Design of Linear Antenna Arrays for Side Lobe Reduction Using theTabu Search Method

Lotfi Merad, Fethi Bendimerad, and Sidi Meriah
Faculty of Engineering, University of Abou-Bekr Belkaïd-Tlemcen, Algeria

Abstract: *A design problem of uniform linear antenna arrays for maximal side lobe level reduction with the constraint of a fixed beam width is dealt with. This problem is modelled as a simple optimization problem. The method of tabu search is used to determine an optimum a set of weights of antenna element that provide a radiation pattern with maximal side lobe level reduction with the constraint of a fixed beam width. Numerical results show the effectiveness of the proposed method although it needs more CPU time and memory.*

Keywords: *Linear antenna arrays, tabu search, side lobe level, optimization, radiation pattern.*

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1. Introduction

A single antenna has a limited radiation pattern. But with the use of several antennas working together (array), it is possible to improve the radiation according to some specifications. In general the characteristics of the array are controlled by the proper choice of the element (dipole, horn, patch, *etc*.), the geometry of the array and the excitation (amplitude and phase) of each element that satisfy a set of specifications on the beampattern.

The synthesis problem has been studied quite a lot. From the first analytical approaches by Schelkunoff [12] or Dolph [5, 3] to the more general numerical approaches such as mentioned in the recent paper by Bucci *et al.* [4], it would be impossible to make an exhaustive list. An important comment in [4] is that in many minimization methods, there is no guarantee that we can reach the absolute optimum unless the problem is convex.

In this paper, a design criterion is considered to evaluate the performance of antenna arrays: the criterion of minimum side lobe level at a fixed main beam width. In this case, the antenna array design problem consists of finding weights that provide a radiation pattern with maximal side lobe level reduction. Due to the great variety of parameters involved, optimization techniques such as Tabu Search (TS) [11, 10, 2, 1, 9] are very appropriate tools to search for the best antenna models. TS techniques are becoming widely used to solve electromagnetic problems due to their robustness, wide range of applications and readiness in their implementation. One characteristic of TS is that it finds good near-optimal solutions early in the optimization run. It does not require initial guesses nor uses derivatives, and it is also independent of the complexity of the objective function under consideration. Because of these fascinating features, we apply TS techniques to the design of linear antenna arrays to be a problem optimizing a single objective function, i.e., the minimization of the side lobe level at a fixed main beam width.

The purpose and contribution of this paper is to present a model of problem that includes design of linear antenna arrays for side lobe level reduction using the method of tabu search. The remainder of the paper is organized as follows. Section 2 states the antenna array design problem we are dealing with. Then, a description of the used algorithm is presented in section 3. Following this description the results are presented in section 4. Finally, the summary and conclusions of this work along with some future line of research are presented in section 5.

2. Problem Statement

Techniques for designing antenna arrays can be divided into two main objectives: (1) finding the excitations, and (2) finding the positions of antenna elements that obtain a set of trade-off solutions between main beam width and the side lobe level. In this paper, we will concentrate on uniform spacing for linear antenna arrays. If the array element are symmetrically situated and conjugated symmetrically excited around the center of the linear array, the far-field array factor of such an array is real, and when the number of array elements is even (i.e., *2N*), it can be written as

$$F(\theta) = \sum_{i=1}^{N} a_i \cos(k_0 X_i \sin\theta + \psi_i) \qquad (1)$$

where $k_0 = 2\pi/\lambda$ is wave numbers, θ is angular direction, and a_i and ψ_i are amplitude and phase of the excitation complex feed.

By considering a uniform space distribution (Figure 1), the position X_i sources become:

$$X_i = (i-1/2)\Delta x,\ i = 1, N \qquad (2)$$

The synthesis is reduced to search of the amplitude law defined by the vector $A = [a_1, a_2, \ldots, a_N]$.

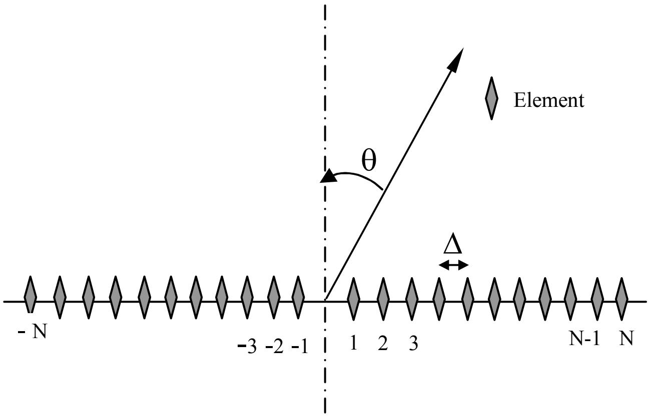

Figure 1. Equidistant elements symmetrical linear array .

