AMSE JOURNALS –2015-Series: Advances B; Vol. 58; N° 1; pp 35-52
Submitted Dec. 2014; Revised March 31, 2015; Accepted April 28, 2015

Application of Genetic Algorithm for Reduction of Sidelobes from Thinned Arrays

G. S. K. Gayatri Devi, G.S.N.Raju, P.V.Sridevi

Dept. of Electronics & Communication Eng., College of Engineering (A), Andhra University, Visakhapatnam-530 003, A.P., India
(gayatrigavalapu@gmail.com; profrajugsn@gmail.com; pvs6_5@gmail.com)

Abstract

Sidelobe reduction is one of the most important aspects in the design of antenna arrays for low Electro Magnetic Interference applications. It can be achieved through non-uniform spacing, amplitude-only synthesis, phase-only synthesis, or a combination of above. Thinning an antenna array not only results in low sidelobes but also reduces cost, weight and design complexity. This paper presents the design of linear array of isotropic elements which generates low sidelobe patterns. The array is excited with prefixed amplitude taper and simultaneously thinned. A Genetic Algorithm is employed to find the optimum thinning configurations. Numerically simulated results are presented for different number of elements.

Keywords

Thinning of arrays, Genetic Algorithm, Linear Arrays, Side Lobe Reduction.

1. Introduction

In design of antenna arrays, one of the most important parameter is sidelobe level(SLL). High sidelobes are undesirable as they result in Electro Magnetic Interference (EMI) which degrades the overall system performance [1], [2]. Large antenna arrays are designed with an intention to increase directivity, so most of the energy must be concentrated in the main beam. This implies the radiation should be minimized in other directions. Antenna arrays designed with low SLLs find several applications in radar, satellite communications, remote sensing and radio astronomy etc.

Low sidelobe patterns can be generated by careful designing of amplitude distribution across the array elements [3]. A uniform amplitude distribution results in narrow beam but with considerably large first sidelobe. An improvement in the first sidelobe level can be achieved by exciting the array with concave downward type of excitation where the central elements have larger amplitude weights than those for the end elements [4]. Several standard amplitude distributions are available like circular, parabolic, triangular, cosinusoidal, raised cosinusoidal which result in lower sidelobe levels compared to uniform amplitude distribution [1]. Another alternative is to use space tapering [5], [6]. In this technique, the array elements are positioned in relation to the desired amplitude taper across the array. One method is to place the elements aperiodically or arbitrarily. Lo [7] stated that simple analytical methods are not available for determining the element positions to achieve desired sidelobe levels. Many of the aperiodic array synthesis methods aim at positioning antenna elements such that element density is proportionate to amplitude density at a particular location in the array. In general, element density is high at the center and decreases toward the edges.

Phase tapering is another method which greatly influences the characteristics of radiation patterns [8]. It can be used for reducing undesired side lobes in linear arrays [9], [10]. It reduces the complexity involved in design of feeding network compared to amplitude tapering.

Array thinning is another approach for synthesizing low sidelobe patterns [11]. This technique reduces the number of active elements without degrading the system performance. As simple analytical methods are not available for synthesis of aperiodic arrays, optimum thinning configuration must be derived either statistically or through optimization techniques. The traditional method for array thinning is to take a uniformly excited linear array with half wavelength spaced elements and then turn off certain number of elements. Using this method, a thinned array was first developed by arbitrarily removing elements [12], [13]. The drawback of this technique was large peak sidelobe level due to arbitrary positioning of the elements.

Peak sidelobe level depends not only on the number of elements turned off but also on their positions in the array. One way to obtain the thinned array configuration which results in minimum sidelobe level is to check all possible combinations. This turns out to be an exhaustive search unless the number of elements is small. For large arrays, it becomes impractical to check all combinations.

Conventional optimization methods make a random initial guess for the solution and they search the region surrounding this point in the solution space. If the number of parameters to be optimized is small, the solution space will be small; hence the above methods are well suited as they search a considerable portion of the total solution space. But if the number of parameters is large, the size of solution space will be large and hence the resulting solution depends on where the initial guess falls in the solution space. Hence these methods are subjected to the problem of stucking at local minima. They are not suitable for array thinning.

Thinning of large antenna arrays with hundreds of elements using analytical methods is a difficult task to achieve. It requires solving complex mathematical functions. A good alternative is to use global optimization techniques to find the optimum solution. Several techniques like GA, Binary PSO, Simulated Annealing, ACO etc. have been successfully applied for the problem of array thinning.

Several works were reported on thinning of linear arrays. In [14], R.L.Haupt used GA to optimize linear and planar arrays for reduced sidelobe levels. In [15], V.Rajyalaksmi applied GA for thinning linear arrays of isotropic elements to achieve lowest sidelobe level. In [16], Carl A.Meijer applied Simulated Annealing to design thinned linear and planar arrays with low peak SLLs. In [17], Quevedo and Rajo proposed Ant Colony Optimization for designing thinned linear and planar arrays using SLL as the desirability parameter. In [18], Jianfeng et al. applied Immunity Algorithm to improve the sidelobe performance of thinned linear array. In [19], U.Singh and Kamal used Biogeography Based Optimization for thinning large linear and planar arrays of uniformly excited isotropic antennas. In [20], Zhang et al. employed an Orthogonal GA to synthesize linear thinned array with minimum SLL. In [21], Wang et al. presented chaotic binary PSO (CBPSO) for the synthesis of thinned linear and planar arrays with the constraints of sidelobe reduction. From the literature survey, it is clear that no work has been reported on thinning a linear array of isotropic elements excited by a prefixed amplitude distribution.

The objective of this paper is to thin a given ‘m’ element isotropic array excited by a prefixed amplitude distribution to reduce the relative peak sidelobe level. The null to null beamwidth obtained after thinning is not allowed to deviate more than 1° from that obtained before thinning. A binary Genetic Algorithm is used for finding optimum configuration which satisfies this condition.

The paper is organized as follows: Section 2 gives a brief description of array thinning. The principle of GA is discussed in section 3. Problem formulation is given in section 4.

Numerical results are presented and analyzed in section 5. In section 6, conclusions are discussed.

2. Array Thinning

Thinning an array means selectively removing some elements in an antenna array to obtain the desired sidelobe level. The elements which are ‘removed’ or ‘OFF’ are terminated in a matched or dummy load and the remaining elements are connected to the feed network. Hence the far field pattern is due to the contribution of ‘ON’ elements only. It has the advantage of considerable reduction in element count, cost, weight, power consumption and complexity. It results in nearly same beam width as for an array of equal size with all elements turned ‘ON’. This technique is simpler than aperiodically spacing the elements as the later can place the elements in an infinite number of ways. For an array of ‘n’ elements, thinning has 2^n possible combinations. For a symmetric array, the number of combinations further reduces. With this approach, highly directive antenna arrays can be constructed at much lower cost compared to a fully filled array. Thinned arrays find many applications like in satellite receiving antennas that operate against a jamming environment, in ground-based high frequency radars, in the design of interferometer arrays for radio astronomy [22].

