Investigation on the Performance of Linear Antenna Array synthesis using Genetic Algorithm

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***Abstract*—Genetic algorithm (GA) is a powerful optimization method which is used in this paper for the synthesis of antenna array radiation pattern in adaptive beamforming. The synthesis problem discussed in this paper is to find the amplitude excitation of the antenna array elements that are optimum to provide radiation pattern with maximum reduction in sidelobe level. Unlike Simple GA (SGA), the Genetic algorithm solver from the optimization toolbox of MATLAB is used with adaptive feasible mutation, which enables search in broader space along randomly generated directions to produce new generations. This improves the performance greatly to achieve the maximum reduction in sidelobe level with minimum function calls. Experiments proved the effectiveness of this method.**

Index Terms— Adaptive Beamforming, Sidelobe level, Genetic Algorithm, Linear antenna array, Array Pattern synthesis, convergence, Array factor.

I. INTRODUCTION

Adaptive Beamforming is an adaptive signal processing technique in which an array of antennas is exploited to achieve maximum reception in a look direction in which the signal of interest(SOI) is present, while signals of same frequency from other directions which are not desired (Signal of not interest) are rejected. This is equivalent to FIR (Finite impulse response) filtering. The overall performance this filter depends on the selection of number of taps and their coefficients. In a similar way, the number of antenna elements acts as the tap and corresponding weight vector supplied to the antenna elements determines the performance of the antenna array. Adaptive beamforming enhances the desired signal while suppressing noise and interference at the output of array of sensor thereby improving the signal to interference plus noise ratio. The basic idea is, though the signals emanating from different transmitters occupy same frequency, they still arrive from different directions. This spatial separation is exploited to separate the desired signal from the interfering signals. In adaptive beamforming the optimum weights are iteratively computed using complex algorithms based upon different criteria.

The characteristics of the antenna array can be controlled by the geometry of the element and array excitation. But sidelobe level reduction in the radiation pattern [1],[2],[3] should be performed to avoid degradation of total power efficiency. Interference suppression [4],[5] must be done to improve the Signal to noise plus interference ratio (SINR). Sidelobe level reduction and interference suppression can be obtained using the following techniques: 1) amplitude only control 2) phase only control 3) position only control and 4) complex weights (both amplitude and phase control). In this, complex weights technique is the most efficient technique because it has greater degrees of freedom for the solution space. On the other hand it is the most expensive to implement in practice.

Pattern synthesis is the process of choosing the antenna parameters to obtain desired radiation characteristics, such as specific position of the nulls [6], the desired sidelobe level [7] and beam width of antenna pattern. In literature there are many works concerned with the synthesis of antenna array. It has a wide range of study from analytical method to numerical method and to optimization methods. Analytical studies by Stone who proposed binominal distribution, Dolph the Dolph-'Chebyshev amplitude distribution, Taylor, Elliot, Villeneuve, Hansen , Woodyard and Bayliss laid the strong foundation on antenna array synthesis [8],[9]. Iterative Numerical methods became popular in 1970s to shape the mainbeam. Today a lot of research on antenna array [4]–[14] is being carried out using various optimization techniques to solve electromagnetic

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problems due to their robustness and easy adaptivity. One among them is Genetic algorithm [10] .

In this paper, it is assumed that the array is uniform, where all the antenna elements are identical and equally spaced. The design criterion here considered is to minimize the sidelobe level [15] with narrow main beamwidth. Hence the synthesis problem is, finding the weights that are optimum to provide the radiation pattern with maximum reduction in the sidelobe level.

II. GENETIC ALGORITHM

Genetic Algorithms are a family of computational models inspired by evolution [10],[16],[17]. GA is a procedure used to find approximate solutions to search problems through application of the principles of evolutionary biology. GA uses biologically inspired techniques such as genetic inheritance, natural selection, mutation, and sexual reproduction (recombination, or crossover).

The genetic algorithm was first introduced in 1975 by Holland [16]. This algorithm has been realized and widely used after Goldberg's studies [17].