During the optimization process, we attempt to reduce the sidelobe level of the radiation pattern while retaining a particular main beam width. This objective is achieved by the following cost function:

$$C_{\cos t} = \min(F(\theta')) \qquad (3)$$

where $F(\theta')$ correspond to the high sidelobe level.

The next section presents the method we use to obtain the design of uniform linear antenna arrays for side lobe reduction.

3. Tabu Search Algorithm

The main purpose of this study is to design a low side lobe radiation pattern for uniform linear antenna arrays with the constraint of a fixed beam width. For this purpose, we propose to use a stochastic procedure denominated tabu search. We choose this algorithm for its easiness of implementation.

TS is a general heuristic search procedure devised for finding a global minimum of a function, which may be linear or non-linear. The modern version of the algorithm was developed by Glover [6, 7, 8]. It has a flexible memory to retain the information about the previous steps of the search, using it to create and exploit new solutions in the search space. A step of TS starts with a present solution x_{now} having an associated set of feasible solutions Q, which can be obtained by applying a simple modification to x_{now}. This modification is called a *move*. In order to avoid a local minima in search space, the move to x^* is applied even if x^* is worse than x_{now}. However, this can cause the cycling of the search. To avoid cycling as much as possible, a tabu list is introduced. The tabu list stores all tabu moves that are not permitted to be applied to the present solution. The moves stored in the tabu list are those carried out most frequently and recently. Therefore, in order for a move to be classified as tabu or not, criteria called *tabu restrictions* are employed. The use of a tabu list decreases the possibility of cycling because it prevents the return within a certain number of iterations to a solution visited recently. After a subset of feasible solutions, Q^*, are produced according to the tabu list and evaluated for the problem, the next solution is selected from Q^* and the tabu list is updated. The solution evaluated as best is selected as the next solution x_{next}. This loop is repeated until a specified stopping criteria is satisfied.

The tabu search employed in this work had two tabu restrictions, which were based on recency and frequency memories:

$$recency(x^*) >= recency\ limit \qquad (4)$$
$$frequency(x^*) <= frequency\ limit \qquad (5)$$

The recency of a move is the difference between the current iteration count and the last iteration count at which that moves was made. The frequency measure is the count of changes of the move.

Tabu restrictions might prevent the search from moving a solution that has not been visited yet, or they might even sometimes cause all available moves to be classified as tabu. For these reasons, the tabu restrictions should be ignored when a freedom is required. An *aspiration* criterion is employed to determine which move should be freed in such cases. In the TS used in this work, the following aspiration criterion was employed when all available moves are classified tabu: a tabu move that loses its tabu status by the least increase in the value of current iteration is freed from the tabu list.

4. Results

To illustrate the effectiveness of the proposed method, we consider reducing the sidelobe level in a linear array, two arrays are considered. These arrays consist respectively of 16 and 24 isotropic elements that are equally spaced at a half wavelength.

TS starts with an arbitrary solution created by a random number generator. In this particular problem, it is equivalent to starting with randomly generated values for the array parameters (amplitude excitations), which will be determined. A solution is represented with a vector of these parameter values and an associated set of neighbors.

A neighbors is reached directly from the present solution by an operation called "*move*". Successive moves are carried out to transform the arbitrary solution to an optimal one. The new solution is the highest evaluation move among the neighbors in terms of performance value and tabu restrictions, which help to avoid moves that were already evaluated in earlier iterations. The recency and frequency factors are chosen as 3 and 2, respectively. The number of iterations is fixed to 1000, which is found to be sufficient to obtain satisfactory desired patterns. For these two examples, the CPU time for 1000 iterations is about 120 using MATLAB software on a Pentium III processor running at 750 MHz. As shown in Figures 2 and 3, the relative side lobe levels obtained -30.4dB and -33dB, respectively. It can be seen that the side lobes close to the main beam are lowered. At the same time, the levelled side lobes indicate that the result is close to optimum solution for that particular beamwidth. This can be confirmed by comparing the solid line pattern by the TS and the dotted line by Chebyshev method [5, 3]. Although Chebyshev method is able to generate perfectly leveled side lobes, it is only applicable to uniform spaced linear arrays with isotropic elements. As for that the TS, it is more flexible and versatile, and it can be applied to arbitrarily spaced arrays.

