Side Lobe Level Optimization of Planar Phased Array Antenna using Genetic Algorithm

Keyur Patel and Rizwan Alad

Abstract: In this paper, the genetic algorithm is applied to optimize side lobe level of planar array antenna with microstrip patch as unit elements. The cost function of genetic algorithm is maximum reduction in side lobe level. The genetic algorithm finds the optimum amplitude current excitations co-efficient of the antenna array elements to provide the radiation pattern with maximum reduction in the side lobe level. The genetic algorithm is modified with introducing the genes in initial population to compare the performance of genetic algorithm with modified genetic algorithm.

Keywords: Genetic Algorithms, Phased Array Antenna, side lobe level

I. INTRODUCTION

Practically, the radiation pattern of antenna array has not only the main beam but also side lobes. Most of the power is confined into main beam which provides the coverage into desired area. Some of the power is also distributed in the side lobes that are nothing but wastage of transmitting power. If the level of side lobe is high, large amount of transmitting power is wastage. For efficient use of transmitting power, it is required to reduce the side lobe level. Side lobe level reduction can be obtained by controlling the following antenna parameters: 1) the amplitude current excitations 2) the phase excitations and 3) the complex weights. Various analytical and numerical methods have been used to optimize the side lobe level at desired level relative to mail beam.

In literature survey, many methods are used from analytical method to soft computing techniques for minimization of side lobe level. The first optimum antenna array distribution was the binomial distribution. It was proposed by Stone [1]. The binomial distribution has large current ratio and the radiation pattern has no side lobe. In 1946, Dolph gave the Chebyshev distribution for optimization of side lobe level which has low current ratio as compared to binomial distribution but side lobes are at same level in this distribution [2]. Taylor developed a method to optimize the side lobe levels [3]. Lots of numerical methods were developed in 1970s to shape the main beam [4-5]. Today a lot of research on antenna array to solve synthesis problem is [6] – [9] is being carried out using various techniques. One most popular technique is Genetic algorithm [10-12]. R.L.Haupt has done lots of research on antenna arrays to solve the synthesis problem using Genetic Algorithm [13]-[19].

Keyur Patel is with Dharamsinh Desai University, Faculty of technology, Nadiad emails: keyurpatel.ec@ddu.ac.in, rizwan_alad.ec@ddu.ac.in

In this paper, the genetic algorithm is introduced with modification in initial population. The optimum chromosome is added into random chromosomes to obtain better result for optimization. Subsequently, genetic algorithm is applied to solve the problem of synthesis antenna array patterns. The reminder of the paper is organized as follows. Section II explains formulation of the pattern synthesis problem for linear antenna array. A general overview of genetic algorithm is introduced in Section III. The cost function that is used in the optimization process for the control of side lobe level and synthesis the pattern shape is presented. In Section IV, the numerical examples are provided to show the capability of optimized, and numerical results are discussed. Finally, the conclusion is made in Section V.

II. PROBLEM FORMULATION

We consider N x N microstrip patch planar array antenna with equally spaced distance d_x along x axis and d_y along y axis respectively. The planar array will be formed as shown in Fig.1.The array factor of entire planar array can be given by

$$AF(\psi) = E_{mn} \sum_{m=1}^{N} e^{j(m-1)\psi_x} \sum_{n=1}^{N} e^{j(n-1)\psi_y} \qquad (1)$$

Where,

E_{mn} is excitation of $(m,n)^{th}$ element,

$$\psi_x = kd_x \sin\theta \cos\phi + \beta_x$$
$$\psi_y = kd_y \sin\theta \sin\phi + \beta_y$$

k is wave number 2π/λ. β_x and β_y are progressive phase shift in x direction and y direction respectively. If main beam is directed along $\theta=\theta_0$ and $\phi=\phi_0$. The progressive phase shift is given by

$$\beta_x = -kd_x \sin\theta_o \cos\phi_o$$
$$\beta_y = -kd_y \sin\theta_o \sin\phi_o$$

