Synthesis of a Thinned Planar Antenna Array with Maximum Reduction in Peak Side Lobe Level using Modified Binary Coded Genetic Algorithm (MBC-GA)

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Abstract: In this paper, we propose a randomized algorithm for the synthesis of a thinned planar antenna (TPA) array that generates a radiation pattern with maximum reduction in peak side lobe level (PSLL). The key purpose of this paper is to achieve a Peak side lobe level (PSLL), equal to or less than -25dB. A Modified Binary Coded GA (MBC-GA) is formulated to find out optimum positions of active and inactive elements by randomly switching on and switching off elements in random position to attain the suppressed peak side lobe level (PSLL). A randomized Crossover and mutation techniques are formulated and included in normal BCGA to devise the MBC-GA. For validating the effectiveness of proposed method, a 12x12 TPA is taken into consideration in present study. Their results are put side by side with the previously proposed works containing similar design specifications. Comparison exhibits the superiority of our method in reducing of peak side lobe levels at bore sight.

Keywords: TPA, PSLL, GA, MBC-GA.

Introduction

One of the most important goals while designing an antenna array is to obtain the best possible narrow beam in the desired direction along with maximum suppression in peak side lobe level. An array represented in a planar layout (N x M) matrix is called as Planar Array (PA). The orthodox way of producing thinned array is taking into consideration a fully filled array, from which where various elements are either switched on or off at random position to actualize satisfactory reduction on the Side lobe level (SLL). This process results in obtaining antenna arrays with PSLL much lesser than that of a fully filled array of identical size. It also scales down the array cost, weight, side lobe level and power consumption dissipation while keeping the other parameters of the antenna same or almost equal to that of a fully filled antenna of same dimensions. Realization of feed network for passive antenna is easy [1].

The parameters such as side lobe level and density of elements are the primal concepts in array thinning. These parameters result in an efficient beam synthesis. To meet that vital function of thinning various global optimization techniques such as particle swarm optimization (PSO) [2]-[4], genetic algorithm (GA) [5]-[6], simulated annealing (SA) [7], ant colony optimization (ACO) [8], Boolean differential evolution algorithm (BDE) [9] and improved binary evasive weed optimization (IBIWO) were devised to synthesize thinned antenna arrays. Although these yield the required results, Binary Coded Genetic algorithm is preferred based on reduced complexity and iterative computations. Synthesising uniformly excited planar array with the desired radiation characteristics is described in this paper along with the formulated algorithm included in it to achieve the same. Genetic Algorithm is used to produce a thinned planar array in the X-band region which can yield a radiation pattern with suppressed PSLL.

Modified binary coded genetic algorithm (MBC-GA) is explained in this paper. The center elements are always turned on since they participate in the main lobe formation. To prevent any hindrance to the radiating elements present in the core we have fixed the center element excitation amplitudes as ‘1’ and then performed thinning to the remaining elements located away from the center and near to the periphery. A Novel randomization technique for implementing crossing over and mutation is formulated such that the elements at the center of the array remain undisturbed. The GA operators .i.e. cross over and mutation are varied randomly, which helps in achieving the best optimal solution with greater suppression in peak side lobe level. The proposed method enhances the global search ability of GA and prevents the algorithm from being stuck in local minima while keeping the thinning percentage equal to or greater than the required one.

The literature in the present research paper varies from those already available in terms of introducing a completely new method to obtain maximum possible suppression in PSLL while maintaining symmetry in element’s position and also preserving the original size.

Mathematical Formulation for Thinned Planar Array

Geometrical representation of a planar antenna array is as shown in Fig (1), the array is consisting of (L x M) elements positioned symmetrically along the origin in x-y plane. It is seen to that no element is placed at the origin. Total field radiated by this Planar Array in the z-axis is Etf(θ, Φ):

$$\boldsymbol{Etf(\theta,\Phi) = \left[Etf\left(element\ at\ reference(\theta,\Phi)\right)\right] \times [AF(\theta,\Phi)]} \qquad (1a)$$

$$\boldsymbol{AF(\theta,\Phi) = \sum_{l=1}^{L}\sum_{m=1}^{M} AM_{lm}\cos\left[\frac{(2l-1)}{2} \times kd_y\, sin\theta cos\Phi\right] \times \cos\left[\frac{(2m-1)}{2} \times kd_x\, sin\theta sin\Phi\right]} \qquad (1b)$$

Where $\boldsymbol{Etf}(element\ at\ refrenece(\theta,\Phi))$ is radiation pattern of individual element, AF is the array factor, $\boldsymbol{AM_{lm}} \in \{\mathbf{1},\mathbf{0}\}$ is the excitation amplitude of the element located at position (l, m) where '1' signify the state of a switched ON element and '0' a switched OFF element. The variable, $\boldsymbol{k = \frac{2\pi}{\lambda}}$, d_x and d_y are the inter-element spacings across x and y-axis respectively and is equal to 0.5 λ. θ *and* Φ are the angles from z and x-axis respectively.