GA consists of a data structure of individuals called Population. Individuals are also called as chromosomes. Each individual is represented by usually the binary strings. Each individual represents a point in the search space and a solution candidate. The individuals in the population are then exposed to the process of evolution. Initial population is generated randomly. The consecutive generations (children) are created using the parents from the previous generation. Two parents are selected for reproduction using recombination. Recombination consists of two genetic operators namely 1) crossover and 2) mutation. Newly generated individuals are tested for their fitness based on the cost function and the best survives for the next generation. Genes from good individuals propagate throughout the population thus making the successive generation more suited to its environment.

In this paper, performance improvement is analyzed in order to obtain a desired pattern of linear antenna array using GA. Fixed mutation rate approach is used in classical GA. In this paper, adaptive feasible mutation rate is used, which shows improvement in performance throughout the evolution. The impact of the crossover scheme to the solution performance is also investigated in this paper. Instead of determining the crossover point in a totally random fashion, the probable crossover points have been kept limited to single.

GAs are typically implemented using computer simulations. Much research on electromagnetics and antenna arrays using GA has been reported in[18],[19],[27]-[31].

The important parameters of GA are:

• **Crossover** – this operator exchanges genetic material which are the features of an optimization problem

• **Selection** – this is based on the fitness criterion to choose which individuals from a population will go on to reproduce

• **Reproduction** – the propagation of individuals from one generation to the next

• **Mutation** – the modification of chromosomes for single individuals

Current GA theory consists of two main approaches – Markov chain analysis and schema theory. Markov chain analysis is primarily concerned with characterizing the stochastic dynamics of a GA system. The most severe limitation of this approach is that while crossover is easy to implement, its dynamics are difficult to describe mathematically. A schema is a conceptual system for understanding knowledge and how knowledge is represented and used.

III. LINEAR ANTENNA ARRAY MODEL

An incident plane wave causes a linear gradient time delay between the antenna elements that is proportional to the angle of incidence. This time delay along the array manifests as a progressive phase shift between the elements when it is projected onto the sinusoidal carrier frequency. In the special case of normal incidence of the plane wave, all the antennas receive exactly the same signal, with no time delay or phase shift.

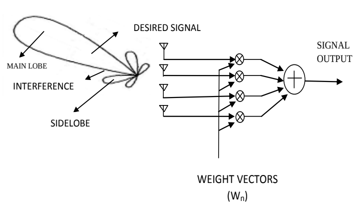

Figure 1: Antenna Array

In this work the antenna elements are assumed to be uniformly spaced, in a straight line along the y-axis, and N is always the total number of elements in the antenna array. The physical separation distance is d, and the wave number of the carrier signal is $k = 2\pi/\lambda$. The product kd is then the separation between the antennas in radians. When kd is equal to π (or $d = \lambda/2$)

the antenna array has maximum gain with the greatest angular accuracy with no grating lobes. The phase shift between the elements experienced by the plane wave is *kd*cosθ and θ is measured from the y-axis, starting from the first antenna, as shown in Fig1. Weights can be applied to the individual antenna signals before the array factor (AF) is formed to control the direction of the main beam. This corresponds to a multiple-input-single-output (MISO) system. The total AF is just the sum of the individual signals, given by [9]

$$AF = \left| \left(\sum_{n=1}^{N} E_n \right) \right| = \sum_{n=1}^{N} e^{jK_n} \quad \text{.......... (1)}$$

where $E_n = e^{jK_n}$ and K= (nkd cosθ + β_n) is the phase difference. β_n is the phase angle. Final simplification of equation (1) is by conversion to phasor notation. Only the magnitude of the AF in any direction is important, the absolute phase has no bearing on the transmitted or received signal. Therefore, only the relative phases of the individual antenna signals are important in calculating the AF. Any signal component that is common to all of the antennas has no effect on the magnitude of the AF.

IV. PROBLEM FORMULATION

Consider an array of antenna consisting of 2N number of elements. It is assumed that the antenna elements are symmetric about the center of the linear array. The far field array factor of this array with an even number of isotropic elements (2N) can be expressed as

$$AF(\theta) = 2\sum_{n=1}^{N} a_n \cos\left(a\frac{\pi}{\lambda} d_n \sin\theta \right) \text{ .... (2)}$$

where a_n is the amplitude of the n^{th} element, θ is the angle from broadside and d_n is the distance between position of the n^{th} element and the array center. The main objective of this work is to find an appropriate set of required element amplitudes a_n that achieves interference suppression with maximum sidelobe level reduction and narrow main beamwidth.

