Generation of Stair-Step Patterns using Modified differential Evolution Algorithm

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ABSTRACT
A new pattern synthesis technique for shaped-beam array antennas of stair-step radiation patterns is discussed. It is well known that several methods are reported to design array synthesis for the generation of shaped beam patterns. It is found that none of them are optimum. However, in this present work, a new swarm intelligence method Modified Differential Evolution based on harmony search algorithm is applied for their optimization technique. The proposed method is most reliable, accurate and best optimization technique so far. The optimum stair-step radiation patterns are numerically computed and the results have been shown that the method improves the performance of the algorithm significantly.

Keywords
Antenna arrays, Pattern synthesis, desired shaped beam, Modified Differential Evolution algorithm, Stair step patterns.

1. INTRODUCTION
Array antennas are widely used in wireless communications, satellite, military and radar communications. Pattern synthesis is required in different applications like phased array radar, cellular and mobile communication for the improvement of signal quality, system coverage, spectral efficiency and so forth [1]. To achieve these, efficient antenna design is the primary requirement. In recent scenario, the need of antenna array synthesis with shaped beam patterns are increased day by day for the purpose of improvement of communication [2].

In this present work, the main objective is to generate a stair case shaped beam radiation pattern from the antenna array pattern synthesis. It is required to find radiation patterns from different array geometry and make these obtain patterns closer to their desired pattern [3] either by varying its element amplitude and phase or by reconfiguration of the array geometry.

In various applications shaped beams are required and often used methods include those of Dunbar [4] and the simplified form of the Woodward technique [5].

While easily applied, neither method provides a particularly optimum reproduction of the desired pattern function. A classical method involves truncation of the Inverse Fourier transform [6] which leads to patterns showing least-mean-square fit to the desired pattern taken over the infinite sinθ domain.

To obtain a desired radiation pattern, a set of element amplitude excitation coefficients and phase excitations are closely produce and that are carried out by the equally spaced linear aperiodic arrays. The shape of the desired radiation pattern can vary depending on the application.

In this paper an original radiation pattern which is some approximation to the desired radiation pattern is generated by a new optimization method. The main aim of this work is to generate a stair stepped radiation pattern from the antenna array using MDE. Many of the antenna array pattern synthesis techniques can be found in the literature for the generation of shaped beam radiation patterns [7]-[8].

G.S.N Raju, A Sudhakar et al., [9]-[10] developed and reported the realization for the generation of ramp and stair-step patterns using amplitude control and phase-only control techniques, to avoid the complexity involved in conventional analytical synthesis methods [11]. A new swarm intelligence population based stochastic methods such as evolutionary algorithm [12], genetic algorithm (GA) [13], Ant colony optimization [14], some PSO variants has been used for the design of linear array in shaped beam pattern synthesis Curletto et. al., [15] suggested a new method for the synthesis on the shaping of the main lobe in wide-band arrays. Synthesis of symmetric flat-top radiation patterns are developed by L.Wu, A. Zielinski et. al., [16] for beam forming on linear antenna array.

Recently most prominent method has been applied for the design of beam shaping array synthesis [17]-[18]. In this paper a Modified differential evolution based on Harmony search algorithm is used as an optimization technique [19]-[20]. There are usually three evolutionary operations in classic DE, which are summed up to two operations in modified DE these modifications help to overcome some drawbacks of classic DE. A new mutation and crossover strategies are considered in this proposed algorithm.

The rest of this paper is organized as follows: Section II briefly introduces MDE section III describes the mathematical problem formulation and the steps involved in related work on MDE. The numerical simulation results are reported in section IV and finally the conclusion is given in section V.

2. MODIFIED DIFFERENTIAL EVOLUTION ALGORITHM

2.1 Initialization:
The idea is to produce the trail vectors according to the manipulation of the target and difference vectors. If the trail vector yields a better fitness than a predetermined population member the new trail vector will be adopted into the vector base.

The classic DE search starts with randomly initiated population of Np N-dimensional parameter vectors. Each vector $X_{i,G}$ = [1, 2, … Np] is a solution to the optimization problem. Where i= [1, 2, …. Np] is the index of the vectors in the population and G_{max} is subsequent generations. There are usually three evolutionary operations in the classic DE which are summed up to two operations in the modified differential evolution.

In this problem, MDE based on harmony search called Harmony search differential evolution algorithm (HSDEA) is developed to optimize the linear aperiodic arrays with a minimum peak sidelobe level, which is inspired by the harmony search algorithm.