The radition pattern of microstrip patch antenna is given by

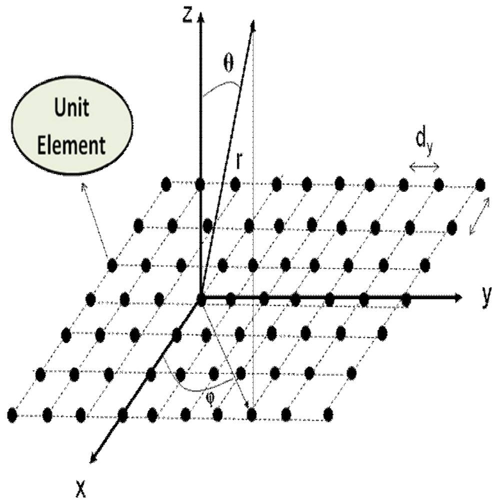

Fig.1 Planar array antenna

$$E(\theta)=\left\{\sin\theta\frac{\sin(\frac{k_o h}{2}\sin\theta)}{\frac{k_o h}{2}\sin\theta}\frac{\sin(\frac{k_o w}{2}\cos\theta)}{\frac{k_o w}{2}\cos\theta}\right\} \quad (2)$$

Where, h is height of substrate and w is width of patch.

The resultant pattern is given by

$$E_{total}(\theta)=[E(microstrip\_patch)]x[array\_factor] \quad (3)$$

Normalized power pattern, P(θ) in dB can be expressed as follows:

$$P(\theta)=20\log\frac{|E_{total}(\theta)|}{|E_{total}(\theta)_{\max}|} \quad (4)$$

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

Maximum side lobe level $(MSLL)=\max_{\theta\in s}\{P(\theta)\}$ (5)

Where, s is the region of maximum side lobe.

III. GENETIC ALGORITHM

The genetic algorithm (GA) is an optimization and search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that minimizes the cost function. This optimization algorithm is more powerful for problems with more number of variables and local minima. GA is very efficient in exploring the entire search space or the solution space, which is large and complex. The Genetic algorithm is implemented using computer simulation. Genetic Algorithm may be represented as shown below in Fig. 2. In computer algorithm, a chromosome is an array of genes, a number of chromosomes make up one population. The chromosomes are generated randomly in the selected space. Each chromosome has an associated fitness function, assigning a relative merit to that chromosome. The algorithm begins with a large list of random chromosomes. Fitness functions are evaluated for each chromosome. The chromosomes are ranked from the most-fit to the least-fit, according to their respective fitness functions. Unacceptable chromosomes are discarded, leaving a superior species-subset of an original list, which is the process of selection. Genes that survive become parents, by crossing over some of their genetic material to produce two new offspring. The parents reproduce enough to offset the discarded chromosomes. Thus, the total number of chromosomes remains constant after every iteration. Mutations cause small random changes in a chromosome. Fitness functions are evaluated for the offspring and mutated chromosome, and the process is repeated. The algorithm stops after a set number of iterations, or when an acceptable solution is obtained.

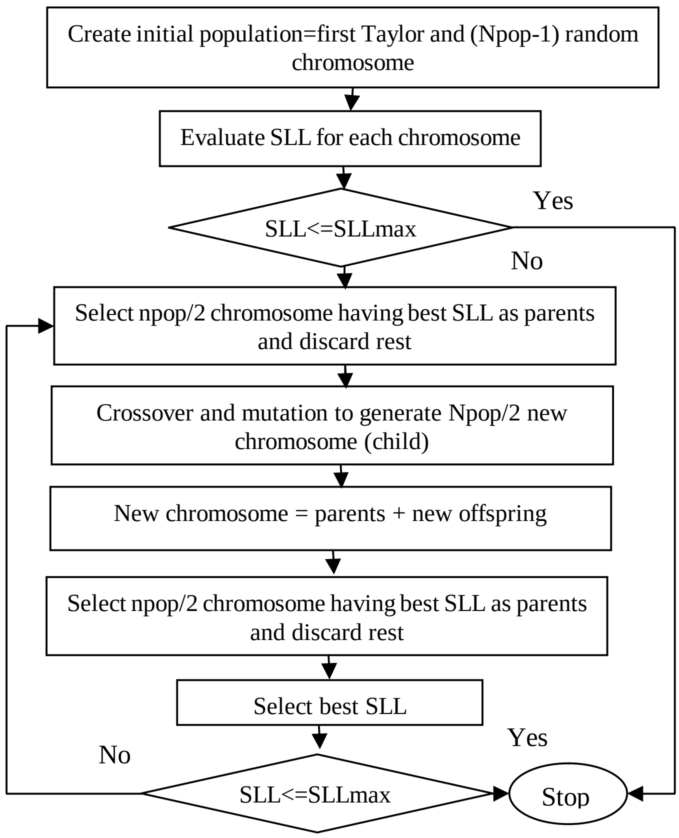

Fig.1 Genetic algorithm for optimization of side lobe level

The important parameters of GA can be summarized as,

1. Crossover type and crossover rate.
2. Mutation type and mutation rate.
3. Population size.
4. Selection procedure.
5. Number of generations.