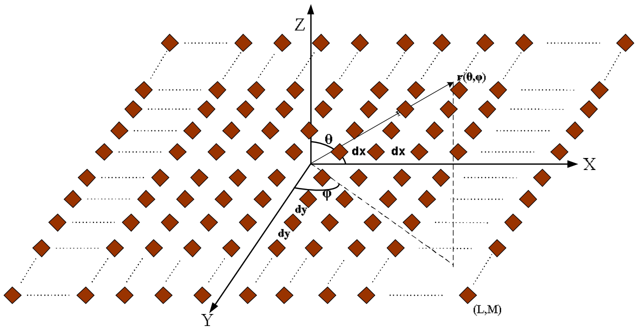

Fig (1): Planar array general design configuration with L×M antenna elements

A fitness function is devised to reduce the peak side lobe level (PSLL) in principal planes ($\Phi = 0^0$ *and* $\Phi = 90^0$) of the radiation pattern. Fitness function is the representation of peak side lobe level in individual plane .i.e. $\Phi=0^0$ and $\theta=90^0$ with respect to the number of iterations. The normalized peak Side lobe level ($f_{PSLL}(AM)$) of the antenna array can be computed using (2)

$$\boldsymbol{f_{PSLL}(AM,\theta,\Phi) = \max_{\forall\theta\in r}\left[20\log\left|\frac{AF(AM,\theta,\Phi)}{AF_{max}}\right|\right]} \quad (2)$$

Fitness value in the individual planes is calculated by formulas in (2a) (2b), (2c) and (2d) which are used to reduce the PSLL.

$$\boldsymbol{fit1 = f_{PSLL}(AM,\theta)|_{\Phi=0^0}} \qquad (2a)$$

$$\boldsymbol{fit2 = f_{PSLL}(AM,\theta)|_{\Phi=90^0}} \qquad (2b)$$

$$\boldsymbol{Tfitness = fit1 + fit2} \qquad (2c)$$

$$\boldsymbol{Desired\ SLL - Tfitness = f_{ASLL}(AM,\theta,\Phi)} \qquad (2d)$$

Where 'AM' is the Amplitude excitation of the elements in the array i.e. either '1' or '0', 'r' indicates the angular side lobe sector exclusive of the main beam and AF_{max} is the maximum value of Array Factor (AF). $f_{ASLL}(AM,\theta,\Phi)$ is the average side lobe level in both the planes.

Modified Binary Coded Genetic Algorithm

The fundamental building block of genetic algorithms is the gene [11]. The gene is encoded with either binary '1' or '0'respectively, for computational purpose in computer programs using MATLAB. An array of genes is called chromosome and a collection of chromosomes make up one population. Every chromosome will have a unique fitness value which followed by the ranking process done by comparing the fitness values of each chromosome with one another in the entire population. The algorithm begins with a large list of random chromosomes generated from thinning operation. Fitness function is evaluated for each chromosome. All the chromosomes are ranked from the most-fit to the least-fit, according to their respective fitness values. Fifty percent of the entire population having least fit chromosomes is discarded, therefore leaving with only the most fit chromosomes of the original list. The process of discarding is based on the survival of the fittest theory which associated with the process of selection.

Chromosomes that survive are treated as parents who go through crossing over operation and exchange some of their genetic material, two new offspring are produced. A randomized cross over technique is included in MBC-GA which is explained in section IV. The parents reproduce enough offspring chromosomes to add up to the discarded chromosomes. Thus, the total number of chromosomes remains constant.

Randomized mutation is done to achieve newer offspring i.e. the offspring chromosomes undergo random changes in a chromosome and help the algorithm from getting stuck in local minima. The process of mutation implemented in the MBD-GA is described in section IV. Fitness values are evaluated simultaneously for the all offspring and mutated chromosomes, and the process is repeated. The algorithm is terminated when the termination criterion is satisfied which is after a prefixed number of iterations or when a prescribed solution is obtained.

