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IMPROVEMENT OF FAR FIELD RADIATION PATTERN OF LINEAR ARRAY ANTENNA USING GENETIC ALGORITHM

Sudipta Das[1], Somen Bhattacharjee[2], Durbadal Mandal[3]

Department of Electronics and Communication, National Institute of Technology, Durgapur, India
Email: sudipta.sit59@gmail.com[1], somen.aec@gmail.com[2], durbadal.bittu@gmail.com[3]

Abstract
In this paper, the beam pattern of Linear Array Antennas with isotropic elements is examined. The design goal is to reduce the sidelobe level with a minimum beamwidth increase for the far field radiation pattern of the array by varying its electrical as well as its physical configuration. In this paper the cases of a uniformly excited and uniformly spaced array, uniformly excited and non-uniformly spaced array, and a non-uniformly excited and uniformly spaced array are examined for both symmetric as well as asymmetric array, and a comparison is done between them. Real Coded Genetic Algorithm (RGA) is used to find the optimal locations as well as the optimal excitations for the problem as per the cases considered.

Keywords:
Symmetric Linear Array Antenna, Asymmetric Linear Array Antenna, Sidelobe Reduction, First Null Beamwidth, Real Coded Genetic Algorithm.

1. INTRODUCTION

A lot of research works have been carried out for optimizing the radiation pattern of Linear Array Antenna for past few decades [1-13]. Array Antenna is formed by assembly of radiating elements in an electrical or geometrical configuration. In most cases the elements are identical. Total field of the Array Antenna is found by vector addition of the fields radiated by each individual element. There are five controls in an Array Antenna that can be used to shape the pattern properly, they are, the geometrical configuration (linear, circular, rectangular, spherical etc.) of the overall array, relative displacement between elements, excitation amplitude of the individual elements, excitation phase of the individual elements, and, relative pattern of the individual elements [1-2]. In many communication applications it is required to design a highly directional antenna. Array Antennas have a high gain and directivity compared to an individual radiating element. A Linear Array Antenna has all its elements placed along a straight line, with a uniform relative spacing between elements [3]. The goal in Array Antenna geometry synthesis is to determine the physical layout of the array that produces the radiation pattern that is closest to the desired pattern [7]. In this paper the design goal is to suppress the maximum relative sidelobe level (SLL) for a Linear Array Antenna of isotropic elements, as well as to restrict the increment of First Null beamwidth (BWFN). [4-6]. A radiation pattern with lower maximum sidelobe, thinner main beam and more and deeper nulls is preferred. This is done by designing the relative spacing between the elements, with a non-uniform excitation over the array aperture. In this paper, RGA is used to get the desired pattern of the array [2].

Now in the rest of the paper, in Section 2, general design equations, both for symmetric and asymmetric array is discussed. In this Section, all the different cases are also discussed. In Section 3, briefly the RGA is introduced, the simulated results are discussed in Section 4 and 5, and the conclusion is drawn in section 6.

2. DESIGN EQUATIONS

Radiation pattern of an array of antenna is strongly dependent on its geometrical as well as its electrical architecture. All the elements constructing a linear array must be placed on a straight line. Geometrical architecture of such an array means how the elements are placed along the line. Array elements may be uniformly placed throughout the array aperture, or symmetrically placed with respect to the centre of the array, or asymmetrically placed throughout the line. Electrical architecture gives the pattern by which the elements are excited. They may be excited with same amplitude and same progressive phase throughout the array aperture, or they may be symmetrically excited with respect to the centre of the array, or they all may be entirely asymmetrically excited. Thus, the configurations that can be considered are,

A. Uniformly placed and uniformly excited array,
B. Uniformly placed but non uniformly excited array,
C. Non uniformly placed and uniformly excited array and
D. Non uniformly placed and non uniformly excited array

In this paper, the performance of the Array Antenna is optimized for only first three conditions. If the elements have symmetry with respect to its centre for geometrical and electrical configuration, it is used to analyze this case as symmetric array and consider the reference point as the midpoint of the array, else the array is referred to as asymmetric array and the reference point in this case is the end point of the array, or, the 1st or last element of the array. Figure 1 depicts a design of an asymmetric linear array and Figure 2 depicts a design of a symmetric linear array.