To find a set of values which produces the array pattern, the algorithm is used to minimize the following cost function

$$cf = \sum_{\theta=-90^\circ}^{90^\circ} W(\theta)\left[Fo(\theta) - F_d(\theta)\right] \quad \text{.... (3)}$$

where $F_0(\theta)$ is the pattern obtained using our algorithm and $F_d(\theta)$ is the pattern desired. Here it is taken to be the Chebychev pattern with SLL of -13dB and W(θ) is the weight vector to control the sidelobe level in the cost function. The value of cost function is to be selected based on experience and knowledge.

V. EXPERIMENTAL RESULTS

The antenna model consists of 20 elements and equally spaced with d =0.5λ along y-axis. Voltage sources are at the center segment of each element and the amplitude of the voltage level is the antenna element weight. Only the voltage applied to the element is changed to find the optimum amplitude distribution, while the array geometry and elements remain constant.

Optimization toolbox with ga-Genetic Algorithm solver in MATLAB has been used in experiments to find the amplitude excitations to achieve minimum sidelobe level of -50 dB. Half the number of elements is used as the number of variables with the Lower Bound (LB) = 0 and Upper Bound(UB) = 1. The details of the other parameters set in these experiments are as follows

Population size = 20
Selection function = Roulette
Reproduction (Elite count) = 1
Mutation function = Adaptive feasible
Crossover function = Single point

A. *Case 1:*

Number of variables = 8;
Number of array elements=16;
The experiment has been conducted for 25 times and the best results are presented here.

Fig 2 shows four different plots viz 1) Best fitness 2) Best individual 3) Score Diversity and 4) Array pattern.

Best result of – 48.9263dB sidelobe level is obtained with a mean value of -48.8641dB. The number of variables is selected as 8, as the antenna array consists of even number of elements which is symmetric about the center. The Score Histogram shows that among 20 of the population, 12 individuals give the best score <-48 dB. It converges to -48dB only after 75 generations.

Fig 3 shows that the sidelobe level is reduced to – 36.7213dB with a mean value of -38.6051dB. The Score Histogram shows 13 individuals get the score < -36.6 dB. The amplitude excitations of best individuals are obtained as

w1 = 0.9853; w2 = 0.9242; w3 = 0.8215;
w4 = 0.6698; w5 = 0.5218; w6 = 0.3527;
w7 = 0.2316; w8 = 0.1406 ;

The same is tabulated in Table1 for 16 elements. The sidelobe levels are almost constant for 6 sidelobes and the last one is wider and less than the remaining. The convergence takes place in 80 generations.

B. Case 2:

Number of variables = 10;
Number of array elements = 20;
The experiment is repeated for 10 variables. Fig.4 shows that the sidelobe level is reduced to -31.147dB whereas the mean is -30dB. All the individuals lie within the range of -30.5dB to -31.5dB. The main beamwidth is narrower but the sidelobes are wider.

C. Case 3

The simulation experiments are conducted with 22, 42, and 62 elements for 25 runs and their performance are compared with that of a table given in [17]. Table2 shows the performance characteristics of five algorithms for an average of 25 runs with random seed values of the amplitude weights. Genetic algorithm performs well when compared to Nelder Mead but poorer when compared to the remaining algorithms. But the function calls are minimum than all other algorithm. Hence it is cost effective in terms of computational time. Genetic algorithm shows the best results of median sidelobe level of -32.04dB with median function calls of 700 when the array size is 16 elements.

Among the three cases the number of elements of the antenna array with N = 16 performed very well with narrow main beamwidth and reduced sidelobe level and minimum number of function calls which cost less computation time and less complexity.

The Genetic algorithm has many variables to control and trade-offs to consider such as

1) Number of Chromosomes and initial random Population: more number of chromosomes provide better sampling number, solution space but at the cost of slow convergence.
2) Random list generation, type of probability distribution and weighting of the parameter – all have significant impact on the convergence time.
3) Selection method – Roulette selection is employed to decide which chromosome to discard.
4) Crossover function – It is for the chromosome mating, and single point cross over is used here.
5) Mutation rate - It is selected to mutate a particular chromosome. Mutate does not permit the algorithm to get stuck at local minimum.
6) Stopping Criteria, set in this program are maxgen = 100 and mincost = -50dB.

