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DIRECTIVITY OPTIMIZATION IN PLANAR SUB-ARRAYED MONOPULSE ANTENNA

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Abstract—In this paper, the Contiguous Partition Method (CPM) is applied to the optimization of the directivity of difference patterns in monopulse planar array antennas. Since the excitations providing maximum directivity of planar arrays can be analytically computed and because of the excitation matching nature of the CPM, the problem at hand is recast as the synthesis of the difference compromise solution close as much as possible to the reference pattern with maximum directivity. Selected results are shown to point out the potentialities of the CPM-based approach.

1. INTRODUCTION

In monopulse radar systems for airborne applications [1, 2] and vehicle tracking radar [3], the synthesis of a sum and two spatially orthogonal difference patterns is required for search-and-track purposes. Since the available space is limited and because of the need of simple feed networks, an ever growing interest has been devoted to sub-arraying strategies [4–9]. In such a case, a set of excitations (either the sum or one difference) is fixed to the optimum, while the others are obtained by clustering the array elements into sub-arrays and weighting each of them. Such a synthesis method allows one to design trade-off solutions with reduced circuit complexity, low costs, and acceptable pattern features. To obtain good radar performances, the compromise solution should guarantee narrow beamwidth and low sidelobe levels (SLLs), high directivity, and deep normalized slope at boresight. Unfortunately, such requirements are incommensurable and the synthesis of compromise solutions has usually dealt with only the minimization of the SLLs [4–10] for a given beamwidth. Other studies concerned with linear arrays have also considered the maximization of the directivity [11]. As regards to the difference modes, the slope at boresight is the most critical feature to be carefully optimized, since it is strongly related to the ability to track a target. On the other hand, the gain values in correspondence with the peaks of the difference patterns are also significant indexes of the radar efficiency in achieving angle lock on of a distant target [12].

In such a framework, this letter considers a CPM-based strategy [13] for the optimization of the directivity of compromise difference patterns in monopulse planar array antenna. Since the CPM is an effective and computationally-efficient excitation matching procedure and the optimal coefficients providing the maximum directivity can be easily computed through well known analytical procedures [14, 15], the synthesis problem at hand is recast as the definition of the compromise solution that better matches the optimal directivity pattern.

2. MATHEMATICAL FORMULATION

Let us consider a planar array of N radiating elements lying on the xy-plane and located on a uniform rectangular grid, $d_x = d_y = d$ being the inter-element spacing. The corresponding array factor is given by

$$E(u,v) = \sum_{n=1}^{N} I_n e^{j\frac{2\pi}{\lambda}(ux_n+vy_n)} \tag{1}$$

where $u = \sin\theta\cos\phi$, $v = \sin\theta\sin\phi$ ($\theta \in [0,\pi/2]$, $\phi \in [0,2\pi]$). Moreover, x_n, y_n and I_n are the coordinates and the real excitation of the n-th element, respectively.

In order to generate the sum pattern and the elevation (E-mode) and azimuth (H-mode) difference beams, the array aperture is subdivided into four quadrants. The sum pattern is obtained by adding the outputs of all quadrants in phase, while the difference beams are generated with pairs of quadrants added in phase reversal. According to the sub-arraying strategy, each quadrant is then subdivided into Q sectors or sub-arrays [5]. Thus, for each difference mode, the synthesis problem is concerned with the definition of the aggregation vector $C = \{c_n \in [1,Q];\ n = 1,\ldots,N\}$ [6], and the Q weights $W = \{w_q; q = 1,\ldots,Q\}$ to obtain the "best compromise" close as much as possible to the optimal difference pattern with maximum directivity. Towards this end, the excitation matching nature of the CPM [13] is exploited by performing a two-stage procedure for each mode:

(a) the optimal excitation coefficients affording a difference pattern with maximum directivity are computed according to the guidelines in [14, 15];

(b) the CPM is used to match the optimal pattern, thus defining the "best compromise" solution.