Array factor of a broadside linear array of M isotropic elements placed along z-axis is

$$AF = \sum_{m=1}^{M} \{ I_{m-1} \exp(jkd_{m-1} \cos\theta \} \quad (1)$$

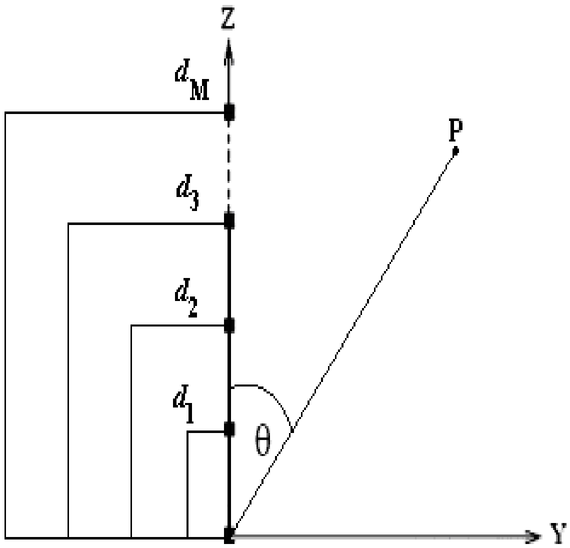

Fig.1. Geometry of M element asymmetric Linear Array Antenna placed along z-axis

Where,

I_m=Excitation amplitude of m^{th} element

$k = 2\pi / \lambda$ where, λ is the operating wavelength

d_m =is the distance of m^{th} element from the reference point

θ Symbolize the zenith angle from the positive z axis to the orthogonal projection of the observation point P.

This is the most general case, and, this equation can be used to analyze an asymmetric array. Here the reference point is one end of the array.

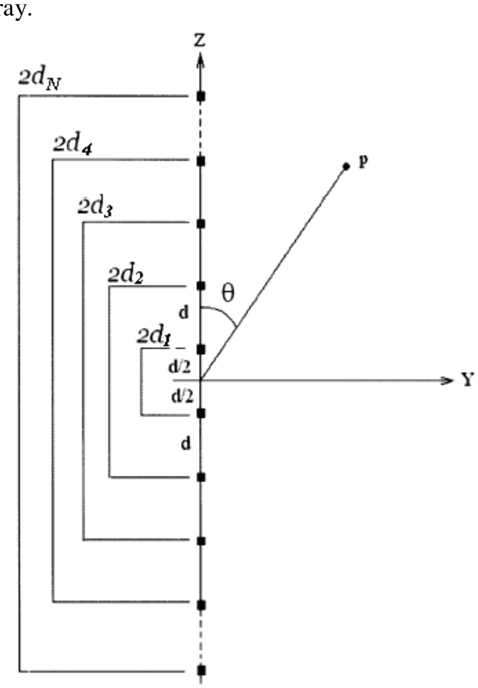

Fig.2. Geometry of 2N element symmetric Linear Array Antenna placed along z-axis

For analyzing a symmetric broadside Linear Array Antenna of ***2N*** isotropic elements along z-axis the following equation can be used

$$AF_s = 2\sum_{n=1}^{N}\{I_n \cos(kd_n \cos\theta)\} \quad (2)$$

Where,

I_n =Excitation amplitude of n^{th} element from its mid-point

d_n=is the distance of n^{th} element from the mid-point of the array

In our case the cost function, or the fitness function, called misfitness (MF) is defined as follows,

$$MF = \frac{|AF(\theta_{msl}, I_m)| + |AF(\theta_{msr}, I_m)|}{|AF(\theta_0, I_m)|} + |BWFN_{initial} - BWFN_{current}| \quad (3)$$

In this case θ0 is the desired direction of scanning, and the main beam should be located here and here, $\theta \in [0, \pi]$, θ_{msl} is the angle of maximum sidelobe for the lower band($AF(\theta_{msl}, I_m)$) and θ_{msr} is the` angle of maximum sidelobe for the upper band($AF(\theta_{msr}, I_m)$). Thus the first term in the right hand side of (3) gives the maximum sidelobe level with respect to the main beam. By the second term in (3), the beamwidth increment is restricted. $BWFN_{initial}$ and $BWFN_{current}$ are the beamwidth between the First Nulls for the initial condition and the current iteration. MF is lower for the Array Antenna which has lower SLL and lower BWFN as compared to the initial array (radiation pattern not optimized). Minimization of MF means maximum reductions of SLL both in lower and upper bands. The evolutionary optimization techniques employed for optimizing the current excitation weights and the inter-element spacing, resulting in the minimization of MF and hence reduction of SLL.

3. REAL CODED GENETIC ALGORITHM (RGA)

GA is mainly a probabilistic search technique, based on the principles of natural selection and evolution [2]. At each generation it maintains a population of individuals where each individual is a coded form of a possible solution of the problem at hand and called chromosome. Chromosomes are constructed with genes of random values between (0, 1). Each chromosome is evaluated by a function known as fitness function, which is usually the cost function or the objective function (called "Misfitness" or *MF*) of the corresponding optimization problem.

