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Pattern Synthesis using Real Coded Genetic Algorithm

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Abstract:

The main aim of this work is to generate the ramp shaped radiation pattern from an array of isotropic radiating elements using Real coded Genetic Algorithm. It is focused to realize the patterns, for meeting its demand and requirements in radar and satellite communication systems for tracking applications. There are many analytical methods available for beam shaping, but GA acquires its significance importance as it uses random search methods which are proved to be robust and capable of solving complicated search problems. Results are obtained for finite ramp width by varying element number. All the results are simulated using matlab software. The simulated results are more close to the desired radiation patterns. The optimized data and radiation patterns are extremely useful for array designers. Any array can be designed for an application specific.

Key words

Antenna Array Synthesis, Beam Shaping, Ramp pattern, Real Coded Genetic Algorithm

1. Introduction

Antennas array synthesis is widely used in different communication systems like phased array radar, satellite and wireless communication etc. in which a specific beam shape is required for scan and non- scan applications. Antenna beam-shaping proposed by various authors belongs to synthesis of antenna array. In Antenna pattern synthesis (G. S. N. Raju 2005), input or source distribution is determined for a specified radiation pattern. In the present work, the main objective is to generate the ramp shaped radiation pattern from the antenna arrays using Real

Coded Genetic Algorithm. To obtain this, a set of element excitation coefficients and excitation phases that closely produce desired beam shapes are required. Most of these techniques have been carried out for equally spaced linear arrays and unequally spaced linear arrays. The shape of the desired pattern can vary widely depending on the application.

Beam shaping can be achieved through amplitude tapering, phase tapering or space tapering or any combination of the above two. The Narrow beams are produced from a line source or from an array of radiating elements by suitable amplitude distribution without introducing additional phase. These Narrow beams are useful for point to point communication. Ramp shaped beams does not exhibit symmetry about the bore sight direction like pencil beams. Both amplitude and phase tapering is used to generate the pattern. These are useful in point to point communication.

Many synthesis methods can be found in the literature to generate the desired beam shapes. The classical synthesis methods are Wood-ward Lawson and Fourier transform method. In Woodward method (G. S. N. Raju , 2005) the excitation coefficients are chosen such that its field strength is equal to the amplitude of the desired pattern at its corresponding sample point. The drawback of Woodward method is that it lacks control over the side lobe level in the tradeoff region of the entire pattern. Fourier transform method (C. A. Balanis, 1997) is used to design the excitation distribution of either a continuous line source or a discrete array for a specified radiation pattern.

In the literature, there are many works related with the antenna array synthesis. The pattern synthesis technique proposed by (R. F. Hyneman and R. M. Johnson, 1967) depends on the controlled location of zeros of pattern function in the complex pattern plane with the relative displacement of these zeros from real Sinθ axis. The locations are approximately constrained by known zero locations of fan or sector pattern. The sector pattern is warped or perturbed to the desired pattern shape by deterministic perturbations of the zeros. W.L.Stutzman employed iterative sampling method for beam shaping. David.J. sadler discussed a sector beam synthesis using linear and nonlinear optimization techniques. In the above synthesis procedures, both the amplitude and phase of each array element are optimized. Also reported stationary phase methods to develop analytical phase distributions (A. Chakra borty et al.) which produce certain patterns with the amplitude specified. The patterns are generated from continuous line sources, discrete array of isotropic radiators and also for discrete array of non-isotropic radiators.

Attempts has been made to develop a nonlinear phase function for the generation of CSc^2 patterns (G.S.N.Raju and A.Chakraborty,1986). The pattern synthesis carriedout for equi- spaced linear arrays (R.S. Elliot and G.J. Stern,1984) , has some control in the trade in region and also in the trade- off region. Also reported (Homayoon Oraizi and MojtabaFallahpour, 2011) sum, difference and shaped beam synthesis using poisson sum expansion of the array factor. Optimized ramp patterns obtained using amplitude only and phase only control methods (A. sudhakar et.al, 2009). Attempts has been made to reduce the close in side lobes of symmetrical pattern using energy relations (M.Satyanarayana and G.S.N.Raju).

To avoid the complexity involved in conventional analytical synthesis techniques, today a lot of research on antenna array synthesis is being carried out using Evolutionary optimization techniques like Genetic algorithm(GA), Particle Swarm Optimization(PSO), Simulated Annealing(SA), Ant colony Optimization(ACO) and etc. The feeding network amplitudes and phases are optimized (Akdagli, A. and K. Guney , 2003) using modified tabu search algorithm to obtain the desired shaped pattern. Synthesis of sum patterns, difference patterns and sector beam using space and phase tapering methods was reported by (O.Homayoon and M.Fallahpour, 2011) using Genetic algorithm.

From the literature survey, it was found that no work was done on generation of ramp shape radiation pattern using Optimization techniques. In this paper, a Real Coded Genetic Algorithm (RGA) was employed to obtain the desired ramp shape radiation pattern from an array of isotropic radiating elements. In this work, Genetic algorithm (R.L.Haupt,1994) method is adopted for synthesis.

2. Real coded genetic algorithm

Genetic Algorithm (R.L.Haupt, 1994) is a kind of heuristic search technique, which came into existence from Darwin's theory of Natural Evolution. It uses certain methods based on the principle of natural genetics and natural selection to obtain the optimization procedures that best satisfies a predefined goal.

Real-coded GA (R.L.Haupt, 1994) uses floating-point number representation for the real variables. In floating-point representation, each chromosome or individual vector is coded as a vector of floating-point numbers of the same length which is same as the solution vector. The

Real coded Genetic Algorithm is free from binary encoding and decoding and it takes less memory space than binary GA.