More in detail, the directivity along the angular direction (u, v) is given by

$$D(u,v) = \frac{I^T A(u,v) I}{I^T B I} \tag{2}$$

where $I = [I_1, \ldots, I_N]^T$, $A(u,v) = FF^*$, $F = [e^{jk(ux_1+vy_1)}, \ldots, e^{jk(ux_N+vy_N)}]^T$, and the generic entry of the matrix B is equal to $b_{mn} = \frac{\sin(k\rho_{mn})}{k\rho_{mn}}$ if $m \neq n$ and $b_{nn} = 1$ otherwise, ρ_{mn} being the Euclidean distance between the m-th and the n-th element positions [15]. Moreover, T and $*$ denote the transpose and the adjoint operation, respectively.

Since the direction $(u_{\max}, v_{\max})$ of maximum directivity, $D_{\max}$, of a difference pattern is not *a-priori* known, the maximization of $D(u, v)$ is obtained by applying the excitation adjustment method [14, 15]. In particular:

(i) Starting from a trial direction $\left(u_t^{(k)}, v_t^{(k)}\right)$, $k = 0$, (e.g., the angular direction of maximum directivity of a uniformly-excited array), the excitation set $I_t^{(k)}$ is computed by solving the matrix equation $I_t^{(k)} = B^{-1} F^{(k)}$;

(ii) The direction $\left(u_t^{(k+1)}, v_t^{(k+1)}\right)$ of the array excited with $I_t^{(k)}$ is determined by identifying the maximum of $E\left(u_t^{(k)}, v_t^{(k)}\right)$;

(iii) The vector F is updated, $F = F\left(u_t^{(k+1)}, v_t^{(k+1)}\right)$;

(iv) The process is then iterated ($k = 1, \ldots, K$) until negligible differences between successive estimates of the angular direction occur [14].

Once the set of optimal directivity excitations $I_{\max} = I_t^{(K)}$ is computed, the cost function

$$\Psi(C, W) = \sum_{n=1}^{N} \left| I_n^{\max} - I_n(C, W) \right|^2 \tag{3}$$

is minimized by means of the CPM approach [13]. The coefficients $I_n = \delta_{qc_n} w_q I_n^{sum}$ are the compromise difference mode coefficients, and I_n^{sum} indicates the n-th optimal sum excitation, δ_{qc_n} being the Kronecher delta function.

3. NUMERICAL ASSESSMENT

Let us consider a rectangular array of $N = 128$ elements disposed on a 16×8 regular lattice with $d = \lambda/2$. The sum excitations are fixed to those of a pattern multiplication Dolph-Chebyshev array with $SLL = -20\,\mathrm{dB}$ [16] and, for the sake of space, the analysis is limited to the synthesis of the E-mode difference pattern. The optimal excitations $I_{\max}^{(E)}$ have been determined at the end of the first stage after $K = 50$ iterations. The synthesized optimal pattern is shown in Fig. 1 where the maximum value of directivity, $D_{\max} = 117.3$, is located at $(u_{\max}, v_{\max}) = (9.1 \times 10^{-2}, 0.0)$. As far as the compromise synthesis is concerned, the values of the maximum directivity obtained with the CPM versus the number of sub-arrays are shown in Fig. 2, where the plot of Ψ^{opt} function is also reported. It is worth noting that the directivity values of the compromise solutions are generally close to the optimum one. In particular, the index $\xi_D = \frac{D^{\max} - D^{CPM}}{D^{\max}}$ turns out to be $\xi_D \leq 4\%$ when $Q \geq 4$ and $\xi_D \leq 1\%$ when $Q \geq 8$ (Fig. 2). For illustrative purposes, Fig. 3 shows the synthesized compromise patterns when $Q = 4$ [Fig. 3(a)] and $Q = 8$ [Fig. 3(b)]. The reference pattern [Fig. 3(c)] is reported, as well.