2.2 Differential Mutation and Crossover:

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

$$V_{i,G} = \begin{cases} X_{i,G} + \sum_{y\geq 1} F.\left(X_{r_2,G} - X_{r_3,G}\right), & \text{rand j } [0,1] \leq C_R \\ & \text{or j} = \text{rand j } [0,1] \\ X_{i,G} & \text{otherwise} \end{cases} \quad (1)$$

Where the indexes r_1, r_2, r_3 ϵ {1, 2, 3 ….Np} are randomly selected such $r_1 \neq r_2 \neq r_3 \neq i$.

The element of mutant vector $V_{i,G}$ 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 $X_{i,G}$.

F is a real and constant factors ϵ [0, 2] which controls the amplification of the differential variation ($X_{r2,\ G}$-$X_{r3,\ G}$). Different values of 'y' could lead to differential mutation strategies such as DE /rand/1/bin and DE/best/2/bin.

2.3 Selection:

The population for the next generation is selected from the individual in current population and its corresponding trail vector according to the following rule.

$$X_{i,G+1} = \begin{cases} V_{i,G} & \text{if } f\left(V_{i,G}\right) < f\left(X_{i,G}\right) \\ X_{i,G} & \text{otherwise} \end{cases} \quad (2)$$

Where f (.) is the objective function to be minimized. It is to say that if the new vector $V_{i,G}$ 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 the modified differential evolution strategy, a new parameter H_R is introduced. The element of mutant vector $V_{i,G}$ is generated randomly in the range between [0, 1] is greater than the specified constant H_R. Otherwise, the element is produced by the classic DE. In this case, the probabilities that each element of mutant vector $V_{i,G}$ is produced in three ways are followed by the schematic structure as shown in the figure 1.

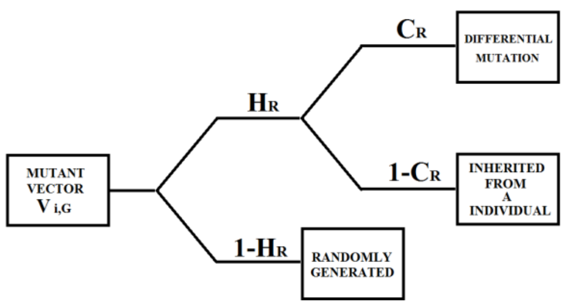

Figure 1: Probability of the new element generated using harmony search differential evolution

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 HSDEA can be referred at that of harmony search algorithm. Here C_R and F are updated as follows.

$$\begin{cases} C_R(gn) = C_{R_{min}} + \left(C_{R_{max}} - C_{R_{min}}\right) \times \frac{gn}{G_{max}} \\ F(gn) = F_{max}\exp(C.gn), C = \ln\left(\frac{F_{min}}{F_{max}}\right)/G_{max} \end{cases} \quad (3)$$

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.

2.4 The steps of MDE are presented as follows:

1. Initialize the model parameters and generate Np the N-dimensional parameter vectors as initial vector base
2. Select two vectors randomly from the vector base
3. Carry out the mutation and crossover operations in HSDEA and produce a new element vector
4. Execute the selection operation in DE update the vector base
5. Adjust the parameters $C_R(gn)$ and $F(gn)$
6. Check the stopping criteria. If not meet, return to step 2.

To show the excellence performance of Modified Differential Evolution Algorithm the specifications have been selected from the parameter values of harmony search. These rules are governed by some parameters, i.e., a scaling weighted factor 'F' and a probability C_R which control the crossover operator. The control parameter values are H_R = 0.95, $C_{R_{max}}$ = 0.9, $C_{R_{min}}$ = 0.2, F_{max} = 0.6, F_{min} = 0.1 and G_{max} = 1000.

3. MATHEMATICAL FORMULATION

3.1 Array Synthesis Methodology:

A linear array having N-isotropic elements placed along Z-axis with equal inter-element spacing 'd' and a symmetric geometry of linear array as shown in figure 2.