Steps of RGA as implemented for optimization [13] of spacing between the elements and current excitations are:

- Initialization of real chromosome strings of n_p population, each consisting of a set of excitations.
- Size of the set depends on the number of excitation elements in a particular array design.

- Decoding of strings and evaluation of *MF* of each string.
- Selection of elite strings in order of increasing *MF* values from the minimum value.
- Copying of the elite strings over the non-selected strings.
- Crossover and mutation to generate off-springs.
- Genetic cycle updating.
- The iteration stops when the maximum number of cycles is reached. The grand minimum *MF* and its corresponding chromosome string or the desired solution are finally obtained.

4. NUMERICAL SIMULATION RESULTS

This section gives the simulated results for various Linear Array Antenna designs obtained by RGA technique. Three Linear Array Antenna structures having 6, 12, and 18 elements are assumed, each maintaining a fixed spacing between the elements. Parameters such as maximum SLL and BWFN are studied for symmetric as well as asymmetric array.

The parameters for the RGA are set after many trial runs. It is found that the best results are obtained for an initial population of 120 chromosomes. Maximum number of generations, N_m is limited to 400. For selection operation, the method of natural selection is chosen with a selection probability of 0.3. Crossover is randomly selected dual points. Crossover ratio is 0.8. Mutation probability is 0.004 [13].

RGA technique generates a set of normalized array parameters. $I_m = 1$ corresponds to uniform current excitation.

Table 1. shows the maximum sidelobe level and the beamwidth values for three sets of linear array designs, with the initial current distribution as $I_m = 1$, and uniform inter-element spacing as $d = \lambda/2$. Tables 2-5 compare the radiation patterns for a symmetric and an asymmetric array for all the cases. Table 2. shows the radiation parameters for all the sets of number of elements (as considered in Table 1), for optimum uniform spacing $d \in (0, \lambda)$ only. Table 3 shows the radiation parameters for the optimum non-uniform spacing $d \in (0, \lambda)$ with uniform excitation amplitude ($I_m = 1$). Table 4. shows the respective radiation patterns for uniformly spaced $(d = \lambda/2)$ arrays with optimal non-uniform excitations.

Table 5. shows the radiation patterns for all the arrays consisting elements with optimum non-uniform excitation ($I_m \in (0,1)$) & optimized uniform spacing ($d \in (0, \lambda)$).

Table 1. Sidelobe Level & Main Beamwidth for Different Sets of Linear Array with Uniform Excitation as 1 and Uniform Spacing as λ/2

Sl.No.	No. of Elements	Initial max SLL (dB)	Initial Beamwidth (°)
1	6	-12.4255	38.9392
2	12	-13.0570	19.1816
3	18	-13.1710	12.7589

Table 2. Optimal Uniform Spacing Only

No of Elements	Optimized Uniform Spacing		Final max SLL (dB)		Final BWFN(°)	
	Symmetric	Asymmetric	Symmetric	Asymmetric	Symmetric	Asymmetric
6	0.8630	0.8624	-12.4255	-12.4255	22.2633	22.2921
12	0.9322	0.9213	-13.0570	-13.0570	10.2532	10.3828
18	0.9105	0.9528	-13.1710	-13.1709	6.9987	6.6819

Table 3. Optimal Non Uniform Spacing Only

No of Elements	Optimized Non-Uniform Spacing		Final max SLL (dB)		Final BWFN(°)	
	Sym.	Asym.	Sym.	Asym.	Sym.	Asym.
6	0.3016 0.6815 0.7474	0.7337 0.6715 0.6000 0.6787 0.7688	-14.6159	-14.7824	29.0028	29.1756
12	0.3150 0.6609 0.6862 0.7664 0.9332 0.7761	0.8823 0.8425 0.7046 0.7165 0.5522 0.6612 0.5106 0.5417 0.7763 0.7954 0.7176	-16.9104	-17.6160	13.6373	15.0054
18	0.2656 0.3862 0.5416 0.4624 0.5230 0.5938 0.6420 0.8453 0.7616	0.7196 0.6967 0.6522 0.4264 0.4106 0.3454 0.4827 0.2715 0.4574 0.3811 0.4096 0.3730 0.5593 0.4596 0.4820 0.6917 0.7407	-21.2280	-22.0242	12.7589	15.3942

Table 4. Optimal Non Uniform Excitation Only (Uniform Spacing As λ/2)

