Synthesis of Linear Antenna Array using Genetic Algorithm with Cost Based Roulette to Maximize Side lobe Level Reduction

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*Abstract:-*This paper discusses the deployment of Genetic algorithm optimization method for synthesis of antenna array radiation pattern in adaptive beam forming. The synthesis problem discussed is to find the weights of the antenna array elements that are optimum to provide the radiation pattern with maximum reduction in the side lobe level. This technique proved its effectiveness in improving the performance of the antenna array.

Key-words: - Adaptive Beam forming, Side lobe level, Genetic Algorithm, Linear Antenna Array, Pattern Synthesis, Convergence, Array Factor

1 Introduction

Adaptive beam forming is a signal processing technique in which the electronically steerable antenna arrays are used to obtain maximum directivity towards signal of interest (SOI) and null formation towards signal of not interest (SNOI) i.e. instead of a single antenna the antenna array can provide improved performance virtually in wireless communication. The characteristics of the antenna array can be controlled by the geometry of the element and array excitation. But side lobe reduction in radiation pattern should be performed to avoid degradation of total power efficiency and the interference suppression must be done to improve the Signal to noise plus interference ratio (SINR)[29], [32], [33], [1], [9]. Side lobe reduction and interference suppression may 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 the specific position of the nulls, the desired side lobe level and beam width of antenna pattern[3], [33]. In literature, there are many works concerned with the synthesis of antenna array. It has a wide range of study from analytical methods to numerical methods and to optimization methods. Analytical studies by Stone who proposed binominal distribution, Dolph the Dolph-Chebyshev amplitude distribution , Taylor, Elliot, Villeneuve Hansen and Woodyard, Bayliss laid the strong foundation on antenna array synthesis[23]-[27]. Iterative Numerical methods became popular in 1970s to shape the main beam. Today a lot of research on antenna array is being carried out using various optimization techniques to solve electromagnetic problems due to their robustness and easy adaptivity [1]-[12], [33]. One among them is Genetic algorithm [12].

In this paper, it is assumed that the array is uniform, where all the antenna elements are identical and equally spaced. The design criterion considered is to minimize the side lobe level at a fixed main beam width[7]. Hence the synthesis problem is, finding the weights that are optimum to provide the radiation pattern with maximum reduction in the side lobe level.

2 Genetic Algorithms

Genetic Algorithms are a family of computational methods inspired by evolution [12], [29], [30]. A genetic algorithm (GA) is a procedure used to find approximate solutions to search problems through application of the principles of evolutionary biology. Genetic algorithms use biologically inspired techniques such as genetic inheritance, natural selection, mutation, and sexual reproduction (recombination, or crossover). Along with genetic programming (GP), they are one of the main classes of genetic and evolutionary computation (GEC) methodologies.

Genetic algorithms are typically implemented using computer simulations in which an optimization problem is specified. For this problem, members of a space of candidate solutions, called individuals, are represented using abstract representations called chromosomes. The GA consists of an iterative process that evolves a working set of individuals called a population toward an objective function, or fitness function. Traditionally, solutions are represented using fixed length strings, especially binary strings, but alternative encodings have been developed.

Holland performed much of the foundational work in Genetic Algorithm during 1960-1970. His goal of understanding the processes of natural adaptation and designing biologically-inspired artificial systems led to the formulation of the simple genetic algorithm [21].Genetic algorithms have been applied to many classification and performance tuning applications in the domain of knowledge discovery in databases (KDD). De Jong *et al.* produced GABIL (Genetic Algorithm-Based Inductive Learning*)*, one of the first general-purpose GAs for learning disjunctive normal form concepts. R.L.Haupt has done much research on electromagnetics and antenna arrays using Genetic Algorithm [13]-[21].

The evolutionary process of a GA is a highly simplified and stylized simulation of the biological version. It starts from a population of individuals randomly generated according to some probability distribution, usually uniform and updates this population in steps called generations. In each generation, multiple individuals are randomly selected from the current population based upon some application of fitness, bred using crossover, and modified through mutation to form a new population.