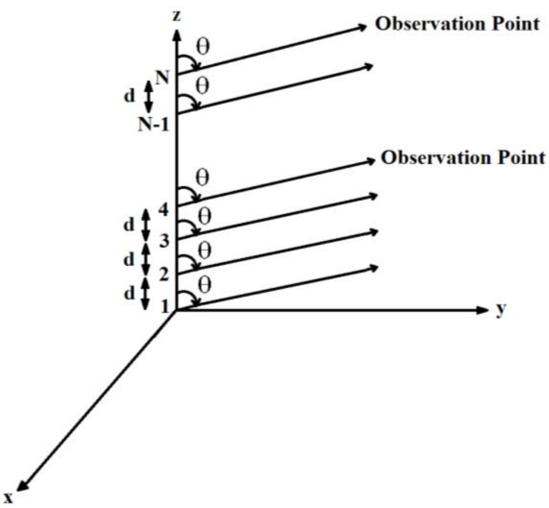

Figure 2: schematic diagram for linear array geometry

Generally suitable values of three parameters as amplitude, phase and the inter-element spacing are considered to design an array factor for the desired radiation pattern. Here the elements are spaced at a distance'd' operated at wavelength of λ/2 in order to avoid mutual coupling and grating lobes. The array factor in the azimuth plane is given as

$$\sum_{n=1}^{N} A(X_n)\ e^{j\frac{2\pi}{\lambda}ndu} \qquad (4)$$

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

'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 respectively and is evaluated by

$$X_n = \frac{2n-N-1}{N}$$

3.2 Objective Function:

The goal of the optimization is to generate a stair-step radiation 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

$$f = \min (w_1e_1+w_2e_2) \qquad (5)$$

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

$$\sum_{i=1}^{2} W_i = 1 \qquad (6)$$

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

$$e_1 = \left[\frac{1}{p}\sum_{i=1}^{p} \mathrm{I}E_1(u_i)\mathrm{I}^2\right]^{1/2} \qquad (7)$$

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

$$E_1 (u) = \{E (u) – F (u);\quad 0 \le u \le -u_0\} \qquad (8)$$

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

Therefore the step pattern is represented by

$$f(u) = \begin{Bmatrix} 1, & 0 \le u \le 0.5 \\ 0, & \text{otherwise} \end{Bmatrix} \qquad (9)$$

e_2 is the least mean square error in the sidelobe region

$$e_2 = \left[\frac{1}{Q}\sum_{i=1}^{Q} \mathrm{I}E_2(u_i)\mathrm{I}^2\right]^{1/2} \qquad (10)$$

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

$$E_2 (u) = \{E (u) – F (u);\quad u < -u_0\ \&\ u > u_0\} \qquad (11)$$

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

3.3 The Steps Involved here with different Staircase Radiation Patterns

Single Stair-step

F(u) =	0	$-1 \le u \le -0.8$
	0.5	$-0.8 \le u \le -0.2$
	1	$-0.2 \le u \le 0.6$
	0.5	$0.6 \le u \le 0.8$
	0	$0.8 \le u \le 1$

Two Stair-step

F(u) =	0	$-1 \le u \le -0.8$
	0.5	$-0.8 \le u \le -0.4$
	0.7	$-0.4 \le u \le -0.2$
	1	$-0.2 \le u \le 0.2$
	0.7	$0.2 \le u \le 0.4$
	0.5	$0.4 \le u \le 0.8$
	0	$0.8 \le u \le 1$

Three Stair-step

F(u) =	0	$-1 \le u \le -0.8$
	0.3	$-0.8 \le u \le -0.6$
	0.5	$-0.6 \le u \le -0.4$
	0.7	$-0.4 \le u \le -0.2$
	1	$-0.2 \le u \le 0.2$
	0.7	$0.2 \le u \le 0.4$
	0.5	$0.4 \le u \le 0.6$
	0.3	$0.6 \le u \le 0.8$
	0	$0.8 \le u \le 1$

Five Stair-step

F(u)=	0	$-1 \le u \le -0.8$
	0.3	$-0.8 \le u \le -0.6$
	0.5	$-0.6 \le u \le -0.4$
	0.7	$-0.4 \le u \le -0.2$
	0.9	$-0.2 \le u \le 0$
	1	$0 \le u \le 0.2$
	0.7	$0.2 \le u \le 0.4$
	0.5	$0.4 \le u \le 0.6$
	0.3	$0.6 \le u \le 0.8$
	0	$0.8 \le u \le 1$

4. NUMERICAL SIMULATION RESULTS

In order to validate the effectiveness of MDE (HSDEA) for non-convex problems, we first considered a linear array of different elements that are spaced λ/2 distance apart. For the optimized stair-step radiation pattern, the normalized amplitude coefficients and the static phase shifts of the array elements are taken as the optimizing parameters of the MDE algorithm. MDE reports the behavior of the cost function versus the number of 1000 iterations that are shown in the figure3.