In this paper the Genetic Algorithm has converged well for a variant of options mentioned above with some trade offs to have main impact on convergence speed.

VI. CONCLUSION

In this paper Genetic algorithm Solver in Optimization toolbox of MATLAB is used to obtain maximum reduction in sidelobe level relative to the main beam on both sides of 0°. The specialty of the Genetic algorithm is that it can optimize the large number of discrete parameters. Genetic algorithm is an intellectual algorithm searches for the optimum element weight of the array antenna. This paper demonstrated the different ways to apply Genetic algorithm by varying values number of elements to optimize the array pattern. Adaptive feasible mutation with single point crossover and Roulette selection showed the performance improvement by reducing the sidelobe level below -30dB in most of the cases with number of variables as 8 and minimum function calls when compared to the other methods shown in Table2. The best result of -48.9dB is obtained for 16 elements proving that this method is efficient with much of the computation time and complexity are reduced.

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TABLE 1

AMPLITUDE EXCITATIONS OF A 16 ELEMENT ARRAY

W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16
0.14	0.23	0.35	0.52	0.67	0.92	0.82	0.98	0.98	0.92	0.82	0.67	0.52	0.35	0.25	0.14

TABLE 2

COMPARISON OF OPTIMIZED SIDELOBES FOR THREE DIFFERENT ARRAY SIZES [17] USING OTHER ALGORITHMS AND GENETIC ALGORITHM

	22 Elements		42 Elements		62 Elements	
	Median Sidelobe Level (dB)	Median Function Calls	Median Sidelobe Level (dB)	Median Function Calls	Median Sidelobe Level (dB)	Median Function Calls
BFGS	-30.3	1007	-25.3	2008	-26.6	3016
DFP	-27.9	1006	-25.2	2011	-26.6	3015
Nelder Mead	-18.7	956	-17.3	2575	-17.2	3551
Steepest descent	-24.6	1005	-21.6	2009	-21.8	3013
Genetic Algorithm	-22.3	830	-20.3	940	-20.9	860

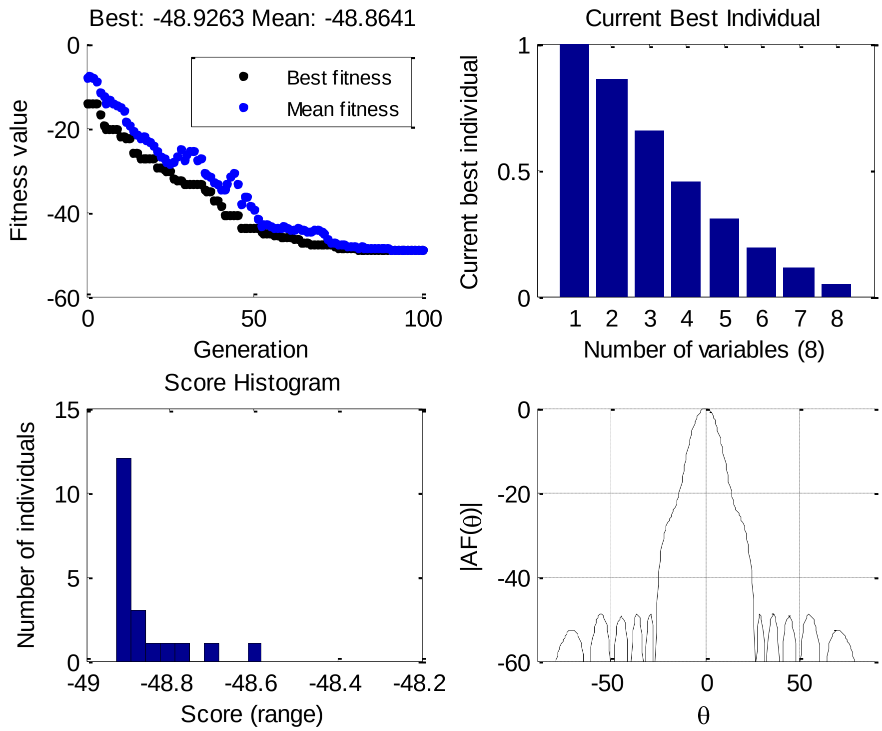

Figure 2 Performance characteristics of an antenna array with number of elements 16.

