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SYNTHESIS OF MONOPULSE ANTENNAS THROUGH THE ITERATIVE CONTIGUOUS PARTITION METHOD

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August 2007

Technical Report # DISI-11-060

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The synthesis of “optimal” compromise sum and difference patterns subject to arbitrary sidelobe bounds is addressed by means of a simple and effective sub-arraying technique based on the optimal excitation method. The obtained results positively compare with those from state-of-the-art methods both in terms of performances and computational indexes.

Introduction: In designing monopulse radar systems, the synthesis of both a sum pattern and a difference pattern that satisfy some specifications [e.g., narrow beamwidth, low side-lobe-level (SLL), etc..] is required. In order to avoid an expensive implementation of independent feed networks, compromise solutions based on sub-arraying techniques have been successfully proposed. In such a framework, two different methodological approaches might be recognized. The former [1] is aimed at determining the "best compromise" difference pattern close as much as possible to the optimum in the Dolph-Chebyshev sense [2] (i.e., narrowest first null beamwidth and largest normalized difference slope on the boresight for a specified sidelobe level). The other reformulates the original synthesis problem in an optimization one. As far as the “optimization” techniques are concerned, [3]-[5] contemporarily optimize the clustering into subarrays and their weights according to the following rationale “for a given beamwidth, find the subarray configuration and the coefficients of the subarray sum signals such that the maximum SLL is minimized.” On the contrary, in [6], a hybrid approach is used for pursuing the following task: “find the subarray configuration and the coefficients of the subarray sum signals such that the corresponding radiation pattern has a null with the maximum possible slope in a given direction, while being bounded by an arbitrary function elsewhere.”

In the framework of optimal matching techniques, this contribution considers a new approach for synthesizing best compromise patterns with SLL control. Towards this end, exploiting the property that the partition minimizing the distance between optimal and synthesized difference excitations is a contiguous partition (CP), the CP method (CPM) determines the difference solution close to the optimal Dolph-Chebyshev pattern with SLL under the user-defined threshold.

Description of the CPM: With reference to a linear uniform array of $N = 2M$ elements, let us consider sum and difference patterns generated by means of symmetric, $S = \{s_m = s_{-m}; m = 1,...,M\}$, and an anti-symmetric, $D = \{d_m = -d_m; m = 1,...,M\}$, real excitations set, respectively. Because of the symmetry properties and according to the guidelines of sub-arraying techniques, the sum pattern is obtained by assuming ideal excitations, $s_m = \phi_m$ [7][8][9], while difference excitations are synthesized as $d_m = \phi_m (\delta_{c_m q} p_q)$, Q being the number of sub-arrays, p_q is the weight of the q-th sub-array, $\delta_{c_m q} = 1$ if $c_m = q$ and $\delta_{c_m q} = 0$ otherwise, and c_m is the sub-array index of the m-th array element.

To obtain the best compromise difference excitations (i.e., a set of excitations giving a pattern as close as possible to the ideal one in the Dolph-Chebyshev sense that satisfies at the same time a constraint on the SLL), the following procedure is performed: (1) initialize the iteration index ($i=0$). Compute the optimal sum excitations $\Phi=\{\phi_m;m=1,...,M\}$ and set the user-desired sidelobe level $SLL^{(des)}$. According to [10], define an optimal – in the Dolph-Chebyshev sense - difference excitations set $\Psi^{(obj)}=\{\theta_m^{(obj)};m=1,...,M\}$ that generates a beam pattern with a sidelobe level $SLL^{(obj)}\leq SLL^{(des)}$. For each element of the array, compute a reference parameter (called optimal gain) $v_m=\theta_m^{(obj)}/\phi_m$. Sort the reference parameters in a list $L=\{l_m;m=1,...,M\}$ where $l_k\leq l_{k+1}$, $k=1,...,M-1$, $l_1=\min_m\{v_m\}$ and $l_M=\max_m\{v_m\}$;