3. Genetic Algorithm

Genetic Algorithm is an evolutionary algorithm developed on the principles of genetics [5]. It is a nature inspired algorithm. It is one of the earliest developed numerical optimization technique. The algorithm aims at finding a set of parameters which are optimum solutions to a problem. Since its introduction, GA found widespread applications in many fields like computational science, engineering, mathematics, business etc. It is a best choice to solve complex optimization problems in antenna array synthesis [23]. Some of the advantages of GA over other traditional search techniques include [24]

- It works with continuous and discrete variables
- Derivative calculation is not required
- It can optimize large number of variables
- It can handle complex optimization problems
- It searches from a number of points in the solution space parallelly

The steps required for implementing the algorithm are as follows:

1. Define the fitness function , select parameters to be optimized by GA

2. Generate initial population
3. Calculate fitness
4. Selection
5. Crossover
6. Mutation
7. Check for stopping criteria, stop if it is satisfied
8. Go to step 3

A flowchart of Genetic Algorithm is shown in fig.1.

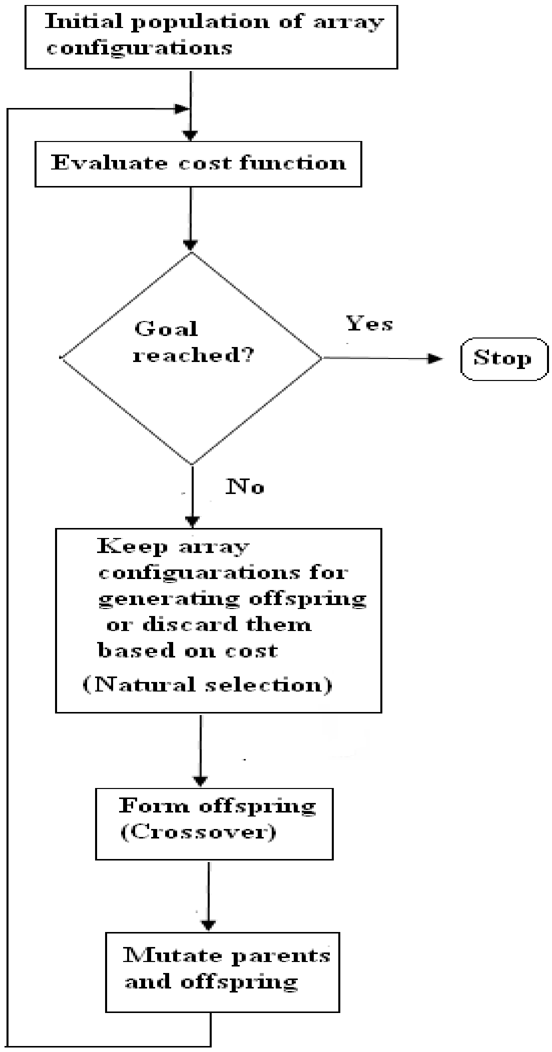

Fig.1. Genetic Algorithm Flowchart

A binary GA is well suited for the problem of thinning. The algorithm starts with a set of randomly generated initial population (antenna array configurations) which are likely solutions to the given 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 a set of genes. A gene represents one or more parameters to be optimized. In a binary GA, genes are represented as binary strings. A fitness function is defined to evaluate each array configuration and a fitness value (or cost) 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 selection, natural selection etc. The selected chromosomes then undergo a crossover operation to generate new offspring (new array configurations). The idea behind performing crossover operation is that information exchange between two good solutions may result in a better solution. Different crossover types include single point crossover, uniform crossover, two point crossover etc. Then the parents and offspring undergo mutation. In this step, a randomly selected variable of a randomly selected array configuration is changed or mutated. This is performed so that the algorithm will not stuck at local minima.

Mutation introduces diversity in population and it helps to explore a larger solution space. Finally, the newly generated chromosomes are again evaluated for their fitness values and the process repeats until the stopping criteria is met. The array configuration with best fitness value is taken as the optimum solution.

4. Formulation

Consider a linear array of 2M elements placed along z-axis as shown in Fig.2. Assume that all elements are isotropic and are placed symmetrically along the axis. Let the spacing between adjacent elements is ‘d’. Further assume that the amplitude distribution is symmetrical about the axis.

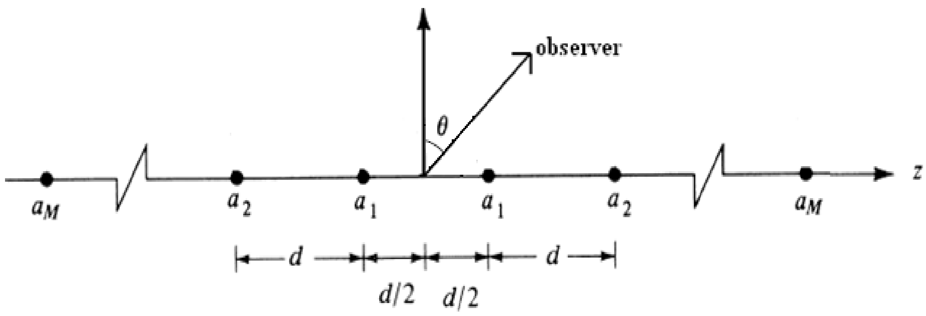

Fig.2. A 2M element symmetric linear array

Then the resulting array factor can be derived [25] as

$$E(\theta)= A_1 e^{j\left(\frac{1}{2}\right)kd\sin\theta} + A_2 e^{j\left(\frac{3}{2}\right)kd\sin\theta} + \cdots + A_M e^{j\left(\frac{2M-1}{2}\right)kd\sin\theta} + A_1 e^{-j\left(\frac{1}{2}\right)kd\sin\theta} + A_2 e^{-j\left(\frac{3}{2}\right)kd\sin\theta} + \cdots + A_M e^{-j\left(\frac{2M-1}{2}\right)kd\sin\theta} \tag{1}$$

$$= 2A_1 \cos\left(\left(\frac{1}{2}\right)kd\sin\theta\right) + 2A_2 \cos\left(\left(\frac{3}{2}\right)kd\sin\theta\right) + \ldots + 2A_M \cos\left(\left(\frac{2M-1}{2}\right)kd\sin\theta\right)$$

$$= 2\sum_{m=1}^{M} A_m \cos\left[\left(\frac{2m-1}{2}\right)kd\sin\theta\right] \tag{2}$$

Here k= (2π/λ)

d= spacing between two elements, (λ/2)

λ= operating wavelength

θ=angle between line of observer and boresight direction

A_m=Excitation coefficient of m^{th} element in the array.

