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Optimization Of Linear Antenna Array Using Relaxed Lexicographic Method

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Abstract:
In this paper, we proposed method based on relaxed lexicographic method for the synthesis of linear antenna array with uniform excitation amplitude and non-uniform inter-element spacing. Presented algorithm was used to obtain the optimal position of the elements in order to get the minimum side lobe level and nulls in desired directions. The main difference compared to other methods is that we used a relaxed lexicographic method. We divided the problem of suppressing the side lobes and setting nulls on the given directions into two problems. First, the problem of suppressing the side lobes was solved. When solving the problem of placing nulls on the given directions, we used the condition resulting from the first problem where we relaxed it. The simulation results reveal that design of antenna arrays using the presented method provides considerable enhancements compared with the synthesis obtained from other published method
Key Word*:* *Array factor, Linear Antenna Array, Null control, Optimization, Side lobe level.*

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I. Introduction

Antenna arrays play an important role in detecting and processing signals arriving from different directions. Research on antenna array synthesis methods based on the distance between antenna array elements has been neglected until recently. The reason lies in the mathematical complexity of finding the optimal solution for the position and phase of the elements of the antenna array. Thanks to the development of computers and their computing speed, antenna array synthesis through the optimization of the antenna array element spacing is possible and increasingly used.

The objective in an array design is achieving minimum side lobe level (SLL), narrow first null beam width (FNBW) and obtaining narrow or broad nulls in directions of interfering signals. The FNBW plays an important role in the synthesis of the antenna array due to its inverse proportionality with SLL It is more common to suppress side lobe level than to achieve narrow first null beam width. Broad nulls are needed when the direction of arrival of interference may vary slightly with time.

. Methods used for the antenna array synthesis can be classified in two categories: deterministic and stochastic. There are several deterministic methods: Schelkunoff Polynomial Method ([1], [2]), Dolph-Chebyshev Method (see [3], [4]), and Fourier Transform Method (see [2], [4]). Some of stochastic methods used for the antenna array synthesis are: Genetic Algorithms (GA) (see [5], [6], [7]), Tabu Search (TS) (see [5], [8]), Particle Swarm Optimization (PSO) (see [9], [10]), Ant Colony Optimization (ACO) (see [1]).

In this paper, we proposed a useful method based on relaxed lexicographic method. Presented algorithm was used to obtain the optimal position of the elements in order to get the minimum side lobe level and put nulls in desired directions. In this approach we will concern arrays of isotropic point sources this is of great value because the pattern of any antenna can be regarded as being produced by an array of point sources. The proposed algorithm is compared with algorithms from other papers. The algorithm showed good results. SLL are suppressed and NULL are set on the given directions.

II. Linear Antenna Array

In practice, the most commonly used antenna array is the linear antenna array. The elements of a linear antenna array are arranged along a straight line. The elements can be arranged with equal or different distances from each other. The linear antenna array that is most widely used is the linear antenna array with an even number of elements. 2N linear antenna array is the subject of research in this paper.
The geometry of the 2N linear antenna array placed symmetrically along the x-axis is given in Figure 1.

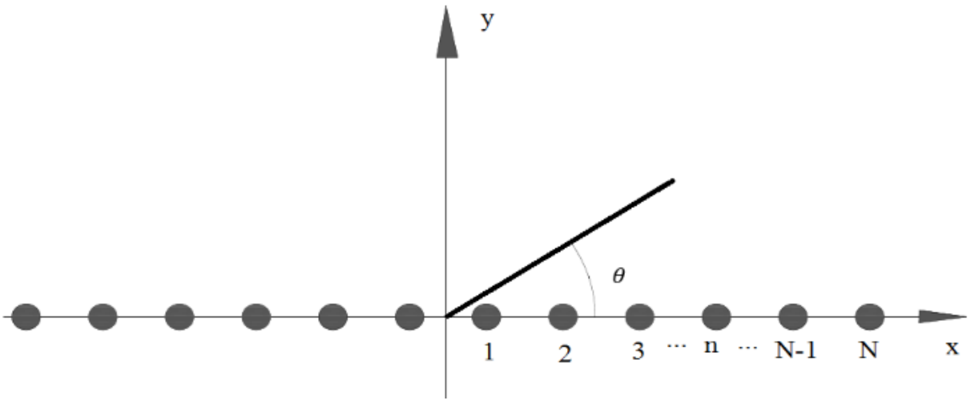

Fig. 1. Geometry of 2N-element linear antenna array.

