A Technique to Optimize Nonuniformly Spaced Arrays with Low Sidelobe Level by Using a Genetic Algorithm

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A Genetic Algorithm procedure for synthesizing the radiation pattern of nonuniformly spaced linear arrays with low side lobe level is presented. Some selected preliminary results are shown to validate the effectiveness and the reliability of the proposed approach.

Introduction

Genetic Algorithms (GA) are widely used to solve many EM problems [1]. They are classified as global optimizers, being their main characteristic the ability to manage solution spaces having discontinuities and large dimensions with many potential local minima. In GA, as well known, the physical parameters to be optimized are encoded into chromosomes. These parametric solutions mate and their offspring create new populations. The evolution process is driven toward an optimal solution by the selective pressure of the fitness function.

The design of large arrays aimed at the reduction of the side lobe level requires handling many independent variables such as the amplitudes and phases of the excitations and the position of the elements. In recent years, many authors addressed the problem of optimizing antenna array patterns by using GA, as for instance [2]-[6]. In our approach, the design parameters (relative position of each element and complex amplitude of the excitation source) are described in terms of polynomial functions. The polynomial roots are therefore derived by employing a GA with a fitness function calculated according to a specific mask of the radiation pattern. The final design parameters are obtained by uniformly sampling the optimized polynomial functions. In this way, the total number of parameters to be optimized is considerably reduced, ensuring at the same time an adequate variability of the solutions in the search space.

Theoretical Approach and GA Implementation

The method is based on some simple assumptions about the configuration of the nonuniformly spaced array. First of all, the elements have symmetric positions with respect to the center of the array. The entire array is considered as composed by an even number of subarrays with symmetric structure. The optimization procedure is applied to a generic subarray: in particular, the position of each element within the subarray is optimized as well as the feeding complex coefficients. Then, as shown in Fig. 1, the excitation of each subarray is tapered by weighting both the amplitude and the phase by proper coefficients again optimized by the same GA. This choice allows to reduce the complexity of the power dividing feeding network [7]. It is worth noting that some parameters must be set *a priori* as for instance the maximum total length of the array, the number of the subarrays and the total number of the elements. The specific GA employed in this work is based on the well-known roulette wheel selection operator and a simple elitism. Moreover, to improve the algorithm speed of convergence, the mutation probability increases if two successive generations show the same fitness value. If an improvement has been observed, the mutation probability returns to its lower value. The class of functions used by the algorithm to produce the unknown parameters of the array is that of *n*-order polynomials. The order is set at the beginning of the optimization procedure and it determines the total length of the chromosome. In fact, the *n* roots of the polynomials are encoded into a binary string to form each chromosome necessary for the evolutionary process. Sampling each one of the resulting functions, we obtain the numerical values of the unknown parameters. The position of the elements in a single subarray is therefore set by using the sampled values of the relevant polynomial (see Fig. 2). In order to define the entire linear array, the subarrays are assembled by displacing each subarray at a distance chosen again by the GA. As regards the feeding complex coefficients, two other polynomials are engaged for the decision of the sources amplitude and the phase in a single subarray. Finally, the last two functions are involved in the determination of the weights for amplitude and phase of each subarray (a_i and p_i in Fig. 1).

The fitness function to be minimized is constructed as the sum of two terms as reported in the following:

$$FITNESS = \left[1\text{-P}(\theta)\Big|_{\theta \in MainLobe} \right] + \left. \frac{\max\left(P(\theta)\right)}{SLL^{*}} \right|_{\theta \notin MainLobe}$$

being $P(\theta)$ the normalized value of the radiation pattern in a linear scale. This fitness function accounts for the maximization of the radiation pattern along the main beam direction as well as for the minimization of the side lobe level outside the main lobe according to the desired linear value SLL*.

Preliminary Numerical Results

Some preliminary results obtained with the previously described algorithm are shown in this section. In particular, the power pattern of a 96 elements array, arranged in 8 subarrays, is plotted in Fig. 3a. The side lobe level is less than -20 dB, according to the desired mask imposed on the shape of the pattern ($SLL^{*}_{dB} = -20$ dB for this example). In the next Fig. 3b, the array is composed by 96 elements, but grouped into 16 subarrays. In this case, the algorithm finds a side lobe level equal to −27 dB, below the required value of $SLL^{*}_{dB} = -25$ dB. This improvement can be connected with the increment in the number of subarrays with consequent enlargement of the search space dimensions. For the specific examples illustrated here, the polynomial order of the functions has been set to 7 for all the parameters to be optimized leading to a total number of parameters equal to 6×7=42 against a total number of 288 parameters needed when using a blind optimization procedure.