A cosine on pedestal distribution as defined below is considered.

$$A_m = 1 + 0.48\cos(\pi x_m) \tag{3}$$

here

$$x_m = \left(\frac{2m-1-2M}{2M}\right) \quad \text{where m=1,2,…2M}$$

Now right half of the distribution is applied and the array is thinned to get minimum possible peak sidelobe level. If 'I_m' represents the thinning coefficient of m^{th} array element, then the array factor now can be written as

$$E(\theta) = 2\sum_{m=1}^{M} A_m I_m \cos[(m-0.5)kd\sin\theta] \tag{4}$$

here I_m = '1' for an element turned 'ON'

= '0' for an element turned 'OFF'

In u-domain, it can be written as

$$E(u) = 2\sum_{m=1}^{M} A_m I_m \cos[(m-0.5)kdu] \tag{5}$$

here $u = \sin\theta$

If we assume all elements are 'ON', then all I_m coefficients will become '1' and the equation now can be written as:

$$E(u) = 2\sum_{m=1}^{M} A_m \cos[(m-0.5)kdu] \tag{6}$$

here $u = \sin\theta$

A GA is applied to eq. (4) to obtain the best thinning configuration. The algorithm started with an initial population of fifty chromosomes. The parameter setting effects the convergence speed of random optimization techniques like GA. In this case, the percentage of crossover is set to 0.6. A natural selection scheme is employed. The mutation rate is set to 0.01. The algorithm is set to stop after 100 generations. The fitness function used for evaluating fitness of chromosomes is formulated as follows:

$$Fit = w1 \times \left(PSLL_o - PSLL_D\right) + w2 \times \left(BWFN_O - BWFN_D\right) \quad (7)$$

Here

$PSLL_O$ = Obtained Peak Side Lobe Level and is given as

$$PSLL_O = \max_{u \in S}\left\{20\log\left|\frac{E(u)}{E_{\max}}\right|\right\}$$

E_{max}= Peak of the main beam

'S' represents the side lobe region.

$PSLL_D$= Desired Side Lobe Level

$BWFN_O$=Obtained beam width

$BWFN_D$=Desired beam width

w1 and w2 are weighting factors which decide the relative preference given to each term in eq. (7) and should be chosen such that their sum equates '1'.

5. Results

A linear isotropic array of 200 elements excited with amplitude distribution given in eq. (3) is considered. Then it is thinned with a goal to achieve lowest possible peak sidelobe level (PSLL). A GA is used to find the optimum thinning configuration. Fig. 3 shows the resultant radiation pattern with a peak SLL of -31.02dB obtained by turning off 14 elements. The element status (ON=1, OFF=0) for right half of the symmetric array is as shown below:

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 0 1 1 1 1 1 1 0 1 1 0 1 1 1 0
1 0 1 1 0 1 1 1 1 1 1 1

Fig. 4 shows the pattern before thinning with a peak SLL of -25.26dB. Fig. 5 shows the pattern when the array is thinned by uniformly exciting the elements. A peak SLL of -

23.06dB is obtained, an improvement of 8dB can be observed when the combination of array thinning and prefixed amplitude distribution is used.

The convergence curve of the algorithm is shown in Fig. 6. The amplitude distribution using eq. (3) for 200 element linear array is shown in Fig.7.