The antenna array radiation pattern (RP) may be found according to the pattern multiplication theorem (see, e.g., Ch. 6 from [11] and [12] and Ch. 3 from [7]):

$$RP = EL \cdot AF \quad (1)$$

where EL (element pattern) is the pattern of the individual array element and AF (array factor) is a function dependent on the physical placement of antenna elements, amplitude, and phase of excitation.

If we replace each element of the antenna array with an isotopic point source the resulting pattern is the array factor, because the element pattern of isotopic point source is equal to 1.

In this paper linear antenna array has identical elements with non-uniform inter element spacing and uniform excitation. Array factor can be expressed as follows (for more see [11], [13-15]):

$$AF(\theta) = 2\sum_{n=1}^{N} I_n \cos[kd_n \cos(\theta)] \quad (2)$$

where $k = {2\pi}/{\lambda}$ is wave number, λ is the wavelength, I_n is excitation amplitude of *n*th element, d_n is location of *n*th element, and θ is angle between the line of observer and the source position.

To achieve the desired radiation pattern with minimum side lobe level (SLL) and narrow or broad nulls in specified directions we need to find the optimal location of elements $d = (d_1, d_2, \dots, d_N)$.

III. Algorithm

The presented algorithm is applied to achieve the desired radiation pattern with minimum SLL and narrow or broad nulls in specified directions. Our approach uses a combination of two problems: first problem has a goal to minimize the side lobe level between the desired angles θ_{11} and θ_{12}, second one is for achieving deep nulls in desired directions θ_l.

The first problem is solved by an algorithm consisting of two global searches. First problem is follow:

$$\min_{d}\left(\max_{\theta}(AF_{2N}(d,\theta)_{norm})\right) \quad (3)$$

s. t.

$$\left|d_i - d_j\right| > 0.25\lambda,\ i < j,\quad i,j = 1,2,\dots,N, \quad (4)$$

$$d_i > 0.125\lambda\ i = 1,2,\dots,N, \quad (5)$$

$$\theta_{11} \le \theta \le \theta_{12},\ \ \theta \in \mathbb{R}. \quad (6)$$

Results of the problem is d^{sll}.

When we get the positions of the elements of the antenna array for which we obtain the minimum SLL we form second problem. In second problem where we have relaxed the limit of SLL that was obtained in the first problem by 10% relation (10).

$$\min_{d}(\textstyle\sum_k AF_{2N}(d,\theta_k)_{norm}) \quad (7)$$

s. t.

$$\left|d_i - d_j\right| > 0.25\lambda,\ i < j,\quad i,j = 1,2,\dots,N, \quad (8)$$

$$d_i > 0.125\lambda,\ \ i = 1,2,\dots,N, \quad (9)$$

$$AF_{2N}(d,\theta)_{dB} \le 0{,}9 * AF_{2N}\left(d^{\mathrm{sll}},\theta^*\right)_{dB}, \quad (10)$$

$$\theta_{11} \le \theta \le \theta_{12},\ \ \theta \in \mathbb{R}. \quad (11)$$

Results of the problem is d^*.

Positions d^* of the antenna array elements provides minimum SLL and narrow or broad nulls in specified directions, and it is a solution to the problem of synthesis of a linear antenna array.

IV. Results

We applied the given algorithm to performed the synthesis of $2N$ = 28 element antenna array in order to get the minimum SLL and nulls at $\theta_1 = 120°$, $\theta_2 = 122.5°$, and $\theta_3 = 125°$, while at the same time we push the side lobes in the region between $\theta_{11} = 94°$, and $\theta_{12} = 180°$. For the excitation amplitude, of linear antenna array elements are taken $I_n = 1, n = 1, \ldots, N$.