The crossover is an exchange of substrings denoting chromosomes, for an optimization problem. It may be a single point cross over, two points cross over, cut and splice, uniform crossover or half uniform crossover. The crossover rate is the rate of exchange of substring of chromosome. The mutation is the modification of genes in the chromosome which are generated from the selected parents. The mutation rate is rate of modification in the chromosome. The population size is the number of chromosome in the one generation. Selection process is evaluation of the fitness criterion to choose which chromosome from a population will go on to reproduce. Some general methods used are Roulette Wheel Selection and Tournament Selection the number of generation is the maximum number of iterations the genetic algorithm can evolve into, before terminating.

The cycle is repeated until a termination condition has been reached such as

1. A solution that satisfies the minimum criteria.
2. Reaching the specified number of generations.
3. Reaching the specified computation time.
4. Arriving fitness value and
5. Manual inspection.

In the genetic algorithm, initial chromosomes are combination of random chromosome and amplitude excitations of Tayor pattern instead of all random chromosomes. The halves of the chromosome are discarded and new half of chromosomes are generated from parents chromosome which are best fits to fitness function. The cost function is the maximum side lobe level for the antenna pattern.

IV. RESULT AND DISCUSSION

To illustrate the effectiveness of the proposed algorithm, simulations are presented here. We consider rectangular planar array antenna of 8 x 8 elements of microstrip patch antenna. They are equally spaced with dx = 0.5λ and dy = 0.5λ along the x-axis and y-axis respectively. The radiation pattern of microstrip patch antenna is computed at frequency 10 GHz with effective dielectric constant 2.2, height of dielectric material 0.1588 cm , width of patch 1.186 cm and length of patch 0.906 cm. Amplitude tapering is used to find the optimum solution while the array geometry and elements remain constant. A genetic algorithm with random initial population, population size 8, column wise crossover of 25 % of total number of elements in one chromosome and a mutation rate of 3% of total number of elements is run and the best result is found. The maximum side lobe level should be less than -20 dB.

Case study 1: Side lobe level <= -20 dB

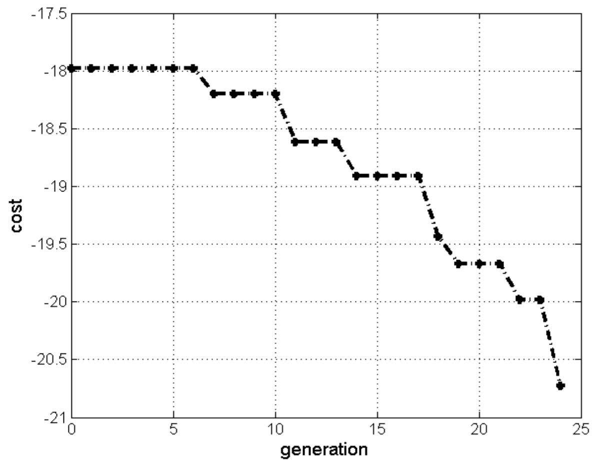

Fig.3 Convergence curve for side lobe level -20 dB

Fig-3 shows the convergence of the algorithm for maximum reduction in the relative side lobe level with N = 64 elements. It starts from -17.98 dB, after 24 iterations it reaches -20.73 dB and converges to a maximum reduction of -20 dB.