(2) Update the iteration index ($i\leftarrow i+1$). If $i=1$, then randomly generate a trial grouping $C^{(i)}=\{c_m^{(i)};m=1,...,M\}$ corresponding to a CP, $\Gamma_Q^{(i)}$, of L in Q subsets $\Gamma_Q^{(i)}=\{L_q^{(i)};q=1,...,Q\}$. Otherwise, update the grouping vector $C^{(i)}$ by deriving a new CP starting from the previous one $\Gamma_Q^{(i-1)}$ and just modifying the subarray membership of the subset border elements ($b_m=l_m\in L_q^{(i)}$ such that $l_{m-1}\in L_{q-1}^{(i)}$ and/or $l_{m+1}\in L_{q+1}^{(i)}$, $q\in[1,Q]$);

(3) Compute the set of weights $P^{(i)}=\{p_q^{(i)}=\delta_{c_mq}e_m^{(i)};q=1,...,Q\}$, where $e_m^{(i)}=\sum_{r=1}^{M}\delta_{c_sq}v_r\Big/\sum_{r=1}^{M}\delta_{c_sq}$. Evaluate the closeness of the i-th trial solution $D^{(i)}=\{d_m^{(i)};m=1,...,M\}$ (or $\{C^{(i)},P^{(i)}\}$) to the reference $\Psi^{(obj)}$ by computing the cost function value $\Xi^{(i)}=\sum_{m=1}^{M}\left|v_m-e_m^{(i)}\right|^2$. Moreover, compute the achieved sidelobe level $SLL^{(i)}=SLL\{D^{(i)}\}$. Update the "optimal" value of the cost

($\Xi_{opt}^{(i)} = \Xi^{(i)}$) as well as the optimal set of coefficients ($D_{opt}^{(i)} = D^{(i)}$) and set $SLL_{opt} = SLL^{(i)}$ if $\Xi^{(i)} < \Xi_{opt}^{(i-1)}$;

(4) If the maximum number of iterations ($i = I$) or a stationary condition [i.e., $\left(\left| I_{win} \Xi_{opt}^{i-1} - \sum_{j=1}^{I_{win}} \Xi_{opt}^{j} \right| \Big/ \Xi_{opt}^{i} \right) \le \eta$ and $SLL_{opt} \le SLL^{(des)}$, I_{win} and η being a fixed number of iterations and an assigned threshold, respectively] is reached, then stop the process and return the final solution $D_{opt} = D_{opt}^{(i)}$ ($i = I_{opt}$). Otherwise, go to step (2);

Numerical Validation: As test cases, let us consider some situations ($Q = 4,6,8$) already tackled in [5][6] and concerned with a $M = 20$ linear array with inter-element spacing $d = \lambda/2$ when the sum pattern excitations have been fixed to produce a Dolph-Chebyshev pattern with $SLL = -20\,dB$. Moreover the desired sidelobe level has been set to $SLL^{(des)} = -20\,dB$ and the CPM has been used for minimizing the SLL_{opt}. The obtained results are shown in Fig. 1 ($Q = 4$, $I_{opt} = 2$), Fig. 2 ($Q = 6$, $I_{opt} = 2$), Fig. 3 ($Q = 8$, $I_{opt} = 3$) and compared in terms of SLL value with other existing techniques in Tab. I. As it can be noticed, although we are not exactly optimizing the same parameter as in [5][6 – Tab. II], the proposed approach outperforms other state-of-the-art approaches in a non-negligible fashion.

Acknowledgments

This work has been partially supported by the "Progettazione di un livello fisico intelligente per reti mobili ad elevata riconfigurabilità," MIUR-COFIN 2005099984.

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Figure captions:

Fig. 1 - Comparison between synthesized difference patterns ($Q = 4$)

——— CPM [$SLL^{(obj)} = -35\,dB$]

- - - - - Hybrid Approach

· · · · · DE Approach

Fig. 2 - Comparison between synthesized difference patterns ($Q = 6$)

——— CPM [$SLL^{(obj)} = -45\,dB$]

- - - - - Hybrid Approach

· · · · · DE Approach

Fig. 3 - Comparison between synthesized difference patterns ($Q = 8$)

——— CPM [$SLL^{(obj)} = -45\,dB$]