The goal of first problem is to suppress the side lobes level between $\theta_{11} = 94°$, $\theta_{12} = 180°$. Results of the first problem are d^{sll}, θ^* When we get results of first problem then we solve a second problem where we have relaxed the limit of side lobe level that was obtained in the first problem by 10%.

Results are shown in the table below with the results of the compared papers. Figure 2 shows a radiation pattern produced by the presented method together with radiation pattern obtained in the work [2].

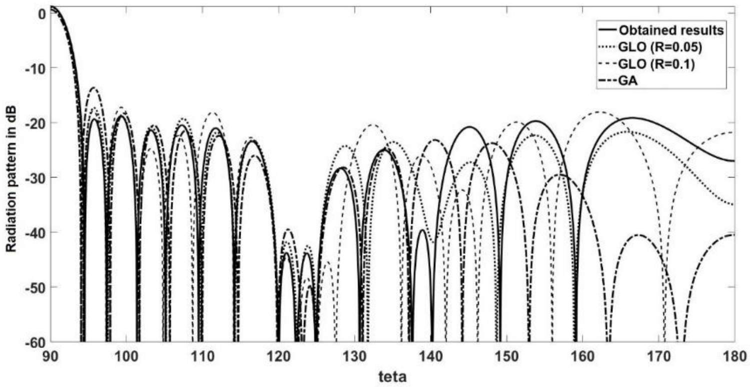

Fig. 2. The normalized radiation pattern of 28-element linear array.

The results are shown in Table 1 and we will see that we suppresed the SLL considerably and that there are nulls in the given directions. SLL is -20dB which is very good. FNBW is wider, which is the result of giving priorities for suppresion of side lobe level. In comparison with the paper [16], the suppression is less compared to [16]. The advantage of the presented algorithm compared to [16] is in the time it takes to reach the solution. In the compared algorithm more than 400 interactions were needed to reach the solution, while in this case only 1 interaction. If it is necessary to reach a solution quickly, the presented algorithm gives good results in a short time.

Table 1. Comparison with published results for 2N=28 elements optimized with respect to position.

	SLL (dB)	ŠZPN	Null depth in dB		
			120°	12.5°	125°
Obtained result	-20.02	9	-85.065	-60.632	-59.767
2GO [16]	–22.23	8.6	-50.88	-192.36	-123.78
2GO [16]	-18.41	8.7	-163.19	-100.01	-186
GA [17]	-14.39	7.8	-71.89	-46.87	-74.13
CSO [18]	-13.23	8.2	-75.00	-67.05	-65.32

We can conclude that resolving the problem with this approach gives satisfactory results and that there has been an improvement in the performance of the system.

Table 2. Element position of the 28-element linear array (normalized with respect to λ/2)

Element	Obtained results	2GO (R=0.05)	2GO (R=0.1)	GA [17]
±1	0.1918	0.1901	0.2081	0.252
±2	0.5918	0.6309	0.6048	0.752
±3	1.0436	1.072	1.0688	1.251
±4	1.4423	1.5273	1.4997	1.754
±5	1.8922	2.0043	1.8792	2.257
±6	2.3714	2.4929	2.4284	2.756
±7	2.8186	2.9220	3.0077	3.284
±8	3.3801	3.5061	3.5671	3.792
±9	3.9190	3.9975	4.1606	4.291
±10	4.4020	4.4910	4.5425	4.790
±11	5.0926	5.2269	5.2225	5.463
±12	5.8865	5.9271	6.0085	5.965

±13	6.4579	6.4800	6.5472	6.465
±14	7.1601	7.1298	7.2607	7.094

V. Conclusion

In the presented paper, is presented way of solving the problem of linear antenna array synthesis. Solving the 2 problems separately resulted in a significant suppression of the side lobes, while nulls maintain in specified directions. The algorithm is very flexible, instead of a 10% relaxation, we can give a 5% relaxation if we want to give more importance to suppression. If we want to give less importance to suppression, then we increase the percentage of relaxation. Due to the speed of finding optimal positions, the algorithm has a good potential for solving the problem of synthesis linear antenna array.

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