Amplitude and Phase Synthesis of Linear Array for Sector Beams using Modified Harmony Search Differential Evolution Algorithm

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Abstract

The work in this area is limited particularly in beam shaping. In the process of pattern synthesis, intensive investigations are carried out to optimize desired beam shapes for small and large arrays. The main objective of this present work is to optimize the new amplitude and Phase distributions for desired flat top beams by using the combination of Harmony Search Algorithm and Differential Evolution Algorithm. It is found that the new algorithm provides great improvement in main lobe shaping control and side lobes which is present in the obtained radiation patterns. The optimized radiation patterns are more close to desired patterns and the numerical simulation results are presented.

Keywords : *Pattern Synthesis, Beam-former, Desired Shaped Beam, Flat-top or Sector Beam Pattern, Side lobe level, Harmony Search Algorithm, Modified Differential Evolution Algorithm.*

I. INTRODUCTION

Certain antenna applications require sector beams of constant signal level over a certain range of observation angle. Beyond that range, the signal level is supposed to decay as fast as possible and stay at a very low level in trade-off region. Aircraft surveillance radars use broad beams that are fan shaped in elevation. The beam is scanned in azimuth at a high rate to provide the rapid sequence of target echoes to track the fast moving aircraft [1].

However, when scanning is required, such high directive beams are not preferred as involved scan time is more. In several applications well-shaped beams are required. The angular region is covered by fanning the beam broadly [2]. These beams are developed by distorting circularly symmetrical beam into asymmetrical elliptical beam. A typical fan beam is presented in figure (1).

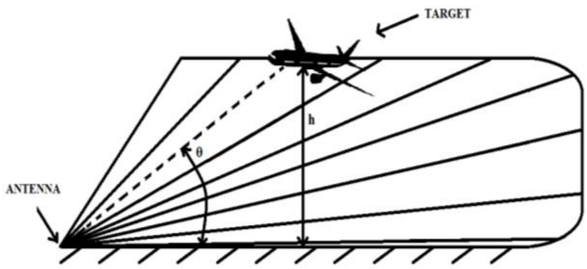

Figure: 1 Beam from Ground Based Antenna Providing Coverage on Aircraft for Air Search

Elliot [3] designed a new synthesis procedure for shaped beams of equispaced linear arrays which will produce a desired radiation pattern with low sidelobes and equal percentage ripple.

Orchard et al. [4] introduced a new approach which uses the conventional polynomial representation of the antenna pattern produced by an equispaced linear array. Certain roots are displaced from the unit circle radially to fill a portion of the pattern. The angular and radial positions of all the roots are simultaneously adjusted so that the amplitude of each ripple in the shaped region and the height of each sidelobe in the non shaped region are individually controlled. Suzuki et al. [5] presented an example of such pattern improvement techniques. He derived a modifying algorithm commonly used for adaptive array antennas. A study of flat-top beam synthesis for cellular systems is presented in [6]-[7].
Sadler [8] discussed a sector beam synthesis using optimization techniques for linear antenna arrays. It involves two methods, by which the amplitude weights are designed. One method is derived from linear optimization theory and the other method is based on genetic algorithm. Both approaches are successful but non linear optimization procedure of genetic algorithm.

Abdelaziz et al. [9] introduced the application of genetic algorithm in dynamic sector synthesis of antenna array for mobile transceiver station. The aim is to have narrow beam widths in heavy handoff areas and wider beam widths in areas with low traffic density. Bregains et al. [10] investigated the variation in the bandwidth of ripple and sidelobe level for linear arrays. It is found that the SLL of flat-topped beam patterns are much greater when the dipoles are collinear and they are parallel.

Ahmad et al. [11] described the synthesis of the flat-top power pattern of linear antenna array using DE. To demonstrate the proposed approach a 32-element equally spaced symmetrical linear antenna array has been taken. The complex excitation coefficients of the elements with two states [0 or π] of their phase value are considered as the optimization parameters. Recently most prominent method has been applied for the design of beam shaping array synthesis [12].

It is evident from the discussion presented above that the methods reported do not meet requirements of sidelobe level and beamwidth. In view of these facts, intensive investigations are carried out to generate desired beams from array antennas with specified sidelobe levels without deteriorating beamwidth.

The main aim of this work is to generate the synthesis of flat-top patterns from an array of isotropic radiating elements using the combination of Differential Evolution algorithm and Harmony Search algorithm [13] as an optimization method. In order to synthesize a desired flat-topped main beam with suppressed sidelobe levels, element amplitude excitations and phase excitations are optimally determined. In the present work a new excitation distributions are proposed and extreme patterns are realized.

The proposed method [14] is most reliable, accurate and best optimization technique. The optimized numerical simulation results show that the method improves the performance of the algorithm significantly in terms of both convergence rate and exploration ability. For the purpose of design specifications for the proposed method have been selected from the control parameter values are H_R = 0.9, $C_{R_{max}}$ = 0.95, $C_{R_{min}}$ = 0.2, F_{max} = 0.65, F_{min} = 0.1 and G_{max} = 5000 to 10000.

