TABU SEARCH ALGORITHM FOR CHEBYSHEV ARRAYS

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Abstract

A new and simple method is presented for the design of Chebyshev arrays. This method is based on the tabu search algorithm. The key point of this method is that no direct use is made of Chebyshev polynomials. Numerical results are presented to illustrate the performance achievable.

1. Introduction

Chebyshev arrays consist of equally spaced isotropic elements which provide the smallest beamwidth for a specified side-lobe level and vice versa. Several methods [1-14] are available in the literature to analyse and design of Chebyshev arrays but care must be taken to insure accuracy when the array is large because some methods involve the subtraction of large and nearly equal numbers for large arrays, leading to inaccuracies. In general, the analysis and design of these arrays have been carried out with the use of Chebyshev polynomials. The process involves expressing the array factor as a polynomial whose coefficients are in terms of element current magnitudes. This polynomial is then compared with a Chebyshev polynomial of the same order and coefficients of like power terms are equated. A linear system of equations then results which is solved for current magnitudes in terms of the current of one element chosen as the independent variable. This approach, while useful in illuminating the fundamental aspects of Chebyshev arrays, becomes quite involved when the number of elements is large. In this work, a new simple method based on the tabu search algorithm for the design of Chebyshev arrays is proposed which makes no direct use of Chebyshev polynomials. Tabu search, which is one of the modern heuristic optimization procedures, is a quite new and promising optimization algorithm for difficult problems [15-22]. It has the ability of getting out of local minima and finding global optimal solutions for multimodal problems. This optimization algorithm has been successfully applied for several engineering problems from different areas [15-22].

In previous works [20-22], we also successfully introduce the tabu search algorithm to calculate the resonant frequencies of rectangular, triangular and circular microstrip antennas.

The tabu search algorithm presented in this study can be used to reconstruct patterns which, because of their complicated nature, can not be expressed analytically. Measured patterns, either of analog or digital form, can also be synthesized using the algorithm. In the following sections, a basic tabu search algorithm and the application of the tabu search algorithm to the Chebyshev array design are described.

2. Tabu Search Algorithm

Recent developments focused on iterative computer methods have allowed the creation of intelligent search procedures capable of finding the best or nearly the best solution to the complex problems. Tabu search is one of the general heuristic search procedure as an iterative procedure for solving discrete combinatorial optimisation problems. It was first suggested by Glover [15-16] and since then has become increasingly used. It has been successfully applied to obtain optimal or sub-optimal solutions to such problems as scheduling, time-tabling, travelling salesperson, layout optimisation.

Tabu search has a flexible memory to keep the information about the past steps of the search and uses it to create and exploit the new solutions in the search space. It has the ability of finding global optimum of a multimodal search space. The process with which the tabu search overcomes the local optimality problem is based on an evaluation function that chooses the highest evaluation neighbour at each iteration. The best admissible neighbour means the highest evaluation neighbour in the neighbourhood of the current solution in terms of the objective value and tabu restrictions. The highest evaluation function selects the neighbour which produces the most improvement or the least disimprovement in the objective function. A tabu list is employed to store the characteristics of accepted neighbours so that these characteristics can be used to classify certain neighbours as tabu (i.e. to be avoided) in later iterations. In other words, tabu list determines which neighbours may be reached by a move from the current solution.

A simple tabu search algorithm consists of three main strategies: forbidding strategy, freeing strategy and short term strategy. Forbidding strategy controls what goes into the tabu list. Forbidding strategy is employed to avoid cycling problem by forbidding certain moves (tabu). The freeing strategy controls what goes out of the tabu list, and when. This strategy erases their tabu restrictions so that they can be reconsidered in any future search. Short term strategy manages the interplay between the forbidding and freeing strategies to select trial solutions. Setting the tabu status to a move is sometimes too restrictive. When a tabu move leads the search to a promising region, then the tabu status has to be overridden. Aspiration criteria is used to override the tabu status of a solution if this solution is good enough and sufficient to prevent cycling. While the aspiration criteria has a role in guiding the search process, tabu conditions has a role in the constraining the search space. A solution is acceptable if tabu restrictions are satisfied. However, a tabu solution is also assumed acceptable if the aspiration criteria apply regardless of the tabu status. The main structure of the basic tabu search algorithm is given below:

1. k=0; Initialize x_{now}; $x_{best} = x_{now}$; Tabu(k) = Ø.
2. Construct a list of candidate moves from the neighbourhood of x_{now}. Evaluate each candidate move.
3. If a move is in Tabu(k), but leads to a highly desired solution, perform the move, update x_{now}, and go to 4. Otherwise, select the non-tabu move with the highest evaluation. Perform the move, and update x_{now}.
4. If x_{now} is better than x_{best}, update x_{best}.
5. If stopping criteria are satisfied, terminate with x_{best}. Otherwise, $k = k+1$; update Tabu(k); go to 2.