The steps involved in implementing the algorithm are as follows:

1. Define the fitness function , select parameters to be optimized by GA
2. Randomly generate initial population within the variable constraint range
3. Calculate fitness of each individual within the population
4. Selection: select two parents from the population based on their fitness
5. Crossover: choose crossover probability to crossover parents to form new children
6. Mutation: with some mutation probability the new chromosomes are then mutated to generate new population for next generation.
7. Check for stopping criteria, if the stopping criteria is met then stop and return the chromosomes with best fitness value from current population
8. Otherwise go to step 3

The flow- chart diagram of Real-coded GA is shown in Fig. 1 below.

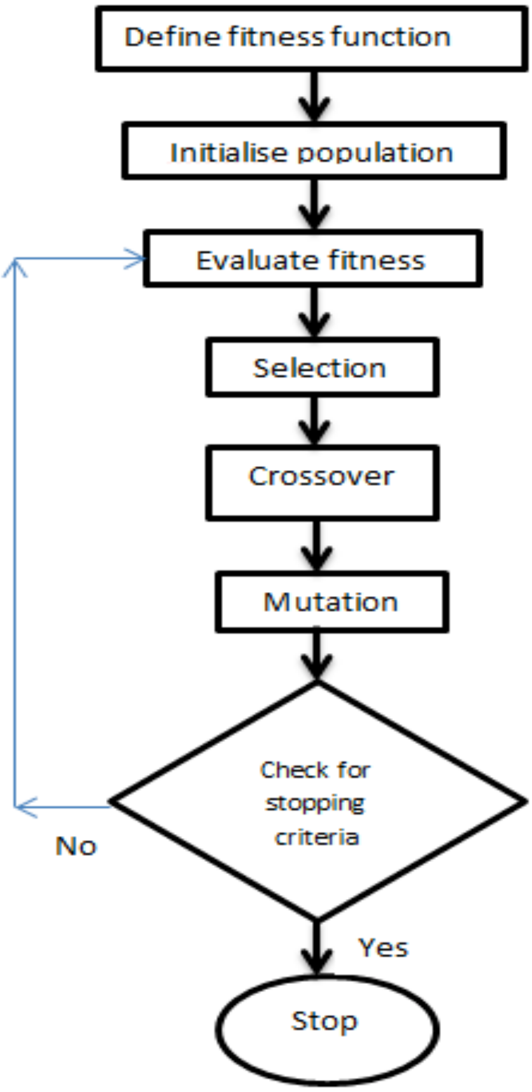

Fig.1. Flow chart of Real coded Genetic Algorithm

The algorithm starts with a set of randomly generated population which are likely solution to the problem. This randomness introduces diversity in the population which allows searching a major portion of the solution space. Each chromosome represents one possible antenna array configuration. A chromosome is array of genes. A fitness function is used to evaluate each array configuration and fitness value is assigned depending on how close is the configuration to the desired one. The evaluated array configurations undergo a selection procedure based on their fitness value. Those having better fitness values are selected to generate offspring.

There are different types of selection Techniques like Roulette wheel selection, Tournament selections, Natural Selection etc. The selected chromosomes then undergo a cross over operation to generate children (new array configurations). The idea behind performing cross over operation is that, information exchange between two good solutions may result in a better solution. Different crossover types include single point crossover , two point crossover , uniform crossover etc. Next, mutation operation is performed. In this operation, a randomly selected variable of randomly selected array configuration is changed or mutated. This is performed so that the algorithm will not stuck at local minima. Finally, the newly generated chromosomes are again evaluated for their fitness values and process repeats until stopping criteria is met. Finally the array configuration with best fitness value is taken as the optimum solution.

3. Formulation

1. The mathematical model of Beam- Shaping:

The linear array is the one of the most commonly used array structure owing to its simplicity and beam shaping property.

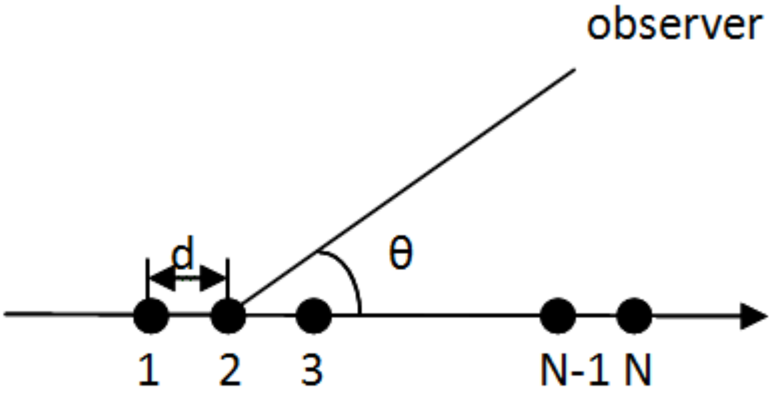

Fig.2. Linear array

Consider a linear array with ‘N’ isotropic elements spaced at a distance of half wavelength (λ/2), its far-field pattern is represented by

$$E(u) = \sum_{n=1}^{N} A(x_n)\, e^{j\left(kLu_1x_n+\phi(x_n)\right)} \qquad (1)$$

Here

$A(x_n)$ = Amplitude excitation of n^{th} element

$\phi(x_n)$ = Normalised phase excitation of n^{th} element

$k = 2\pi/\lambda$

L= length of the array

$u_1 = u-u_0$

$u = \sin\theta$

$u_0 = \sin\theta_0$

θ_0 = scan angle

x_n = Element position in the array.

A. Ishimaru (1962) has suggested a spacing function, which is useful for odd and even number of elements in the array. It is given by

$$x_n = \left(\frac{2n - N - 1}{N}\right)$$

In the synthesis, the main aim is that the beam shape should approach the optimization target in the shaped region.