II. HARMONY SEARCH DIFFERENTIAL EVOLUTION ALGORITHM

In this present work, novel based music inspired Harmony Search Differential Evolution Algorithm (HSDEA) is developed to optimize the linear arrays with a minimum peak side lobe level. The harmony search algorithm with a new differential mutation and cross over base strategy, namely, best of random, is applied to the synthesis of equally spaced antenna arrays.

A. Initialization

The classic DE search starts with randomly initiated population of n_p D-dimensional parameter vectors. Each target vector $X_{i,G}$ = [1, 2, … n_p] is a solution to the optimization problem, where the index ‘i’ denotes the population, i= [1, 2, ... n_p] and ‘G’ denotes the subsequent generation to which the population belongs.

For each target vector $X_{i,G}$, i= 1, 2, 3…n_p, a mutant vector is generated according to the follow

$$MV_{i,G+1} = X_{r_1,G} + F.\left(X_{r_2,G} - X_{r_3,G}\right) \qquad (1)$$

Where the indexes r_1, r_2, r_3 Є {1, 2, 3 … n_p} are randomly selected such that $r_1 \neq r_2 \neq r_3 \neq i$, F is a real and constant factor Є [0, 2] which controls the amplification of the differential variation $\left(X_{r_2,G} - X_{r_3,G}\right)$.

B. Differential Mutation and Crossover

For each individual $X_{i,G}$ in the population, a mutant vector $MV_{i,G}$ is produced according to the following formula.

$$MV_{i,G+1} = \begin{Bmatrix} X_{r_1 G} + \sum_{y \geq 1} F.\left(X_{r_2,G} - X_{r_3,G}\right), \text{rand b(j)[0,1]} \leq C_R \\ \text{or } j = \text{rand b(j)[0,1]} \\ X_{i,G} \qquad \text{otherwise} \end{Bmatrix} (2)$$

Where the indexes r_1, r_2, r_3 Є {1, 2, 3 …. N_p } are randomly selected such $r_1 \neq r_2 \neq r_3 \neq i$, and rand b(j) is the j^{th} evaluation of a uniform random number generator with outcome Є [0,1]. The element of mutant vector $MV_{i,G}$ is generated by the differential mutation, whenever a randomly generated number between [0, 1] is less than or equal to the C_R value otherwise, it is equal to the corresponding element of the individual $X_{i,G}$. Finally selection takes place where a tournament is held between the target vector and the one with better fitness function is allowed to enter the next generation.

C. Selection

The population for the next generation is selected from the individual current population and its corresponding trail vector is

$$X_{i,G+1} = \begin{Bmatrix} MV_{i,G+1} & \text{if } f\left(MV_{i,G+1}\right) < f\left(X_{i,G}\right) \\ X_{i,G} & \text{otherwise} \end{Bmatrix} \qquad (3)$$

Where f (.) is the objective function to be minimized. It is to say that, if the new vector $MV_{i,G+1}$ produced by differential mutation and crossover operations yields a lower value of the objective function, it would replace the corresponding individual $X_{i,G}$ in the next generation. In harmony search algorithm, a New Harmony vector ‘X’ is generated based on three approaches; memory consideration, pitch adjustment and random selection. Using memory consideration the new vector is chosen from the specified Harmony Memory (HM), which is initialized at the start and updated by previous iterations.

In this method a new parameter H_R is introduced. The element of mutant vector $MV_{i,G}$, generated randomly in the range between [0, 1] is greater than the specified constant H_R. In this case the probability that each element of mutant vector $MV_{i,G}$ is produced in three ways, which is followed by the schematic structure as shown in the figure (2).

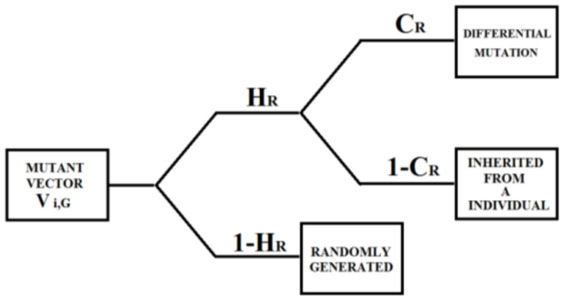

Figure: 2 Probability of the New Element Generated Using HSDE.

The new way to produce mutant elements injects the random noise into the population and improves its diversity. The changes of two key parameters C_R and F have a great influence on the algorithm performance. The parameter selection of HSDE can be referred to that of harmony search algorithm. Here C_R and F are updated as follows.

$$\begin{cases} C_R(G) = C_{R_{min}} + (C_{R_{max}} - C_{R_{min}}) \times \dfrac{G}{G_{max}} \\ F(G) = F_{max}\exp(C.G), C = \ln(\dfrac{F_{min}}{F_{max}})/G_{max} \end{cases} \quad (4)$$

Where $C_{R_{max}}$ and $C_{R_{min}}$ are the maximum and minimum adjusting rate of C_R and F_{min} , F_{max} are the minimum and maximum values of 'F' respectively.

III. NUMERICAL FORMULATION PROCEDURE

A. *Desired Pattern Synthesis Methodology*

A linear array having N-isotropic elements placed along Z-axis with equal inter-element spacing 'd' operated at wavelength of λ/2 in order to avoid mutual coupling and grating lobes. A symmetric geometry of linear array is shown in figure (3).