In the above algorithm, x_{now}, x_{best}, k, and Tabu(k) represent, respectively, the solution at the current iteration, the best solution found so far, the current iteration counter, and the set of tabu moves at iteration k.

Tabu restrictions used here are based on the recency and frequency memory storing the information about the past steps of the search. The recency of a move is the difference between the current iteration count and the last iteration count at which that move was made. The recency-based memory prevents cycles of length less than or equal to a predetermined number of iterations from occurring in the trajectory. The frequency measure is the count of changes of the move. The frequency-based memory keeps the number of change of solution vector elements. If an element of the solution vector does not satisfy the following tabu restrictions, then it is accepted as tabu:

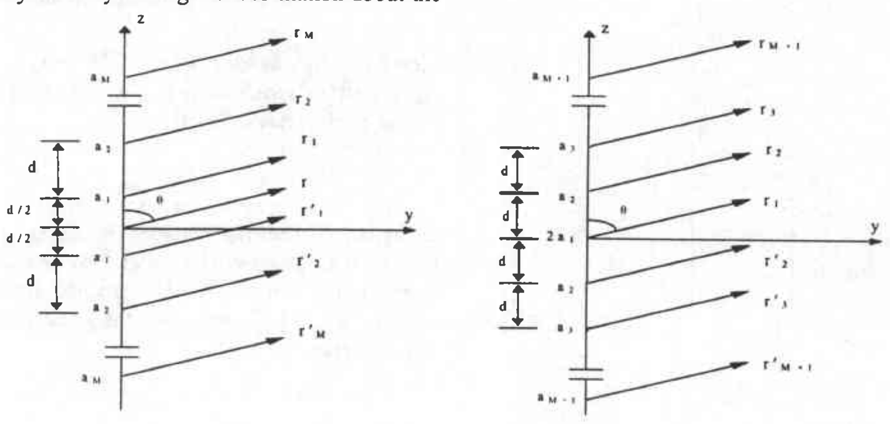
$$\text{Tabu Restrictions} = \begin{cases} \text{recency(k)} > \text{recency limit} \\ \text{or} \\ \text{frequency(k)} < \text{frequency limit} \end{cases} \tag{1}$$

3. Application of Tabu Search Algorithm to the Design of Chebyshev Arrays and Its Results

Consider a broadside linear array of N equispaced isotropic antenna elements, as shown in Figure 1. The far-field array factor is given by

$$\begin{aligned} (AF)_{2M} &= \sum_{n=1}^{M} a_n \cos\left[\frac{(2n-1)}{2} kd\cos\theta\right], \quad N = 2M \\ (AF)_{2M+1} &= \sum_{n=1}^{M+1} a_n \cos[(n-1)kd\cos\theta], \quad N = 2M+1 \end{aligned} \tag{2}$$

where a_n is the excitation amplitude of the nth element, the wave number $k=2\pi/\lambda$, λ is the wavelength, and d is the element spacing. In order to obtain the desired Chebyshev array pattern, the excitation coefficients in Eq. (2) are optimally determined by using the tabu search algorithm just described.



a) N is even

b) N is odd

Figure 1. The geometry of a linear antenna array.

In the tabu search algorithm, the initial solution consists of randomly produced positive coefficient values. The performance values of all neighbours are compared with each other and the neighbour which produces the maximum performance is selected as the next solution. If there are some tabu-neighbours which are better than the best solution found so-far, then those tabu solutions are freed. This process continues until a predetermined termination criteria is reached, e.g., every move is tabu or a maximum number of iterations has been reached. The performance of a neighbour can be computed using various formulas. In this article, the following is employed:

$$P(k) = A - \sum_{j=1}^{L} \left| AF(\theta_j) - D(\theta_j) \right| \tag{3}$$

where A is a positive constant selected to be large enough so that P (k) values are positive for all possible solutions, which is taken as 100 in this work, L is the data size, $AF(\theta_j)$ and $D(\theta_j)$, represent, respectively, the array factor whose excitation coefficients determined by the tabu search and the desired array factor (objective function).