1. ***Initialization and Cost function:***

To generate the desired pattern, limit the amplitudes of elements from 0 to 1 and phase values in between –π and π. Cost function determines the direction of evaluation and it has great influence on obtained optimal solution.

The desired ramp pattern is represented by

$$\mathrm{F(u)} = \begin{cases} \frac{u}{u_0} & ; 0 \leq \mathrm{u} \leq \mathrm{u_0} \\ 0 & ;\ \text{elsewhere} \end{cases} \qquad (2)$$

Here u_0 =width of the finite ramp

This is sampled at fixed number of values of ‘u’. At the same points the error between desired pattern and obtained pattern is evaluated.

The error in the main beam region is calculated as

$$E_1(u) = \begin{cases} E(u) - F(u) & ; 0 \leq \mathrm{u} \leq \mathrm{u_0} \\ 0 & ;\ \text{elsewhere} \end{cases}$$

Least mean square error of the main beam region is $e_1 = \left[\frac{1}{Q}\sum_{i=1}^{Q}|E_1(u_i)|^2\right]^{\frac{1}{2}}$

Here ‘Q’ represents the number of sampling points in the main beam region.

The error in the sidelobe region is calculated as

$$E_2(u) = \begin{cases} E(u) - F(u) & ; 0 \leq \mathrm{u} \leq \mathrm{u_0} \\ 0 & ;\ \text{elsewhere} \end{cases}$$

Least mean square error in the sidelobe region is $\mathrm{e_2} = \left[\frac{1}{S}\sum_{i=1}^{S}|E_2(u_i)|^2\right]^{\frac{1}{2}}$

Here ‘S’ represents the number of sampling points in the sidelobe region

$$\textit{Cost function} = min(w_1\, e_1 + w_2\, e_2)$$

Here w_1 and w_2 represents the weights of e_1 and e_2 respectively and it should be such that

$$\sum_{i=1}^{2} w_i = 1$$

4. Simulation Results

In the present work, an isotropic linear array is considered for beam shaping. Real coded Genetic algorithm is applied to eq.(1) to obtain the optimized radiation pattern and desired radiation pattern is obtained from eq.(2). An initial population of 80 chromosomes was randomly generated. The probability of crossover and probability of mutation are set to 0.8 and 0.02 respectively. Both amplitude and phase excitations of each element is optimized to generate the desired Radiation pattern. Results are obtained for ramp width (u_0) of 0.4 by varying number of elements. The excitations obtained through algorithm are used in the calculation of array factor and simulation results are plotted for N=200, 100, 80, 60 and 40 elements.

From the results obtained in the present work, the realized patterns are optimum and are very close to the desired ones with small ripples. Also it can be observed that all patterns are generated with lowest possible sidelobe levels.

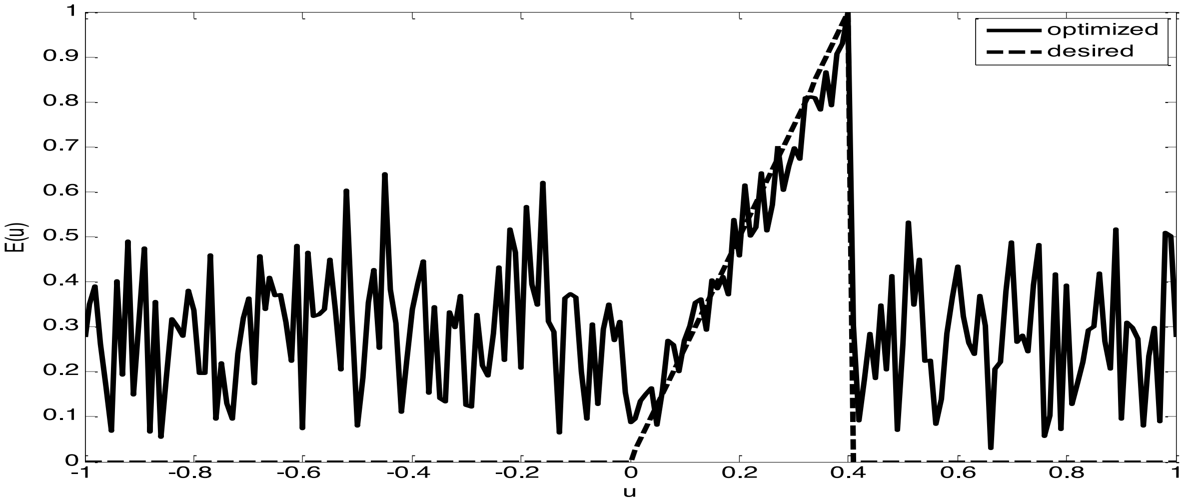

Figure.3.Radiation pattern for N= 200 elements

Figure(3) shows the radiation pattern of 200 elements and figure(4) and figure(5) shows its corresponding amplitude distribution and phase diatribution respectively. The optimized results are compared with desired results.