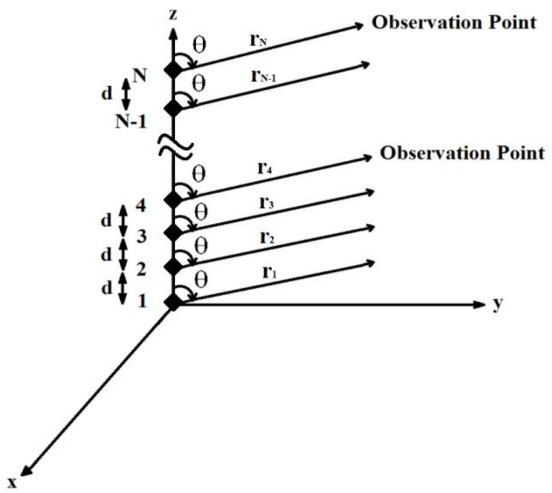

Figure: 3 Schematic Diagram for Linear Array Geometry

The array factor is designed in a normalized far field pattern and it is represented in the equation (5). If the radiating elements are designated from 1 to N with an element spacing 'd', the radiating field can be expressed as

$$E(u) = \sum_{n=1}^{N} A(X_n)\, e^{j\frac{2\pi}{\lambda}ndu} \quad (5)$$

The normalized field of array factor is given by

$$E(u) = \sum_{n=1}^{N} A(X_n)\, e^{j(kLu X_n + \emptyset(X_n))} \quad (6)$$

Where u = sin θ and K=2π/λ is the wave number

$A(X_n)$is element amplitude excitation level of the n^{th} element.

$\emptyset(x_n)$ is element phase excitation level of the n^{th} element.

'L' is the length of the array

'N' is the number of elements

'λ' is the wave length in integer times of fundamental frequency

'd' is the spacing between the elements

X_n is the position of the n^{th} element which is useful for both odd and even number of elements in the array and is given in equation form is shown below

$$X_n = \frac{2n - 1 - N}{N} \quad (7)$$

B. *Objective Function*

The goal of the optimization is to generate a desired flat-top pattern of a specified width with acceptable sidelobe level by employing non-uniform excitations to individual elements of the antenna array. The normalized amplitude in the search range

[0, 1] with static phase shift in the range of [-π, π] are taken as the optimization parameters.
Therefore the objective function is given as

$$f = \min(w_1 e_1 + w_2 e_2) \quad (8)$$

Where w_1 and w_2 are the controlled weights and sum of the weights should be one that is represented as

$$\sum_{i=1}^{2} W_i = 1 \quad (9)$$

Where 'e_1' is the mean square error of the main beam region

$$e_1 = \left[\frac{1}{p}\sum_{i=1}^{p} IE_1(u_i)I^2\right]^{\frac{1}{2}} \quad (10)$$

Here 'p' represents the number of sampling points in main lobe region and $E_1(u_i)$ is the error in main beam region and it is calculated as

$$E_1(u) = \{E(u) - F(u);\ \ 0 \le u \le -u_0\} \quad (11)$$

Where F (u) is desired sector pattern and E (u) is pattern obtained in the evolutionary process.
Therefore the desired sector pattern is represented by

$$F(u) = \begin{cases} 1\ ;\ \ 0 \le u \le 0.5 \\ 0\ \ ;\ \ \text{otherwise} \end{cases} \quad (12)$$

e_2 is the least mean square error in the sidelobe region

$$e_2 = \left[\frac{1}{Q}\sum_{i=1}^{Q} IE_2(u_i)I^2\right]^{\frac{1}{2}} \quad (13)$$

Where 'Q' is the number of azimuth angles in the sidelobe region and $E_2(u_i)$ is the error obtained in sidelobe region and it is calculated as

$$E_2(u) = \{E(u) - F(u);\ \ u < -u_0 \& u > u_0\} \quad (14)$$

Where E (u) is the pattern obtained in the evolutionary process and F (u) is desired sector pattern.

IV. SIMULATION RESULTS AND DISCUSSIONS

The advanced method is applied to obtain the desired radiation pattern with a uniform linear array separated by a distance λ/2 with various numbers of isotropic radiators. The target is to synthesize a flat-top shaped beam patterns of 0.4, 1.4 and 2 in width at the broadside array with ripple level ≤ 0.5 dB, the narrowest transition and suppressed SLL = -25dB. Using the array factor equation (6) radiation patterns are computed with the coefficients so obtained. Both the amplitude and phase excitation coefficient weights for each element are optimized to generate the desired flat-top radiation pattern. The behavior of the fitness function is shown in the figure (4).

Flat-top beams are generated for null to null beam width of 0.4 (-0.2 to 0.2) with different number of elements 20, 30 and 50, its corresponding amplitude and phase distributions are presented in the figures (5) – (10). Figures (11) – (16) reported the shaped beam patterns of 1.4 (-0.7 to 0.7) width for 20, 30 and 50 elements and its amplitude and phase distributions also presented. Figures (17) – (22) reported the flat top beams, corresponding amplitude and phase distributions of 2 (-1 to 1) in width for 20, 30 and 50 elements also presented.