No. of Elements	Optimized Non-Uniform Excitation		Final max SLL (dB)		Final BWFN(°)	
	Sym.	Asym.	Sym.	Asym.	Sym.	Asym.
6	0.3633 0.5274 0.6797 0.6797 0.5274 0.3633	0.4805 0.6588 0.8654 0.7790 0.6367 0.4468	-20.1307	-19.2682	48.1843	47.2339
12	0.3757 0.4318 0.6164 0.7756 0.9048 0.9801 0.9801 0.9048 0.7756 0.6164 0.4318 0.3757	0.3822 0.4251 0.6816 0.7500 0.9082 0.9807 0.9342 0.9165 0.7601 0.5320 0.4577 0.3310	-25.7899	-25.4513	26.2378	26.2378
18	0.2977 0.3665 0.4831 0.4815 0.6735 0.8015 0.7921 0.9596 0.9236 0.9236 0.9596 0.7921 0.8015 0.6735 0.4815 0.4831 0.3665 0.2977	0.2538 0.2487 0.3832 0.4037 0.6414 0.6707 0.7408 0.8200 0.8620 0.8422 0.8569 0.8427 0.6988 0.5252 0.6274 0.4525 0.3882 0.3926	-26.4653	-25.7016	17.7847	17.5543

Table 5. Optimal Non Uniform Excitation with Optimal Uniform Spacing

El.	Symmetric		Asymmetric		Final max SLL (dB)		Final BWFN(°)	
	Exc.	Sp.	Exc.	Sp.	Sym.	Asym.	Sym.	Asym.
6	0.2042 0.5067 0.7583 0.7583 0.5067 0.2042	0.7504	0.2250 0.5611 0.9035 0.8916 0.6608 0.2782	0.7519	-32.0239	-29.8703	41.2288	40.2928
12	0.1466 0.2857 0.4926 0.7051 0.8837 0.9919 0.9919 0.8837 0.7051 0.4926 0.2857 0.1466	0.8277	0.2877 0.4200 0.5883 0.7951 0.9317 0.9775 0.9803 0.8624 0.6783 0.5118 0.2951 0.1883	0.8203	-36.5069	-30.6349	20.1464	18.0295
18	0.1085 0.1982 0.2821 0.4382 0.5408 0.6976 0.8067 0.8975 0.9368 0.9368 0.8975 0.8067 0.6976 0.5408 0.4382 0.2821 0.1982 0.1085	0.8703	0.1505 0.2039 0.3171 0.4127 0.5492 0.6488 0.7597 0.8787 0.9318 0.8940 0.8773 0.8559 0.7785 0.6234 0.5143 0.3910 0.2421 0.2471	0.8387	-36.7818	-31.8153	12.8885	12.1397

5. ANALYSIS OF RADIATION PATTERNS OF LINEAR ARRAY SETS

Figure 3 depicts the radiation patterns for a uniformly excited linear array having 18 isotropic elements with fixed inter-element spacing. The patterns are got directly from the respective values from Table 2. Finding optimized uniform spacing results in thinning of main beam. Moreover, a lot extra nulls are inserted in the radiation pattern. For all the sets of elements symmetric array gives lower BWFN as compared with that of the asymmetric array, except for the set of 18 elements. The sidelobe for all the sets for both symmetric and asymmetric array is not altered except for the case of asymmetric array with 18 elements. While SLL is unaltered for the corresponding symmetric array, that for the asymmetric array is rather increased. Thus asymmetric array has poorer performance in this case. The result can be verified from Table 2. It is seen that, with a negligible sacrifice in the SLL, 18 element asymmetric linear array antennas gives lower BWFN as compared to the corresponding symmetric linear array. SLL for all other sets are the same as that of the initial pattern, both for symmetric and asymmetric array. Symmetric array gives better result by providing lower BWFN except for the set of 18 elements.

Figure 4 depicts the radiation pattern for 18 element linear array for non-uniformly varied inter-element spacing. In this case, it can be seen that, for both symmetric and asymmetric array, BWFN is reduced, and SLL reduction is a bit better for symmetric array, except for the set of 6 elements. Again lower BWFN is provided with symmetric array. From Figure 4, it can be seen from the figure that unlike symmetric array, for asymmetric array the previously existing nulls are almost disappeared. But for the symmetric Array, inserted nulls are quiet deep. Thus symmetric array gives better result for the sets of larger number of elements. The results can be verified by Table3.

Figure 5 depicts the radiation pattern of 18 element linear array with non uniform excitation. BWFN is increased for both symmetric as well as asymmetric array from that of the corresponding initial array. While symmetric array gives lower SLL, the respective asymmetric array provides lower BWFN (except for the set of 12 elements). Moreover, while almost all the previously existing nulls are filled up for asymmetric array, some of the nulls are retained for symmetric array. The results can be verified from Table 4.