The flowchart in Fig (2) demonstrates the procedure followed during implementing the Modified Binary Coded Genetic Search Algorithm (MBC-GA) and the randomization done in the genetic operators is detailed in section IV with necessary equations to support the novelty in this research paper.

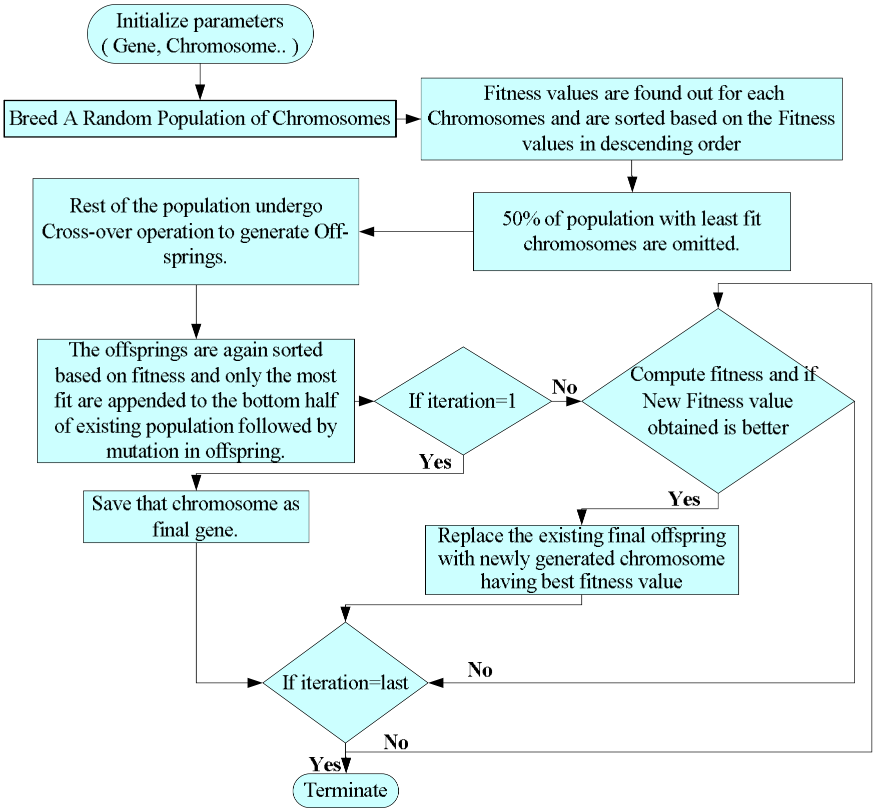

Fig (2): Flowchart of the proposed MBC-GA

Crossover And Mutation

In TPA array optimization, let us consider that P_i and P_{i+1} are two consecutive parents which take part in generation of new chromosome called offspring's. A random variable co_n is used to generate two random numbers to perform the crossover operation is given as:

$$co_n = random\ (q, 2), \left\{ \left(\frac{L}{2} < q \leq L-1 \right), \forall\ M\ values \right\}$$

Where, L is the total number of rows and M is the total number of columns in TPA array.

The selected parents go through crossover operation as per equations defined below in (3) and (4) to produce new chromosomes called offsprings as given below.

$$B_i = \left\{ \begin{array}{c} (P_i)_{1 \leq c < co_n(1), \forall M}, (P_{i+1})_{co_n(1) \leq c \leq co_n(2), \forall M} \\ , (P_i)_{co_n(2) < c \leq L, \forall M} \end{array} \right\} \quad (3)$$

$$B_{i+1} = \left\{ \begin{array}{c} (P_{i+1})_{1 \leq c < co_n(1), \forall M}, (P_i)_{co_n(1) \leq c \leq co_n(2), \forall M} \\ , (P_{i+1})_{co_n(2) < c \leq L, \forall M} \end{array} \right\} \quad (4)$$

where 'c' is a random variable which signify the rows being selected to preserve from the parent chromosomes and B_i and B_{i+1} are two consecutive offsprings.The mutation is carried out by the formulated equation (5) given below

$$C_{mup}=CN*0.025 \qquad (5)$$

Where C_{mup} is the no of chromosomes will be chosen from the newly generated offspring chromosomes and CN is the total number of newly generated offspring's. The chromosome that has to go through mutation operation is decided by the equation below:

$$(B_j)_{1\leq j\leq Cmup} = random\ (G, C_{mp}),\ (1<G\leq CN) \qquad (6)$$

From each of the chosen chromosomes, the gene that has to undergo be mutation is got from the point of intersection of the randomly selected row and column by:

$$RM_p=\{random(v,1),random(w,1)\},\begin{cases}\left(\frac{L}{2} < v \leq L\right)\\ \left(\frac{M}{2} < w \leq M\right)\end{cases} \qquad (7)$$

where RM_p represents the mutation point.

