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Low Sidelobe Synthesis of Dipole Arrays by Element Orientation Selection Using Binary Coded Genetic Algorithm

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Abstract—Selecting appropriate element orientations can significantly reduce the sidelobe level of the antenna array. In this paper, a binary coded genetic algorithm (BCGA) which selects the element orientations from specified discrete angles, is proposed to reduce the sidelobe level (SLL) of the array. Compared to the conventional GA, the BCGA is much faster in this application. Synthesis results show the effectiveness and efficiency of the proposed method.

Index Terms—antenna array, sidelobe level, element selection, genetic algorithm.

I. INTRODUCTION

In the array synthesis, low sidelobe level (SLL) and low cross-polarization level (CPL) are usually preferable [1], [2]. To achieve the desired low sidelobe performance, some optimization algorithms such as the genetic algorithm (GA), differential evolution algorithm (DEA), and particle swarm optimization (PSO), have been proposed [3]–[7]. The main idea of these methods is optimizing the amplitudes and phase of the array's excitation weights to achieve the desired pattern performance. It is very effective but with an additional complexity in the feeding network to implement the synthesized excitation weights. Different from the conventional way of changing the excitation weights, an alternative technique was presented in [8] where the orientation of each element in a dipole array optimized by the GA for reducing the SLL. Lately, such an idea was also applied to reduce the SLL for some other arrays such as the microstrip patch antenna array [9].

In this work, it is shown that the SLL reduction can be implemented through selecting the element orientation from a set of discrete angles. In this case, the binary coded GA can be adopted to find the optimal element orientation with the time cost that is much less than that of the conventional GA used in [8]. Two examples are given for synthesizing the element orientations of linear and planar dipole antenna arrays with SLL and CPL control. The synthesis results show the effectiveness and superiority of the proposed method.

II. ALGORITHM DESCRIPTION

The GA is a heuristic optimization algorithm, which is inspired by the evolution and genetic mechanism of nature. It has been applied to many areas including the synthesis of

antenna arrays[1], [3]. In a conventional GA process, variable parameters are coded into chromosomes, and then the fitness function is employed to judge each chromosome's fitness. The chromosomes with good fitness is retained while those with bad fitness is eliminated. For the next step, crossover and mutation are used to increase the diversity of the population. Finally, the fitness of new chromosomes will be calculated and ranked until the best chromosome is generated or the maximum number of iterations is reached.

Different from the conventional GA, a BCGA whose chromosomes or individuals are encoded by a series of binary numbers, is utilized to optimized the orientation of the elements in this work. The selection and copy are implemented by a roulette wheel method.

A. Coding and Fitness Function

As is known, every digit of the binary chromosome has two forms, 0 and 1. Hence, for an antenna array, eight elements with different orientations can be expressed by three digits of the chromosome. The fitness function is given through the following equation:

$$Fit. = \min(\max(SLL, CPL)), \quad (1)$$

where the *SLL* denotes the sidelobe level of the co-polarization pattern and the *CPL* denotes the maximum value of the cross-polarization level. Chromosomes with higher fitness values will be maintained more easily while those with lower fitness values may be in high risk of being eliminated.

B. Selection and Copy

For a population with M chromosomes, their fitness values could be ranked by descending orders. Their copy probabilities own a relationship with their rank orders as follows:

$$p_i = e(1 - e)^{i-1}, \quad (i = 1, 2, \dots, M) \quad (2)$$

where i represents the rank order of the chromosomes, $e \in (0, 1)$ is the copy probability of the first chromosome with the highest fitness value, p_i denotes the copy probability of the i th chromosome. It is evident that when i is increased, p_i will become smaller and smaller, which obeys the law of survival of the fittest. As also can be seen, every chromosome owns

TABLE I
CALCULATION OF THE COPY PROBABILITY IN THE ROULETTE
WHEEL METHOD

i	fitness	$p_i = e(1 - e)^{i-1}$	$q_i = \sum_{j=1}^I (p_j)$
1	10	0.40	0.40
2	8	0.24	0.64
3	6	0.14	0.78
4	2	0.09	0.87



Fig. 1. The optimized elements arrangement

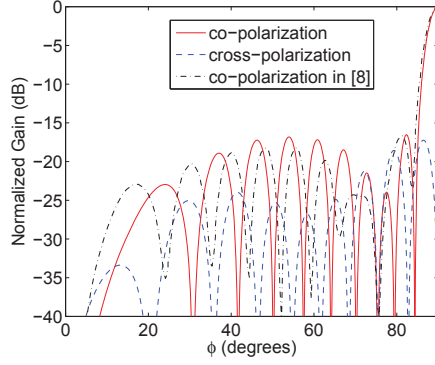


Fig. 2. The co-polarization and cross-polarization pattern of a GA optimized result compared with the co-polarization in [8].

the right of breeding, but the lower the fitness value is, the smaller the breed probability will be.

