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Optimization of Difference Pattern Features in Sub-arrayed Monopulse Antennas through and Excitations Matching Procedure

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Introduction

Radar tracking operations are aimed at determining the flight path of a target. They are usually carried out by means of a “monopulse radar tracker” able to recover the position of the target by the reflected echo of a previously transmitted pulse [1]. Towards this purposes the antenna of the tracker system is required to generate two difference beams on the same aperture: a “sum” beam and a “difference” one. These beams have to satisfy some constraints as low side lobe level (SLL), narrow beam-width and high directivity. In order to fit these conditions, a possible solution consists in using independent feed networks. In this case, the excitations of the radiating elements are computed by means of analytical techniques. The sum pattern is usually set to the “optimal” pattern in the Dolph-Chebyshev sense [2]. On the other hand, different choices are possible for the difference pattern. More in detail, if the antenna system works in high interferences scenario the difference pattern should be optimal in the Dolph-Chebyshev sense [3]. Otherwise, it should have the maximal directivity [4] if it is necessary to increase the monopulse efficiency. Nevertheless, the presence of independent feed networks is usually unacceptable because the complexity of the electronic circuit, the costs, and the arising electromagnetic interferences. In order to overcome such drawbacks, McNamara proposed in [5] a compromise solution where the sum pattern is generated by a set of excitation coefficients analytically computed, while the difference pattern is generated through sub-arraying. Towards this end, the array elements are grouped in different subsets and a weight is associated to each of them. This leads to a simpler network, but to a degradation of the synthesized difference pattern compared to the optimal one. Efficient sub-arraying techniques are aimed at minimizing such a difference. Thus, the synthesis problem can be stated as follows: “how to group the array elements and which weights have to be assigned to them to obtain a difference pattern satisfying the user-defined constraints”. In order to solve such a problem, different approaches have been proposed. Analytically technique [5] (Excitation Matching Method EMM), or optimization approaches [6][7] or hybrid approaches [8]. Whatever the method, the attention has been mainly focused on the searching of the pattern with the lower SLL. Otherwise, a hybrid real/integer differential evolution method (hybrid-DE) has been used in [9] to maximize the directivity of the sub-arrayed beam. In such a framework, this paper deals with an innovative method based on the optimal excitation matching. Thanks to an efficient exploitation of the optimal sum and difference excitations, the solution space is significantly reduced. Moreover, an effective searching algorithm is design to sample such a space. It considers just some elements more suitable to change array membership in order to update the trial solution until the convergence one. In the following, the problem is firstly formulated, then selected results are reported in order to show the effectiveness and flexibility of the proposed method.

Problem Statement

Let us consider a linear array of $N=2M$ elements. As far as the sub-array technique is concerned, the sum pattern is generated by means of a symmetric real set of excitations $\underline{A}=\{\alpha_m=\alpha_{-m};m=1,\ldots,M\}$, while the difference pattern is obtained by grouping the array elements in Q sub-arrays weighted by the coefficients $w_q=1,\ldots,Q$ (Figure 1).

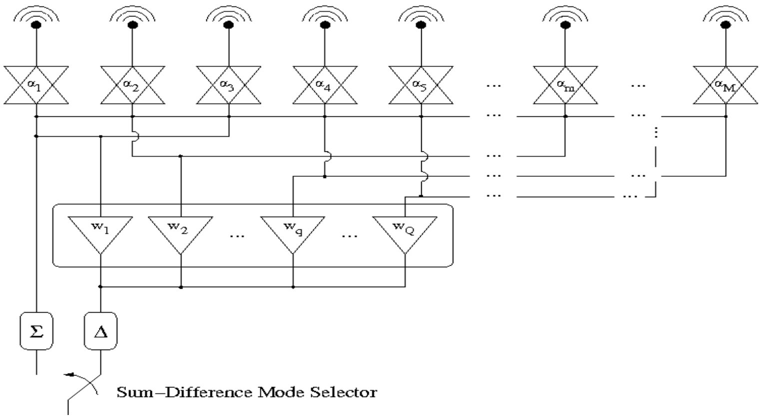


Figure 1: Geometry of the antenna feed network.