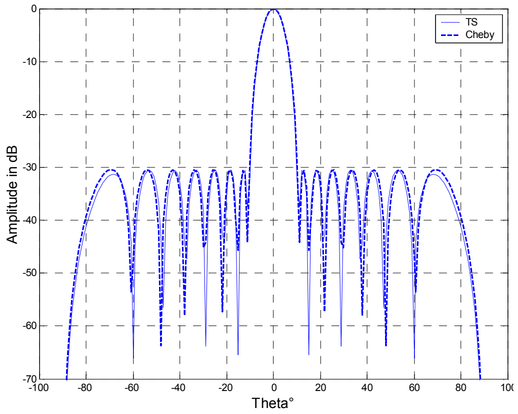

Figure 2. Comparison of the radiation patterns of the broad side linear array with excitation coefficients by the Chebycheff and the TS method.

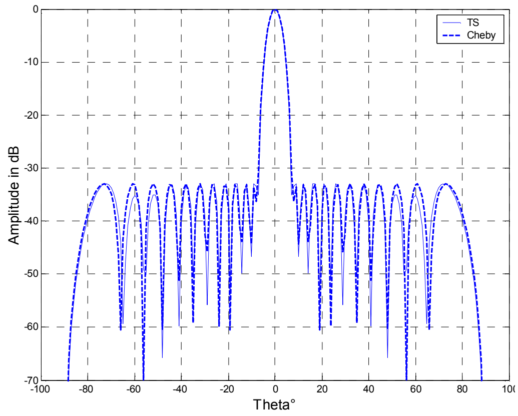

Figure 3. Comparison of the radiation patterns of the broad side linear array with excitation coefficients by the Chebycheff and the TS method.

The required element amplitude of each array element for the patterns of Figures 2 and 3 are given in Figures 4 and 5 respectively. All elements amplitude excitations are almost identical.

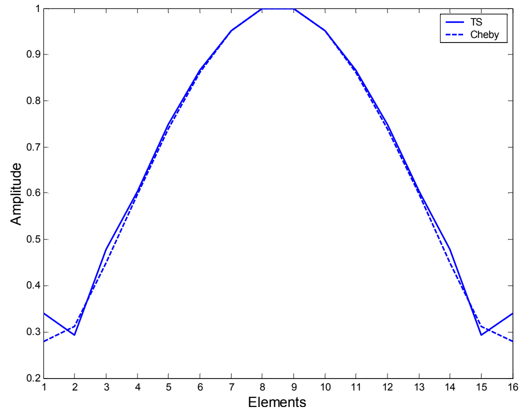

Figure 4. Comparison of the optimized amplitude excitations computed by Chebycheff and TS.

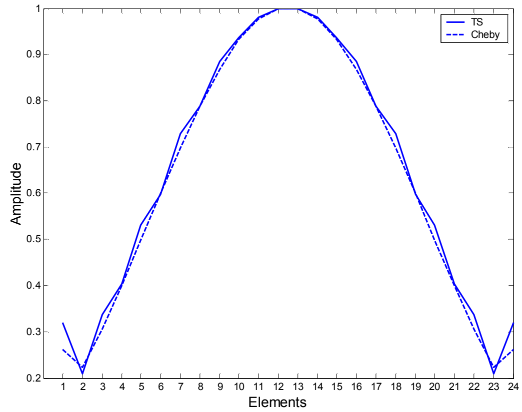

Figure 5. Comparison of the optimized amplitude excitations computed by Chebycheff and TS.

5. Conclusion

This paper illustrates how to model the design of uniform linear antenna arrays for maximal side lobe level reduction under the constraint of a fixed beam width. The well-known method of TS is proposed as the solution for this problem design. The method of TS efficiently computes the design of uniform linear antenna arrays to generate a radiation pattern with maximal side lobe level reduction with the constraint of a fixed beam width.

Future research will be aimed at dealing with other geometries and constraints. Many different areas of antenna design and analysis require a feasible and versatile procedure, being able to perform array synthesis by tuning antenna characteristics and parameters. Because of the versatility of the method of TS it seems a good candidate to face this problem.

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Lotfi Merad received the Diploma of state engineer in electronics in 1998, MS in electronics in 2001, and PhD from Tlemcen University in 2005. He is a junior researcher within the Telecommunications Laboratory. His field of research is centered on the optimization process and their application on antenna array synthesis.

Fethi Bendimerad received the Diploma of state engineer in electronics in 1983 from Oran University, MS in electronics in 1984, and PhD from Nice Sophia-Antipolis University in 1989. He worked as a senior lecturer in Tlemcen University and is the director of the Telecommunications Laboratory. His main area of research is the microwave techniques and radiation and is responsible of the antenna section.

Sidi Meriah received the Diploma of state engineer in electronics in 1992 from National Polytechnic College, MS in electronics in 1997, and Doctorate degree from Tlemcen University in 2005. He is a senior lecturer in Tlemcen University and researcher within the Telecommunications Laboratory. He worked on smart array antenna.