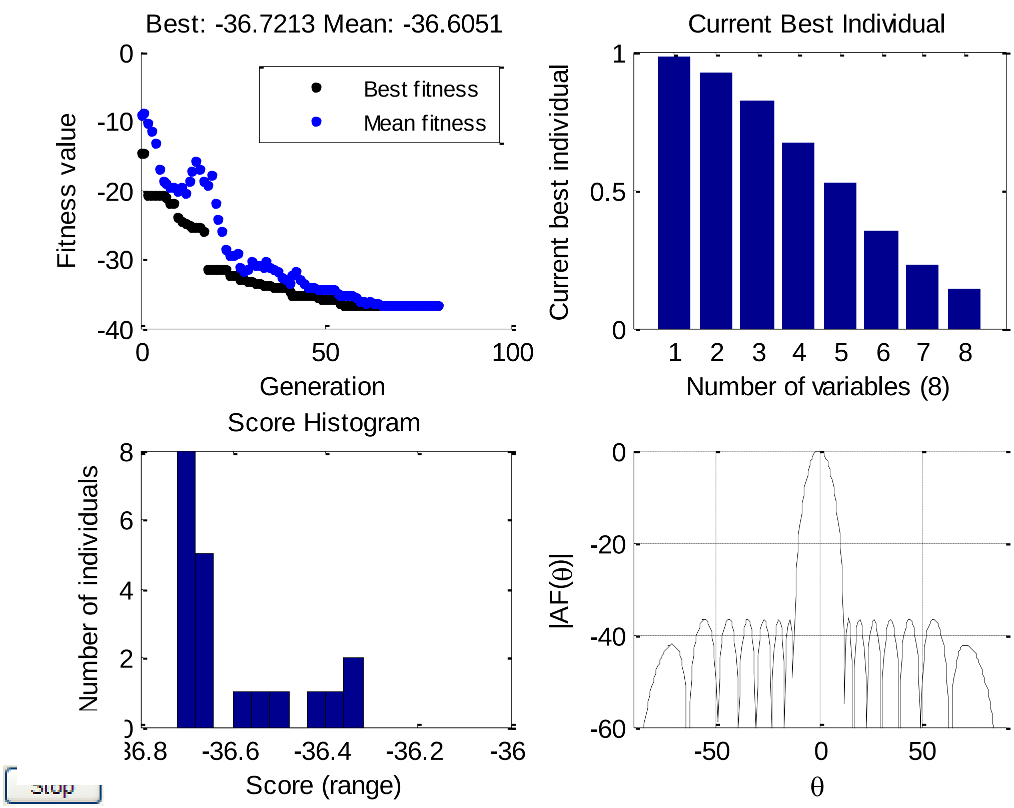

Figure 3 Performance characteristics of an antenna array with number of elements 16.