MATLAB version 7.13 [10] is used for implementation of the algorithm and the steps followed are as indicated from the flowchart shown in Fig.2.

I. The algorithm was initiated with a population of 2000 chromosomes which are randomly generated. Each chromosome configuration is of 12 x 12 genes .i.e. 144 elements. Every gene has an amplitude excitation of either '1' or '0' depending on thing point.
II. For each individual chromosome fitness value is calculated using equation (2) and they are graded from most fit to least fit in accordance to their suitable fitness values. The roulette wheel selection is utilized where the most fit chromosomes are selected over the least fit chromosome for the next operations such as cross over and mutation.
III. The selected chromosomes are considered as parents who generate new chromosomes, called as offsprings or children by interchanging some of their genetic properties using crossing over equations indicated in (3) and (4).
IV. The offsprings go through mutation process as described in equations (5), (6), and (7). This ensures that the algorithm does not get stuck in the local minima.
V. These steps are iterated for 300 times to obtain the optimum combination of turned on and turned off elements corresponding to lowest possible PSLL.

The advantages of MBC-GA is its ability to escape from problems related to local minima and maxima, it is successful in finding the best optimum solution in a huge population, its process of randomization in the cross over and mutation parameters and also higher convergence rate with efficient results.

Numerical Results

In this numerical study, a 12x12 planar array was considered. For optimization, Genetic Algorithm was initiated with a population size of 2000 chromosomes and iterated for 300 times to reduce the fitness function pointed out in equation (2). The most optimum combinations of ON and OFF positions of the elements in the array is obtained using MBC-GA as indicated in the Fig (3). Only one quarter of the entire square array i.e. right top quadrant (x-axis in horizontal plane and y-axis in vertical plane) or a 6 x 6 array is shown below.

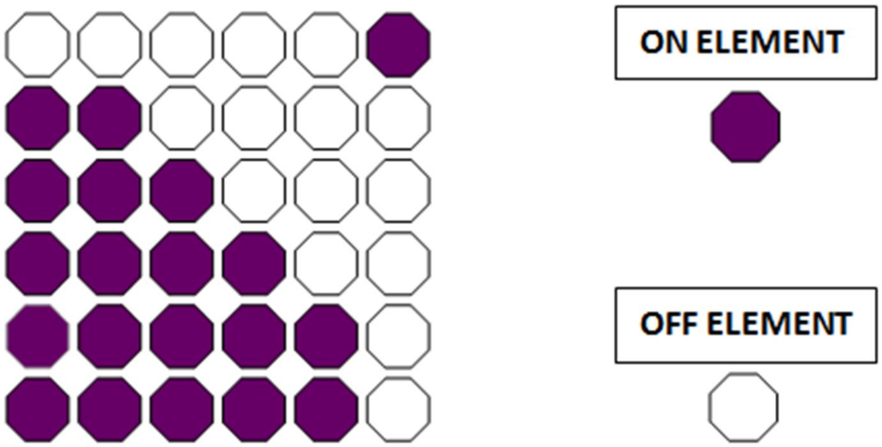

Fig (3): Optimum positions of active and inactive elements of the proposed 12x12 Thinned Planar Array. The white blocks indicate the turned OFF elements and grey indicates the turned ON elements

The entire 12 x 12 array is generated by flipping the quadrant to left and resultant array downwards, which ensures that the symmetry in the array is maintained. The entire 12 x 12 array is then generated by mirroring in the other three quadrants thereby maintaining symmetry in the array structure.

The square array shown in the Fig (3) has an inter element spacing of 0.5λ in both the X and the Y direction and it is operated at 9.5GHz in X-band. The blocks that are shaded represents Active elements and the blocks that are not shaded represent Inactive elements. The proposed thinned array obtained using MBC-GA is compared with the arrays published in earlier literatures [12], [13], [14] and the improvements in the radiation characteristics is indicated in the TABLE I.

A side lobe level of -25.87dB obtained in both the elevation plane ($\theta=0^0$) and the azimuth plane ($\theta=90^{0)}$ as shown in Fig (4) and Fig (5).