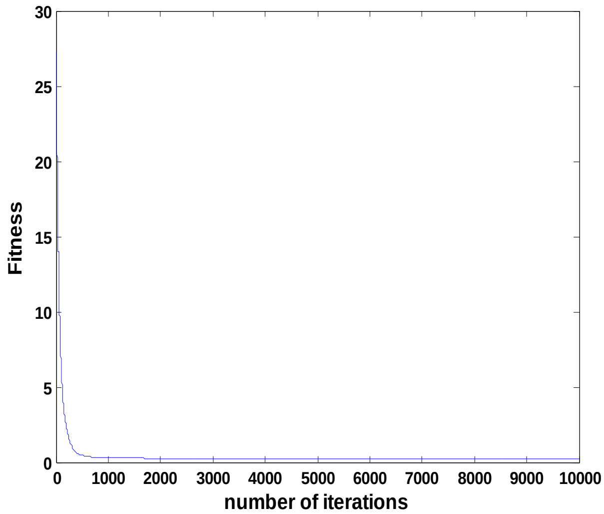

Figure: 4 Behavior of Fitness Function for Flat-Top Pattern

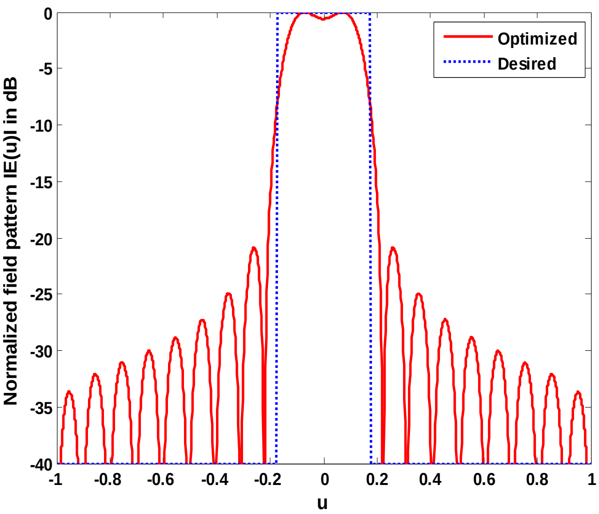

Figure: 5 Flat-Top Radiation Pattern of 20 Elements for NNBW=0.4

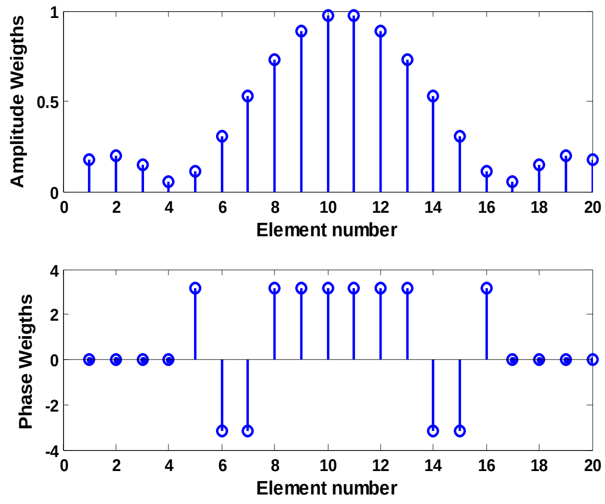

Figure: 6 Amplitude and Phase Plots of 20 Elements for NNBW=0.4

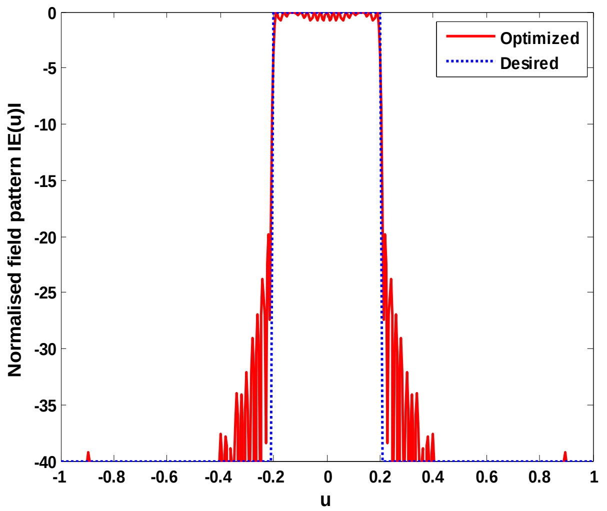

Figure: 9 Flat-Top Radiation Pattern of 50 Elements for NNBW=0.4

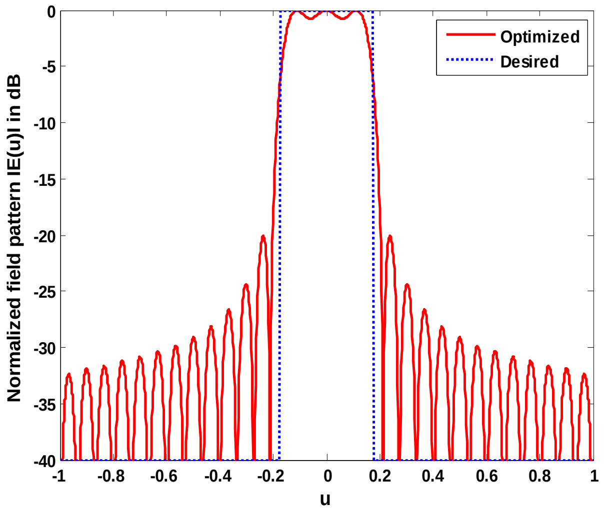

Figure: 7 Flat-Top Radiation Pattern of 30 Elements for NNBW=0.4

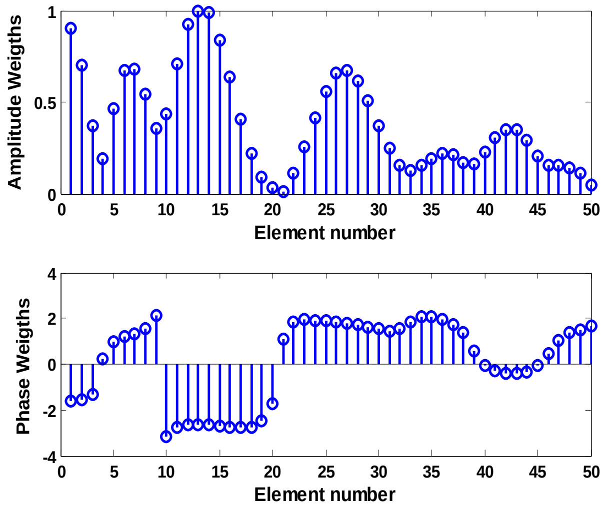

Figure: 10 Amplitude and Phase Plots of 50 Elements for NNBW=0.4

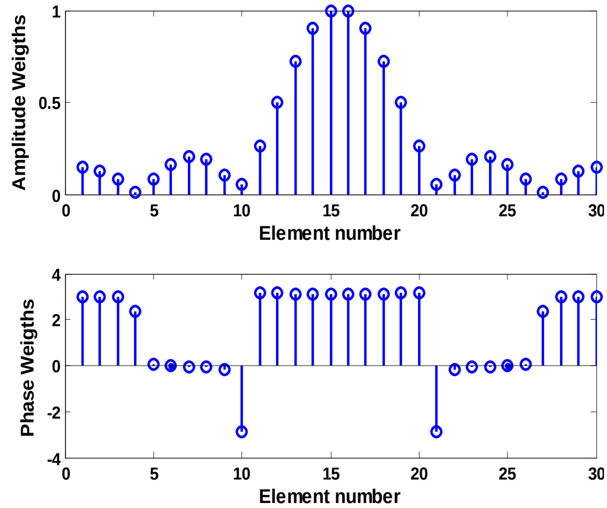

Figure: 8 Amplitude and Phase Plots of 30 Elements for NNBW=0.4

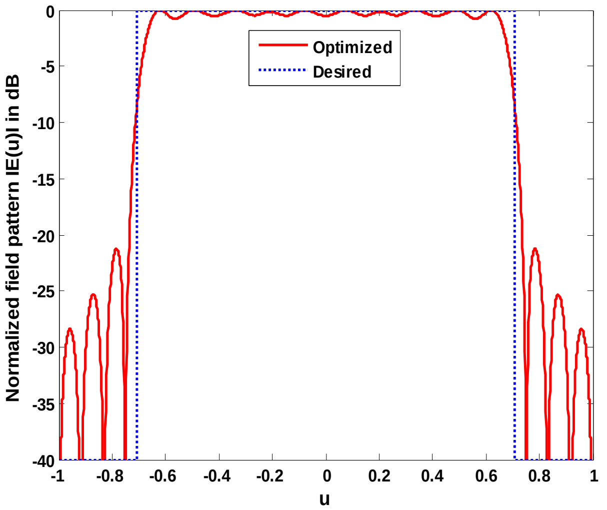

Figure: 11 Flat-Top Radiation Pattern of 20 Elements for NNBW=1.4

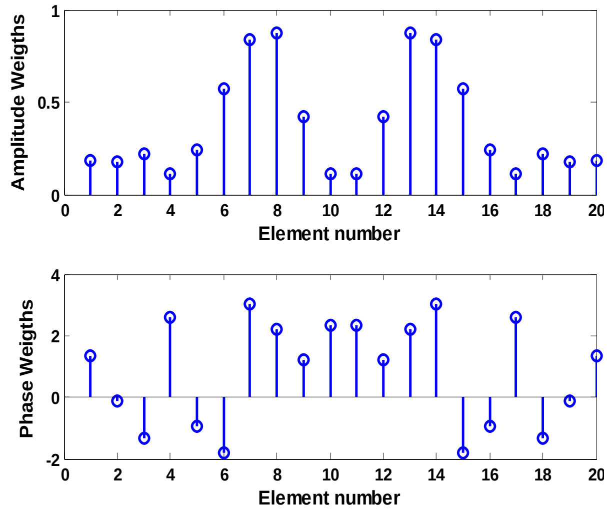

Figure: 12 Amplitude and Phase Plots of 20 Elements for NNBW=1.4

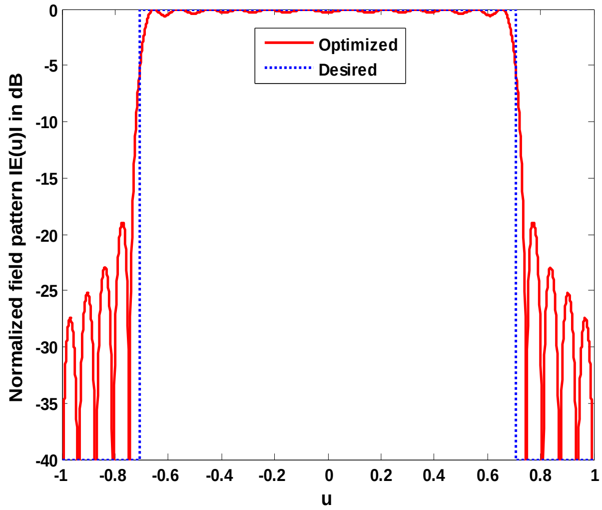

Figure: 13 Flat-Top Radiation Pattern of 30 Elements for NNBW=1.4

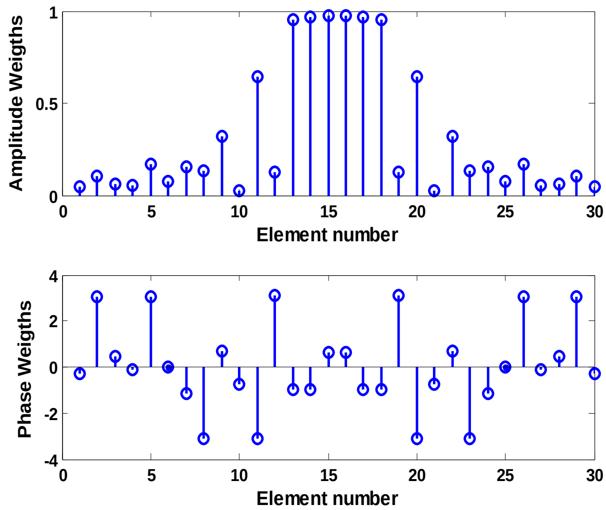

Figure: 14 Amplitude and Phase Plots of 30 Elements for NNBW=1.4