- - - - - Hybrid Approach

· · · · · DE Approach

Figure 1

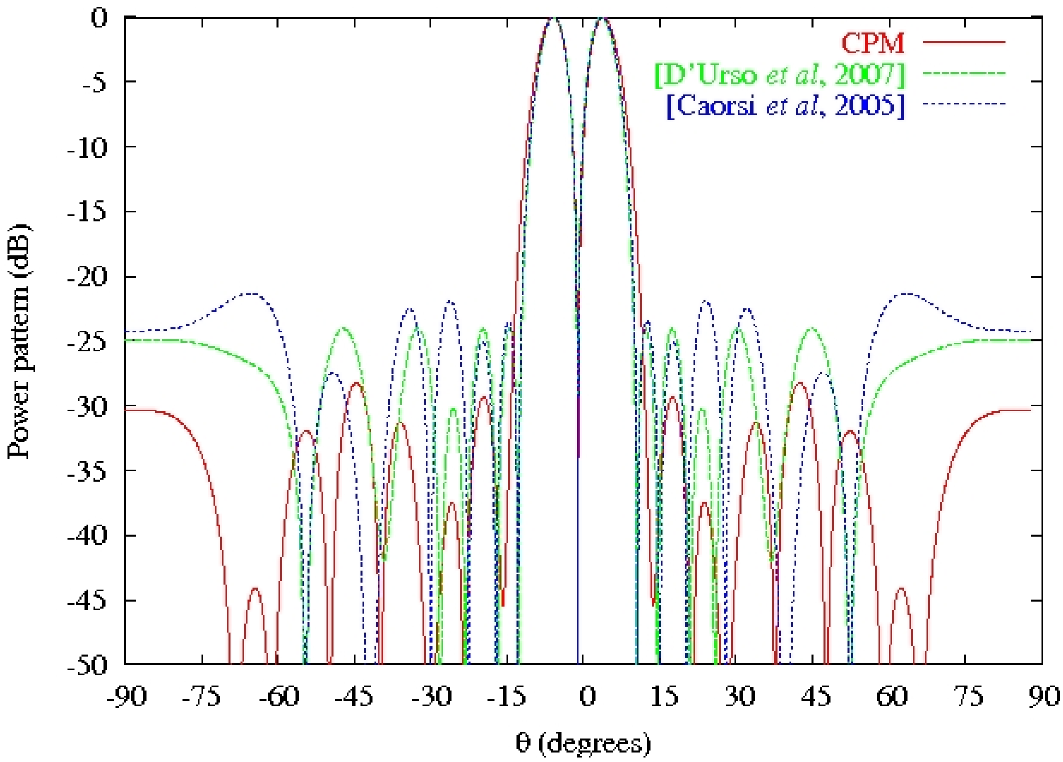
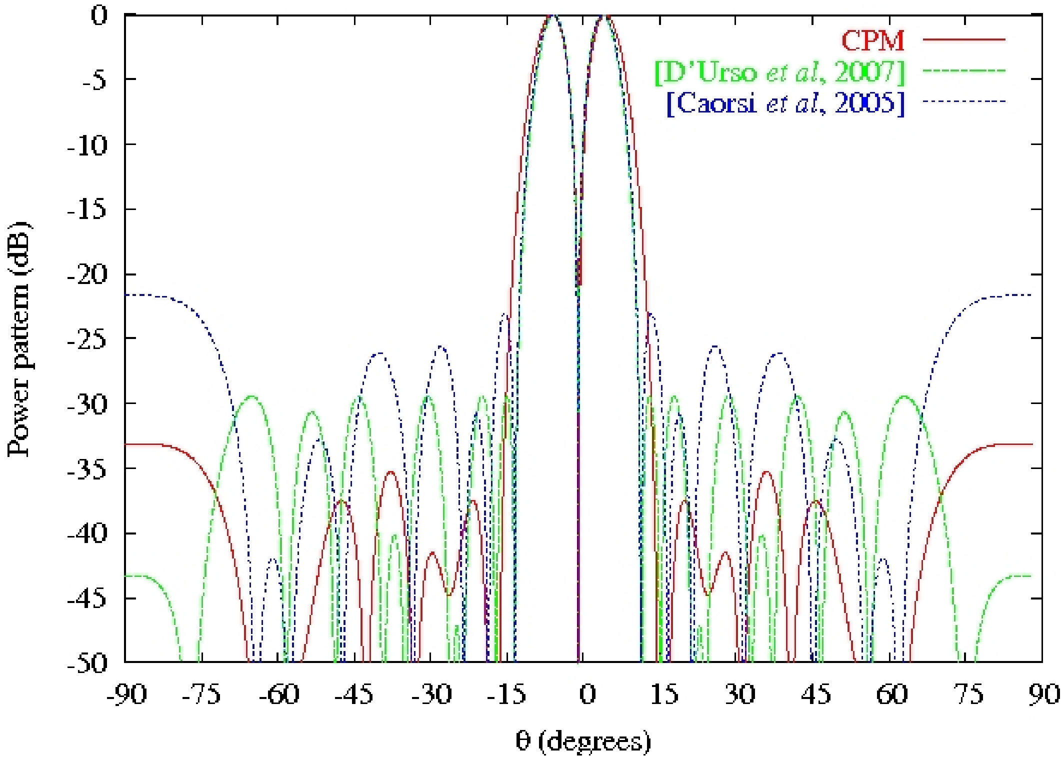

