Innovative Approaches based on a Reactive Sorting Algorithm for Sum and Difference Antenna Pattern Design

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This work presents two new approaches for the design of sum and difference antenna array. The first approach considers a configuration of sub-arrays that minimizes a "*residual error*" functional, while the second one a configuration that minimizes a "*gain sorting*" functional. The obtained results show that by means of such methods difference pattern close to the optimal ones can be obtained with simpler feed networks.

Introduction

Monopulse radar antennas are aimed at generating sum and difference patterns at the same time for target detection. Toward this end, some design considerations have to be taken in account to guarantee low side lobe levels, high directivity and narrow beam-width. It is well known that the optimal excitation coefficients for the sum and the difference pattern can be independently computed using analytical methods as described in [1] for the sum pattern and in [2] for the difference pattern. Unfortunately, the implementation of two independent feed networks is usually expensive, therefore there is the need of finding an optimal trade-off between sum and difference solutions. Usually, first the optimal excitation coefficients for the sum pattern are computed and successively the weights of the subarrays are determined to synthesize the difference pattern. When the problem is formulated in these terms, two sets of unknowns are taken into account: the aggregations of the N elements of the array in Q subarrays and the weights of each subarray.

Such a problem can be solved using different techniques based on analytical methods [3][4] or optimization procedures [5][6]. The proposed approaches consider that the partition of the elements of the array is not "blind" but it can be carried out considering the elements that have similar properties. Such an observation and the introduction of some concepts as the equivalence between aggregations allow one to reduce the investigation space and to generate all the possible aggregations without considering a complete binary tree. The problem of finding the minimal cost path from the root to the leaves is addressed by looking for an array configuration that minimizes a suitable cost function different for each approach. In the following, selected numerical results will be shown for assessing the effectiveness and the current limitations of the proposed methods.

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Description of the Methods

Let us consider the geometry of a linear uniform array and the subarray configuration for half of the system composed by 2N elements shown in Fig. 1. Each element of the array is fed by a real excitation coefficient a_n. A symmetric $\{a_n = a_{-n}\}$ or anti-symmetric $\{a_n = -a_{-n}\}$ excitation set is assumed for the sum and for the difference pattern, respectively, so that only half of the array excitations are considered. Therefore, the synthesis problem requires the definition of the following sets of unknowns parameters: the set of local excitations, $\{a_n; n = 1,..., N\}$, and their aggregations.

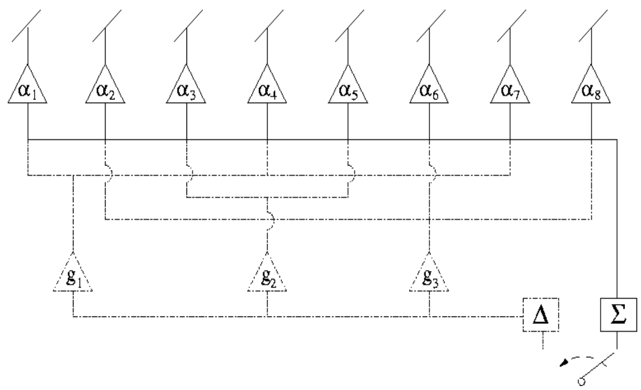

Figure 1. Sketch of the antenna feed networks.

The latter are composed by 2Q subarrays that contain a subset of array elements. K_q elements belong to the qth subarray, thus $K_1 + K_2 + ... + K_q = N$. A gain g_n^q is associated to the nth element of the qth sub-array. As Fig. 1 shows, such an antenna can be switched between sum and difference pattern by suitably varying the signal feed path. Starting from an assigned sum-pattern configuration the synthesis methodology is aimed at defining Q subarrays and successively to assign a gain (weight coefficient) to each sub-array in order to obtain the excitations for the difference pattern. This work proposes two different solution procedures based on a reactive sorting algorithm.