Figure 6 depicts the radiation pattern for 18 element liner array with non uniform optimized excitation and uniform optimized inter-element spacing. While lower SLL is provided by symmetric array, the corresponding asymmetric array gives lower BWFN. It is clear from the figure that SLL is noticeably reduced both the symmetric and asymmetric array. From the figure it can be seen some extra nulls are inserted in the radiation pattern. While asymmetric array suffers from low null depth, corresponding symmetric array has all such nulls quiet deep. Symmetric array has an advantage over asymmetric array by better SLL reduction performance and deeper nulls in the radiation pattern, but it suffers from the main beam broadening, though negligibly small. This result can be verified from Table 5.

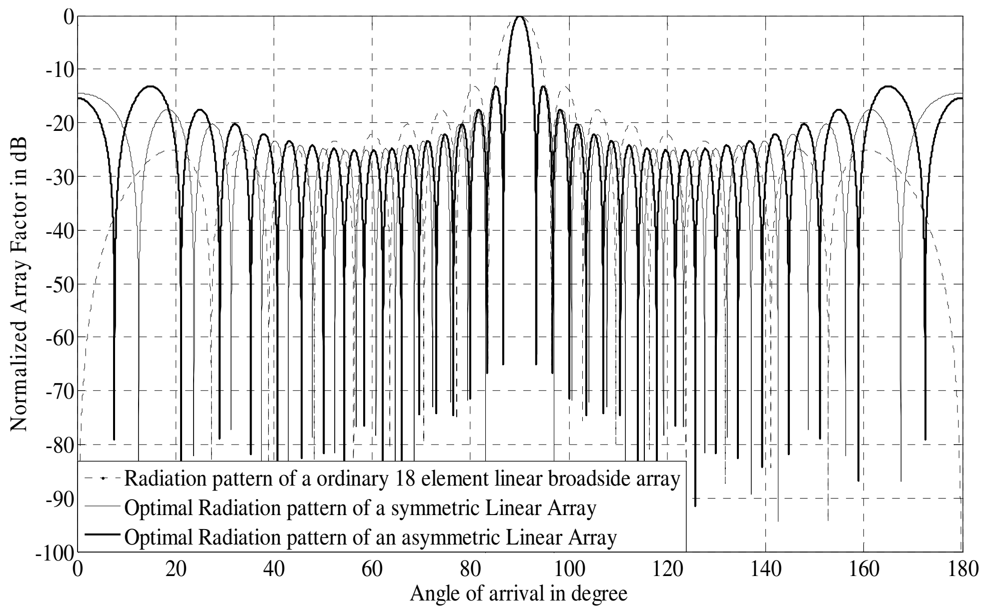

Fig.3. Radiation pattern of the 18-elemnt Uniformly spaced Linear Array Antenna obtained using RGA

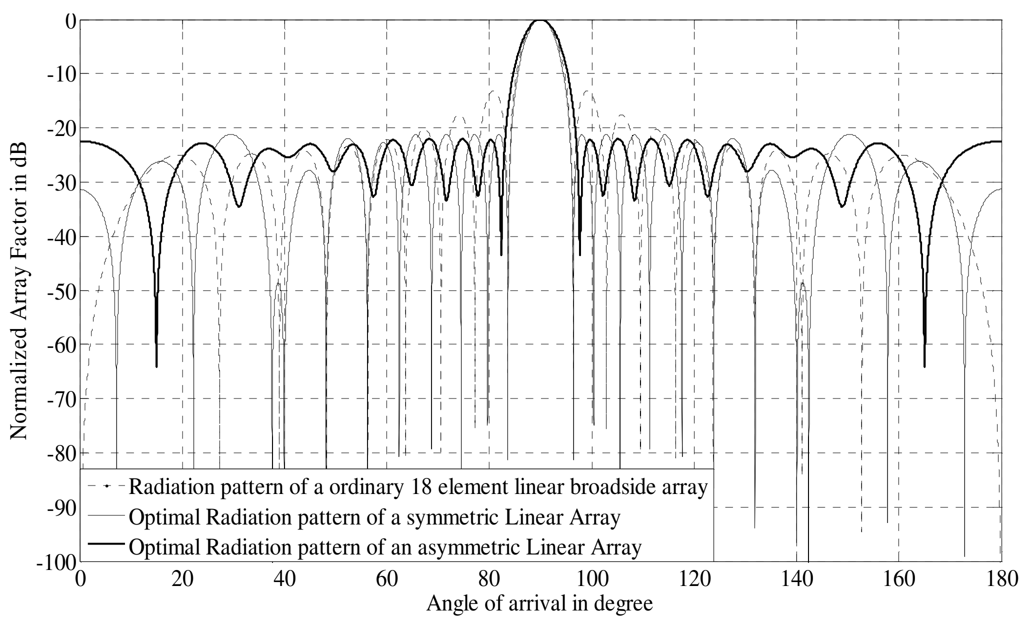

Fig.4. Radiation pattern of the 18-element Non-uniformly spaced Linear Array Antenna obtained using RGA.