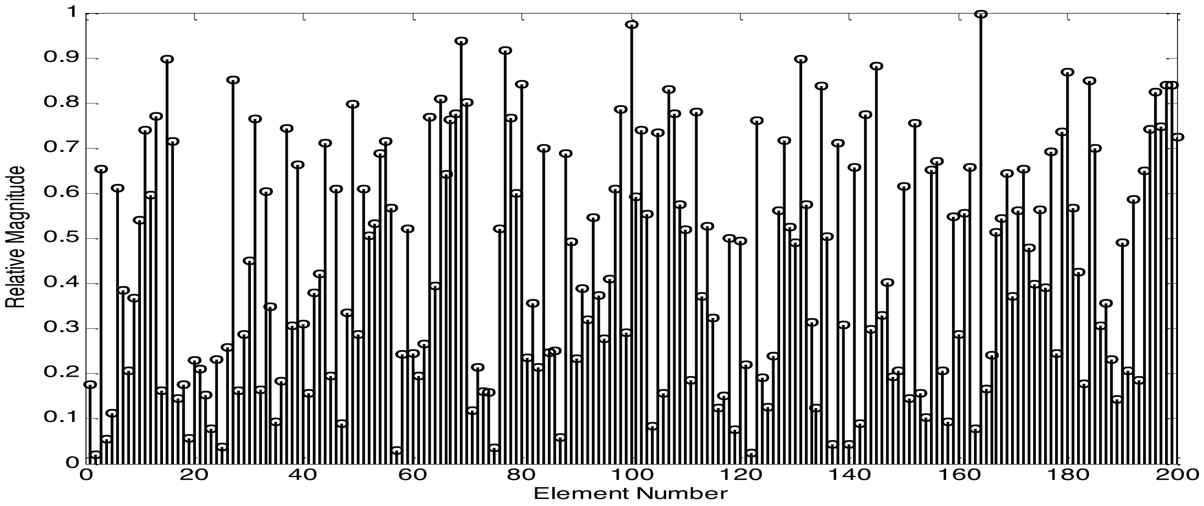

Figure.4. Amplitude Distribution for N= 200 elements

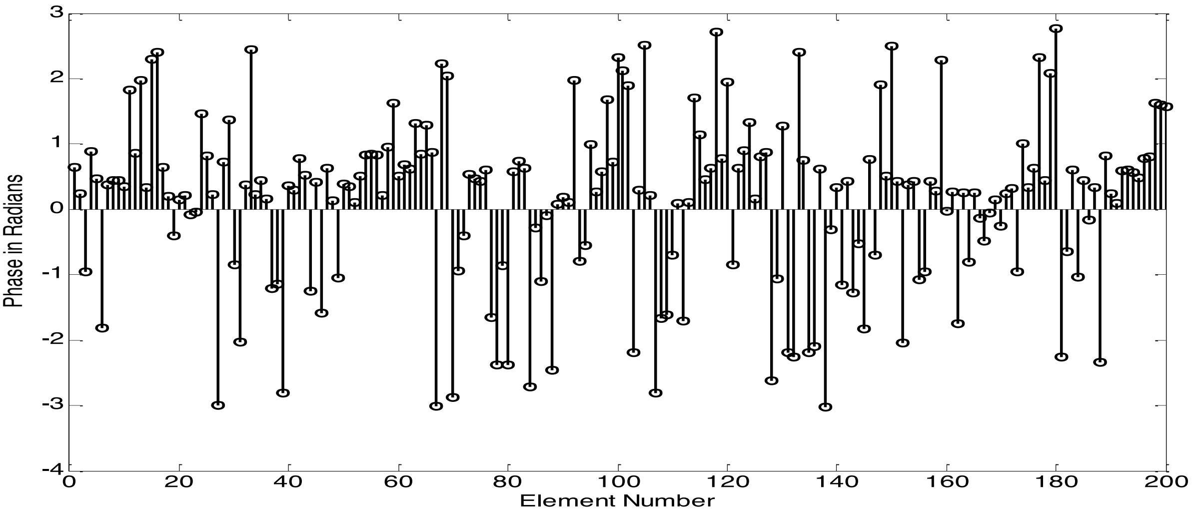

Figure.5. Phase Distribution for N= 200 elements

Similarly the simulated results for different number of elements are also presented in the figures (6-17). From the results, it was clear that optimized results are more close to the desired one with lowest possible side lobe levels.