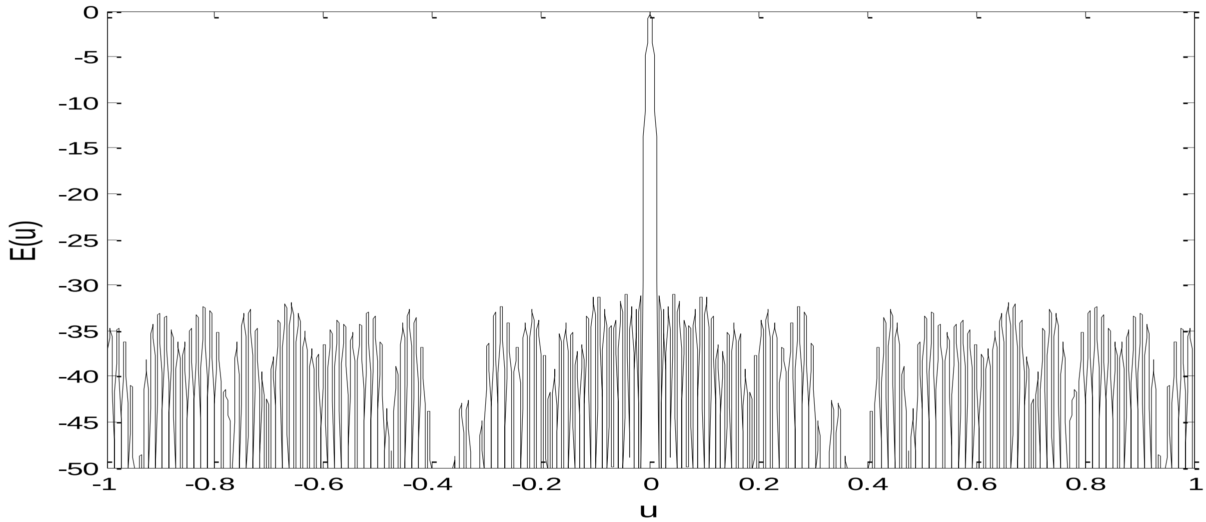

Fig. 3. Radiation pattern for N=200elements after thinning

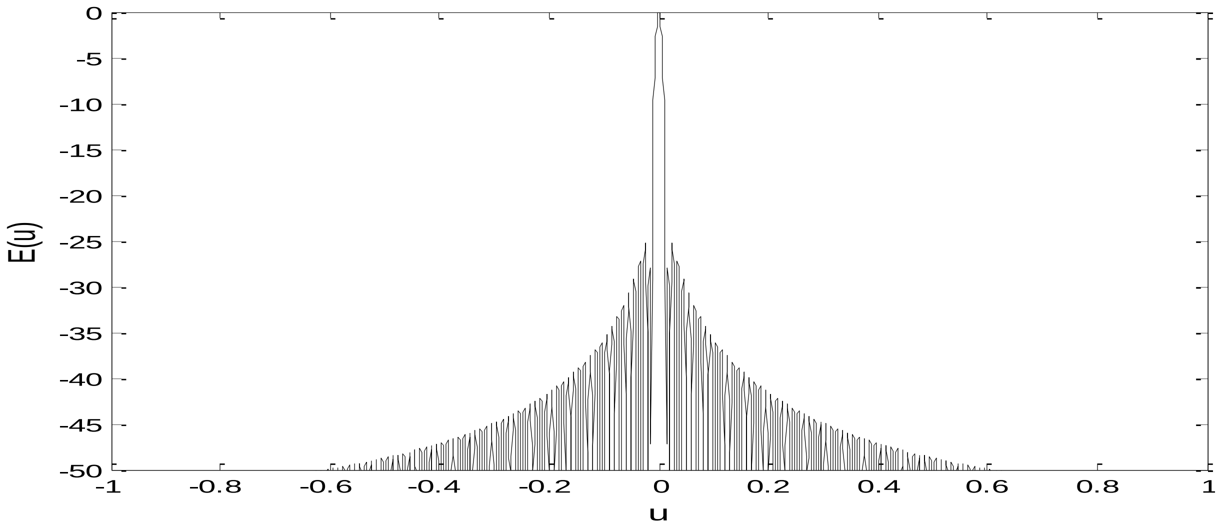

Fig. 4. Radiation pattern for N=200 elements before thinning

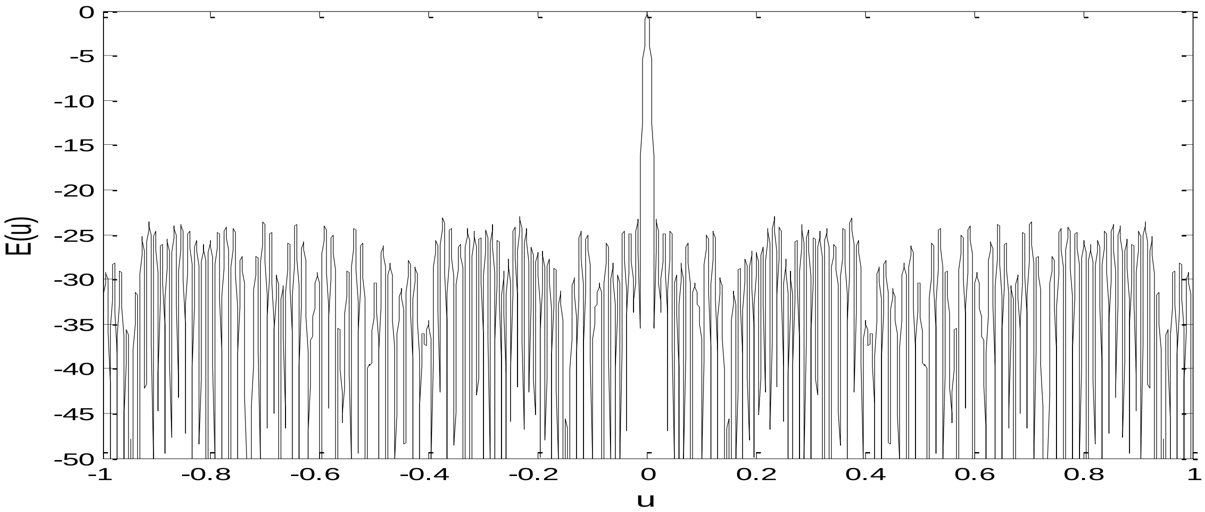

Fig. 5. Radiation pattern for N=200 elements with uniform excitation (A_m='1') after thinning

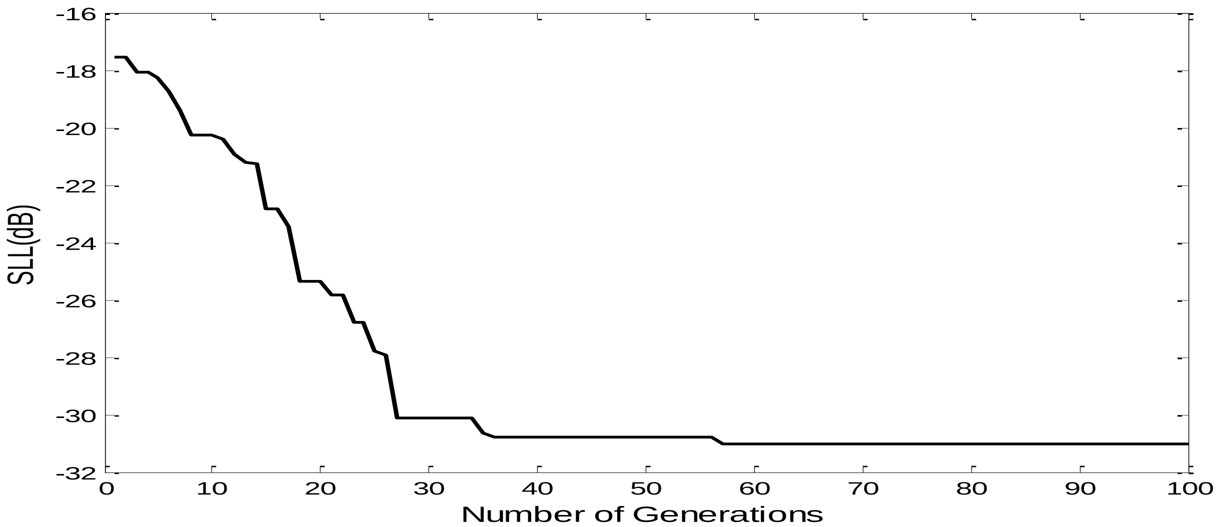

Fig. 6. Convergence curve of GA for 200 element array

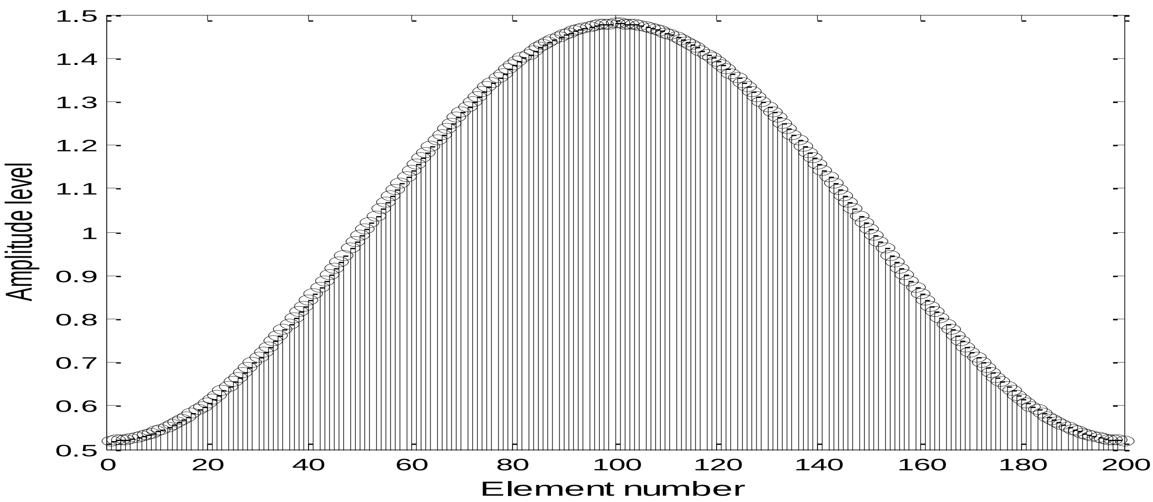

Fig. 7. Amplitude distribution for N=200elements

Fig. 8 shows the radiation pattern for a 150 element array thinned after excited with the amplitude distribution shown in Fig.11. Fig.9 shows the pattern before thinning. The element status (ON=1, OFF=0) for right half of the symmetric array with 10 elements turned off is as given below:

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 0 1 1 1 1 0 0 1 1 1 1 1 1 0 1 1

Fig.10 shows the pattern for a uniformly excited 150 element array after thinning. A peak SLL of -21.70dB is obtained, an improvement of 8.375dB can be observed after providing amplitude excitations.

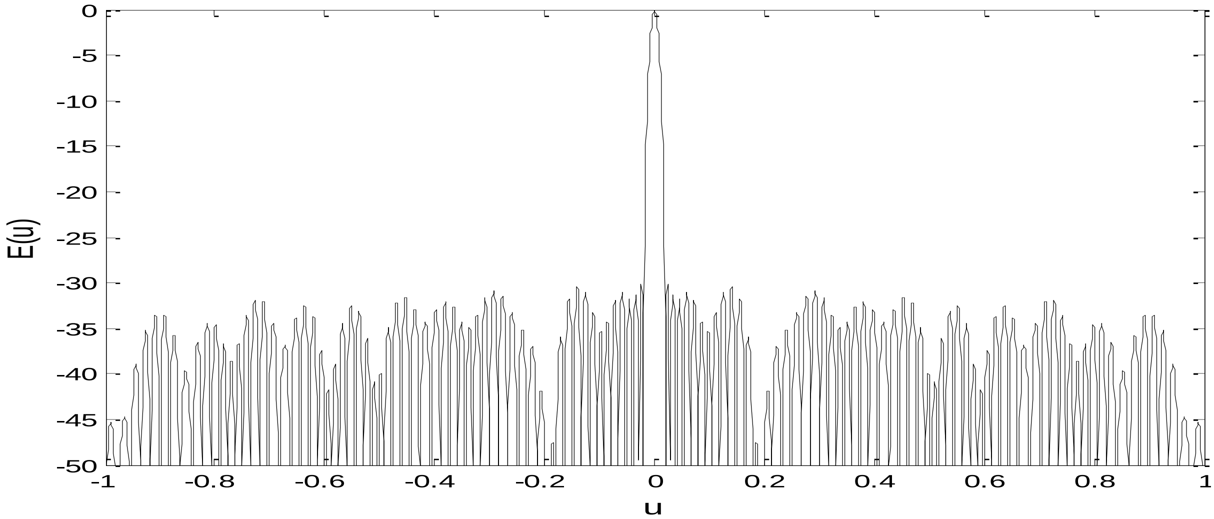

Fig. 8. Radiation pattern for N=150elements after thinning

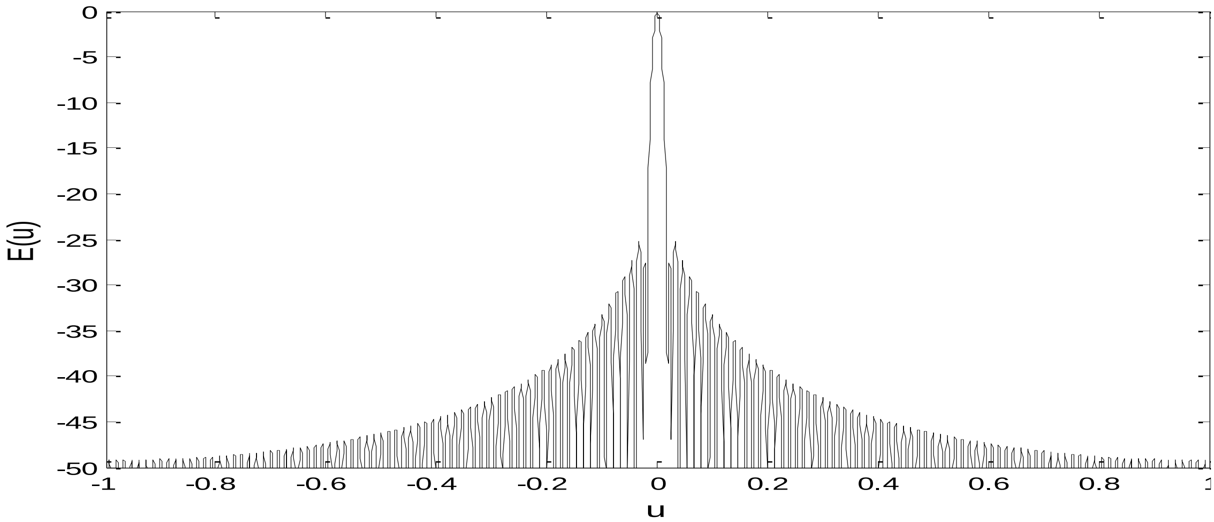

Fig. 9.Radiation pattern for N=150 elements before thinning

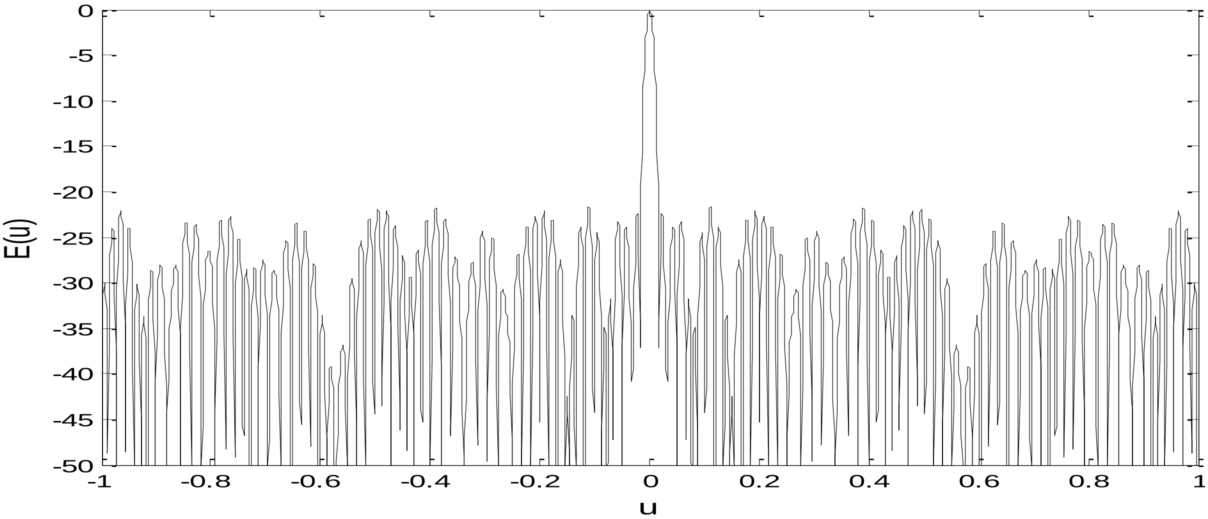

Fig. 10. Radiation pattern for N=150 elements with uniform excitation (A_m='1') after thinning