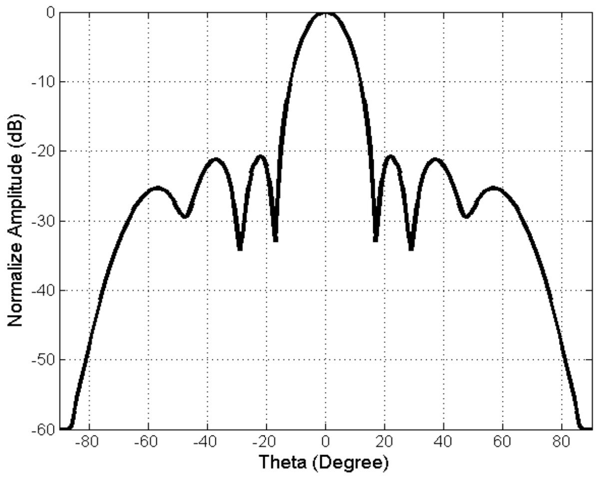

Fig.4 Optimized radiation pattern with reduced side lobe level -20 dB

Fig -4 shows the radiation pattern of planar array antenna with N = 64 elements which is normalized for a gain of 0 dB along the angle 0° and the maximum relative side lobe level of -20 dB.

Case study 2: Side lobe level <= -25 dB

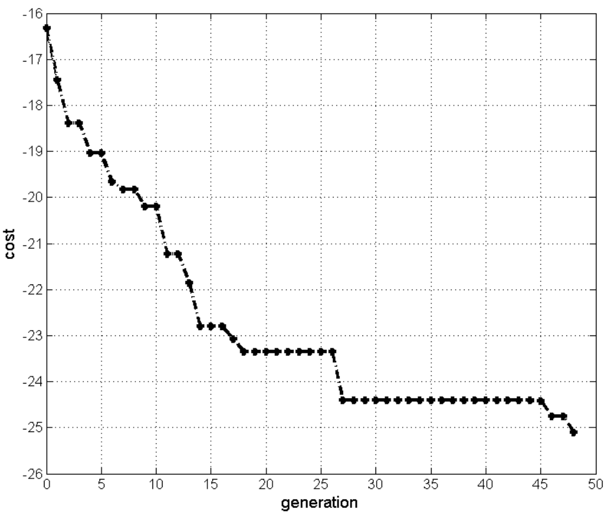

Fig.5 Convergence curve for side lobe level -25dB

Fig 5 shows convergence curve for this case. The convergence curve shows that it converges to -25.10 dB after 48 generations. Fig. 6 shows the optimized radiation pattern with relative side lobe level of -25dB with 8x8 planar array antennas

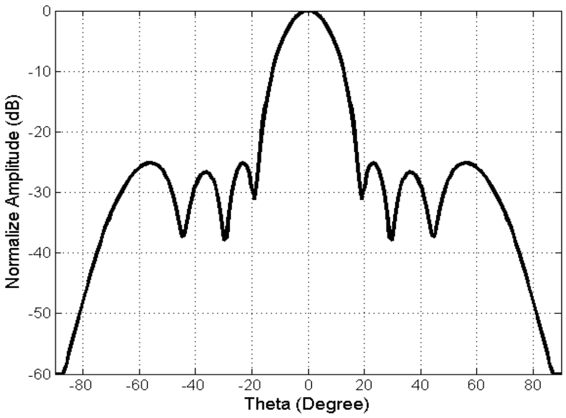

Fig.6 Optimized radiation pattern with reduced side lobe level -25 dB

Case study 3: Side lobe level <= -20 dB

A genetic algorithm with amplitude excitation of -15 dB Taylor pattern as first chromosome and rest of random chromosomes (7 chromosomes), population size 8, column wise crossover of 25 % of total number of elements in one chromosome and a mutation rate of 3% of total number of elements is run and the best result is found. The maximum side lobe level should be less than -25 dB. Fig.7 shows the convergence of the algorithm for maximum reduction in the relative side lobe level. It starts from -17.17 dB and it reaches -20.32 dB after 15 iterations and converges to a maximum reduction of -20 dB. Fig.8 shows radiation pattern for a maximum reduction of side lobe level -20 dB.