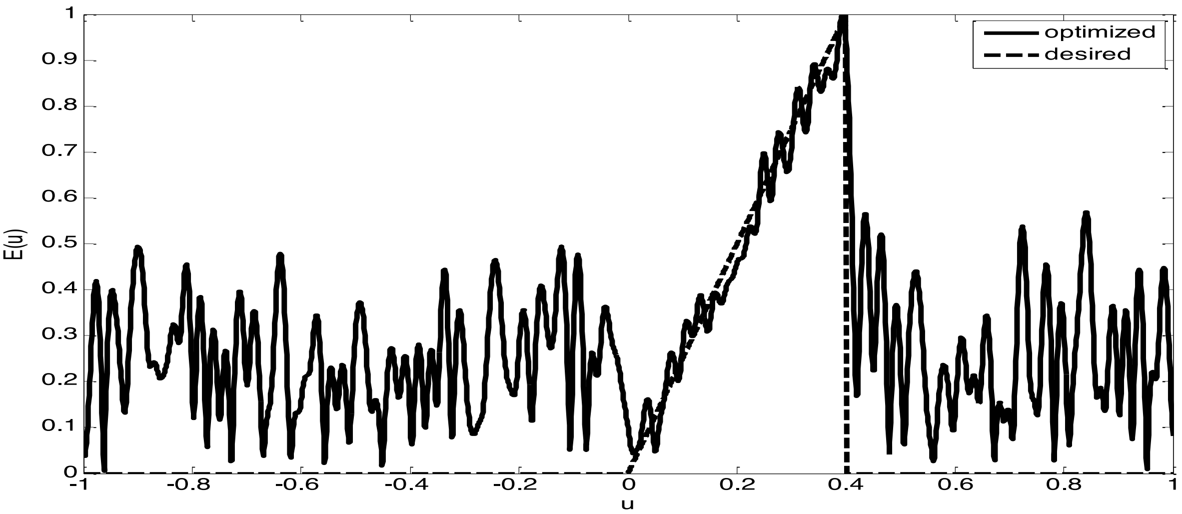

Figure.6. Radiation pattern for N= 100 elements

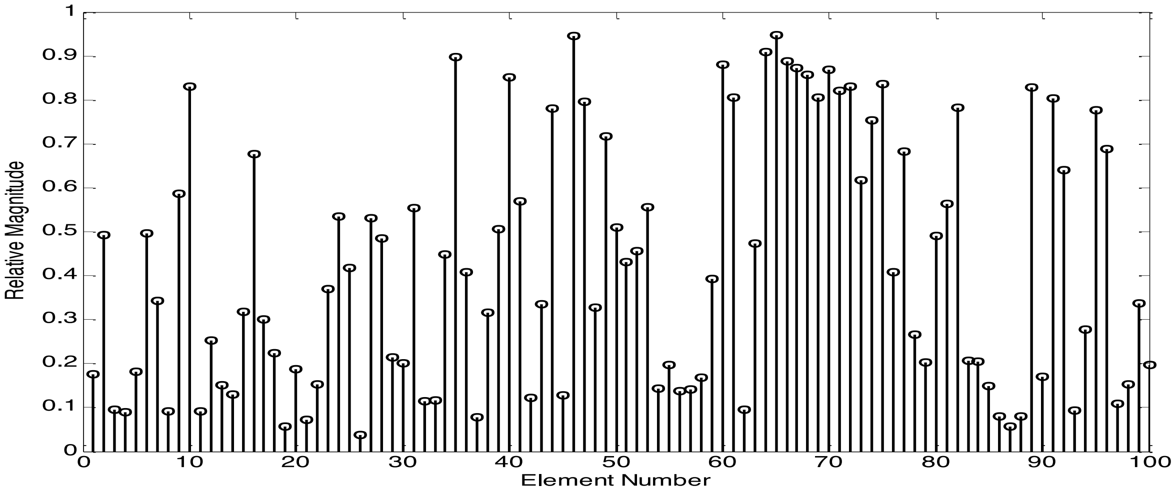

Figure.7. Amplitude Distribution for N= 100 elements

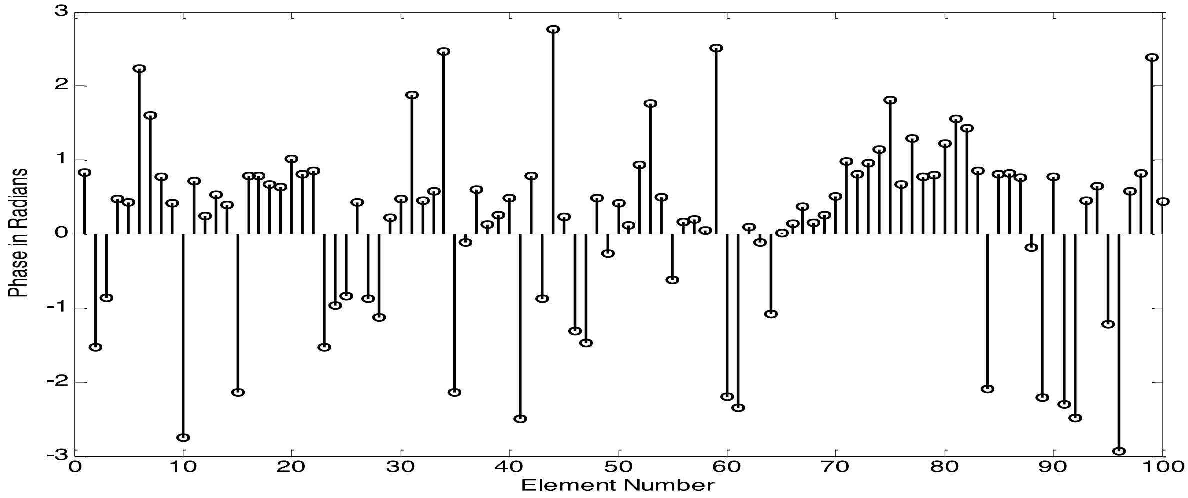

Figure.8. Phase Distribution for N= 100 elements

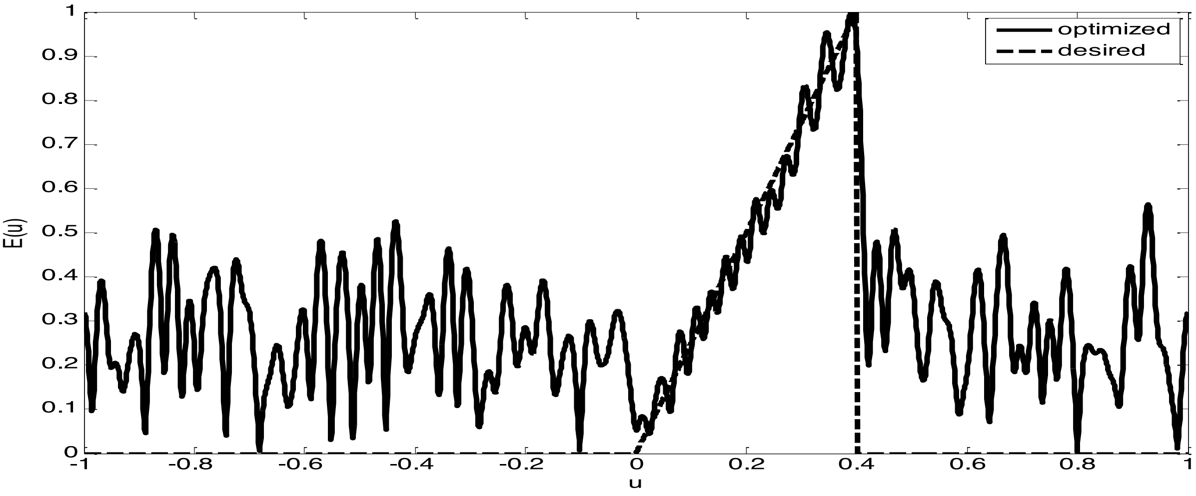

Figure.9. Radiation pattern for N= 80 elements

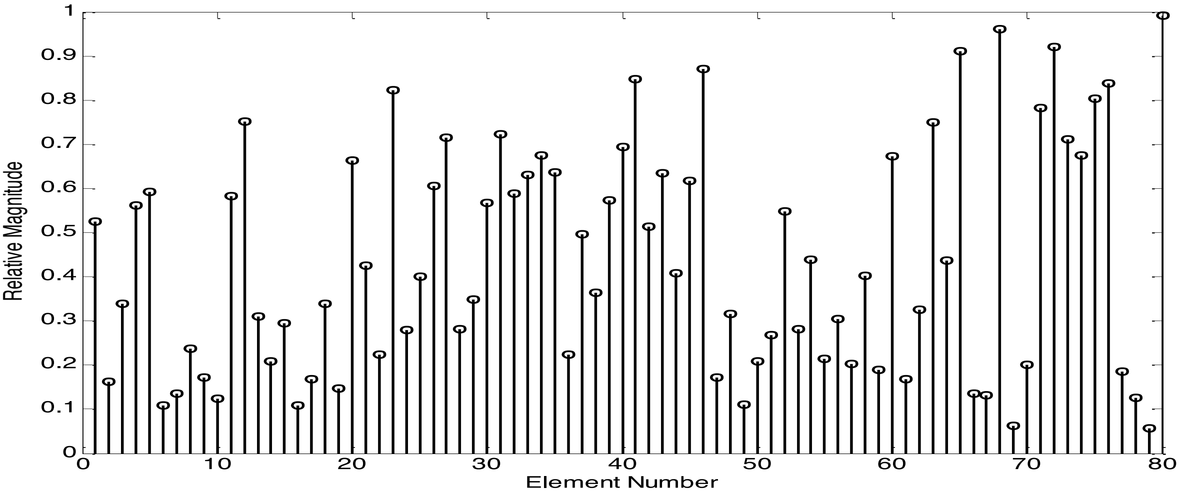

Figure.10. Amplitude Distribution for N= 80 elements

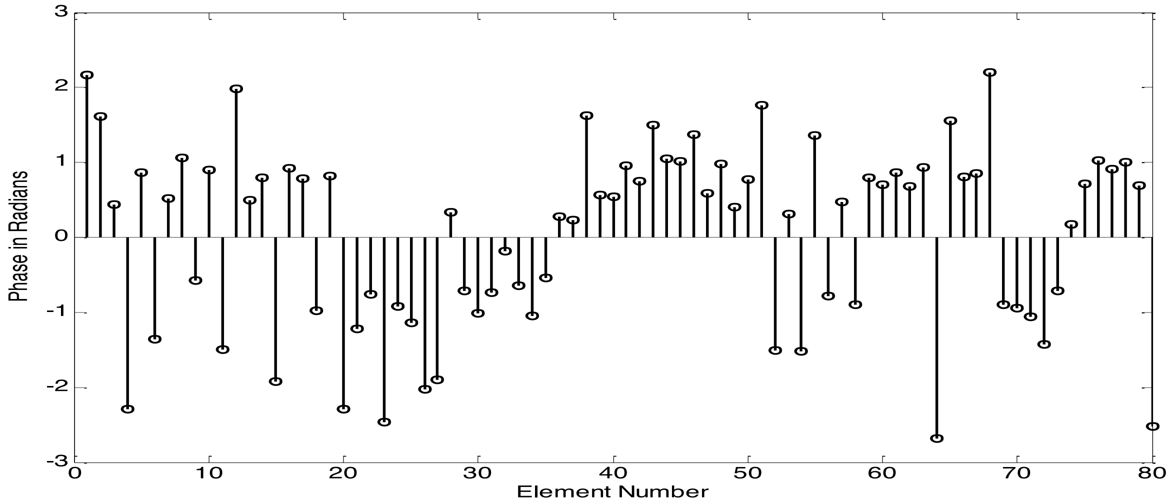