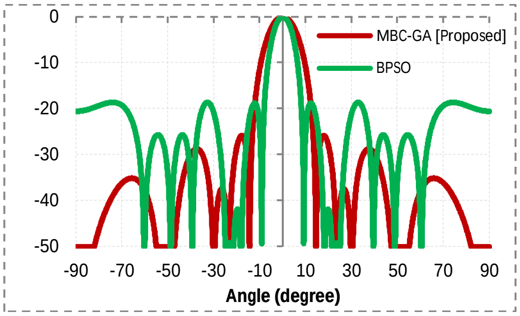

Fig (4): The elevation cut graph is plotted against theta. It is clear that the gene generated using the proposed method gives better reduction in the peak side lobe level in the plane ($\theta=0^0$)

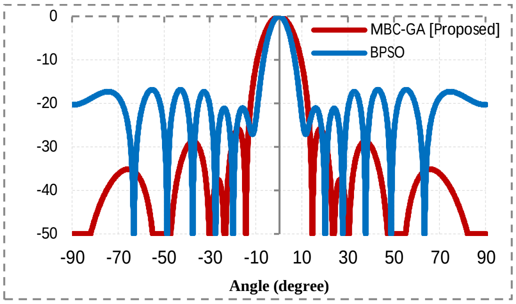

Fig (5): The azimuth cut graph is plotted against theta. It is clear that the gene generated using the proposed method gives better reduction in the peak side lobe level in the plane ($\theta=90^0$)

A fitness curve proving the superiority of the MBC-GA is shown in fig (6), where the best average PSLL is obtained at the 117[rd] iteration out of the 300 iterations. The convergence to an optimal solution as indicated by the fitness curve proves the upper hand of the MBC-GA compared to other techniques. A 3D radiation plot in Fig (7) shows that there are no grating lobes and no side lobe greater than the peak side lobe levels claimed in the aforementioned radiation pattern figures.

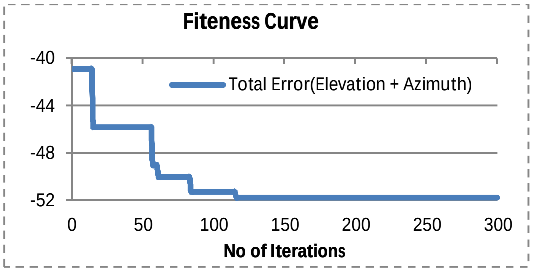

Fig (6): Variations in fitness value i.e. total PSLL values in both the planes ($\theta=0^0$ and $\theta=90^0$) with number of iterations for the proposed 12×12-element TPA array

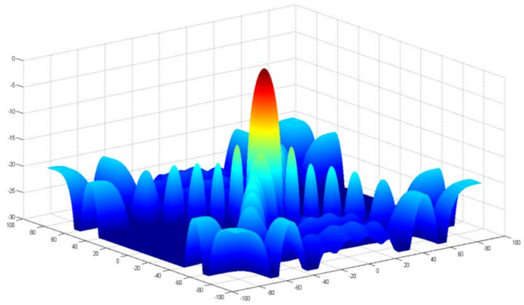

Fig (7): 3D intensity of the proposed 12×12-element TPA array

Table 1: Comparison Of Numerically Evaluated Results For The Proposed 12×12-Element Tpa Array With Those Of The Arrays Reported In [12], [13] And [14]

12x12 Comparison				
Optimization Method	***MPT[12]***	***BPSO-adv-GF[13]***	***BPSO[14]***	***MBC-GA [Proposed]***
Elevation PSLL $\theta=0^0$	-17.6	-19.78	-18.65	***-25.87***
Azimuth PSLL $\theta=90^0$	-17.6	-19.78	-16.83	***-25.87***
Thinning percentage	65.9	45.8	38.8	***44.4***

Conclusion

A thinned planar array is synthesized using MBC - GA which renders maximum reduction in peak side lobe level (PSLL). This approach proves to be effective in achieving aforementioned objective. Numerical results are evaluated and compared with the arrays in the literatures [12],[13],[14] published earlier. It is found that better peak side lobe level (PSLL) is achieved by using MBC - GA. Though the thinning percentage is fairly less compared to the other literatures in [12], [13], the primary objective of the paper is reduction of PSLL which is achieved successfully as indicated in the Table I.

From the 3D radiation pattern obtained for the proposed thinned 12x12 array, it is evident that there is no SLL that is greater than **-25.87 dB** in both the elevation and azimuth plane, therefore concluding it to be the best PSLL. The proposed technique MBC-GA can be effectively used to synthesize arrays of larger dimensions with reduced peak SLL. To summarize, we proposed the present study to reduce peak side lobe levels.

Acknowledement

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