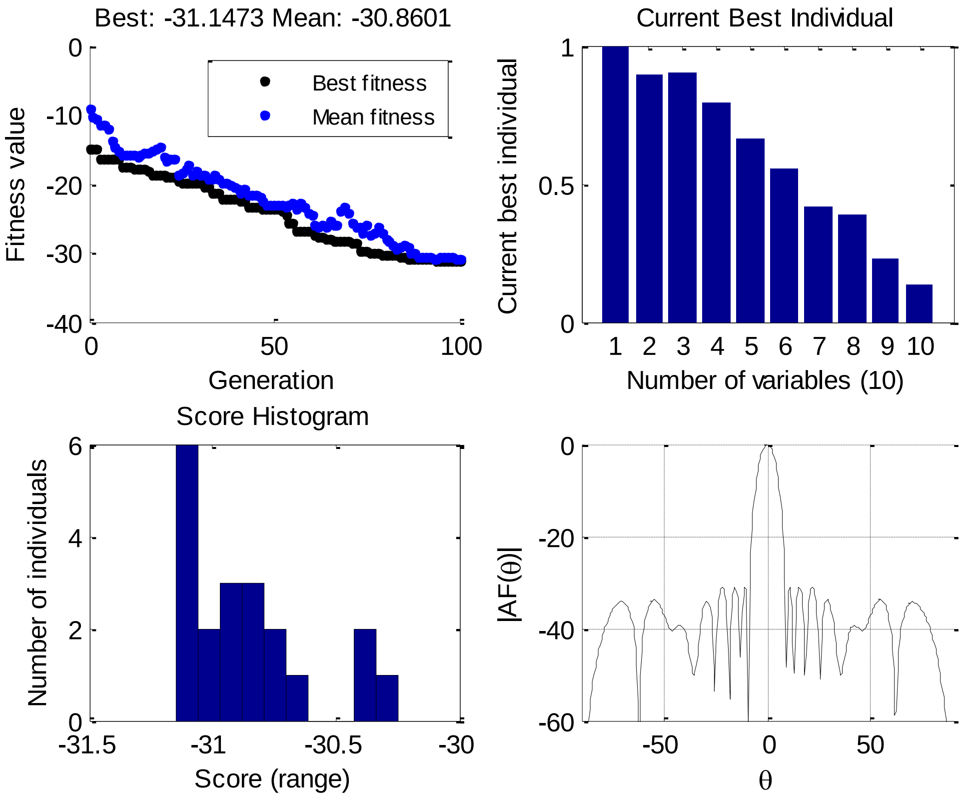

Figure 4 Performance characteristics of an antenna array with number of elements 20.

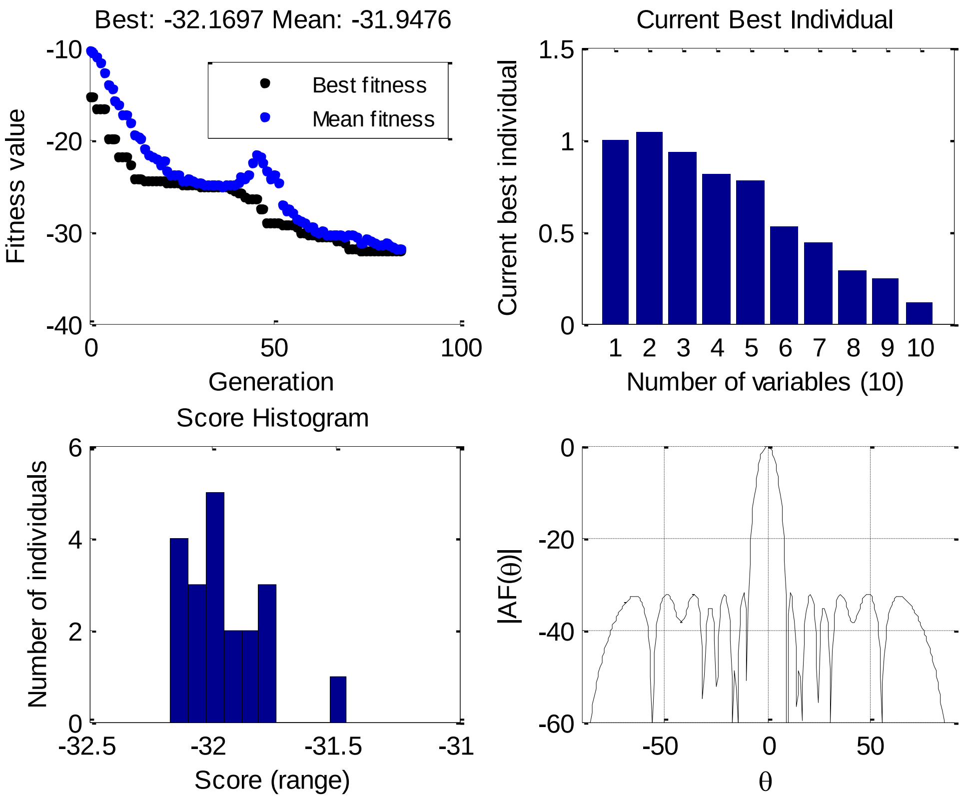

Figure 5 Performance characteristics of an antenna array with number of elements 20.