CPM
[D'Urso *et al*, 2007]
[Caorsi *et al*, 2005]
Power pattern (dB)
θ (degrees)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90

Figure 2



CPM
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Power pattern (dB)
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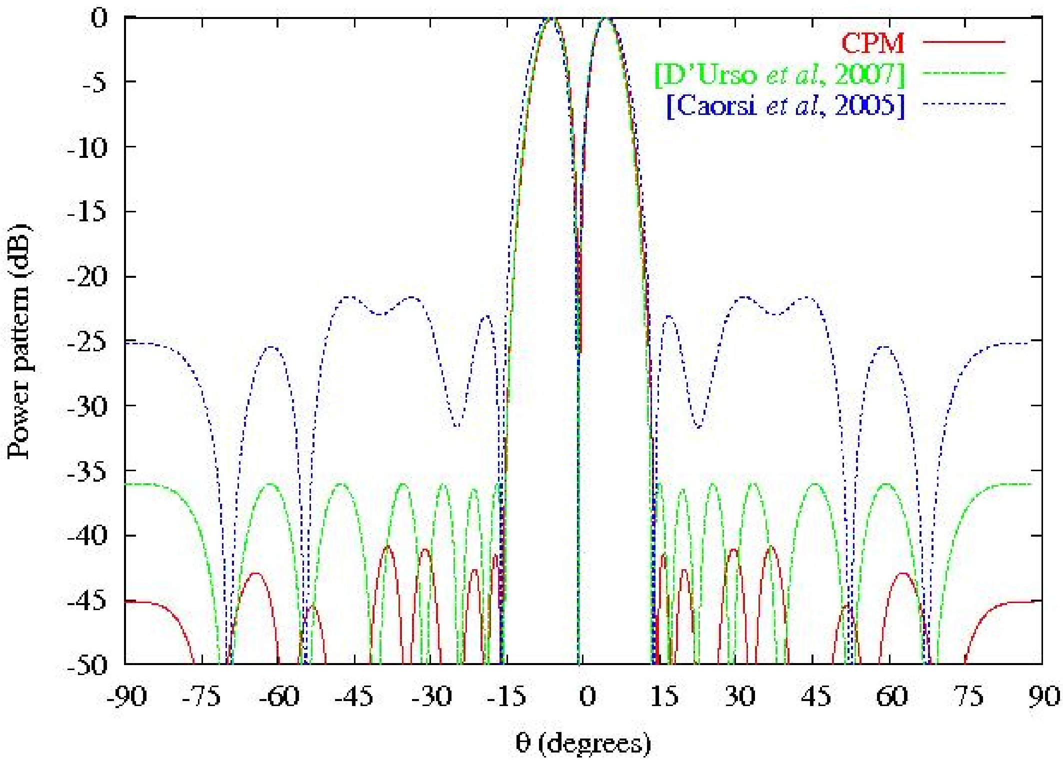
-45
-50
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90

Figure 3



CPM
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Power pattern (dB)
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-40
-45
-50
-90
-75
-60
-45
-30
-15
0
15
30
45
60
75
90
θ (degrees)

Table I

	Q = 4	*Q = 6*	*Q = 8*
CPM	- 28.23	- 33.00	- 40.85
Hybrid Approach	- 25.00	- 30.00	- 36.50
DE Approach	- 21.30	- 21.66	- 21.59