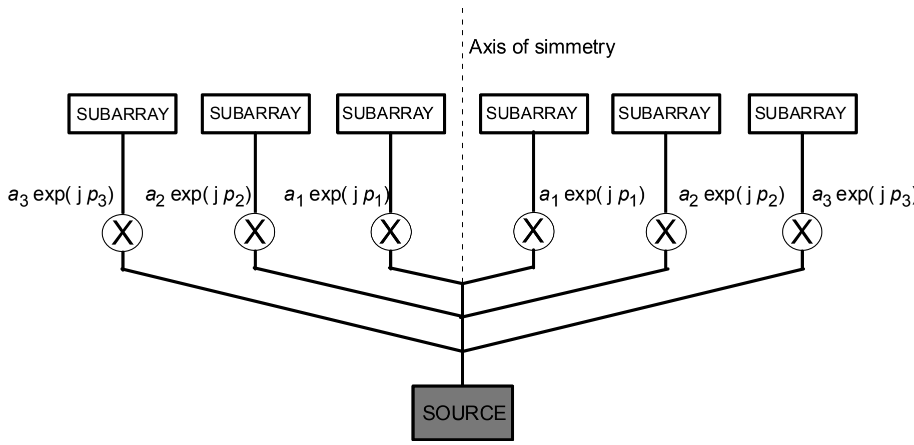


Fig. 1 - Example of a linear symmetric array composed by six subarrays.

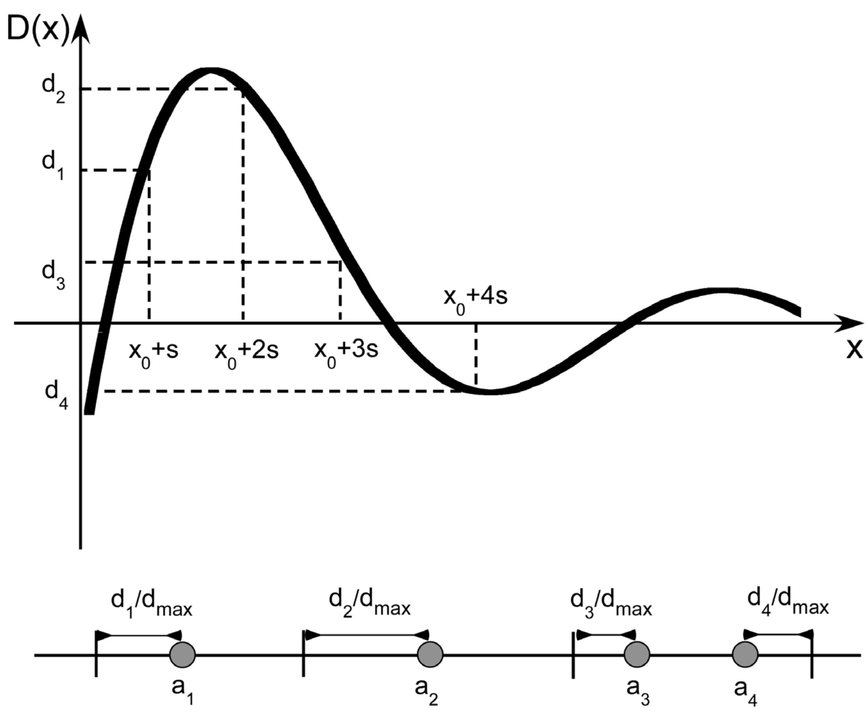
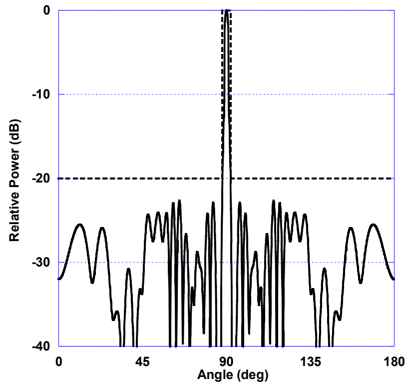
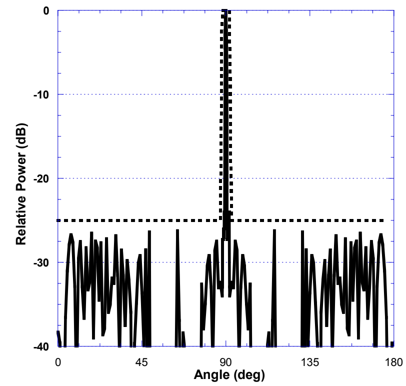


Fig. 2 – Determination of the relative position of each element within a subarray: the displacement function *D(x)* has a polynomial form with roots derived by the optimization process. The final position of each element is derived by uniformly sampling *D(x)*, each value representing the relative position with respect to the uniform array.



a)



b)

Fig. 3- Far field pattern (continuous line) for a 96-element array, and relative mask (dashed line): a) case of an array arranged into 8 subarrays; b) arrangement into 16 subarrays.

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