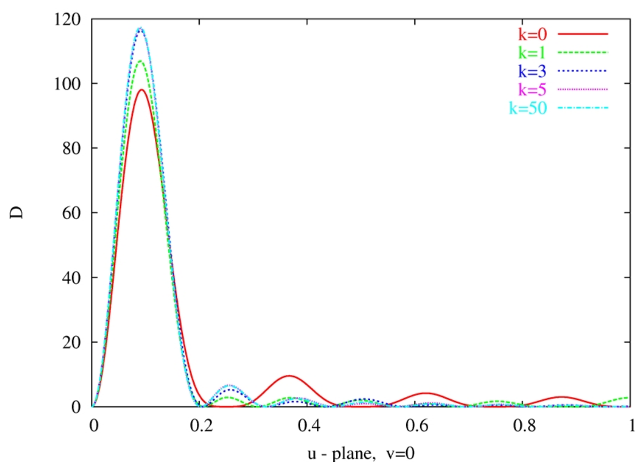

Figure 1. Reference patterns synthesized at different iterations of the first stage.

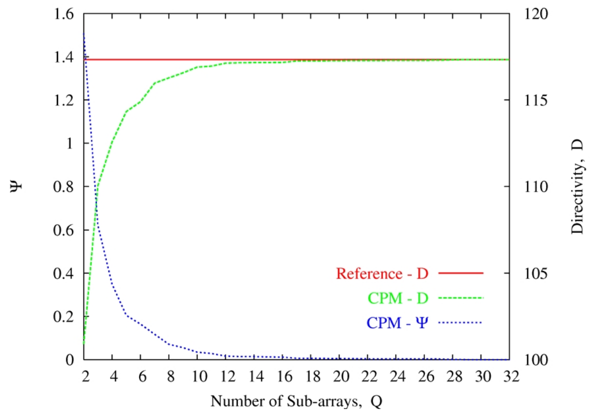

Figure 2. Behaviors of the synthesized value of D and of the cost function Ψ versus Q.

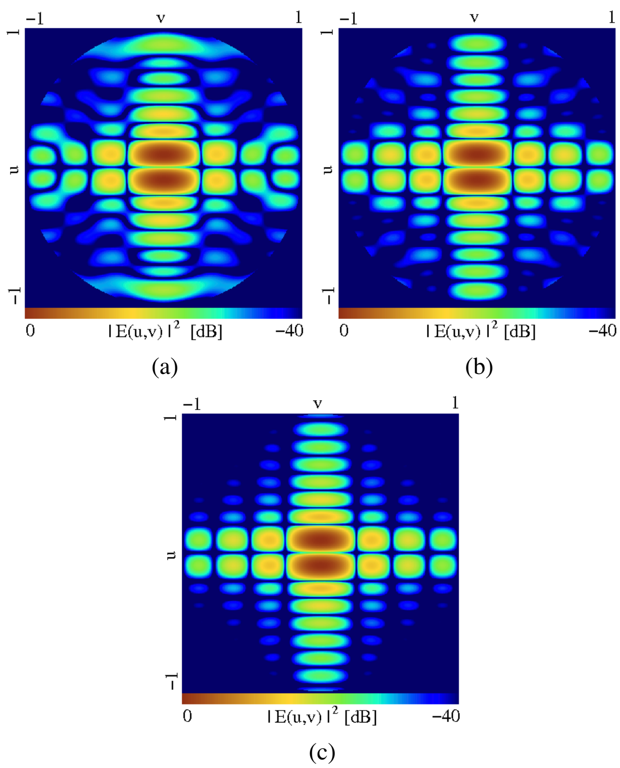

Figure 3. E-mode difference pattern: (a) compromise with $Q = 4$, (b) compromise with $Q = 8$, and (c) reference.

4. CONCLUSIONS

In this paper, a two-stage procedure for the optimization of the directivity of compromise difference patterns in monopulse planar sub-arrayed antennas has been considered. The CPM has been used to define the "best compromise" solution that better matches the optimum with maximum directivity for a given array geometry. Selected results have been reported to assess the effectiveness of the proposed approach.

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