Synthesis of Rotated Sparse Linear Dipole Array with Shaped Power Pattern

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***Abstract*—A new shaped pattern synthesis method is presented in which element rotations, positions and phases are co-optimized to produce a shaped beam pattern for a sparse dipole array. Compared with conventional shaped pattern synthesis using excitation amplitude and phase optimization, the proposed method can not only reduce the number of elements but also avoid the usage of unequal power dividers. A synthesis example is provided to verify the performance of the proposed method.**

***Index Terms*—Antenna synthesis, shaped pattern, element rotation, sparse arrays.**

I. Introduction

Application of antenna arrays with shaped pattern in radar, wireless communication and air detection system have attracted much attention over decades years. Nevertheless, synthesis of shaped pattern is a nonconvex and nonlinear problem. To achieve the desired radiation performance, some global optimization algorithms such as genetic algorithm (GA), ant colony optimization (ACO), differential evolution (DE), and particle swarm optimization (PSO) have been extensively applied [1]–[4]. Most of them can obtain the desired shaped-beam by employing excitation amplitude and phase optimization. However, they usually need to assign a large number of equally-spaced antenna elements. Obviously, element positions can be regarded as additional degrees of freedom for pattern synthesis, which can save antenna elements and provide some potentials to obtain better radiation performance. Therefore, many synthesis methods for sparse or thinned arrays have been extensively developed [2], [3], [5], [6]. Although these methods can save antenna elements, but they usually adopt nonuniform amplitude distribution, which means that multiple unequal power dividers are required in the feeding network of the antenna array.

Particularly, the element rotation technique has successfully applied to reduce the sidelobe level (SLL) of focused beam [7], [8]. Recently, this technique was also extended to shaped pattern synthesis [9]. However, to the best of our knowledge, the element rotation has never applied to synthesis of sparse arrays. In this work, a novel synthesis method for uniform amplitude sparse array with a shaped pattern is introduced by optimizing the rotation angle, position and phase of each element by utilizing PSO. A synthesis example is conducted to show the effectiveness and efficiency of the proposed method.

II. Algorithm Description

PSO is a swarm-based global optimization algorithm, which was originally proposed by Kennedy and Eberhart [10]. Due to its simplicity and effectiveness, PSO is used to optimize the rotation angle, position and phase of each element in this work.

A. Mechanism

In PSO algorithm, each particle represents a candidate solution, which is associated with its position $\boldsymbol{X}$ and velocity $\boldsymbol{V}$. Mathematically, the search mechanism is described as follows

$$\boldsymbol{V}_{i,j} = k\boldsymbol{V}_{i,j} + c_1 r_1(\boldsymbol{B}_{i,j} - \boldsymbol{X}_{i,j}) + c_2 r_2(\boldsymbol{G}_j - \boldsymbol{X}_{i,j}) \quad (1)$$

$$\boldsymbol{X}_{i,j} = \boldsymbol{X}_{i,j} + \boldsymbol{V}_{i,j}, \quad (2)$$

where j denotes the dimension index of the problem, $\boldsymbol{B}_i$ denotes personal best position of the ith particle in the population, $\boldsymbol{G}$ denotes global best position in all the particles, k is inertia weight, c_1 and c_2 are random number selected from the range of [0,1].

B. Fitness selection

The element rotation technique can change amplitude distribution so that being regarded as an additional degree of freedom. However, it maybe increase the cross polarization level (XPL) of array pattern. Naturally, we will suppress both the SLL and XPL to obtain the desired shape pattern. Thus, the fitness function in PSO algorithm is selected as

$$f = W_1\|P(u) - P_d(u)\|_2^2 + W_2\|\max(\mathrm{SLL}, \mathrm{XPL}) - \mathrm{DSLL}\|_2^2, \quad (3)$$

where $u = \sin\theta$, $P(u)$ and $P_d(u)$ denote the obtained and desired power pattern, respectively. DSLL denotes the desired SLL and XPL, W_1 and W_2 denote penalty factors.

III. Simulation Experiment

To verify the effectiveness and superiority of the proposed method, one example for synthesizing sparse linear dipole array is shown in this section.

Next, we will synthesize a flat-top pattern shown in Fig. 6a of [11]. The pattern with HPBW = 29°(half power beam width), ripple of 0.56 dB, and maximum SLL of -14.5 dB

TABLE I
THE OBTAINED ELEMENT ROTATION ANGLES, POSITIONS AND EXCITATION PHASES FOR THE 15-ELEMENT DIPOLE ARRAY WITH FLAT-TOP PATTERN

n	$\xi(^\circ)$	δ/λ	$\varphi(^\circ)$
1	-135.37	0.68	191.84
2	-17.12	1.40	309.90
3	-179.99	2.14	80.08
4	3.48	2.81	228.16
5	-0.74	3.32	210.14
6	-178.78	3.89	13.70
7	1.39	4.59	149.72
8	2.08	5.35	119.51
9	1.25	6.10	142.15
10	0.23	6.79	188.72
11	-0.54	7.39	205.51
12	2.58	7.89	224.75
13	-0.17	8.54	250.88
14	-16.23	9.27	294.11
15	-146.93	9.99	183.55

was obtained by modifying just the phase distribution of uniform amplitude 10λ-length line source in [11]. In this work, we try to reconstruct this pattern by using 15 uniform amplitude dipoles but with optimized rotations, positions and phases. In PSO algorithm, we set the population size as 150, $c_1 = 1.5, c_2 = 2, k = 1, W_1 = 2, W_2 = 1$ and DSLL $= -15$ dB. The minimum-element spacing is prescribed as a 0.5λ. TABLE I shows the obtained element rotation angle ξ, position δ and excitation phase φ of each element. It is shown that the obtained array aperture is almost equal to the one in [11]. Furthermore, the achieved co- and cross polarization patterns compared with the Fig. 6a in [11] are depicted in Fig. 1. It is observed that the obtained co-polarization pattern has lower ripple level (0.55 dB) and maximum SLL (-14.80 dB) than those in [11]. And the obtained XPL is -14.85 dB which is also close to the specification. In this example, we save 25% antenna elements if compared with a $\lambda/2$-spaced array occupying the same aperture.

IV. Conclusion

A novel method for synthesizing shaped pattern of a sparse linear array has been proposed. Different from conventional shaped pattern synthesis using excitation amplitude and phase optimization, this method can save antenna elements and do not require the design of unequal power dividers. The effectiveness of the proposed method has been verified by synthesizing a rotated sparse dipole array with a flat-top pattern.

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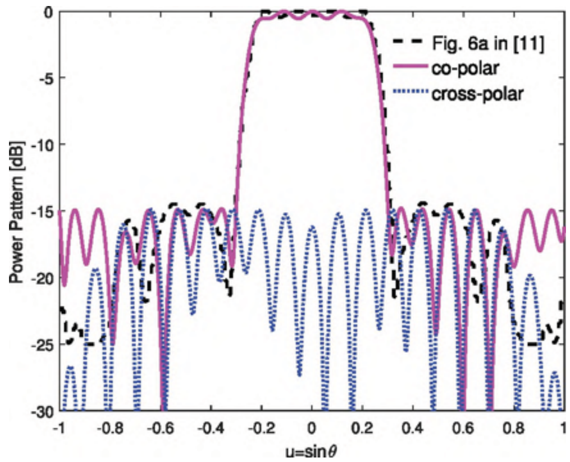

Fig. 1. The co-polarization flat-top pattern and cross-polarization pattern synthesized by the proposed approach with 15 elements, and the shaped pattern in Fig. 6a of [11] obtained by optimizing only excitation phase of a 10λ-length line source.

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