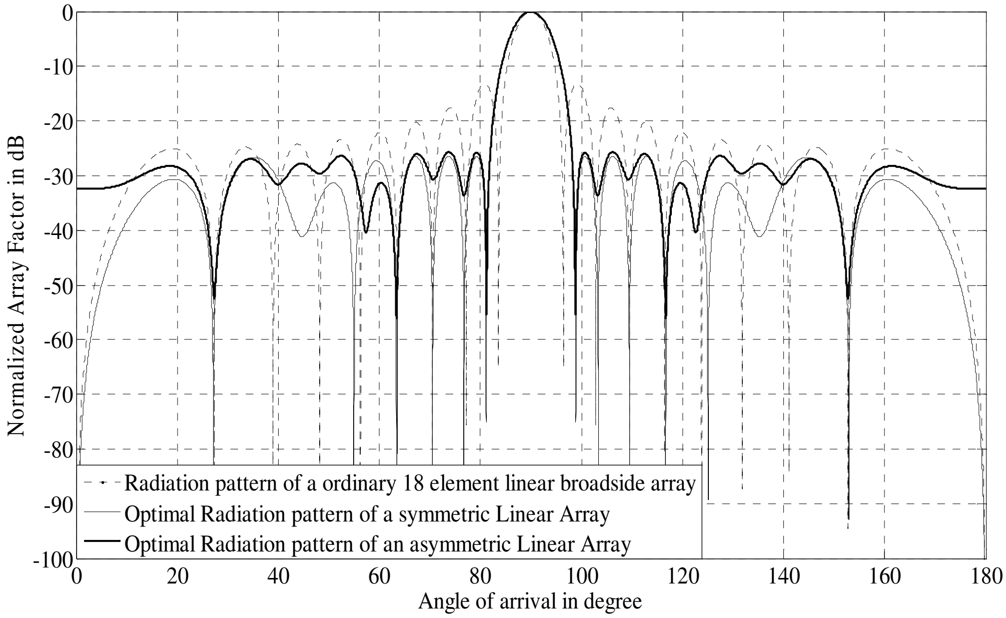

Fig.5. Radiation pattern of the 18-element Non-uniformly excited Linear Array Antenna obtained using RGA.

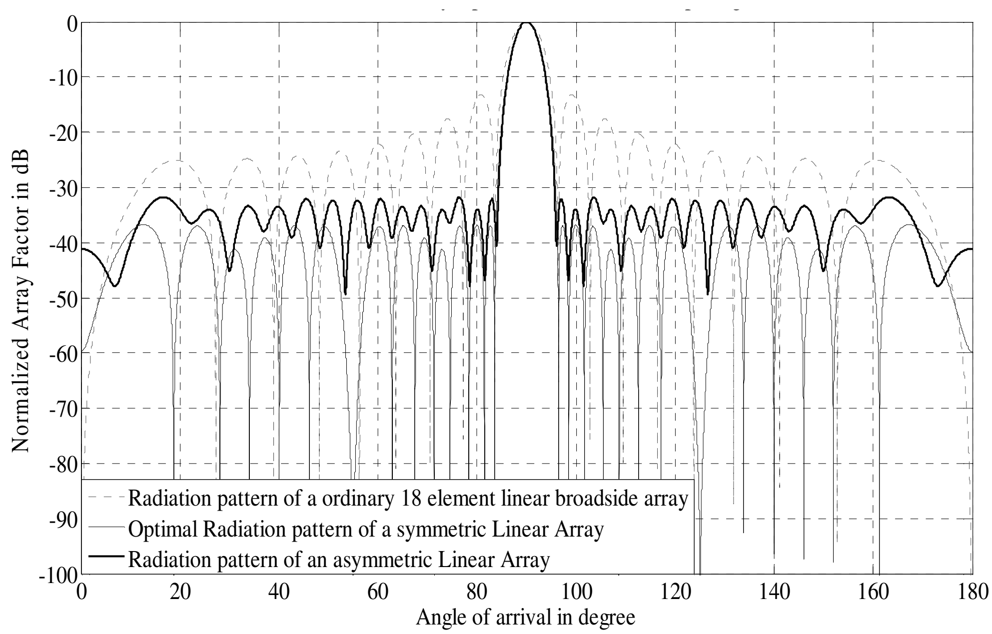

Fig.6. Radiation pattern of an 18 element Non Uniformly excited Linear Array Antenna with uniform spacing obtained using RGA

The minimum MF values against number of iteration cycles are recorded to get the convergence profile of each set. Figures 7-8, 9-10 and 11-12 portray the convergence profiles of minimum MF of linear array set having 18 elements. Figure 7, 9 and 11 shows the convergence profiles for only non uniformly spaced, only non uniformly excited with uniform spacing $d = \lambda / 2$ and only non uniformly excited and uniformly spaced symmetric array respectively. Figures 8, 10 and 12 shows the convergence profiles for an asymmetric array for the respective cases. The programming has been written in MATLAB language using MATLAB 7.5 on core (TM) 2 duo processor, 1.83 GHz with 2 GB RAM.