•**Crossover** – exchange of genetic material (substrings) denoting rules, structural components, features of a machine learning, search, or optimization problem

•**Selection** – the application of 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, *i.e.*, the behavior of the random sampling mechanism of a GA over time. The most severe limitation of this approach is that while crossover is easy to implement, its dynamics are difficult to describe mathematically. Markov chain analysis of simple GAs has therefore been more successful at capturing the behavior of evolutionary algorithms with selection and mutation only. These include evolutionary algorithms (EAs) and evolutionary strategies. A schema is a generalized description or a conceptual system for understanding knowledge-how knowledge is represented and how it is used. According to this theory, schemata represent knowledge about concepts: objects and the relationships they have with other objects, situations, events, sequences of events, actions, and sequences of actions.

3 Model of an Antenna Array

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.

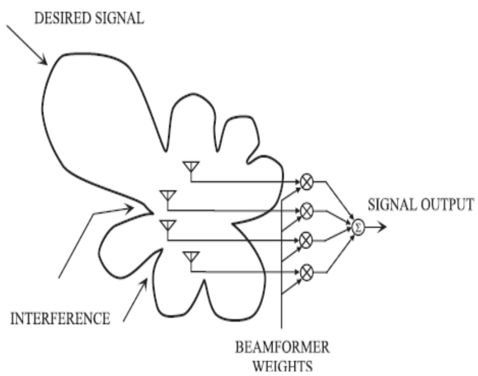

Fig.1 Antenna Array

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 $kd\cos\theta$ and θ is measured from the y-axis, starting from the first antenna, as shown in Figure 1. 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]

$$AF = \left|\left(\sum_{n=1}^{N} \overrightarrow{E_n}\right)\right| = \sum_{n=1}^{N} e^{jK_n} \qquad (1)$$

The factor $K = (nkd\cos\theta + \beta_n)$ is the phase difference. 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.

4 Problem Formulation

Consider an array of antenna consisting of N 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

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

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 amplitude a_n that achieves interference suppression with maximum sidebobe level reduction.

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

$$cf = \sum_{\theta=-90^\circ}^{90^\circ} W(\theta)[F_o(\theta) - F_d(\theta)] \quad (3)$$

where $F_o(\theta)$ 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 $W(\theta)$ 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.

5 Roulette Wheel Selection

In this paper the following parameters are defined as maxgen=500, maxfun=1000 and mincost=-50dB. Population is generated randomly. Then it is sorted based on its cost - minimum side lobe level. For choosing mates for reproduction Roulette wheel selection is used. Each weight vector is assigned a probability of selection on the basis of either its rank in the sorted population or its cost. Rank order selection is the easiest implementation of roulette wheel selection.

Fig.2 Shows the Roulette wheel selection probabilities for five parents in the mating pool. The chromosome with low side lobe level has higher percent chance of being selected than the chromosomes with higher side lobe level. In this case first or the best weight vector has a 42% chance of being selected.

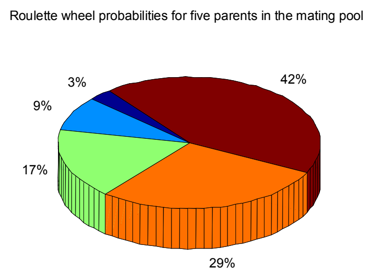

Fig.2 Roulette wheel probabilities for five parents in the mating pool

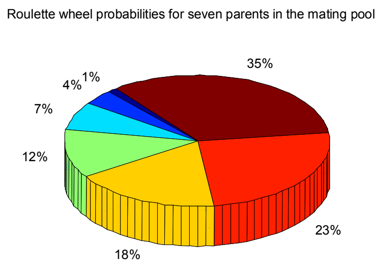

Fig.3 Roulette wheel probabilities for seven parents in the mating pool

As more generations are added, the percent chance of weight vector being selected changes. Fig 3 shows the Roulette wheel selection for seven parents in the mating pool. The best weight vector has 35% chance of being selected. The roulette wheel selection needs to be computed only once, because the number of parents in the mating pool remains constant from generation to generation.

6 Results and Discussion

The antenna model consists of N elements and equally spaced with d =0.5λ along the 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 number of elements remain constant. A continuous GA with a population size 10 and a mutation rate of 0.25 is run for a total of 100 generations using MATLAB and the best result was found for each iteration. The cost function is the minimum side lobe level for the antenna pattern. Fig 4 shows that the antenna array with N = 10 elements which has been normalized for a gain of 0dB along the angle 0° and the maximum relative side lobe level of -15dB.

