Analysis of Rectangular Planar Array with Different Distributions and Optimization of Sidelobe Level using GA and PSO

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Abstract — In this paper, analysis of rectangular planar antenna array (RPAA) with different amplitude distributions like uniform, binomial and Dolph-Tschebyshev distributions is done. Comparison of radiation characteristics of rectangular planar arrays with different amplitude distributions is done. The sidelobe level (SLL) is optimized using genetic algorithm (GA) based optimization and particle swarm optimization (PSO) techniques.

Keywords — Rectangular planar antenna array (RPAA), Sidelobe level (SLL), Half power beam width (HPBW), Genetic algorithm, Particle swarm optimization.

1. INTRODUCTION

An antenna array is a system of similar antennas similarly oriented and they are used in applications where the radiation characteristics obtained from a single antenna are not adequate to fulfill the requirements of the application. Arrays can be basically of three types - linear arrays, planar arrays, volumetric arrays. Based on application, the type of array used is varied. Planar arrays are more versatile and can provide more symmetrical patterns with lower side lobes. In communication applications it is desirable to achieve a very low side lobe level, which is possible using planar arrays with non-uniform amplitude. The basic types of non uniform planar arrays are Binomial and Dolph-Chebyshev etc. For better communication, the side lobe levels should be as low as possible. In transmitting antennas, excessive side lobe radiation wastes energy and may cause interference, which in turn results in increase of noise level in the receiver. In designing antenna arrays, it is frequently desirable to have a low side lobe level and narrow main beam [1].

A rectangular planar array as the no of elements is increased in the array the beamwidths decrease while side lobe level remains almost constant at ~13.5db. In non uniform planar arrays the side lobe level is considerably reduced compared to uniform planar arrays. But beamwidths are larger compared to uniform planar arrays.

In this Paper, an attempt is made to reduce the SLL of rectangular arrays using random amplitudes for the elements of the array with Genetic algorithm and PSO based approaches. The optimized results are compared.

The rest of the paper is arranged as follows: In Section 2, the general design equations for the non-uniformly excited RPAA and the cost function used in achieving the desired goal are stated. In Section 3, GA and PSO is introduced for solving the cost function obtained in Section 2. Numerical results are presented in Section 4 and finally the Section 5 concludes with a summary of the work.

II. DESIGN EQUATIONS

A. Planar array

Planar arrays provide the designer additional variables to control and shape the pattern of the array. Planar arrays are more versatile and can provide more symmetrical patterns with lower side lobes[1].

B. Array factor of RPAA

The array factor for the entire planar array can be written as

\[ AF = A_1 A_2 \]

Where

\[ A_1 = \text{Array factor of array in } x - \text{direction} \]
\[ = \sum_{m=1}^{M} I_{m} e^{j(m-1)(kd_{x} \sin \theta \cos \phi + \beta_{h})} \]
\[ A_2 = \text{Array factor of array in } y - \text{direction} \]
\[ = \sum_{n=1}^{N} I_{n} e^{j(n-1)(kd_{y} \sin \theta \cos \phi + \beta_{v})} \]

Where

\[ d_{x} = \text{Distance between elements in horizontal direction} \]
\[ d_{y} = \text{Distance between elements in vertical direction} \]
\[ \beta_{h} = \text{Progressive phase shift between elements in horizontal direction} \]
\[ \beta_{v} = \text{Progressive phase shift between elements in vertical direction} \]
C. Cost Function
The Cost function in GA and PSO is the objective function which will help in achieving the desired goal of reducing sidelobe level. The Cost Function CF is

$$CF = SLL_{cur} - SLL_{des}$$

SLL\text{cur} is the main sidelobe level in dB for the current iteration and SLL\text{des} is the desired sidelobe level in dB.

III. OPTIMIZATION PROCEDURE

A. Genetic Algorithm (GA)

The Genetic Algorithm is a method for solving optimization problems that is based on the evolutionists’ natural selection concept. The GA repeatedly modifies a population of individual solutions.

The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals at random from the current population to be parents and uses them to produce the children for the next generation. Over the successive generations, the population gives off towards an optimal solution. The genetic algorithm mainly uses three types of components at each step to create the next generation from the current population, namely, selection, crossover and mutation\cite{2-3}.

The algorithm has the following steps:

1. The GA begins with a random set of variables called ‘chromosomes’ within the constrained limits. A set of such chromosomes is called a ‘population’. Size of each chromosome depends on number of elements of RPAA.
2. Evaluate fitness function or cost function of each chromosome.
3. Create a new population from the present one by selection, crossover and mutation. Selection of chromosomes for mating pool is done based on their fitness values (Better the fitness, better the chance of selection)
4. Perform crossover and mutation on the selected chromosomes to generate new population
5. Update the genetic cycle.

The iteration stops when the maximum number of cycles is reached or a certain maximum or minimum fitness value is obtained. The best chromosome satisfying the desired requirement is finally obtained.