To illustrate the performance of the proposed algorithm, the broadside Chebyshev arrays of 7, 11 and 14 isotropic elements with the side-lobe levels=25 dB, 15 dB, and 20 dB, and the interelement spacing=0.5λ, 0.5λ, and 0.25λ, are considered here, respectively. Symmetrical excitation is assumed. In the examples, the tabu search algorithm is carried out in five runs of 150 iterations each. For these three examples, the CPU time for 150 iterations is about 100 seconds using Pascal software on a Pentium 150 MHz PC.

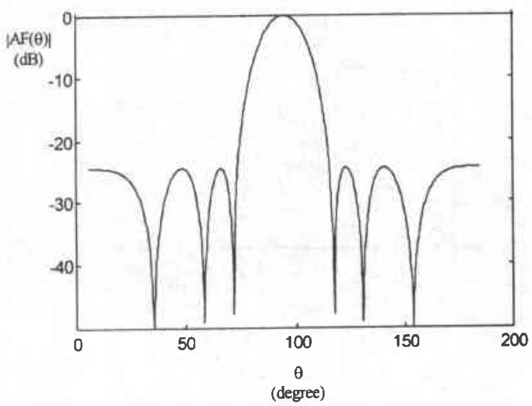


Figure 2. Array factor pattern of a broadside Chebyshev array with 7 elements and element spacing d=0.5λ. The side lobe level is 25 dB.

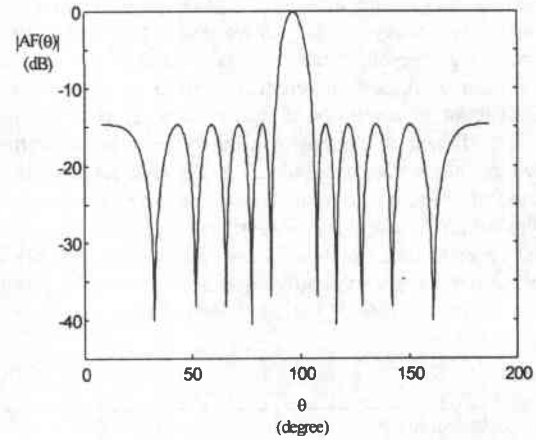


Figure 3. Array factor pattern of a broadside Chebyshev array with 11 elements and element spacing d=0.5λ. The side lobe level is 15 dB.

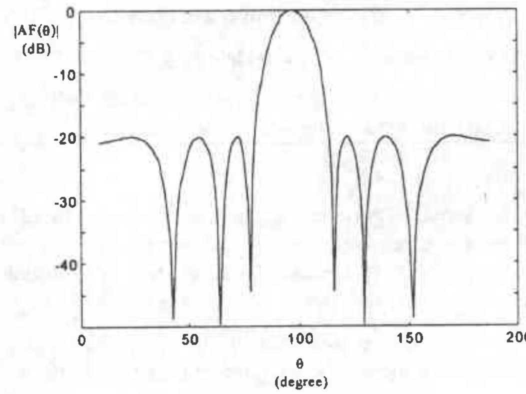


Figure 4. Array factor pattern of a broadside Chebyshev array with 14 elements and element spacing d=0.25λ. The side lobe level is 20 dB.

The resulting array patterns calculated from the excitation coefficients obtained by using tabu search algorithm are shown in Figures 2-4. As can be seen from Figures 2-4 the results obtained from the tabu search algorithm provide the specified design requirements.

4. Conclusion

In this work, the excitation coefficients of a linear antenna array whose array factor will closely approximate the desired Chebyshev array pattern have been optimally determined by using the tabu search algorithm. It was observed that the array factor patterns obtained by using these excitation coefficients meet the desired design specifications. This harmony supports the validity of the tabu search algorithm.

Tabu search algorithm can be used on a large class of antenna design problems. Unlike the classical Chehyshev method, the algorithm can be used on arrays with nonuniformly spaced elements and with non isotropic and unequal element patterns. It can also handle problems where the desired side lobe level varies with angle.

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