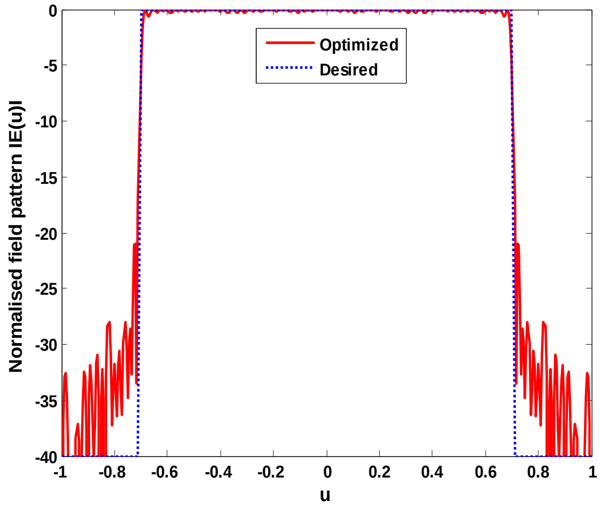

Figure: 15 Flat-Top Radiation Pattern of 50 Elements for NNBW=1.4

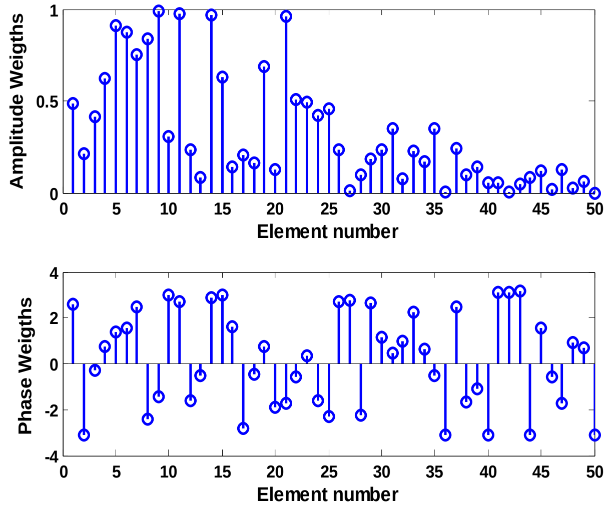

Figure: 16 Amplitude and Phase Plots of 50 elements for NNBW=1.4

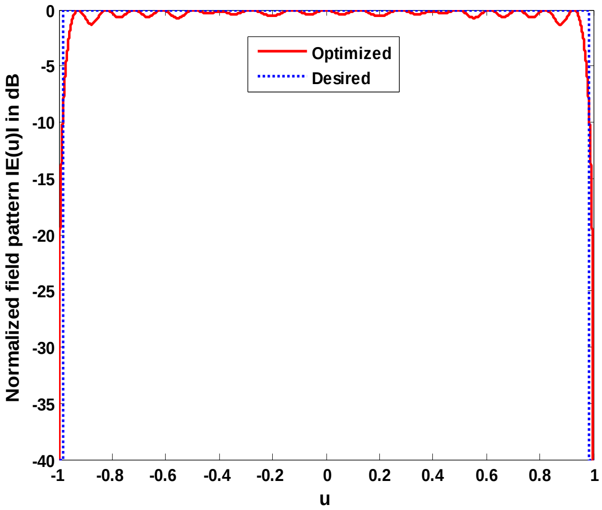

Figure: 17 Flat-Top Radiation Pattern of 20 Elements for NNBW=2

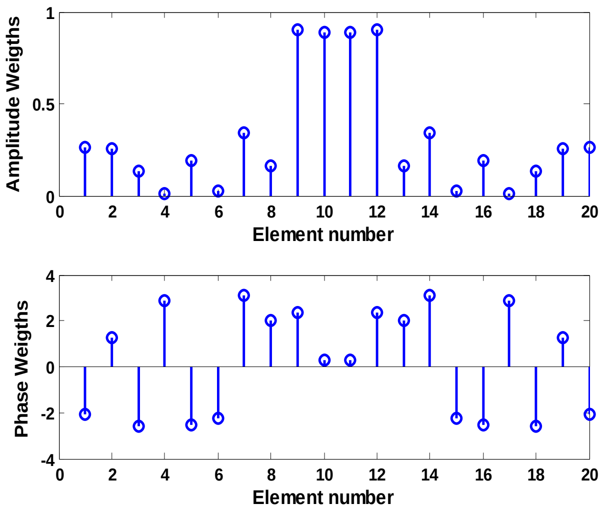

Figure: 18 Amplitude and Phase Plots of 20 Elements for NNBW=2

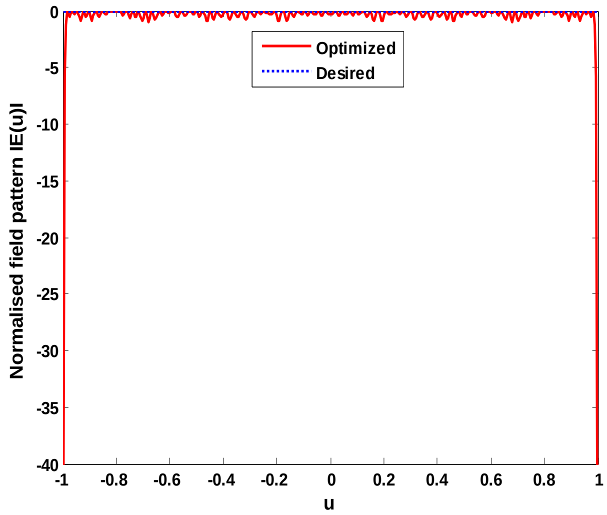

Figure: 21 Flat-Top Radiation Pattern of 50 elements for NNBW=2

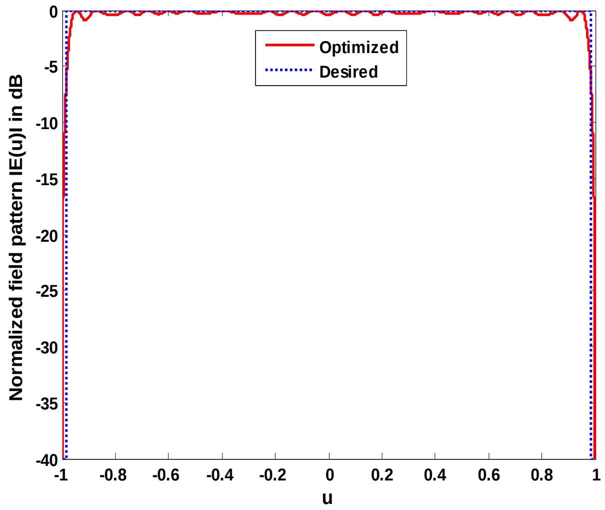

Figure: 19 Flat-Top Radiation Pattern of 30 elements for NNBW=2

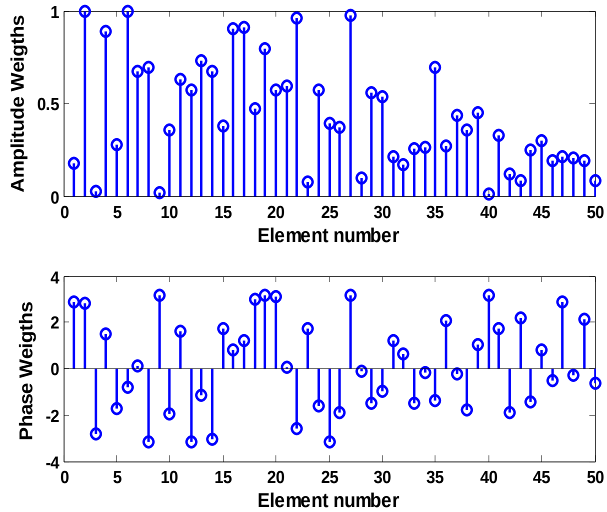

Figure: 22 Amplitude and Phase plots of 50 elements for NNBW=2

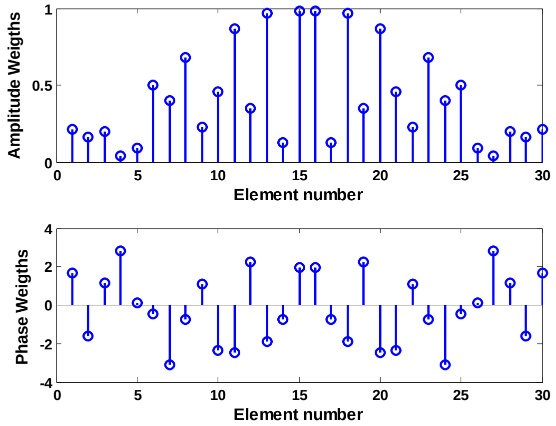

Figure: 20 Amplitude and Phase Plots of 30 Elements for NNBW=2

V. CONCLUSION

As evident from the results using the new method, it is clear that the optimized flat-top radiation patterns are found to have considerable ripples in the trade-in region and low sidelobes in the trade-off region. However, the element amplitude and phase excitation levels of different beam widths are computed for