B. Particle swarm optimization (PSO)

The PSO algorithm performs its maintaining several possible solutions in the search space. The PSO algorithm performs its task by maintaining several possible solutions in the search space at the same time. In each iteration of the algorithm, the possible solution is evaluated by the objective function being optimized, ascertaining the fitness of that solution.

Each particle keeps its position which is composed of the possible solution and its evaluated fitness, and its velocity. Further, it recalls the best fitness value it has attained during the operation of the algorithm, called as the individual best fitness, and the solution that accomplished this fitness, referred to as the individual best position or individual best candidate solution (\textit{pbest}). Lastly, the PSO algorithm maintains
the best fitness value achieved among all particles in the swarm, called the global best fitness, and the solution that accomplished this fitness, called the global best position (gbest) or global best candidate solution[4-5].

The PSO has been shown to be efficient in optimizing complicated multidimensional nonlinear problems in a variety of fields. Moreover, this computation technique, based on the movement and intellect of swarms, has been shown in certain instances to surpass other methods of optimization like genetic algorithms (GA).

Algorithm:
1. Initialize population of particles with random position and velocity vectors.
2. Evaluate fitness of each particle.
3. Compare each particle’s fitness evaluation with current particle’s to obtain pbest.
4. Compare fitness evaluation with population’s overall previous best to obtain gbest.
5. Update particle’s velocity and position.
6. If the desired condition is not satisfied, go to step 2, otherwise stop the process .

The velocity vector \( v_n \) for the calculation of the particle position in the next iteration is calculated as:

\[
v_n = w \cdot v_{n-1} + c_1 \cdot \text{rand} ( ) \cdot ( \text{pbest} - x_{n-1}) + c_2 \cdot \text{rand} ( ) \cdot ( \text{gbest} - x_{n-1})
\]

where \( v_{n-1} \) is the particle velocity in the previous iteration, \( \text{rand} ( ) \) is the function that generates uniformly distributed random numbers in the interval from 0.0 to 1.0, \( w, c_1 \) and \( c_2 \) are the constant coefficients. The next position of the particle in the optimization space is calculated as:

\[
x_n = x_{n-1} + v_n
\]

IV. SIMULATION RESULTS

For 10x10 planar array, the optimized values of SLL, HPBW and the corresponding excitation coefficient using GA and PSO are show in TABLE1. Analysis of RPAA is shows TABLE2.Comparison of both GA and PSO is carried out by taking various array elements which is show in TABLE3. Consider a X-Y plane (\( \phi = 0 \)), The spacing between elements is given in units of wavelength (0.5\( \lambda \)). The progressive phase shift between elements is zero. The optimized parameters are obtained using GA and PSO optimization codes planar array in MATLAB R2010a.

In Dolph-Chebyshev arrays, the side-lobe levels are assumed to be 20 dB below the maximum of the major lobe.

Fig.3 shows the radiation pattern for a uniformly excited RPAA \( (l_{mn} = 1) \), it has a radiation pattern with –12.96 dB side lobe level and a HPBW of 7°.

Fig.4 shows the radiation pattern for a Binomial excited RPAA, it has a radiation pattern with –304.94 dB side lobe level and a HPBW of 21°.

Fig.5 shows the radiation pattern for a Dolph-Chebyshev excited of 10x10 RPAA, it has a radiation pattern with –20 dB side lobe level and a HPBW of 11.5°.
<table>
<thead>
<tr>
<th>Optimization technique</th>
<th>Excitation coefficients</th>
<th>SLL (in dB)</th>
<th>HPBW (in deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td>0.2140, 0.8303, 0.4525, 1.9474, 0.5684, 1.5927, 1.1440, 0.2919, 0.1470, 0.0139, 2.4896, 0.0399, 1.3507, 1.6181, 0.0412, 0.0305, 1.9650, 0.8145, 0.0188, 1.6832, 0.9832, 1.6780, 2.2390, 1.5310, 0.1244, 0.3048, 0.0439, 0.4478, 1.5797, 2.3140, 2.4781, 2.6204, 3.0186, 3.0194, 2.6239, 0.3916, 0.9108, 0.0460, 0.9337, 0.0297, 0.0137, 0.0780, 2.4324, 2.9975, 1.3900, 0.0123, 2.9183, 2.5975, 1.9967, 0.3220, 1.1087, 1.8174, 4.3385, 3.2317, 1.2080, 0.4325, 1.9059, 2.1520, 0.4643, 0.0237, 2.0775, 0.1017, 0.3377, 2.4130, 2.7926, 2.4531, 3.0884, 0.7125, 0.0380, 1.4312, 1.4907, 0.3026, 1.0243, 0.9681, 0.0604, 0.0194, 0.1392, 0.1234, 1.0593, 2.8555, 0.0323, 0.4578, 1.3046, 1.6130, 1.5011, 1.8537, 0.7154, 0.0652, 2.5304, 0.8786, 0.7235, 1.6804, 0.2984, 0.0202, 0.0886, 1.2237, 0.0739, 0.0280, 0.4450, 0.3946</td>
<td>-35.41</td>
<td>15°</td>
</tr>
<tr>
<td>PSO</td>
<td>0.0360, 0.1023, 0.2793, 0.1370, 0.0307, 0.0038, 0.1241, 0.6709, 0.2574, 0.1424, 0.9457, 0.2376, 0.1529, 0.3685, 0.6304, 0.1828, 0.4515, 0.0113, 0.0005, 0.4485, 1.2184, 0.4017, 0.0030, 0.4992, 0.6696, 0.4925, 0.4852, 0.0032, 0.3063, 0.4904, 0.3159, 0.7600, 0.3861, 0.0065, 1.0748, 0.8355, 0.2565, 0.7366, 0.6591, 0.2012, 0.3159, 0.7600, 0.3861, 0.0065, 1.0748, 0.7647, 0.6712, 1.0626, 1.1128, 0.0706, 0.7303, 0.8840, 0.4920, 0.6829, 1.1406, 0.6101, 0.2802, 0.1759, 0.8852, 1.1828, 0.0794, 0.0633, 0.1052, 0.8347, 0.0984, 0.0713, 1.1232, 0.7526, 0.8910, 0.8876, 0.8207, 0.4838, 0.5920, 0.4440, 0.8156, 0.6553, 0.4428, 0.8465, 0.0289, 0.0015, 0.2291, 0.0008, 0.7814, 0.0058, 0.3123, 0.0013, 0.3709, 0.8357, 0.0843, 0.2362, 0.3303, 0.0356, 0.0028, 0.3168, 0.0645, 0.3920, 0.0887, 0.1380, 0.0610, 0.1479</td>
<td>-59.11</td>
<td>15°</td>
</tr>
</tbody>
</table>