Figure.11. Phase Distribution for N= 80 elements

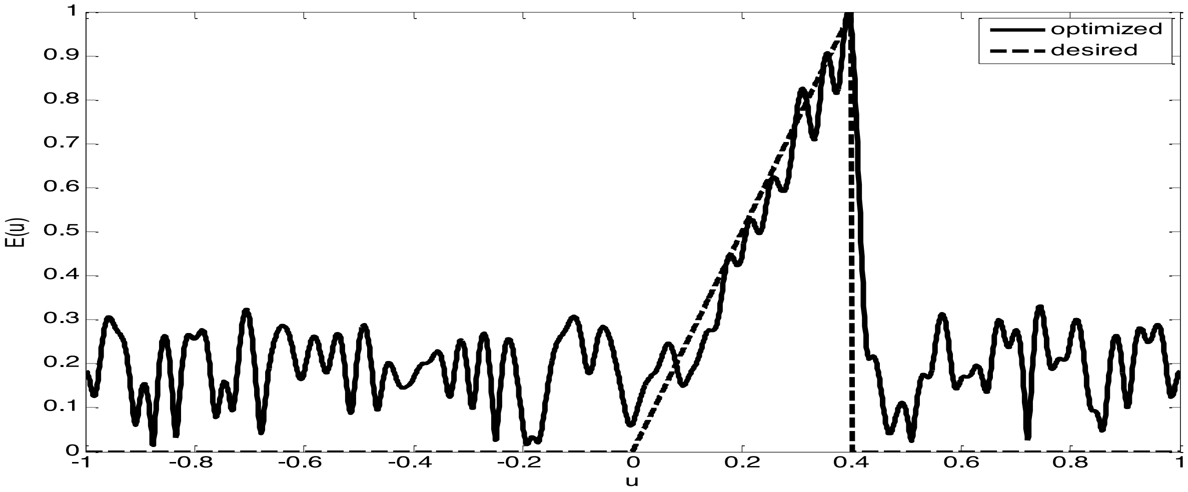

Figure.12. Radiation pattern for N= 60 elements

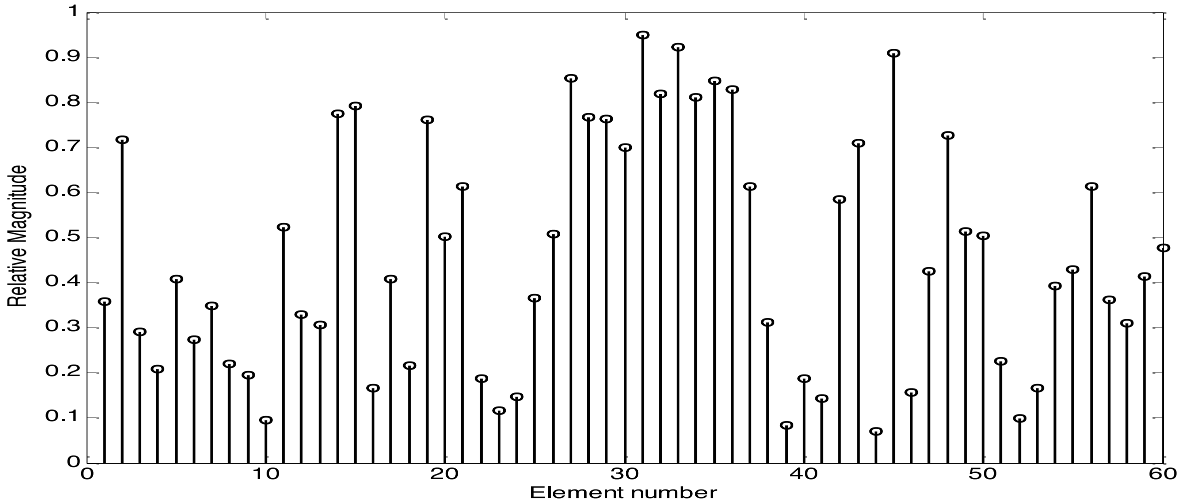

Figure.13. Amplitude Distribution for N= 60 elements

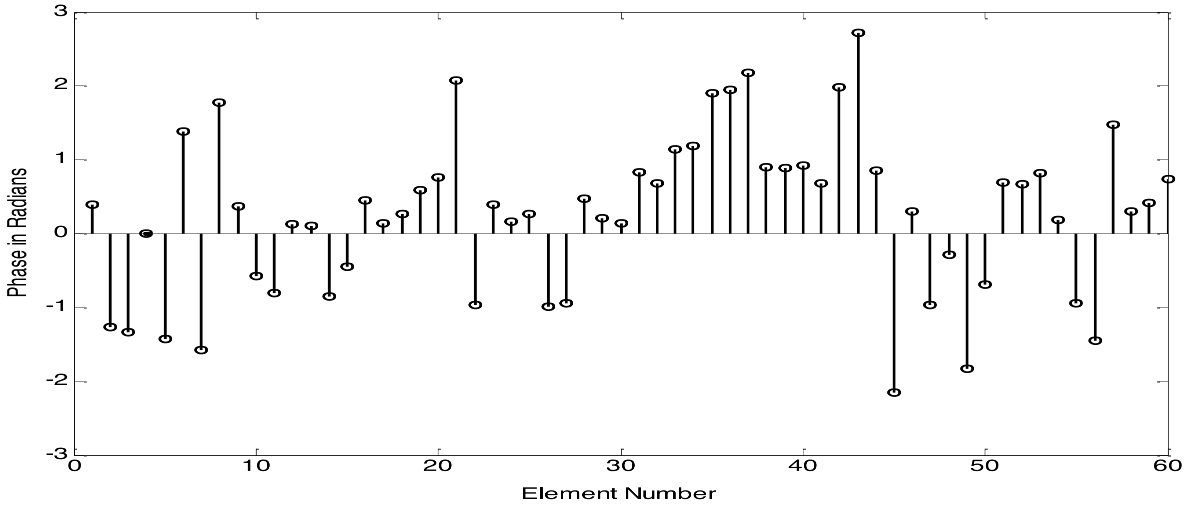

Figure.14. Phase Distribution for N= 60 elements

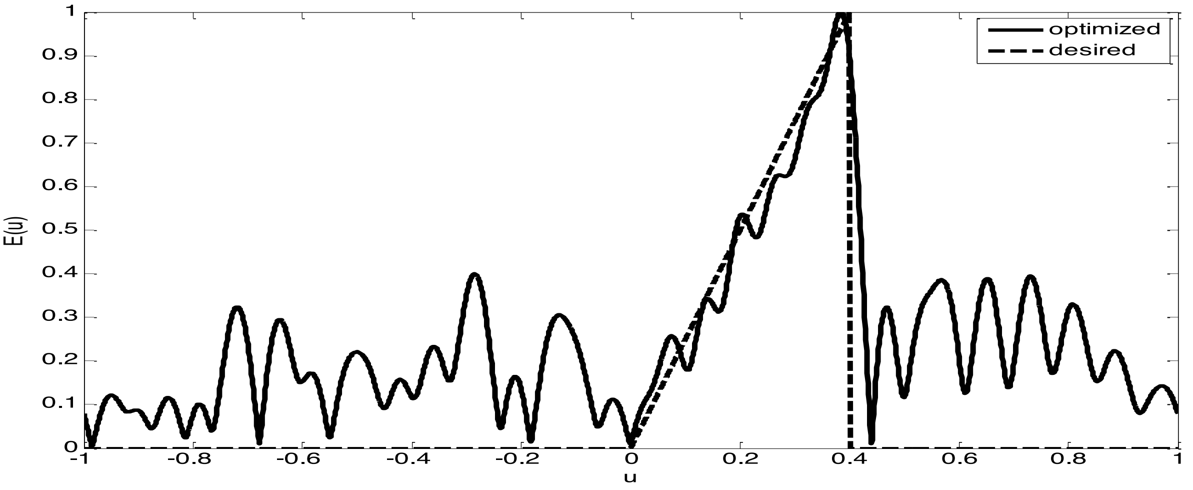

Figure.15. Radiation pattern for N= 40 elements

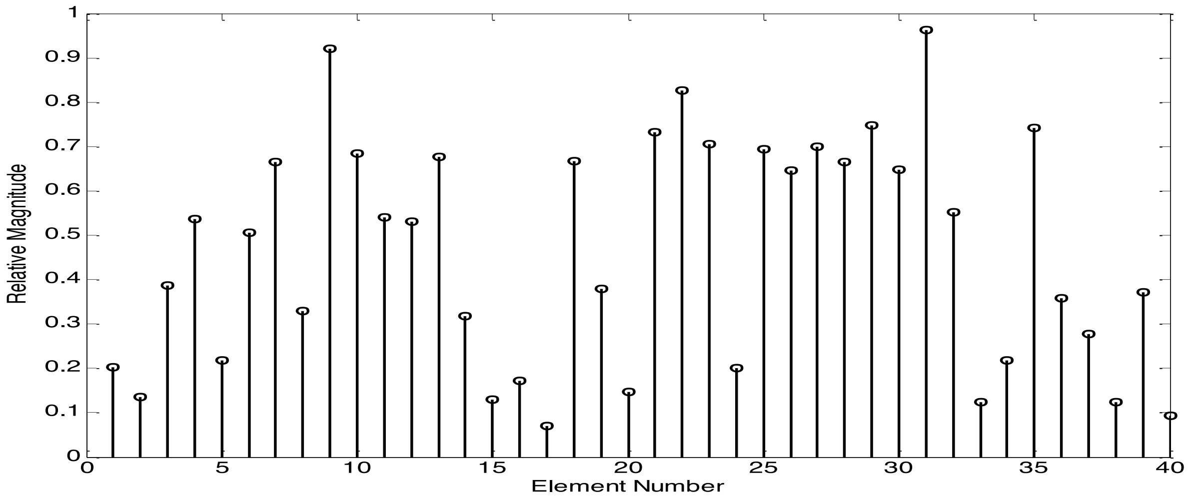

Figure.16. Amplitude Distribution for N= 40 elements