various numbers of small and large arrays. The suitable element of normalized amplitude excitation coefficients and static phase shifts are determined by the algorithm which reduces the sidelobe level of the array to satisfactorily low values. It is found to satisfy the specified beam width with low side lobes even in trade-off region.

To show the excellent performance of Modified algorithm combines the good local search capability of the classic DE and the great search diversity of Harmony Search algorithm. A new method provides convenient main lobe shape control and also the obtained patterns are compared to the flat-top plot in the desired region at different null to null beam widths. The optimized simulation results of flat-top main beam radiation patterns are observed and it clearly shows that the superiority proposed method over the other methods in terms of finding optimum solutions for the presented problem.

REFERENCES

[1] I. A. Leonov, I. K. Formichev, "Monopulse Radar," Norwood, Artech House, 1986.

[2] G. S. N. Raju, "Antennas and Wave Propagation," Pearson Education, 2005.

[3] R. S. Elliot, "A new technique for shaped beam synthesis of equispaced arrays," IEEE Transactions on Antennas and Propagation, Vol. AP-32, No. 10, October 1984.

[4] H. J. Orchard, R. S. Elliot, and G. J. Stern, "Optimizing the synthesis of shaped beam antenna patterns," Proc. Inst. Elect. Eng., Vol. 132, PP. 63-68, February 1985.

[5] Y. Suzuki and T. Chiba, "An Algorithm for Pattern Synthesis Improvement," IEEE Transactions on Antennas and Propagation, Vol. AP-34, No. 6, PP. 825-829, June 1986.

[6] A. Sabharwal, D. Avidor, L. Potter, "Sector beam synthesis for cellular systems using phased antenna arrays," IEEE Transaction on Vehicular Technology, Vol. 49, No. 5, September 2000.

[7] A. Akdagli and K. Guney, "Shaped-Beam Pattern Synthesis of Equally and Unequally Spaced Linear Antenna Arrays Using a modified Tabu Search Algorithm," Microwave and Optical Technology Letters, Vol. 36, No. 1, PP. 16-20, January 2003.

[8] D. J. Sadler, "Sector beam synthesis using antenna arrays," The 2nd IEE/EURASIP Conference on DSP enabled radio, PP. 7, September 2005.

[9] A. Abdelaziz, and H. A. Kamal, "Sector synthesis of antenna array using Genetic algorithm," Journal of theoretical and applied information technology, PP. 160-169.