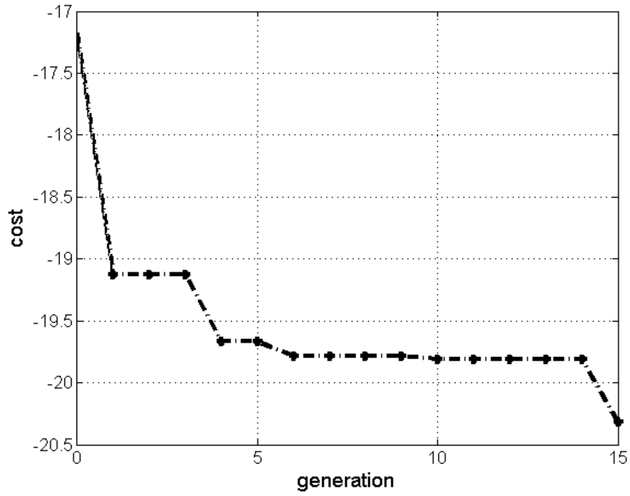

Fig.7 Convergence curve of optimized GA for side lobe level -20 dB

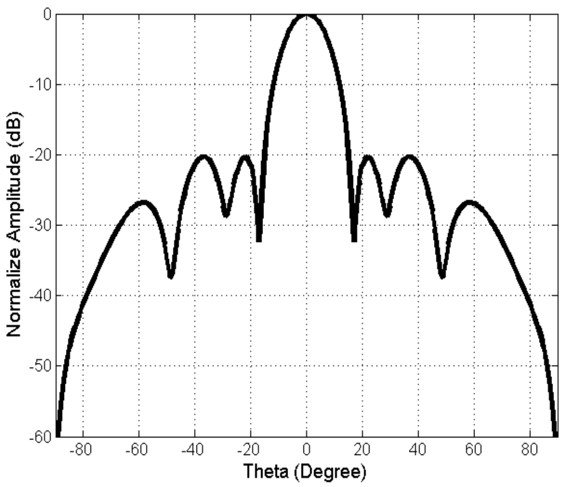

Fig.8 Optimized radiation pattern with reduced side lobe level -20 dB

Case study 4: Side lobe level <= -25 dB

A genetic algorithm with amplitude excitation of -20 dB Taylor pattern as first chromosome and rest of random chromosomes (7 chromosomes) with population size 8, column wise crossover of 25 % of total number of elements in one chromosome and a mutation rate of 3% of total number of elements is run and the best result is found. The maximum side lobe level should be less than -25 dB.

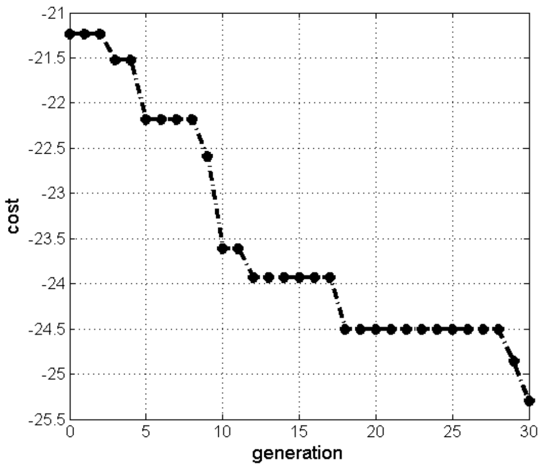

Fig.9 Convergence curve of optimized GA for side lobe level -25 dB

Fig.9 shows the convergence of the algorithm for maximum reduction in the relative side lobe level. It starts from -21.23 dB and it reaches -25.30 dB after 30 iterations and converges to a maximum reduction of -25 dB. Fig.10 shows radiation pattern for a maximum reduction of side lobe level -25 dB.

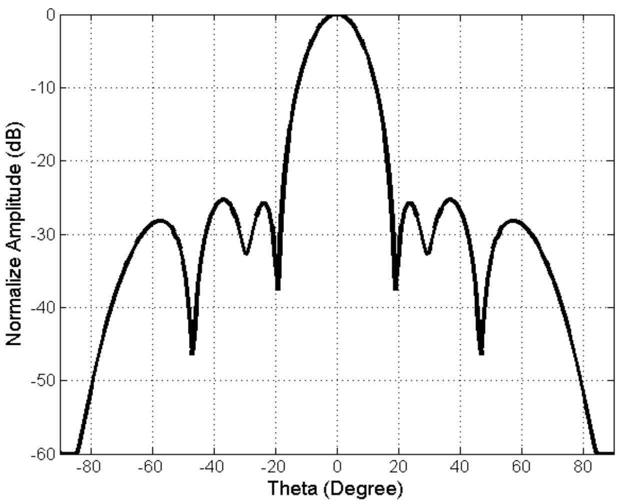

Fig.10 Optimized radiation pattern with reduced side lobe level -25 dB

Table 1. Comparison of iterations

Desired SLL(dB)	No of iteration	
	GA	modified GA
-20	24	15
-25	48	30
-30	95	42
-35	219	167

Table 1 shows the comparison of required number of iterations to get optimum side lobe level for Genetic algorithm and modified genetic algorithm.