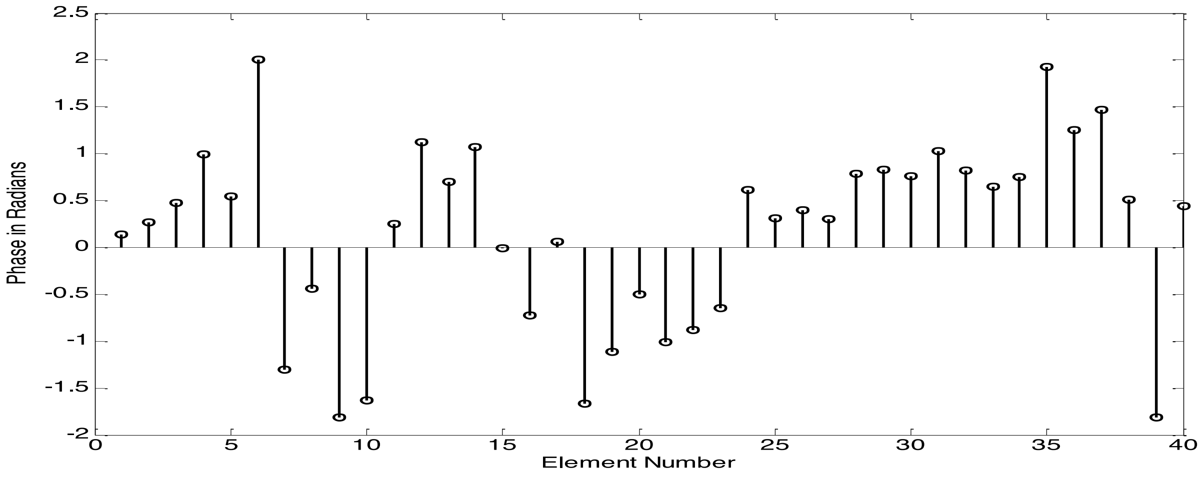

Figure.17. Phase Distribution for N= 40 elements

5. Conclusion

In the open literature there are many works available on shaped beams using optimization techniques but to the best of the author's knowledge no work is available on ramp shape radiation patterns. In the present work, a Real coded Genetic Algorithm is adopted to optimize the amplitude and phase excitations of equi-spaced linear array to generate the ramp shape radiation patterns. The obtained results show that the beam shape is retained in the desired region while keeping the sidelobe levels at lowest. The generated patterns are very useful in point to point communication. The lowest side lobe levels reduce problems due to EMI. Although the present work is focused on array of isotropic radiating elements, it can be extended for practical radiating elements. This method is suitable for small and large arrays.

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