[10] J. C. Bregains, F. Ares and E. Moreno, "Variation in the Bandwidths of Pattern-Quality Parameters and Maximum Embedded Impedance among the Solution to Shaped-Beam Synthesis Problems for Collinear Dipole Arrays," IEEE Antennas and Wireless Propagation Letters, Vol. 2, PP. 267-268, 2003.

[11] A. Ahmad, A. K. Behera, S. K. Mandal, G. K. Mahanti and R. Ghatak, "Synthesis of Flat top power pattern in linear antenna arrays using differential evolution algorithm," International Journal of Electronics & Communication Technology (IJECT), Vol. 4, No. 1, March 2013.

[12] A. Mandal, H. Zafar, S. Das, and A. Vasilakos, "A Modified Differential Evolution Algorithm for Shaped Beam Linear Array Antenna Design," Progress In Electromagnetics Research, Vol. 125, pp. 439-457, March 2012.

[13] F. Zhang, W. Jia, and M. Yao, "Linear Aperiodic Array Synthesis Using Differential Evolution Algorithm," IEEE Trans. Antennas Propag., Vol. 12, no.7, pp. 797-800 July 2013.

[14] T. Vidhyavathi, G. S. N. Raju, "Generation of Ramp Patterns using Modified Differential Evolution Algorithm," IOSR Journal of Electronics and Communication Engineering (IOSR–JECE), Vol. 9, No. 6, Ver. III, PP. 01-12, Nov-Dec. 2014.