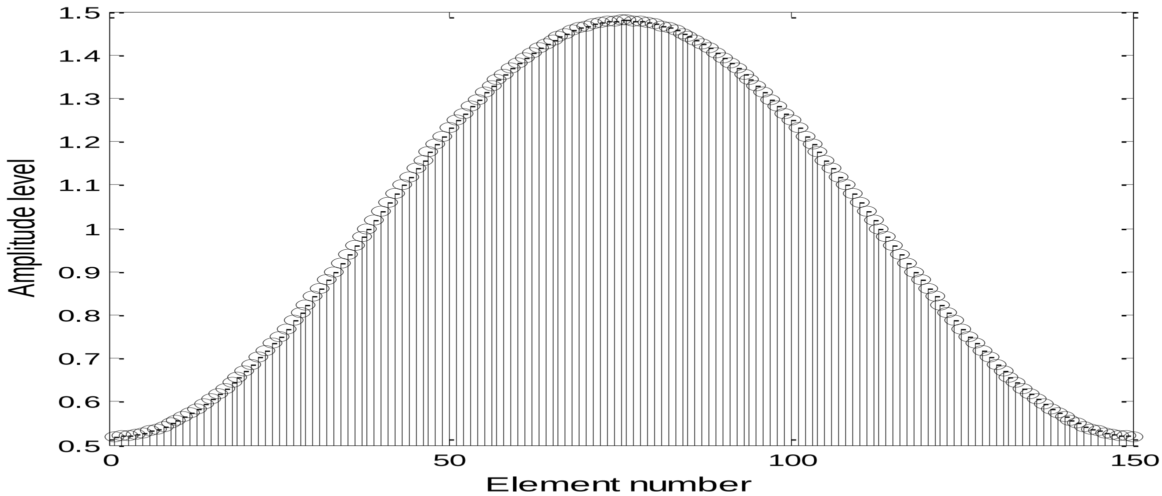

Fig. 11. Amplitude distribution for N=150elements

Fig.12 compares the radiation patterns obtained before and after thinning a 40 element array excited with the amplitude distribution obtained from eq. (3). It is shown in Fig.14.

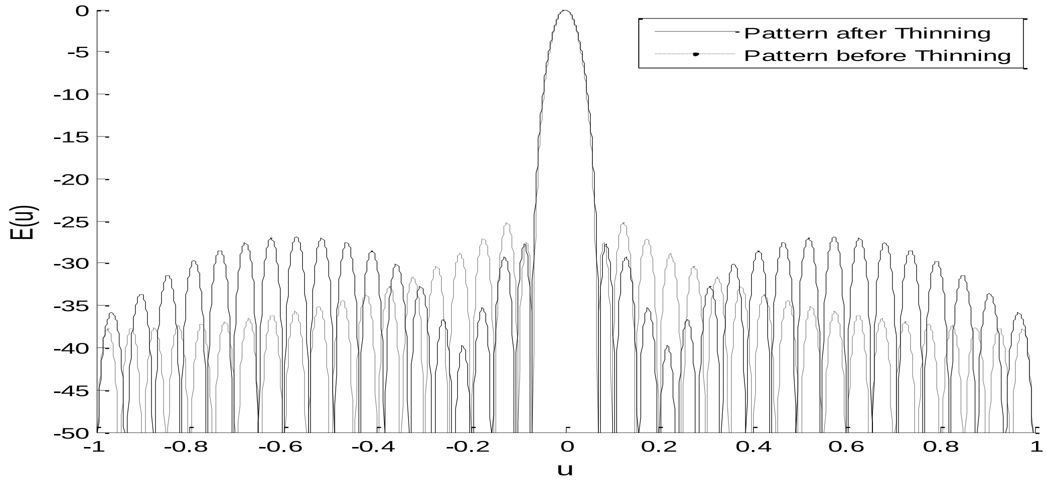

Fig. 12. Comparison of Radiation patterns for N=40elements before and after thinning

Fig. 13 shows the element status (ON=1, OFF=0) for right half of the symmetric array. The element at eighteenth location is turned off.