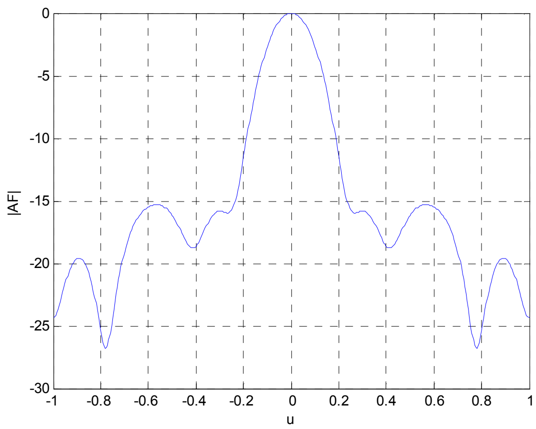

Fig.4 Optimized Radiation pattern with reduced side lobe level of -15dB for N=10 elements

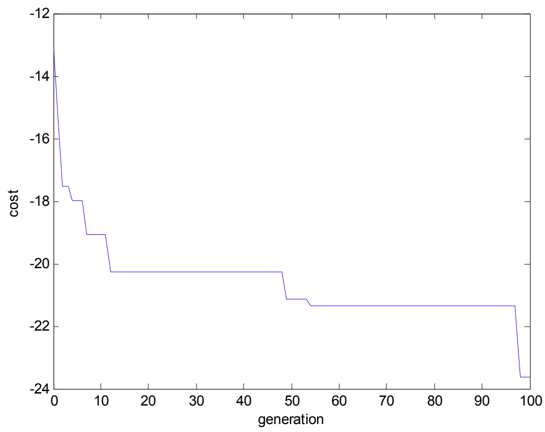

Fig.5 Convergence of side lobe level with respect to evolving generations for N=10 elements.

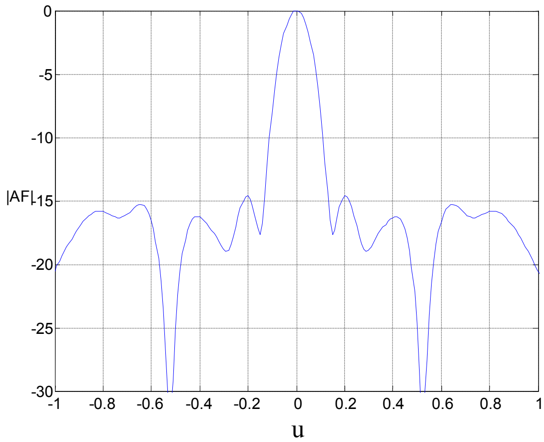

Fig.6 Optimized Radiation pattern with reduced side lobe level of -15 dB for N = 16 elements

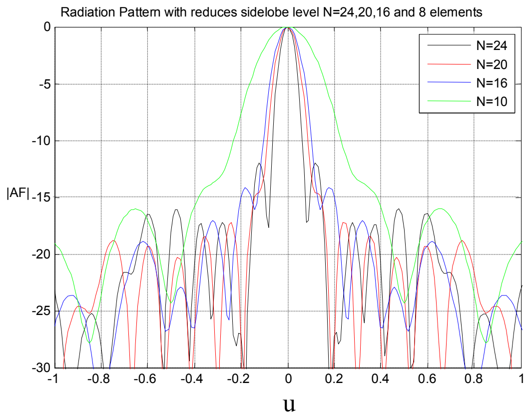

Fig.7 The optimized radiation pattern with reduced side lobe level for N= 10, 16, 20,and 24

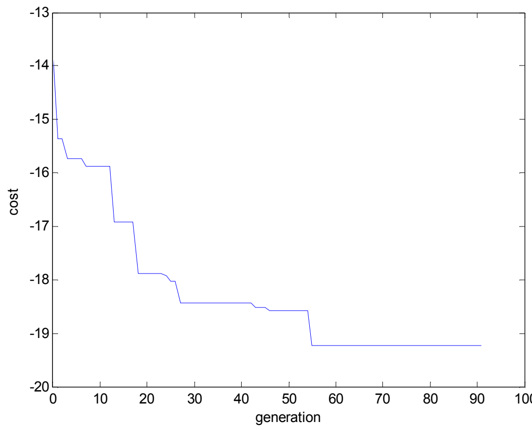

Fig.8 Convergence of side lobe level with respect to evolving generations for N=16 elements.