The first method consists in finding a configuration of subarrays and the values of the gain coefficients that minimize the following normalized cost function Φ:

$$\Phi = \sum_{n=1}^{N} \frac{\left|\Delta_n^{opt} - \Delta_n\right|}{\left|\beta_n\right|} \tag{1}$$

where

$$\Delta_n^{opt} = \alpha_n - \beta_n, \quad n = 1,..., N \tag{2}$$

α_n being the nth excitation element for the optimal sum pattern and β_n being the nth excitation element for the optimal difference pattern. Moreover Δ_n is defined as

$$\Delta_n = \alpha_n - e_n, \quad n = 1,...,N \tag{3}$$

where $e_n = g_n^q \alpha_n$ is the nth excitation element for the difference pattern calculated defining a configuration of subarrays and their weights. In order to minimize (1) a suitable greedy procedure (called RSA) is used. In more detail, starting from the initial aggregation obtained grouping the elements that have similar Δ_n^{opt} (*residual error sorting*, RES), the optimal solution, defined as the minimal cost route in a non-complete binary tree of depth N, is reached by means of greedy search with tabu direction by using the property of sorting between residuals Δ_n.

The second approach (*gain sorting*, GS) uses the same optimization algorithm (RSA) but it considers as fitness solution the following functional Θ

$$\Theta = \left\| \underline{\Gamma} - \underline{G} \right\|_{L^1} \tag{4}$$

where $\underline{\Gamma} = \{\gamma_n; n = 1,..., N\}$ is the optimal gain array obtained as described in [1] for Q=N, and $\underline{G} = \{g_n^q; n = 1,..., N\}$ is the computed gain array.

Numerical Simulations

In order to validate the proposed approaches, some numerical simulations have been performed by considering an array of $N = 10$ elements spaced by $d = \lambda / 2$. The sum pattern excitation has been chosen according to the Villenueve distribution [7] with $\bar{n} = 4$, for which $SLL = -25\,dB$. Different number of sub-arrays (Q=2 and Q=6) are considered and the results are compared to the optimal configuration obtained with independent feed networks with excitations defined in [2] being $\bar{n} = 4$ and $\varepsilon = 3$ ($SLL = -25\,dB$).

The obtained difference patterns are compared (Fig 2) with those achieved with other state-of-the art algorithms. As can be observed in Fig. 2, even though $Q < N$, the arising patterns are still close to the optimal one, especially in the main lobe shape. Moreover, the GS and RES algorithms seem to provide lower SLL with respect to other techniques. In particular, the maximal SLL for the GS method does not overcome the $-19\,dB$ threshold. Certainly, further and deeper analysis is needed to fully assess and generalize the positive conclusion carried out in this preliminary analysis.

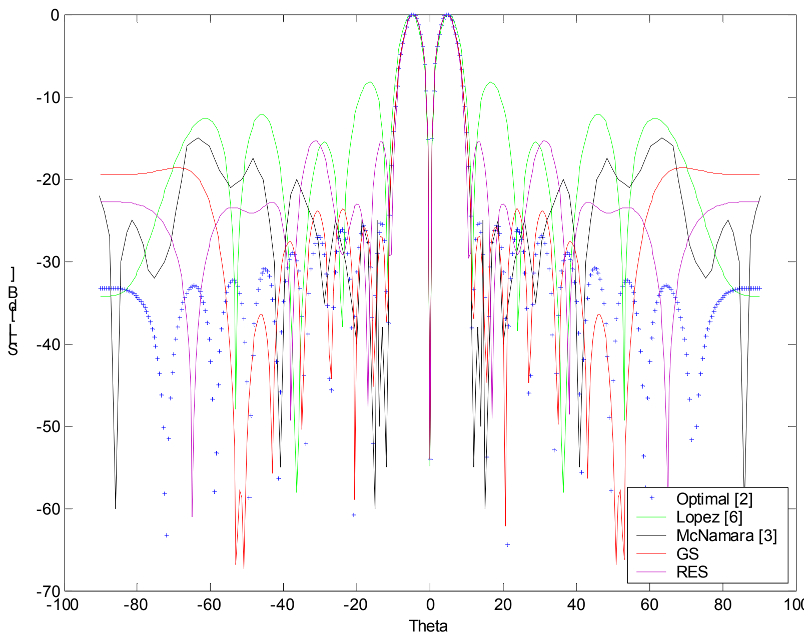

Figure 2. Comparison of the difference pattern obtained using RES and GS methods and other state-of-the art strategies.

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