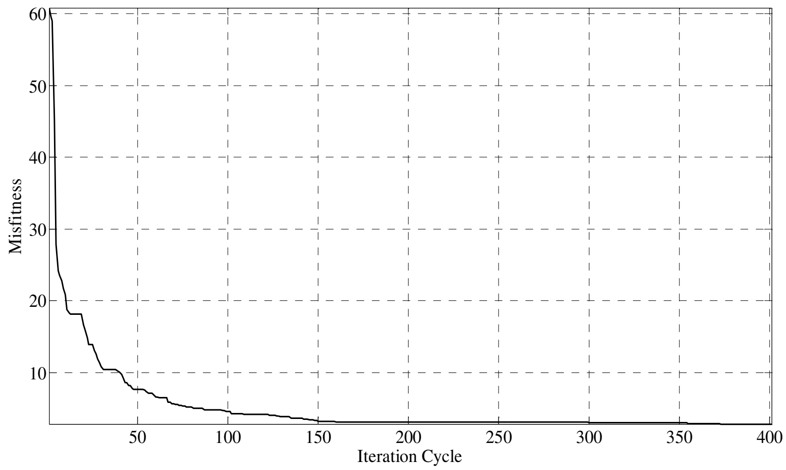

Fig.7. Convergence curve for RGA for non-uniformly spaced 18-element symmetric Linear Array Antenna

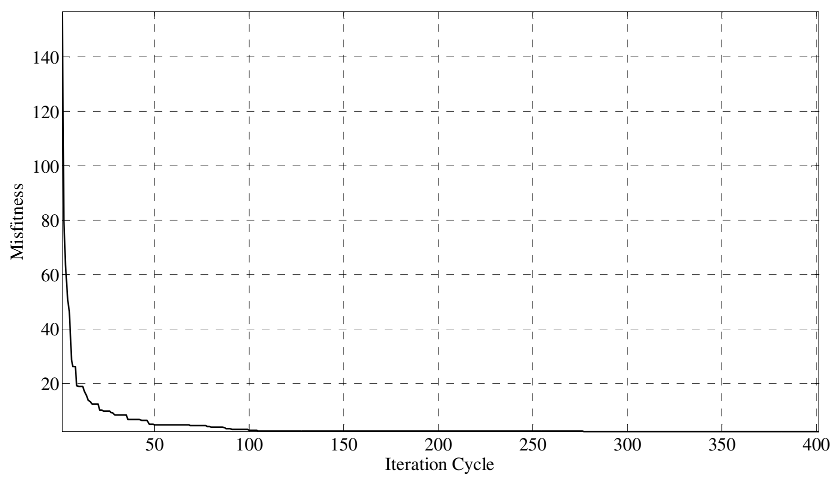

Fig.8. Convergence curve for RGA in case of non-uniformly spaced 18-element asymmetric linear array

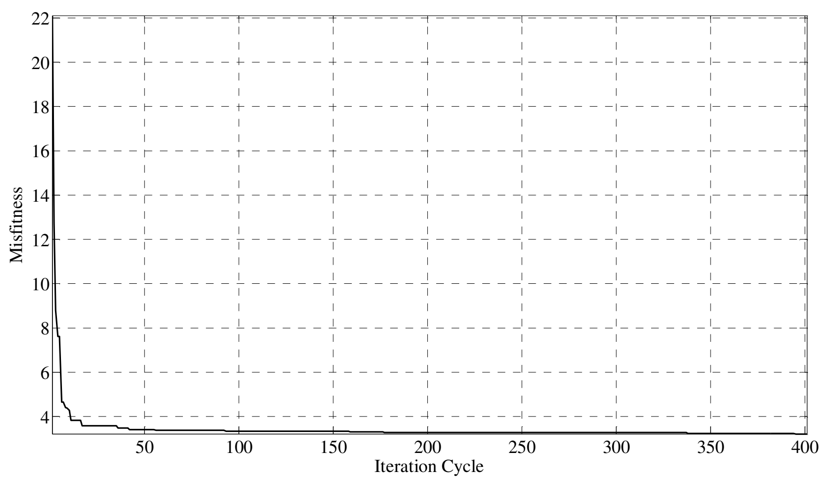

Fig.9. Convergence curve for RGA for non-uniformly excited 18-element symmetric Linear Array Antenna