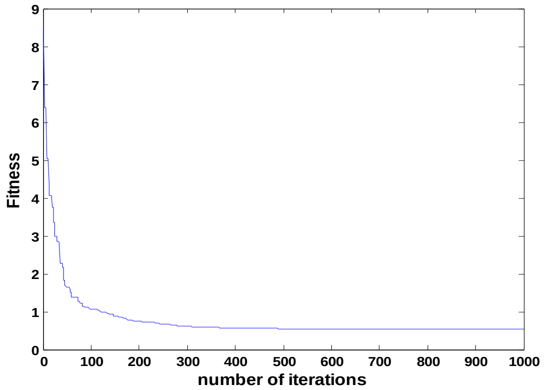

Figure 3: Behavior of fitness function versus number of iterations

Figure 4 reports the optimized radiation pattern of single stair-step, its corresponding amplitude and phase distributions are given in figure 5 and figure 6. Double stair case radiation pattern is reported in figure 7 and its amplitude and phase distributions are given in figure 8 and figure 9. Three stair-step radiation pattern has been showed in figure 10, its amplitude and phase distributions are presented in figure 11 and figure 12. Finally five stair-step optimized resultant pattern are obtained by MDE that are reported in figure 13, its amplitude and phase distributions are given in figure 14 and figure 15.

