Particle Optimization Algorithm, " International Journal of Computer Applications (0975-8887) Volume 103- No.3, October 2014.

[11] Shaoqiu Xiao, Chunrong Zheng, Mei Li, "Varactor-Loaded Pattern Reconfigurable Array for Wide-Angle Scanning With Low Gain Fluctuation, " IEEE Transactions on Antenna and Propagation, Vol. 63, No. 5, May 2015.

[12] K. S. S. Sharma, N. Venkateswara Rao, "Design of Low Side Lobe Level and Narrow Beam Width Antenna Array using Genetic and Particle Swarm Optimization Methods, " International Journal of Engineering Research & Technology, Vol. 4 Issue 06, June 2015.