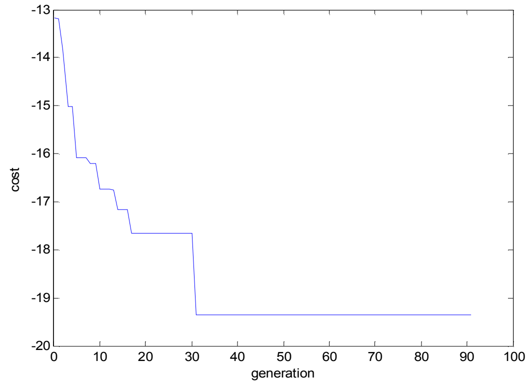

Fig.9 Convergence of side lobe level with respect to evolving generations for N=20 elements.

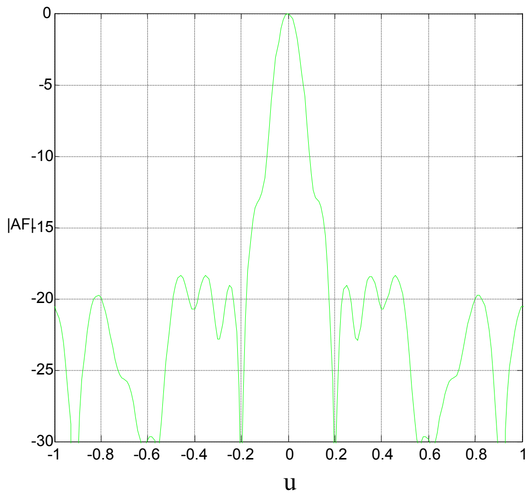

Fig.10 The optimized radiation pattern with reduced side lobe level for number of elements N= 20

Fig 5 shows the convergence of the algorithm for maximum reduction in the relative side lobe level with N = 10 elements. The convergence curve shows that it converges to -21.6dB after 52 generations. Changing the number of elements causes the contiguous GA to get different optimum weights. Fig 6 shows the radiation pattern for N = 16 elements. Among N=10, 16, 20, and 24, N=20 performed well and thus selected as optimized element number. The corresponding array pattern for N = 10, 16, 20, and 24 are shown in Fig 7. In this the radiation pattern for N=20 has the best directivity with minimum relative side lobe level of -14.67dB below the main beam. Fig 8 and Fig 9 show the convergence of side lobe level for N=16 and 20 respectively. Fig 10 and 12 show the optimized radiation pattern with Relative side lobe level(RSLL) of -18.7dB with N=20 and RSLL of -14.97dB with N=24 elements respectively. Fig 11 shows the convergence curve for N=24 elements

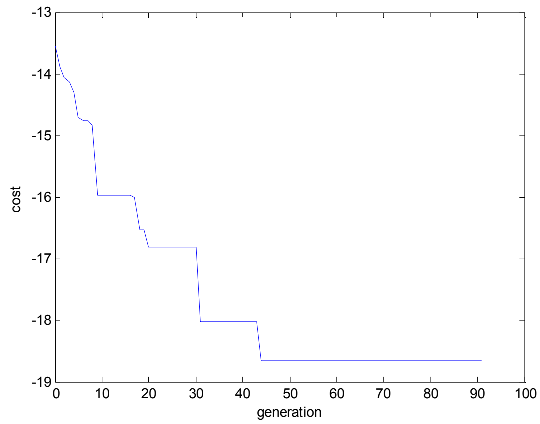

Fig.11 Convergence of side lobe level with respect to evolving generations for N=24 elements.

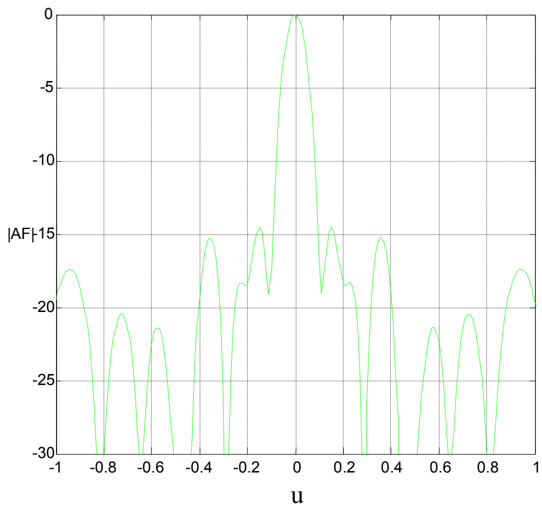

Fig.12 The optimized radiation pattern with reduced side lobe level for number of elements N= 24

According to the Rank order selection in the Roulette Wheel, the obtained costs are ranked from best to worst. The usual procedure is to discard the bottom half and to keep the top half of the list. But in our paper, the selection criteria is modified to discard any chromosome that has relative side lobe level less than -15dB. Table 2 shows the cost function relative to the population that has a SLL less than -15 dB. Among the 10 populations presented, only 5 are selected. This is done to speed up the convergence of the algorithm. After this selection, the chromosomes mate to produce offspring. Mating takes place by pairing the surviving chromosome. Once paired, the offspring consists of genetic material from both parents.