A roulette wheel method is proposed to deal with the selection in the BCGA. As an example, four individuals are considered in the population. The copy probability is calculated as shown in the Table I, where q_i denotes the accumulation of p_i . When the copy and selection are conducted, four numbers belongs to $(0, 0.87)$ are randomly generated at first. And then the selection and copy are implemented with the following rule. That is, when the randomly generated number is located in $(0, 0.40]$, the $i = 1$ individual will be selected and copied, else if the number is located in $(0.40, 0.64]$, the $i = 2$ individual will be selected and copied, etc. It can be seen that those chromosomes with larger fitness value could be selected and copied with a larger chance.

C. Crossover and Mutation

Crossover and mutation play an important role in the GA since these two steps can keep GA away from earlier convergence and stuck local minimum. During the crossover process, some crossover positions are randomly generated in the parents chromosomes and the exchange of the gene happens between two generated positions to become two new individuals. Similarly, the positions of the mutation are randomly determined and the mutation is carried out through altering one or more digits in every chromosome.

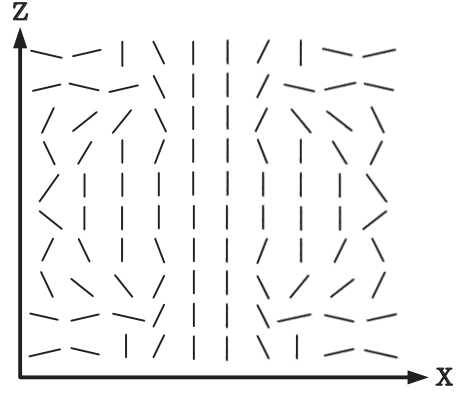


Fig. 3. The elements layout of the optimized planar array.

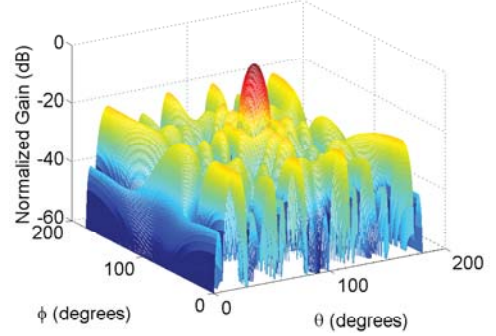


Fig. 4. The pattern of the optimized planar array, with a maximum sidelobe level of 19.33 dB.

III. OPTIMIZED EXAMPLES

In order to illustrate the effectiveness of the stated approach, two examples for synthesizing linear and planar dipole arrays are presented in this section.

A. Linear Array

As the first example, a linear array composed of $\lambda/2$ -spaced dipole elements is considered. The elements are placed along x-axis in x-z plane. Hence, the co-polarization component is along θ -polarization. For each element, the orientation is chosen from eight discrete directions $[0, \pi/15, 2\pi/15, 3\pi/15, 4\pi/15, 5\pi/15, 6\pi/15, 7\pi/15]$ in the elevation plane. In this case, the population size is chosen as 500 while the maximum number of iterations is set to 50. The crossover and the mutation probability are $p_c = 0.6$ and $p_m = 0.3$, respectively.

Fig. 1 shows the element orientation distribution of the linear array optimized by the proposed BICG. Fig. 2 shows the radiation pattern of this array. As can be seen, the synthesized pattern can achieve a SLL of 16.64 dB which is very close to the result of 16.7 dB optimized by the continuous orientation rotation using conventional GA in [8]. Note that in this example, the proposed BICG takes 30.28 seconds on a computer with an Intel Core i5 Processor 2400 (@3.10 GHz) and 4 GB RAM memory, while the conventional GA takes about 16.75 minutes on the same computer.

B. Planar Array

In the second example, a 10×10 planar dipole array is synthesized. The array is arranged in x-z plane with uniform spacing $d = \lambda/2$. Due to the symmetric structure of this array, only a quarter of elements in the array is optimized. The alternative polarization angles are $-3\pi/7$, $-2\pi/7$, $-\pi/7$, 0 , $\pi/7$, $2\pi/7$, $3\pi/7$, respectively. The crossover and the mutation probability used in this synthesis are also $p_c = 0.6$ and $p_m = 0.3$, respectively.

A planar array layout optimized by the BCGA is shown in Fig. 3, and the obtained pattern is shown in Fig. 4. This pattern has a maximum SLL of 19.33 dB which is roughly equal to 19.4 dB obtained in [8] for the array of the same size. In this example, the proposed BCGA takes about 1.1 hours while the conventional GA takes 18.63 hours for the optimizing the element rotations in the continuous angle space.

IV. CONCLUSION

This paper presents a novel element orientation synthesis method which applies the BCGA to efficiently determine the best orientation of every array element from prescribed several discrete angles in terms of the lowest sidelobe level and cross-polarization level. The proposed method is much faster than the method of applying the conventional GA to find the element orientation in continuous angle space, while maintaining a similar pattern performance. This advantage has been validated in the examples of synthesizing the element orientations of both linear and planar dipole arrays. The proposed method can be further generalized to more complicated conformal arrays with different antenna element structures.

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