V. Conclusion

In this paper, genetic algorithm is used to obtain optimize side lobe level at desired level relative to the main beam which is oriented at 0^o. The modified genetic algorithm is better than continuous genetic algorithm because it requires less number of iterations compared to continuous genetic algorithm. The performance of genetic algorithm can be improved by introducing the optimum genes in the initial population.

REFERENCES

[1] J. S. Stone, US Patents 1,643,323 and 1,715,433.
[2] C. L. Dolph, 'A current distribution for broadside arrays which optimizes the relationship between bream width and side-lobe level,'Jun.1946.
[3] T.T. Taylor, 'Design of line source antennas for narrow beamwidth and low side lobes,' IRE AP Trans., AP-7, pp. 16-28, 1955.
[4] C. A. Balanis, 'Antenna Theory' , John Wiley, 'Analysis and design', 2nd Ed., 1997.
[5] Orchard H. J., R.S. Elliot,, and Steen G.J.: 'Optimizing the synthesis of shaped beam antenna patterns', IEE Proc., Pt. H, pp. 63-68, 1985.
[6] E.T.Bayliss, "Design of Monopulse Antenna difference Patterns with low sidelobes", Bell Syst. Tech.J.47 pp623- 650 May-June 1968.
[7] W.L.Stutzman and E.L Coffey, "Radiation pattern synthesis of planar antennas using the iterative sampling method", IEEE Trans.AP 23(6) pp762-769 November 1975.
[8] J.H.Holland, "Adaptation in Natural and Artificial Systems, Univ. Michigan Press,Ann Arbor 1975.
[9] B.Widrow et.al. "Adaptive antenna system", IEEE.Proc 55(12) pp2143-2159 Dec 1967.
[10] T.B.Chen,Y,B.Chen,Y.C.Jiao and F.S.Zhang, "Synthesis of Antenna Array Using Particle Swarm Optimization", Asia-Pacific Conference proceedings on Microwave Conference,2005 ,APMC,2005,pp.4.
[11] Oscar Quevedo-Teruel and Eva Rajo-Iglesias, "Application of Ant Colony Optimization Based Algorithm to solve Different Electromagnetic Problems", Proc.EuCAP 2006, Nice, France 6-10, November 2006.
[12] M.A.Panduro, "Design of Non-Uniform Linear Phased Arrays using Genetic Algorithms To Provide Maximum Interference Reduction Capability in a Wireless Communication System", Journal of the Chinese Institute of Engineers,Vol.29 No.7,pp 1195-1201(2006).
[13] R.L.Haupt and Sue Ellen Haupt, "Practical Genetic Algorithm",2nd ed.,Wiley, New York,2004.
[14] R.L.Haupt, Douglas H.Werner, "Genetic Algorithm in Electomagnetics", Wiley interscience Publication 2007.
[15] R.L.Haupt, "Directional Antenna System Having Sidelobe Suppression,Us Patent 4, pp571-594 Feb 18,1986.
[16] R.L.Haupt, "Thinned arrays using genetic algorithm", IEEE Transaction on Antenna and Propagation, Vol.12 Issue 7, pp 993-999 July1994.
[17] R.L.Haupt, "Optimum quantized low sidelobe phase tapers for array",.IEEE Electronics Lett 31(14) pp1117- 1118 July 1995.
[18] R.L.Haupt, "Synthesizing low sidelobe quantized amplitude and phase tapers for linear arrays using genetic algorithms, Proc Inte.Conf. Electromagnetics in Advanced Application, Torino, Italy, pp 221-224 Sept.1995.
[19] R.L.Haupt, "Adaptive Nulling With Weight Constraints", Progress In Electromagnetics Research B, Vol. 26, pp 23- 38, 2010.