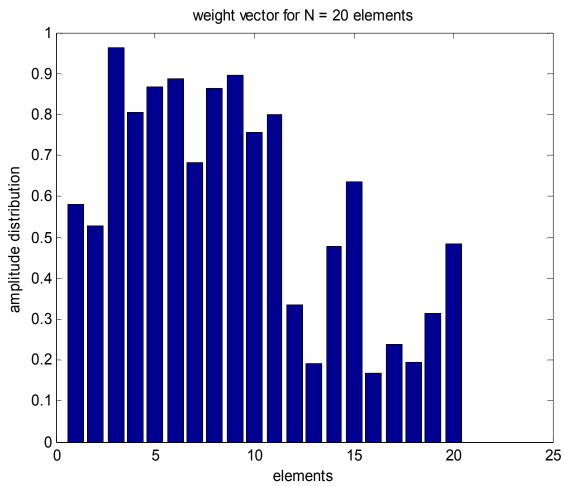

Fig.13 Amplitude distribution for optimized antenna array with N=20 elements

The procedure is repeated till the termination condition is met. Fig 13 shows the amplitude excitation for optimized antenna array as given in Table 1.

The Genetic algorithm has many variables to control and trade-offs to consider which are discussed below

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) Generating the random list, the type of probability distribution and weighting of the parameters have a significant impact on the convergence time.

3) Selection criteria decide which chromosome to discard.

4) Crossover technique: the chromosomes selected for mating, may be paired using any one method i.e. from top to bottom randomly or from best to worst.

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: This in general based on anyone of the following criteria such as maximum number of generations, maximum number of function calls and minimum cost.

7 Conclusions

In this paper, Genetic algorithm is used to obtain minimum side lobe level relative to the main beam on both sides of 0° with Roulette Wheel selection by optimizing the weight of the array elements. The uniqueness of Genetic algorithm is that it can optimize a large number of discrete parameters. Genetic algorithm has been applied with different values of mutation, population size, and number of elements to optimize the radiation pattern. This paper demonstrates the effect of varying the array size with number of elements 10, 16, 20 and 24. It has been realized that the performance of 20 element array is the best among all. The weights for the 20 element array has been optimized for a minimum side lobe level which proved the effectiveness of cost based GA algorithm.

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Table 1 : Amplitude excitation values for N=20 elements corresponding to Fig.13

W_n	Amplitude excitation
W_1	*0.9028*
W_2	*0.9645*
W_3	*0.7259*
W_4	*0.6910*
W_5	*0.7026*
W_6	*0.9491*
W_7	*0.7789*
W_8	*0.3478*
W_9	*0.5097*
W_{10}	*0.6319*
W_{11}	*0.5358*
W_{12}	*0.5625*
W_{13}	*0.4696*
W_{14}	*0.4828*
W_{15}	*0.2411*
W_{16}	*0.5464*
W_{17}	*0.0060*
W_{18}	*0.1060*
W_{19}	*0.4043*
W_{20}	*0.4334*

Table 2: Population and Respective Cost Function Values

Index	Chromosome (weight vector)								Relative sidelobe level(dB)
1	*0.893*	*0.909*	*0.795*	*0.716*	*0.588*	*0.372*	*0.264*	*0.223*	*-26.96*
2	*0.893*	*0.765*	*0.598*	*0.531*	*0.929*	*0.721*	*0.741*	*0.205*	*-19.08*
4	*0.463*	*0.765*	*0.633*	*0.539*	*0.929*	*0.259*	*0.741*	*0.205*	*-18.20*
7	*0.893*	*0.765*	*0.871*	*0.430*	*0.929*	*0.259*	*0.741*	*0.205*	*-17.55*
5	*0.837*	*0.427*	*0.782*	*0.532*	*0.542*	*0.823*	*0.964*	*0.305*	*-17.51*

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