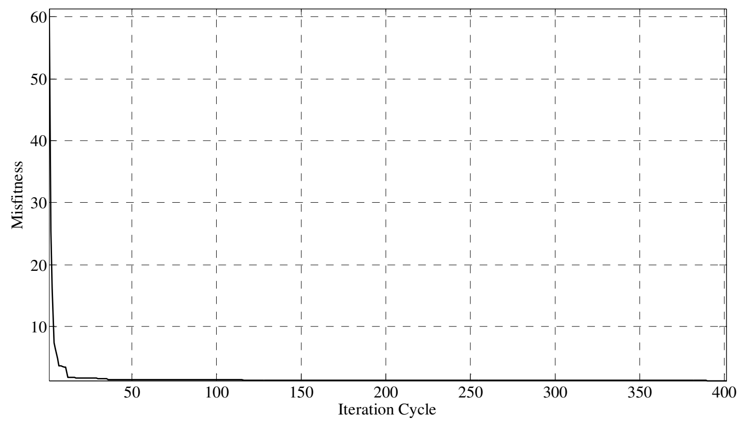

Fig.10. Convergence curve for RGA for non-uniformly excited 18-element asymmetric Linear Array Antenna

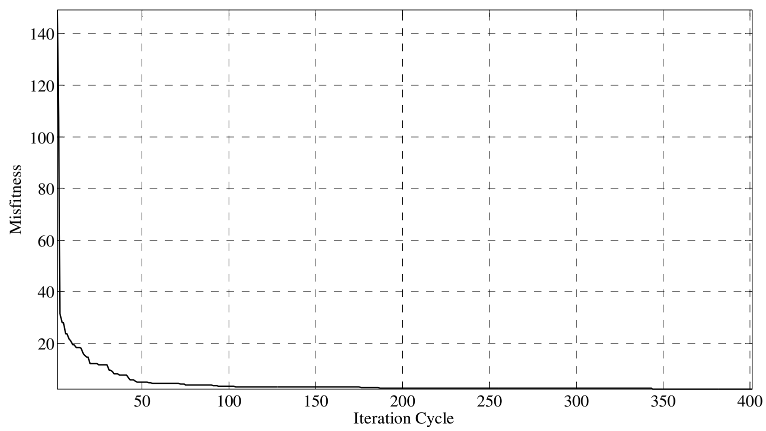

Fig.11. Convergence curve for RGA for non uniformly excited 18 element asymmetric Linear Array Antenna with uniform spacing

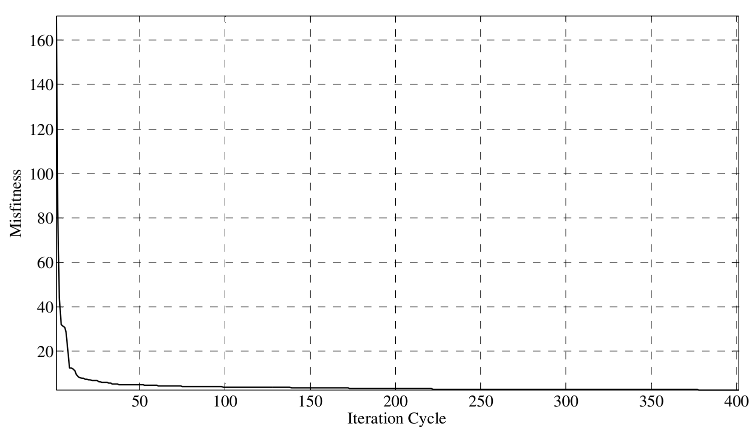

Fig.12. Convergence curve for RGA for a non uniformly excited 18 element asymmetric Linear Array Antenna with uniform spacing

6. CONCLUSION

In this paper three Linear Array Antenna structures with variable spacings and excitations are considered. For the set of 18 element linear arrays SLL is reduced upto -36.7818 dB for symmetric and -31.8153 dB for asymmetric array, while the respective main lobe beamwidths are 12.8885° and 12.1397° against the initial SLL of -13.1710 dB and initial beamwidth of 12.7589°. From the Tables and the corresponding figures it can be easily seen that, as the number of the elements are increased, SLL reduction and BWFN maintainance performances are improved for both symmetric and asymmetric array. Simulated results show that a optimal non uniformly excited and optimal uniformly spaced Linear Array Antenna has a considerable sidelobe reduction with least first null beamwidth increment. Moreover, extra nulls are inserted in the radiation pattern and this ultimately gives a design of an Array

Antenna with lower interference from undesired directions without significant sacrifice in directivity. Thus RGA is found to be promising evolutionary optimization technique for global optimization of any design problem.

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