Fig.6 shows the radiation pattern for a Random Excitation of 10x10 RPAA using GA, it has a radiation pattern with –35.41 dB side lobe level and a HPBW of 15°.

Fig.7 shows the radiation pattern for a Random Excitation of 10x10 RPAA using PSO, it has a radiation pattern with –59.115 dB side lobe level and a HPBW of 15°.
TABLE II COMPARISON OF SLL AND HPBW OF UNIFORM AND NON-UNIFORM OF PLANAR ARRAY

<table>
<thead>
<tr>
<th>ANTENNA ARRAY TYPE</th>
<th>NUMBER OF ELEMENTS (M X N)</th>
<th>SIDELOBE LEVEL (DB)</th>
<th>HPBW (DEG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIFORM</td>
<td>10 x 10</td>
<td>-12.96</td>
<td>7°</td>
</tr>
<tr>
<td>BINOMIAL</td>
<td>10 x 10</td>
<td>-304.94</td>
<td>21.5°</td>
</tr>
<tr>
<td>DOLPH-TSCHEBYSHEV</td>
<td>10 x 10</td>
<td>-20</td>
<td>11.5°</td>
</tr>
</tbody>
</table>

TABLE III COMPARISON OF GA AND PSO WITH VARIED M X N EXCITATIONS

<table>
<thead>
<tr>
<th>MXN</th>
<th>SLL (in dB)</th>
<th>HPBW (in deg)</th>
<th>SLL (in dB)</th>
<th>HPBW (in deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5X5</td>
<td>-35.39</td>
<td>25°</td>
<td>-41.49</td>
<td>25°</td>
</tr>
<tr>
<td>7X7</td>
<td>-36.82</td>
<td>21°</td>
<td>-55.14</td>
<td>21°</td>
</tr>
<tr>
<td>10X10</td>
<td>-35.41</td>
<td>15°</td>
<td>-59.11</td>
<td>15°</td>
</tr>
<tr>
<td>11X11</td>
<td>-34.26</td>
<td>11°</td>
<td>-43.56</td>
<td>11°</td>
</tr>
<tr>
<td>12X12</td>
<td>-30.39</td>
<td>11°</td>
<td>-37.01</td>
<td>11°</td>
</tr>
</tbody>
</table>

V CONCLUSIONS

In planar array, when number of elements increases half power beamwidth (HPBW) decreases and sidelobe level (SLL) is slightly decreased. To optimize SLL we applied genetic algorithm (GA) and particle swarm optimization (PSO). The best values of SLL and HPBW obtained by applying PSO for 10X10 element array are -59.11 dB and 15° respectively. Similarly, for the case of GA, the best values of SLL and HPBW are -35.41 dB and 15° respectively. From above all calculations PSO gives the better results.

This work can also be extended by applying phase control techniques to binomial, Dolph-Tschebyshev, triangular amplitude distributions of planar arrays. Not only SLL, but also BWFN can be optimized by using Genetic algorithm and particle swarm optimization.

VI REFERENCES


Prof N Venkateswara Rao has been working since 1983 in S.R.K.R Engineering college Bhimavaram and his area of interest include antenna array synthesis and electromagnetics.

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