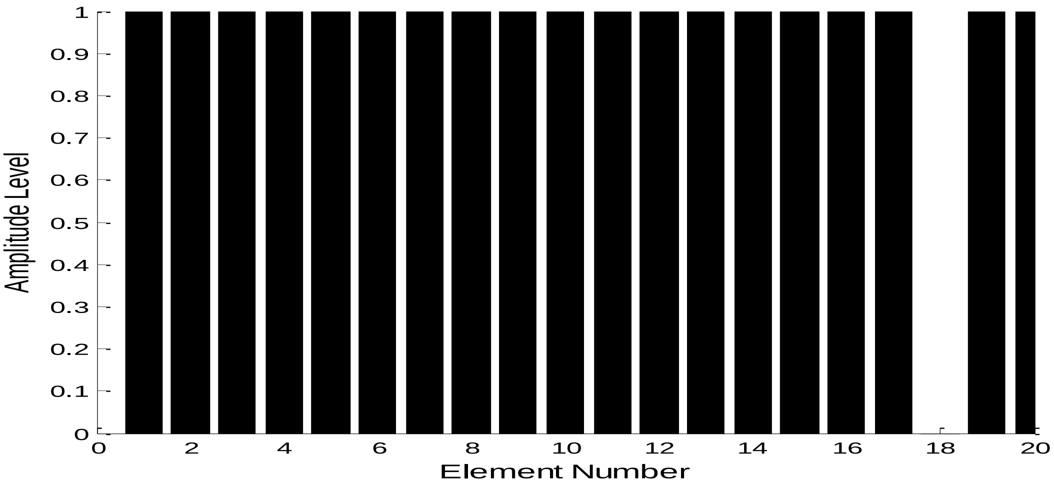

Fig. 13. Element status for N=40 elements

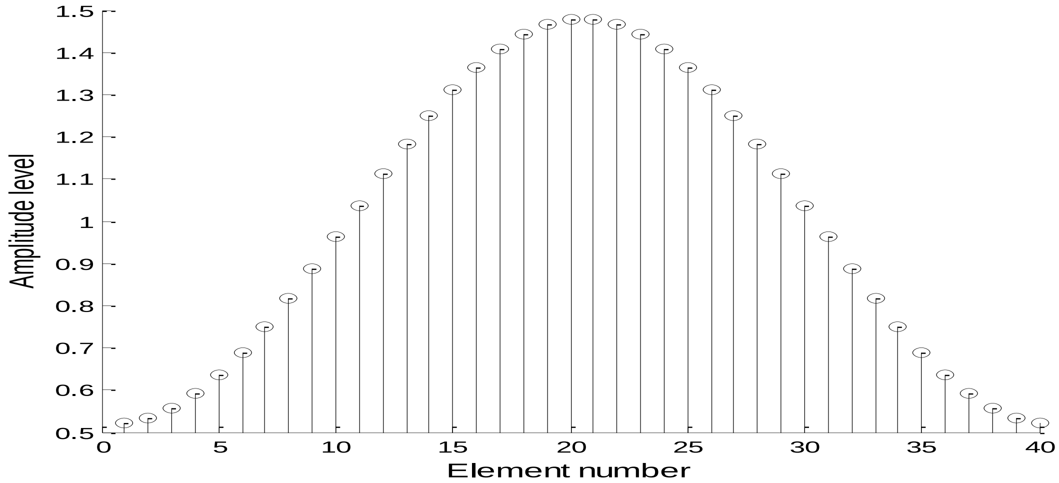

Fig. 14. Amplitude distribution for N=40elements

Table I shows the comparison of peak SLLs obtained for different array lengths before and after thinning. Table II shows the comparison of Beamwidth between First Nulls (BWFN) for different array lengths before and after thinning.

Table I:

Comparison of peak SLLs

Number of elements	Peak SLL(dB) After thinning	Peak SLL(dB) Before thinning
10	-24.1992	-24.1992
20	-24.9785	-24.9785
30	-25.139	-25.1276
40	-26.87	-25.1778
50	-27.88	-25.2033
60	-28.42	-25.2187
70	-28.431	-25.2236
80	-28.95	-25.2279
90	-29.24	-25.2328
100	-29.35	-25.2505
110	-29.55	-25.2371
120	-29.6253	-25.2557
130	-29.91	-25.2431
140	-29.96	-25.2803
150	-30.075	-25.2412
160	-30.22	-25.2404
170	-30.4954	-25.2515
180	-30.5428	-25.3096
190	-30.792	-25.2465
200	-31.02	-25.2586

Table II:

Comparison of BWFNs

Number of elements	Beamwidth(°) After Thinning	Beamwidth(°) Before Thinning
10	31.9240	31.9240
20	15.8643	15.8643
30	11.1329	10.5574
40	8.2577	7.9131
50	6.65	6.3057
60	5.5025	5.2731
70	4.8143	4.5849
80	4.2409	4.0115
90	3.6676	3.5529
100	3.4383	3.2090
110	3.0943	2.8651
120	2.8651	2.6358
130	2.6358	2.4066
140	2.4066	2.2920
150	2.2920	2.1774
160	2.1774	1.9482
170	2.0628	1.8335
180	1.9482	1.7189
190	1.8335	1.7189
200	1.7189	1.6043

The comparisons are presented graphically in Fig. 15 and Fig. 16. All results are simulated using Matlab Software.