In particular, the difference beam is generated by means of a set of real anti-symmetrical excitations given by $\underline{B}=\{b_m=-b_m;b_m=\delta_{mq}w_q\alpha_m;\ m=1,\ldots,M;q=1,\ldots,Q\}$. In order to determine the sub-array grouping and the related weights w_q, let us consider as reference the optimal excitation coefficients $\underline{B}=\{\beta_m=-\beta_{-m};m=1,\ldots,M\}$ computed by means of the analytical methods described in [3] and [4] that provide the optimal value of the SLL and of the directivity, respectively. More in detail, once $\underline{B}$ has been determined the so called *optimal gains* are computed as follows:

$$g_m=\frac{\beta_m}{\alpha_m};m=1,\ldots,M. \tag{1}$$

Then, for a given grouping of the array elements, the sub-array weights w_q are computed as the mean of the optimal gains of the elements that belong to the same sub-array. Since the weights w_q are automatically defined once the sub-array configuration has been determined, the original compromise problem reduces to that of finding the aggregation of array elements that optimizes the following cost functions:

$$\Psi(\underline{C}) = min(SLL) \tag{2}$$

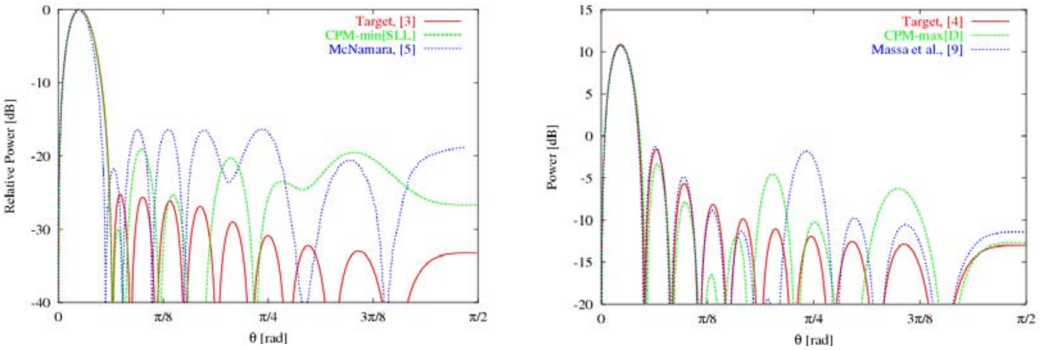
or

$$\Phi(\underline{C}) = max(Directivity) \tag{3}$$

where $\underline{C} = \{c_m ; m = 1, \ldots, M\}$ is the grouping vector and the $c_m \in [1, Q]$ is the m-th sub-array index. In order to determine $\underline{C}$ a reduced set of solutions, called contiguous partitions [10], is considered. Successively, the exploration of the solution space is performed just modifying some elements of the solution called "border elements". They are candidates to change array membership because their subarray changing ensures to still obtain another contiguous partition. For such a reason the method is called "contiguous partition method" (CPM).

Results

In order to show the effectiveness of the proposed approach, let us consider two test cases described in [5] and in [9] and concerned with the minimization of the SLL and the maximization of the directivity, respectively. Both cases deal with an array of $N = 20$ elements $\lambda / 2$-spaced and $Q = 3$ sub-arrays. The synthesized difference beams are shown in Figure 2. For completeness, the pattern features and the computational cost are summarized in Table I.



(a) (b)

Figure 2: Synthesized difference pattern – SLL (a) and Directivity (b) optimization.

In both cases, the CPM outperforms the other state-of-art techniques. The SLL optimization procedure shows a SLL 2.5[dB] below that of the EMM method with close beam-width. On the other hand, the proposed solution allows one to obtain a small improvement in terms of directivity compared to the DE approach, but a SLL 2.06 [dB] lower.

	$\max\{\mathrm{SLL}\}$ [dB]	$\max\{\mathrm{D}\}$ [dB]	BW [rad]	Time [sec]
$CPM - \min\{SLL\}$	-19.06	10.40	0.087	$4.14x10^{-2}$
$EMM - [5]$	-16.50	-	0.083	-
$\mathrm{Target}[3]$	-25.26	10.50	0.087	-
$CPM - \max\{D\}$	-14.06	10.71	0.077	$5.02x10^{-3}$
$Hybrid\ DE - [9]$	-12.00	10.68	0.074	70.11
$\mathrm{Target}[4]$	-12.49	10.86	0.072	-

Table I: Pattern features of the synthesized patterns – Computational cost.

Conclusions

An innovative approach for the optimization of a set of user-defined features of sub-arrayed difference beams has been presented. The obtained results assess the effectiveness as well as the reliability of the proposed approach. Moreover, thanks to the exploitation of some properties of the solutions of the problem and the efficiency of the searching procedure, the proposed method demonstrated a significant saving of computational costs. For such reasons, the CPM seems to be a very promising tool for the optimization of the features of the sub-arrayed beams also with arrays of very large dimensions.

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