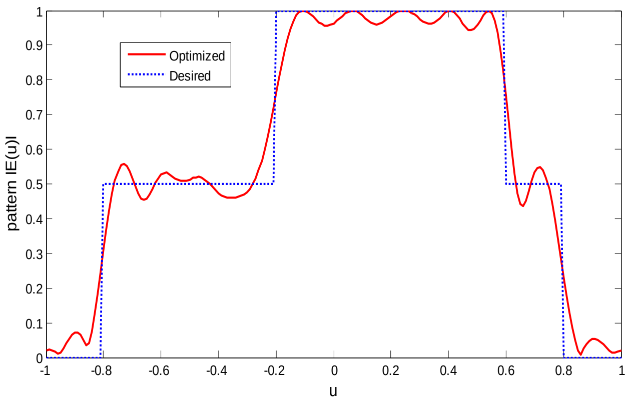

Figure 4: Single Stair-step Radiation pattern

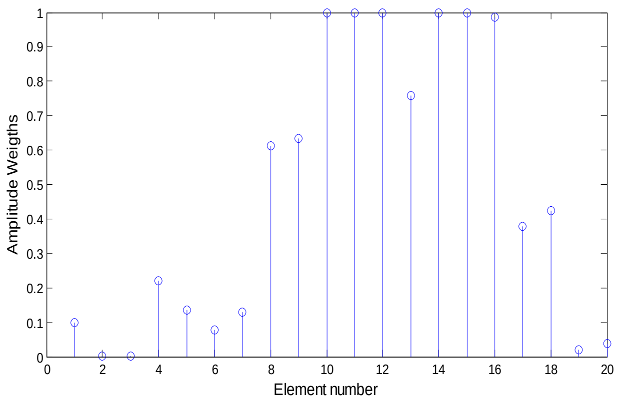

Figure 5: Amplitude distribution for Single Stair-step

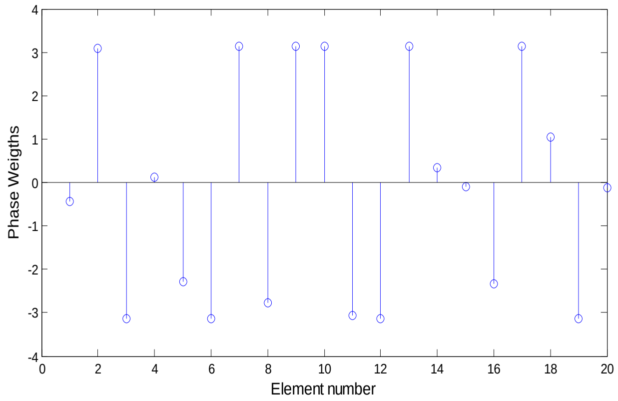

Figure 6: Phase distribution for Single Stair-step

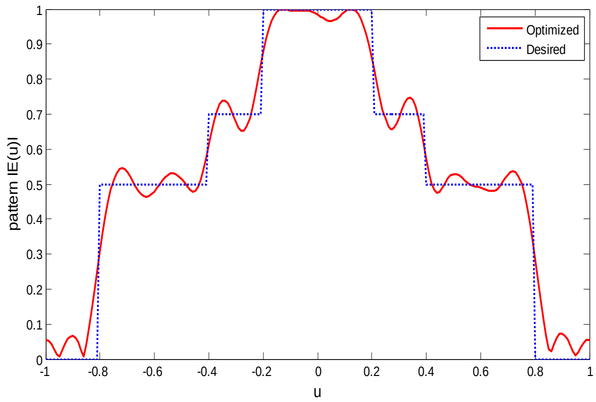

Figure 7: Double Stair-step Radiation pattern

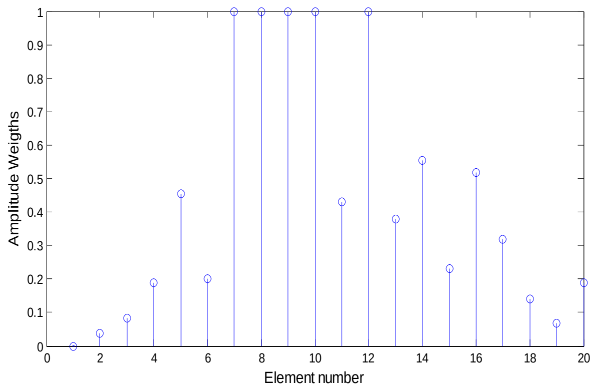

Figure 8: Amplitude distribution for Double Stair-step

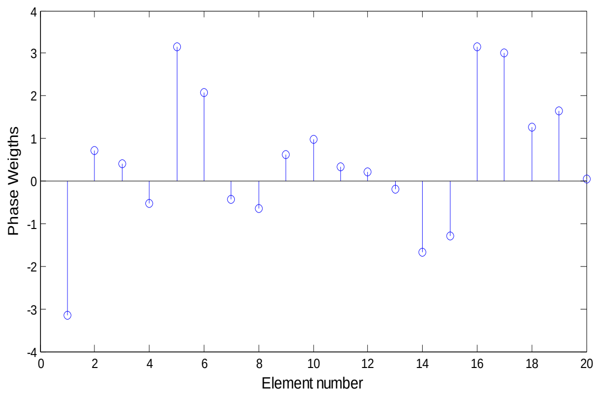

Figure 9: Phase distribution for Double Stair-step

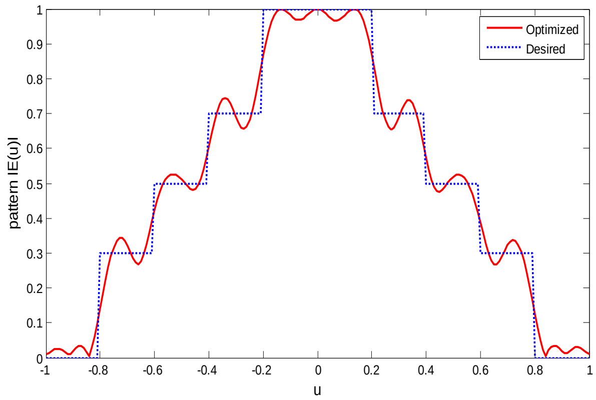

Figure 10: Three Stair-step Radiation pattern

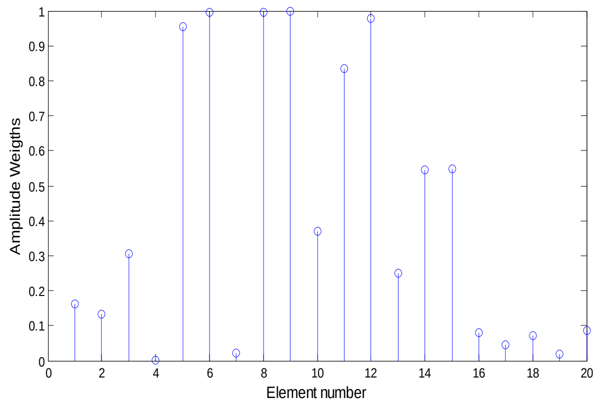

Figure 11: Amplitude distribution for Three Stair-step

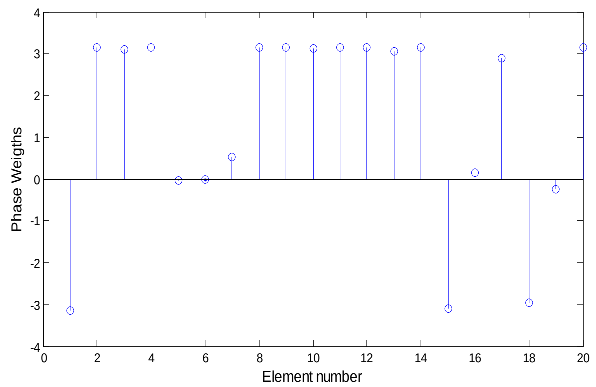

Figure 12: Phase distribution for Three Stair-step

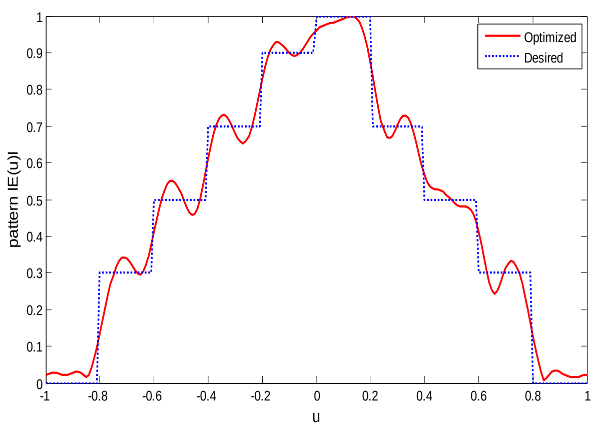

Figure 13: Five Stair-step Radiation pattern

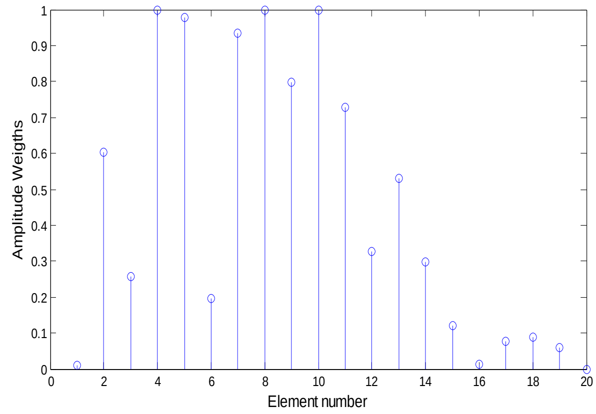

Figure 14: Amplitude distribution for Five Stair-step

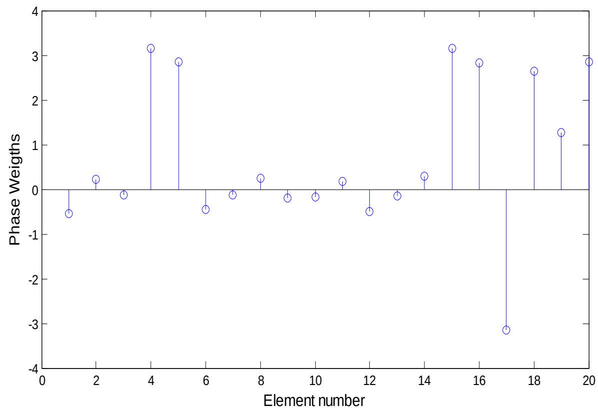

Figure 15: Phase distribution for Five Stair-steps

5. CONCLUSION

Synthesis of shaped beam radiation patterns from a linear array antenna using modified differential evolution algorithm has been presented. The proposed method is applied to the synthesis of 20 element linear antenna array that are spaced λ/2 distance apart for which the stair stepped radiation patterns are generated. The suitable element amplitude excitations and static phase shifts are determined by the algorithm those reduce the sidelobe level of the array to satisfactorily low values. A new method provides convenient mainlobe shape control and also the obtained patterns are more close to the desired radiation patterns.

This technique is very effective and its capability for extremely satisfactory improvement of patterns has been verified in the cases of shaped beam antennas with particularly sharp cut off characteristic requirements at low elevation angle and antennas with low sidelobe level required over a limited angle region only.

Although limited examples of simulations have been presented in this paper, the optimized simulation results of stair-step radiation patterns are clearly observed that the superiority of the MDE over the other methods.

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7. AUTHOR'S PROFILE

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