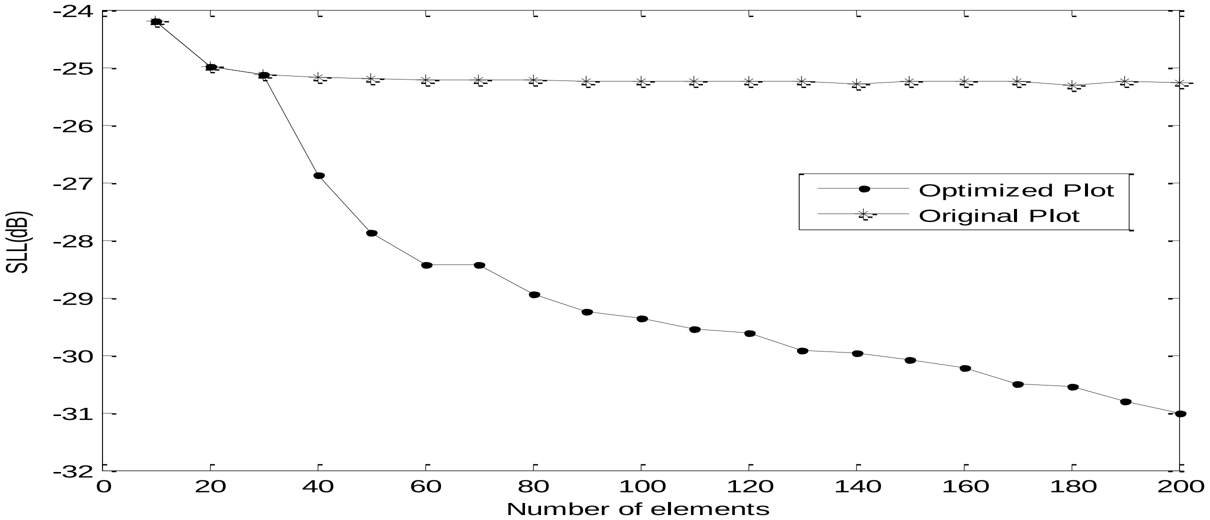

Fig. 15. Variation of PSLL with Number of Elements

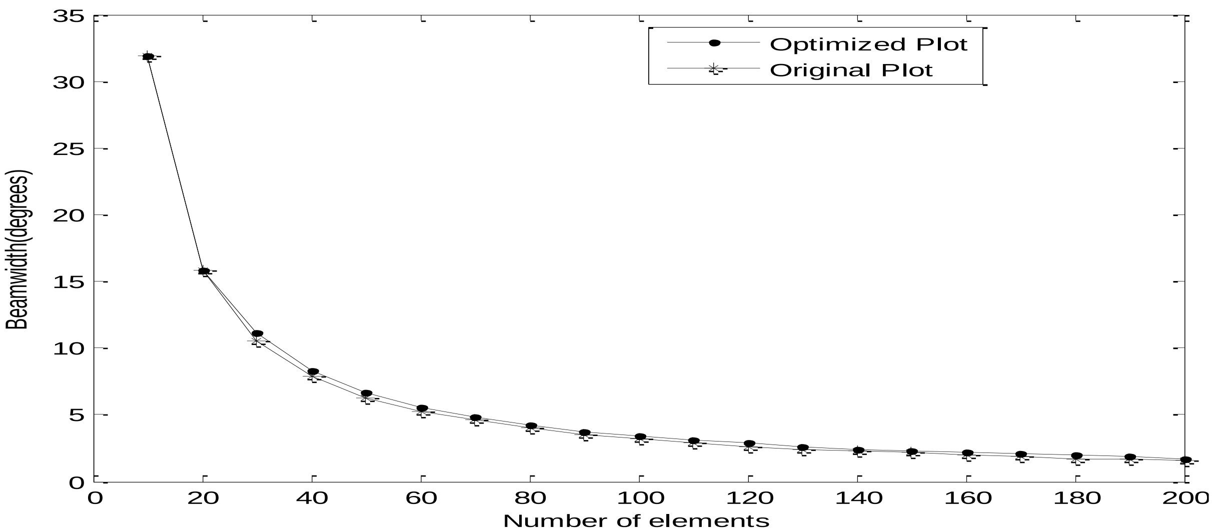

Fig. 16. Variation of BWFN (°) with Number of Elements

Results show that the combination of array thinning and nonuniform amplitude distribution across the array results in better low side lobe levels.

6. Conclusion

Thinning an antenna array results in reduced side lobe levels while using minimum number of elements. Low side lobe levels can also be achieved by exciting the array elements with suitable amplitude weights. As there is no work reported on low sidelobe generation from thinned arrays excited by prefixed distribution, the present work presents useful results for thinning a linear array excited with prefixed amplitude distribution. The process is carried out with a constraint on Beam width between First Nulls. Genetic Algorithm is used for obtaining the desired thinning configurations. Results satisfying the above set criteria are presented for different number of elements. The paper presents array designs which find use in low EMI applications. The present work can be extended for arrays of practical elements.

References:

1. G. S. N. Raju (2005), “Antennas and wave propagation,” Pearson Education.
2. Rao.P.M, Sridevi.P.V, Gutti.C.S, Prasad.M.V.V, Raju. G.S.N, Raju.K.V.L (6-8th December 1995), “Some Studies on Arrays for Sidelobe Reduction required for EMI Control,” International Conference on Electromagnetic Interference and Compatibility, Madras, Madras, pp. 314-320, IEEE.

3. G. S. N. Raju, G. M. V. Prasad (2003), “ Some investigations on the generation of sum and difference patterns from array antennas,” AMSE Journal, Advances A, France, vol.40, no.1, pp.31-40.
4. Sudhakar, G. S. N. Raju, A. Kalyan Venu Gopal, P. Srikanth and K. R. Gottumukkala (2001), “ Generation of stair step radiation patterns from an array antenna,” AMSE Journal, Modelling A, France, vol.74, no.1, pp.7-16.
5. Subrahmanyam N. B., G. S. N. Raju, K. R. Gottumukkala, and H. Khan (2002), “Studies on new and highly tapered amplitude distribution for low EMI applications,” Proceedings of the International Conference on Electromagnetic Interference and Compatibility, 2001/02., pp. 277-282, IEEE.
6. M.T.Maa (1974), Theory and Application of Antenna Arrays, John Wiley & Sons, Inc.
7. R.L.Haupt and D.H.Werner (2007), Genetic Algorithms in Electromagnetics, New York:John Wiley & Sons.
8. Raju, K.V.S.N, Raju G.S.N (2010), “Study on radiation patterns of arrays using new space distributions,” AMSE Journal, France, vol.83, no.4, pp.14-26.
9. Y.T.Lo (1988), “Aperiodic arrays,” in Antenna Handbook, Theory, Applications, and Design, Y.T.Lo and S.W.Lee, Eds. New York:Van Nostrand.
10. Subrahmanyam N. B., G. S. N. Raju (23-24th February 2006), “Influence of standard phase distributions on array radiation patterns,” Proceedings of 9th the International Conference on Electromagnetic Interference and Compatibility, Bangalore, pp.522-525.
11. P.Rocca, R.L.Haupt, Andrea Massa (2009), “ Sidelobe Reduction Through Element Phase Control in Uniform Subarrayed Array Antennas,” IEEE Antennas And Wireless Propagation Letters, vol.8, pp.437-440.
12. R.L.Haupt (1995), “Optimum Quantized Low Sidelobe Phase Tapers for Arrays,” Electronic Letters, vol.31, no.14, pp.1117-1118.
13. R. Willey (1962), "Space tapering of linear and planar arrays," IEEE AP-S Trans., vol. AP-10, pp. 369-377.
14. H.Unz (1956), “Linear arrays with arbitrarily distributed elements,” Rep. Serial no. 60, Electron. Res. Lab., Univ. California, Berkeley.
15. H.Unz (1960), “Linear arrays with arbitrarily distributed elements,” IRE Trans.Antennas Propagat., vol. AP-8, pp. 222–223.

16. Randy L. Haupt (1994), "Thinned Arrays using Genetic Algorithms," IEEE Transanctions on Antennas and Propagation, vol. 42, no. 7, pp. 993-999.
17. V.Rajya Lakshmi and G.S.N.Raju (12-16 September 2011), "Optimization of Radiation Patterns of Array Antennas," PIERS Proceedings, Suzhou, China, pp.1434-1438.
18. Carl A.Meijer (7-8th September 1998), "Simulated Annealing in the Design of Thinned Arrays having Low Sidelobe levels," Proceedings of the 1998 South African Symposium on Communications and Signal Processing, Rondebosch, pp. 361-366.
19. Quevedo and Rajo (2006), "Ant Colony Optimization in Thinned Array Synthesis with Minimum Sidelobe Level," IEEE Antennas and Wireless Propagation Letters, vol. 5, no. 1, pp. 349-352.
20. U. Singh and T. S. Kamal (2012), "Optimal synthesis of thinned arrays using Biogeography Based Optimization," Progress In Electromagnetics Research M, Vol. 24, pp. 141-155.
21. Wang, W. B., Q. Feng, and D. Liu (2012), "Synthesis of thinned linear and planar antenna arrays using binary PSO algorithm," Progress In Electromagnetics Research, vol. 127, pp. 371-387.
22. Mailloux, R.J. (1994): Phased array antenna handbook , Artech House, Boston.
23. V.Rajya Lakshmi and G.S.N.Raju (2011), "Pattern Synthesis using Genetic Algorithm for Low Sidelobe Levels," International Journal of Computer Applications (0975-8887), vol.31, no.4, pp. 53-57.
24. Randy L. Haupt (2010), Antenna Arrays: A Computational Approach, John Wiley & Sons, New York.
25. C.A.Balanis (2005), Antenna Theory Analysis and Design, 3rd Edition, John Wiley & Sons, Inc.